Tadpole Tandem Electrically Assisted Tricycle

"Electrike"

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<u>Electric Tandemonium</u>

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Table of Contents

Table of Figures

Design Challenge

Cars today are becoming more and more expensive, roads are becoming more congested, and air pollution levels are still causing issues in our world and our health. In order to help with these issues and the nullify the possible rippling effects that follow, cities like San Luis Obispo have been promoting public transport, riding bikes, and other “green” solutions that limit or rid the need of driving a car everywhere. A very popular solution in Europe is the use of an electric assist bicycle, otherwise known as E-bikes. In Europe, car sales have been on the decline since the 2008 global recession while E-bike sales have begun to rapidly increase. Table 1 from the article "Europe’s E-Bike Imports and Market Size", shows the countries in Europe that published their E-bike sales by units from 2010-2012 (1).

Table 1: Number of E-Bikes sold in six European countries from 2010-2012.

Country	2012	2011	2010
Germany	380,000	310,000	200,000
Netherlands	171,000	178,000	166,000
Switzerland	52,900	50,000	35,000
France	46,100	40,000	38,000
Italy	48,200	45,000	40,000
Austria	40,000	32,000	20,000
Total EU states	**738,200**	**655,000**	**499,000**

Source: ZIV, RAI Vereniging, Velosuisse, CNPC, ANCMA, Arge Zweirad *(1)*

While E-bikes are becoming more popular in a large spread of different countries, E-bikes have had a very small presence and market in the United States up until about three years ago when E-bikes became more available for people to buy. As a resulting interest of electrically assisted bicycles being a new and cheaper form of transportation, companies such as Specialized Bikes, Giant Bikes, Audi, Pedego Electric Bikes, Evelo Electric Bikes, EvoBike, and Organic Transit have emerged and have created a larger market full of many innovative solutions for E-bikes. While the majority of the E-bikes are meant for single riders, there are a few solutions available that can assist more than one rider at a time. Most of the solutions for multiple riders either use a second rider attachment to their normal bike or use a tandem bike which is like an extended normal bike that has two seats. As far as the market goes for multiple rider E-bikes, there is a very small market and we hope to expand that market. The challenge that was proposed requires us to find a new solution for multiple riders with the use of a tadpole tandem recumbent tricycle.

For this project we are faced with the challenge of developing an electrically assisted tandem tricycle from an existing TerraTrike Tandem Pro. This project will go to serve as an everyday alternative to cars in which it will transport up to two people to and from a destination in a quick, easy, cheap, healthy, and economically friendly way. This everyday alternative is meant to be used by anyone, whether it would be a mom taking her kid to soccer practice, the daily carpooling commuters who travel to work every day, or the casual couple wanting to go on a bike ride together.

The main goals for this project are to:

- Implement an electric propulsion system to an existing tandem tricycle that will assist in the pedaling of two people
- Generate a “bionic feeling” for the rider in which a lower than normal input force to the pedals would result in a greater output torque than normal
- Create a final product that is aesthetically pleasing to other people
- Implement features into the trike that one may have in a car or may want in car.
- Create a solution that is economically friendly and user friendly
- Create a product that is marketable
- Make a product that is safe to use and fun to ride
- Have fun and be innovative!

Background

An important part of our research was looking at existing products; we looked at many bicycles, including the contestants’ entries into a bike design competition. Looking at the advancements that these entries had was very insightful, it helped us to see some of the current innovative ideas that bike makers are working on (2). A summary of some current bicycles/concepts that we found interesting and applicable can be found in Table 2.

Table 2. Summary of current innovative urban bicycle design projects. Pictures from oregonmanifest.com/vote/

Current Urban Bicycle Designs	Features
Elf 	• Equivalent 1,800 MPG • Total weight is 150 lbs • Payload is 350 lbs • 600 Watt electric motor • 20 mph electric speed • 15 mile electric range • 2.5 hour charge via outlet • 7 hour charge via sunlight

Blackline

- Custom steel frame with 2” single main tube
- Tool-free 12 inch rear rack with pannier mounts
- SRAM sealed internal 3-speed kick-back hub
- Integrated LED headlight and side indicators
- Hands free turn-by-turn navigation blinkers
- Custom design grab-and-go waterproof panniers with stow away messenger style shoulder straps
- Balloon tires
- U-lock storage

Merge

- USB charging pocket and lock holster
- Spring loaded rear retractable rack with integrated bungee and lighting
- Rear light and retractable fender
- Integrated cable storage for wheel lock
- Front light and USB charging port

Solid

- 3D printed titanium handlebars with integrated electronic shifters
- Self-regulating integrated light sensors
- Detachable rack system
- Smartphone app with haptic handlebar navigation
- Self-charging electronic front hub with embedded GPS module for security
- Gates carbon drive belt system with Shimano Afine Di2 11-speed rear hub

Evo

- Cable lock stows in seat tube
- Front and rear quick connect enable multiple accessory options and combinations
- Front wheel lockout enables stable freestanding lean for loading and unloading
- Light works with all attachments
- Quick connect cargo carriers

Denny 	• Handlebar is an integrated u-lock system which allows for that quick stop security • Handlebar can be fully removed to secure the frame to the wheel • Visual of a handlebar less bicycle acts as a visual deterrent • Front of the bike frame functions as a carry tray with a flexible netting design • Fender is designed to remove water from the tire by disrupting the flow with rubber bristles • Fully integrated smart lighting system that adapts the intensity based on the natural light conditions

The previous table showed us a lot of innovative ideas such as integrated u-locking systems and fenders that prevent water from spinning around and making the rider damp or wet. Some of our favorite ideas include: integrated lighting systems and charging capabilities, modular storage capabilities, smartphone application integration, self-regulating lighting, and spring loaded storage.

Motor

The main goal of this project is to create a fun and innovative alternative to cars in the form of an electrically assisted tandem tricycle. The first challenge we will face with this project is the selection of the best possible motor for this trike. When looking into motors, we had to find a balance between a motor that was light (because of the limited weight capacity of the trike) and powerful (to move a large trike with two people on it). Some other worthwhile thinks to note about our trike is that it contains an independent pedal system (IPS) which allows for either or both of the riders to pedal and only the front rider has control of shifting the gears, braking, and steering. Considering these factors (as well as many more), we looked into a number of electric motors that are available on the market and in use today by a number of E-Bike users.

From a quick search on the internet, we found that there are two main types of electric motors that are available on the market. One option is a hub-mounted motor in which the motor is implemented into the front or rear wheel – independent from the chain drive. The other type of motor is a mid-drive motor which is directly integrated into the drive system though the chain or through the crank set. Examples of both are below in Figure 1.

Figure 1: The left picture shows a hub motor inside the frame of a wheel; the right shows a mid-drive motor that is integrated into the bottom bracket and crank set.
Pictures from ebike.com and endless-sphere.com

The hub motor is by far the most widely used motor in the electric powered bicycle community due to fact that it is cheap, easy to implement, quick to install, and easy to use. In fact, it was the first type of electric motor to receive a patent for an electric bicycle. This motor was patented by Ogden Bolton in 1895 (Patent No. 552,271) and is still being used today (3). Hub motors consists of very minimal components, they are lighter in weight compared to most mid-drive motors due to being a compact design and having few parts, and they have a wide range of low to high power and torque outputs. One drawback to the hub motor is that having additional rotating weight of the hub cause the balance of the bike to be different than normal – that is, it takes more effort to keep the bike pointed in the same direction. This feeling is analogous to a car with poor alignment that constantly pulls slightly to one direction. Fortunately, we are working with a trike (which has three wheels) so this problem will have minimal consequences. Another issue of using the hub drive motor is that it uses a large amount of energy when starting up, causing the overall efficiency of the motor to be less. The hub motor also puts a lot of stress on the spokes and tire it is attached to. In our case, the weight of the bike is significantly higher (because it is a tandem bike), so the amount of stress on the spokes and tire will be even larger. This would increase the chances of the wheel and tire failing. It is also important to keep in mind that our wheels are specially made for the weight of two riders. Any alteration to the wheel structure may result in shortened lifetime of the wheel. Another limiting factor of the hub motor drive is that the hub motors have a wheel size limit that they can fit in. Because our wheels are 20 inches, a majority of the larger and more powerful hub motors will not fit in that small space. This limits the variety of different hub motors we can use. Having two motors (one on each front wheel) would help compensate for the lack of power available, but the cost of two motors would quickly go out of the range of our budget. Two very popular hub motors that are widely used by E-Bike riders are the Falco 750 Watt e-motor and the Leaf 48V Hub Motor. See Figure 2 for motors. The Leaf motor package comes with everything you would need for installation, has a long usage time, but reviews say the motor doesn't last long and doesn't have a lot of power. The Falco E-motor has a lot of power and it fits in a large number of wheels, but it comes at a very steep price.

Figure 2: Leaf hub motor on the left and the Falco E motor on the right
leafbike.com and falcoemotors.com

The mid-drive motor is the least used motor for electric bikes; this is main due to the fact that they are more complex and expensive. However, the benefits of these motors clearly outweigh the financial and technical shortcomings. The mid-drive motors are more efficient overall than the hub, because unlike the hub-motor, they are able to operate at their most efficient operating speed due to the fact that they are directly incorporated in the drive train. The motors will spin at a constant efficient speed and it is up rider to determine what speed that is based on the gear and their input they desire. This results in a longer range than the hub drive if both were to have the same battery size (4). Having the mid-drive motor also removes a lot of the stresses off of the wheel, which was a concern associated with the hub-motor. One issue with some mid-drive motors is that they tend to keep spinning after shut down which causes the pedals to move when not wanted. What the mid-drive lacks in weight savings makes up for in power output. Mid-drive motors are known for their efficiency and ability to produce relatively high amounts of power. Another great convenience of the mid drive motor is the fact that it is independent from almost all of the other bike components. This makes it easier to work on the bike, as it doesn't require a major disassembly due to deep integration (like the hub motor does on the wheel). Some of the most widely used mid-drive motors used in North America, Europe, and Asia are the Bosch, Evelo, Rubbee, Bafang, Sunstar, and Stokemonkey mid drive motors (See Figures 3 and 4). The Bosch and Evelo are powerful electric drive motor that provide power at the crank; they are very efficient being able to travel long distances, and are very powerful. The Rubbee is a cheap motor meant for short commutes and can be quickly removed and attached. The Bafang and Sunstar are two very similar motors that have a lot of power, an efficient motor, and are easily integrated into the frame.

Figure 3: Evelo Left, Rubbee middle, Bafang Right - Evelo.com, Kickstarter.com, szbaf.com

Figure 4: Sunstar left, Bosch middle, Stokemonkey Right - sunstar.com, boschmotors.com, grintech.com

Batteries

When looking into the possible battery options that other E-Bike riders use to power there electric motors, we found that there are very few types of batteries that are safe enough for E-Bike users and powerful enough for the motors they use. These few include lead acid, Nickle cadmium, Nickle Metal Hydride, Lithium Polymer, Lithium Manganese, and Lithium Iron Phosphate (5).

Lead acid batteries are by far the least expensive of the other battery types. They are most commonly used in the automotive industry and used for backup power for generators. They are used in these fields mainly because they are not used frequently, they are being used for a very short period of time, they are cheap, and the weight constraint for the purpose is little to none. However, lead acid batteries are heavy and have a short cycle life. Lead acid batteries are also known to loose there charge capabilities if they are not charged after usage and drained all the way.

Nickle Cadmium and Nickle Metal Hydride batteries are very similar in the fact they have similar discharge and charge characteristics. Both have higher energy densities than the lead acid batteries meaning they can be a lot smaller and ultimately lighter than lead acid batteries. In addition, they both tend to have long cycle lives meaning they will last longer than the lead acid batteries before having to be replaced. Both of these battery types are most commonly used in cordless power tool and remote controlled toys due to their low weight and long cycle life. The main difference between the Nickle Cadmium and Nickle Metal Hydride batteries is that the Nickle Metal Hydride batteries are 20% lighter and use 30% less volume of space for the same power of Nickle Cadmium in addition to being easily disposable according to Waste Management.

Lithium ion batteries are by far the lightest option on the market. There able to handle very high discharge currents, they charge fairly quickly, and they come is small cell making it easier for customizing the entire battery pack shape. The most common uses for Lithium ion batteries are in electric vehicles, portable electronics, and the aerospace industry due to their high energy output, long cycle life, and low weight advantage. The main caution for these batteries is to make sure they are well protected and contain a battery management system because they are known to fail (catch fire or explode) if the cells are punctured/damaged and then used. In addition their cycle life decreases if they are charged/discharged unevenly. The battery management will prevent usage/charging of the batteries if batteries are shorting/damaged and will also make sure all the cell charge and discharge evenly.

Lithium Manganese batteries are the most commonly used batteries in E-Bikes. They have a higher discharge capability and lower weight than the lead acid and nickel series batteries, but a slightly lower discharge capability and higher weight than the lithium ion battery. What makes these batteries stand out more is their more stable chemical structure.

Lithium Iron Phosphate batteries are the longest lasting battery in terms of numbers of cycles they can go through. They are most commonly used in power tools due to their high discharge rates and long cycle lives. They are lighter than the Nickle Metal Hydride batteries, but they tend to have much lower current ratings than the Lithium ion batteries. Of the batteries talked about so far these last the longest, but as a result they cost the most.

Security

One of the key aspects differentiating a bicycle from a car is security. Not only is a bicycle open to its environment, but it is also often secured using a common U-lock or cable lock that can easily be cut through with an angle cutter. This is a huge problem for bike manufacturers as many people who use a bike on a daily basis opt for a less expensive or used model because of their fear of theft. This is extremely prevalent on college campuses where bikes are widely popular for short distance transportation. According to Stanford's Department of Public Safety, "bike theft was the number-one reported crime on campus last year, with a total of 329 bikes reported stolen" (21). In order to combat this, we have researched various methods of securing a bike and possibly integrating this into the bike itself.

We came to a variety of different options that could possibly be the needed solution to this problem. One of these is an integrated frame lock that would lock through the spokes of the wheel, rendering the bike useless and preventing the removal of the wheel itself. This is a very interesting idea to us as it can be easily implemented without much risk of problems. Upon further research, we found that this type of lock is already produced by a few different companies such as AXA (Figure 5) and ABUS. These locks range in cost from $50-$70 and are easily accessible (22) (23).

Figure 5: AXA Defender with cable lock attachment *(7)*.

Another discussed method of securing the bike was a chain lock that would clamp onto the chain and locked in place. This could be mounted to the frame to prevent all motion or just free on the chain to prevent the chain from being fed through the sprocket. Further research on this concept will be needed before any decisions can be made.

Finally, we explored the idea of engine braking when there is no key or basic tamper alarms to deter theft. These methods would be useful in slowing down the thief but wouldn't prevent the thief from possibly disabling these systems after stealing the bike.

In addition to securing the bike, we also wanted to make the customer feel safe about leaving their valuables with the bike as well. In order to do this, we are looking at installing a "glove box" somewhere in the bike that the customer could put their valuables while away from the bike. This would need to be securely fastened to the bike so that it could not be removed by a thief.

Theft Protection

In our research, we tried to find all of the components of a car that we would like to see in a tricycle. For example, cars have a product called LoJack which helps stolen cars to be recovered (10). We are interested in something similar for our tricycle seeing as this tricycle will be replacing a car and will be worth a few thousand dollars. In our research, we found three systems that are similar to the LoJack system in that they have a GPS so that the user knows of the tricycle's location.

The simplest of the three is called SpyBike and is a device that can be stealthily placed on a bike as a functioning tail light or a top post. These discreet GPS trackers then send a text or alert to the user's phone if the bike is being stolen while in the locked position. The bike can then be tracked online from there (11).

The second product is called Bike+; this product has a GPS receiver in it along with a cellular modem to alert the user via text if the bike is being stolen. The product has a locked position feature that allows the user to “lock” the bike; this means that if the bike moves in the locked position the product knows it is being stolen. This product is much more advanced than SpyBike in that it also has performance analytics, an anti-theft alarm with buzzer, ride statistics, Bluetooth connectivity to the user’s smartphone, real time location mapping, real time ride information available via smartphone or computer, a mobile app, crash detection, geofencing protection, and an open application programming interface (API). Bike+ costs $159 with a $4.00/month subscription necessary for the GPS and cellular alerts. This product is in beta but after contacting the company, we were told it should be available soon. A few of these features should be explained. Crash detection determines if the user/bike have been in an accident or crash and then can alert emergency contacts of the crash. Geofencing protection allows the user to limit the bike to a certain geographical location, and if the bike goes outside of the designated area then Bike+ will alert the user. The open API is very important as it will allow our team to adjust the application to add any other features that we deem necessary (12).

The third product is called BikeSpike; it has a GPS receiver and will alert the user via text if the bike is being stolen. BikeSpike has an accelerometer in it, so that if the user’s bike falls while in the locked position, the user will be alerted. In addition to these features, BikeSpike also has geofencing protection, bicycle profiles, theft reports, ride statistics, a mobile app, crash detection, an open API, sensitivity adjustments, and proprietary screws to attach the product to the frame. BikeSpike costs $129 with a $4.99/month subscription. A lot of these features are similar to that of Bike+, but BikeSpike does have a few others. For example, the bicycle profile allows the user to take pictures of the bike and create a profile for it. This allows the user to easily upload the bike’s profile to social media or the police if the bike is stolen so that the bike will be easily recognized and recovered. This product also has sensitivity adjustments which means that the user can make the bike more/less sensitive to features such as crash detections. Another important aspect of this product is its ability to attach BikeSpike to the frame of the bike. BikeSpike uses proprietary screws to attach the product to the bike which makes it very difficult for a thief to get rid of this system (13).

Microcontrollers

Making this tricycle interactive was another challenge we had to solve. There is quite a bit of data that we need capture and use. For our mobile situation, microcontrollers are effective, efficient, and a viable option. Arduino is an open-source electronics platform that has microcontrollers and the software that would allow us to interpret data from sensors such as the heartbeat sensor. There are many different hardware options that are available through Arduino, each with their own advantages and disadvantages (18). Many of the microcontrollers are very small, making them useful for a project such as ours in which weight and size are very important, but these small boards may not have enough computing power or the correct connections to utilize possible sensors.

A microcontroller would be very useful for many other applications such as safety. For example, turn signals, brake lights, and head lights are imperative for our riders’ safety; we can use the Arduino platform to programmatically control the lights. We have researched available lighting options and one option that stands out is programmable LEDs (19). These lights can be purchased in flexible strips with a weather protection casing.

One of the reasons that we are interested in a microcontroller such as Arduino is because of their fantastic support. There are many different applications for Arduinos that should fit right in with our tricycle, such as buttons to signal turning. Another important aspect is that these microcontrollers are not expensive, the most common one costing less than $40 (20).

Heart Rate Monitor

In addition to researching a product with rider performance statistics, we also researched what cyclists would like to have and know about their rides (14). This means what type of information they want about their workout, such as distance traveled, average speed, etc. One health aspect that we found important is the heart rate monitor. It's important to know the user's heart rate but we couldn't find any heart rate systems integrated into bicycles. We found plenty of mobile heart rate monitors but none that were built into the bicycles. We know that there is exercise equipment such as treadmills and ellipticals that have hand grip heart rate sensors on them (15). From there we found that there are two main types of heartbeat sensors that we could use. They are an infrared pulse sensor and an electrical pulse sensor.

Exercise equipment generally uses the electrical pulse sensor. They determine the heart beat by measuring the electrical signals of the heart through the hands, then amplify the signal about 1,000 times and send it to the CPU. These grip sensors do have their problems though, because the hands cannot be too dry otherwise the connection isn't good, or if the hands are too wet, the connection shorts which is not good either. In addition to this, the hands need to be attached to the grips steadily otherwise the lack of signals will negatively affect the data. For example, running while holding hand grips can prove to be problematic unless the user is firmly grasping the handles the entire time which is rather difficult. Another problem with the grips is that the slight tightening of hand muscles produce small electrical signals that mimic that of a heartbeat; this is troublesome for the CPU because it then becomes very hard to distinguish said hand muscle tightening between legitimate heart beat readings. This type of heartbeat sensor is not readily available for bicycles. There are no kits or conversions to make one's bike handle bars heartbeat sensors that we could find (16).

The second option is to use an infrared pulse sensor. This sensor measures the variation in blood volume in the tissues using a light source/detector. This process is restricted to certain body parts though, because the skin can't be too thick for this method. The preferred body parts are the tip of the finger and the earlobe although it has been tested on the user's palm and forehead which produced reliable results also. A good example of this type of sensor is called the Pulse Sensor (17). We plan to perform some experiments in the future to test how accurate both this infrared pulse sensor and the grip pulse sensor are.

Fairing

One large difference between a bike and a car is the weather protection. A car is enclosed which allows the driver to avoid bad weather by getting in the car and driving to the desired location. On the other hand, a bike does not have an enclosure on it, so the rain drenches the biker. This is a large reason that commuters do not use an electric bike to commute to work; it is very difficult to use during months of rainfall.

To combat this, we investigated the possibility of incorporating a fairing into the design of the bike. A fairing has two main purposes: to decrease aerodynamic drag and to protect from weather

effects (6). Additionally, there are two main types of fairings: partial fairings and fully enclosed fairings. In our project, the main purpose of the fairing is to protect from weather. We are very confident in our ability to overcome drag forces without a fairing, so decreasing aerodynamic drag is not a main concern. Now that we have established that the main purpose is to protect from weather, mainly rain, we can begin to compare the differences between using a partial fairing and a full fairing.

Electric-assisted recumbent bikes with fairings are typically known as "Velomobiles." The first Velomobile was designed and built by Charles Mochet, in 1925 in France. There was a large material shortage during World War 2, so the demand for non-human powered vehicles rose quickly, as automobile production decreased. These first Velomobiles were 4-wheeled, with a fairing. Then, a similar version called the Fantom was made in Sweden in 1940, followed by the Leitra in Denmark in the 1980s, and then the Alleweder, in the 1990s in the Netherlands. The term Alleweder literally means "All-Weather," and this vehicle in particular is important to the discussion of fairings, because it was designed to be used in any weather (7).

To learn more about fairings, we sought out people who had worked on fairings before. To accomplish this, we spoke to Marren Miller, the innovation team leader of the Human-Powered Vehicle (HPV) Team, associated with the Cal Poly Mechanical Engineering Department. When asked about the price, time, and number of people necessary to design and create the fairing, Marren responded, "It took $9,000 dollars for materials, 2 quarters to design and build it, and 12 people working on that project." The fairing that the HPV team built was a carbon fiber shell that included layers of Kevlar as well (8). However, this is not the only option in materials. In researching different materials that could be used to build a partial or full fairing, we came across the following most often: Vivak, ABS, Coroplast, PC, and Lexar materials. To compare each material effectively, we focused on a few properties that would be important to our design. Because the fairing will have to protect the rider from rain, the rider will have to look through the fairing. The only way this can be safe is if the fairing is some sort of see-through material with high visibility. It should also be treated with some sort of paint or epoxy that will prevent the shell from refracting sunlight into the eyes of the rider. The material that we choose for the fairing should not lose significant strength when it is subjected to temperature cycling, and it also should not trap much heat inside the compartment where the driver will be sitting. After all, if cars are comfortable, so should this trike!

Figure 6 contains an example of a partial fairing that is sold at zzipper.com. As shown, the partial fairing does not protect the rider of the bike from rain; this is why many people do not ride a bike to work! Figure 7, on the other hand, contains an example of a fully-enclosed fairing. This does effectively protect the rider from rain.

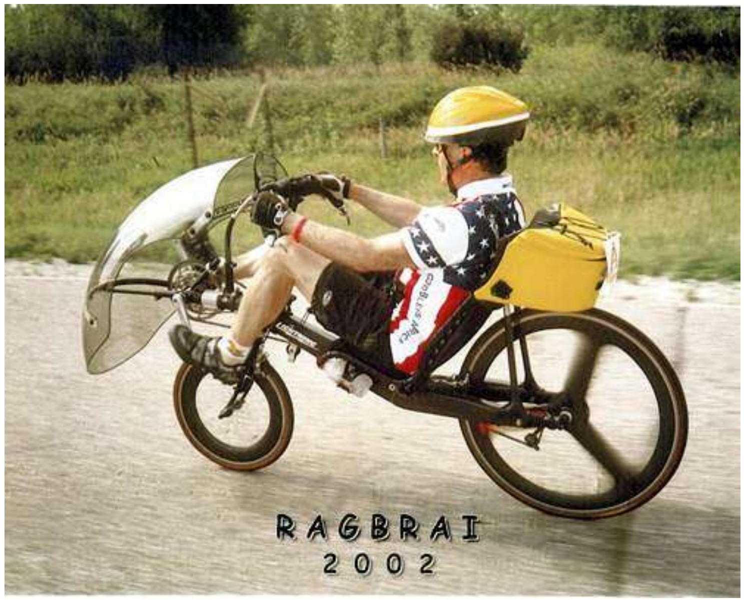


Figure 6: An example of a partial fairing, taken from zzipper.com

Figure 7: An example of a fully enclosed fairing, taken from a thread on recumbent.com.

Table 3, shown below, outlines the differences between certain materials that are used in the creation of fairings. Polycarbonate is the strongest material, while Coroplast is the lightest material. It will be important to weigh the importance of each property, and rate them against each other in the future. This will allow us to choose the best material for our specification. The data in this table is found on various supplier websites. It is important to note that there are some properties of each material that, although important, are not listed in the table below such as cost, manufacturability, aerodynamic drag coefficient, etc. These properties are not found on data sheets, and we will determine the values of those properties by speaking to manufacturers and suppliers who have worked with the materials in the past.

Table 3: Comparing the material properties of different plastics used in bicycle fairings.

Material	Density (g/cm^3)	Heat Deflection Temperature (°F)	Flexural Modulus (ksi)	Ultimate Tensile Strength (ksi)
Polycarbonate	1.2	270	332	9.5
ABS	1.04	190-192	326-331	6.16-6.5
Lexan Resin 940A	1.21	151	325	8
Coroplast	0.9	194		4
Vivak	1.27	176	290	0.65

The last important item we came across was a type of fairing that is entirely composed of a fabric. The fabric is often referred to as a "bodysock," and it accomplishes the same thing as a hard shell, except it does so with much less weight. One thing that is not currently available is a transparent bodysock; this would help keep the weight of the structure very low, while still providing the protection from weather that is desired (9). Figure 8 shows an example of the bodysock.

Figure 8: An example of a bodysock, which is a piece of fabric that provides the contour of the fairing.

Lighting

An important aspect to our tricycle is how visible it is to other drivers. We want our tricycle to be seen by the rest of the people on the road, especially since our tricycle is recumbent; it is low to the ground which makes it harder to be seen. In order to be seen, we plan on adding lights to grab the attention of other drivers.

To be seen from the front, we plan on having light emitting diode (LED) strips that will light up when braking or turning. There are two main LED strips that are applicable; the first is made by Neopixel and the second is made by Adafruit. Both of these strips are programmable, the main difference being that the Neopixel has 60 LEDs per meter whereas the Adafruit strip has 32 LEDs per meter. More LEDs per meter sounds better, but this also requires more power, and depending on our available power, more LEDs may not be possible.

To see in the dark and to be seen from the front, we will have bicycle headlights. There are many available headlights currently available. There are very powerful headlights that come with their

own rechargeable battery. For our purposes, we will want something like the NiteRider Minewt Mini 350 Headlamp because it turns on when power is supplied. Other headlights have a manual button on them which makes it much more complicated to programmatically control.

Our tricycle still needs to be easily seen from the sides, in order to achieve this we found the Lunasee Lighting System. Lunasee has created a solution for this problem in the form of glowing strips that are placed on the rims and light up when passed through a black-light LED on the fork of the bike. This creates a very noticeable circle of light outlining the wheels and making the bike much more visible at night. This protects the bike from all angles at night and gives the bike a futuristic and high-tech look. The Lunasee system is pictured below in Figure 9.

Figure 9. Motorcycle equipped with the Lunasee Lighting System.

The Lunasee system can be easily installed by applying the glow tape to the rims and installing the black-lights. This system costs $24.99 for the tape and about $7 for each LED. With all of these lights, our tricycle should easily grab the attention of other riders without being distracting.

Objectives

As previously stated, the principle reason fueling this project is the want and need to replace the use of automobiles for short distance commutes or generalized urban transportation scenarios. Therefore, to attain a better understanding of what the consumer potentially would want to see in a

product such as this, we met with influential people that would be the key to this success. These people included our sponsor, Bob Shanbrom, and experienced, avid bikers within our biking community. After asking them a variety of questions, and listening to their feedback, the following stood out to us as chief consumer requirements.

Customer Requirements:

- “Bionic” feeling while pedaling
- Electric power assisted
- Visible by other cars or people
- Safe to operate with car and foot traffic in urban setting
- Low carbon footprint
- Protects from light weather scenarios
- Competitively priced
- Quiet for rider(s)
- Secure
- Comfortable for riders
- Adjustable levels of assist
- Adjustable seating
- Marketable
- Aesthetically pleasing
- Storage for groceries, backpacks, etc.
- Good field of view for operator(s)
- Light weight

By using these previously stated requirements, in conjunction with the input received from the consumers, we created a quality function deployment (QFD) (Figure 10, below) to determine what our most important requirements are and what engineering specifications would need to be determined to become a competitor in the bicycle and/or transportation market. In order to have a competitive advantage in the marketplace, our bike must supersede the other bicycle models currently on the market, such as the ELF (competitor #1 on the QFD), while also maintaining many features a car such as the Toyota Camry (competitor #3 on the QFD). Engineering specifications were set to determine this niche of customers that our product would satisfy. Individual specifications such as speed and power were determined by state and national bicycle codes. Whereas other specifications such as weight, range, torque, and cost were set so that we can best the other competitors currently in the marketplace. The time to secure, visual appeal, number of parts, storage, estimated time to charge, and noise level were targets set from the experience of the questioned bicyclists and from our own personal experiences. The size on the contrary was in large part set by the pre-existing size of the bike. These engineering specifications are further detailed and quantified in Table 4 on the next page.

Table 4: Formal Engineering Specifications Table. Risk is ranked High (H), Medium (M), and Low (L). Letters under 'compliance' stand for different methods of validating specifications: Analysis (A), Test (T), Similarity to other designs (S), I = Inspection (I).

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Speed	20 mph (assisted speed)	Max	L	T, S
2	Range	20 miles (electric only)	Min	M	T
3	Cost	$5,500	Max	M	A
4	Weight	150 lbs	Max	M	A, T
5	Power	500 W/750 W	Min/Max	L	T, S
6	Torque	50 Nm	Min	L	S
7	Time to secure	30 seconds	Max	M	T
8	Size	10ft x 4ft x 5ft	Max	M	I
9	Aesthetically pleasing	60%	Min	M	T
10	Water hitting rider	10%	Max	H	T
11	Manufacturability	TBD	TBD	TBD	TBD
12	Storage	2 ft^3	Min	M	I
13	Time to charge	3 hours	Max	M	T, S
14	Number of parts	TBD	TBD	TBD	TBD
15	Sound	60 dB (normal speech)	Max	L	T
16	Blind Spots	2 added blind spots	Max	M	I

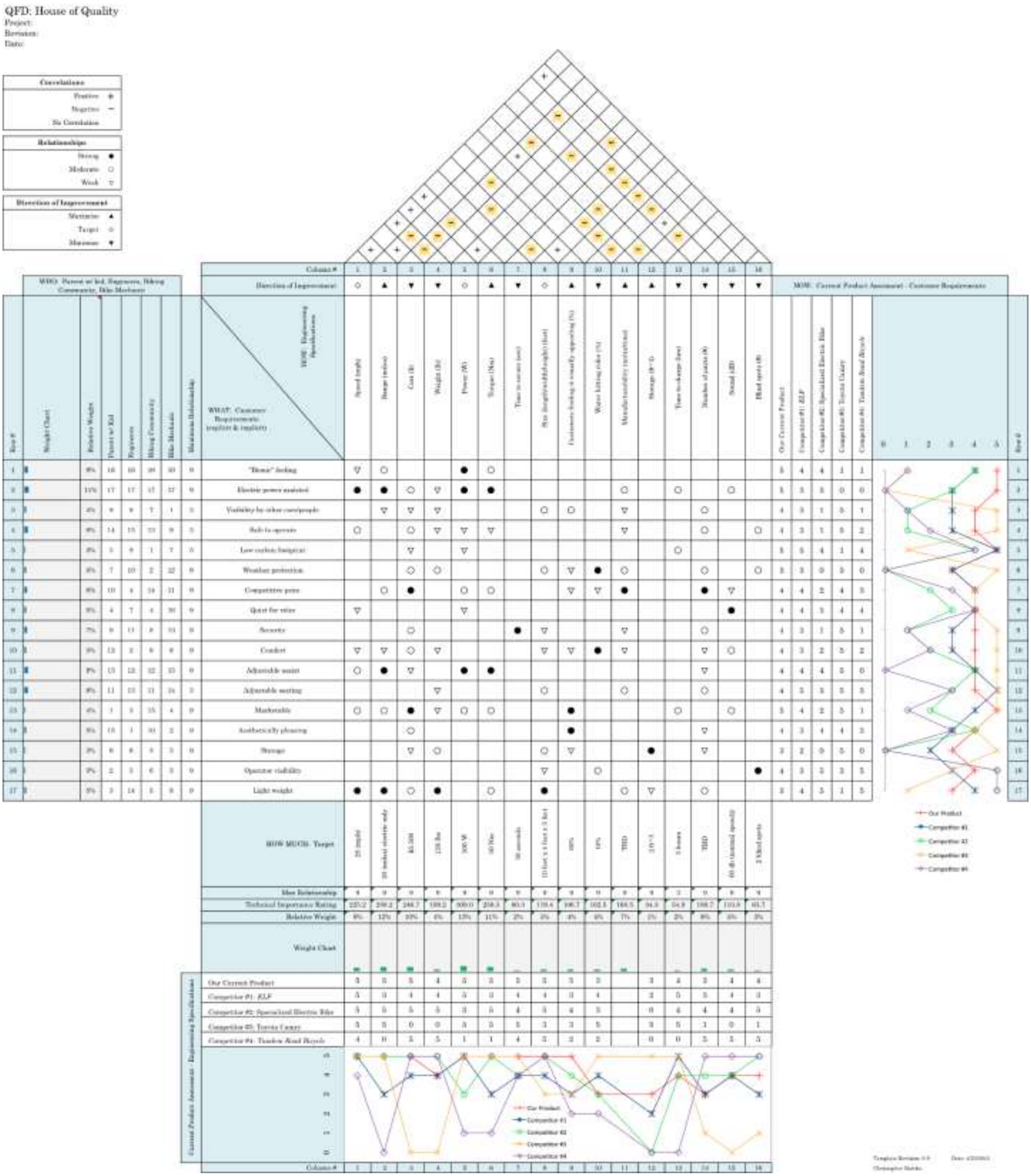


Figure 10: QFD for assisted tandem tricycle

Management Plan

Table 5: Responsibilities of each member.

Team Member	Subsystem Responsibility
Austin Frederickson	Security, Vehicle Codes, Innovation
Anthony Jacques	Theft Protection, Electronics
Kris Lawrence	Fairing, Innovation
Preston McElroy	Motor, Safety Features

Table 6: Roles of each member.

Team Member	Roles
Austin Frederickson	Information Gathering, Data Analyst
Anthony Jacques	Testing Plans, Integration
Kris Lawrence	Minutes, Point of Contact, Prototype Fabrications
Preston McElroy	Manufacturing, Project Progress

Table 7: Timetable of milestones relevant to sponsor.

Date	Milestone
10-3-14	Meet Sponsor
10-21-14	Project Proposal Report
11-4-14	Present Concept Models
11-14-14	Preliminary Design Report
1-30-15	Final Design Report
3-30-15	Prototype Testing
5-29-15	Senior Project Design Exposition
6-5-15	Final Project Report

Gantt Chart

The Gantt chart was an excellent tool for organization. Also, it allowed us to show our plan and progress to the sponsor of our project. The first step to making the Gantt chart was to determine a long list of small goals that we have to reach by the end of the project. Then, we set a start date and end date for working on those small projects. As time progressed and we worked on each of these projects,

updated this chart. This will allowed us to look at our progress and determine if we were generally on schedule, or if we were habitually falling behind. The left column of the chart, found in Figure 11, shows all of the goals we hope to accomplish. The right columns show dates (by week, until the end of the school year in June) and expected work dates for each goal.

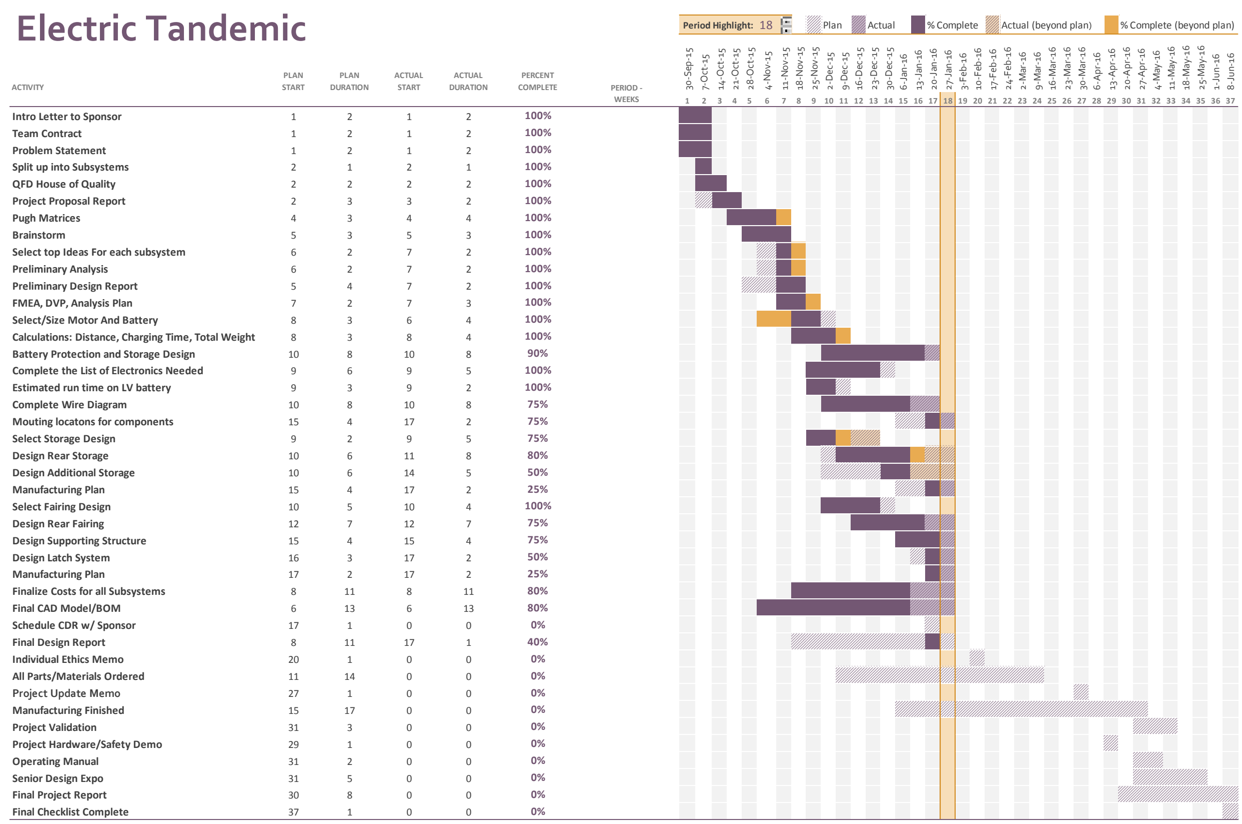


Figure 11. Gantt chart estimating when our goals will be completed. See Appendix AB for larger print

Design Development

Motor

Idea Selection

In the selection process for the motor, we decided to compare eight different electric motor options in which we used the very first electric bicycle motor as a datum of reference (see Table 9). The very first electric motor was a hub motor that was capable of reaching speeds of 12-14 miles per hour. With the use of a throttle the rider would be able to slowly power their bike. Because the motor was not the most powerful, the rider had to be moving in order for the motor to work, but once the motor was running it would be able to provide assistance for up to 12 miles. Using this electric system as a reference for our chosen list of criteria, we were able to compare the eight different motors with a decision matrix and narrow down our decision to which motor was best for our tandem trike.

The criteria for this decision matrix was selected from our list of requirements discussed earlier in this report as well as some of these additional engineering and safety requirements:

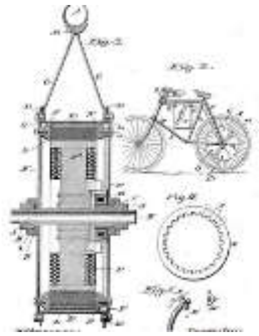
- Must not exceed a 750 watts power rating per the U.S. Congress Consumer Product Safety Commission (CPSC) legislation 15 U.S.C. 2085b – (24)
- Must not provide assist on level ground at speeds over 20 mile per hour per CVC 406-b – (24)
- Must have a minimum range of 20 miles on a single charge – customer requirement
- Must be easy to implement onto the trike (minimal to no changes to the original frame/structure) – customer requirement
- Must not interfere with the movement or comfort of the rider – customer requirement
- Must have an assisting mode in which the rider's input force controls the propulsion of the motor (throttle optional) – customer requirement
- Must be able to vary the amount of assist the motor puts out – customer requirement
- Have low resistance when motor is not operating – customer requirement
- Must cost less than $2000 – budget limitation

The way the decision matrix was completed and filled out is as follows:

Table 8: Criteria ranking schematic for motor decision matrix

Motor Criteria received a _ if…	**+**	**S**	**-**
Can assist to a speed of 20 mph	>20 mph	14 - 19 mph	14 – 19mph
Can Limit assist at 20 mph	Assist shuts off at 20 mph	Doesn't shut off like datum	(None got this)
Complexity of installation	Attaches to bike or replaces a part on bike	Numerous parts replaced and/or min. parts modified	Large and/or many modifications to make
Motor stops when slowing down	Motor can be stopped	Motor doesn't stop	(none got this)
Cost of motor	> $750	$300-$750	< $300
Number of parts needed	Motor, controller	Motor, controller, sprocket, custom spokes	Any more than "S" category
Assists when pedaling	Pedaling initiates motor	Throttle only	(none got this)
Variable levels of assist	> 1 level of assist	1 Level of assist/throttle	(none got this)
Motor Weight	< 20 lbs	20 lbs	> 20 lbs
Motor Size (Volume)	Smaller than datum	Similar size as datum	Larger than datum
Bike behavior when motor off	Behaves like nothing is attached	More force needed to compensate for friction	Motor prevents bike from moving easily
Includes a controller	Has a controller	No controller	(none got this)
Power/torque	Capable of moving two riders from stand still	Capable of moving a single rider from stand still	Not able to move rider from stand still
Sound Level	Quiet/almost non-existent when riding	Able to hear motor when riding	More noise than just more
Range (assume with 48V battery)	> 20 miles	12-20 miles	< 12 miles
Safe to operate	Moving parts enclosed & away from rider, motor stop when not in use	Moving parts enclosed and away from rider	Moving parts not fully enclose/away from rider, motor doesn't slow immediately
Availability to purchase	Can purchase in US	Out of country purchase	Cannot purchase motor, must be bike manufacturer

Table 9: Motor ideas and specifications to be compared in the Pugh Matrix in Appendix A



Datum - 6-pole brush and commutator DC Hub motor

First electric motor for bike

Large, quiet, throttle to accelerate, speed of 12-14 mph

Motor winds down after acceleration

Heavy due to limitation in manufacturing and large batteries

Range of about 10-12 miles

Not a lot of torque but got the rider moving

1) Leaf Hub Motor

Cheap Brushless-gearless motor, ($261.00)

comes with controller

Mechanical brake, regenerative braking

Pedal assist 1-5, reverse, throttle, max speed of 21 mph

Weighs about 22 lbs

2) Bafang bbs02 mid drive motor

Expensive ($720.00)

More powerful and efficient than hub motor (moves 600 lb trailer)

Can assist up to 28 mph (can be limited to 20 mph by controller)

Easy to install, Pedal assist (1-9) and throttle option, motor brake

Weights about 11 lbs, range of about 20+ miles with 48v Battery

3) Sunstar S03+ Mid drive motor

Expensive (£1,318.99 and only available in Europe)

More powerful and efficient than hub motor

Can assist up to 30 mph (can be limited to 20 mph by controller)

Easy to install, Pedal assist and throttle option, motor brake

Weights about 11 lbs, range of about 20+ miles with 48V

4) Rubbee Friction Motor

Inexpensive (£699 but only available in Europe and in development)

~15 mph max. throttle only

Easy to install battery pack built in

Only used when moving, can’t use to start

Not a lot of power, but small, compact, and 22 lbs w/ battery

Meant for single rider

Not the quietest, low range 7-10 miles

5) EVELO mid drive motor

Expensive and only comes on custom bikes they make ($2000+)

20-25mph in assist, throttle and pedal assist option (3 levels)

500 watt motor max, but very long range 40-60 miles

Battery and motor = 62 lbs…Yikes

Quiet, custom mount needed to install

Meant for single rider

6) Bosch Mid Drive Motor

Expensive and only sold to bike manufacturers (price not given)

Up 30 mph (can be limited), gear shift detection

Throttle and pedal assist

Needs custom built mounting location

About 40 mile range with provided motor

Heavy and larger

7) Falco E-motor hub drive – rear wheel

Expensive – ($2000 for motor, controller, and batteries)

20-50 mile range (pedelec version vs e-Bike version)

Only available with 36W battery

Up to 30+ miles per hour with 48V battery

Zero resistance pedaling when off

Assist and throttle option

8) StokeMonkey Mid Drive motor

High torque, Large amount of power

Noisy, large, heavy (motor 20 lbs), separate from the drive train

Would require a large space and custom rigging to install

Expensive ($1250.00 motor and controller)

Able to carry large loads (480lbs up a 30% incline)

Throttle only

Using the criteria ranking schematic and information gathered on each motor we were able to generate a Pugh decision matrix to help us select the motor that would best meet the requirements we had set for this project. See Appendix A for the results of the matrix.

The motor that seemed to meet the most criteria and requirements was the Bafang bbS02 Mid Drive motor followed by its twin the Sunstar S03+ Mid Drive motor, the Bosch mid-drive motor, and Evelo motor. I would like to note that all these top choices were mid drive motors which helps to

conclude that the mid drive motor is the way to proceed in the motor selection process. The main reasons that the Bafang stands out the most from the other top three mid drive motors is because it is lower in cost than the others, it is easily adaptable to our trike (no custom mounts needed or alterations to the bike), and most importantly the motor is able to be purchased on its own (the other top motors cannot be purchased separately from the bike they are installed on).

To be sure that we made the right decision in the selection of the Bafang mid drive motor, our team participated in a Bafang workshop at the Bike Kitchen in San Luis Obispo (October 29, 2014) in which we saw how to install the Bafang motor and test the motor. We were happy with how the motor performed and even happier with the fact that the motor was compatible with our trike. At the very end of the workshop we were promised a discount on the motor if it was the motor we wanted to use. All of these facts have led us to the conclusion that the Bafang mid drive motor will be the motor we will use. Bafang motor specifications can be found in Appendix B.

Features and Implementation

The Bafang motor, as previously stated, is normally mounted in bottom bracket of the bike, replacing the original crank set. For the trike it will replace the front crank set and be installed in the front bracket just like it would in a normal bike. This will allow the trike to keep all of its gears due to the fact that there is only one cassette in the front. Since our trike will be equipped with an independent pedaling system (IPS), the motor will be able to run without moving either of the rider's pedals when operating. However, at least one of the riders must be pedaling in order for the pedal assist option to work on the motor. As for the throttling option, nobody will have to pedal or be forced to pedal for the IPS will allow the entire drivetrain to move except for the rider's pedals.

As far as time goes for implementing this motor onto the bike, we estimated that it should take about two hours to fully implement the motor, motor brake, controller, throttle, and wiring. We are basing this off of the demonstration we attended in which the Bafang specialist was able to implement the entire system onto a bike in less than two hours. We are confident in being able to reproduce this time frame because notes were taken on the "tip and tricks" for installing the motor and we have access to installation videos.

High Voltage Battery

Idea Selection

Before selecting a type of battery for our motor, the battery size and power specifications had to be calculated in order to provide the required amount of power needed for the motor. Since we have decided to move forward with the Bafang mid-drive motor we had to base our calculations around the motor's power limits, requirements, and performance. The first limit for the motor is that the battery must have between a 5-15 Ah (amp-hour) rating meaning the battery will be able to supply a constant 5-15 amps for an hour. The performance of the motor is generally determined by the amount of Watt-hours available which is calculated by multiplying the battery voltage by the amp-hour rating. One thing to note is that the weight and size of the battery linearly increases as you increase the rated amp-hours.

As a result we want to pick a voltage that would place our amp-hour rating within the motors limits and a voltage that does not exceed the limits of the controller for the motor (which is 48 Volts). Given that the Bafang motor we want to use is a 750 Watt motor, the user manual suggests that the motor be paired with a 48V battery based on the type of loads we will be putting the motor under. From

this we determined that a 48V battery would to be the voltage rating we would use. Using the 48V battery as a starting point, we then moved forward in a calculation to estimate the actual amp-hour rating we would need from a battery sizing equation for mid-drive motors (5). See hand calculations in Appendix D.

The calculation estimated that we would need a minimum of 8Ah in order to travel 20 miles with a "typical assist motor output". A "typical assist motor output" means that the rider is pedaling along with the assist of the motor which is on all the time (5). With the power ratings of the battery determined, we moved forward in the selection process of the battery which could meet the 48V and 8+Ah rating.

In the selection process for the motor battery, we decided to compare eight different battery options in which a lead acid battery was used as a datum of reference of comparison (see Table 11 for list of batteries). Lead acid batteries are by far the most widely used and understood battery types on the market. They are easy for manufactures to make, mass produce, and they are reliable to the point that can be used in virtually any electrical system that needs a battery (24). In the short run they are the cheapest type of battery out there, but when a higher power output, lighter weight, and/or multi-use battery is needed the lead acid battery falls short in some cases. The other competing types of batteries for the E-Bike motor are the Nickel Cadmium, Nickle Metal Hydride, Lithium Ion, Lithium Manganese, and Lithium Iron Phosphate.

The criteria for this decision matrix was selected from our list of requirements discussed earlier in this report. The way decision matrix was completed and filled out is as follows:

Table 10: Criteria ranking schematic for battery decision matrix

Motor Criteria received a _ if…	**+**	**S**	**-**
Cost of battery Pack	< $30	$30 – $100	> $100
Number of charge cycles	> 750 cycles	500 – 750 cycle	< 500 cycles
Ah rating	10 – 15 Ah	8 –10 Ah	< 8 Ah or > 15Ah
Weather resistant	Batteries are covered and protected	Batteries not protected,	(none got this)
Securable to bike	Locks to bike	Needs a strap/custom mount/custom storage	Cannot be secured to bike
Power Switch	Able to allow/cut current from system with switch/button	No switch, must disconnect to remove power from system	(none got this)
Comes with charger	Yes, part of package	No, must order separately	(none got this)
Charge time	0-2 hours	3 – 6 hours	> 6 hours
Safe to use	Battery packs have safeguards built it, protective cover, no exposed wires/connections	No protection, wires and connections exposed	Unsafe, uncontrollable, will fail
Safe to dispose of	Can throw away in trash (approved by Waste Mang.)	Recyclable	Can Recycle
Able to Store	Can store for 4+ months w/o having to connect to charger	Can only last 2 weeks – 3 months w/o being put on charger	Must always be charging when not in use

Table 11: Battery ideas and specifications to be compared in the Pugh Matrix below

Datum - Lead Acid Battery

Cheap ($30 - $100)

Heavy

short cycle life (~500 cycle before 15% decay)

Common to come in 12V and 7-12Ah blocks

Most likely use two 12V batteries in series

Not covered, no lead wires, large in volume

1) LiFePO4 PingBattery

48V 10Ah rating

Expensive ($382 w/o shipping)

Recommended for 750 watt motors

High cycle life (~1000 cycles before 15% decay)

About 10.8 lbs

Comes with lead and charger

Cells wrapped together, BMS included

2) Lithium ion Samsung Frame Pack

Semi-Expensive ($500)

48V 9.8Ah

Light weight (~8.2 lbs)

Locks to frame with key

Medium Life cycle (~700 cycles before 10% decay)

Power buttom, USB connection, High Cycle life

3) Lithium Manganese – ALLCELL

Expensive ($800)

48V – 13AH

Lightweight (~8.3lbs)

Medium cycle life (~700 cycles before 10% decay)

BMS inside pack, battery wrapped in plastic covering

Comes with leads and battery charger

4) Lithium Iron Phosphate – Golden motors

Expensive ($534)

48V – 10Ah

Lightweight (~9lbs)

High Cell Life (~2000 cycles before needs replacing)

Contains BMS, Safe as Lead acid batteries

Comes with charges, Locks to rear storage (sold separately)

5) Lithium Manganese – Grin Tech.

Expensive ($790)

48V -11Ah

Lightweight (~8.5lbs)

On/Off key switch, comes with charger, battery rail slide/lock

Leads included, needs topping off every 3 months,

6) Nickel Cadmium - Tenergy

24V – 5AH (would need 4 of these)

Semi-expensive ($82 each x 4 = $328)

Needs 2 in series and 2 in parallel to meet 48V and 10Ah req.

Comes with leads, no charger, Simple wrapping around batteries

Not secured down

7) Nickel Metal Hydride - Tenegy

24V – 10AH (would need 2 of these)

Semi-expensive ($185 each x 4 = $370)

Needs 2 in series to meet 48V and 10Ah req.

Comes with leads, no charger, Simple wrapping around batteries

Not secured down

Using the criteria ranking schematic and information gathered on each battery we were able to generate a Pugh decision matrix to help us select the battery that would best meet the requirements for the motor and the requirements we had set for this project. See Appendix E for the matrix.

From the matrix there were two batteries that seemed to meet the most criteria and requirements: the Lithium Ion battery pack made by Samsung and the Lithium Iron Phosphate pack made by Golden Motors. Both packs are known for being lightweight, being compact, being able to be secured down, having the capability to be powered on and off by a switch, coming with leads already attached, coming with chargers, meeting the 48V and 8Ah minimum, and containing battery management systems for safety. As can be seen, both batteries are very similar in what they offer, but when it comes down to choosing one of the two battery options the Golden Motor is the favored option. It is slightly more expensive since shipping is from Canada, but overall the Lithium Iron Phosphate batteries are more chemically stable and will not be prone to catching fire and exploding if damaged like Lithium Ion batteries are prone to doing (25). The Samsung batteries have multiple layers of protection to prevent this from happening such as a more advanced BMS board, a rigid and structurally-sound casing for all the cells, and a water resistant casing but the warnings are too big to ignore. Safety is a very highly ranked criteria for the entirety of this project. Since we are dealing with high voltage, we have added this battery and its potential harms to a concept design hazard identification checklist. This helps us to identify possible hazards and take the appropriate steps accompanying this hazard throughout the development and testing of our final design. Please see the attached document in Appendix C.

With the Golden Motor Lithium Iron Phosphate battery we would be providing the key power element to this project. It meets the voltage and amp-hour requirement of the motor and with this battery will be able to meet the 20 mile design requirement (assuming the motor is always running and the riders are pedaling). The battery pack is said to be much safer than the Lithium Ion batteries and just as safe as lead acid batteries. Environmentally, these batteries are considered to be very safe in materials that were used in the process of making them and the fact that they are recyclable when they are at the end of their cycle. This helps us in our overall goal to be green and environmentally friendly.

Technical Content

As far as implementation into the system, we are limited in the locations for mounting this battery pack due to the very few locations for storage. The best option was to mount the battery pack to a rear storage rack that would sit right behind the rear passenger right above the rear wheel (see Figure 12 below).

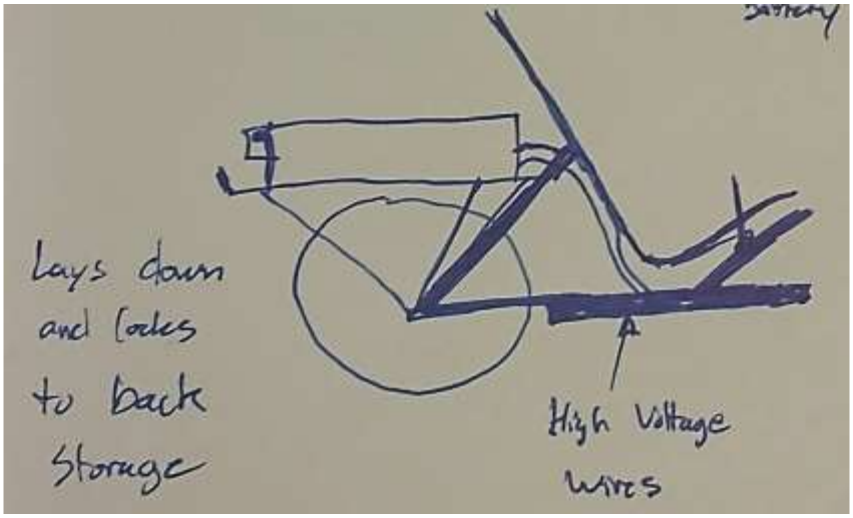


Figure 12: Sketch of the battery mounting idea on the rear storage rack.

This rack would also allow us to install the battery mounting plate onto which the battery can lock. Possible welding or mounting-hole locations may need to be made in order to install the plate correctly. Most electric recumbent trikes that we have researched run a very similar set-up in which they store their battery pack in the rear due to the little space the trikes have for mounting locations. The only part of this concept that is still incomplete is how to keep precipitation off of the battery during wet weather conditions.

Security

Concept Generation

Our first option was the standard U-lock or cable lock is the most common method of securing a bike. These are widely used due to their ability to quickly and securely lock up a bike almost anywhere. There was some risk that the lock may damage the paint or spokes of the bike due to the fact that it was free to rub against the bike.

Figure 13. Common U-lock currently available on the market.

The second concept was a frame lock; this involved a lock that protrudes through the spokes of the wheel, preventing the wheel from rotating. Many frame locks already exist on the market, the large suppliers being ABUS, AXA, and TRELOCK. These locks vary in security levels, prices, and additional attachments.

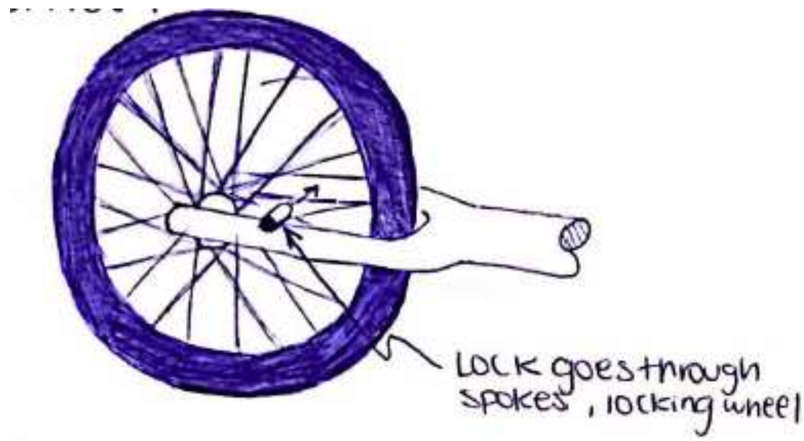


Figure 14. Concept sketch of a frame lock for the rear wheel. When activated, a bar slides through the spokes, preventing the wheel from rotating.

Our third concept was a chain lock, as shown in Figure 15. This option varies significantly from the other options on the market. Instead of locking through the wheel or to the frame, this device locks the motion of the chain by clamping down on the chain with a fixed sprocket. This prevents pedaling however does not stop the bike from being rolled away.

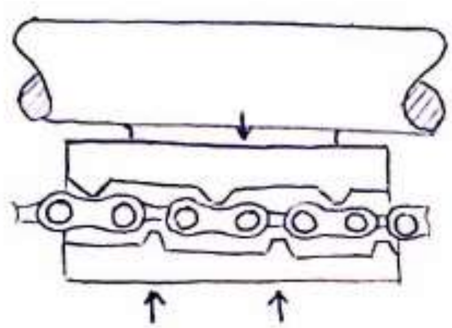


Figure 15. Sketch of chain lock mechanism. This concept works by clamping down on the chain, stopping the chain from being fed through the sprocket.

The fourth option is a brake lock and can be found in Figure 16. A brake lock is a device that fits on the brake caliper and locks onto the disk brake; this makes pedaling the bike near impossible. Some versions of this concept currently exist on the market today but are very crude.

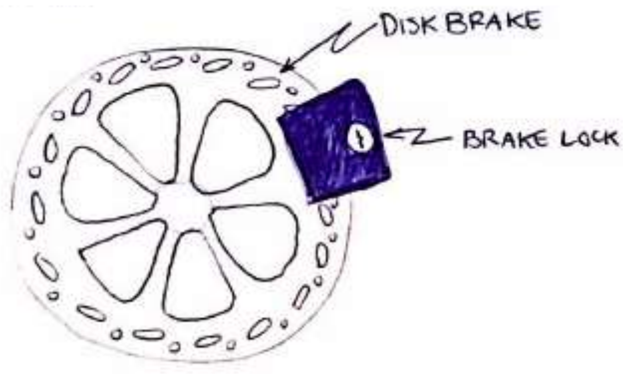


Figure 16. Concept drawing of a brake lock. The lock would be integrated into the brake caliper and lock the wheels from spinning.

The fifth option is the steering lock and can be found in Figure 17. Commonly seen on motorized scooters, the steering lock works by steering the wheel to one side and locking the steering column in one position. This prevents a thief from steering the bike however doesn't prevent the bike from rolling.

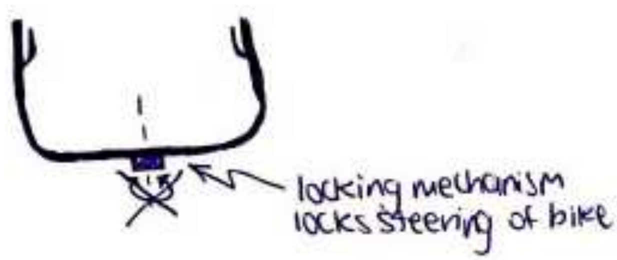


Figure 17. Concept sketch of a steering lock. This works by locking out the steering column, preventing thieves from riding the bike.

Our sixth concept is a roof lock and it can be found in Figure 18. This concept is similar to that of cars in that you first have to unlock a door to get in. This adds some security in terms of stopping thieves from stealing the bike but doesn't protect from riding the bike or pushing the bike.

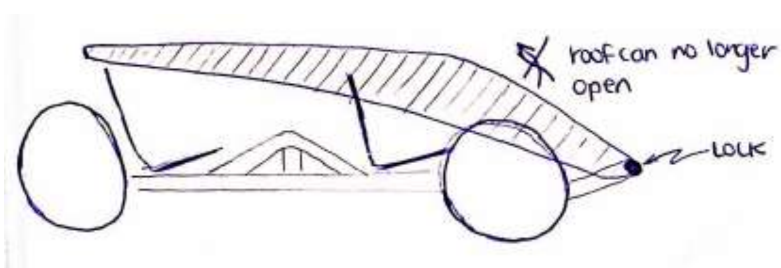


Figure 18. Sketch of the roof lock concept. In this concept, the roof is locked from opening so that a thief cannot get inside.

The seventh concept is the locking "kickstand." The best way to describe this design is as a kickstand that is too long for the bike and props the back wheel of the bike off the ground. This kickstand can then be locked, preventing the bike from being ridden or pushed. See Figure 19 below.

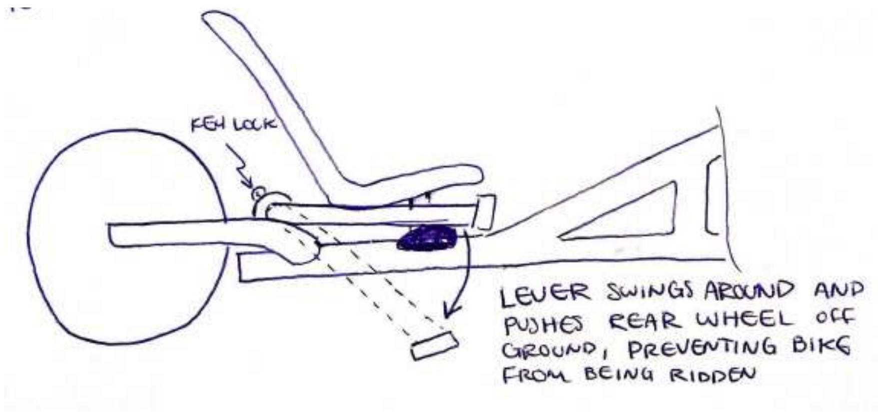


Figure 19. Concept sketch of the locking "kickstand" option. The user will deploy a kickstand that will prop the rear tire off the ground and lock.

Idea Selection

To narrow down these concepts to find the best performing idea, a Pugh matrix was created, it can be found in Appendix F. The concepts were judged based off the baseline, a commonly used U-lock, for the following areas: ability to stop a bike from being ridden, ability to access inside of the bike, ability to push or steer the bike, ability to pick up or move the bike, ease of use, lockable locations, risk of damage to the bike, and integration. These metrics were given an importance rating between 1 and 5 and the concepts were given either an S for same, a (+) for better performing, and a (-) for worse performing.

From the Pugh matrix shown in Appendix F, option 2, the frame lock, scored the highest; the steering lock was a close second. Although very effective at stopping a thief from riding the bike, the steering lock does not stop the bike from rolling. Therefore an additional lock or parking brake would needed which would increase the complexity of the system. Due to this, the frame lock will be the pursued option for this application.

Many frame locks already exist on the market, the large suppliers being ABUS, AXA, and TRELOCK. These locks vary in security levels, prices, and additional attachments. Due to the combination of its low price, cable attachment, and availability in the United States, the ABUS Amparo 4850, shown in Figure 20, will be used.

Figure 20. ABUS Amparo 4850 Frame lock on bike.

The ABUS Amparo 4850 Frame lock was a light, simple, and easy to lock bike lock that mounted to the frame near the rear tire of the bike. The lock can both lock the movement of the wheel using a bar placed through the spokes and can also lock the bike to a stationary object using an attachable chain or cable. The Lock itself comes with 4 keys and costs around $45 while the cable attachments range from $15-$20. This was a simple and elegant solution for this application.

Electronics

Concept Generation

Our first concept for the electronic subsystem is shown in Figure 21. This concept places two LED strips along the back perimeter of each of the chairs. The sides of each chair act as turn signals while the entire strip acts as a brake light. This would correspond to about 10 feet of LED strips. The length of LEDs would require anywhere from 5.7 to 11 Amps of current depending on which LED strip we choose. The rider needs some way to know if the turn signals are on or not because the front rider won't be able to see the LED strips. We planned on placing a buzzer on the microcontroller that would make noise when the turn signals are flashing. There will be a microcontroller that has Bluetooth capability that will send data to the rider's phone. His or her phone would have an app that received the data and interpreted it accordingly. We would place the battery, Arduino, and breadboard in the back behind the second rider's seat. The glove box will be placed behind the front rider. There will be one headlight that shines straight ahead, it would be powered by its own battery and turned on manually.

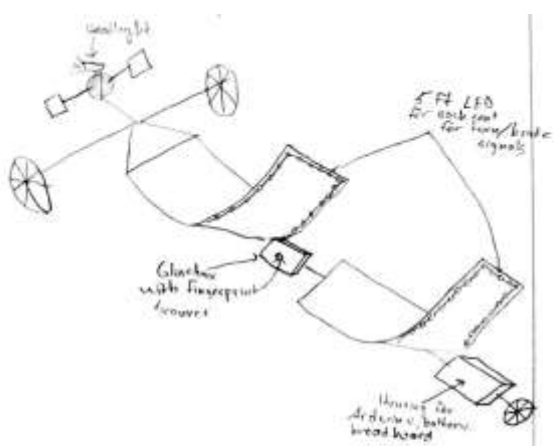


Figure 21. Concept drawing with LED strips along the perimeter of the back of each chair.

Our second concept can be seen below in Figure 22. This concept involved placing the LED strips on the fairing itself, going along the sides and across the back of the fairing. This would lead to even more LED strips than the previous concept, about 20 feet of LEDs, and the LEDs would be susceptible to all of the elements. Although the LED strips do have a weatherproof casing, testing needs to be performed to confirm that the casing can handle the intensity of biking 20 mph in the rain. This would require between 11.5 and 22.2 Amps of current depending on which LED strip we choose. We will place the battery and Arduino behind the front rider on the frame. There will be a heartbeat sensor located in the handles/grips of the front seat to measure the rider's heart rate. There will be two headlights, one on each of the front wheel's fender. This allows the headlights to change direction when the bike is turned, letting the rider see where he/she is headed. We will have a luminosity sensor that will detect when it is dark. When it is dark, the headlights will turn on and the LED strips will light up to a quarter of their full brightness, similar to cars at night.

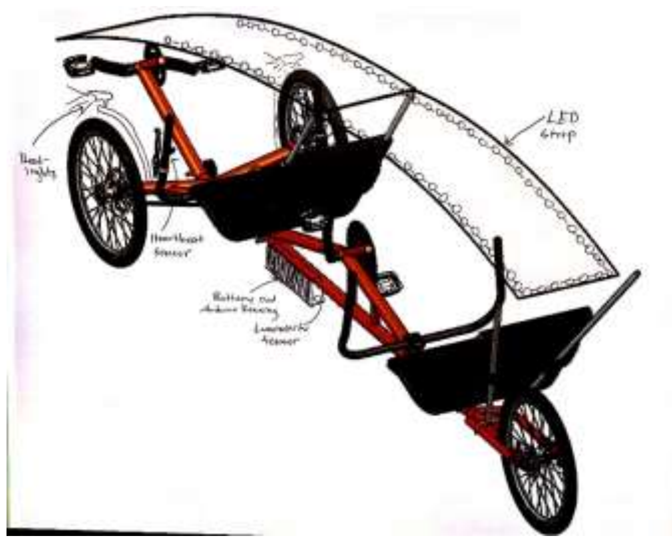


Figure 22. Concept drawing with LED strips along the entire fairing.

Our third concept is shown in Figure 23 and Figure 24; this concept only has two LED strips, one strip across the top of each of the chairs. This would reduce the number of LEDs that would be necessary, dropping the required length to 3.3 feet or 40 inches. This will require between 1.9 and 3.7 Amps of current depending on which LED strip we choose. There are fewer LEDs in this concept but the locations are ideal for being seen by other drivers. There will be a heartbeat sensor on the handle of the front seat. There will be a LCD and keypad which will allow the rider to interact with the tricycle. This will allow each rider to log in with a rider ID, this data can then be used with the heartbeat sensor to provide real time information about the number of calories burned from riding. There will also be pushbuttons that allow the rider to activate the turn signals/hazard lights. There will be a secure compartment (we will call it a glove box for our purposes) that will be able to store small items such as a phone, wallet, and/or purse. This glove box will have a fingerprint sensor on it that will only open when a stored fingerprint is recognized. The Arduino and battery will be placed below the legs of the front rider, with the glove box behind the front rider, mounted onto the frame.

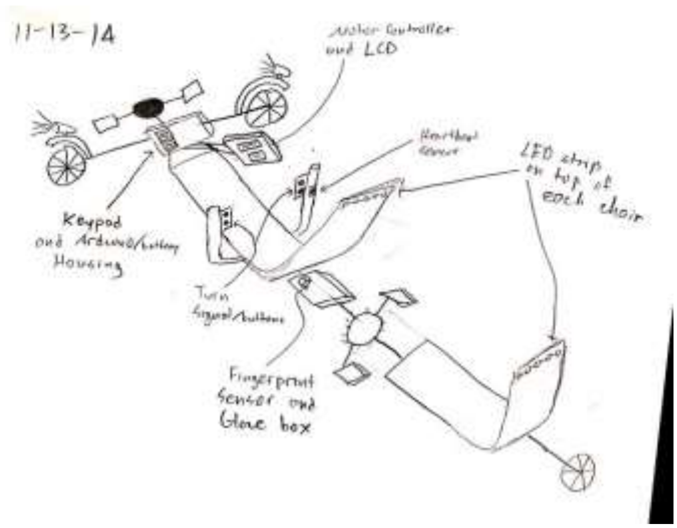


Figure 23. Concept drawing with LED strips along the top of the back of each rider's chair.

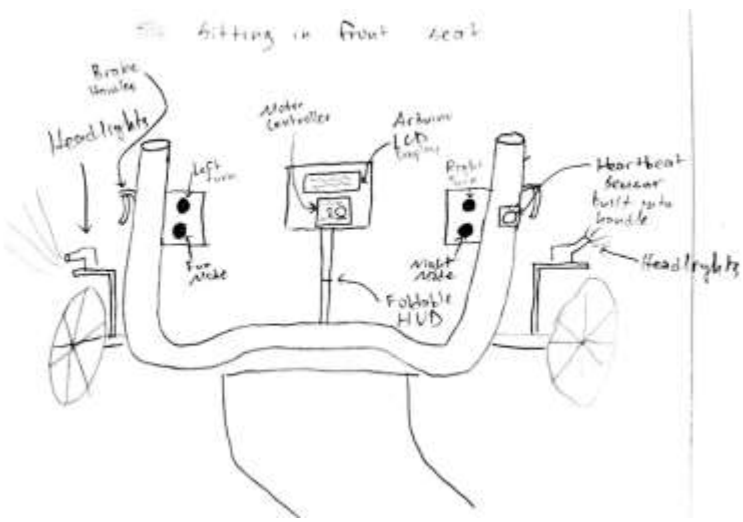


Figure 24. Concept drawing of the front rider's point of view.

Idea Selection

To select our final idea, we placed these three concepts into a Pugh matrix which can be seen in Appendix G. Before evaluating our concepts, we determined what was most important for our design. Power and weight are very limited on our tricycle. Adding too much power requires us to either increase the number of batteries that we place on the tricycle or it forces us to find a bigger and more powerful battery, both of which are negative influences. Another very important consideration is the features associated with the design, because without certain features, our product will not be marketable. Some other aspects that we considered include how the placement of certain parts affects the amount of necessary wiring and the visibility associated with each concept.

After evaluating our concepts, we determined that the concept with the lights located on the top of the back of each chair was the winning concept. This concept won due to its lesser power, lesser weight, and more features. This concept only has LEDs along the top of the back of each chair, this lessens the power required whereas the other designs required much more power and therefore more

batteries. Another reason this concept won is because of its features such as the heartbeat sensor and interactive ability with the LCD and keypad. This will make the rider really feel like they are a part of the tricycle.

Once a specific concept was chosen, we had to then answer a lot of questions specific to that concept including which microcontroller to use and which battery/batteries to use.

Microcontroller Selection

We used a decision matrix to determine which microcontroller to use. From our background research, we decided that the number of pins the microcontroller had was the most important. With all of our ideas regarding features on this tricycle, we realized that we would have a lot of sensors and components requiring input/output (I/O) pins. Without these pins, we cannot use the sensors we need. We also realized that many of our components would require their own software, which is why the memory was the next most important factor in our decision. If the microcontroller doesn't have enough flash memory to support the software, then we can't use that component.

The number of serial pins is important also because many of our components will need serial communication which are different than I/O pins. Another important factor is the size of the microcontroller. After ranking the Arduino Uno r3, Arduino Mega 2560 r3, and Arduino Yun against each other, we determined that the Arduino Mega 2560 r3 was the best choice. The Mega has by far the most I/O pins and serial pins. The Mega is slightly bigger than the other microcontrollers, but the Mega has significantly more flash memory than the others. Without the flash memory and the pins that the Mega has, we would seriously have to limit the number of sensors we can use on our tricycle.

Low Voltage Battery Selection

Another decision we needed to make was how we were going to power all of our electronics, excluding the electric motor. The motor's battery runs on 48 volts, but the microcontroller and most of its compatible components run on 5 volts. We had three concepts in order to power all of the available low voltage components. Our first concept was to put a regulator on the 48 volt battery and take some of the power from there. Our second idea was to buy a 12 volt motorcycle battery and place a regulator on that one. Our third concept was to buy two USB Battery Packs.

When creating our decision matrix, we determined that the most important factor in our decision was whether or not the concept affected the 20 mile electric range we had for our motor. The5next most important decision was the weight because that would also reduce the range. The other important factors include the size, the ease of mounting, and the ease of charging. The winner of this decision matrix was the two USB Battery Packs due to it being lightweight, easy to mount and charge, and it doesn't draw power from the 48 volt motor. Our first concept in which we draw power from the 48 volt battery would lower our range below our requirement of 20 miles and this is not acceptable. Our second concept with the motorcycle battery weighs too much and takes up too much space in addition to being difficult to mount in order for it be a viable option.

We decided that it would be best to only have two plug in sources for our tricycle, a plug for the low voltage battery and a plug for the high voltage battery. We decided this because we didn't want our user having to plug each separate component into an outlet because that becomes cumbersome. There are readily available USB hubs in which we can charge multiple batteries from one power input. After researching available USB battery packs, we found that 10,000mAh was the limit for most readily

available batteries. There were some batteries with a larger capacity, but they became increasingly expensive and exponentially larger. The battery that we found that was reasonably sized and less expensive than the rest is the USB Battery Pack sold by Adafruit. This battery has two USB ports, one port outputting 1 Amp, the other outputting 2 Amps. This battery is charged by a microUSB. Depending on our final design, we will need at least two of these batteries to power all of our low voltage electronics mainly due to the LED strips and headlamps.

An important consideration for our battery decision is what type of LED strip we are using. There are two choices for programmable LED strips compatible with our microcontroller. The first set is by Neopixel and has 60 LEDs per meter, whereas the other set, which is by Adafruit, has 32 LEDs per meter. Our initial thought was that more LEDs means better visibility so we want the Neopixel LEDs. After more research and some calculations, we found out that with our low voltage battery, we can only power 21 inches worth of the Neopixel LEDs, but we can power 42 inches worth of the Adafruit LEDs.

The battery can power the same amount of LEDs for each brand, the only difference is the distance between consecutive LEDs. With the LEDs spreading out over a larger area, we can place the LEDs across the tricycle instead of in a small concentrated location. This allows the tricycle to be more easily seen. The following table shows the different number of extra USB battery packs that would be required with each LED configuration and brand.

Technical Content

To decide which concept to use, we had to analyze the power usage of each concept. The analysis for this information can be found in Appendix H. Below, in Table 12, is a summary of the analysis.

Table 12. The required extra batteries based on each concept and each LED strip.

Concept	LED Strip Brand	Additional Amps Required	Extra Batteries Required
Perimeter Lights Concept (10 feet)	Neopixel	9	3 USB Battery Packs
	Adafruit	3.7	1 USB Battery Pack
Fairing Lights Concept (20 feet)	Neopixel	20	7 USB Battery Packs or 1 Large Motorcycle Battery
	Adafruit	9.5	3 USB Battery Packs
Back Top Lights Concept (42 inches)	Neopixel	1.7	1 Extra Battery Pack
	Adafruit	0	0 Extra Battery Packs

To confirm that we could utilize all of the sensors in our Back Top Lights Concept, we created a diagram which shows how all of the components are connected. This diagram can be seen below, in Figure 25. The red lines represent power distribution and the blue lines represent how the data will flow between sensors and the Arduino.

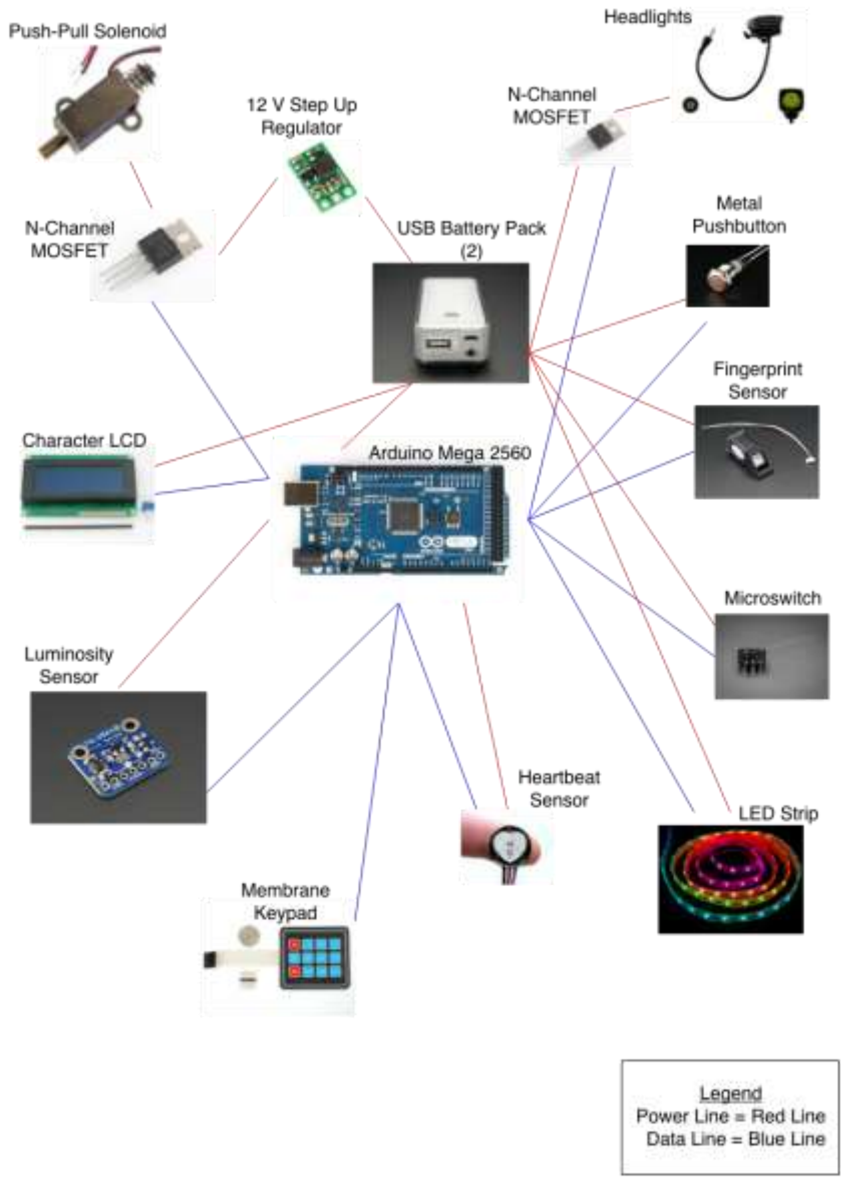


Figure 25. Component diagram of winning concept and all of its features.

From the electronics component diagram, we can see how all of the components will work together. Let us explain what each component's purpose; these purposes can be seen in Table 13.

Table 13. Purposes of all of the components and sensors in the final concept.

Component	Purpose
USB Battery Pack	• Powers all of the electronic components
Arduino Mega 2560 r3	• Receives input signals • Outputs data to control certain components
Push-Pull Solenoid	• Unlocks and locks the secure glove box
12 V Step Up Regulator	• Solenoid requires more than 5 V, this allows us to increase the voltage to 12 V
N-Channel MOSFET	• Allows us to easily switch power to the solenoid using the microcontroller
Metal Pushbuttons	• Allows rider to turn on turn signals • Allows rider to turn on hazard lights • Allows rider to start a specific function
Heartbeat Sensor	• Inputs heart rate data
Fingerprint Sensor	• Alerts Arduino if a valid fingerprint is present
Luminosity Sensor	• Alerts Arduino of the brightness outside
Micro switch	• Alerts Arduino when brakes are being pulled
LED strip	• Acts as our turn signals, brake signals, and hazard lights • Serves as an attention grabber so other drivers see the tricycle
Membrane Keypad	• Allows the rider to input relevant information • Allows the rider to control certain aspects of electronics
Character LCD	• Alert the rider of relevant information such as heartbeat, turn signals, glove box state, rider ID, etc.
Headlight	• Allows rider to see ahead at night

To explain the power distribution, let us start with the USB Battery Packs; each battery pack will has 2 output USB ports; one port outputs 1 Amp, the other outputs 2 Amps, both outputs are at 5 Volts. For the first battery, the 2 Amp output will be used to power the LEDs on our tricycle. The other output will be used to power the rest of the components, which include: an Arduino Mega 2560, metal pushbuttons, a fingerprint sensor, an LCD, and a micro switch. The second battery pack will be used to power the headlights and possibly more LEDs. We can wire it so that there is still one power input for charging, but that one input will split to charge both battery packs. This will simply make the amount of time charging a little longer to get to fully charged but make charging much simpler.

The heartbeat sensor and the luminosity sensor, will be powered by the Arduino. The heartbeat sensor will connect to the Arduino's 5 V output while the luminosity sensor only needs to connect to the Arduino's 3.3 V output.

All of the data will go through the Arduino, because this is the microcontroller that interprets all of the data and acts on it. The Arduino will receive data from the heartbeat sensor, luminosity sensor, membrane keypad, micro switch, fingerprint sensor, and metal pushbuttons. The Arduino will output data to the MOSFETs, LCD, and LED strip.

Storage

Concept Generation

Our first concept is the baseline for storage, the standard rear basket. This option is similar to those currently seen on the market and includes a basket on either side of the rear wheel. This pre-existing concept would need to be modified to fit our smaller wheel size (See Figure 26). This allows for simple storage of grocery bags, backpacks, etc. with no effort to set up needed. Although simple, this concept has a fairly large visual impact, as the baskets are rather large.

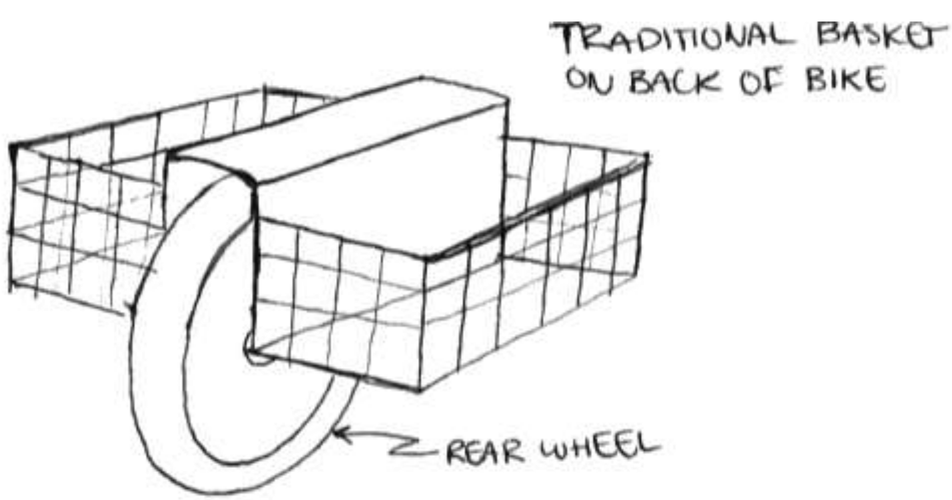


Figure 26. Standard rear basket attachment currently available on the market.

Our second concept is storage baskets that fold, it can be seen in Figure 27. This option is similar to the previous in terms of the two side baskets surrounding the rear tire. However, these baskets may be able to fold inwards towards the rear tire. In the folded position, these baskets would fit nicely against the tire. This allows for a smaller visual impact with some added complexity.

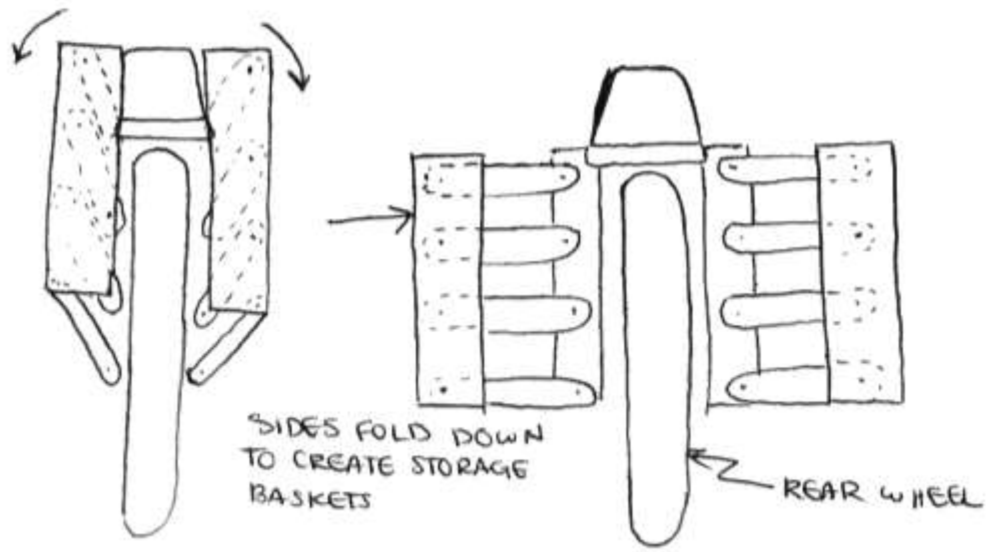


Figure 27. Folding basket concept in which baskets are in the upright position until needed.

Our third concept is having storage baskets that are modular; it can be seen in Figure 28. Also similar to the previous concepts, these baskets are modular and can be attached to or removed from the bike when necessary. When detached, the rear tire looks uncluttered and aesthetically pleasing. The bike will only have the visual impact of the baskets when the user has a need for storage. This can also reduce the weight that the user needs to lug around on the bike.

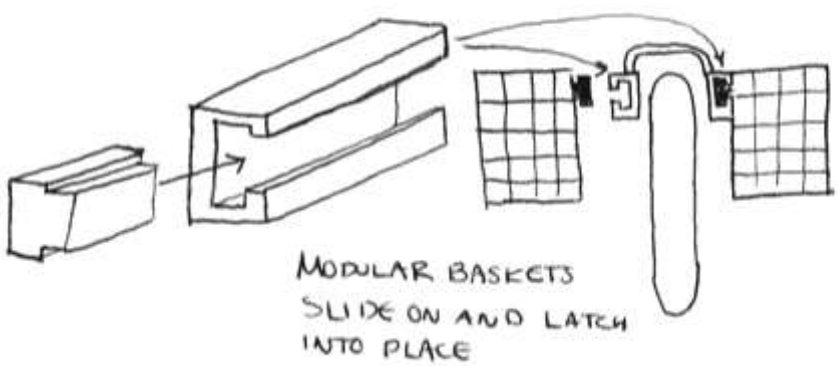


Figure 28. Concept sketch of a modular basket option. These baskets are removed when not needed.

Our fourth concept is a basket that replaces the back seat. Unlike the other concepts, this storage only applies when there is only one rider in the tandem. The basket makes use of the rear seat mount and allows a substantial amount of storage space surpassing that of the other concepts (See

Figure 29). This option not only has the obvious downside of requiring only one rider, but also requires additional time to remove the seat and attach the basket.

Figure 29. Concept sketch of the seat replacement basket option. This concept uses the seat mount for the rear seat for extra storage when there is only one rider present.

The fifth idea we came up with is a bungee net that creates a makeshift basket as seen in Figure 30. This concept also utilizes the absence of a second rider, but unlike the previous concept, does not require removal of the seat. Instead, the user would pull a bungee net from behind the seat and stretch it around the rear handle posts, creating a storage "box." This attachment would require little time and allows for much more storage space.

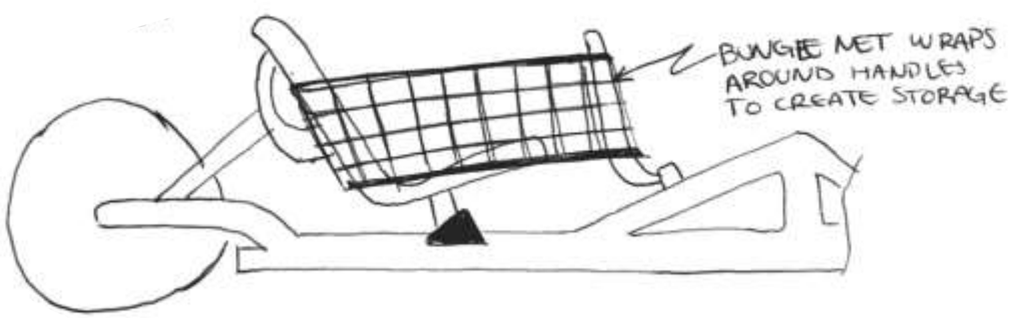


Figure 30. Bungee net storage concept in which a net is stretched around the seat and handlebars to create extra storage space with one rider.

Idea Selection

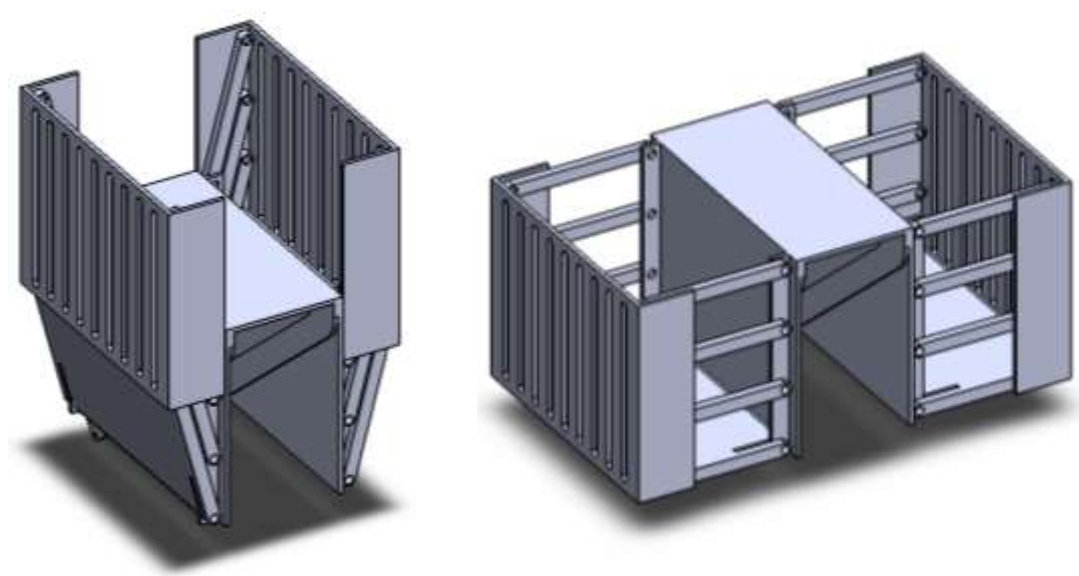
To narrow down these concepts to find the best concept, a Pugh matrix was created, which can be seen in Appendix I. The concepts were judged based off the baseline, a standard rear basket, for the following areas: storage space, availability, allows for 2-riders, visual impact, ease of use, weight, and

ease of installation. These metrics were given an importance rating between 1 and 5 and the concepts were given either an S for same, a (+) for a better performance, or a (-) for a worse performance.

After looking at the results from the Pugh matrix, options 2, 3 and 5 seem to be viable options, scoring 5, 5, and 4 points respectively. Moving forward, either option 2 or 3 or some combination of the both will be used for rear storage and option 5 will also be employed, as it requires little space and development while being able to store a substantial amount.

Technical Content

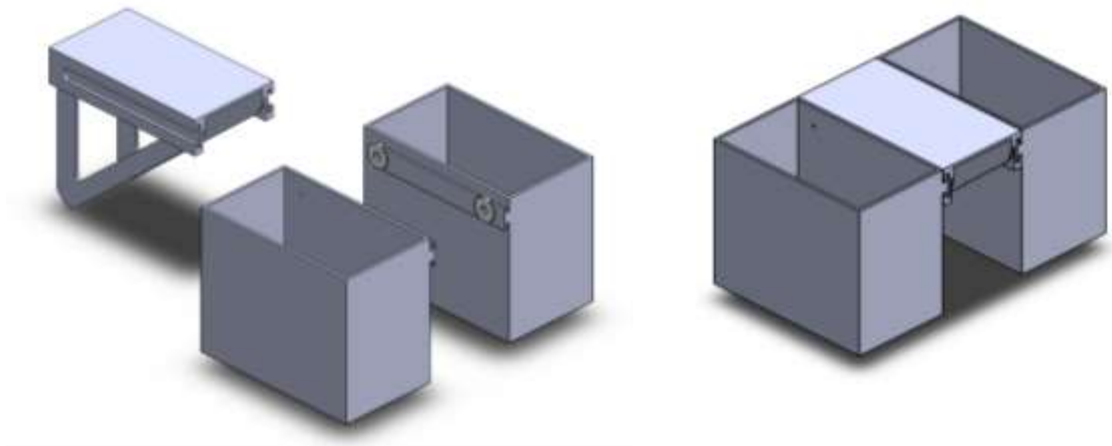
Figure 31 below shows the current state of option 2. In the upright position, (a), the storage baskets are folded inward against the rear tire of the bike allowing for a cleaner look. There is a simple latch mechanism at the top and mechanical stops for the bottom position that allows the baskets to stay in these two positions. When the bins are then put into the storage position, (b), the 13”X9”X11” bins may be utilized. This allows for 2,574 cubic inches of storage, or 1.5 cubic feet, around the rear tire. Each storage location is perfectly sized for a standard paper grocery bags (12”X7”X17”), and can fit most backpacks, purses, and laptop bags.



(a) (b)

Figure 31. CAD model of option 2 in both the upright (a) and storage (b) positions.

Instead of folding the storage in the above mentioned concept, the modular concept, option 3 (shown below in Figure 32) would simply have removable baskets that are only added to the bike when needed. The baskets are fitted with rolling wheels that fit into the slot of the base and click into place when slid in by a spring-loaded button. When the baskets are to be removed, the user simply presses down the button and rolls out the basket. This design allows for a clean look most of the time and only cluttering the bike when the storage is needed, such as going to the grocery store or going to work. These baskets are also sized for a common grocery bag and each measure 14”X8”X12”. This allows 2,688 cubic inches of storage space, which equates to about 1.5 cubic feet.



(a) (b)

Figure 32. CAD model of option 3 for the modular baskets in the detached (a) and attached (b) positions.

Both basket options would be made from a combination of basic mill and bending operations. The basic frame support around the rim would be cut out of Aluminum sheet metal and bent, then the different basket attach methods would be secured to that structure by welding or mechanical fasteners. The material of the baskets themselves would either be a bent thin aluminum sheet or a steel wire mesh for weight and durability purposes.

These options may also be combined creating foldaway baskets that may also be removed when needed. This allows for the most flexibility but also creates the most complexity.

When extra space is needed and there is only one rider present, option 5 (Figure 33 below) may be utilized. This is completed by pulling the bungee cargo net from behind the rear seat, stretching it around the handlebars and attaching the hooks to the other side of the seat. Extra hooks along the bottom of the net clip on to the bottom of the seat to make sure that no luggage can slip through the cracks. When utilized, this option allows for approximately 5 additional cubic feet of storage. The cargo net used for this application will be an 18”X58” bungee cargo net from *Manufacturer Express, Inc.* This net was selected due to its size and capability to stretch. According to the manufacturer, this net may stretch up to 36”X116” without being damaged (27).

Figure 33. Concept rendering of rear bungee net storage.

Fairing

Concept Generation

To come up with the best design possible for the fairing, it was necessary to come up with as many ideas as possible. Listed below are 9 of the best ideas along with the advantages and disadvantages of each.

Figure 34 depicts the first idea. In this idea, there are two sections to the fairing: a front, and a rear. There is no side coverage to the fairing, but there is coverage from the front, and the top as well. The rear section has aluminum tubing that provides the frame for the fairing. This section of the fairing contains a see-through fabric plastic sheet. The front section is a solid plastic sheet that latches into place at the front of the trike. This allows the rider to lift the front section of the fairing, sit down into the bike, and then lower the fairing into place. The rear section of the fairing does not move, but this is acceptable because it is much easier to get into the rear seat of the trike.

Figure 34: Concept 1, with a fabric rear section, and a movable hard plastic front section.

The second idea is found below in Figure 35. It is very similar to the idea that is found in Figure 34, with a few differences. The first idea has a stationary rear section, while this idea has a moving one. Both sections of the fairing, front and rear, have a roof that can be moved to allow the passenger to enter the tricycle. However, entering the vehicle is still slightly difficult with this design. This could be solved by making the entire front of the fairing modular, but that could cause some problems in providing stability to the fairing.

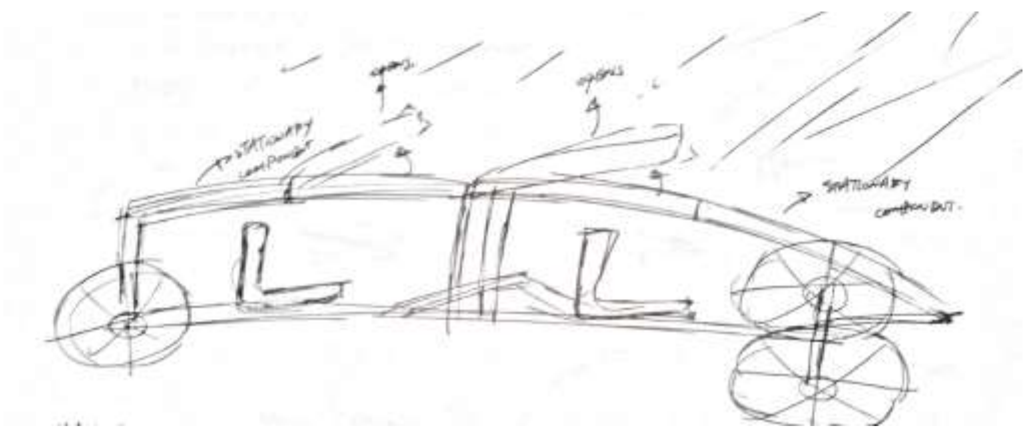


Figure 35: Concept 2, with a movable section for both the front and rear sections.

Figure 36 shows one solution that is already widely implemented; it is known as a partial fairing. The main positive of this design is the availability, while the main pitfall is its effectiveness. The main purpose of the fairing in our design is to protect the rider from light rain. The partial fairing does not protect from rain; it is meant to decrease aerodynamic drag. The upper-most surface of the fairing is located below the head of the rider. Even though this concept doesn't protect the rider from light rain, it is important to look at this idea so we can understand how to adapt a similar design to our project.

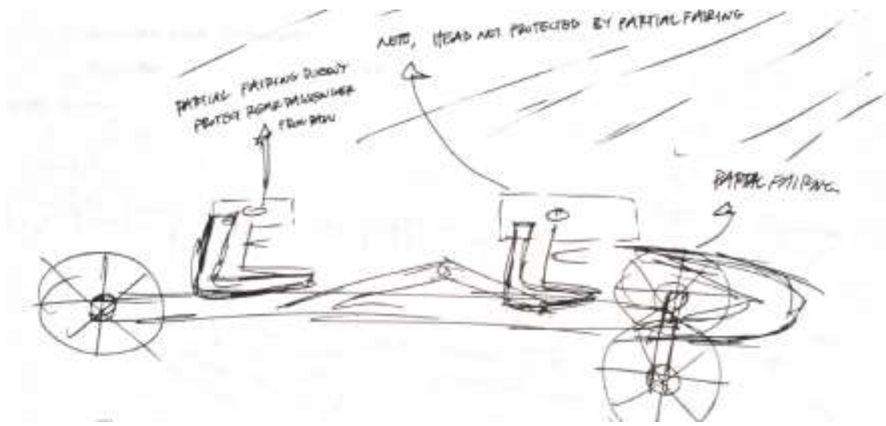


Figure 36: Concept 3, a partial fairing.

Figure 37 shows another common solution to the weather problem. Many fairings are full fairings, which means that there is coverage on both sides as well as on the top. In fact, vision is achieved via a “windshield” in the front of the fairing. This fairing is extremely effective when it comes to protecting the rider from rain but it limits the rider’s visibility. The visibility is even worse for the person in the rear seat. Additionally, it is very difficult to climb into the fairing, and a full fairing takes much more development effort and money than we have available. However, this is another design that is important to understand, so that we can use its positives in our design.

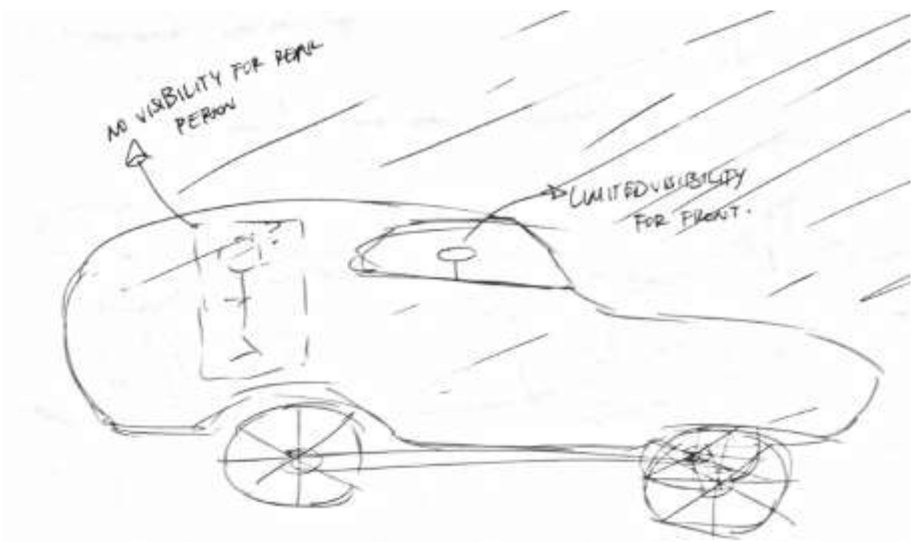


Figure 37: Concept 4, a full fairing

Figure 38, depicted below, shows a design in which the fairing is one section. The fairing is made of a hard plastic sheet, and it is connected to the frame of the bike. When the riders wish to enter the bike, they rotate the fairing back, moving it out of the way. Then, when they are seated, they pull the fairing down to latch it into place. There does, however, need to be a good amount of support to the plastic sheet. This means that there will be structural bars to hold the fairing plastic in place, which means that there will be some blind spots for the rider.

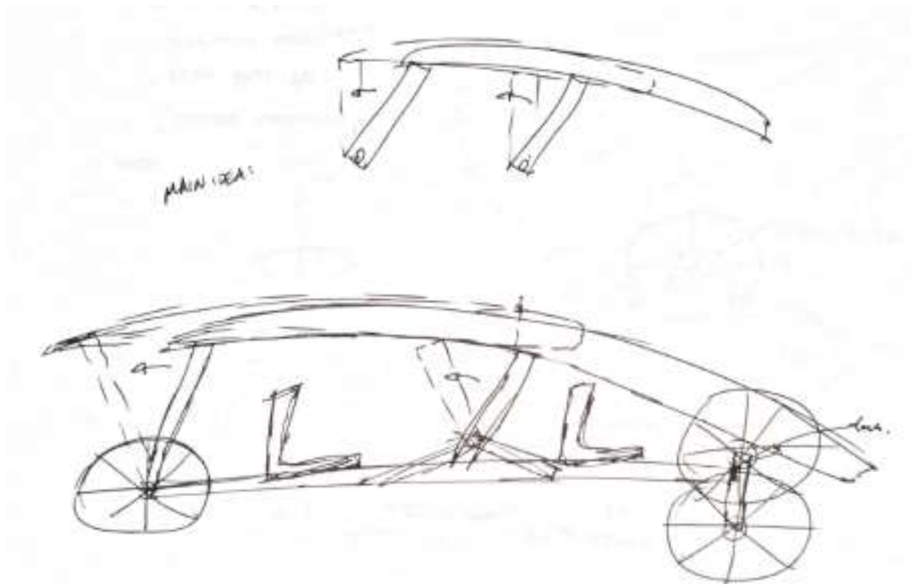


Figure 38: Concept 5, one large hard plastic fairing with two members for rotation.

Figure 39 shows an idea that has two moving parts. Both parts are constructed of hard plastic, and they both have fixed-axis rotation systems. The rear part rotates counterclockwise, allowing the rear rider to enter the car easily. After that rider gets in, they can latch the system into place. Similarly, the front section of the fairing rotates out of place, allowing the front rider to get into the trike. Obviously, it is not a perfect design. Rotating the front fairing out of the way does not allow the front rider to enter the trike very easily; the fairing is still slightly in the way.

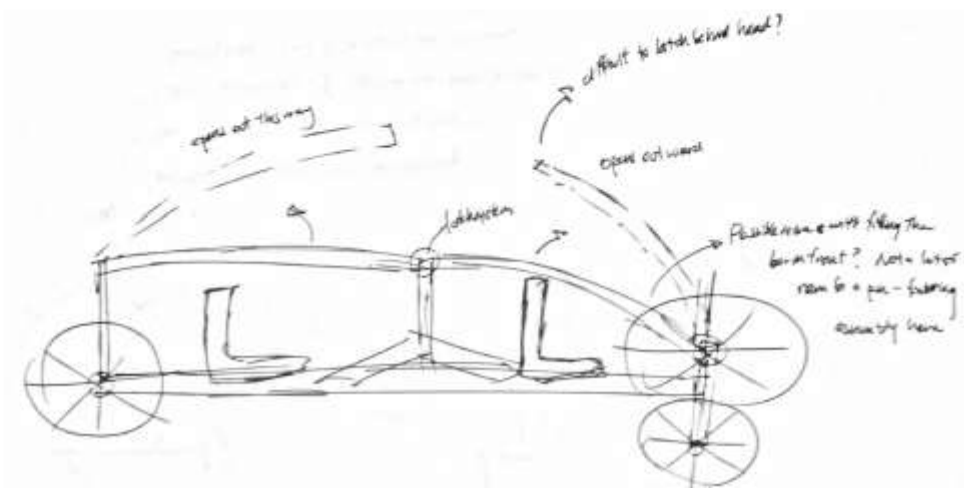


Figure 39: Concept 6, with two fixed-axis of rotation sections to the fairing (both hard plastic)

Figure 40 depicts a conceptual design that mainly allows a way to fix the fairing to the bike. There is curved bar that can be fixed to the bike, and a plastic sheet that can be attached to that bar. The most difficult thing to overcome in this design is how to make sure that the rider can easily enter the trike from the front. Additionally, this design contains a box on the back of the design. This box helps provide a structural base to put the fairing structure on; it also provides a case for the battery that protects the battery from weather.

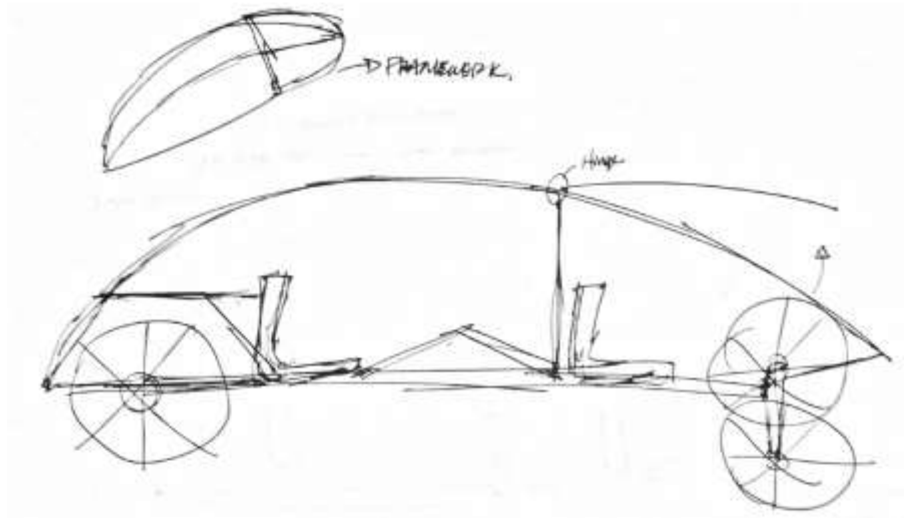


Figure 40: Hard plastic front with fixed-axis rotation, connecting to the storage unit in the back.

Figure 41 demonstrates an idea that attacks the issue from the side, as opposed to the front. The frame is set up so that the rider can sit in the trike, and then they can pull a bar from the right, all around the profile of the car, over to the left. This bar will unravel a cloth fairing, and it will surround the car with that fairing. However, it is difficult to get this design to work perfectly every time, and there are some shortcomings when it comes to using a fully cloth fairing. The shortcomings greatly outweigh the benefits, but it is a good way to think outside the box.

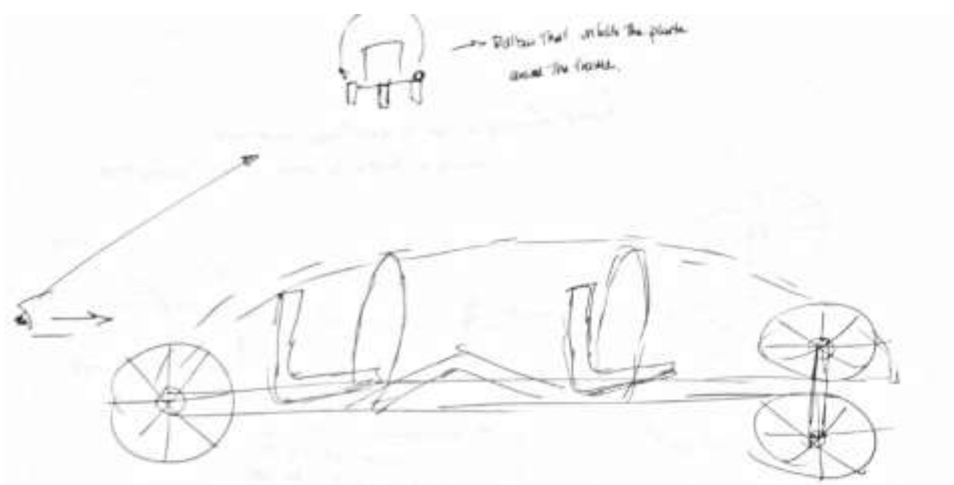


Figure 41: Concept 8, with a rollbar, and an unrolling fairing on the side.

The ninth idea is merely a combination of the other 9 ideas. As shown in Figure 42, the rear section of the fairing is a cloth fairing (preferably see-through), and it is held in place by straps that pull the fairing back towards the rear of the trike. Around the wire is a box mentioned in the previous figure that serves the dual purpose of protecting the battery from weather and providing some structural

stability as well. The front section of the fairing is a hard plastic that can be rotated out of the way, to allow easy access for the front rider. This idea pulls the best aspects from many different designs.

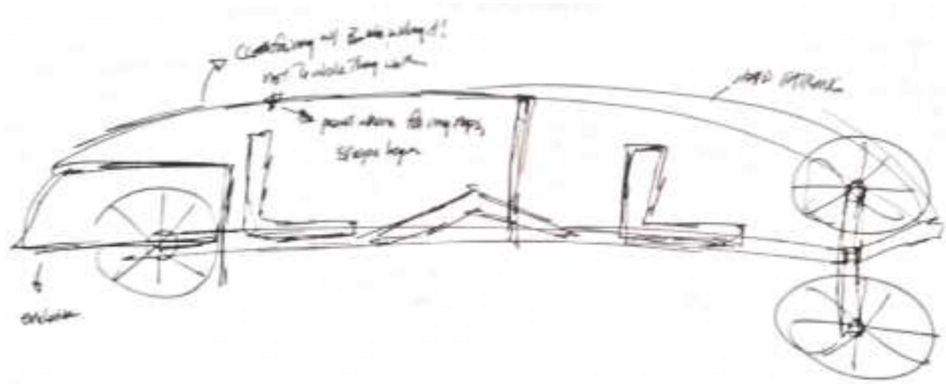


Figure 42: Concept 9, with a cloth fairing in the back, connected via wire to the storage assembly, with a hard plastic fixed-axis of rotation front section for the fairing.

It should be noted that in all of these designs, some type of wheel cover is necessary – this will prevent the rain on the ground from being flung onto the rider. Additionally, this might even help provide a solution when it comes to fixing the fairing to the bike frame.

Idea Selection

In order to down select our ideas, the ideas were put into a Pugh matrix. Pugh matrices are a useful tool for quantitatively comparing ideas to each other, and finding the strengths and weaknesses of each idea. This matrix can be found in Appendix J. In this matrix, each idea was compared to a datum; our datum was the partial fairing concept. The partial fairing concept is an appropriate datum because it is a type of fairing that is widely used and it is commercially available. The hope is that the fairing on this bike would be even better than the fairing that is most widely used. There is a column on the table that is titled “Weights.” This column is meant to provide a quantitative measure of the relative importance of each parameter. For example, having good rain protection (with a weight of 4) is much more important than having low aerodynamic drag (with a weight of 1).

The more heavily weighted parameters included entry difficulty, rain protection, and design effort. This trike is meant to replace a car in as many scenarios as possible. A car is extremely easy to enter and exit; if a fairing made it more difficult to enter the trike, it would be a large deterrent to riding this bike. However, if the fairing was made so that it was still very easy to enter the trike, then more people would want to ride it. Rain protection is highly weighted because the main purpose of the fairing is to protect the rider from light rain. If the fairing does not successfully accomplish this goal, then it is simply not worth it to have a fairing on the trike. Lastly, design effort is a parameter that is very important. This team has just 7 more months to finish designing, building, and testing this trike. If the design of this fairing cannot be finished in the next 7 months, then it is not worth it to develop. The concepts that are easy to enter and exit, that protect the riders from the rain, and that are simple enough to design in 7 months are the ones that constitute the best ideas.

The Pugh matrix shows that idea number 9 is the best idea. This idea is remarkable because it is so lightweight. The rear section, shown in Figure 42, is a cloth fairing that is held in place by two cables

that hold tension between the back of the cloth fairing and the rear storage unit. Because tension is holding the assembly in place, a frame for the rear section of the fairing is not necessary. This is advantageous because most of the weight of the fairing comes from the frame. The less frame there is, the less weight.

The front section, shown in Figure 43, is a hard plastic piece with fixed-axis rotation. To enter the trike, the front rider will simply lift up the front section of the fairing, climb into the seat, and close it. This section is made of hard plastic to maintain its structure under the forces of wind. Because this section is made of hard plastic, no frame is necessary; this cuts down on weight even more. There will be a structure placed behind the front seat; this will be the connection point between the front and rear fairings. At this connection point, there will be two hydraulics, one on the left of the bike and one on the right; they will help make the movement of the front fairing smooth. Additionally, there will be a fixture on the front of the bike that will allow the front section of the fairing to click into place, and stay there until released. This design will allow both riders of the trike to enter easily, see the road with minimal blind spots, and be protected from the rain.

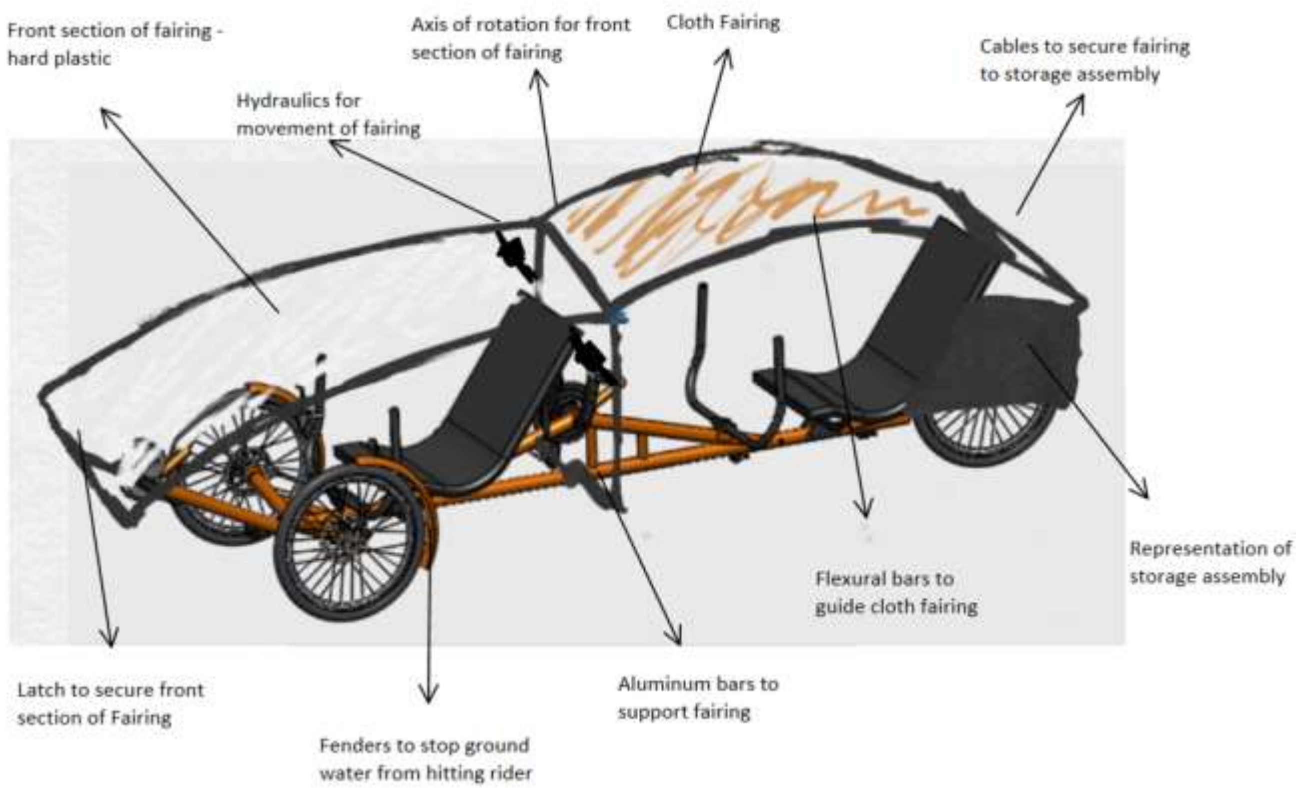


Figure 43: The final concept (similar to concept 9 in Figure 20)

Technical Content

The main concern, where preliminary calculations are concerned, is with the weight of the fairing assembly. The Terratrike has a relatively small weight limit of about 450 lbs; it is important for the fairing to be as light as possible (26). As shown in Appendix K, the estimated weight of the fairing and the aluminum bar that supports it is just over 10 pounds. This leaves about 440 pounds for other

things on the bike. Of course, there will be a few more pounds added as hardware is added to the bike, because this weight is so light, that is not a large concern.

Although the overall design has been outlined, there are still many things to determine. For example, the exact material of the fairing has not been chosen. There are many materials that are available and appropriate for use in a fairing application. Most of these materials would work very well in this specific application. In order to narrow down and pick a material, we will create a final design for the shape of the fairing. We will then get feedback and price quotes from plastics manufacturers. It seems most likely that we will choose ABS plastic, because it is so available, easy to form, and cheap. However, it would be short-sighted to make this decision without consulting someone who works in the plastics field. Also, we will have to do a full analysis of typical forces on fairings to see how our specific shape will deform under forces supplied by wind and rain. It is possible that we will need a plastic stronger than ABS to fulfill our needs. Additionally, a simple latch system has to be developed for the fairing to latch into place; this should not be very difficult. Lastly, putting some sort of hydraulic cylinder to control the movement of the fairing also needs to be designed which is also not very difficult.

In manufacturing the fairing, there will be only three manufacturing processes. We will be machining a lot, to make fixtures to attach our parts to the bike frame. Along the way, we may have to weld a few parts together – especially when it comes to the structural support for the fairing. We may also manufacture the plastic fairing. However, if this is too much for us to do, then we will have a manufacturer make it for us. The limiting factor in this case is time. When we finish manufacturing the bike, we will come to a time of testing and validation. For the fairing, the biggest test will be how it holds up against wind at riding speeds. To test this, we will probably test the structure inside a wind tunnel, so that we can get quantitative measurements for the deformation of the structure. If that passes, then we will do the same thing outside, to get an idea of what will happen in real-world circumstances. The goal here is to design a structure that will deform as little as possible. The less deformation, the less the risk of damaging the plastic fairing.

Theft Protection

Concept Generation

The concepts generated for theft protection include three products: BikeSpike, Bike+, and SpyBike. More details on these three products can be found in the theft protection background section or in Appendix L.

Idea Selection

The features found in Appendix L were taken into consideration in the pairwise comparison, found in Appendix M. The pairwise comparison determines which features are the most important for a theft protection system. We comparison showed that size was the most important aspect of this product. The product's attachment style and whether or not it had a mobile application also played considerate roles in choosing the product. Using the results, we created a decision matrix in which we were able to rank the three products. The decision matrix can be found in Appendix N.

Based on the results of the decision matrix, our first choice is BikeSpike, our second choice is Bike+, and our last choice is SpyBike. BikeSpike was the winner due to the fact that it was less expensive and had a better attachment style than Bike+ but included many more features than SpyBike. Bike+ came in second place because it had many more features than SpyBike, but the fact that it didn't have

bicycle profiling or a specified attachment style really hurt its score. SpyBike was the simplest of all three products; it could track down your bicycle but was missing many of the features the other two products had.

We contacted BikeSpike and Bike+ only to find out that neither of them are in production yet. They will not be in production by the time that we need our theft protection system. This means that SpyBike is our only choice. It wasn't our first choice, but it completes the task it was assigned to do – to make sure that your bike is found.

Preliminary Design Model

After all of our concept generating and idea selecting, we created a physical model that incorporated different aspects of all of our subsystems. This model can be found in Appendix O. The point of this model is to be able to see the trike, fairing, and storage components working together. This will give the reader an idea of the size of the trike and its components.

Final Design

Figure 44: Final design rendering.

The final design is a mixture of the chosen ideas from the preliminary design; it can be seen above in Figure 44. The design will have a fairing that rotates in the front; this allows the front rider to enter/exit the tricycle easier. The back rider will be covered by a cloth fairing. There will be brake lights, turn signals, an LCD, a keypad, buttons, and a security system in addition to the motor and battery used to assist the rider. There will be a couple storage options. There will be two baskets behind the second rider in addition to a bungee net that will convert the second seat into one large basket.

There are a few improvements and changes that will be implemented since our preliminary design. The fairing will now consist of a thin film to save weight and money. The security system has been simplified by using a product called Lock8, which has GPS capability in addition to a tamperproof

locking mechanism that alerts riders if their bike is being harmed. There will now be one LED strip behind the back rider with two turn signals located on the front of the bike. Previously there was a second LED strip placed in front of the rear rider but after testing the LED strips, we found that the LEDs will be quite obnoxious if placed directly in front of the rear rider. The last significant change from the preliminary design is the battery. After further calculations, a higher quality battery will be used to power to tricycle. All of these considerations will be discussed in greater detail in the following sections.

Motor

Overall Description of Design

As previously stated, the Bafang BBs02 750 watt mid-drive motor was motor that was selected to help assist the trike. Repeating what was stated previously, the motor is designed for easy installation in which it will replace the front crank set of the trike and will be installed into the front bracket. This will allow the trike to keep all of its gears due to the fact that there is only one cassette in the front. Figure 45 below shows the mounting location for the motor in addition to the motor controller which will be integrated into the fairing's front latch structure.

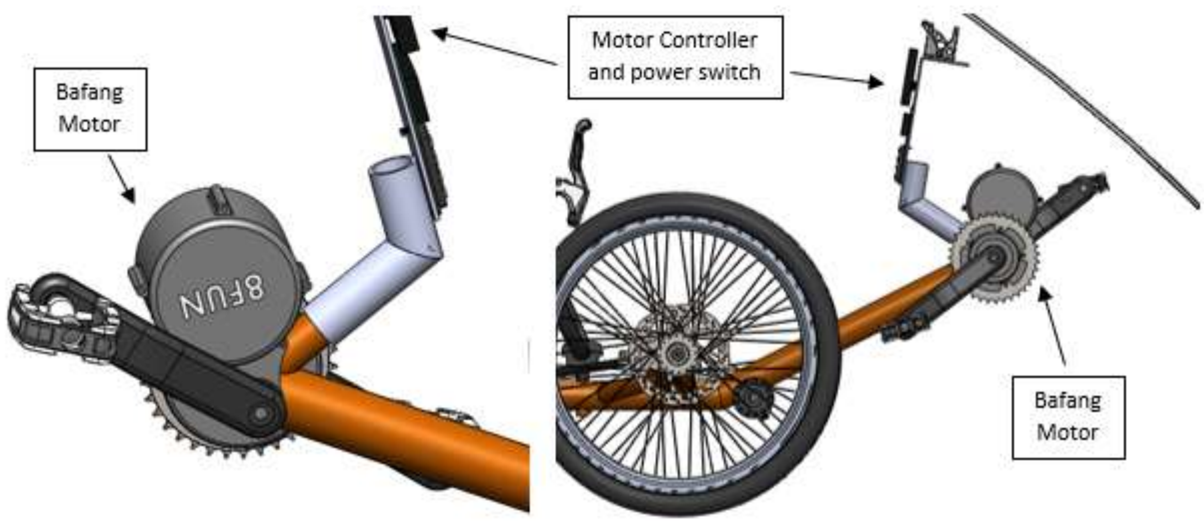


Figure 45: The image on the left is the Bafang motor integrated into the front bracket. Pedals and sprocket attach directly to the motor. The image on the right shows how relatively small the motor is compared to the rest of the bike.

Detailed Design Description

Since our trike and the motor will be equipped with an independent pedaling system (IPS), the motor will be able to run without moving either of the rider's pedals when operating. Although, at least one of the riders must be pedaling in order for the pedal assist option to work on the motor. For the pedal assist option, the motor controller allows for 9 different levels of assist ranging in speeds from 15-31 mph. Due to the U.S government's restriction of speed on "Low-Speed Electric Bicycles", the motor

can only assist up to 20 mph, so the controller will be modified through its advanced options menu to restrict the speed of the motor to 20 mph (24).

There are many other features to this motor which includes a throttle, motor brake, wheel speed sensor, and a power switch. The throttling option is available in addition to the pedal assist which allows the rider to accelerate to their desired speed without any pedal input required. This component will be mounted to the front rider's right-hand handlebar. The motor brake is a brake handle that will apply an electrical brake on the motor in unison with the trike's brakes when the brake is pulled so that the motor immediately stops moving along with the bike. This special brake handle will replace the currently installed one. The wheel speed sensors will be responsible for informing the rider how fast he or she is going in addition to providing speed information to the motor controller. The controller requires this feedback information in order to calculate how much additional torque is needed in order to maintain a constant speed. This sensor will be mounted to the rear wheel as per the installation instructions and will require additional wiring due to the length of our bike. The power switch is responsible for completing the circuit from the battery pack to the motor and will be mounted next to the motor controller, LCD screen, and keypad for the convenience of having most buttons and screens in the same location.

The majority of the motor's wiring will be located along the left hand side and along the center frame of the trike in order to keep away from the chain and rotating sprockets. The only two sets of wires extending the full length of the bike is the high voltage battery wire and the wheel speed sensor wire. These wires will need to be extended from their standard lengths because the kit is meant for standard bicycles. As a result, we will use 12 gauge wire as the extension to the battery and use off-the-shelf extensions for the wheel speed sensor because those wires require special waterproof connectors.

When it comes to the installation of the motor, there are a variety of installation tutorials available online for us to follow, Youtube.com being the best one with many detailed videos showing exactly how the parts go together and mount. We also have the support of a Bafang motor specialist, Doug Snyder from California E-bikes, who is able to help us with any trouble we may run into if problems occur during the installation process.

Analysis Results

For the motor, analysis was completed in unison with the battery in order to calculate the speed, distance, and battery duration for each of the nine settings on the motor controller. Please read over the analysis result in the High Voltage Battery section for a more in-depth explanation of our analysis.

Maintenance and Repair

There is very little maintenance for the motor. The main concern is to keep the motor and the surroundings clean. In addition to ensuring that the motor is clean, the sprocket needs to be inspected to confirm that it is not seeing any significant signs of wear. If the sprocket is wearing down, then it will need to be replaced to ensure that the motor is functioning correctly and efficiently.

If the motor or any of its hardware fails within the first year, it needs to be sent back to Bafang Motors who can be reached at http://www.szbaf.com/en/service/contact.html. If it fails in the first year, it is under warranty. If the motor fails after the first year, unfortunately this motor will not be able

to be repaired at most common bike shops. We recommend contacting Bafang Motors to seek advice for the best course of action.

High Voltage Battery

Overall Description of Design

The battery pack we initially decided upon, the Golden Motors lithium iron phosphate 48V-10Ah battery, ended up being turned away after a discussion with the representative of California E-bikes, Doug Snyder. He said that that battery would barely meet the 20 mile requirement that we had set for our design. He recommended a 15-20 Amp hour 48V battery that was capable of providing a continuous 40amp or more of current. He also gave us some input in how to optimize our calculation for the sizing of the battery. Revisiting our calculations, we optimized our excel Battery and Performance Calculator (Appendix Q) to calculate what size battery we would need for the Bafang 750W motor. From our new calculations we found that a minimum of 12Ah - as to the previous calculation of 8Ah - would be needed in order to meet our 20 mile requirement. When we were researching again there were not many 48V 12Ah batteries capable of providing a continuous 40 amp or more of current. Of the batteries we looked into already there were, however, a few that were capable meeting the new specifications. Revisiting the decision making process (Appendix P), we compared the previously updated and newly added batteries through a weighted decision matrix and came to the conclusion that the Ping Battery lithium iron phosphate 48V 15Ah battery was the best option for this project. A dimensioned picture of the battery can be seen in Figure 46.

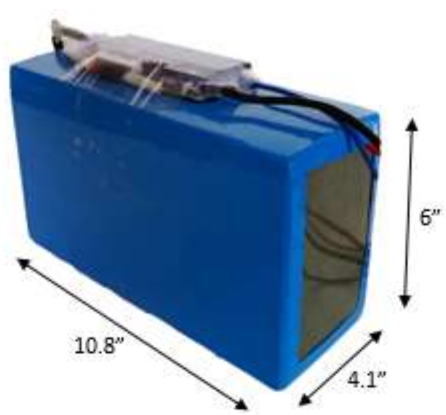


Figure 46: Ping Battery 48V-15Ah and its dimensions

Rated as a 48V 15Ah battery with a max continuous amp output of 60 amps, we calculated that we would be able to achieve a max distance of about 28.9 miles. This exceeds our requirement of 20 miles theoretically, but the actual performance will vary. Testing will need to be carried out to validate the accuracy of our calculation and assumption. Our calculations assume that the trike does not stop, the motor is continuously providing power, and the original hill times were from biking unassisted up a hill at 8 mph.

Analysis Results

The calculator we developed takes into account the motor performance specifications, the duration of max amp draw from the battery to the motor, the number of assist levels used by the motor controller, and the battery specifications of the battery into which we are looking. The performance

specifications of the motor were provided online from a manual that was provided by *lectriccycles.com*. The motor controller setting and amp limits were given to us by Doug Snyder from California E-bikes. The duration of the max amp draw was determined by physically testing how long it took us to bike up hills; for hills that took 60 seconds or less to climb we categorized them as a small hill. For hills that took between 60 and 150 seconds to climb we categorized them as medium hills. For hills that took over 150 seconds to climb we categorized them as large hills. Initial hill times were determined from personal tests with bike speeds ranging in speeds from 6 mph to 10 mph. For our calculations we averaged the span and went with 8 mph.

By categorizing the hill sizes, placing standard time limits/distances for the type of hills, and counting the number of the types of hill, we were able to estimate the projected total uphill distance that would be traveled and the amount of time that the maximum number of amps would be drawn from the battery pack at each of the motor's nine settings. For the purpose of this calculation we used a pre-determined 20 mile route that would go from Cal Poly to Avila Beach. This ride consisted of four small hills, six medium hills, and two large hills.

The last part to our calculator was the specifications of the battery that was to be analyzed. Using the Ah rating of the battery as the main parameter in this calculator, we were able to calculate the minimum Ah needed for our system through trial and error until we reached a theoretical distance of about 24 miles (safety factor of 1.2 to be safe). The minimum rating, as previously stated, was 12Ah for a 48V battery. Because we decided to go with the Ping Battery, which has a 15Ah rating, we calculated that we could theoretically go 28.9 miles on a single charge (safety factor of 1.45 using 20 miles requirement).

Detailed Design Description

Having decided on the Ping Battery as the power source to our motor, we needed a way of protecting the battery from the elements (water mainly), protecting the battery from being damaged (no protective casing), protecting people from the high voltage (shock hazard), and preventing the battery from being stolen (expensive). Even more importantly we needed to find a location on the bike that would hold the battery without interfering with the rider. The solution we came up with involves the usage of an ammunition box in combination with a rear rack for the trike.

We decided to use an ammunition box for the application of holding our battery mainly because ammunition boxes are durable and are meant to keep one's gun ammunition dry and secure. Water, security, protection, and safety are some of the biggest concerns with this battery and the ammo box is able to serve all of these needs. The box is molded from polypropylene plastic which is tough and durable. It comes with a reinforced bottom allowing it carry up to 30lbs. The lid is sealed with an O-ring making the box moisture resistant. This box also offers a heavy-duty latch with double padlock tabs meaning the lid will be tightly sealed and box can be securely locked to prevent other people from accessing the battery and potentially harming one another. See Figure 47 below for storage orientation.

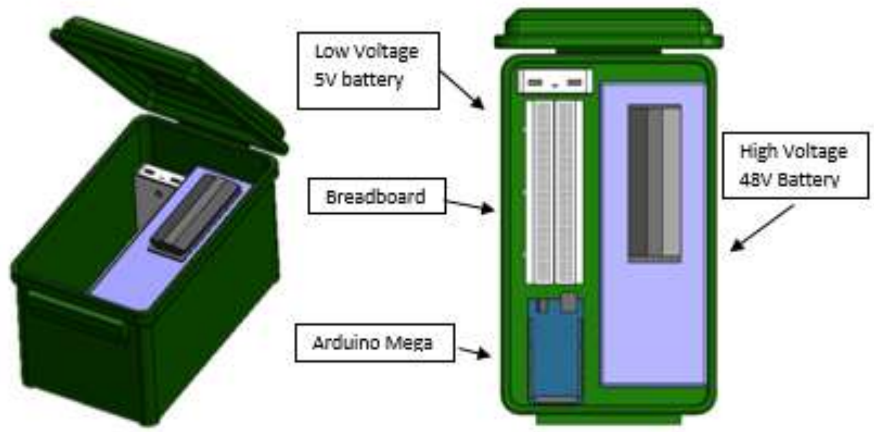


Figure 47: Model of how battery will fit inside the ammunition box in addition to the orientation of some of the additional low voltage electrical equipment

The ammo box also serves the function of holding some of the low voltage electronics. These include the Low Voltage 5V battery that powers all the electronics in the trike such as the LED lights, headlights, LCD screen, heartbeat sensor, etc.; a breadboard which will be in charge of distributing that power provided by the battery and sending signal commands to all the other components; and the Arduino Mega which is in charge of controlling and monitoring all the electronics.

Another concern we had was finding a box that would be able to withstand the possible high operating temperatures of the lithium iron phosphate battery. The battery itself has the potential of reaching operating temperatures of up to 203°F (95°C) (29), but fortunate enough for us the ammunition box is made of polypropylene plastic which has a melting temperature of 266°F (130°C) (30). As far the as the electronics go, the Arduino Mega has a max temperature limit of 257°F (125°C), the breadboard has a max temp of 220°F (105°C), and the low voltage 5V battery has a temperature limit of 100°F (37°C). A battery insulation sleeve may be necessary for both or one of the batteries to keep the batteries relatively cool, but further testing will need to be conducted to verify the true operating temperatures of both the batteries. If the inside temperature of the ammo box is still too hot for the low voltage 5V battery then we will move that battery into a smaller water tight electrical box that will sit on top of the lid of the ammo box.

The next issue is where to mount the ammunition box that will hold the battery. The solution we came up with is to bolt the battery box to the rear rack we plan on using for the trike. The rear rack (See Figure 48 and 49 below) has a plate along the middle portion that will allow us to drill holes though and bolt the battery box to. Bolts will be inserted in through the battery box and out through the rack plate. The bolts will then be secured with lock nuts. An additional strap will go around the battery box as an additional level of security.

Figure 48: Side view of Battery Box and Rear rack

Figure 49: Battery box sitting on rear rack. Showing the plate the box will be bolted to

Safety Consideration

Since we are dealing with a high voltage battery (48V), electrocution is our biggest hazard and we are taking extra precaution to prevent injury wherever we can. However, we will be making sure that all high voltage wiring will be covered meaning no bare copper wire is exposed. All high voltage containers will be labeled as such along with all high voltage wires. For our design, we will only be having one high voltage box that is completely insulated in plastic and can be locked to prevent access. There will also only be one pair of high voltage wires running the length of the trike from the battery to the motor.

We spoke with Ben Johnson, Cal Poly's Electrical supervisor, and he concluded that we should have no problems with our design. The limit for arc flashing is 50 volts, and we are just under it at 48 volts. He warned us of a power switch for the battery, which we have included in our design. His last concern was to ensure our design has a fuse so our equipment doesn't fail; the battery contains a Battery Management System (BMS) which has a fuse built into it. When everything is assembled and ready for testing Ben will overlook our system one last time before any power is provide to the system to be sure everything looks safe.

Maintenance and Repair

If anything were to happen to the battery such as loss in performance, loss in voltage, loss of all power, or any other type of problem, we first recommend looking online for similar issues that might have been experienced and resolved by other owners. Do not disassemble the battery from its packaging for any reason, for there is a higher risk of electrocution and risk that the warranty will be voided if you do. If the solution cannot be resolved or resolved easily, email Ping Battery directly at pingping227@hotmail.com and they will assist with the problem or take the battery to a specialist.

Security

Functional Description of Final Design

The trike we are building will be very sophisticated, therefore it will need an equally sophisticated security system. For this, the security system we will be using is currently in development

and is called Lock8. This device is mounted in the back of the bike near the rear tire and serves as both a physical lock via a cable lock as well as a LoJack system. Lock8 has features such as iPhone locking/unlocking, GPS tracking, geofencing, sound alarm system, and tamper alerts. The device can tell when any part of the trike is being tampered with, which is a huge benefit with a large tandem tricycle with expensive parts mounted on it. The Lock8 system may be seen below in Figure 50.

Figure 50. The Lock8 system being unlocked via an iPhone app.

Supporting Analysis

Previously, in our preliminary design review, we planned on using a combination of a common ABUS frame lock and a separate LoJack by SPYBIKE. The previous decision to go with the SPYBIKE LoJack came from the fact that the other options we were currently looking at, Bike+ and BikeSpike, wouldn't be available by the time we needed them as they were in the earlier stages of development. Due to SPYBIKE's lack of features, we felt that the bike wasn't properly protected from tampering with the bike or stealing expensive components.

This system surpasses the engineering specifications set for our tandem tricycle due to its many features. The iPhone locking/unlocking allows for quick access to the trike, much shorter than the 30 seconds allotted in the specifications. Also, the many tamper alerts protect the trike from thieves trying to disable the alarm system by overcooling, overheating, or cutting off the device.

Electronics

Functional Description of Final Design

The final design of the tricycle's electronics include quite a few different components. The most important components are the ones used to ensure the safety of the rider. These items include: an LED strip, turn signals, micro switches, a headlight, and turn signal buttons. The turn signal buttons allow the rider to indicate when he/she is making a left or right hand turn which then illuminates the corresponding part of the LED strip in addition to two turn signals located towards the front of the

tricycle. The micro switches measure when the rider pulls the brakes and then illuminates the center part of the LED strip with red light to indicate to other riders that the tricycle is braking. There will also be a headlight that will be illuminated by the microcontroller when the rider pushes the corresponding key to do so.

In addition to these safety components, the tricycle will also have an LCD, keypad, and heart beat sensor. The LCD and keypad will allow the rider to input relevant information to the microcontroller about the rider. The heart beat sensor will be integrated into the handle so that the user will be in contact with it is long as he/she is holding onto the handles. This sends the heart rate to the microcontroller which then calculates relevant information to display on the LCD.

Supporting Analysis

The main analysis for the electronics can be found in the electronics section of the preliminary design report. The calculations can be found in Appendix H. The new analysis can be seen in Appendix R. This is a wiring diagram that shows exactly where each pin will go for each component. There is supporting analysis which demonstrates the flow chart of the microcontroller, this can be found in Appendix S. The microcontroller can work in the states shown in the flowchart. Some of the states include riding mode, turn signal mode, or create a rider mode. In riding mode, the microcontroller will calculate the calories burned and how long the rider has been active. In turn signal mode, the microcontroller recognizes that one of the turn signal buttons was pressed and turns on/off the turn signal. In create a rider mode, the user is inputting information to create and store new rider information. These are just a few of the possible states, the rest can be seen in Appendix S.

Testing

The best way to test all of these parts is to first ensure that they work individually. Before explaining all of the code, take a look at the wiring diagram, found in APPENDIX X, to see how the different components interact with each other.

To test the keypad, we wired the keypad's 7 pins to a breadboard and then to our microcontroller. From there, we set up the program so that when a button is pressed, the microcontroller relays that key to the computer so we can see what is being pressed. This code can be found. To sense the numbers pressed, the microcontroller senses when a pin is connected to ground because when a button is pressed, it connects that pin with ground. Numbers or letters (depending on the application) are assigned to each pin. When a pin is pressed, the microcontroller uses that input to perform its next task. To first test the keypad, whenever a key is pressed, we printed the corresponding number to the computer screen.

Another part that needed to be tested is the LCD. To test this we connected the correct wires to the microcontroller and ran code that outputs letters to every possible location on the LCD to ensure that all parts are working and that the LCD outputs what we expect. To start off we simply output a sentence to the LCD. After this, we combined the keypad and LCD functionality. This code takes inputs from the keypad and displays them on the LCD. This code can be found online at github.com (31). Key presses as an input and then also times how long in between each key was pressed. We measure the time in between because there are times when the user will need to input his/her initials similar to the way that old phones used to text. This works as each key contains 3 or 4 letters. For example, the 2 key would contain A, B, and C. To type C, the user would need to push 2 three times quickly. There is a lot

of logic that goes into making this happen, but it basically measures the time difference between each key press and if it is less than 1 second or so, then it assumes it is a completely new key press. An example of how this setup works can be seen in Figure 51.

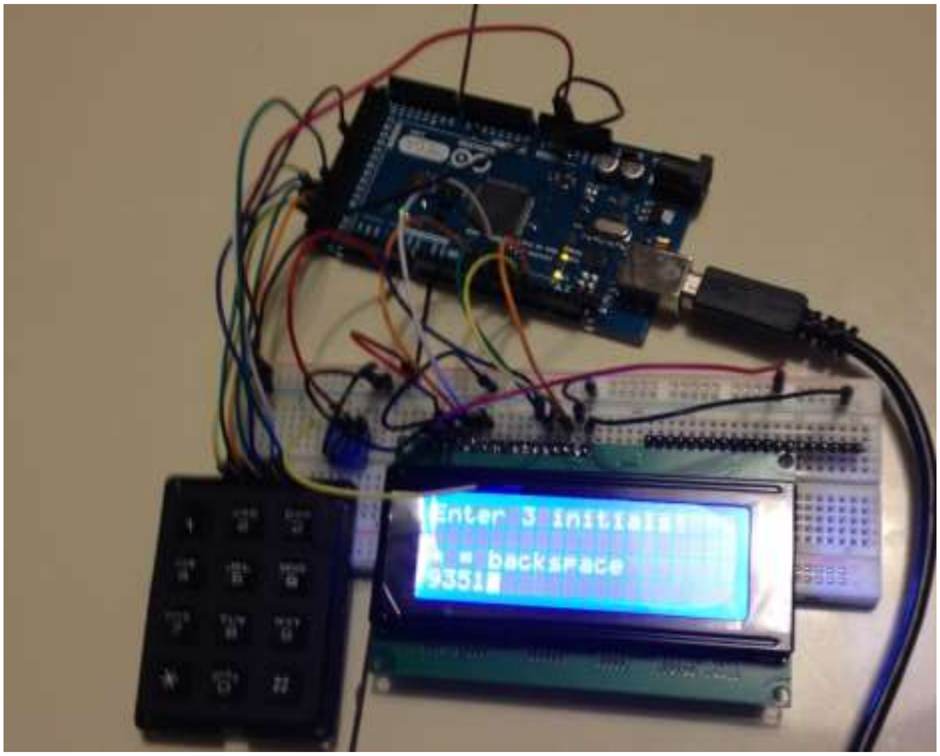


Figure 51. Example of how the keypad and LCD are used to interact with the microcontroller.

We also needed to confirm that the headlights would run on 5 volts. We contacted the manufacturer asking about this information but they would not tell us. To test this we used a voltmeter to measure the power supply input going into the headlight; the power supply was 5 volts which is good news for our system because it primarily runs on 5 volts. This makes it simpler so that we do not have to add a regulator or a boost converter. We then connected our battery to our adapter and then to the headlight to ensure that it would illuminate, which it did.

We also needed to confirm that the LED strip was functional and working correctly. To test it, we first soldered attachments to the strip so that we could easily attach pins/wiring to the strip. We then powered the strip using our battery, and connected the clock and data pins to our Arduino. After this, we used code to test the turn signal and brake functionality of the LED strips. The code functions using two button inputs and an LED strip. If it receives an input from the button labeled as the left turn signal button, then it turns on the left turn signal until the button is pushed again. This turn signal function works by turning on the left third of the LEDs to orange and then starting a timer. After about half a second or so, the lights will toggle on or off; this gives the lights a flashing turn signal appearance. There is also a micro switch that will be connected that will be connected to the microcontroller. The micro switch will be mounted so that whenever the brakes are pulled, it will activate the micro switch

which will send a voltage. As long as the micro switch is sending a voltage to the microcontroller, then the brake lights will remain illuminated. Examples of the LED strip being used can be seen below.

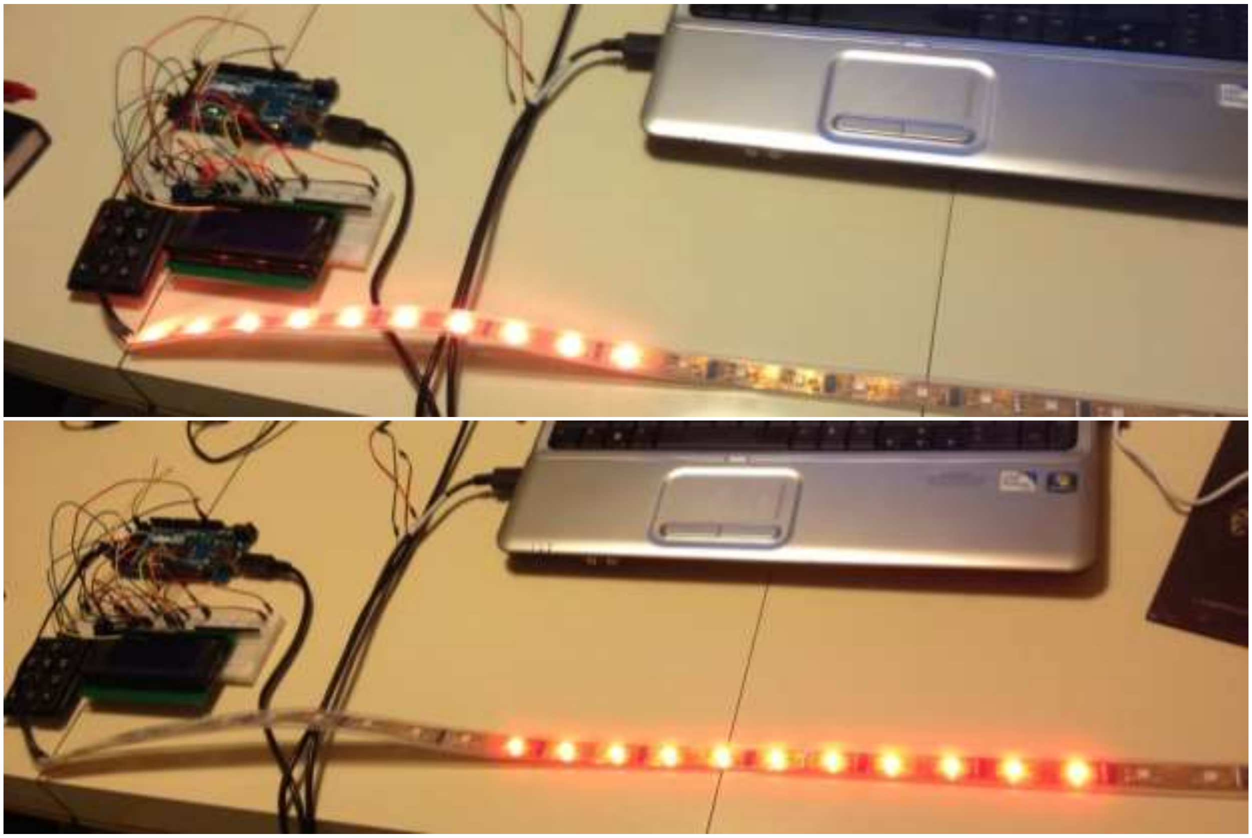


Figure 52. Demonstrating the different pixels illuminating on the LED strip.

Another important aspect of this system is the ability to store rider information. This process is more difficult than originally thought because Arduino's typical memory is deleted every time the microcontroller is reset or loses power. This would be a problem, because we do not want each rider to have to input his/her age, weight, gender, and recommended heart rate every time he/she rides the tricycle. To avoid this problem, there is a way to permanently store data in Arduino's. To do this, we have to store information byte by byte in the microcontroller's Electronically Erasable Programmable Read-Only Memory (EEPROM). Storing data in this manner is tedious and requires complicated data management. We wrote code (found online at github.com (31)) that demonstrates this ability. We tested it by writing a rider's information to the Arduino's EEPROM, we then turned off the power to the Arduino. Next, we turned the Arduino back on and read the information in the EEPROM to find that the original data was still there.

To help us keep data managed, we had to create a class for each rider. Each rider has certain information that is important such as the rider's: initials, recommended heart rate, gender, and age. The rider should only have to enter this information once and creating a class was the best way to organize all of this information. The header file and cpp file that correspond to this class can be found online at github.com (31). This class information was used in the testing of the EEPROM to confirm that the EEPROM could write data from our own class, we confirmed that this was possible in the EEPROM test code.

Another important piece of hardware that we needed to test is our Pulse Sensor Amped. This piece of hardware measures the rider's heart rate. To test this we supplied power to the heart rate sensor. We then connected the data pin from the sensor to the Arduino. Before we could actually use the heart rate sensor, we needed to ensure that the moisture from our hands didn't create problems with the small electronics. To do this, we had to apply hot glue to the back of the sensor. Hot glue is a wonderful tool in the world of electronics as it won't alter the connections but insulates the sensor effectively. The code used for the Pulse Sensor Amped can be found online at github.com (31). The test program simply blinks an LED with the user's heartbeat.

Mounting

The LCD and the keypad will be mounted in front of the front rider. Both of these electronics will be bolted to a plate near the rider's knees. The LCD and keypad are meant to be mounted so they have four holes in them that are meant to be nailed or screwed into. We also have two micro switches that have two holes each. We will attach these to the holes near the center of the wheels. We will then shape the long, thin metal wire coming from the micro switch to activate when the brake is pulled.

The headlight will be located on the beam between the front two wheels. NiteRider makes a nice mount in which the headlight sits on top of the beam with a band that wraps around the beam to secure the headlight. This band allows the headlight to be adjusted relatively easily but ensures that the headlight is secure. We will be using this band to secure the headlight. We are initially going to use one headlight because each headlight with the mounting material costs $50-$60. We will test this set up by biking around at night to see if the one headlight provides enough light, if it does not then we will be another headlight to mount on the other side of the beam that we are mounting the first headlight.

The LED strip will be attached to the back of the rear seat using Velcro and glue. We will sew the Velcro to the back of the seat and then glue the other part of Velcro to the LED strip. We are choosing this mounting method because the fabric on the seat is flexible and can be moved for each rider. This makes a permanent connection between the LED strip and the fabric very difficult and inconvenient. Also the fabric is able to be removed on the tricycle, but if we permanently added the LED strip, then the rider would not be able to replace the fabric.

The last few components that we need to worry about include the two turn signal buttons and the heart beat sensor. The two turn signal buttons need to be located conveniently close to the rider's hands and the heart beat sensor needs to be touching the rider's hand in order to receive accurate readings. To do this, we designed a hand grip that we will 3D print that will go around the left handle. This grip will have an indentation for us to place the heart beat sensor in so that the user's hand will be in touch with the sensor without it jutting into the rider's hand uncomfortably. The turn signals will be placed in the grip at a convenient height so that the rider can comfortably push the buttons without extending his hands or taking his eyes off of the road. An isometric and exploded view of the controls grip may be seen below in Figure 53.

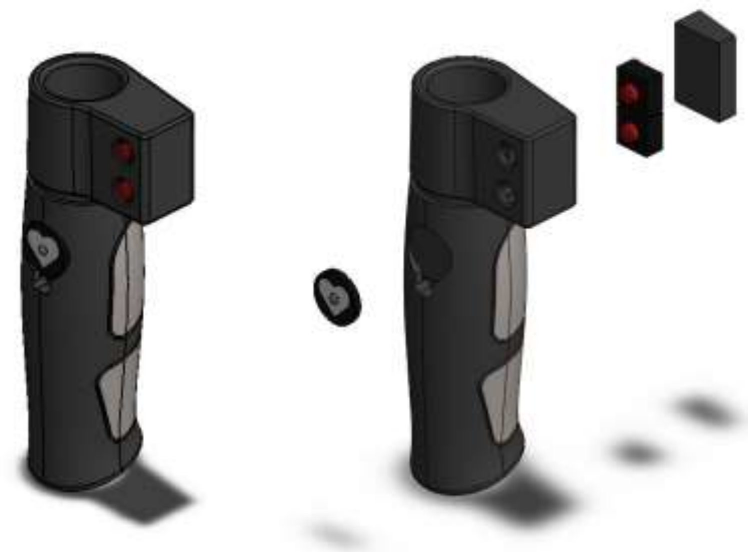


Figure 53. The controls grip in both an assembled and exploded view. The toggle switches will activate the turn signals when pressed and the pulse sensor will provide the user's heart rate.

In order to install the controls grip, a specific process must be followed. First, the buttons must be inserted into the cavity with their wires routed through the slot shown in Figure 54. Once the buttons are installed, apply hot glue to backs of buttons and apply backing piece, sealing off interior components.

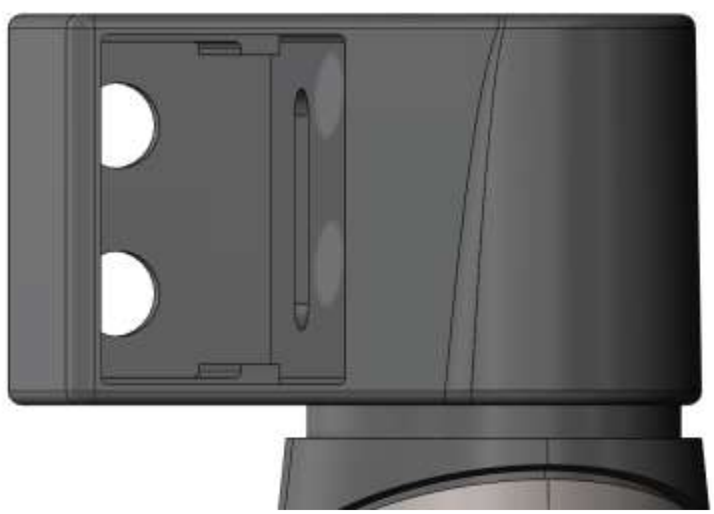


Figure 54. A depiction of the interior cavity of the controls grip. The slot allows for the cables to be nicely hidden inside the handlebars of the trike.

Next, the pulse sensor will be hot glued on the circular cutout with its wires running through the inner trough depicted in Figure 55.

Figure 55. The mounting location of the pulse sensor (left) and the cable routing trough (right).

After these components are installed, route the wires through holes in handlebars and slide grip assembly onto handlebars.

Material Selection

This part will be 3-D printed using an ABS Plastic due to its complex shape and our inability to cheaply compression mold rubberized plastic. Although the grip will be hard plastic, it will still be comfortable due to the contours that match the hand.

Maintenance and Repair

The electronics on this tricycle need to be kept clean and most importantly, dry. We have put the electronics battery and microcontroller in a weatherproof case, but there are a few components that are a little more open to the environment that need to remain dry. The LCD, keypad, and micro switches need to be kept dry also. These components are under the cover of the fairing but if there is extreme rain and/or wind, these components should be wiped dry with a towel or cloth as soon as possible while still remaining safe, as in do not try to dry the components while biking. The heart beat sensor should also be kept dry, but we have insulated it with hot glue to make it more water resistant. Having said this, the rider should still use caution to not get excessive amounts of water on the heart rate sensor.

If there are any problems with the electronics, the first thing to do is ensure that the battery is charged. If the battery is low or empty, the electronics will behave oddly or not work at all. If charging the batteries doesn't solve the problem, then ensure the wiring is still secure. Confirm that none of the wires loosened during riding or became dislodged as this will cause many problems. If some of the wires did come undone, refer to the wiring diagram in Appendix R to reconnect the wires. If the batteries are charged and no wires are undone, then try resetting the microcontroller. This can be accomplished by accessing the weatherproof box in the back of the tricycle. There is a microcontroller with one button in the middle of it. Press that button, the electronics might take a second to reset it; give the microcontroller a few seconds to allow it to load its programming and then check if the problem has been solved.

Future Work

Something that we will add in our future work section is our secure glove box. The total idea is to have a small box with a solenoid and a fingerprint sensor integrated into it. The fingerprint sensor would be located on the top of the box with the solenoid located inside of the box. When there was a matching fingerprint, the solenoid would retract, which would allow the user to open the box. Unfortunately, we will be putting this project in the future work mainly due to budget concerns. The fingerprint sensor alone is $50 and we are running out of money quickly.

We are considering implementing the glove box minus the fingerprint sensor; the glove box would open and close based off a passcode entered on the keypad at the front of the tricycle. We have been working on some code for this project, it can be found online at github.com (31). We hope to be able to get to this section of the project but seeing as it is an added feature and not required for the safety of our rider, it is being added to the future work section. The brake lights, turn signals, and headlights are all safety concerns that need to be handled first. We also need to work on the heart beat sensor because this is a requirement from our sponsor so this must also be implemented.

Another aspect of the project that we will place in the future work section is implementing a luminosity sensor. This sensor would be used to turn on/off the night time mode automatically. It would do so by measuring the light, and if it was below a certain threshold it would signal to the microcontroller to turn on the night time mode. We are adding this to the future work section because we would need a waterproof enclosure that was still open to the sunlight. This enclosure and this sensor are rather expensive for a feature that is not necessary. Night time mode can be turned on by simply pushing a button so as of right now, this sensor and the designs that go along with it are going to be placed in the future work section.

Storage

Functional Description of Final Design

The final design for the rear storage includes an off the shelf rear storage rack from TerraTrike and two Sunlite collapsible pannier baskets. These baskets are mounted to the TerraTrike rack by means of basic nut and bolt mounting provided with the baskets. When the baskets are needed, the user simply pulls the basket out, unfolding the assembly and locking it into place by swinging the base down. Similarly, when the baskets are no longer needed, the user folds the baskets flat by pushing up the base and folding the sides inward. The TerraTrike rack and Sunlite baskets may be seen below in Figure 56.

Figure 56. The components of the rear storage assembly. On the left is the TerraTrike rack and on the right is a Sunlite collapsible pannier basket.

If additional storage is needed and only one rider is present, extra space may be made available by stretching an 18” X 58” bungee net around the handlebars. This net is located in a zippered pouch attached to the back of the seat.

Supporting Analysis

Previously, the design called for a custom-made rear rack with built in collapsible baskets. The decision to switch to the off the shelf configuration, was due to its cost reduction, ease of manufacturing, weight reduction, and overall confidence in the design.

Buying off the shelf parts has the obvious advantage of little to no manufacturing necessary to make the finished product. While the off the shelf configuration needs only to be screwed on, the custom-made rack had over 100 parts. Although these parts were common, off the shelf components (angle iron, U-channels, pop rivets, dowel pins, etc.), many had to be modified and then put together to create the overall product. With modifications, there will be some mistakes and therefore reworked or wasted material. This is something that cannot be estimated, but would need an additional allotment in the budget so that it does not become an issue in the future. In addition to wasted material, the manufacturing process alone would take a significant amount of time (~25 hrs.). This is time that could be better spent on fine-tuning other parts of the project.

As the rear storage rack was designed using conservative approximations, the overall rack is much heavier when compared to the off the shelf version. These conservative approximations accounted for eccentric loading and variable profile (ends of tubes were crimped for easy attachment points) of the tubing, and dynamic loading of bolts and pins in double shear.

The dynamic load factor was found by using an iPhone accelerometer to measure the Gs seen from the racks perspective when riding over curbs, bumps, etc. Although this gave a repeatable value, there was still some lack of confidence with the testing methods available for the project budget. Taking these factors into consideration, the off the shelf alternative seemed to be the better option to pursue.

In order for the rear storage to meet the design specifications, it must have a storage capacity of 2 ft^3 (including additional rear seat storage) and must be able to hold 50 lbs of cargo in in the rear only. The rear baskets measure 13” x 8-5/8 ” x 8-5/8” (0.56 ft^3 each) when deployed and can fold up to only a

couple inches wide when not in use. Each basket weighs 2.75 lbs and is rated for a 24 lb load. The additional bungee net storage offers 5 ft^3 of extra storage space, exceeding the specification by about 4 lbs. Similarly, with the 10lb cargo of the batteries supported by the rack, and an additional 24 lbs in each basket, the total weight of the cargo carried is 58lbs, surpassing the 50lb specification.

Maintenance and Repair

As the storage assembly is made up of off-the shelf parts, little repair will be needed. Replace with common off the shelf parts readily available in bike stores if any part breaks. If the baskets have issues with folding, WD-40 may be applied to the joints.

Fairing

Functional Description of Final Design

The next part of the design was the fairing. The fairing assembly consists of many small components, and each of them has been given a particular geometry and material, in order to satisfy the structural requirements. Below is a detailed picture of the final design of the fairing assembly.

Figure 57. Rendering to show the final fairing design.

Originally, we had a strong desire to make the front half of the fairing a solid plastic sheet. The reason behind this was that it would be rigid enough to eradicate the need for any kind of frame to follow the profile of the shape. If there was no need for a frame, then there would be no blind spots caused by that frame, which is ideal. However, as the design process continued, we realized that using heat to form a quarter-inch thick piece of polycarbonate was time consuming, complicated, and nearly impossible to get right the first time. Given our desire to keep a low budget, we looked for an alternate idea. Additionally, the thick sheet of plastic brought up a few concerns about maintenance. If the sheet was damaged at all, it would cost at least 200 hundred dollars (including shipping) to replace it. It would also take hours of labor and tedious work to perfect the shape of the fairing.

Given the difficulties in the design above, we looked towards other ideas from the past. After examining multiple ideas, it was decided that the aluminum frame with thin (0.040 inch) polycarbonate

sheet stretched across the shape would be the most advantageous design. The thin polycarbonate sheet is substantially cheaper than the thick piece in the previous design; additionally, the cost and difficulty of replacing the fairing is lower. In the final design, the fairing of the bike is made up of a thin polycarbonate sheet stretched across a thin (3/8") aluminum frame. There are two axes of curvature, because this helps disperse the forces that are felt by the plastic fairing.

The top end of the fairing is bolted to two aluminum brackets that are in turn TIG welded to a 1.5 inch diameter aluminum tube. The aluminum frame that supports the fairing is fixed to these brackets through the use of loop clamps. These loop clamps (pictured in Figure 58) use rubber to prevent the tubes from moving out of place; in addition, they can be tightened to increase the compression that holds them still. These brackets also have bent aluminum tubes that are welded to them; these are meant to act as handles to lift and lower the fairing. This design works well because it puts the force directly on the aluminum frame which in turn spares the polycarbonate sheet from unnecessary stress.

Figure 58. The loop clamps that will fix the frame to the brackets.

The purpose of the 1.5 inch diameter tube (mentioned previously) is to allow the fairing to rotate. This rotation happens because there are two bushings on in the inside of the large shaft. These bushings are held in place by two snap rings fall into the profile of a small groove on the inside of the tube. There is also a one-inch diameter shaft that spans the entire width (two feet) of the fairing support structure. An exploded view of this assembly is shown below, in Figure 59.

Figure 59. Exploded assembly view of the support structure.

The internal shaft on this assembly has a 1 in outer diameter with a 0.5 inch inner diameter. It is also a stepped-diameter shaft; that is, the middle 19 inches of the shaft have a diameter of 1.125 inches, while the remaining 6 inches (on the ends) has a diameter of 1 inch. The purpose of this design is to prevent the bushings from sliding towards the center of the shaft. This feature, combined with the effect of the snap rings, ensures that the bushings do not move from their desired locations. Bushings were chosen as the rotating elements because this scenario is a relatively low-stress, low-rpm scenario. A high performance ball-bearing is simply not needed for this application. This decision will be discussed quantitatively later. It should also be noted that the internal shaft is fixed on both ends, so it never rotates.

The inner shaft (mentioned above) is held on either side by a U-shaped bent aluminum tube. The tube is of 1-inch diameter, and it is about 63 inches long. This bent tube is then connected to a rectangular aluminum tube that is projecting upward from the bike frame, as shown to the right in Figure 60. Note that the rectangular aluminum tube is notched, so that the 1-inch bent aluminum tube will slide into place. Then, there is a steel bracket that wraps around the bent aluminum tube, and the bracket uses rivets to connect to the rectangular aluminum tube. Rivets were chosen because the aluminum structure will always be on the bike, so it is a permanent assembly. Quantitative analysis were also used to justify the use of rivets in this situation; this will be shown later.

Figure 60. The tube will extend up out of the way of the rider's legs to support the fairing.

This rectangular aluminum tube is connected to the frame of the bike by using similar brackets (with rivets) as described above. Originally, the rectangular aluminum tube was going to use a bracket to connect to the top bar of the trike frame, and that would have been sufficient. However, in order for the bar to stay vertical, the bracket would have had to grip the frame very tightly. This produces two more problems – first, the tolerances on the bracket and the notched end of the rectangular aluminum tube would have had to be extremely small. Even if those dimensions had been achieved, there is a considerable amount of torque that would be going straight into the frame of the bike (an estimated 45 ft*lbf). To avoid these problems, a second rectangular aluminum tube was added to connect to the lowest bar on the bike frame.

Because this second tube was added, it makes the stability of the fairing design rely on the entire frame of the bike, as opposed to a steel bracket. This is favorable because our bracket is 0.25 inches thick steel, while the frame of the trike is made of 1.75 inch chrome moly steel (which is significantly stronger). Rivets are used to fix all of the brackets in place, because (as stated before) it is a permanent assembly, and there will be no need to replace it.

The rear fairing, on the other hand, is a cloth fairing. The fabric used for the fairing is lycra, a spandex-like material that is extremely popular in the building of cloth fairings. Lycra is not typically used for protecting from a light rain, so we found it necessary to order a sample of the material and conduct some testing to observe the behavior of the material when water falls on it. The material became extremely discolored, and it took a long time to dry. Additionally, water fell through it with ease. Although lycra is not the best material to use for this application, it is still a highly recognized material in the biking community, and we believe that this will help the project gain traction with bikers. To compensate for the poor performance where water is concerned, we will insert a film of plastic (like an even thinner version of polycarbonate sheet) between the two layers of lycra; this will allow the aesthetics of lycra, while maintaining the performance of a plastic sheet. A form is given to the lycra by .25-inch diameter fiberglass poles. Fiberglass is a material that is commonly used in the manufacturing of tent poles, and it is also used to provide the structure for the lycra to stretch across in cloth fairing applications. The fiberglass rods (as shown in Figure 62) stretch out from the center fairing assembly, and they project towards the back of the trike, where it collides with a 90-degree bend adapter, that in turn connects to two fiberglass rods that are inserted into the holes located on the back of the chair.

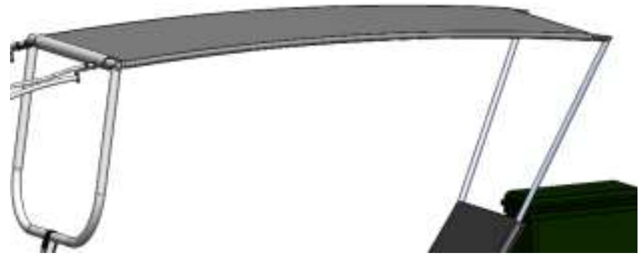


Figure 61. The cloth fairing and its supports.

Figure 62. The heads up display that holds the motor controller, LCD, and keypad for user interaction.

On the very front of the bike, there is a small latch assembly. This assembly serves two purposes: first, it holds in place all of the electronic interfacing components. Secondly, it holds a latch that holds the fairing in place. The latch is actuated by a lever (bike break lever), which pulls the enclosed cable (break cable), releasing the latch. This lever is located conveniently under the front seat so that the user can simply pull the lever while sitting down. From the outside, this lever is still accessible as it is on the side where no fairing is blocking. A rendering of this assembly may be seen in Figure 61. The validity of this design will be discussed in the analysis section.

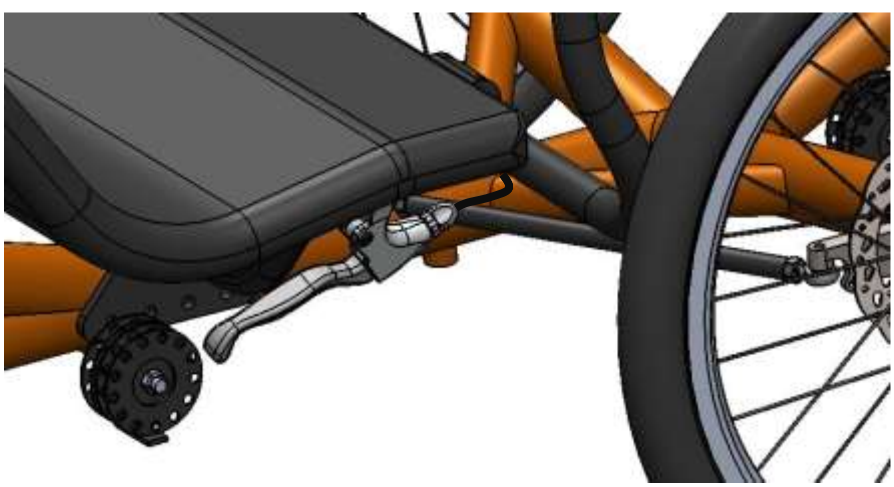


Figure 63. The location of the fairing release lever. Once pulled, the fairing will release, allowing the user to exit the trike.

The part and assembly drawings for each component can be found in Appendix Y.

Supporting Analysis

After researching common materials for a see-through fairing, polycarbonate and ABS plastic were the most common and cheap materials available. There is a great deal of difficulty in working with thick sheets of plastic. On the one hand, ABS is known for being easy to form using heat; however, it is difficult to find and expensive to buy a completely transparent piece of ABS plastic. On the other hand, polycarbonate is much more tedious to form using heat; however, it is almost always transparent, and it is not difficult to find. In the end, we decided to go with an aluminum frame design for reasons that have been listed already.

Figure 64. The frame of the front fairing.

Initially, when the design involved a thick slab of polycarbonate, the main concern was deformation. In an effort to decrease the deformation, a plastic was chosen that had a high enough modulus of elasticity to minimize the amount of deflection in the profile of the fairing. However, now that the design involves an aluminum frame covered by a much thinner sheet of polycarbonate, the deformation of the frame is not as much of a factor. The new frame has a much stronger modulus of elasticity (that of aluminum) and the weight is only 6.7 lbf, which is just about a third of the previous weight. The calculations to prove this are found in Appendix U***.***

After the weight of the fairing was found, the next step was to determine the structural effects of the entire fairing structure on the trike frame. In order to do this, the weight of every component of the fairing assembly was calculated, and all of the worst-case scenarios were assumed. In addition, the weights of the passengers, battery, and motor were also accounted for. The weight of the fairing will be held at two points: at the front of the trike (by the latch) and at the fairing support structure (at the back of the fairing). For this calculation, it was assumed that all of the weight of the fairing was located at the fairing structure. Then, a free-body diagram was drawn to represent all of the forces acting on the structure of the trike. This diagram was normalized to a single cantilever beam of 4130 chrome moly steel, with a 1.75 inch outer diameter and a 1.58 inch inner diameter. The maximum moment along the profile of the trike frame was 620.2 ft*lbf, and the associated stress associated with this moment was 42.15 ksi. For 4130 chrome moly steel, the ultimate tensile strength is 97.2 ksi, and the yield strength is 63.1 ksi. Because the maximum stress along the profile of the trike frame was so much less than the yield and ultimate strengths of the material, the design for the aluminum fairing structure was valid. The calculations that were performed in this analysis were originally geared towards a fairing that

consisted solely of a thick sheet of polycarbonate. Because the updated design is lighter and stronger, the calculations above still prove that the structure will not cause failure in the trike frame. In fact, the factor of safety will be even higher than it was before. These calculations can also be found in Appendix U.

Because the fairing structure is so rigidly connected to the frame of the trike, cyclic loading is only related to the vibrations and roughness of the road that the trike is riding on. Additionally, the shape and fluid performance of the fairing may reveal cyclic loading where the fairing structure is concerned. This information is too complicated to derive analytically, so estimates obtained via analysis will be used to select components that will not cause failure. Then, once the bike has been assembled, forces and vibrations will be tested to determine to what extent fatigue is a formidable factor in this design problem. Until then, it will be assumed that because there is no cyclic loading, fatigue will not be a mode of failure. Under the current design, the safety factor of the structure is 1.5 (for yield). For reliable materials where loading and environmental conditions are not severe and weight is an important consideration, a factor of safety from 1.3 to 1.5 is generally recommended. By those standards, the factor of safety for this system is appropriate.

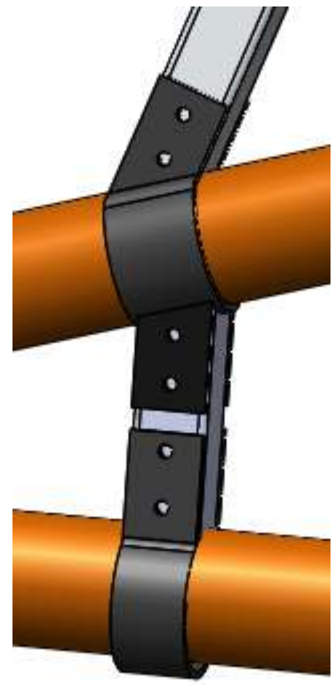


Figure 65. The mounting for the fairing support.

Bushings will be used for the rotating assembly because the design scenario is not severe in the slightest. The term “rpm” is really not even applicable in this situation, because the outer shaft of the assembly will never rotate 360 degrees; on the contrary, it will only rotate a maximum of about 90 degrees. Additionally, there is very little weight that is being held by the assembly, so the amount of pressure on the bushings themselves is relatively small. Lastly, there will not be much temperature rise in the model, because there is so little energy output around that area. Because the aspects of the scenario are so mild, bushings will suffice.

Appendix U shows calculations that were performed to determine the validity of using fiberglass rods to provide form to the cloth fairing in the rear of the trike. The ultimate tensile strength of fiberglass is about 440 ksi; from this value, we calculated the maximum moment that a ¼” fiberglass rod could handle. From this value, we calculated the maximum deflection that a 6 foot rod could handle. Amazingly, this rod can handle 670 in*lbf of torque, or a 37.5 lbf force. The rod can also handle a considerable amount of deflection without breaking. This shows that fiberglass is a good choice for our design, because it will easily provide the curved shape we are hoping to achieve.

Some of the weight of the fairing is resting on the latch assembly bracket at the front of the trike. This raises the concern of bending in that bracket. In Appendix U, the weight of the fairing is show to be about 6.7 lbf. If *all* of that weight rested on the very edge of the bracket (worst-case assumption) then the overall deflection in that plate would be -0.17 inches. This is such a small amount of deflection that it does not cause any concern.

Rivets are used plenty in this design; this poses the question, “Is there danger of failure at the rivets?” On the data sheet for a ¼” rivet, the shear strength is 950 lbf. The weight of the fairing and associated components is so light in comparison to this that there is no real danger of shear.

The only specifications pertaining to the latch of the fairing are that the latch should stay closed while riding and should be able to open easily. With the design of the lever release latch and enclosed cable, the only way the latch can be released is by means of pulling the lever. As the lever is located on the bottom of the seat, there are few if no situations that the lever may be unintentionally pressed. For instance, if a piece of debris somehow managed to hit the lever, there is some chance that the lever could be actuated but this possibility is so minute that it will not be considered. Any alterations to accommodate this would add complexity for the user.

Due to the simplicity of the latch mechanism and the location of the lever, the process of releasing the fairing will be very easy. The only consideration is the amount of travel that the break lever will have so that the latch can completely open. We are getting these parts from the Bike Kitchen in town so we will have our choice of a variety of different break levers with different amounts of travel. In order to account for the amount of travel required, a v-brake lever will be needed.

Material Selection

Lycra will be the material used to create the overhead cloth fairing on the back of the fairing. The foremost reason that Lycra will be used is that it is the most widely accepted material for this type of application. Secondly, it is a stretchy material that will conform to whatever structure you place it in. In our case, fiberglass rods are being used to create the frame of the cloth fairing, and Lycra is a stretchy material that will follow the profile created by the fiberglass rods.

Fiberglass rods are widely used to create a structure that fabric can follow. These rods are used in tents, to serve the same purpose that is desired on this project (providing form to a formless material). Also, the analysis discussed above proves the validity of choosing fiberglass, because it allows enough bending to produce the desired shape.

In the design of the fairing support structure, the most important aspect was low weight. The structure also needed to be strong enough to support the weight of the fairing, without danger of buckling. Lastly, the material had to be easy to join to itself, in order to have a sleek design that did not take up a large amount of room. Aluminum was the best answer to most of these problems, and aluminum tubing can also be bent, as is needed in this design. It also happens to be a relatively low-cost material, and the tooling that is available to the manufacturers (our team) is well-suited to work with aluminum.

Thin polycarbonate sheet is the best material for the given situation because it is thin enough that it will easily mold to match whatever shape it is formed to; additionally, it will be transparent enough to see through. This material is also a great choice because it is a plastic that will protect the rider from rain. It is also easily replaceable, and it is not a very expensive part to replace.

The brackets used to hold much of the fairing structure assembly together are made of 0.1 inch thick steel. These brackets are then fixed to the aluminum tubing via rivets; rivets are especially useful in this situation because the structure will not be removed from the bike. The material needed to be strong enough to hold the fairing support structure together, so steel was selected for its high material strength. Because the brackets were so small, having them be extremely low weight was not a big concern. Additionally, one of the brackets needs to be welded to form it – steel is a common material, and welders are well-equipped to work with it. The

Pre-Fabrication and Assembly Instructions

There are many different manufacturing and assembly processes that will be used to build this project. As discussed, there are two components to the fairing itself. There is an assembly of bent aluminum tubes, and there are sections of polycarbonate sheet that span the width of those tubes. The aluminum tubes will be bent, and they will be notched, to allow for an easier and more efficient welding process. The plastic sheets will be wrapped around the tubes, and they will be joined together as well. In the fairing support structure (located just behind the front seat), the aluminum tubes will be bent and notched. The steel brackets that hold much of the assembly together will be machined and then bent. In one case, a bracket needs two extensions to be welded to it; this welding will take place after the bracket has been bent. The brackets will hold the aluminum pieces together through the use of rivets, which have a high strength, and they are permanent fixtures.

The rotating element that controls the angle of the front fairing is assembled in a very specific order that is listed below: (See Figure 66 for reference)

Figure 66. The rotating component of the fairing shown in detail.

1. Machine inner shaft to obtain each stepped diameter.
2. Machine outer shaft to create the groove to house the snap rings.
3. Press fit the bushings onto the inner shaft
4. Slide the outer shaft onto the bushings
5. Insert snap rings on either side, to secure bushings
6. Weld the ends of this assembly to the notched tube below it.
7. Weld fairing handle brackets to the outer shaft, ensuring that they are parallel to each other. (The handles themselves should already have been welded to the brackets at this point.
8. Use bolts to secure the loop clamps to the brackets, and put the fairing frame bars through the loop clamps.

Figure 67. The heads up display shown in detail.

The assembly process for the front latch system is as follows:

1. The sheet bent sheet metal should have the holes and slots milled out before the sheet metal is bent.
2. Heat the material and then bend it (heating is recommended for aluminum)
3. Mill the aluminum pipes to length, and cut the angle into the ends of them as well.
4. Weld the two aluminum pipes together.
5. Weld the aluminum pipes to the inside of the bent sheet metal part.
6. Screw all of the extra components into place using screws, nuts, and spacers as needed.
7. Slide the piece onto the shaft of the bike, and use a set screw (not pictured) to fix the rotational position of the assembly.

The detailed drawings for the fairing can be found in Appendix V. The final model dimensioning can be found in Appendix W.

Detailed Cost Analysis Estimate

Our detailed budget with specific costs for each part can be found in Appendix X. Our initial budget was $5,000. With all of these parts and including a rough estimate for tax and shipping of the parts we have not ordered yet, we are about $350 over our budget of $5,000. We are applying to scholarships such as CPConnect, requesting money to help us fund our project. We requested $500 from CPConnect and are optimistic about our chances of receiving funding.

Our budget can be broken down into 6 main sections: frame, electronics, drivetrain, fairing, security, and storage. The two sections that have the largest dent on our budget are the frame and the drivetrain, costing $2,259 and $1,547 respectively. After these two sections, the next most expensive is the fairing at $480. The electronics section costs $435. The security section costs $305, and lastly, the storage section costs $164.

Conclusion to Final Developed Design

The final design that we plan on moving forward with includes quite a few exciting aspects. One of the most exciting aspects is the Bafang 750 W motor which will be powered by a 48 V 15 Ah Lithium Iron Phosphate battery from Ping Battery. In addition to this electric assist, the rider will be covered by a fairing. This fairing will be split into two main sections. The front section will be able to rotate; this allows the front rider easy access to his/her seat. It will be made from a thin plastic. The back section will just be made from cloth and be stationary.

The trike will also have two main storage sections. There will be two baskets behind the second rider for storage. There will also be a bungee net that will wrap around the second seat to create one

large basket. The trike will also have a few exciting electric features. There will be a heart beat sensor in addition to a keypad and LCD that provide relevant riding information to the front rider. There will also be quite a few safety components such as brake lights, turn signals, and headlights. All of these components are used to make the tricycle as visible as possible. Another important consideration is security; Lock8 is a new security system that will be implemented on our tricycle. This system alerts the owner if the tricycle is being tampered with or harmed.

Our team plans to start manufacturing in the next two weeks. Testing for the electronics has already started and is underway. Long lead time items, such as the motor and the battery, have already been ordered and received. In the next month, we will test the motor and battery to ensure they perform as anticipated. After manufacturing the fairing parts and testing the motor and battery, we plan on implementing all of these components.

There are a couple of ideas that we are considering for future work. These ideas include adding a secure glove box with a fingerprint sensor; this will allow the rider to store valuable items with the trike. Another future work consideration is adding a Bluetooth capable mobile speaker into the tricycle. It could potentially be powered by one of the 5 V batteries that are already integrated into the tricycle. This would help to add entertainment value to the tricycle.

We are very excited to start combining the different aspects of this tricycle. We are very optimistic about the capabilities of this tricycle. Below is the latest rendering of our project.

Figure 68: Final CAD Design of the Electrike

Product Realization

Manufacturing

Center Support

Brackets for the center support were manufactured by bending about welded fixtures. These bend fixtures consisted of a round steel tube welded to a square steel tube with a corresponding width. Two of these fixtures were made – one for the connections to the thick frame tubes and one for the upper fairing support structure. One of these fixtures may be seen on next page in Figure 69.

Figure 69. Special bend fixture made to match curvature of bracket to that of the frame.

Both the bottom bracket and the intermediary bracket were fabricated using the larger tube diameter fixture and the upper bracket was manufactured using the smaller fixture. This upper bracket was later scrapped as discussed later. First, the brackets were cut to size by hand-feeding the guided plasma cutter. The resulting bracket material then needed to be grinded down to smooth out the edges and control the width. To bend the brackets, the cut to size bracket material and fixture were clamped in a vice in a position in which the middle of the bracket would fall on the top of the fixture. These brackets were then hammered into shape using the flat side of a ball-peen hammer. Any excess length on one side was grinded off with a rotary sanding wheel.

Three square tubes made up the remainder of the center support – two smaller 1 inch tubes and one larger 1.75 inch tube. These tubes were first cut down to size using a horizontal band saw. In order to get the tubing to sit flush against the frame of the trike, the tubes were notched using the Tube Shark tube notcher. The required angles of the tubing were measured and the tube shark was set to the corresponding angle. The tubes were then individually cut using different sized hole-saw bits to create the necessary radius. Once these were cut, any excess length was grinded off to create a flush fit between the structure members.

In order to create the mating drilled holes to fix the brackets and tubing to the trike, a specific process was followed. This process proved to not be 100% effective, however was the most accurate method that we found. The holes in the brackets were first marked with a center punch and then drilled using a drill press with 9/64” clearance holes for the 1/8”rivets. Once these holes were drilled, the bracket was placed around the frame tubing in the location that it would be secured and a center punch was used to mark where the holes would be located on the square tubing. Once these holes were marked, they were then drilled using the same 9/64” drill bits on the drill press. Once the individual components were completed, they were painted using a semi-gloss black spray paint and fixed to the trike using blind rivets.

Front Fairing:

The fairing structure consists of a rotating hinge assembly, a series of bent steel rods, a latch assembly, and three polycarbonate sheets. The rotating hinge assembly was fabricated by first cutting down the concentric tubes to length. Two brackets were then cut from thin aluminum bar stock and mounting holes were drilled. These brackets were TIG welded to the outer concentric aluminum tube. Fairing lifting handles were fabricated by cutting down round steel tubes and welding them to flanged steel brackets. Thrust bearings were press-fit to the inner concentric steel tube to constrain the rotation

of the outer tube. Unfortunately, these bearings were not tight enough of a fit and tabs were welded against the bearings to prevent sliding. A U-shaped post was then manufactured by bending a 1-inch diameter steel tube with the Tube Shark and then notching the tube ends with the Tube Shark tube notcher. This U-shaped post was welded to the rotating concentric tubes using TIG welding. To connect this to the center support, a square tube was notched and welded onto the U-shaped post. This square tube slides easily over the square tube of the center support. This design came about from many problems with the original design of a single wrap around bracket that would interface with the center support. This bracket may be seen to the right in Figure 70.

Figure 70. Square tube interface between fairing and center support.

The first attempt to bend the steel rods to shape consisted of creating an 80/20 fixture (pictured on right in Figure 72) that would hold the rods to the desired shape while simultaneously heating with a torch. After hours of heating the rods, they sprung back after removing from the fixture. An alternative method needed to be pursued. This alternative method made use of the sheet metal roller in the back of the hangar. This roller had shallow grooves on one side of the roller wheels, which were used to feed the rods through. In order to get the desired shape, the rods were fed through one pass at a time, increasing the curvature of the bend one turn at a time. Once the desired bend was achieved, the other side was bent to match the first. A bottom piece and two cross supports were then bent using the same methods as described above. To create the desired shape to mate with the rotating hinge assembly, the two side rods were bent by hand using a carefully controlled bend and measure method within a vice. This method is depicted to the left in Figure 71.

Figure 72. 80/20 Fairing rod bending fixture. Rods were placed in fixture and then heated to retain the desired shape. This however, did not work.

First, the rods were marked where the first bends were to take place and then were fixed in the vice at the location of the first bend mark. Next, the rods were bent 30 degrees from straight and verified using a protractor. Once the desired angle was achieved, the rods were flipped in the vice and the second bend was measured out from the center of the first. These second bends were then made using the same process as above.

Figure 71: Preston measuring out the required "jog-over" to determine next bend location

Brackets to fix the fairing to the rotating hinge assembly were then made by plasma cutting rectangles of metal to size, cleaning up the edges, and drilling holes using the drill press. Tabs to fix the polycarbonate sheets to the frame were made by cutting out small rectangles using a cut-off wheel. One side was then rounded off and 9/64" clearance holes were drilled. Once these parts were to a point in which we were happy with them, they were all welded together using TIG welding for the mounting brackets and MIG for everything else. Figure 73 on the right depicts welding of this frame. This assembly was then painted and bolted to the rotating hinge assembly.

Figure 73. Kris welding the front fairing frame together using MIG.

Figure 74. Latch bracket with cable activated trunk latch attached. Cable will feed through the flanged bracket on the right.

Originally, it was planned to use a common gate latch bolted to the HUD bracket however once physically testing the latch it was determined that a much more sophisticated latch would be needed. The latch chosen for this application was a common trunk latch. To fix this to the bike, a special bracket was cut out using a plasma cutter and grinded down to shape using a grinding wheel and Dremel tool. Two holes for the trunk latch were then located and drilled using a sharpie and drill press. A flanged bracket to serve as a cable stop was made by bending sheet metal in the sheet metal bender and drilling locating holes with the drill press. This flanged bracket was connected to the latch bracket by use of a rivet. This bracket, pictured to the left in Figure 74, was welded to the fairing frame structure with MIG welding after sanding off the paint and then re-applying extra coats after welding was finished.

Figure 75. Polycarbonate sheets were marked and cut and then secured into place with duct tape to drill holes and rivet on.

To fix the polycarbonate sheets to the fairing structure without wrinkling, a very controlled method was used. First the polycarbonate sheets were placed over the frame and marked where they would be cut to shape. These sheets were then cut to shape using a band-saw and de-burred. Once again, these sheets were placed over the fairing frame and secured using duct tape in the position desired. The locations of the holes were marked using a center punch and were drilled using a cordless hand held drill with a 9/64” bit. Once the holes were drilled, rivets were placed without fastening in the holes to maintain the location of the polycarbonate sheet. One by one, each rivet was fastened in an alternating pattern to avoid misalignment. Once secured, the protective film was peeled off and the untouched polycarbonate was revealed.

Rear Fairing:

The rear fairing is made up of an oilcloth material that was measured and cut to size and then sewed to allow slots for fiberglass poles to slide through. These fiberglass poles were cut using a hack saw and connected together using rubber joints. For the rear, steel rods were hand bent through previously noted procedure and welded together with a steel spacer rod. These rods were spaced apart enough to slot into the holes in the top of the seat. Once welded, the rods were painted and attached to the oil cloth top. The free end was then slotted through holes machined in the front fairing structure and pinned in place.

Heads-Up Display:

The heads up display started from a 0.1”thick steel plate. This plate was first cut with a cut-off wheel and grinded down to the basic shape. Once the required shape was achieved, the plate was bent by clamping it in a vice and hammering one side down. The required mounting holes were then drilled and slots for electronics were milled out. Once this was finished, a steel tube that would fit concentrically over a front bike handle was cut and welded in an angle. This was then welded to the HUD bracket and painted. To secure this to the bike, two rivet holes were drilled, preventing the HUD to rotate.

Manufacturing Changes:

As mentioned in the previous sections, things didn't always go to plan. Some of these design changes were made in the very beginning of the process before substantial manufacturing took place however some came very late requiring quick re-designs and material purchases. The first re-design we had was changing a lot of the fairing structure from aluminum to steel. This was done because we determined the aluminum wouldn't be able to undergo some of the bends that we were planning on making. This added a substantial amount of weight, however was necessary to get the desired outcome. Another quick change we made was widening the support tube at the bottom so that it was the same width as the diameter of the frame tubing. This allowed for easier manufactured brackets. When starting to manufacture the rotating hinge assembly, we quickly realized that flange bushings instead of bushings and snap rings would be the better bet to constrain the rotating tubes however we did see some issues as noted previously with the press-fit being too little of an interference. The final pre-manufacturing change came from after testing our lycra material. This material was not water resistant and would be difficult to waterproof for our application. Thus, we switched to a water resistant oil cloth material.

The remainder of the manufacturing changes came from issues with manufacturing other components. As all of our parts for the fairing were custom made and required fairly tight tolerances, we ran into some issues with keeping the structure stable. First of all, when we first riveted on the center support, it was very rigid and had no movement whatsoever. However, after resting the fairing on top of the structure and riding the bike around, this support loosened and could be moved around slightly. To combat this, an extra center support was made to serve as a backing to the first. This completely removed any "wobble" seen before. A later and very serious issue we discovered was when we were trying to fasten our fairing onto our center support. Our initial design called for a single bracket welded onto the U-shaped post that would interface with the tube. This however, bent easily when trying to secure to the bike and had poor hole alignment. We attempted to stiffen this by adding two side support brackets however these broke off easily and still failed to secure the fairing. Finally we ditched the brackets and decided to move to a mating tube design in which we welded a larger square tube onto the U-shaped post and slid it over the smaller tube of the support. This worked extremely well and added no additional movement of the fairing. Another design change we made after initial manufacturing was swapping the gate latch for a more sophisticated trunk latch. This allowed for more consistent opening and closing and didn't require modification of the latch itself to spring closed when needed. When securing the polycarbonate sheets to the fairing we noticed that it would bubble up in the areas of complex 2-directional curvature. We originally planned for 2 sheets, however needed to make the change to 3 sheets as we could not get it to follow the shape we wanted in an aesthetically pleasing fashion. These sheets were then riveted on with aluminum rivets which were not planned for the original design.

Future Recommendations

Because the product of this senior project is a prototype, there are many things that could be improved upon, if there was another iteration of this project. For example, an issue that arose was that the headlight did not have enough power to shine at full brightness. This is because many electrical components were being powered by one battery; it would be advantageous to have two separate

batteries in the future, providing more power. Another issue that arose was that the on position for the brake switches was in a different position than the off position. Although this did not affect the functionality of the switches, it would be nice to calibrate that more efficiently, so that the on and off positions could be in the same locations.

The heart beat sensor was located on the 3D-printed hand grip in a location that required the rider to consciously place his/her finger on the heartbeat sensor. After this piece was manufactured, and the position was tested, it became clear that the heartbeat sensor should be located in a position that picks up the heartbeat while the rider is not paying attention. Because of a shortage of funds and time, a protective cover for the electronics was not purchased; however, this would be extremely advantageous as it would protect the electronics from water/wind/dirt damage. Another point of improvement is the organization of the wires. Currently, zip ties are being used to hold the wires to the frame of the trike. A possible solution to this would be to drill a few holes in the frame of the bike, and to direct the wires through the frame. That would be aesthetically pleasing, although the holes would have to be small enough to prevent any fatiguing issues in the frame itself.

From a visibility standpoint, the front and rear lights are very helpful in increasing the visibility of the trike. However, one concern is the visibility from the side. During the day, a flag may be enough to make the trike visible to other vehicles. At night, another programmable LED strip may help illuminate the vehicle. Because of budget and time limitations, these solutions could not be implemented during the first iteration of the project.

The plan for security on this trike was to purchase the Lock8, which was substantially better than every other locking system. However, the company that produces Lock8 is behind schedule in terms of their testing and manufacturing; as a result, the Lock8 could not be shipped in time for the end of the project. However, the product is still on its way to production, and it will be available in the next few months. If this project were to continue, buying Lock8 would be high on the list of priorities. Another feature that would help increase the security of the trike would be to replace all bolts with a torx screws, so that a special bit would be required to replace all the bolts. Lastly (for storage), a bungee system idea had arisen that would allow the rear seat to be transformed into a trunk. However, financial and time limitations prevented this idea from coming to fruition. This idea would be a great addition to the trike, and it should be considered in offshoot project.

The air springs on the fairing are slightly too weak; because of this, the fairing does not stay open once it is lifted. Because time was short, we were unable to purchase new air springs. In the future, the next size of air springs (15 lbf) should be purchased. Also, the plastic does not match the radius of curvature on the fairing frame. Apparently, the plastic should be bent before manufacturing, so that the designer can develop an understanding for the tendencies of the plastic. Then, the frame should be designed to match the plastic tendencies. In this project, the plastic was expected to match the frame – however, we did not realize that this was the issue until after the fairing had been assembled. In the future, it is recommended that the frame be designed to match the tendencies of the plastic sheet that spans it. The trunk latch system that holds the fairing closed works, but it is directly in the line of sight of the rider. After testing, it became clear that it does not make it very difficult to see the road; however, there is probably a more elegant solution. This should be a point of focus on any future rendition of this project. Lastly, the rear fairing is made of straight fiberglass poles. However, if

the fiberglass poles could be pre-bent to match a previously defined profile, it would greatly increase the strength and the appearance of the fairing. This should be examined in the future.

Design Verification

In order to validate some of the calculations and designs we made, we conducted a number of tests that would be used to prove concepts and be used to further optimize our calculations. Below are the tests we completed along with the results that were obtained. A more compact and simplified version can be found in Appendix Y

Rear Fairing Material Testing

For the design of the rear faring, we wanted to go with a material that would serve the purpose of providing some protection from water for the back rider in addition to providing shade. The materials to be tested were lycra, plastic film, wet-suit material, and oil cloth. The test was simple in which the materials were hung in a horizontal position after which they were sprayed with water (equivalent to half a water bottle). Materials were tested for whether or not they would repel or absorb the water, whether or not they let water leak through, and whether or not they would keep their shape as to prevent pooling of water.

Figure 76: Moisture testing of the lycra and oil cloth. Lycra was saturated on the left and the oil cloth remained dry on the right.

From the tests we conducted, we found that the lycra was not at all water resistant because it absorbed all the water that was sprayed on it and then it continued to become saturated and leak. See Figure 76 above. The plastic film worked great and did not allow water to pass through or absorb, however the material was transparent and would not be able to provide shade to the rear rider in addition to being very difficult to sew. The wet-suit material was able to keep water from passing through but it did absorb a significant portion of the water that was used allowing the material to gain unwanted weight. The best material that was tested and was ultimately used in our design was the oil cloth. This material was water resistant and didn’t allow water to pass through. It was not transparent allowing it to be used for shade as well. In addition, the material is sew-able making it the ideal material to use for making a pattern for sleeves that would hold the fiberglass structure.

Basic Bike Component Test

Since we were given the bare frame of the bike along with the seats and steering mechanism, we were in charge of finding and implementing the missing components of the bike that would ultimately make it move and stop. The missing components included that entire drivetrain (i.e. chain, shifters, rear cassette, derailleurs, and pedals) and the braking system (i.e. brake cables, disk brakes, calipers, brake handles). Once these components were installed we had to confirm that the components we implemented would work with the bike in order to confirm that the motor would work properly with the bike.

To test the system, we first placed the bike in a stand and did a no-load pedal test to confirm that the drive train was working. Issues were found with the derailleur (Figure 77 below on right) and tension of the shifting cables but they were able to be fixed with some adjustment. The next validation test was a braking test in which we had one rider (then two) sit in the trike while another pushed the bike to a speed of about 10 miles per hour on flat ground. Once the trike was at full speed, the driver would then attempt to lock the brakes to confirm that the brakes were working and could stop the trike. See Figure 77 below and on the right. This test was conducted a number of times to ensure that everything was working properly. Each time, the bike stopped quickly and easy – qualitatively, there were no concerns associated with the braking system.

Figure 77: Rear cassette and derailleur on the left. Brake test with two people in trike on the right.

The final validation test was the loaded test in which two riders would pedal to confirm the drive system is working properly. Issues were found in the rear cassette in which the chain would skip from gear 7 to 6. This resulted from the design of the trike's chain guide system placing the chain at too large of angle, resulting in a chain that was not aligned with the gear 7. As a result, the chain would come in contact with gear 6 while engaged with gear 7 and every so often get caught on gear 6 for a split moment before switching back to gear 7. Again this was due to the design of the bike. This issue could be resolved with the creation of some sort of siding chain guide that would help align the chain when it is changing gears. The rear derailleur only guides the chain to a new gear, but doesn't fully align the chain when it approaches the chain. Another solution would be to get a smaller cassette in the rear (possible 5 gears) with wider spacing between the gears so that the chain does not catch like it does. As a result of this, a new chain and shifters would have to be implemented as well. At this point, the components added to the trike were considered to be working well enough for the addition of the motor. It is just advised that the user try to refrain from using the higher gears too much.

Motor Testing

After implementing the motor and battery onto the trike we wanted to verify that system was going to perform as planned in which we would be able test the motor's functions which included placing a speed limit on the motor (20 mph), confirming the motor would power up when pedaling or throttling, ensuring the motor would stop when the brakes were engaged, testing how the motor performs when starting from a standstill and when moving, and making sure the rear rider couldn't control the motor.

Figure 78: No load test on a stand while monitoring battery temperature.

Testing of the motor's functionality went very smoothly in that motor was easily implemented into the trike's drivetrain. The first test conducted was the speed limitation test for the motor. When we first tested the motor on a test stand (Figure 78), the motor reached a top speed of 34 mph before the motor stopped providing assist. After going into the motor controller's advanced menu, we were able to reduce the top assisted speed to 20 miles per hour.

The next test was more for understanding how the motor reacts to the different power inputs. We tested the pedaling assist function and found that there is a slight delay from the motor when the riders begins to pedal. This feature was actually beneficial to this system because it allows the rider to get the chain engaged/tensioned to a normal load before the assist starts. If the assist was immediate, damage to the drivetrain could result. Although, the throttle option results in an immediate motor response. This is a slight issue because the trike does not like to start from a stand-still with anything more than human power. The high torque capability of the motor in addition to the immediate response from the throttle is not ideal for trike when starting from a stand-still and it is advised that the driver not start the trike with the throttle. The throttle is sensitive and has no assist settings like the pedaling assist option does meaning it has the full range of power needed to reach the top speed of 20 mph without the help of the rider. Next, we wanted to verify which assist options took priority when both were being used at the same time. We found that the throttle option takes control over the pedal assist. The next verification test we wanted to conduct was to see if in any way the rear rider could control the motor since the chain loops are connected. We found that the rear rider has no control over the motor and cannot accidentally trigger it. The front rider has complete control and will not have to worry about the rear rider accidentally engaging the motor when he or she does not want to use it. The final verification test was ensuring that the motor disengaged every time one or both of the brakes were pulled. The motor behaved as advertised and immediately stopped when the brakes were pulled. This didn't prevent the riders from still pedaling, it just cut power to the motor and applied a brake to it as well to prevent it from providing a "winding down" kind of assist.

Battery Testing

The battery testing provided the best and most exciting results that ended up meeting and even exceeding our expectations. Testing was performed to determine the range the trike could go on a single charge as well as to determine the operating temperature of the battery while in an enclosed box. The temperature and distance tests were conducted on a fairly warm day of around 82 degrees Fahrenheit and consisted of us biking along a specific loop containing a number of hills.

Figure 79: Preparing the bike for testing. Battery is in the green box in rear along with the thermocouple being prepped for mounting. Front rider controlled the bike while the rear rider took data.

The battery was located in a sealed off container in the back of the trike that contained a thermocouple to measure the temperature of the battery through the duration of the ride. See Figure 79 above. For this test we measured the battery box temperature, distance, battery level, and time at multiple points during the ride. The results we obtained showed a maximum temperature spike of five degree above the outside temperature which occurred after going up the largest hill each time while using max power output from the motor. See Figure 80 below for results.

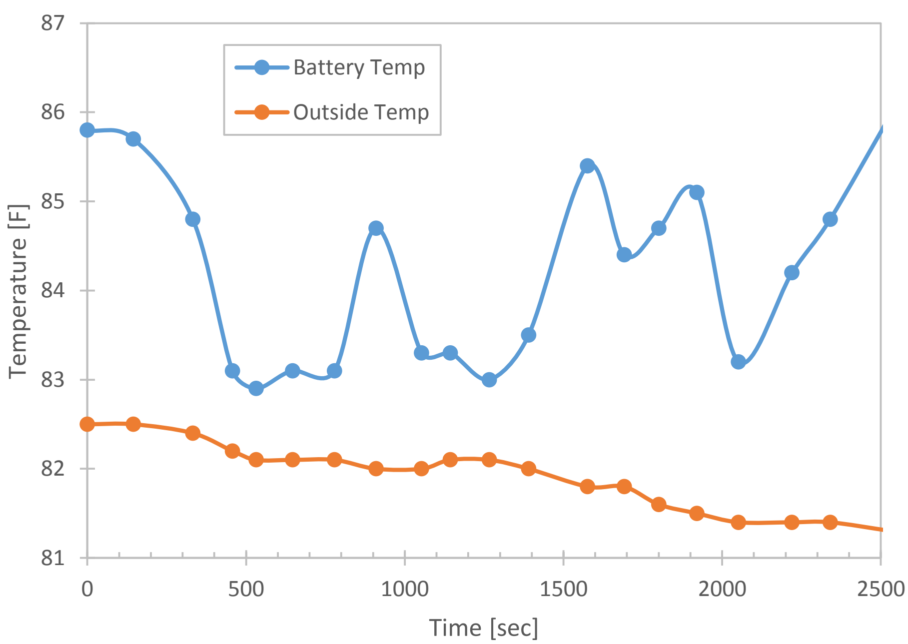


Figure 80: Temperature readings of the battery being compared to the outside temperature.

From the above figure, it can easily been seen when the hills were approached, as shown by the spikes in temperature of the battery. Our initial concern was the battery operating temperature growing to be too large for the battery box to be able to handle. Online resources claimed the Lithium Iron phosphate batteries can have high operating temperatures up to 203°F for quick discharge applications. As can be clearly shown by our data, our operating temperature comes nowhere close to these types of operating temperatures even during a fairly warm day. From this temperature test we can conclude that our battery will be fine in an enclosed environment and will not require ventilation for

cooling. It also mean that our other electronics can be incorporated into the same enclosed box without fear damage due to high temperatures. Please note that the data for the temperature test was only conducted for the first 40 minutes (15 miles) of riding due to a dead battery in the thermocouple. This ended up being sufficient data to see a trend.

As for the distance test, we continued on riding the bike after the temperature test completion and ended using the rest of the battery with a total distance of 29.4 miles. Comparing that with the estimated range of 28.9 miles we calculated earlier on, we exceeded our estimate by only 0.5 miles indicating that methods we used for calculating the range were accurate and that we sized the battery correctly. In addition, we had exceeded our sponsor's requirement of 20 miles of assist.

Welding Bend Test

Part of the manufacturing for the fairing required welding of metal tabs and tubes to one another. Some of these tabs and joints were going to have an induced load due to bending applied to them once the full assembly of the fairing was complete and testing needed to be carried out to ensure that the welds were getting full penetration. To test this we conducted a number of simple bend tests on sample test welds for each day we welded. This ensured that we were on the correct welding settings and getting good penetration.

Figure 81: Testing the MIG weld on a replica fairing structural piece. Weld held strong and base material yielded first.

For these tests, a mock-up test piece was welded together in a similar orientation to real piece then allowed to cool. Once cooled, we placed the bonded material in a vice and tried breaking the bond at the weld through bending. If the weld was holding and the base material was bending, as can be seen in Figure 81 below, the weld had enough penetration and would work for the application. A failing weld would shear cleanly off the base material with relative ease and show no sign of material penetration in the base material. Of the six tests we conducted we had five steel test and 1 aluminum test. Of the steel bend tests there was only one failure in which a welded test tab sheared cleanly off the base material with the entire weld still intact on the tab. This was traced back to the voltage setting on the MIG welder being too low such that the weld was able to penetrate the tab material but not the other base material. As for the Aluminum weld test, we conducted one bending test to ensure that the hired student welder could get a strong enough weld and found that his welds had good penetration. The base material actually cracked right above the weld indicating that that weld improved the stiffness of the material at the site of the weld, but also made us go back to our design of the fairing structure due the cracking of the Aluminum. This test ultimately ended up changing the design of the rotation portion of the front fairing in which we redirected some the bending moment into the steel structure of the fairing. See Figure 82 on the next page.

Figure 82: Added a structural member on both sides so that the bending moment induced by the fairing on the aluminum tabs would be reduced and partially directed into the handles.

Electronics Testing

For the low voltage electronics on the bike, testing and debugging was progressively done throughout the coding process for the Arduino microcontroller. The first test for the microcontroller was the compatibility test of the LCD and Keypad. See Figure 83 for testing configuration. There were issues with providing the correct amount of power to the LCD initially, but after going through numerous online tutorials and data sheets providing us with a working interface for the electronics system.

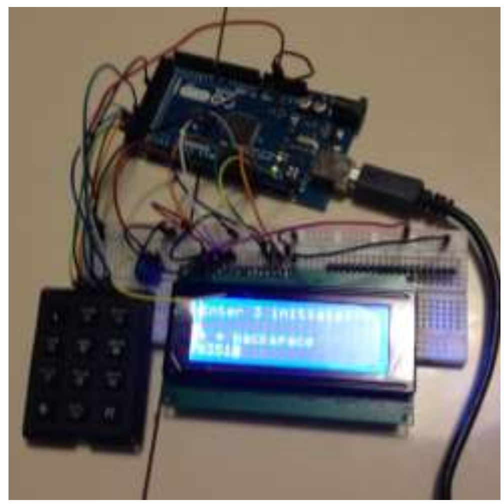


Figure 83: Compatibility testing of the LCD screen and number pad with the microcontroller.

The next compatibility tests were the turn signal and brake lighting system. This consisted of implementing micro-switches and buttons switches into the microcontroller's code to control the LED lights. These were implemented fairly quickly and easily into the system, but issues arose with the LED Lights being really bright. This was solved through the microcontroller's code being altered to decrease the amount of power going to the LED lights. See Figure 84 below.

Figure 84: Testing the Brake Switches with the LED Lights to ensure brightness is ideal.

The most challenging portion of the electronics was the incorporation of the heartbeat sensor and calorie calculator with the LCD screen. The heartbeat sensor was very sensitive on how it measured one's heartbeat in that it only worked on certain portions of the hand and that it would not be able to get an accurate reading if moisture was on the censor. This issue was resolved to best of our ability by changing the sensitivity settings in the heartbeat sensor's library code. When it came to the calorie calculator, there was an issue of the calories displaying a negative value. This was due to the heartbeat sensor measuring a very low heartrate when little to no contact was made with the sensor resulting in an error for the calorie equation. As a result the code was changed so that the heartrate's measured values were stored and averaged for ten consecutive readings then re-averaged to rid the issue of slight removal from the sensor. To rid the issue of misread heartbeat readings when there is no contact on the sensor, code was implanted to remember the last averaged heartbeat reading and keep calculating the amount of calories burned to ensure a more accurate calculation of calories burned.

The final testing was the implementation of the front head light with the microcontroller. The headlight was meant to be controlled by the microcontroller; unfortunately, the headlight was unable to perform as intended due to a lack of power that is available for the light. The light was hooked to the same power source as the rest of the electronics and the remaining power left for the light was not enough to illuminate the light. As a result, an additional battery pack was purchased that was dedicated for the headlight.

Note: More in depth explanations and debugging can also be found earlier in the report of the electronics section of the Final Report Chapter.

Water Resistance Testing

Water resistance was the only test not performed, due to budget and time constraints. Due to us nearing our budget and still needing to purchase components for rest of the trike to work, some of the waterproofing components were not purchased which included bulkhead connects for the battery box, covers for the LCD screen, caps for the LED lights, protective covering for the wiring behind the LCD screen and number pad, and most importantly the front and rear fenders to protect the riders and fairing from backsplash of the tires. As a precaution to the riders, the bike has not been tested and approved for light rain situations.

Conclusion and Recommendations

The end goal of this project is to create a daily alternative to cars. Our project has shown that this is possible. This tricycle has proven that many of the negatives of bicycles can be overcome. One of the main negatives of bicycles is the rider getting too sweaty and uncomfortable while riding. With the electric assist and the recumbent seats, the rider is much more comfortable and can adjust the motor to assist as much as possible; this prevents the rider from exerting too much energy which would cause him/her to sweat. The trike also acts as an exercise machine as it measures and reports the rider's heart rate in addition to his/her calories burned. This tricycle overcomes the dilemma of storage also; with the rear racks, a rider could easily carry a few bags of groceries or a couple of sports bags. This tricycle is very positive as it greatly reduces the emissions that would be produced by cars traveling the same distance. Although the tricycle reduces emissions, it is still a rather large vehicle. Storing this trike could be a problem; parking especially, it would require special bike racks if not just a normal parking spot.

Another concern is the trike's speed. While the trike is electronically limited to 20 mph, the rider doesn't recognize the limited speed around town. The trike keeps up with traffic between stop lights and stop signs during around town travels.

We are exciting about our sponsor's challenge of creating a bicycle that is a daily alternative to cars. We believe that this project is just the tip of the iceberg. This is the first prototype; many more types and models could be produced in the future. There is much room for improvement and there is a large amount of room for customizability in this field. A person might want a singular bike instead of a tandem, and with different bikes and models, this is possible. By creating different types of bicycles, hopefully more people will ride bicycles and use them as daily alternatives to cars.

One problem with this trike, is that it is rather expensive for a bike. Our initial budget was $5,000; we received a $500 grant making our budget $5,500. Our initial cost analysis was that our project would cost $5,350 dollars and after finishing, we spent $5,340. Our initial cost was very close, but this is because Lock8 wasn't able to be integrated into the project, which would've added $300. This being the prototype, it cost more to make than if it was to be mass produced. With some more modifications and with hindsight, we would be able to reduce the cost of the trike when building more models. This is still a rather expensive product to sell, but another positive is that we built the trike with all of the accessories built into it. If this trike was too expensive, ideally, a customer could order one with less accessories so that it is more affordable; this would keep the dream of bikes as alternatives to cars alive.

We really enjoyed working on this project together. It gave all of us some real insight on what it takes to actually create a working prototype. It also showed us what it takes to work together as a team. We think that this entire process has been incredibly helpful and truly prepares us for the real world. We look forward to utilizing this knowledge in future applications!

Figure 85: Finished Electrike prototype

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Appendix A – Pugh Matrix for Motor Selection

Criteria \ Concept	Datum	Leaf	Bafang	Sunstar	Rubbee	Evelo	Bosch	e-Falco	StokeMon.
Can assist to a speed of 20 mph		+	+	+	-	+	+	+	S
Can Limit assist at 20 mph		+	+	+	-	+	+	+	-
Complexity of installation		S	+	+	+	-	-	S	-
Motor stops when slowing down		+	+	+	-	+	+	+	-
Cost of motor		+	-	-	S	-	-	-	+
Number of parts needed		S	S	S	+	-	-	S	-
Assists when pedaling		+	+	+	S	+	+	+	S
Variable levels of assist		+	+	+	S	+	+	+	S
Motor Weight		S	+	+	+	-	-	S	-
Motor Size (Volume)		S	+	+	+	-	-	S	-
Bike behavior when motor off		S	+	+	S	+	+	S	-
Includes a controller		+	+	+	-	+	+	+	-
Power/Torque		-	+	+	-	+	+	+	+
Sound Level		S	S	S	-	S	S	S	-
Range (assume with 48V battery)		+	+	+	-	+	+	+	S
Safe to operate		S	+	+	S	+	+	S	-
Availability to purchase		+	+	-	-	-	-	+	+
∑+		9	14	13	4	10	10	9	3
∑-		1	1	2	8	6	6	1	10
∑S		7	2	2	5	1	1	7	4

Appendix B – Bafang Motor Specifications

1 Central motor

★ Can be installed on standard bike frame easily.

★ High starting torque, Max torque≥80Nm, good performance on climbing.

★ Double clutch is used on drive unit, more safety.

★ Speed sensor and torque sensor can be applied, controller integrated.

★ High efficiency, low consumption, long travel mileage.

1.1 Scope of application and numbering rule

Countermark serial number on motor casing as following:

BBS01 36V 250W
15A 25km/h
13010001

1. "BBS01": motor type(speed sensor); "BBS02": motor type(speed sensor with coaster brake); "BBT": motor type (torque sensor)
2. "36V": rated voltage; 250W: rated power.
3. "15A": limited current, 25km/h: max speed.
4. "1301": production date, produced in January of 2013.
5. "0001": serial number.

1.2 Material and waterproof grade

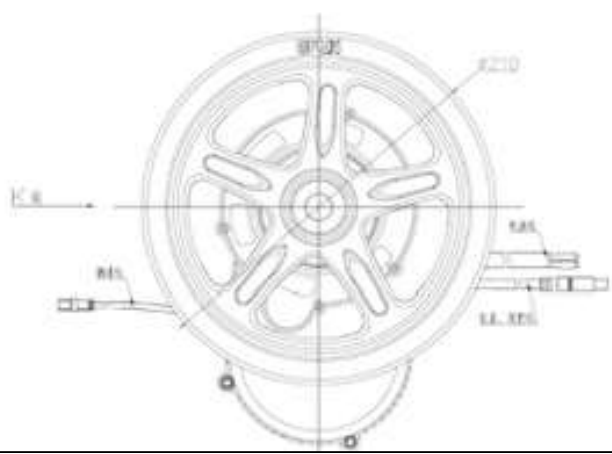
Die-cast aluminum electrophoresis black treatment, working environment temperature:-25℃-55℃, waterproof grade: IP65.

1.3 Main technical parameters

Voltage		DC36V						
Limit current		15A						
Limit speed		25KM/H						
Motor weight		3.7KG						
Chain wheel tooth		46T						
no-load value		Rated value					Max value	
current (A)	speed (RPM)	Output power (W)	speed (RPM)	efficiency (%)	torque (N m)	current (A)	MAX torque	MAX efficiency (%)
≤1.0	83±5	250	78±5	≥80%	≥30	≤9	≥80N.m	≥80%

Above parameters as the default parameters, can be customized according to customer requirements.

1.4 Installation diagram



The Bafang BBS02 Mid-Drive kit includes the following. This option is for a 750W kit, when the 500W option is selected, it will be a de-tuned 750W. This way you have the benefit of the more robust 25A controller:

- Motor with integrated controller.
- 500W kits will be re-programmed (18A current) 750W kits. 750W kits will be configured with teh standard 25A current limit.
- 48T chainwheel and pedal arms (does not include pedals).
- Waterproof interconnecting cabling.
- Thumb throttle.
- Pair of ebrakes for cable pull brakes.
- LCD display (C965) including power switch.
- The kit can only be used on a 48V batterry or thereabouts. It absolutely cannot be used with a 36V battery (41V LVC), or any battery with a charge voltage of 60V or more.

We are able to adjust the controller software. Kits will be shipped with throttle configured for full power in all assist levels. There are also many user adjustable settings available in the display. The BBS02 is a more powerful version of the BBS02, which has a larger motor structure, which can deliver higher power levels than the smaller BBS01. See below links to view documentation on the kit and display.

The standard settings are as follows:

- 18A or 25A according to the chosen option.
- LVC (low voltage cut) 41V, suitable for 48/50V battery.
- number of assist levels are adjustable by the display.
- wheel size can be adjusted from the display.
- speed limit can be set via the display, up to 50km/h, it is not possible to completely remove the speed limit, but you could set the wheel size to be smaller than it really is, to trick the kit into measuring a lower speed and effectively increase the speed limit. Of course the indicated speed will no longer be correct and this 500W kit is only really powerful enough to reach speeds in the region of 50km/h on the flat.

http://em3ev.com/store/index.php?route=product/product&product_id=166

Appendix C – Design Hazard Identification Checklist

SENIOR PROJECT CRITICAL DESIGN HAZARD IDENTIFICATION CHECKLIST

Team: Electric Tandemonium Advisor: Fab

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.

Description of Hazard	Corrective Actions to be Taken	Planned Completion Date	Actual Completion Date
There is a large capacity battery with a 48V 10Ah rating.	Battery is fabricated at plant inside a protective casing so batteries cannot be tampered with. Battery management system built into system to prevent battery usage if it senses fault in batteries or connection		

Appendix D – Hand Calculations for Battery Sizing

Sizing Battery - Estimate

48 Volts for battery

Trip distance - 20 miles ~ 32 km

Typical assist - 12 Wh/km

Watt-hours required: Trip dist × Energy Usage

$$(32\,km) \times (12\,Wh/km) = 384\,Wh$$

Amp Hour estimate $= \dfrac{\text{Watt-hours}}{\text{Voltage}}$ $(P = V \cdot I \cdot t)$

$$= \frac{384\,Wh}{48\,V}$$

$$= \underline{8\,Ah}$$

Calculation done by Preston McElroy. Determined through battery sizing equation provided by Grin Technologies website for mid-drive motors.

Appendix E – Pugh Matrix for High Voltage Battery

Concept / Criteria	Datum	PingBattery	Samsung	ALLCELL	Golden Motors	Grin	Tenergy NiC	Tenegy NiMH
Cost of battery pack		-	-	-	-	-	-	-
Number of charge cycles		+	+	+	+	+	+	+
Ah rating		S	S	+	S	S	S	S
Weather resistant (water)		S	+	S	+	+	S	S
Secured to bike		S	+	S	+	+	S	S
Power switch		S	+	S	+	+	S	S
Comes with charger		+	+	S	+	+	S	S
charge time		+	+	+	+	+	+	+
Safe to use		+	S	S	+	S	S	S
Safe to dispose of		+	+	S	+	S	S	S
Able to store		+	+	+	+	+	+	+
∑+		6	8	4	9	7	3	3
∑-		1	1	1	1	1	1	1
∑S		4	2	6	1	3	7	7

Appendix F – Pugh Matrix for Security

	IMPORTANCE RATING	BASELINE/OPTION 1 CABLE/U-LOCK	OPTION 2 FRAME LOCK	OPTION 3 CHAIN LOCK	OPTION 4 BRAKE LOCK	OPTION 5 STEERING LOCK	OPTION 6 ROOF LOCK	OPTION 7 LOCKING "KICKSTAND"
Stops ability to ride bike	4	S	S	S	S	S	(-)	S
Stops ability to access inside of bike	2	S	S	S	S	S	(+)	S
Stops bike from being pushed/steered	4	S	S	(-)	S	S	(-)	(+)
Stops bike from being picked up/moved	3	S	S	(-)	(-)	(-)	(-)	(-)
Ease of use	3	S	(+)	S	S	(+)	S	(-)
Lockable locations	3	S	(+)	(+)	(+)	(+)	(+)	(+)
Risk of damage to bike	2	S	S	(+)	(+)	(+)	(+)	(+)
Integration	4	S	(+)	(+)	(+)	(+)	(+)	(+)
Sum of (+)			3	3	3	4	4	4
Sum of (-)			0	2	1	1	3	2
Sum of S			4	3	4	3	1	2
Weighted Sum of (+)			10	9	9	12	11	13
Weighted Sum of (-)			0	7	3	3	11	10
TOTAL SCORE			10	2	6	9	0	3

Appendix G – Pugh Matrix for the Electronic Concept Idea

Criteria \ Concept	Weight	Perimeter Lights (Datum)	Fairing Lights	Back Top of Chair
Cost	7		-	+
Wiring Required	6		-	+
Power Required	14		-	+
Weather Resistance	8		-	+
Visibility	9		+	-
Weight	13		-	+
Security	5		S	S
Ease of Use	10		S	+
Features	12		S	+
Interactive	11		-	+
Connectivity	4		-	-
∑+		0	9	81
∑-		0	63	13
∑S		0	27	5

Appendix H – Analysis of Power Usage for Low Voltage Electronics

11-19-14 ~~Concept~~ LED Analysis → Both strips at 5V

Neopixel LED's 60 LED/m : $\frac{60\,mA}{0.65''}$

Adafruit LEDs 32 LED/m : $\frac{120\,mA}{2.5''}$

Neopixel: $\frac{60\,mA}{0.65''}\left(\frac{39.37''}{1\,m}\right) = \boxed{3{,}634.15\ \frac{mA}{m}\ \text{Neopixel}}$

Adafruit: $\frac{120\,mA}{2.5''}\left(\frac{39.37''}{1\,m}\right) = \boxed{1{,}889.76\ \frac{mA}{m}\ \text{Adafruit}}$

Concept 1 → $(10\ \text{ft LEDs})\left(\frac{0.3048\,m}{1\,ft}\right) = 3.048\ m\ \text{LED}$

- Neopixel → $3.048\,m\left(3{,}634.15\ \frac{mA}{m}\right) = 11{,}076.9\ mA$
- Adafruit → $1{,}889.76\ \frac{mA}{m}(3.048\,m) = 5{,}759.99\ mA$

Concept 2 → 20 ft LEDs = 6.096 m

- Neopixel → 22,153.78 mA
- Adafruit → 11,519.98 mA

Concept 3 → $(40\ \text{in LEDs})\left(\frac{1\,ft}{12\,in}\right)\left(\frac{0.3048\,m}{1\,ft}\right) = 1.016\ m\ \text{LED}$

- Neopixel → $1.016\,m\left(3634.15\ \frac{mA}{m}\right) = 3692.296\ mA$
- Adafruit → $1.016\,m\left(1{,}889.76\ \frac{mA}{m}\right) = 1919.996\ mA$

Using the 10,000 mAh USB Battery Pack:

2 outputs at 5V $\longrightarrow$ 2 A

$\hookrightarrow$ 1 A

We will have at least one of these battery packs, the 1 Amp output will power the following:

- Arduino Mega
- Fingerprint Sensor
- Microswitch
- Pushbuttons
- Solenoid
- Luminosity Sensor
- LCD

The other 2 Amp output goes towards LEDs

Concept 1: Neopixel: $11\ A - 2 = 9\ A \left(\frac{1\text{ battery}}{3\ A}\right) = 3$ extra battery

Adafruit: $5.7\ A - 2\ A = 3.7\ A\left(\frac{1\text{ battery}}{3\ A}\right) \approx 1$ extra battery

Concept 2: Neopixel: $22\ A - 2\ A = 20\ A\left(\frac{1\text{ batt}}{3\ A}\right) \approx 7$ extra batteries

Adafruit: $11.5\ A - 2\ A = 9.5\ A\left(\frac{1\text{ batt}}{3\ A}\right) \approx 3$ extra batteries

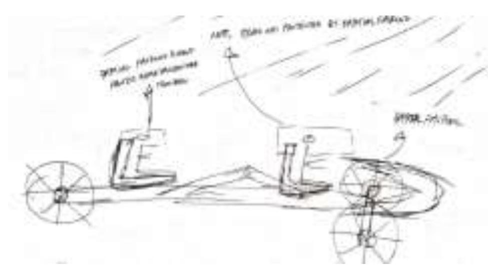
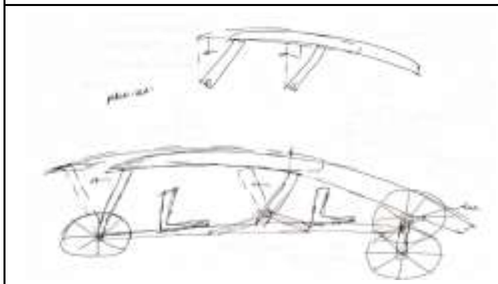
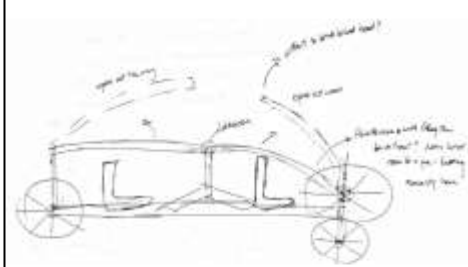
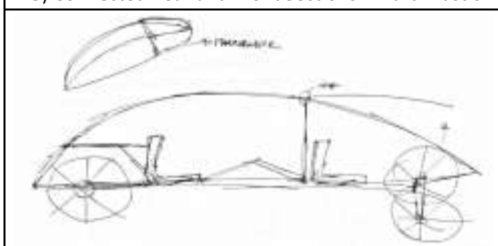
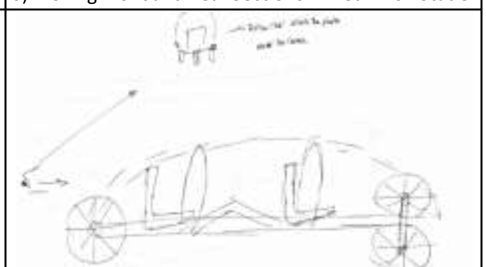
Concept 3: Neopixel: $3.7\ A - 2\ A = 1.7\ A\left(\frac{1\text{ batt}}{3\ A}\right) \approx 1$ extra battery

Adafruit: $1.9\ A - 2\ A = 0\ A \longrightarrow$ NO EXTRA BATTERY

Appendix I – Pugh Matrix for Storage

	IMPORTANCE RATING	**BASELINE/OPTION 1** STANDARD REAR BASKET	**OPTION 2** FOLDING BASKETS	**OPTION 3** MODULAR BASKET	**OPTION 4** SEAT REPLACEMENT BASKET	**OPTION 5** BUNGEE NET BASKET
Storage Space	5	S	S	S	(+)	(+)
Availability	2	S	S	(-)	(-)	(+)
Allows for 2 riders	3	S	S	S	(-)	(-)
Visual Impact	3	S	(+)	(+)	S	S
Ease of Use	4	S	S	S	(-)	S
Weight	4	S	S	(+)	(+)	S
Integration	2	S	(+)	S	S	S
Sum of (+)			2	2	2	2
Sum of (-)			0	1	3	1
Sum of S			5	4	2	4
Weighted Sum of (+)			5	7	9	7
Weighted Sum of (-)			0	2	9	3
TOTAL SCORE			5	5	0	4

Appendix J – Pugh Matrix for Fairing

 1) Soft Plastic Rear Section, Hard Plastic Movable Front Section	 2) Hard Plastic Movable Rear Section, Hard Plastic Movable Front Section
 3) Partial Fairing	 4) Full Fairing
 5) Connected Rear and Front Sections - Hard Plastic	 6) Moving Front and Rear Sections - Fixed Axis Rotation
 7) Moving Front Section, Stationary Rear Section with Rear Wheel Cover Assembly	 8) Unrolling Fairing - Rollbar Frame

9) Movable Front Section, Cloth Fairing with Straps with Rear Wheel Cover Assembly

Criteria \ Concept	Weights	1	2	3	4	5	6	7	8	9
Aesthetics	2	S	S		-	S	-	+	-	+
Entry Difficulty	4	+	S		-	+	+	+	+	+
Design Effort	3	-	-		-	-	-	-	-	-
Sturdiness	1	+	+		+	+	S	+	-	+
Visibility	2	S	-		-	S	S	S	-	+
Aerodynamic	1	S	S	D	+	S	S	S	S	S
Rain Protection	4	+	+	A	+	+	+	+	+	+
Noise Reduction	3	+	+	T	+	+	+	+	-	+
Complexity	3	-	-	U	-	-	-	-	-	-
Manufacturability	3	+	S	M	-	S	S	S	-	S
Estimated Cost	2	-	-		-	-	-	-	S	-
Maintenance	1	-	S		S	-	-	S	-	S
Weight	2	-	-		-	-	-	-	+	S
∑+		15	8		9	12	11	16	10	16
∑-		11	12		20	11	13	10	18	8
∑S		4	-4		-11	1	-2	6	-8	8

Appendix K – Weight Estimate for Top Fairing Idea

PRELIMINARY CALCULATIONS

WEIGHT CALCULATIONS: PLASTIC FAIRING.

ABS PLASTIC density: 1.04 g/cc, or 0.0376 lbm/in^3

$$\rho = 1.04 \frac{g}{cm^3}$$

$$m = \rho \cdot V.$$

→ estimated volume - assume sheet of 1.5mm thickness.

~~length is about 5 ft. width of~~

try $L = 5ft \approx 1.5m$,

$W = 3ft \approx 1m$

$$V = L \cdot w \cdot t.$$

$$= (1.5m)(1m)(1.5 \times 10^{-3} m)$$

$$\boxed{V = 2.25 \times 10^{-3} m^3}$$

$$m = \rho \cdot V = \left(1.04 \frac{g}{cm^3}\right)\left(\frac{100cm}{1m}\right)^3 \times \left(\frac{1kg}{1000g}\right)(2.25 \times 10^{-3} m^3)$$

$$m = 2.34 kg$$

$W = \cancel{2.34}\ mg = \cancel{(2.34kg)(22.932}$

$$W = (2.34kg)(9.8 m/s^2)$$

$$\boxed{W \approx 22.93 N}$$

Convert to lbf → $\boxed{W = 5.15 lbf}$

weight of aluminum tubing

ASSUME 6 FT. OF ALUMINUM TUBING:

ASSUME 2 in ϕ TUBE, ALUMINUM 6061-T6, .125 wall thickness.

Aluminum 6061-T6 ρ = ~~2.7 g~~ .0975 lbm/in^3

$$\forall = L \cdot \frac{\pi}{4}(D_{out}^2 - D_{in}^2)$$

$$= (6\ ft)\left(\frac{\pi}{4}\right)\left[(2in)^2 - (2-.\cancel{125})^2\right]$$

$$= \left(\frac{72\pi}{4}\right)in\left[(2)^2 - (1.75)^2\right]in^2$$

$$\underline{\forall = 53\ in^3}$$

$$m = \rho\forall = (.0975\ lbm/in^3)(53\ in^3)$$

$$m = 5.1675\ lbm$$

$$W = mg = 5.1675\ lbm \times \cancel{32.2}\frac{ft}{\cancel{s^2}} \times \frac{lbf}{\cancel{32.2}\ lbm\frac{ft}{s^2}}$$

$$\boxed{W = 5.1675\ lbf}$$

TOTAL FAIRING WEIGHT (FRAME & HARD PLASTIC)

$$= 5.15\ lbf + 5.1675\ lbf$$

$$\boxed{W_{equit} = 10.3175\ lbf}$$

TOTAL WEIGHT LIMIT OF BIKE IS $\underline{\underline{450\ lbf}}$

there will be some more weight from fixtures, hardware, etc.

MAIN POINT: 10 lbf is not bad!

Appendix L– Theft Protection Product Feature Summary

Product | Features

SpyBike

- $149.37 with no monthly subscription
- GPS capability
- Text alert
- Online Tracking
- Stealthily attached to the bike

Bike+

- $159.00 with $4.00/month subscription
- GPS capability
- Text alert
- Crash detection
- Online tracking
- Mobile application
- Bluetooth
- Open API
- Geofencing protection
- Performance analysis

BikeSpike

- $129.00 with $4.00/month subscription
- GPS capability
- Text alert
- Email alert
- Crash detection
- Online tracking
- Mobile application
- Open API
- Geofencing protection
- Bike profiling
- Can upload theft reports to social media and to law enforcement
- Charges through wall charging unit or micro USB port
- Proprietary key and security screws make it very difficult to remove product

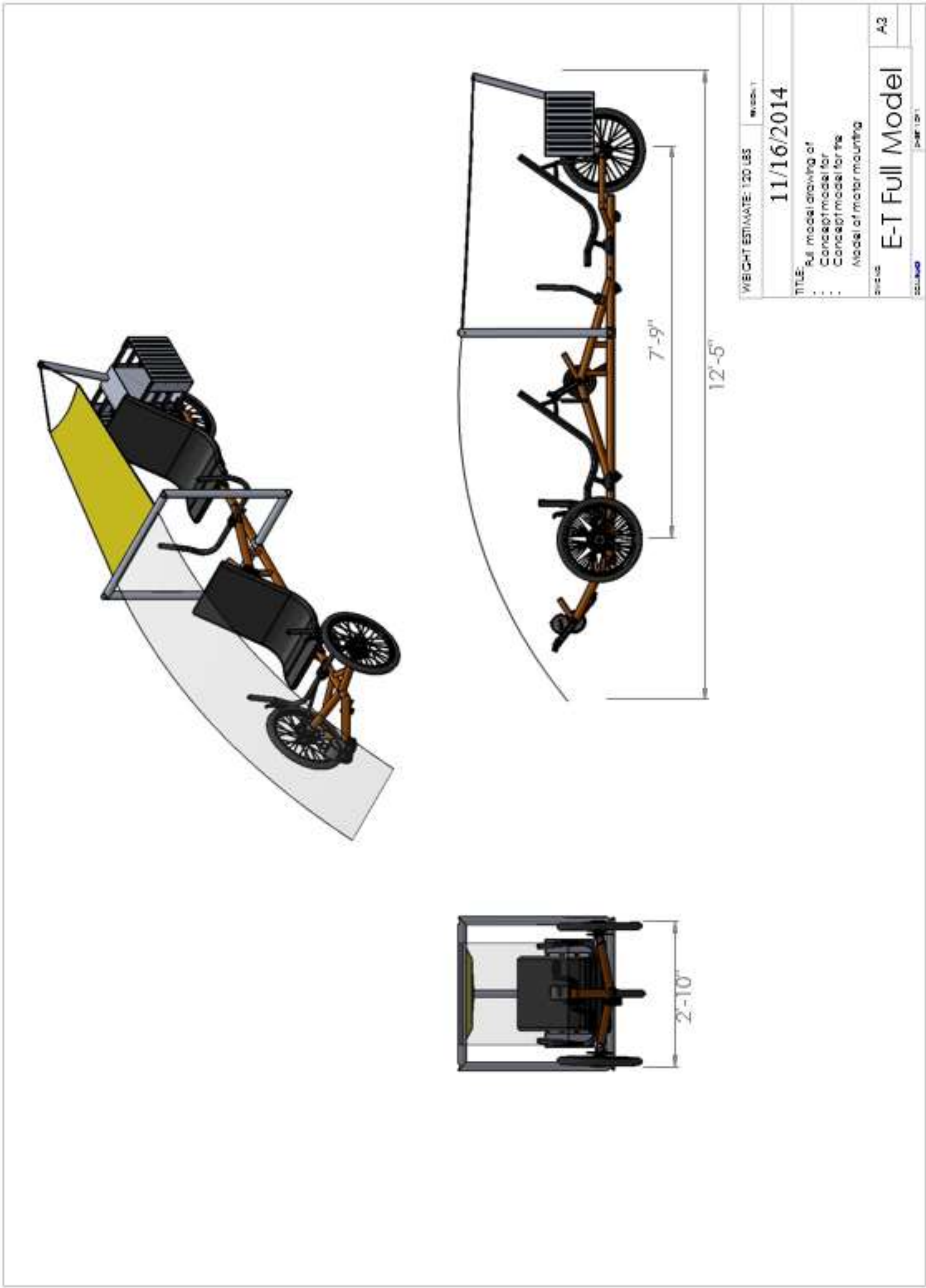
Appendix M – Pairwise Comparison for Theft Protection

	Bike+				BikeSpike				SpyBike			
Model	Value	Rank	Factor	Factor*Rank	Value	Rank	Factor	Factor*Rank	Value	Rank	Factor	Factor*Rank
Cost	159	2	9	18	129	4	9	36	149.37	2	9	18
Subscription	4/month	1	6	6	4.99/month	2	6	12	NA	5	6	30
Size	NA	3	12	36	Two fingers	3	12	36	Bike light or top cap	5	12	60
Mobile App	Yes	4	10	40	Yes	4	10	40	NA	1	10	10
Crash Detection	Yes	5	3	15	Yes	5	3	15	NA	1	3	3
Performance Stats	Yes	4	8	32	Yes	4	8	32	NA	1	8	8
Attachment Style	None	2	10	20	Either special water bottle holder or proprietary screws	3	10	30	Stealth	5	10	50
Features	Real time data accessible through mobile or web access, bluetooth connectivity	5	8	40	Accelerometer tamper detection, geo-fence lock, theft reports, crash detection	5	8	40	NA	1	8	8
Geographic Zones	Yes	1	5	5	NA	5	5	25	Yes	1	5	5
Profile your bike	No	1	2	2	Yes	5	2	10	No	1	2	2
Bluetooth connectivity	Yes	5	3	15	No	1	3	3	No	1	3	3
Total				229				279				197

Appendix N – Decision Matrix for Theft Protection

Feature	Cost	Subscription	Size	Mobile App	Crash Detection	Performance Stats	Attachment Style	Features	Geographic Zones	Profile your bike	Bluetooth Connectivity	Total	Normalized
Cost		1	0	0	1	1	1	0	1	1	1	7	9
Subscription	0		0	0	1	0	0	0	1	1	1	4	6
Size	1	1		1	1	1	1	1	1	1	1	10	12
Mobile App	1	1	0		1	1	0	1	1	1	1	8	10
Crash Detection	0	0	0	0		0	0	0	0	1	0	1	3
Performance Stats	0	1	0	0	1		0	1	1	1	1	6	8
Attachment Style	0	1	0	1	1	1		1	1	1	1	8	10
Features	1	1	0	0	1	0	0		1	1	1	6	8
Geographic Zones	0	0	0	0	1	0	0	0		1	1	3	5
Profile your bike	0	0	0	0	0	0	0	0	0		0	0	2
Bluetooth connectivity	0	0	0	0	0	0	0	0	0	1		1	3

Appendix O – Preliminary Design Model



Appendix P – Battery Weighted Decision Matrix Revisited

Concept / Criteria	Weighted Score	Datum		PingBat.		Samsung		ALLCELL		Golden		Grin		Tenergy NiC		Tenegy NiMH	
Cost of battery pack	4		0	-	-4	-	-4	-	-4	-	-4	-	-4	-	-4	-	-4
Number of charge cycles	2		0	+	2	+	2	+	2	+	2	+	2	+	2	+	2
Ah rating	5		0	+	5	-	-5	+	5	-	-5	S	0	-	-5	-	-5
weather resistant (water)	3		0	S	0	+	3	S	0	+	3	+	3	S	0	S	0
secured to bike	2		0	S	0	+	2	S	0	S	0	+	2	S	0	S	0
power switch	2		0	S	0	+	2	S	0	+	2	+	2	S	0	S	0
comes with charger	4		0	+	4	+	4	S	0	+	4	+	4	S	0	S	0
charge time	3		0	+	3	+	3	+	3	+	3	+	3	+	3	+	3
Safe to use	5		0	+	5	S	0	S	0	+	5	S	0	S	0	S	0
Safe to dispose of	4		0	+	4	+	4	S	0	+	4	S	0	S	0	S	0
Able to store	2		0	+	2	+	2	+	2	+	2	+	2	+	2	+	2
∑Sum of weighted scores			0		21		13		8		16		14		-2		-2

Appendix Q – Battery and Performance Calculator

Motor Specifications			
Power [watts]	750		
Normal Voltage	48		
Max Current (Amps)	25		
Max Speed (Mph)	31		
	#	**Time to go up hill (s)	total time (s)
#of Small hills	4	45	180
# of med. Hills	6	120	720
# of Lrg. Hills	2	240	480
***Hill Speed Reduction Factor	1.6	T-active (s)	1380
		Hill distance (mile)	3.07

Battery Specifications	
Rated Current [Ah]	15
Rated Voltage [V]	48
Max Current Discharge [A]	60

Motor and Battery Performance - Default								
Assist Level	Default Current Limit [%]	Limit Current [Amps]	Actual Current* [Amps]	Avg. Amps per hour [Ah]	Battery Discharge time [minutes]	Speed on flat road [mph]	Speed on hill [mph]	Distance traveled [miles]
0	0	0.0	0.0	inf	---	---	---	---
1	52	13.0	9.3	9.4	96	16.1	10.1	28.9
2	58	14.5	10.4	10.4	86	18.0	11.2	28.9
3	64	16.0	11.5	11.5	78	19.8	12.4	28.9
4	70	17.5	12.6	12.6	72	21.7	13.6	28.9
5	76	19.0	13.6	13.7	66	23.6	14.7	28.9
6	82	20.5	14.7	14.7	61	25.4	15.9	28.9
7	88	22.0	15.8	15.8	57	27.3	17.1	28.9
8	94	23.5	16.9	16.9	53	29.1	18.2	28.9
9	100	25.0	18.0	18.0	50	31.0	19.4	28.9

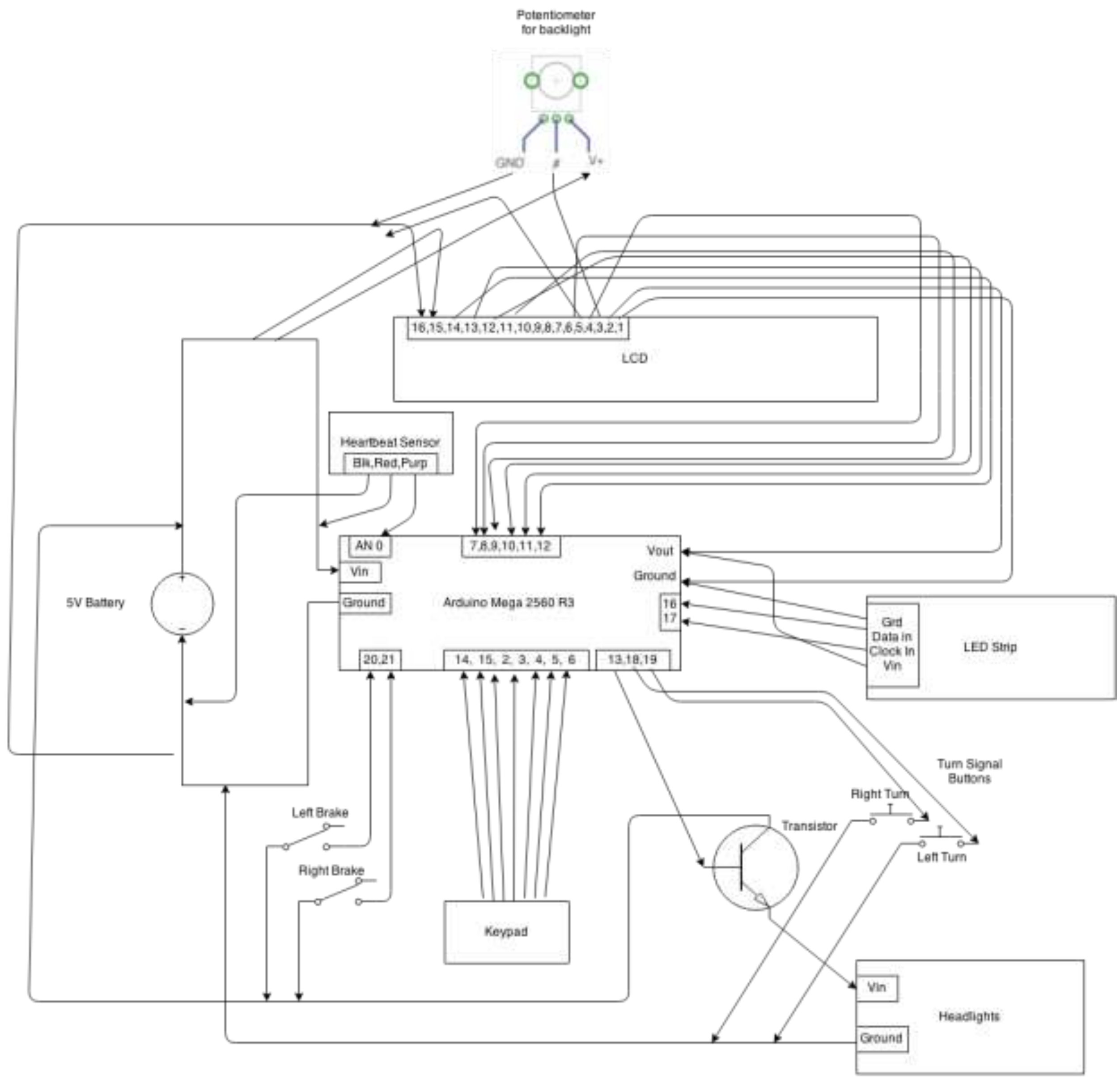
= User can change these values

*Inverter Efficiency to convert DC to AC (usually 87%) <http://whatis.techtarget.com/definition/ampere-hour-Ah-or-amp-hour>

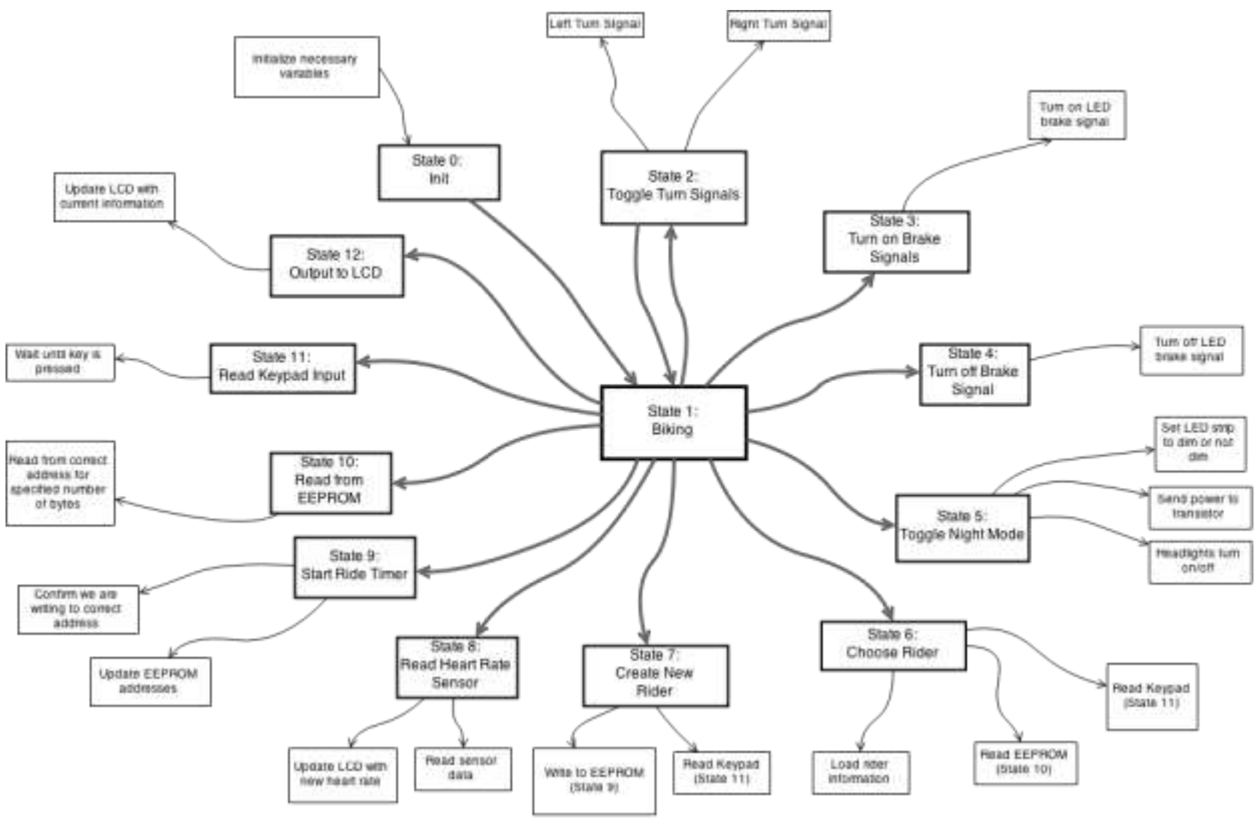
** Assuming at 8mph

***Hill Speed Reduction Factor (HSRF) –> Uphill speed = (Speed on flat road/HSFR)

Appendix R – Wiring Diagram



Appendix S – Flowchart of Microcontroller



Appendix T – Cost Analysis/Budget Estimate

TOTAL BUDGET	$5,000	**Actual Remaining budget**	$635.55		
Frame	$2,259	**Amount spent for: Frame**	$2,259.00		
Electronics	$435	**Electronics**	$230.70		
Drivetrain	$1,574	**Drivetrain**	$1,555.98		
Fairing	$480	**Fairing**	$13.88		
Security	$305	**Security**	$304.89		
Storage	$164	**Storage**	$16.73		
REMAINING	($218)	**OVER BUDGET**			

Subsystem	Part #	Product/Material	Price (Per Unit)	Quantity	Total Cost
Frame	FR-001	Terratrike Tandem Pro	$2,259	1	$2,259.00
Electronics/ Lighting	EL-001	Arduino Mega 2560 R3	$45.95	1	$45.95
	EL-002	3x4 Phone-style Matrix Keypad	$7.50	1	$7.50
	EL-003	TSL2561 Luminosity Sensor (Light Sensor)	$5.95	1	$5.95
	EL-004	Standard LCD 20x4 + extras white on blue	$17.95	1	$17.95
	EL-005	Fingerprint Sensor	$49.95	1	$49.95
	EL-006	Pulse Sensor Amped	$25.00	1	$25.00
	EL-007	Small push-pull solenoid	$9.95	1	$9.95
	EL-008	Weatherproof Metal Pushbutton with Red LED ring for turn signals and fun/night mode (*Need to order 2 more)	$4.95	2	$9.90
	EL-009	Microswitch	$2.95	2	$5.90
	EL-010	Male/Male Jumper Wires 40x12"	$7.95	1	$7.95
	EL-011	Female/Female Jumper Wires 40x12"	$7.95	1	$7.95
	EL-012	Full Sized Breadboard	$5.95	1	$5.95
	EL-013	Female/Male Jumper Wires 20x12"	$3.95	1	$3.95
	EL-014	Hook up wire Spool Black 25ft	$2.50	1	$2.50
	EL-015	Hook up wire Spool Red 25ft	$2.50	1	$2.50
	EL-016	Breadboarding Wire Bundle	$6.00	1	$6.00
	EL-017	Solder Wire 60/40 Rosin Core - 0.5mm/0.02" diameter 50 grams	$5.95	1	$5.95
	EL-018	N channel power MOSFET	$1.75	1	$1.75
	EL-019	Digital RGB LED Weatherproof Strip - LPD8806 32 LED - 1m	$29.95	1	$29.95
	EL-020	USB Battery Pack for Raspberry Pi - 10,000mAh - 2 x 5v @ 2a (*need to order 1 more)	$49.95	1	$49.95
	EL-021	Perma-Proto Half sized breadboard PCB	$4.50	1	$4.50
	EL-022	Perma-Proto Full sized breadboard PCB	$6.95	1	$6.95
	EL-023	USB Cable with switch	$2.95	1	$2.95
	EL-024	Electrical Tape	$1.97	2	$3.94
	EL-025	Lunasee Glow Rim Tape	$24.99	1	$24.99
	EL-026	2 pc Turn Signals	$11.75	1	$11.75
	EL-027	Minewt Mini 350 Headlamp	$39.99	1	$39.99
	EL-028	Hook up wire Spool Yellow 25 ft	$2.50	1	$2.50
	EL-029	4 pin JST SM Plug and Receptacle Cable Set	$1.50	1	$1.50
	EL-030	1 Female DC Power Adapter 2.1mm jack to screw termianl	$2.00	1	$2.00
	EL-031	On/Off Power Button/Pushbutton Toggle Switch	$1.95	2	$3.90
	EL-032	Hand Grip-Body for Heart Sensor and Turn Signals	TBD	1	
	EL-033	Hand Grip-Back for Heart Sensor and Turn Signals	TBD	1	
	EL-034	1W 365nm LED	$6.99	4	$27.96
Drivetrain	DR-001	Bafang bbs02 mid drive motor - Wire extensions - battery Connectors	$882.98	1	$882.98
	DR-002	Lithium Iron Phosphate Battery - Ping Battery	$673.00	1	$673.00
	DR-003	Disk Brakes	FREE	2	
	DR-004	Break Calipers	FREE	2	
	DR-005	Brake Lines	COVERED	2	
	DR-006	Brake Handles	COVERED	2	
	DR-007	Friction Shifters	COVERED	2	
	DR-008	8-Speed Rear Cassette	COVERED	1	
	DR-009	Rear Derailer/Tensioner	COVERED	1	
	DR-010	Chain	COVERED	3	
	DR-011	Pedals	COVERED	4	
	DR-012	Single Speed Chain Tensioner	17.93	1	$17.93
Fairing	FA-001	Aluminum Tubing	$124.30	1	$124.30
	FA-002	Hard Plastic for Fairing	$187.24	1	$187.24
	FA-003	Fabric Fairing	$40.00	1	$40.00
	FA-004	Shaft Collars and Bearings	$65.00	1	$65.00
	FA-005	Shipping Costs	$13.88	1	$13.88
	FA-006	Miscellaneous Components	$50.00	1	$50.00
Security	SE-001	Lock 8	$304.89	1	$304.89
	SE-002				
	SE-003				
Storage	ST-001	18"X58" Bungee Cargo Net	$19.50	1	$19.50
	ST-002	Aluminum Rack with Elastic strap	$76.90	1	$76.90
	ST-003	Axiom Folding Rear baskets (x2)	$50.98	1	$50.98
	ST-004	Additional Materials for bungee net		1	$0.00
	ST-005			1	$0.00
	ST-006	Plastic Battery Box	$16.73	1	$16.73

Appendix U – Fairing Hand Calculations

These are included in the pages at the end of the document.

Appendix V – Fairing Detailed Drawings

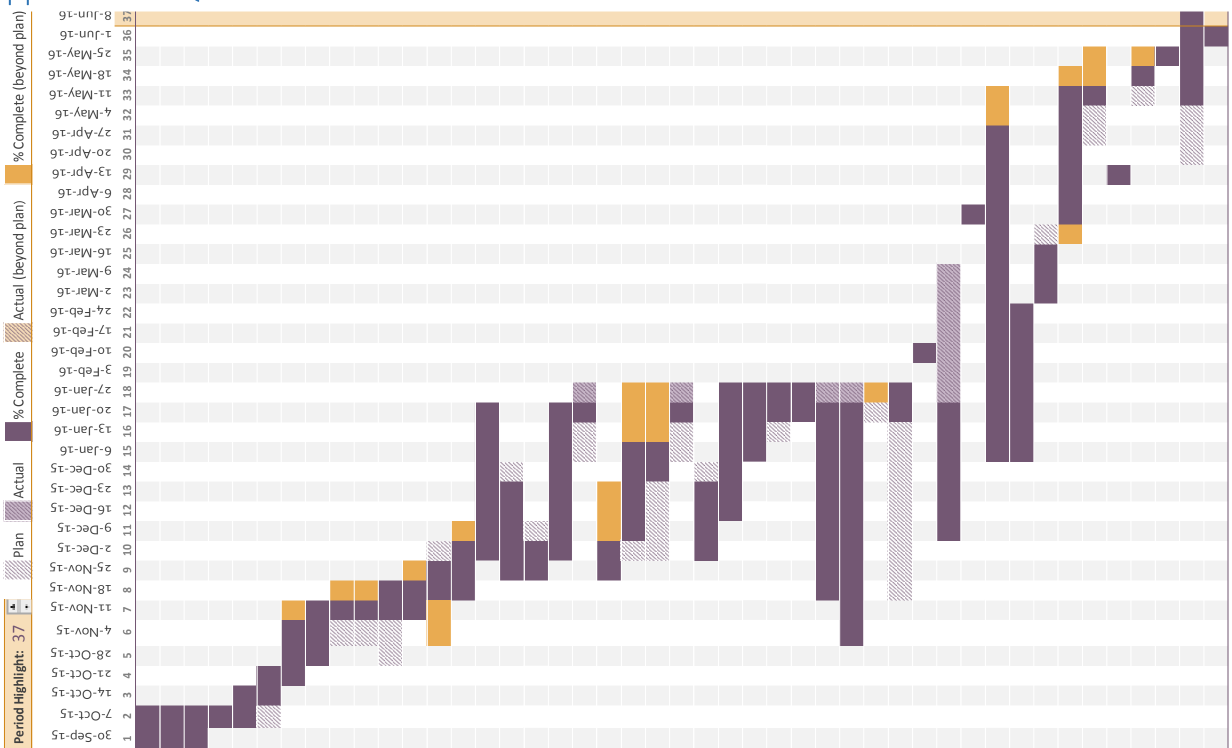
These are included in the following pages

Appendix W – Final Model Dimensioning

These are included in the following pages

Appendix X – QFD

Electric Tandemic



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Intro Letter to Sponsor	1	2	1	2	100%
Team Contract	1	2	1	2	100%
Problem Statement	1	2	1	2	100%
Split up into Subsystems	2	1	2	1	100%
QFD House of Quality	2	2	2	2	100%
Project Proposal Report	2	3	3	2	100%
Pugh Matrices	4	3	4	4	100%
Brainstorm	5	3	5	3	100%
Select top Ideas For each subsystem	6	2	7	2	100%
Preliminary Analysis	6	2	7	2	100%
Preliminary Design Report	5	4	7	2	100%
FMEA, DVP, Analysis Plan	7	2	7	3	100%
Select/Size Motor And Battery	8	3	6	4	100%
Calculations: Distance, Charging Time, Total Weight	8	3	8	4	100%
Battery Protection and Storage Design	10	8	10	8	100%
Complete the List of Electronics Needed	9	6	9	5	100%
Estimated run time on LV battery	9	3	9	2	100%
Complete Wire Diagram	10	8	10	8	100%
Mouting locatons for components	15	4	17	2	80%
Select Storage Design	9	2	9	5	100%
Design Rear Storage	10	6	11	8	100%
Design Additional Storage	10	6	14	5	100%
Manufacturing Plan	15	4	17	2	90%
Select Fairing Design	10	5	10	4	100%
Design Rear Fairing	12	7	12	7	100%
Design Supporting Structure	15	4	15	4	100%
Design Latch System	16	3	17	2	100%
Manufacturing Plan	17	2	17	2	100%
Finalize Costs for all Subsystems	8	11	8	11	95%
Final CAD Model/BOM	6	13	6	13	95%
Schedule CDR w/ Sponsor	17	1	18	1	50%
Final Design Report	8	11	17	2	100%
Individual Ethics Memo	20	1	20	1	100%
All Parts/Materials Ordered	11	14	11	14	50%
Project Update Memo	27	1	27	1	100%
Manufacturing Finished	15	17	15	19	100%
Rough Draft of Code Finished	15	8	15	8	100%
Testing of Electronic Hardware	23	4	23	3	100%
Code and Electronic Hardware Testing	27	7	26	9	100%
Project Validation	31	3	33	3	100%
Project Hardware/Safety Demo	29	1	29	1	100%
Operating Manual	33	2	34	2	100%
Senior Design Expo	35	1	35	1	100%
Final Project Report	30	8	33	5	100%
Final Checklist Complete	36	1	36	1	100%

Appendix Y – DVPR Test Plan

DVP&R													
Report Date		6/2/2015	Sponsor	Bob Shanbrom					Component/Assembly		REPORTING ENGINEER: Kris Lawrence		
TEST PLAN										TEST REPORT			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES Quantity	SAMPLES Type	TIMING Start date	TIMING Finish date	TEST RESULTS Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
1	Speed	Top speed with assistance - zero headwind, level ground, with two people pedaling	Motor stops at 20mph	Preston	CV	30+	-	4/11/2015	5/28/2015	20.1 mph	30+	0	Motor shut off every time as planned
2	Range	Mileage on Full Battery Charge - zero headwind, level ground, no pedaling	20 miles or more	Preston	CV	2	-	5/13/2015	5/28/2015	29.4 miles	2	0	Distance was 0.5 miles off of calculated value
3	Power	Power output of motor - level ground, 20 mph, two riders	750 W or less	Preston	CV	30+	-	4/11/2015	5/28/2015	18 mph avg.	20+	10	When battery was low on charge, the output power from the motor was noticably lower resulting in a lower speed.
4	Welding strength	Bend test of a sample welded piece	base material fails before weld	Preston	CV	5/1	Steel/AL	4/30/2015	5/21/2015	Welds strong	4/1	1/0	Mig and Tig Welds tested. All Tigs welds passed, first mig weld failed due to improper settings and not prepping material for welding
5	Storage	Quantity of available space - both baskets in open configuration	4 gallons of milk	Austin	CV	1	-	4/6/2015	4/6/2015	4 gallons	1	0	Fits sponsor's requirement easily with still more room available
6	Time to Charge	Time to charge bike - dead to full charge, normal charging conditions	3 hours or less	Preston	CV	2	2.5A charger	5/5/2015	5/25/2015	6 hour chrage time	0	3	Battery requires a 5 amp charger for 3 hour charge time. Budget didn't allow for that charger
7	Rear Visibility	Brightness of brake lights	40 lumens or more	Anthony	CV	2	-	5/15/2015	5/28/2015	Visible during day and night	2	0	LED lights bright enough at night. Visibility during day limited (dim at far distance). Brakes and turn signals work without flaws.
8	Front Night Visibility	Brightness of headlights	100 lumens or more	Anthony	CV	2	-	5/15/2015	5/28/2015	Bright enough for rider, visible by others	2	0	Front headlight originally not bright enough in low voltage system. Needed own power source for full power.
9	Side Night Visibility	Visibility of the bike from the side at night	Visible from 20+ yards away	Anthony	CV	2	-	5/15/2015	5/28/2015	Visible	2	0	Front fairing illuminates due to the shining of the front headlight making it more visible

Appendix Z – Actual Budget Analysis

Subsystem	Part #	Product/Material	Total Cost
Frame	FR-001	Terratrike Tandem Pro	$2,259.00
Electronics/ Lighting	EL-001	Arduino Mega 2560 R3	$45.95
	EL-002	3x4 Phone-style Matrix Keypad	$7.50
	EL-003	TSL2561 Luminosity Sensor (Light Sensor)	$5.95
	EL-004	Standard LCD 20x4 + extras white on blue	$17.95
	EL-005	Fingerprint Sensor	$49.95
	EL-006	Pulse Sensor Amped	$25.00
	EL-007	Small push-pull solenoid	$9.95
	EL-008	Weatherproof Metal Pushbutton with Red LED ring for turn signals and fun/night mode (*Need to order 2 more)	$9.90
	EL-009	Microswitch	$5.90
	EL-010	Male/Male Jumper Wires 40x12"	$7.95
	EL-011	Female/Female Jumper Wires 40x12"	$7.95
	EL-012	Full Sized Breadboard	$5.95
	EL-013	Female/Male Jumper Wires 20x12"	$3.95
	EL-014	Hook up wire Spool Black 25ft	$2.50
	EL-015	Hook up wire Spool Red 25ft	$2.50
	EL-016	Breadboarding Wire Bundle	$6.00
	EL-017	Solder Wire 60/40 Rosin Core - 0.5mm/0.02" diameter 50 grams	$5.95
	EL-018	N channel power MOSFET	$1.75
	EL-019	Digital RGB LED Weatherproof Strip - LPD8806 32 LED - 1m	$29.95
	EL-020	USB Battery Pack for Raspberry Pi - 10,000mAh - 2 x 5v @ 2a (*need to order 1 more)	$49.95
	EL-021	Perma-Proto Half sized breadboard PCB	$4.50
	EL-022	Perma-Proto Full sized breadboard PCB	$6.95
	EL-023	USB Cable with switch	$2.95
	EL-024	Electrical Tape	$3.94
	EL-025	Lunasee Glow Rim Tape	$24.99
	EL-026	2 pc Turn Signals	$11.75
	EL-027	Minewt Mini 350 Headlamp	$39.99
	EL-028	Hook up wire Spool Yellow 25 ft	$2.50
	EL-029	4 pin JST SM Plug and Receptacle Cable Set	$1.50
	EL-030	1 Female DC Power Adapter 2.1mm jack to screw termianl	$2.00
	EL-031	On/Off Power Button/Pushbutton Toggle Switch	$3.90
	EL-032	Hand Grip-Body for Heart Sensor and Turn Signals	$147.93
	EL-034	10 gage wire and zip ties	$29.51
	EL-035	Battery connectors - Bullet and Deans connectors	$8.61
	EL-036	Battery connectors - 6mm Bullet connectors	$5.24
	EL -037	Sprinkler Wire	$32.91
	EL -038	Buttons, Breakout Board, LED caps	$14.01
	EL -039	Female to Male Jumper Wires	$8.02
	EL -040	Crimp Connectors	$12.07
	EL -041	Breakout Board and USB cables	$13.27
	EL -042	ScrewShield	$14.43
	EL -043	Connectors	$5.34
	EL -044	Headlight	$17.39
	EL-045	1W 365nm LED	$27.96

Drivetrain	DR-001	Bafang bbs02 mid drive motor - Wire extensions - battery Connectors	$882.98
	DR-002	Lithium Iron Phosphate Battery - Ping Battery	$673.00
	DR-003	Disk Brakes	
	DR-004	Break Calipers	
	DR-005	Brake Lines	
	DR-006	Brake Handles	
	DR-007	Friction Shifters	
	DR-008	8-Speed Rear Cassette	
	DR-009	Rear Derailer/Tensioner	
	DR-010	Chain	
	DR-011	Pedals	
	DR-012	Single Speed Chain Tensioner	$21.42
		Stainless tandem Shifter cable	$8.63
	DR-013	8 speed master link	$4.99
	DR-014	Bike Coalition Purchases	$97.00
Fairing		All Metal and Plastic for Fairing Assembly	$164.00
		Misc. Metal Testing	$38.03
		Misc. Mcmaster purchases	$10.77
		Misc. Mcmaster purchases	$32.77
		Misc.. Metal testing	$16.36
		More Online Metals	$85.22
		Home Depot Run - Rivots, gate latch, metal, grinder wheel	$19.15
		KRIS NEW	$14.47
		KRIS NEW	$30.62
		KRIS NEW	$50.88
		kite connectors	$14.59
		Spray Paint black	$4.30
		Gas Springs	$27.49
		Oil cloth	$21.21
		Velco	$10.50
		Faring Bolts and more spray paint	$8.89
		Camry Trunk Latch	$30.24
		Second Round of Gas Springs	$33.89
		Cal Poly Decal	$11.81
		.25" steel rods	$20.55
		Ferrule	$1.34
		Misc. Fairing materials	$20.00
		Rear fairing stuff	$9.89
		Misc. Mcmaster purchases	$30.10
Security	SE-001	Lock 8 (Reimbursed)	$0.00
Storage	ST-001	Aluminum Rack with Elastic strap	$76.90
	ST-002	Axiom Folding Rear baskets (x2)	$50.97
		Hardware for battery box and mounting	$14.03
	ST-004	Plastic Battery Box	$16.73

Account	ME	CPC
Actual Remaining budget in account	$160.29	$ 1.59
Amount spent for: Frame	$2,259.00	$ -
Electronics	$496.07	$ 43.36
Drivetrain	$1,555.98	$ 132.04
Fairing	$528.66	$ 178.41
Security	$0.00	$ -
Storage	$14.03	$ 144.60

Appendix AA – FMEA

Potential
Failure Mode and Effect Analysis
(Design FMEA)

___ System | **FMEA Number: 1**
___ Subsystem
___ Component | **Design Responsibility:** | **Page 1 of 1**

Model Year(s)/Vehicle(s): Terratrike Tandem Pro (2014) | **Key Date: 11/25/14** | **Prepared By: Core Team**

Core Team: Preston McElroy, Anthony Jacques, Kris Lawrence, Austin Fredrickson | **FMEA Date (Orig.) 11/25/15** | **(Rev.) 6/5/15**

									Action Results			
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**	**Actions Taken**	**Sev**	**Occur**	**Crit**
Trike Frame	Bending of frame	Bike Unusable	8	Overloaded	2	16	Have a weight limit for riders (below 400lbs) and any additional attachments (below 50 lbs)	Preston - 1/30/14	Limit the weight of riders	8	2	16
Wheels	Spoke failure due to too much weight	wheels roll loppsided, weight distrobution uneven resulting in total wheel failure	7	Overloaded	3	21	Have a weight limit for riders (below 400lbs) and any additional attachments (below 50	Preston - 1/30/15	weight limit	7	3	21
Chain	derailer mis-alignment	gear skipping, wear gears more quickly, noise,	4	not calibrated, faulty equipment, derailer bumped out of place	4	16	Unpreventable on all bikes. Would need new part or simple realignment	Preston - 1/30/16	Limited what gears can be used	4	3	12
Tire tube	Tubes pop	unable to ride, lflat tires = no traction	7	Too much weight, tire tube over-inflated	5	35	monitor weight and pressure rating on tube	Preston - 1/30/17	meausure tire pressure before each ride, check for leaks	7	5	35
Fairing structure	Frame cracking/fracturing	Structure hits ground, structure breaks, structure falls on rider	4	Stress fatigue, strength of weld, weakness of material	3	12	Make the frame strong, with safety factor of 2 or more. Use fixturing and machining if possible	Kris - 1/30/14	None, be cautious when riding	4	3	12
	corrosion due to weather	Rust, weakening of joints, discoloration, potential for skin harm	2	Weather cycling, rain and subsequent rust	1	2	Choose appropriate material, protective epoxy applied	Kris - 1/30/14	painted everthing that can rust with spray paint	2	1	2
Fairing plastic	plastic cracking	Cracked plastic, lowered effectiveness of rain shielding	2	Impact with frame, temperature cycling	2	4	Choose impact-resistance material, easily reparable, low thermal expansion	Kris - 1/30/14	cheap and easily replaceble plastic	1	3	3
Fairing Lift Assist	Hydraulic leaking, fairing fracture	Difficult to lift fairing, uneven lift assist, Damage to fairing	4	Overuse, temperature cycling, over-extension, wrong size	2	8	Choose right size of hydraulic	Kris - 1/30/14	gas springs	2	1	2
Latch Mechanism	Latch Breaks	Fairing cannot close	4	Latch not sized correctly, material too weak, impact with pedals	2	8	Choose strong material, design for strength and reliability	Kris - 1/30/14	went with trunk latch	3	1	3
Fairing cloth	Tearing	Rain goes through fairing, size of vehicle enlarged	1	Fatigue on cloth, snagged on outside object	1	1	Choose strong fabric, fit in profile of trike	Kris - 1/30/14	oil cloth	1	1	1
Cloth Fairing Cables	Cables snap, lose tension	Cloth fairing is not held down, Hits rear rider (in head)	2	Cut cables, fatigue, wind undoes assembly, too much tension	3	6	Choose appropriate material, make reliable assembly	Kris - 1/30/14	spring mechanized trunk latch	2	1	2
Cloth Fairing	Twist, undergoes deformation	Rain falls on rider, adds forces to fairing structure and cloth	2	Crosswind, fairing structural flexing	2	4	Use flexural bars to maintain form of cloth fairing	Kris - 1/30/14	fiber glass rods and steel rods	2	1	2
Motor	Motor provides power when not wanted	loss of control of bike, crashing, injury to rider	8	Throttle stuck	3	24	Motor brake, Emergency stop, limit bike components that throttle can get stuck	Preston - 1/30/14	Motor brake	8	1	8

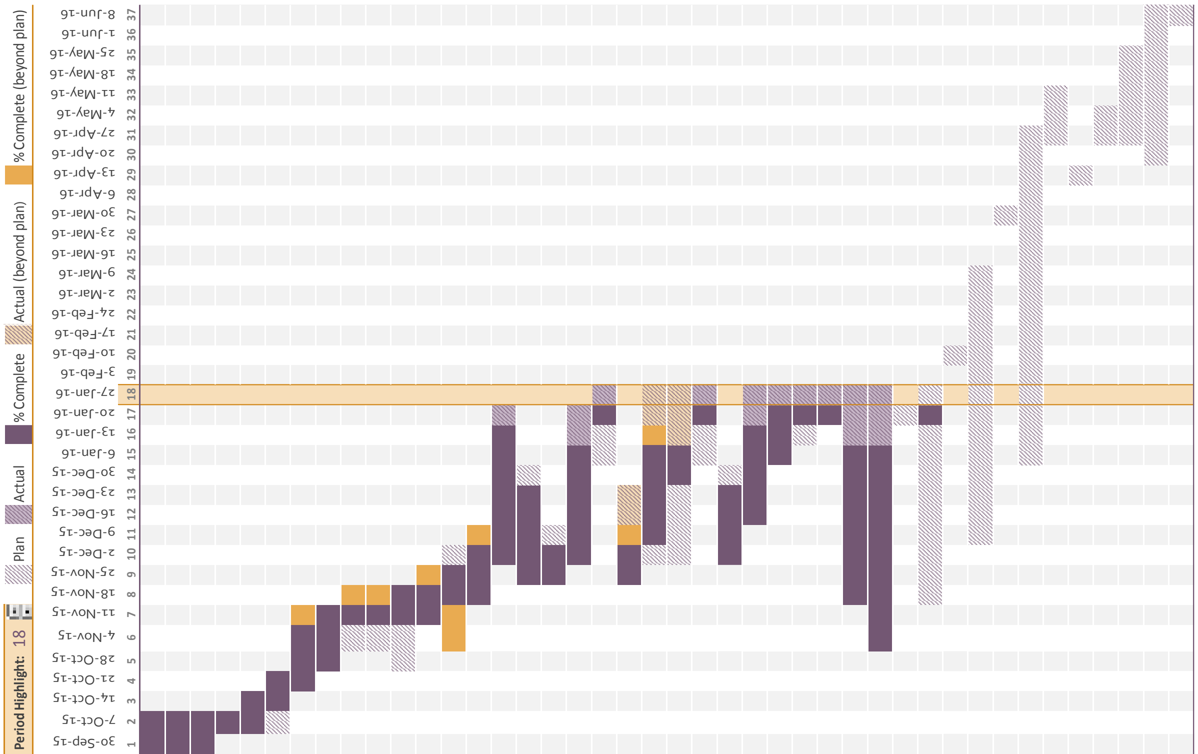
High / low Voltage Wiring	wires fray	Shorting, malfunction of controller and motor, electricution to rider(s)	7	dragging on ground, rubbing	4	28	Secure all wires to a stationary structure, no wires running along bottom of frame.	Preston - 1/30/14	springler wiring and house wiring	7	2	14
	wires shear	electricution, sparks, and fire	8	get caught in moving and rotating components	4	32	Secure all wires to a stationary structure, no wires running along bottom of frame, no	Preston - 1/30/14	quick disconnects from battery, help stop issue quicker	8	4	32
Batteries	batteries overheart/ power output decreased	decreased performance, electrical fire	9	overcharged, uneven discharge of batteries	5	45	System that monitors charge of each cell and prevents further charging when cells are fully charged	Preston - 1/30/14	Battery management system incorporated into battery pack, make the battery pack water resistant	9	1	9
	shorting	sparks, fire, and overheating of batteries	9	water gets into battery pack	3	27	Detection system in battery pack that senses a shortage and doesn't allow battery cells to be used, have batteries in a waterproof/resistant casing	Preston - 1/30/14	Battery management system incorporated into battery pack	9	1	9
	Structural damage of cells	No power to motor, batteries short, loss of cell life	9	Batteries fall on theground and damage the cell structure	5	45	Secure the battery pack to the bike	Preston - 1/30/14	Mounted in the rear of the bike in a protective battery box	9	2	18
Storage	Mechanical stops shear off	Storage unusable, damages luggage	6	Overloaded, mechanical stop weakened by corrosion	3	18	Have a weight limit of the storage, design with non-corrosive materials	Austin - 1/30/14	24lb limit each basket	6	1	6
	position lock doesn't hold in upright position	Storage box always in storage position, cant be stowed away	3	Storage swung closed too hard or fatigue fracture	4	12	Design the position locks accounting for fatigue and repeated use. Have warning to not slam storage closed	Austin - 1/30/14	always kept open, ziptie if not locking	2	4	8
	corrosion	rust, health hazard, weakening of structure	3	Weather	2	6	Design the storage with non-corrosive materials	Austin - 1/30/14	painted baskets	3	1	3
	Shears off rear rack	gets caught in rear wheel,	7	Overloaded	2	14	design rack with factor of safety to prevent shearing off or bearing failure of the bolt holes	Austin - 1/30/14	replacable clamps	7	1	7
Wheel lock	Bends/breaks spokes	unable to ride, lock gets stuck in wheel, need new wheel	7	rider forgets about lock and tries to pedal off	4	28	Some kind of reminder that the lock is still engaged on the bike	Austin - 1/30/14	cable lock through the frame	7	1	7
LEDs	Lighting stops working	Does not emit light, can't be seen by other drivers	7	Wiring failure	2	14	Ensure wiring is intact before attaching LEDs	Anthony - 1/30/14	screw shield	6	1	6
	Lighting stops working	Does not emit light, can't be seen by other drivers	7	Weather Water ruins circuitry	5	35	Ensure LEDs are weatherproof and not directly in danger of rain	Anthony - 1/30/14	protected under fairing, caps onLED strip	7	2	14
Microswitch	Switch is bent	Brake signals aren't activated	5	Overuse Switch moved around during ride	2	10	Ensure switch is in the correct location	Anthony - 1/30/14	away from rider so contact can be mae with it	3	1	3
Pushbuttons	Pushbutton doesn't transmit necessary signal	Unable to indicate turn signals	4	Overuse	2	8	Ensure wiring is intact and button in comfortable location	Anthony - 1/30/14	created a handle grip to hold buttons, buttons easily replacable	4	2	8
Character LCD	Doesn't display necessary information	Rider unable to interact with microcontroller	4	Weather	3	12	Ensure LCD is in weatherproof location	Anthony - 1/30/14	under fairing but not water protected from side	4	3	12
Keypad	Doesn't send necessary signals	Rider unable to interact with microcontroller	4	Weather	3	12	Ensure keypad is in weatherproof location	Anthony - 1/30/14	under fairing but not water protected from side	4	3	12
Hearbeat Sensor	Doesn't communicate with microcontroller or doesn't recognize hand	Rider unable to see heartbeat	3	Weather Faulty Code	2	6	Ensure sensor is in a waterproof casing and code is correct before integration	Anthony - 1/30/14	under fairing and integrated into handle grip	2	1	2
Headlights	Do not emit light	Rider cannot see ahead	8	Weather Faulty wiring	2	16	Have weatherproof casing for wiring	Anthony - 1/30/14	protected under fairing, water proof light	8	0	0
Microcontroller	Not emitting data or signals	No turn signals, brake signals, headlights, ability to enter glove box	7	Weather Faulty Wiring	2	14	Ensure microcontroller is in a weatherproof encasing and working before integration	Anthony - 1/30/14	in water resistant box	6	1	6

Appendix AB – Gantt Chart

Electric Tandemic

Period Highlight: 18

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Intro Letter to Sponsor	1	2	1	2	100%
Team Contract	1	2	1	2	100%
Problem Statement	1	2	1	2	100%
Split up into Subsystems	2	1	2	1	100%
QFD House of Quality	2	2	2	2	100%
Project Proposal Report	2	3	3	2	100%
Pugh Matrices	4	3	4	4	100%
Brainstorm	5	3	5	3	100%
Select top Ideas For each subsystem	6	2	7	2	100%
Preliminary Analysis	6	2	7	2	100%
Preliminary Design Report	5	4	7	2	100%
FMEA, DVP, Analysis Plan	7	2	7	3	100%
Select/Size Motor And Battery	8	3	6	4	100%
Calculations: Distance, Charging Time, Total Weight	8	3	8	4	100%
Battery Protection and Storage Design	10	8	10	8	90%
Complete the List of Electronics Needed	9	6	9	5	100%
Estimated run time on LV battery	9	3	9	2	100%
Complete Wire Diagram	10	8	10	8	75%
Mouting locatons for components	15	4	17	2	75%
Select Storage Design	9	2	9	5	75%
Design Rear Storage	10	6	11	8	80%
Design Additional Storage	10	6	14	5	50%
Manufacturing Plan	15	4	17	2	25%
Select Fairing Design	10	5	10	4	100%
Design Rear Fairing	12	7	12	7	75%
Design Supporting Structure	15	4	15	4	75%
Design Latch System	16	3	17	2	50%
Manufacturing Plan	17	2	17	2	25%
Finalize Costs for all Subsystems	8	11	8	11	80%
Final CAD Model/BOM	6	13	6	13	80%
Schedule CDR w/ Sponsor	17	1	0	0	0%
Final Design Report	8	11	17	1	40%
Individual Ethics Memo	20	1	0	0	0%
All Parts/Materials Ordered	11	14	0	0	0%
Project Update Memo	27	1	0	0	0%
Manufacturing Finished	15	17	0	0	0%
Project Validation	31	3	0	0	0%
Project Hardware/Safety Demo	29	1	0	0	0%
Operating Manual	31	2	0	0	0%
Senior Design Expo	31	5	0	0	0%
Final Project Report	30	8	0	0	0%
Final Checklist Complete	37	1	0	0	0%



Appendix AC – Operator's Manual with Safety Guidelines

The Electrike User's Guide

Thank you so much for using this senior project and showing people the many advantages that electric tricycles have to offer. We hope that you thoroughly enjoy the trike and have a great ride! Before you ride it though, we insist that you read the following disclaimer and owner's manual.

Statement of Disclaimer

This project is the result of a class assignment; it has been graded and accepted as fulfillment of the course requirements, but it unfortunately does not entail technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the product. California Polytechnic State University, San Luis Obispo and its staff cannot be held responsible or reliable for any misuse of the project.

Parts List

1. Terratrike Tandem Pro

2. Bafang Electric Motor and Controller

3. Ping Battery

4. Collapsible bicycle storage racks

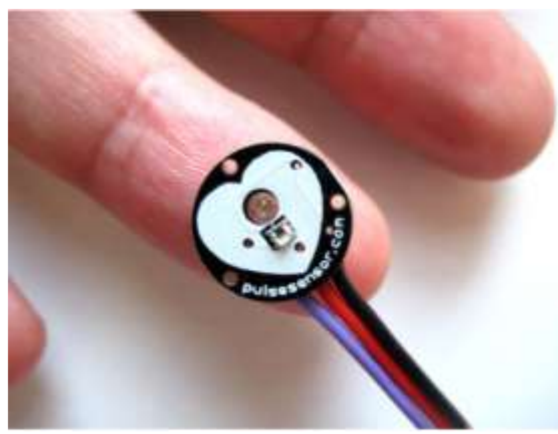
5. Removable Fairing

6. LCD screen

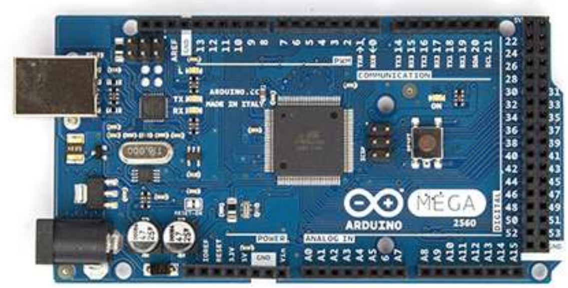
7. Keypad

8. 3D printed hand grip

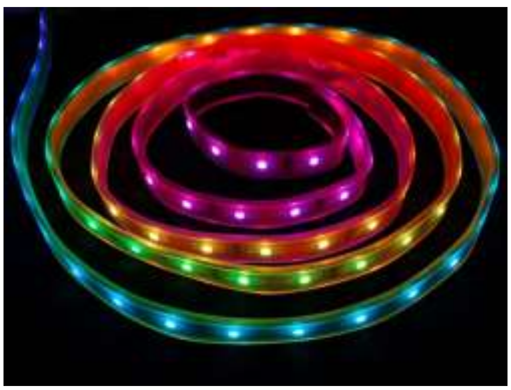
9. Heartbeat sensor



10. Arduino Mega 2560



11. LED strip



12. Headlight and headlight battery

Tricycle Assembly

The entire trike can be split into two parts. This is not recommended as it would be very difficult to remove all of the wiring to do this, but it is possible. Use the silver Terratrike tool to unfasten the silver threads in the middle of the trike. This will allow the trike to be pulled apart; the wiring must be removed before this otherwise the two parts will not be able to move apart.

The fairing is easy to attach/detach. The fairing is split into two portions: the front portion with the clear plastic and the rear portion with the black cloth above the rear rider. We will first discuss detaching the fairing. The rear fairing must be removed first. The rear fairing is attached to the front fairing via two pins and a Velcro strap. The two pins attach at the rotating portion of the front fairing; just pull these pins out. Next, undo the Velcro strap. After this, the back of the fairing has two poles that are inserted into the back of the rear seat. After undoing the Velcro and removing the pins, the rear fairing will come off when you pull those poles out of the back of the rear seat. Now it's time to remove the front fairing. At the front of the trike, there is a latch; this latch must be released. The next point is attached to the rear of the front fairing. It slides onto the mount located in between the back of the front rider and the back rider's feet. This connection contains no permanent connections, but it is snug and might take some force to remove. At this point, the front fairing should easily come off of the trike as long as the two previously mentioned points are removed/released. Now you have a convertible! To attach the fairing, just follow these steps in reverse order.

The code for this project can be found on github, at https://github.com/ajaxjjj20/Electrike

Tricycle Operation

The two seats can be adjusted to allow for more or less leg room. To move the seat, an allen wrench is required; the bolt must be removed first. Then the seat can be adjusted forward or backwards. Align the seat correctly and place the bolt back through the appropriate hole.

This tricycle is water resistant, but again, it is a prototype and it is not recommended to be used in heavy water conditions. It is not recommended that the trike is used while raining or be left outside where it could be exposed to water.

The electronics run on two different batteries. The motor and its controller are powered by the larger Ping battery. The Ping battery must follow a few rules. There is one cable that goes from the Ping battery to the motor, two cables that go from the top of the battery to the main part of the battery, and one cable for charging. When the battery is in use, the cable from the battery to the motor must be connected in addition to the two cables from the top to the main part of the battery. When the motor is not being used, all four of the cables must be disconnected otherwise the battery can lose its charge much quicker. When charging the battery, the cable to the motor must be disconnected, while the other three must be connected.

The rest of the electronics are run by the smaller white battery. To power the electronics (minus the battery/controller), the black USB cables must be plugged into the battery. Once the cables are plugged in, the circular button on the battery must be pushed. This will ensure that power is being output; pushing the button also illuminates the four LEDs on the front of the battery. This indicates the battery life. It should be noted though that this button is not an on/off button. It will continue to output; to charge this smaller battery, plug the smaller, white cable (the micro B USB cable) into the middle, smaller port of the battery. Plug the other end of the micro B USB cable into a USB power source. To turn off the electronics, disconnect the black USB cables from the battery.

Safety Precautions

This tricycle is a prototype. There are inherent risks in a premarket product that you must accept if you are to use. There are inherent safety precautions that need to be considered when riding a tricycle. Terratrike has a manual that outlines many of these problems. The manual can be found on Terratrike's website, terratrike.com under the tandem tricycle section.

There are safety precautions that need to be considered when using the motor's battery, these can be found at http://www.pingbattery.com/content/wiringguide.pdf. Their motor has a user's manual also that can be found on Bafang's website, szbaf.com, or at this address: https://onedrive.live.com/?cid=92088474CCB8CD05&id=92088474ccb8cd05%2111067&authkey=%21APKz85S7ICdbE4M.

There are inherent risks in riding a tricycle such as spinning wheels. Please ensure all loose clothing and anything that could get caught in a wheel are secured before riding the tricycle. Ensure that nothing in the rear racks is loose and swaying, as it could easily get caught in the back wheel. This trike is capable of high speeds; ensure that safe driving habits are followed as this trike can and will tip if a turn is taken too sharp while going too fast. Both riders need to be comfortable when riding the

tricycle; ensure the seats are set to the correct distance before riding. Do not try to sit in the seats without them being fully attached and bolted to the frame as this can cause injury to the rider and harm to the trike.

Be sure to not touch or try to repair the chain or any part of the drivetrain if the motor is connected to the battery. If the motor is attached to the battery, there is a chance that the throttle could be hit or the motor could activate and this could turn the chain which could injure the person and/or the chain. Make sure to wear close toed shoes at all times when riding the trike as there are a lot of moving parts and it is much safer to wear close toed shoes.

Make sure that the flag is always visible and attached to the trike as it improves visibility and makes the trike much safer. Also, ensure that night mode is turned on when it is dark as this turns on the LED strip and makes the trike more visible and this makes it safer. Failing to turn on night mode or use the flag makes the trike much harder to see as it is low to the ground and hard to see from the other taller, larger vehicles.

Use special caution and the correct signals when riding on the streets with much larger vehicles. This tricycle should be ridden in the bike lane whenever possible. Please follow the rules of the road such as stopping at stop signs and stop lights whenever riding this trike because failing to do so will greatly increase the risk of injury to the riders of the trike. Lastly, have a blast! Be sure to not work too hard and let the motor do the hard labor, after all, that’s why it’s on there!

41.

Aluminum stress failure

~~from shigley's Section 6-7, 6-8? (see S'_e) for non ferrous materials~~

~~↳ see 6-9 for modifying factors.~~ pg. 282 only for fatigue!

~~6-14? (combined loading modes)~~

Hollow cylinder properties:

$$m = \frac{\pi(d_o^2 - d_i^2)L\rho}{4g} \qquad I_x = \frac{m}{8}(d_o^2 + d_i^2)$$

$$I_y = I_z = \frac{m}{48}(3d_o^2 + 3d_i^2 + 4L^2)$$

Aluminum 7075 properties:

T6 heat treated

$S_y = 78.6\text{ksi}$ $\quad \sigma_f = 102\text{ksi}$

$S_{Ultimate} = 86.0\text{ksi}$

Aluminum 6061 properties, T6 heat treated:

$E = 10{,}000\text{ksi}$

$S_{UT} = 45000\text{psi}$ (ultimate tensile) $\quad S_T = 40{,}000$ psi (tensile yield strength)

$\rho = 0.0975$ ~~psi~~ lb/in³

weights calculated for calculations on next page:

Large shaft on rotating assembly:

$$w = \frac{\pi[(2.5\text{in})^2 - (2\text{in})^2]\cdot 19\text{in}(.0975\ \text{lbm/in}^3)}{4(32.2\ \text{ft/s}^2)} = \boxed{3.274\ \text{lbf} = w}$$

Inner shaft on rotating assembly

$$w = \frac{\pi[(1.125\text{in})^2 - (0.625\text{in})^2]18\text{in}(.0975\ \text{lbm/in}^3)}{4} + \frac{\pi[(1\text{in})^2 - (0.625\text{in})^2]6\text{in}\cdot(.0975\ \text{lbm/in}^3)}{4}$$

$$\boxed{w = 1.486\ \text{lbf}}$$

Assume ≈ 1 lbf for 2 bearings

↳ $\boxed{w = 1\ \text{lbf}}$

for bent aluminum, $L = 2(14\text{in}) + 16\text{in} + \frac{\pi}{2}(12) = 57.85 \approx 60\text{in}$

$$w = \frac{\pi[(1.0\text{in})^2 - (.875\text{in})^2]\cdot 60\text{in}\cdot .0975\ \text{lbm/in}^3}{4} = \boxed{1.08\ \text{lbf} = w}$$

rectangular aluminum:

$$\frac{[(1\text{in})^2 - (.875\text{in})^2]\cdot \cancel{16\text{in}}\ 20\text{in}\cdot .0975\ \text{lbm/in}^3}{\cancel{4}} = \boxed{\cancel{0.11\ \text{lbf}} = w}$$

also accounts for small section

$\boxed{\cancel{w = 0.366\ \text{lbf}}}$

$\boxed{w \approx 0.5\ \text{lbf}}$

Steel brackets:

~~mass~~

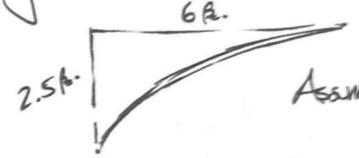
$\forall = 0.67\ in^3$

$\rho_{steel} = .282\ lbf/in^3$

$W = \rho\forall = (.282\ lbf/in^3)(0.67\ in^3) = 0.19\ lbf$

$W \times 4$ (There are 4 brackets) $\Rightarrow \boxed{W = 0.76\ lbf}$

weight of fairing



Assume shape of $y = \sqrt{x}$

$y = C\sqrt{x},\ x = 6,\ y = 2.5$

$2.5 = C\sqrt{6} \rightarrow C = 1.02$

$y = 1.02\sqrt{x} \rightarrow \frac{dy}{dx} = \frac{1.02}{2\sqrt{x}}$

$$S = \int_A^B \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\cdot dx = \int_0^6 \sqrt{1 + \frac{1.02}{2\sqrt{x}}}\ dx \simeq 7.99\ ft = 8\ ft$$

width = 2 ft   thickness = 0.375 in.

0.375 in Thick $\rightarrow \forall = (8\ ft)(2\ ft)(\frac{.375}{12}\ ft) = 0.5\ ft^3$

density of Lexan = $1.217\ g/cm^3 \times \frac{62.4\ lbf/ft^3}{1\ g/cm^3} = 75.9\ lbf/ft^3$

$0.5\ ft^3 \times$ ~~62.4~~ $75.9\ lbf/ft^3 = 38\ lbf \rightarrow$ too heavy

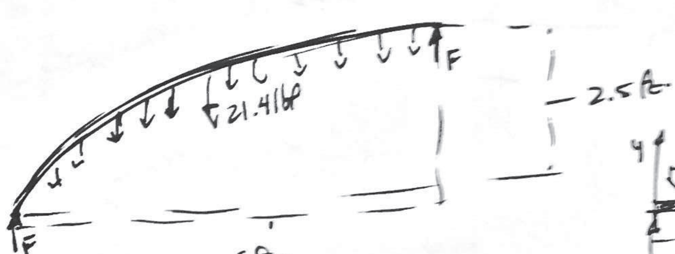
try 0.25 in Thick $\rightarrow \forall = (8\ ft)(2\ ft)(\frac{.25}{12}\ ft) = 0.33\ ft^3$

density of ABS $\rightarrow .0376\ lbm/in^3$

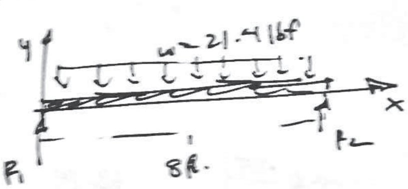
$w = 0.33\ ft^3)(.0376\ \frac{lbm}{in^3})\left[\frac{1728\ in^3}{1\ ft^3}\right] = 21.44\ lbm \times \frac{32.2\ ft/s^2}{32.2\ lbf} = 21.4\ lbf$

$\boxed{w = 21.4\ lbf}$

FAIRING



treat as cantilever, simple supports, uniform load.



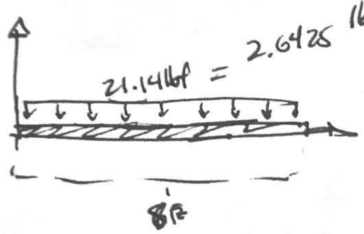
$y = \frac{wx}{24EI}(2Lx^2 - x^3 - L^3) \rightarrow$ max deflection at $x = \frac{L}{2}$

$$y_{max} = -\frac{5wL^4}{384EI} = \frac{-5(21.14\ lbf)(8\ ft)^4}{384(331\times10^3\ \frac{lbf}{in^2})(\frac{144\ in^2}{1\ ft^2})(1.507\times10^{-6}\ ft^4)} = \cancel{15.7\ ft} \rightarrow \text{1 Messed up code}$$

$G = 331\ ksi$

$I = \frac{1}{12}bh^3 = \frac{1}{12}(2\ ft)\left(\frac{.225}{12\ ft}\right)^3 = 1.507\times10^{-6}\ ft^4$

43.



$y_{max} = \cancel{-\tfrac{5}{3}}(\cancel{2.6425}\ lbf/ft)$ do in inches

$$y_{max} = -\frac{5wL^4}{384EI}$$

~~w = 24 in~~
$L = 96\,in$
$w = 2.6425\,\frac{lbf}{\cancel{ft}} \times \frac{1\,\cancel{ft}}{12\,in} = 0.22\ lbf/in$

$E = \cancel{2000\,ksi} = 331\ ksi = 331{,}000\ lbf/in^2$
$I = \frac{1}{12}\cdot b\cdot h^3 = \frac{1}{12}(24\,in)(.25\,in)^3 = .03125\,in^4$

$$y_{max} = \frac{-5\left(0.22\,\frac{lbf}{in}\right)(96\,in)^4}{384\left(331{,}000\,\frac{lbf}{in^2}\right)(.03125\,in^4)} = \boxed{-23.5\,in} \rightarrow \text{too much!}$$

$y_{max} = 4\,in = \cancel{\ldots}$

$$4\,in = \frac{-5\left(\frac{W}{\cancel{96\,in}}\right)(96\,in)^{\cancel{4}\,3}}{384(E)(.03125\,in^4)} \rightarrow \frac{W}{E} = 1.085\times10^{-5}\ in$$

$W = \rho V$, ~~..~~ $V = 576\,in^3$

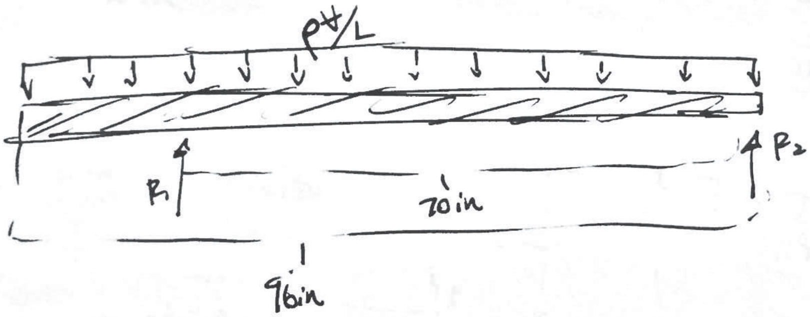
~~...~~ $\frac{\rho}{E} = 1.883\times10^{-8}$

$\rho = 1.883\times10^{-8}\,E$ → required relationship between density and elastic modulus

↳ this is ridiculous

take into account that the plastic is not fixed at the separate edges!

new model:

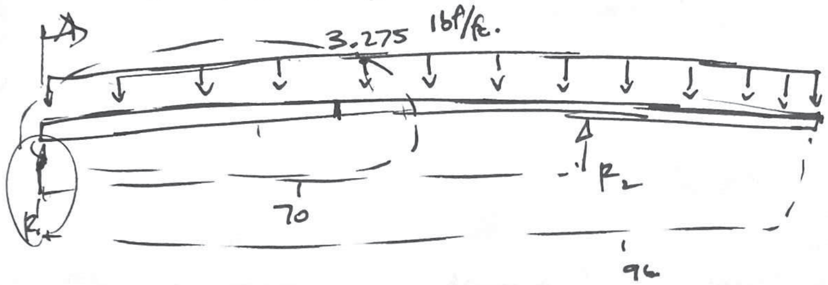


$V = (8ft)(2ft)\left(\frac{.25}{12}ft\right) = \underline{0.33\ ft^3 = V}$

Castiglano's to find max deflection

$$\delta = \int \frac{1}{EI}\left(M \frac{\partial M}{\partial F}\right) dx$$

Assume density of 1.2 g/cm³ = .0459 lb/in³



$\rho = .0459 \frac{lb}{in^3} \times .33 ft^3 \times \frac{(12 in)^3}{1 ft^3}$

$w = \frac{~~86~~\ 26.2\ lbf}{8 ft} = 3.275\ lbf/ft.$

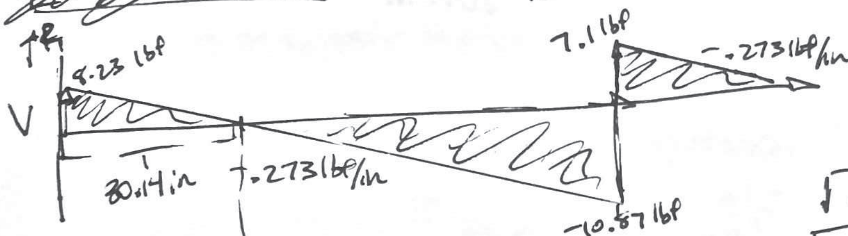
$\Sigma M = 0$

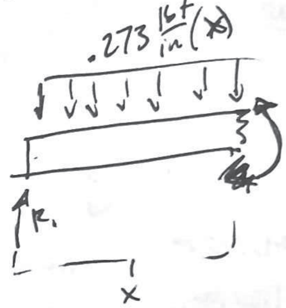
$R_2(70) = 3.275(8)(48)$

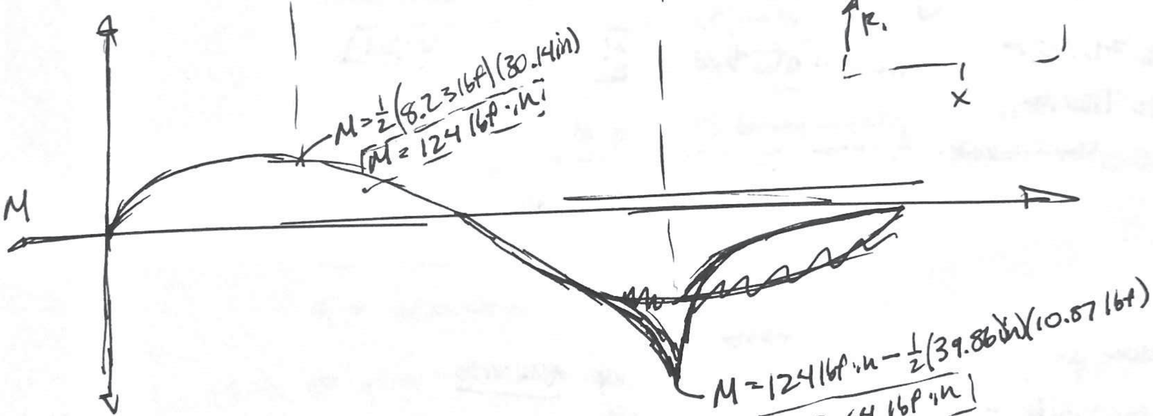
$\boxed{R_2 = 17.97\ lbf}$ →

$R_1 + R_2 = 3.275(8 ft)$

$\boxed{R_1 = 8.23\ lbf}$







max moment/deflection at $x = 30.14 in.$

$$\delta = \int_0^{30.14} \frac{1}{EI}\left[\left(-.273 \frac{lbf}{in}\right)(x^2)\,dx\right) + (8.23\ lbf)\,x\,dx\Big] = 4 in$$

$$\cancel{\frac{1}{EI}\left[\frac{-.273 x^3}{3} + \frac{8.23 x^2}{2}\Big/_0^{30.14}\right] = 4}$$

$$\cancel{4EI = -2491.6 + 3738}$$

$$\cancel{EI = 311.6}$$

$$\cancel{E = \frac{311.6\ lbf}{\frac{1}{12}(24 in)(.25 in)^3}} =$$

$M = \underbrace{\left(+.273 \frac{lbf}{in}\right)(x)}\frac{(x)}{2} = ~~.273x^2~~ + .1365 x^2$

$\frac{dM}{dF} = +x$

$M = (-8.23\ lbf)x$

$\frac{dM}{dF} = -x$

$$\int_0^{30.14} -(+.273 x^3) + 8.23 x^2 = 4EI$$

$$-\frac{.273 x^4}{4} + \frac{8.23 x^3}{3}\Big/_0^{30} = 4EI$$

$\boxed{E = 158.6\ ksi}$ → for 4 in. deflection, use E = 158.6 ksi or higher! for 0.25 in. Thick PC

Use ABS >> easiest to thermoform..

45.)

~~A~~ Use ABS ⇒ easiest to thermoform, cheapest to buy,

higher E than PC ≈ 331 ksi, twice what we need!

Final weight of plastic fairings:

$V = (8\,ft)(2\,ft)\left(\frac{.25}{12}\,ft\right)$

$V = 0.33\,ft^3$

$\rho_{ABS} = .0376\ lb/in^3$

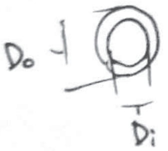
$m = \rho V = .0376\,\frac{lbm}{in^3} \times \frac{(12\,in)^3}{1\,ft^3} \times 0.33\,ft^3$

$m = 21.44\ lbm \times \frac{32.2\,ft/s^2}{32.2\,lbm \cdot ft/s^2} \times 1\,lbf = 21.44\ lbf$

$\boxed{W = 21.44\ lbf.}$

Stress analysis of bike frame:

Cross section of aluminum tubing:



$D_o = 1.775\,in$

$D_i = 1.60\,in$

material of frame: $\boxed{\text{4130 chromoly steel}}$

↳ not stock size. Assume $D_o = 1.75\,in$

$D_i = 1.584\,in$ (O.D. 1.75, t = .083 in).

what's chromoly?

i.e., how does it affect material properties?

chromoly is a higher strength steel, it's just AISI 4130

material properties of AISI 4130

$\rho = 0.284\ lbm/in^3$

$S_{UT} = 97.2\,ksi$ (ultimate tensile strength)

$H_B = 197$

$S_Y = 63.1\,ksi$ (yield tensile strength).

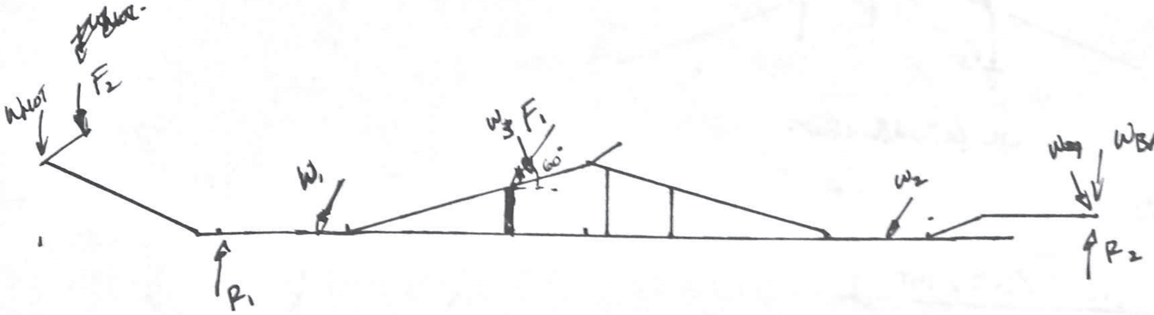
CALCULATE WEIGHT OF FRAME.

from solid model: $V = 104.24\,in^3$

$m = (104.24\,in^3)(.284\,lbm/in^3)$

$= 29.6\,lbm \times \frac{32.2\,ft/s^2}{32.2\,lbf} = \boxed{29.6\,lbf = W}$

BIKEFRAME
SIDEVIEW, scale = 1:20
STATIC LOADING, no pedaling



Assign values to forces, resolve to single beam problem.

for W_1 & W_2, assume $W = 180$ lbf

assume ≈ 80% weight on front section:

$W_1 = .8(180) = \boxed{144 \text{ lbf} = W_1}$

$W_3 = .2(180) = \boxed{36 \text{ lbf} = W_3}$

assume same for rear:

$W_2 = .8(180 \text{ lbf}) = \boxed{144 \text{ lbf} = W_2}$

$W_4 = .2(180 \text{ lbf}) = \boxed{36 \text{ lbf} = W_4}$

assume F_1 = total weight of Al plus 80% fairing weight. (see pgs. 41–43 for calcs)

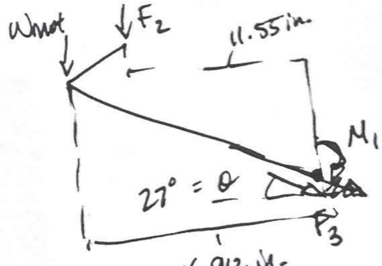
$F_1 = 3.274 \text{ lbf} + 1.486 \text{ lbf} + 1 \text{ lbf} + 1.08 \text{ lbf} + 0.5 \text{ lbf} + 0.70 \text{ lbf} + 0.8(21.44 \text{ lbf})$

$\boxed{F_1 = 25.25 \text{ lbf}}$

$F_2 = .2(21.44 \text{ lbf}) = \boxed{4.3 \text{ lbf} = F_2}$

$M_{motor} = 6.5\text{kg} \rightarrow 6.5\text{kg} = 14.33 \text{ lbm} \times \frac{32.2 \text{ ft/s}^2}{32.2 \text{ lbm ft/s}^2 \cdot \text{lbf}} = \boxed{14.33 \text{ lbf} = W_{mot}}$

from pingbattery.com $\rightarrow \boxed{W_{BAT} = 16.5 \text{ lbf}}$



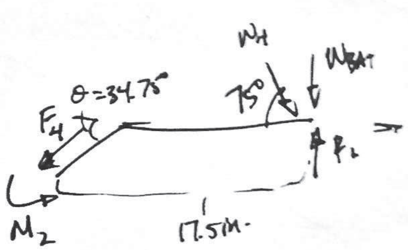
$\Sigma F = 0$

$F_3 \sin 27° = W_{mot} + F_2$

$F_3 = \frac{14.33 \text{ lbf} + 4.3 \text{ lbf}}{\sin 27°} = \boxed{41 \text{ lbf} = F_3}$

$M_1 = (16.912 \text{ in})(14.33 \text{ lbf}) + (11.55 \text{ in})(4.3 \text{ lbf})$

$= 292 \text{ lbf} \cdot \text{in} \times \frac{1 \text{ ft}}{12 \text{ in}} = \boxed{24.33 \text{ ft} \cdot \text{lbf} = M_1}$



$M_2 = \cancel{W_4 \sin 75 + W_{BAT}}$

$= W_4 \sin 75 (17.5\text{in}) + W_{BAT}(17.5\text{in}) - R_2(17.5\text{in})$

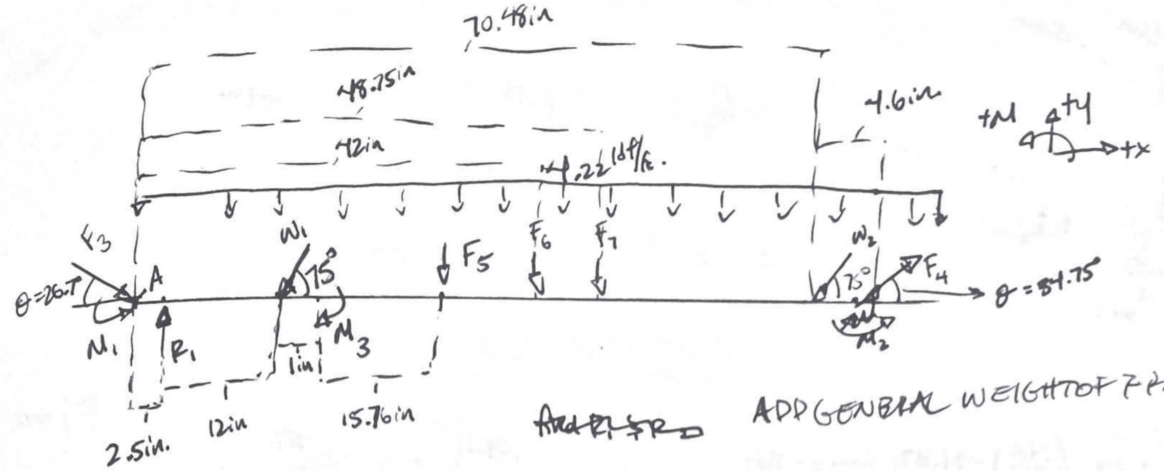
$= (36 \text{ lbf})(\sin 75)(17.5\text{in}) + (16.5 \text{ lbf})(17.5\text{in}) - 17.5 R_2$

$\boxed{M_2 = 74.77 - 1.46 R_2}$

$F_4 \sin 34.75 = W_4 + W_{BAT} - R_2$

$F_4 = 1.75(36 + 16.5 - R_2) =$

$\boxed{F_4 = 91.875 - 1.75 R_2}$



~~Add R1 & R2~~ ADD GENERAL WEIGHT OF FRAME

Find R_1 & R_2

ΣM about pt. A.

$$0 = -M_1 + R_1\left(\frac{2.5 ft}{12}\right) - W_1\sin(75°)\left(\frac{\cancel{16.05}\ 14.5}{12}\right) - F_5\left(\frac{\cancel{31.6}\ 30.26}{12}\right) - F_6\left(\frac{42 in}{12}\right) - F_7\left(\frac{48.75}{12} ft\right) - W_2\sin(75°)\left(\frac{70.48}{12} ft\right) + F_4\sin(34.75)\left(\frac{75 in}{12}\right) - 29.6\left(\frac{42}{12} ft\right)$$

$$0 = (-24.33 lbf\cdot ft) + (.208 R_1) - (168.07 lbf\cdot ft) - (\cancel{58.25}\ 55.14 ft\cdot lbf) - (70 ft\cdot lbf) - (81.25 ft\cdot lbf) - (816.94 ft\cdot lbf) + (91.875 - 1.75R_2)3.56 - 29.6\left(\frac{42}{12} ft\right)$$

~~901.55 ft·lbf = 0.208R₁ − 6.23R₂~~ $\rightarrow 901.85 lbf\cdot ft + (29.6 lbf)(3.5 ft) = .208R_1 - 6.23R_2$

$\cancel{1005.215}\ 992.3 = .208R_1 - 6.23R_2$

ΣF = 0

$$0 = -F_3\sin 26.7° + R_1 - W_1\sin 75° - F_5 - F_6 - F_7 - W_2\sin 75° + F_4\sin 34.75 - 29.6 lbf$$

$$0 = (-18.42 lbf) + R_1 - (139 lbf) - 21.87 - 40 lbf - (139 lbf) + 0.57(91.875 - 1.75R_2) - 29.6 lbf$$

$\cancel{305.42}\ 335.52 lbf = R_1 - .998R_2$

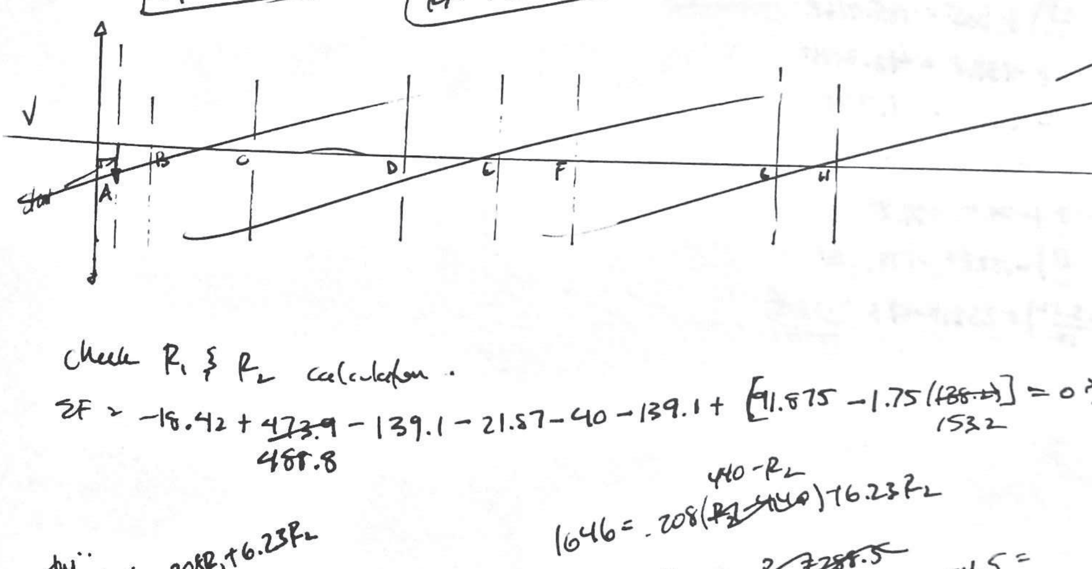
$\hookrightarrow R_1 = 335.92 + .998R_2 \rightarrow \cancel{901.55}\ 992.3 = .208(335.92 + .995R_2) - 6.23R_2$

$\cancel{884.12} = 6.02R_2 = \cancel{884}\ 922$

~~R₂ = 18? lbf~~ $\boxed{153.2 lbf = R_2}$

$R_1 = 335.92 + .998(158.2 lbf)$

~~R₁ = 494.84 lbf~~ ~~R₁ = 473.9 lbf~~ $\boxed{R_1 = 488.8 lbf}$



A = 18.42 lbf

$B = -18.42 - 4.22\left(\frac{2.5}{12}\right) + 473.9 = 454.6$

$C = 454.6 - 4.22(1) - 139 = 311.4 lbf$

$D = 311.4 - 4.22\left(\frac{15.76}{12}\right) - (21.87) = 284 lbf$

$E = 284 - 4.22\left(\frac{10}{12}\right) - 20 = 260 lbf$

$F = 260 - 4.22\left(\frac{6.75}{12}\right) - 20 = 237.3 lbf$

$G = 237.3 - 4.22(1.81) - 139 = 90.66$

H =

Check R_1 & R_2 calculation.

$$\Sigma F = -18.42 + \cancel{473.9}\ 488.8 - 139.1 - 21.87 - 40 - 139.1 + [91.875 - 1.75(\cancel{158.2}\ 153.2)] = 0?$$

try: $1646 = .208R_1 + 6.23R_2$

$440 = R_1 + R_2$

$R_1 = \cancel{R_2 - 440}\ 440 - R_2$

$1646 = .208(\cancel{R_2 - 440}\ 440 - R_2) + 6.23R_2$

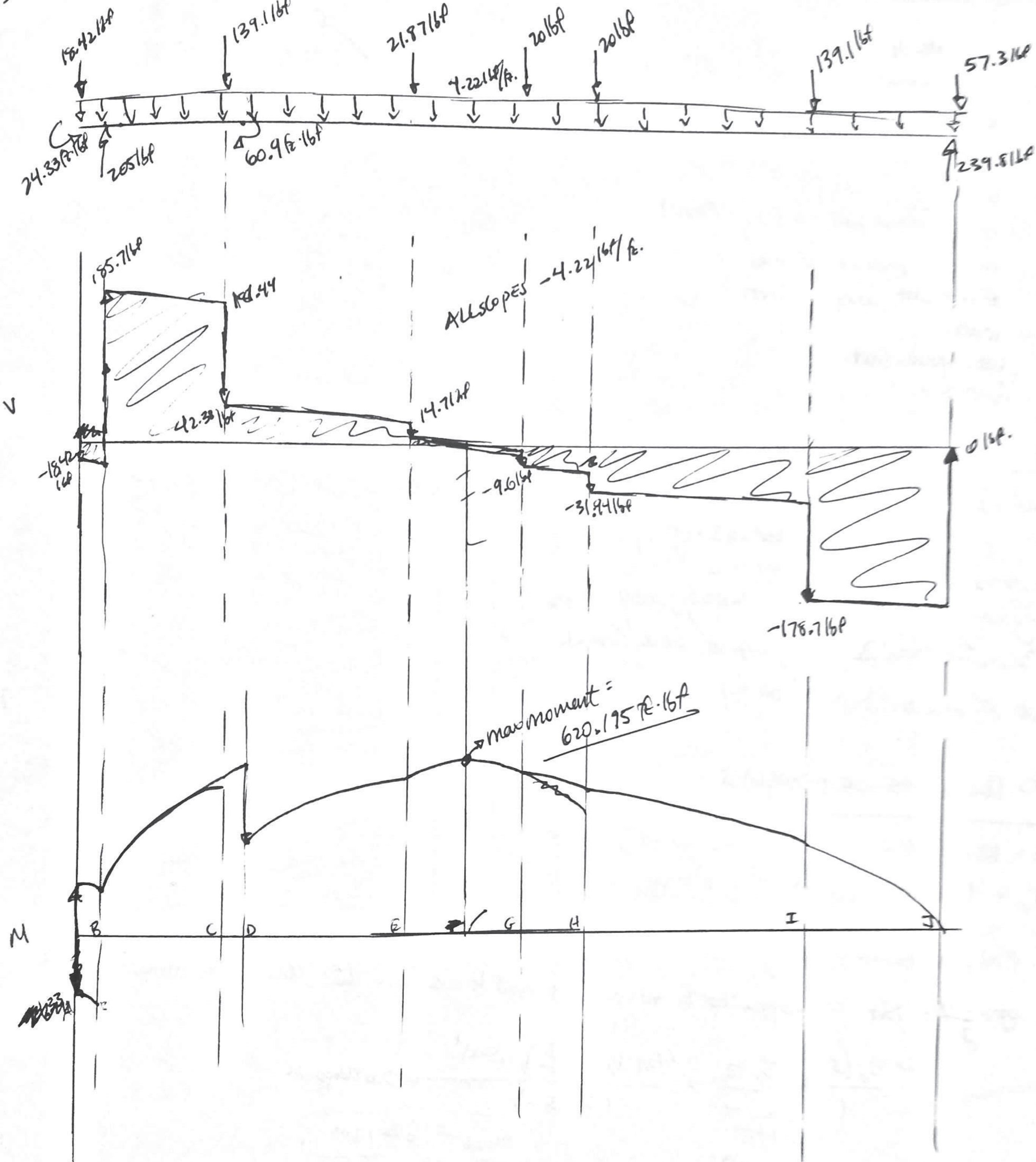
~~1646~~ ~~R₂ = 258.5~~ ~~R₁ =~~

1554.5 =

$R_2 = 258.13 lbf$

$R_1 = 181.87.$

Scale: 1:14



A = +24.33 ft·lbf.

B = +24.33 ft·lbf − 18.42$\left(\frac{2.5}{12}\right)$ − $\frac{1}{2}$(.877)$\left(\frac{2.5}{12}\right)$ = ~~20.826 ft·lbf~~ 20.4

C = ~~20.826~~ 20.4 + 183 + $\frac{1}{2}$(1)(4.27) = ~~184.8~~ 205.535

D = 205.535 − 60.9 = 144.635

E = 144.635 + $\frac{1}{2}$(16.66)(27.67) + 245.0686.

F = 620.1947 → Max moment is 620.1947 ft·lbf

, Then drops to zero from there.

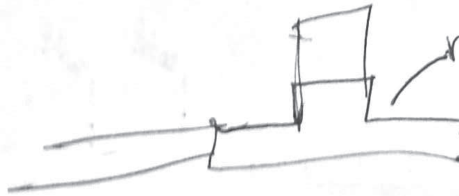
$\sigma = \frac{My}{I} = \frac{(620.1947 \text{ ft·lbf})(.875 \text{ in})\left(\frac{12 \text{ in}}{\text{ft}}\right)}{\frac{\pi}{64}(1.75^4 - 1.55^4) \text{ in}^4}$

$\boxed{\sigma = 42.15 \text{ ksi}}$ < 97.2 ksi

42.15 ksi < 63.1 ksi

no failure in structure of bike, even with loading onit!

DRAWINGS TO MAKE:



FAIRING Plastic
Bent aluminum
O.D. bearing shaft.
I.D. bearing shaft
~~B~~ Bearings
stock aluminum bar x2 (long and short)
bracket w/ small bracket pieces
other bracket, and other bracket.
rivets
Latch system in front.
Assembly.

CLOTH
FAIRING TEST RESULTS

- added water to 2 layers of Lycra felt there was a need for plastic sheet.
  - water was absorbed instead of repelled
- Lycra provides good stretch and resistance
- spacing support bars that travel horizontally, every 2 ft.
- Loop the cloth around the fiberglass poles, to hide the poles
  * Use 90° elbows (flexible) for rear fairing

MATERIAL PROPERTIES OF FIBERGLASS

$E = 10\ Msi = 10{,}000\ ksi = 10 \times 10^3\ ksi$

$S_{UT} = 439{,}900\ psi = 439.9\ ksi$

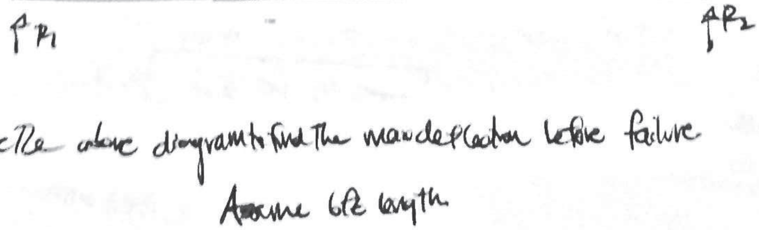
Find max moment on a rod of 0.25in diameter

$\sigma = \frac{My}{I} = S_{UT}$ => assume that the max moment must be less than the ultimate tensile strength

$$M = \frac{S_{UT}(I)}{y} = \frac{S_{UT}(I)}{c} = \frac{(439.9ksi)(\frac{\pi}{64})(.25in)^4}{(0.125in)} = 0.67 kips \cdot in$$

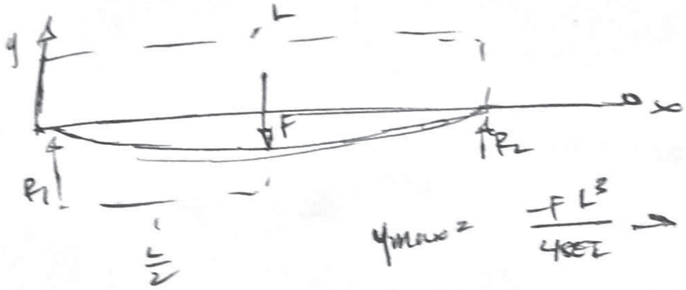
equivalent, Rod diameter.

$\boxed{M_{max} = 670\ lb \cdot in}$



Use the above diagram to find the max deflection before failure.

Assume 6ft length.



$$y_{max} = \frac{-FL^3}{48EI} \rightarrow \Sigma M = F \cdot \frac{L}{2}$$

$$\cancel{F = \frac{2M}{L} = \frac{2(670\ lb \cdot in)}{6ft\left(\frac{12in}{ft}\right)} = 18.611\ lbf = F_{max}}$$

$$\cancel{y_{max} = \frac{(-18.611\ lbf)\left(6ft \cdot \frac{12in}{ft}\right)^3}{48(10\times10^3\ ksi)\left[\frac{\pi}{64} \cdot (.25in)^4\right]}}$$

$\Sigma M = 0$

$$\frac{-FL}{2} + R_2 L = 0$$

$$-\frac{F}{2} + R_2 = 0 \Rightarrow R_2 = \frac{F}{2} \rightarrow 2R_2 = F$$

$\Sigma F = 0$

$R_1 + R_2 - F = 0$. B/c of symmetry $R_1 = R_2$. Thus, $F = 2R_1 = 2R_2$

$$M_{max} = R_1 \cdot \frac{L}{2} = \frac{FL}{4}$$

$$F = \frac{4M_{max}}{L} = \frac{4(675\ lbf \cdot in)}{(6ft)\left(\frac{12in}{ft}\right)} = 37.5\ lbf$$

$$y_{max} = \frac{(37.5\ lbf)(6ft)^3}{48(10\times10^3\times10^3\ psi)\left(\frac{144in^2}{ft^2}\right)\frac{\pi}{64}\left(\frac{.25}{12}ft\right)^4} = \underline{12.678}$$

NOTES ON SW PARTS

16.82°, 1.5" down

Keypad = 51mm × 64mm h

LCD = 98mm × 60mm ht

rest = 54mm wide

~~23~~ ~~box high~~ 23.78

~~25.4mm~~ wide 21.1

~~Bushing Justification~~

Stress Analysis of ~~Latch Bent Al Plate~~

$\rho_{Al} = .098 \ lbm/in^3$

The frame of the fairing (made of aluminum) has a ~~mass~~ of volume of ...

$\forall = 2(8.5 in^3) + 2.48 in^3 + 2(2.73 in^3) = \boxed{25 in^3}$

$m = \rho\forall = .098 \ lbm/in^3 \times 25 in^3 = 2.44 \ lbm$

$W = 2.45 \ lbf$ ~~assume added 3 lbf for plastic fairing (overestimation)~~

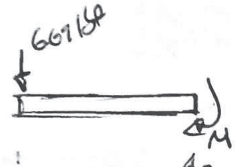
~~W = 5.44 lbf~~ fairing volume $= (8 ft)(2 ft)(.04 in)$

$= 0.64 \ ft^2 in \times \frac{144 in^2}{1 ft^2} = 92.16$

$\rho_{PC} = .043 \ lbm/in^3$

$m = \rho\forall = (.043 \ lbm/in^3)(92.16 in^3) = 4.24 \ lbf = W$

$\boxed{W_{fairing} = 6.69 \ lbf}$



Assume worst case, weight at the very end of part.

$y_{max} = \frac{-FL^3}{3EI}$ → $L = 3 in$

$E = 10 \ Msi$

$I = \frac{1}{12} b(h^3) = \frac{1}{12}(2.36 in)(0.12 in)^3$

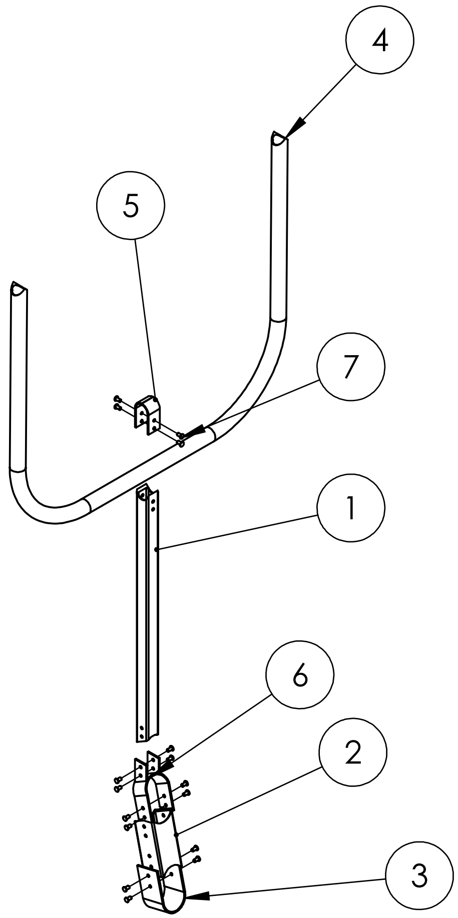
$= 3.4 \times 10^{-4}$

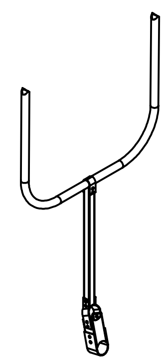
$$y_{max} = \frac{(-6.67 \ lbf)(3 in)^3}{3(10 \times 10^6 \ lbf/in^2)(3.4 \times 10^{-4} \ in^4)} = \underline{-0.17 in}$$

the beam will deflect $-0.17 in$, at the worst case!

That is, if the whole fairing rested on the very edge of this part.

ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	ETAB-003	RECTANGULAR FAIRING SUPPORT	6061-T6 ALUMINUM	1
2	ETAB-001	LOWER RECTANGULAR SUPPORT	6061-T6 ALUMINUM	1
3	ETBR-002	1.75ID STRAIGHT BRACKET	1018 Steel	1
4	ETAB-004	BENT SPLIT SUPPORT	6061-T6 ALUMINUM	1
5	ETBR-001	1IN STRAIGHT BRACKET	1018 STEEL	1
6	ETBR-004	ANGLED SUPPORT BRACKET	6061-T6 ALUMINUM	1
7	97525A515	.1875IN RIVET	18-8 STAINLESS STEEL	16





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/8"
ANGULAR: MACH ± 1 BEND ± 2
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

	NAME	DATE
DRAWN	KIL	1/30/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
ALL RIVETS 3/16", PURCASED AT MCMASTER

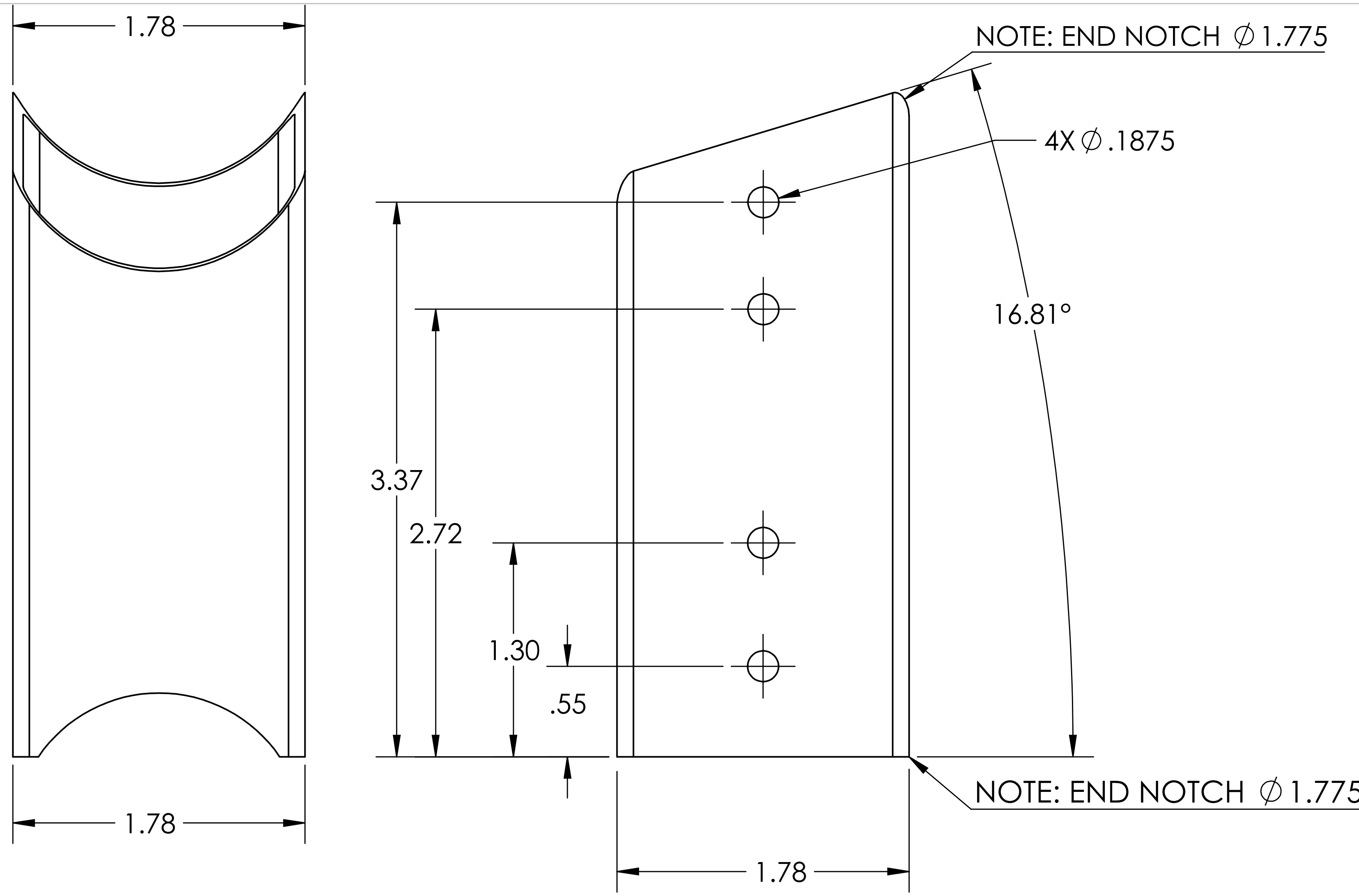
PROJECT: ELECTRIKE

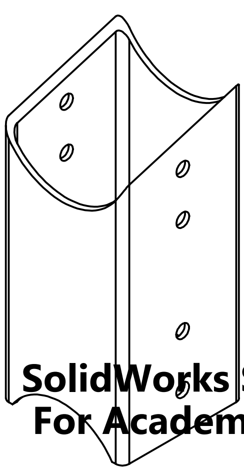
TITLE:
CENTER SUPPORT ASSEMBLY

SIZE	DWG. NO.	REV
A	ETAB-005	1

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Aluminum

FINISH

	NAME	DATE
DRAWN	PM	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

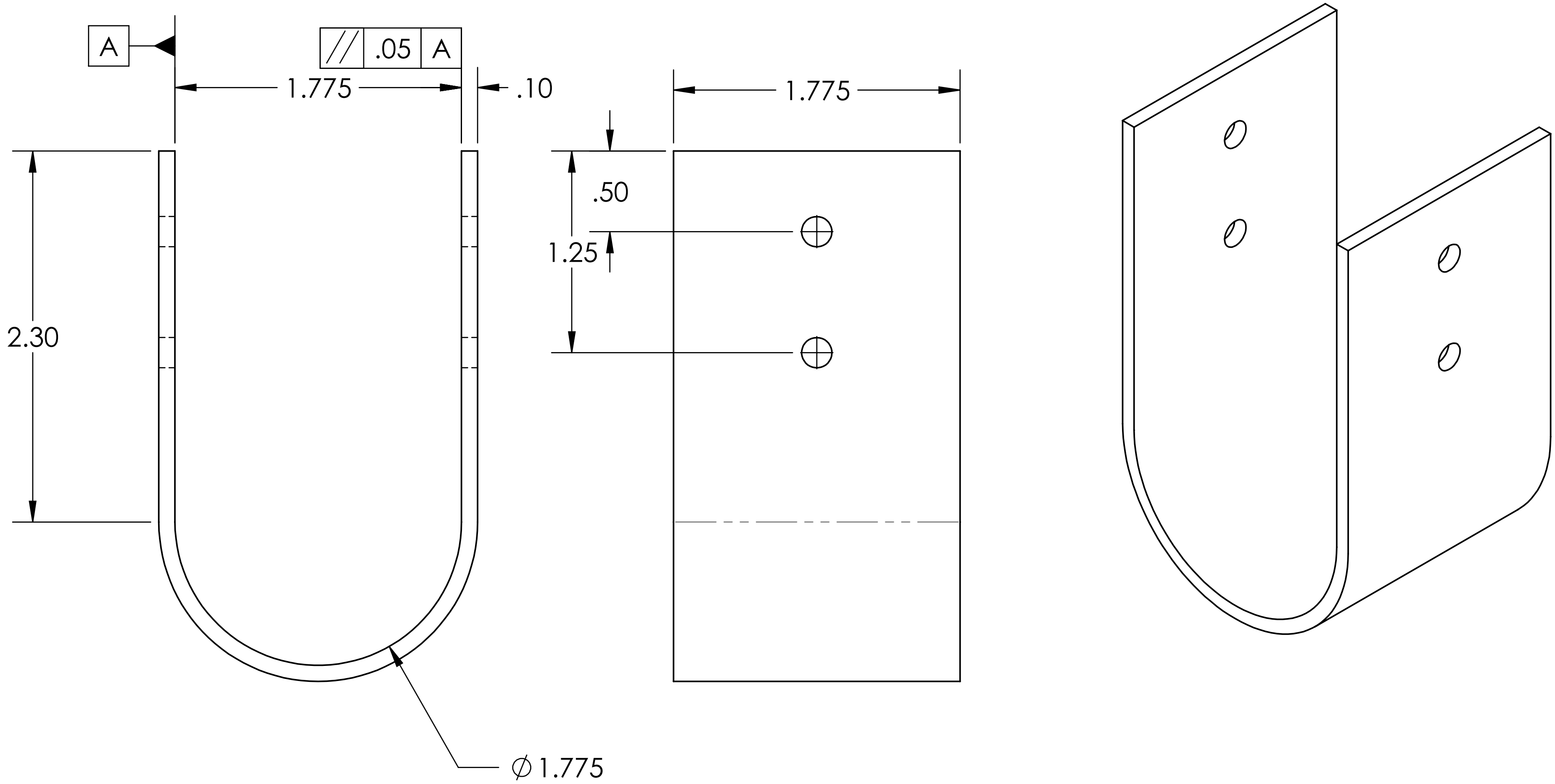
PROJECT: ELECTRIKE

TITLE:
LOWER RECTANGULAR SUPPORT

SIZE	DWG. NO.	REV
A	ETAB-001	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1018 Steel

FINISH

	NAME	DATE
DRAWN	KIL	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
BENT SHEET METAL PART
HOLES CLEARANCE FOR 3/16" RIVET

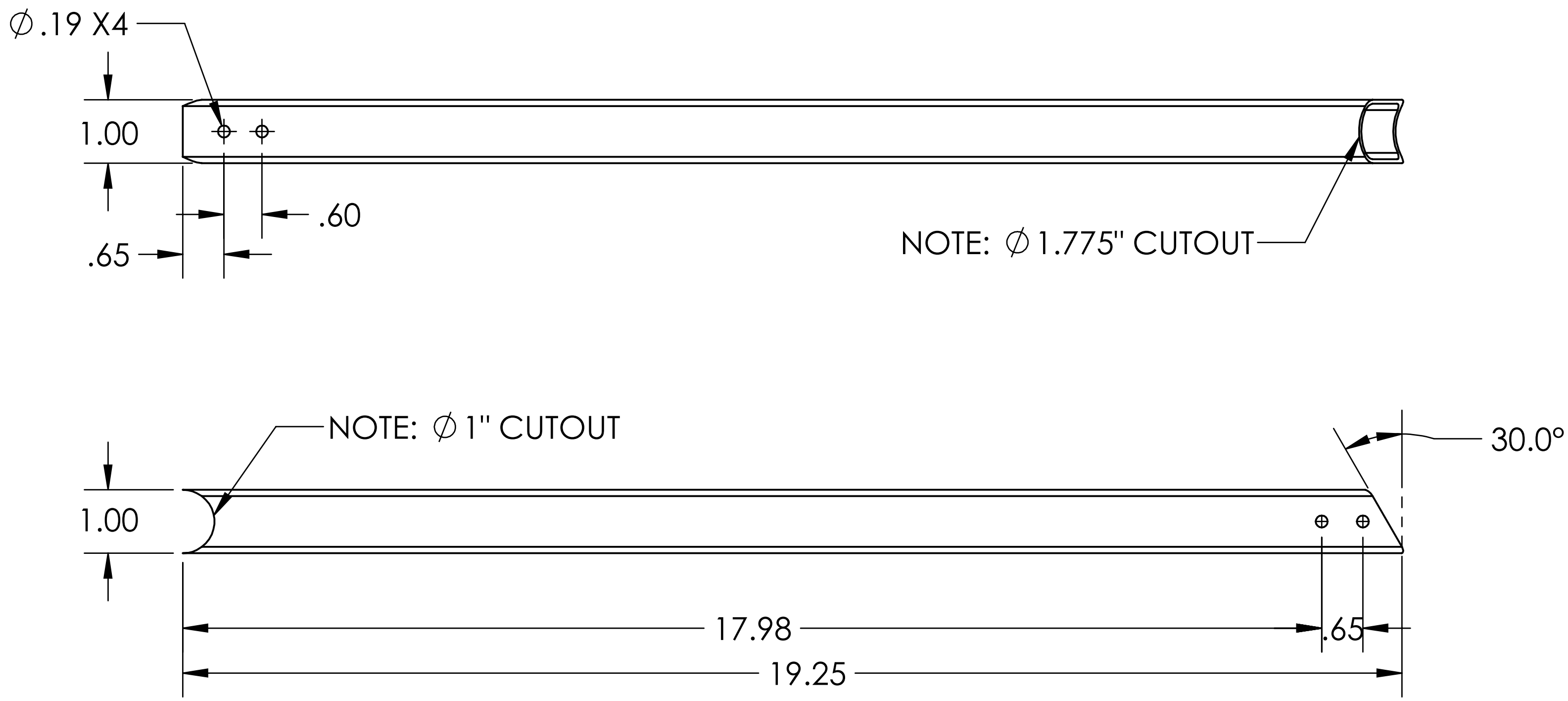
PROJECT: ELECTRIKE

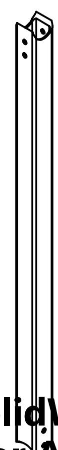
TITLE:
1.775IN STRAIGHT BRACKET

SIZE	DWG. NO.	REV
A	ETBR-003	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





Electric Tandemonium	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/8" ANGULAR: MACH ±1 BEND ±2 TWO PLACE DECIMAL ±.05 THREE PLACE DECIMAL ±.005	DRAWN	PM	1/28/15
		CHECKED	KIL	1/30/15
		ENG APPR.		
		MFG APPR.		
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	MATERIAL 6061-T6 ALUMINUM	COMMENTS:		
	FINISH			

PROJECT: ELECTRIKE

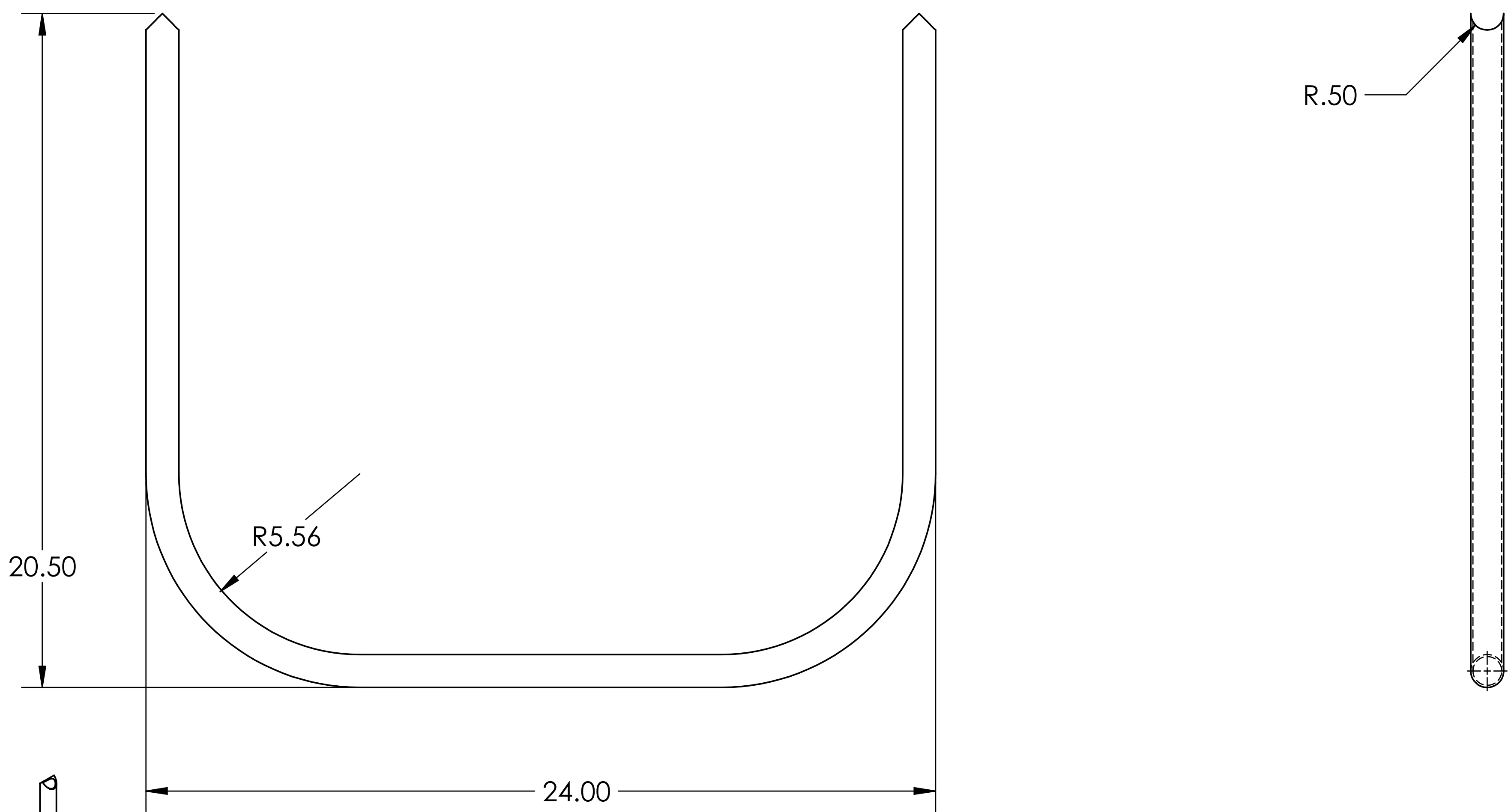
TITLE:

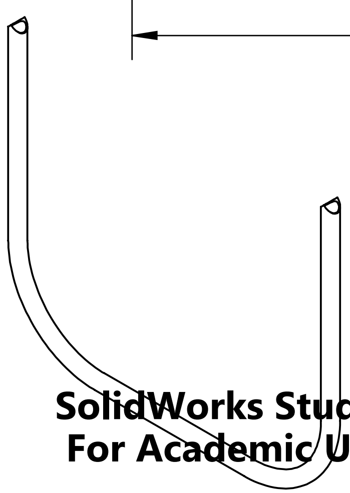
CENTER SUPPORT FOR FAIRING - MID SECTION

SIZE	DWG. NO.	REV
A	ETAB-003	1

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

5 4 3 2 1





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	PM	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

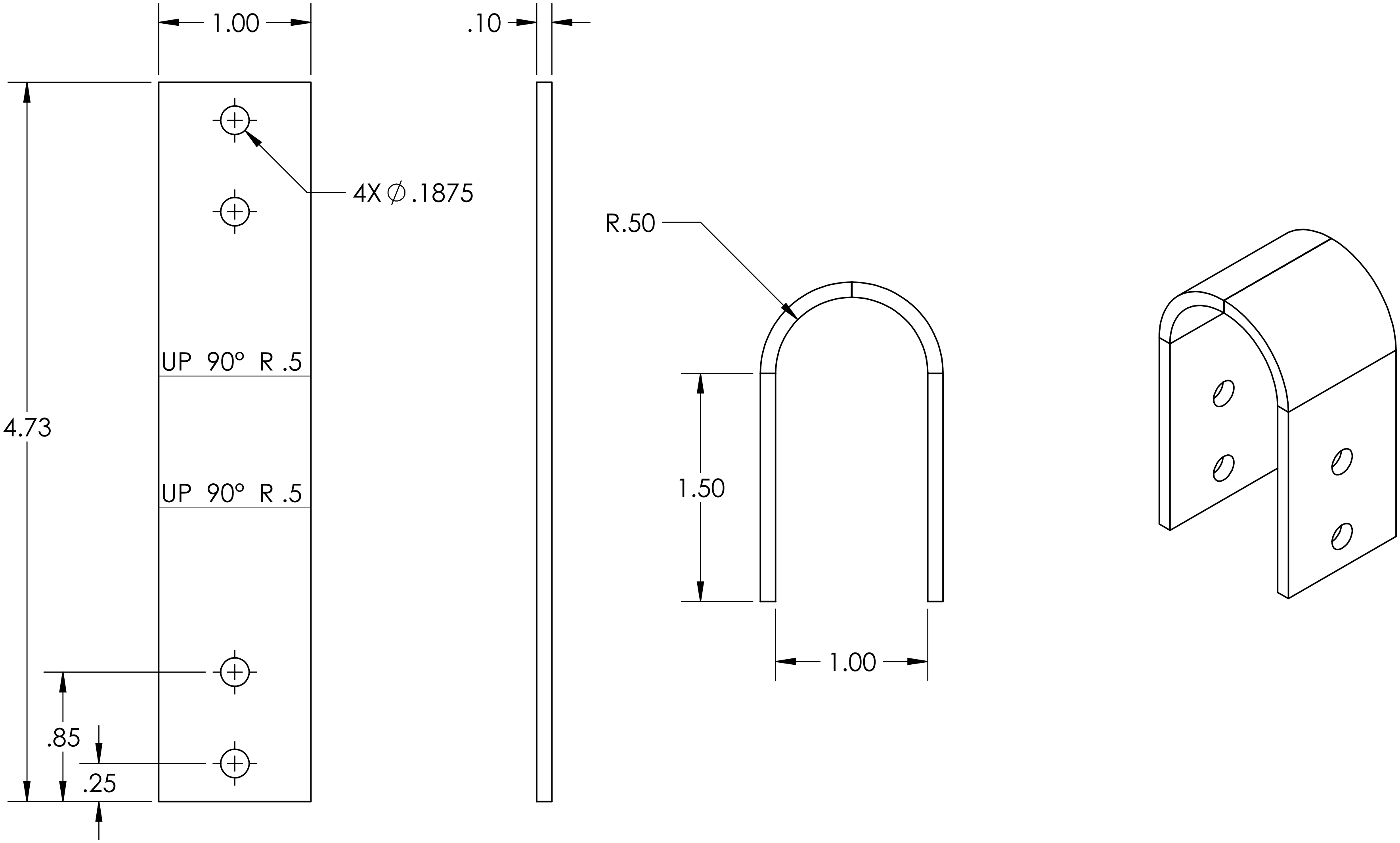
COMMENTS:
HEAT THE ALUMINUM TO GOLDEN COLOR BEFORE BENDING

PROJECT: ELECTRIKE

TITLE:
BENT SPLIT SUPPORT

SIZE	DWG. NO.	REV
A	ETAB-004	1

SCALE: 1:5	WEIGHT:	SHEET 1 OF 1



Electric Tandemonium	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/8" ANGULAR: MACH ± 1 BEND ± 2 TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	KIL	1/28/15
		CHECKED	KIL	1/30/15
		ENG APPR.		
		MFG APPR.		
	INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
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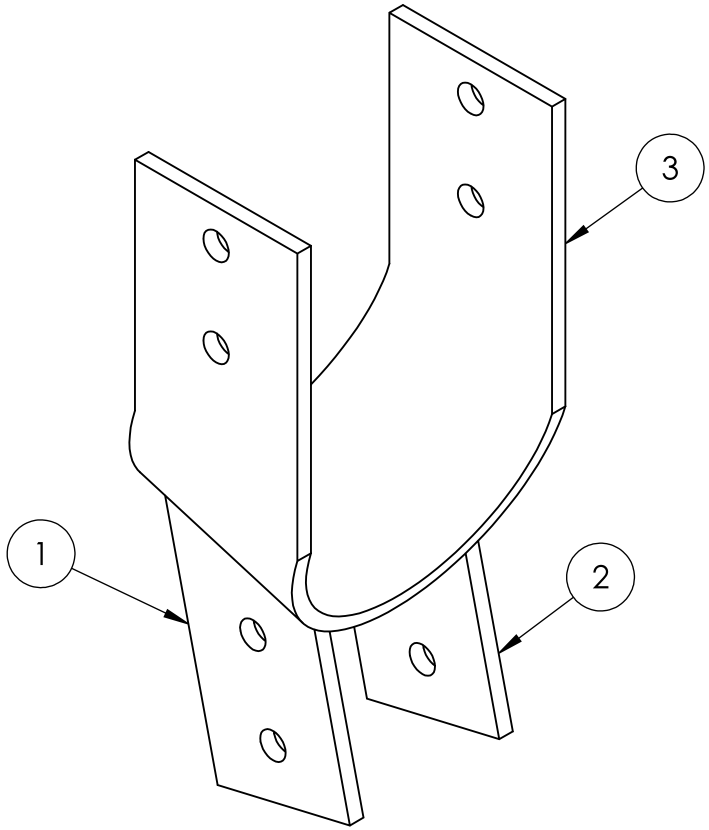
PROJECT: ELECTRIKE

TITLE:
1 IN STRAIGHT BRACKET

SIZE	DWG. NO.	REV
A	ETBR-001	1
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	Material
1	ETBR-005	ANGLED ADAPTER L	1	1018 STEEL
2	ETBR-006	ANGLED ADAPTER R	1	1018 STEEL
3	ETBR-004	ANGLED SUPPORT BRACKET	1	1018 STEEL



Electric Tandemonium

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1018 STEEL

FINISH

	NAME	DATE
DRAWN	KIL	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
PARTS COMPONENTS WELDED TOGETHER
WELD TO BRACKET BEFORE BIKE ASSEM.

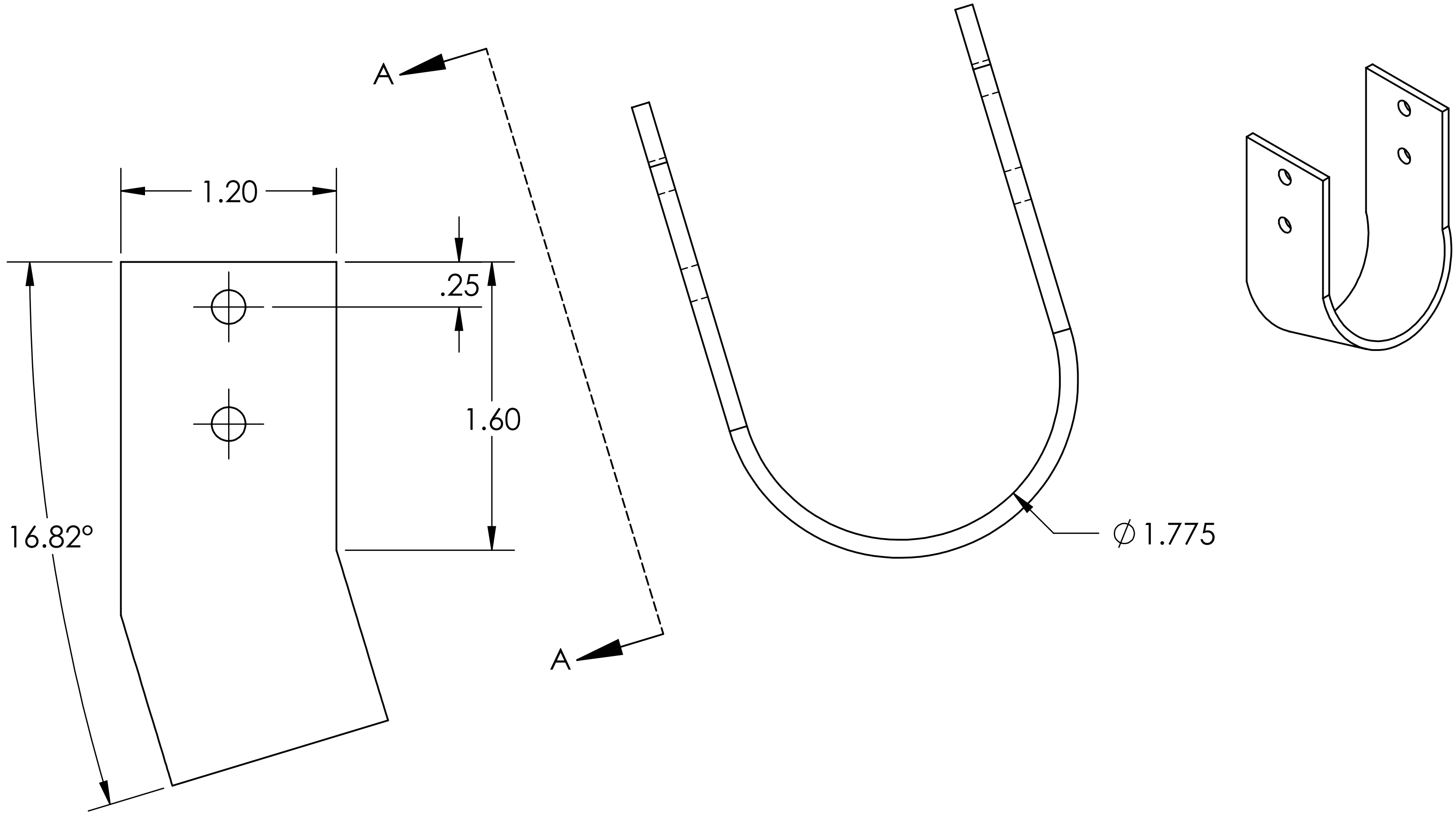
PROJECT: ELECTRIKE

TITLE:
ANGLED SUPPORT BRACKET ASSEMBLY

SIZE	DWG. NO.	REV
A	ETBR-007	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Electric Tandemonium	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/8" ANGULAR: MACH ±1 BEND ±2 TWO PLACE DECIMAL ±.05 THREE PLACE DECIMAL ±.005		NAME	DATE	PROJECT: ELECTRIKE
		DRAWN	KIL	1/28/15	TITLE: 1.775" DIAMETER ANGLED BRACKET
		CHECKED	KIL	1/30/15	
		ENG APPR.			
		MFG APPR.			
PROPRIETARY AND CONFIDENTIAL	INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
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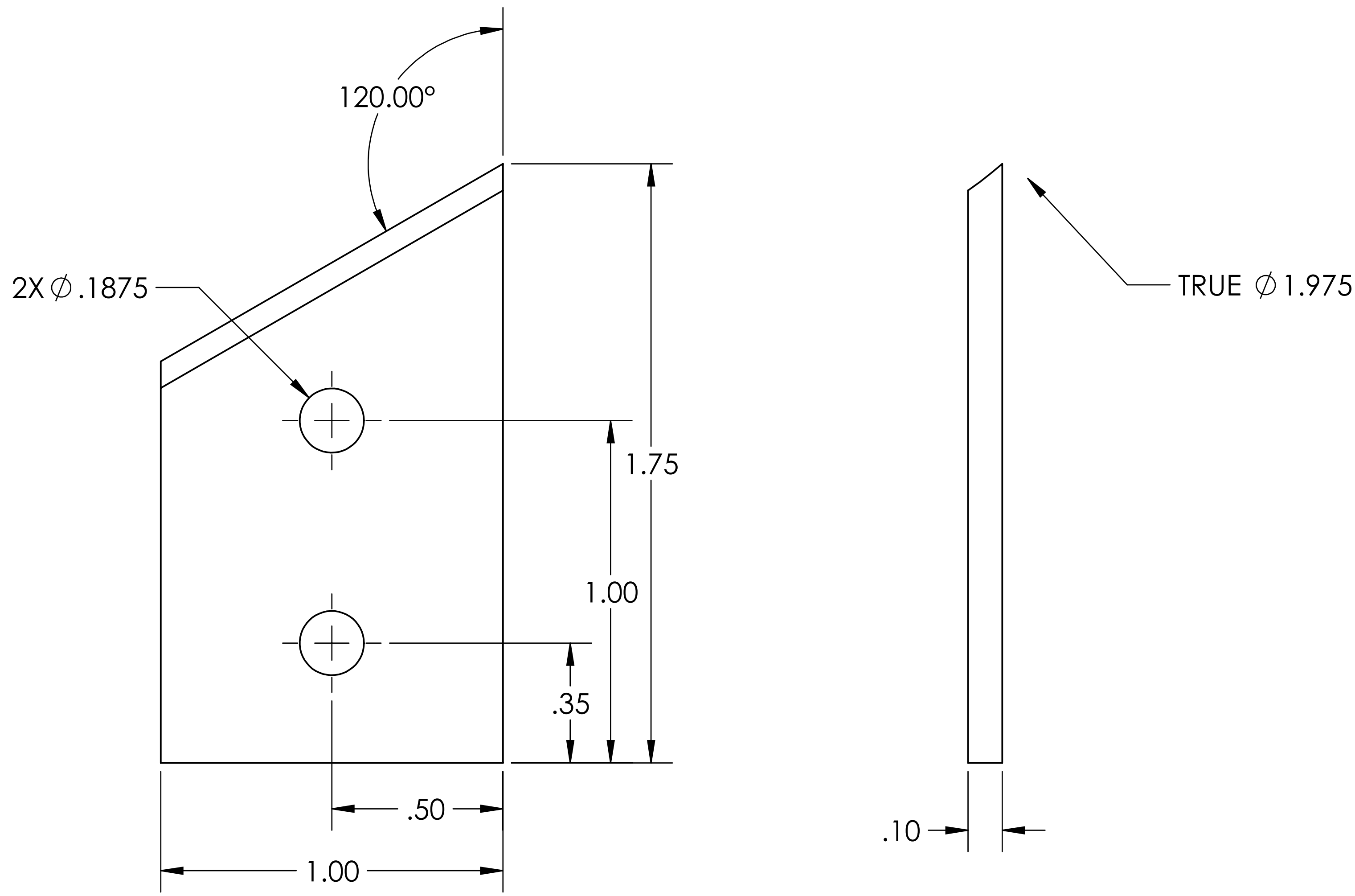
	FINISH				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1

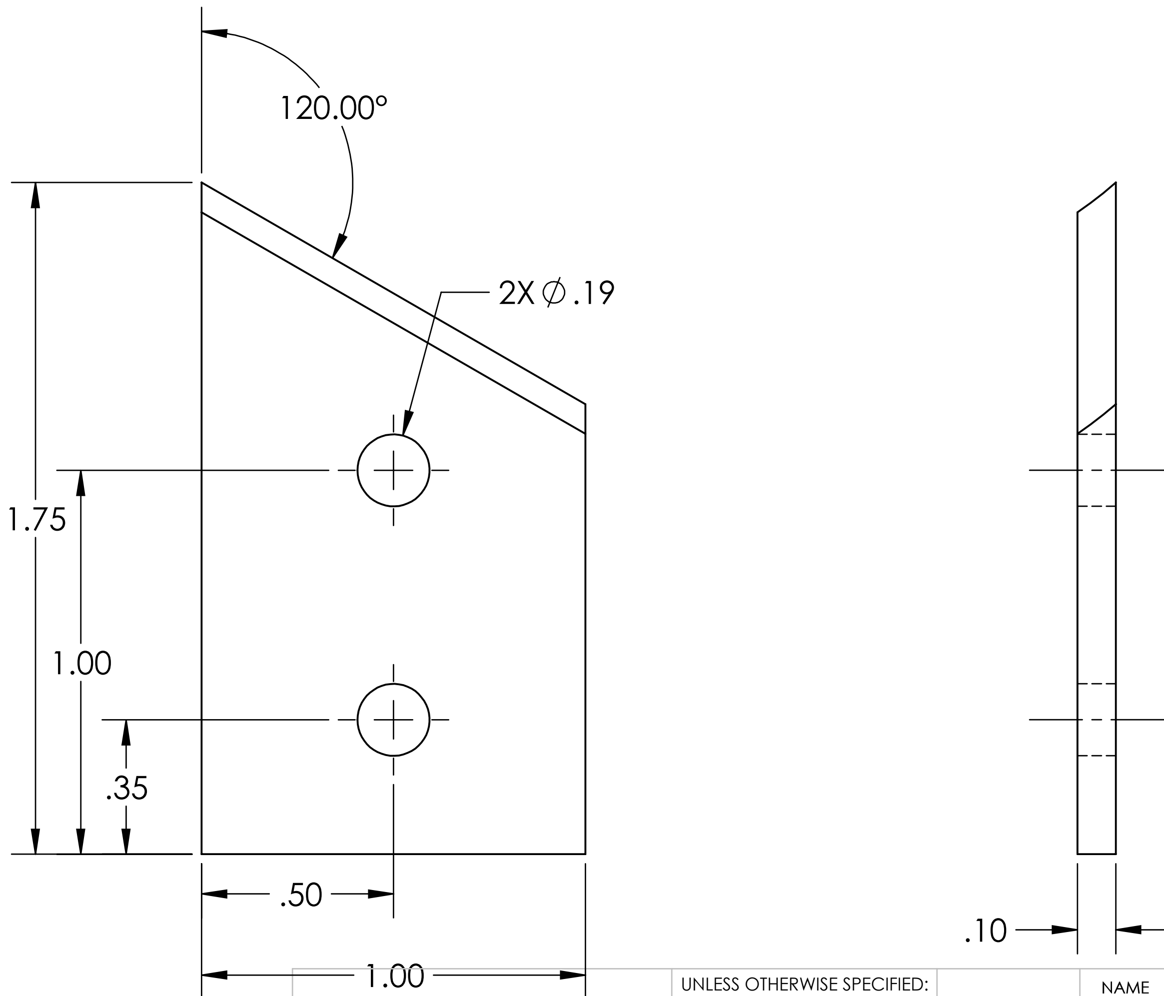


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	PROJECT: ELECTRIKE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/8" ANGULAR: MACH ±1 BEND ±2 TWO PLACE DECIMAL ±.05 THREE PLACE DECIMAL ±.005	DRAWN	KIL	1/28/15	TITLE: ANGLED BRACKET EXTENSION L
	CHECKED	KIL	1/30/15	
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 1018 STEEL	COMMENTS: SHEET METAL PART HOLES SIZED FOR 3/16" RIVETS			SIZE A DWG. NO. ETBR-005 REV 1
FINISH				SCALE: 2:1 WEIGHT: SHEET 1 OF 1

Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/8"
ANGULAR: MACH ± 1 BEND ± 2
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
1018 STEEL

FINISH

	NAME	DATE
DRAWN	KIL	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
SHEET METAL PART
CLEARANCE HOLES FOR 3/16" RIVET

Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

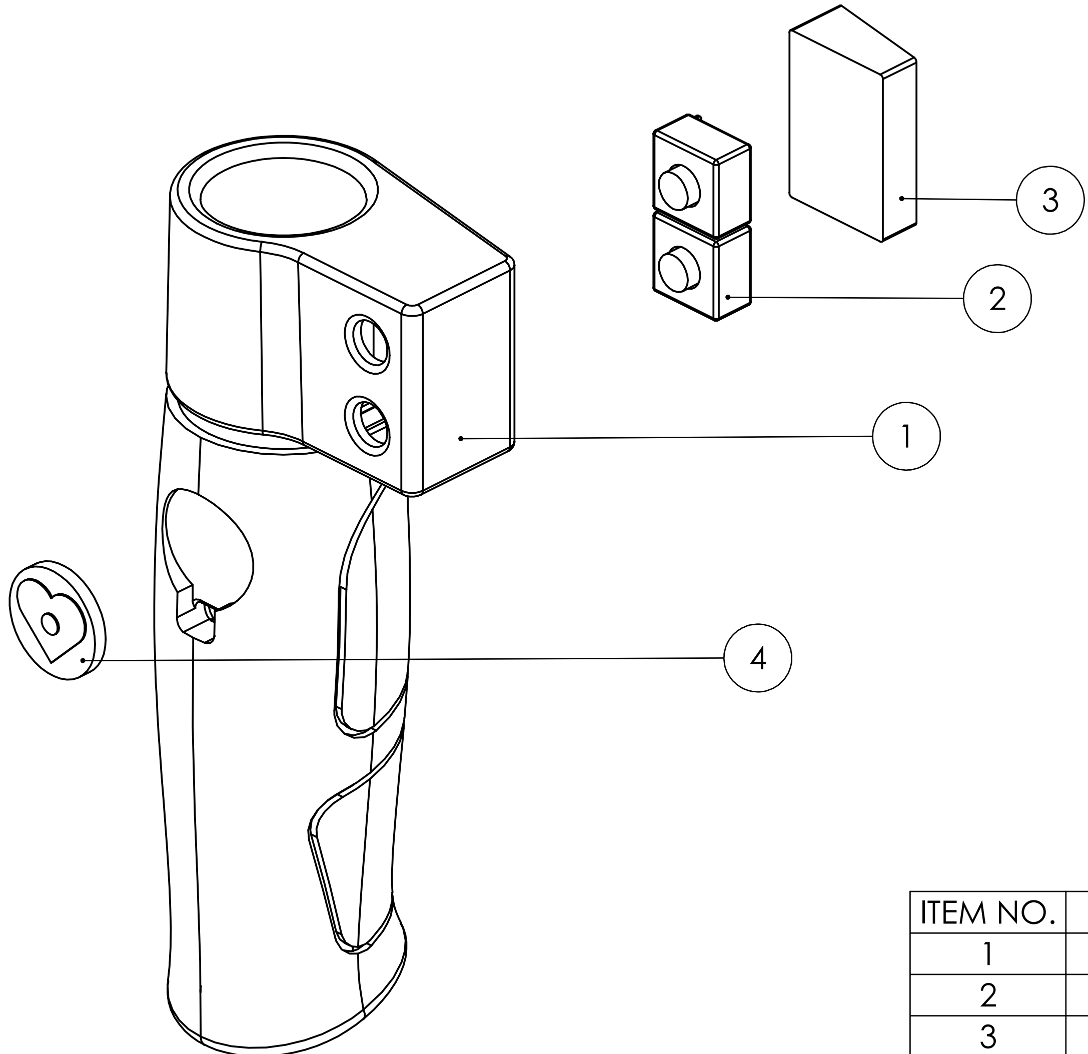
PROJECT: ELECTRIKE

TITLE:
ANGLED BRACKET EXTENSION R

SIZE: **A** DWG. NO. ETBR-006 REV 1

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NUMBER	PART NAME	QTY.
1	EL-033	GRIP BODY	1
2	EL-031	TURN SIGNAL SWITCH	2
3	EL-034	GRIP BACK	1
4	EL-006	PULSE SENSOR	1

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FRACTIONAL ± 1/8"
ANGULAR: MACH ± 1 BEND ± 2
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
3D PRINTED

FINISH

	NAME	DATE
DRAWN	AF	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PROJECT: ELECTRIKE

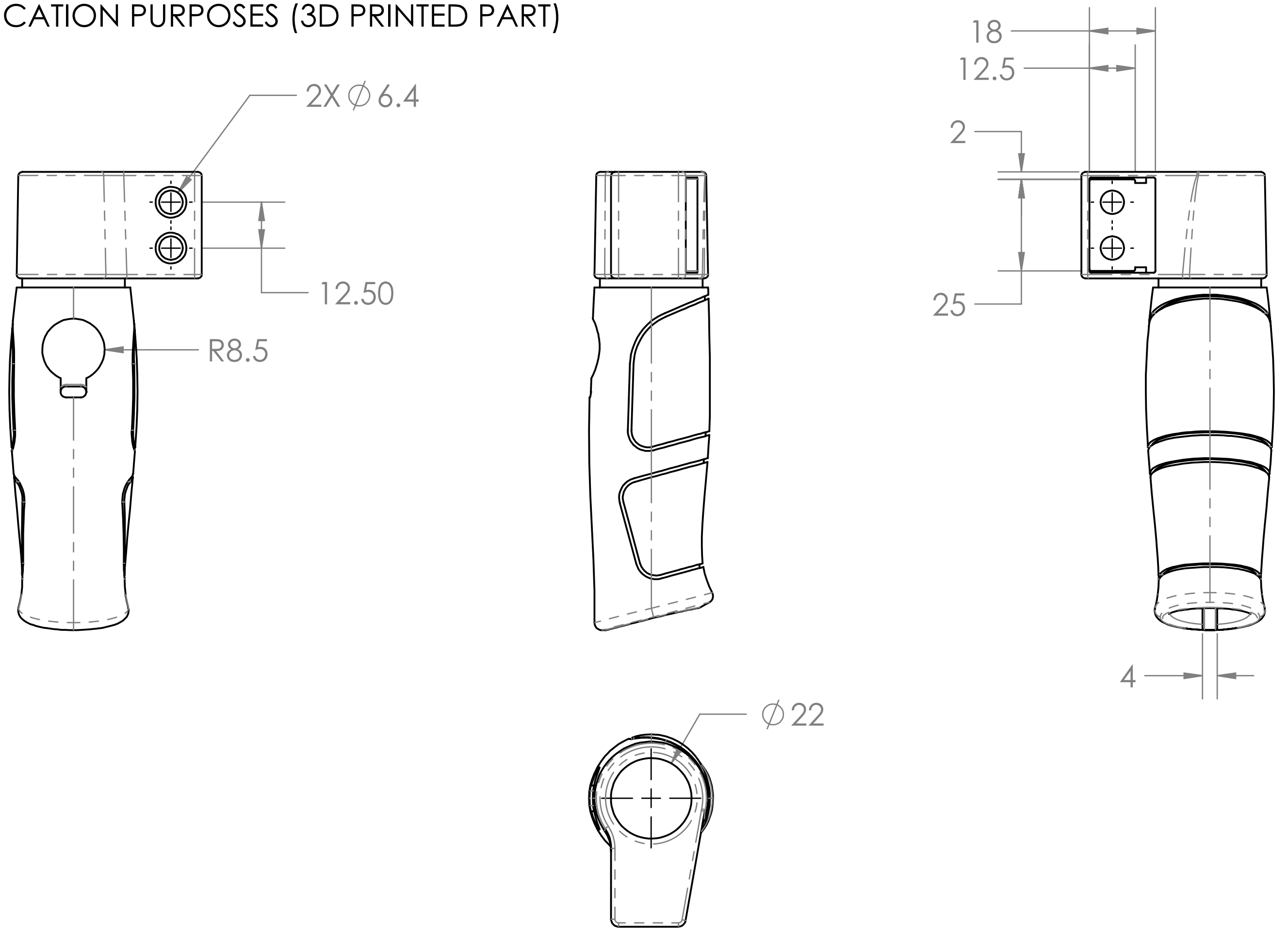
TITLE:
BUTTON GRIP ASSEMBLY

SIZE	DWG. NO.	REV
A	ETHB-001	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

NOTE: DIMENSIONS GIVEN ARE FOR INSPECTION PURPOSES AND
NOT FABRICATION PURPOSES (3D PRINTED PART)



Electric Tandemonium	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
	DIMENSIONS ARE IN MILIMETERS TOLERANCES: ANGULAR: MACH ±1 BEND ±2 ONE PLACE DECIMAL ±.1 TWO PLACE DECIMAL ±.05	DRAWN	AF	1/29/15
		CHECKED	KIL	1/30/15
		ENG APPR.		
		MFG APPR.		
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	MATERIAL 3D PRINTED	COMMENTS:		
	FINISH			

PROJECT: ELECTRIKE

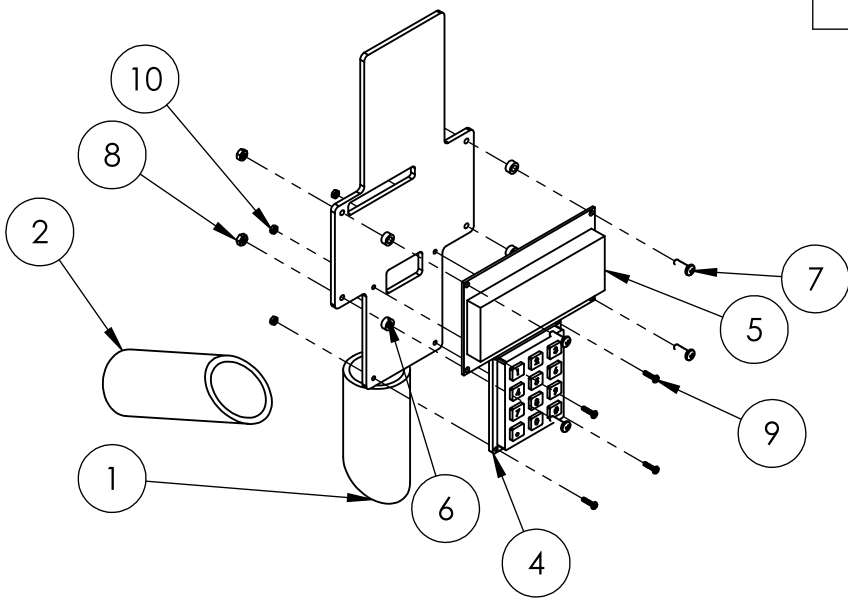
TITLE:
GRIP BODY

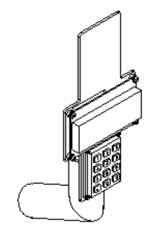
SIZE	DWG. NO.	REV
A	ETHB-002	1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	ETLA-002	ANGLED 1.40ODX3L SHAFT	6061-T6 ALUMINUM	1
2	ETLA-001	ANGLED 1.40ODX4L SHAFT	6061-T6 ALUMINUM	1
3	ETLA-003	BENT SHEET METAL ADAPTER	6061-T6 ALUMINUM	1
4	ADA-1824	KEYPAD	N/A	1
5	ADA-198	LCD SCREEN	N/A	1
6	94639A299	#6ID 1.25OD SPACER	NYLON 6/6	4
7	90116A155	M3X10L SCREW	316 STAINLESS STEEL	4
8	90591A121	M3 HEX NUT	ZINC-PLATED STEEL	4
9	90116A015	M2X8L SCREW	316 STAINLESS STEEL	4
10	90591A111	M2 HEX NUT	ZINC-PLATED STEEL	4





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FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
VARIES

FINISH

	NAME	DATE
DRAWN	KIL	1/30/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

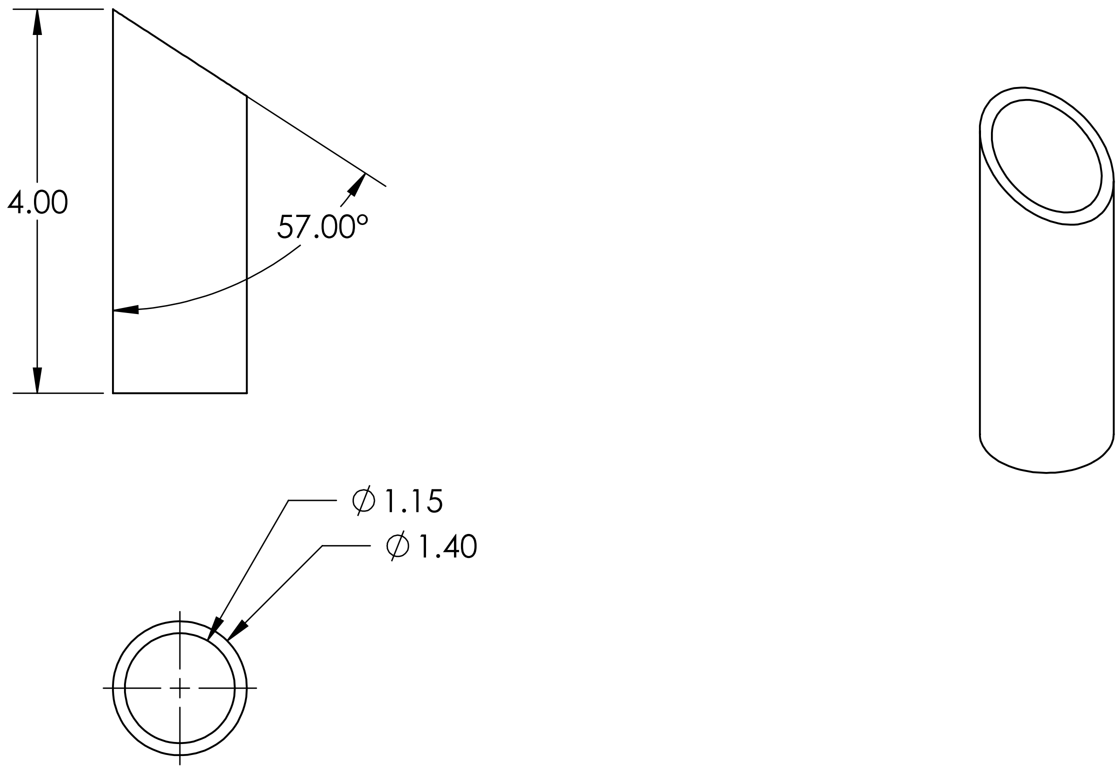
PROJECT: ELECTRIKE

TITLE:
LATCH ASSEMBLY

SIZE	DWG. NO.	REV
A	ETLA-004	1

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
MACHINED FROM ALUMINUM

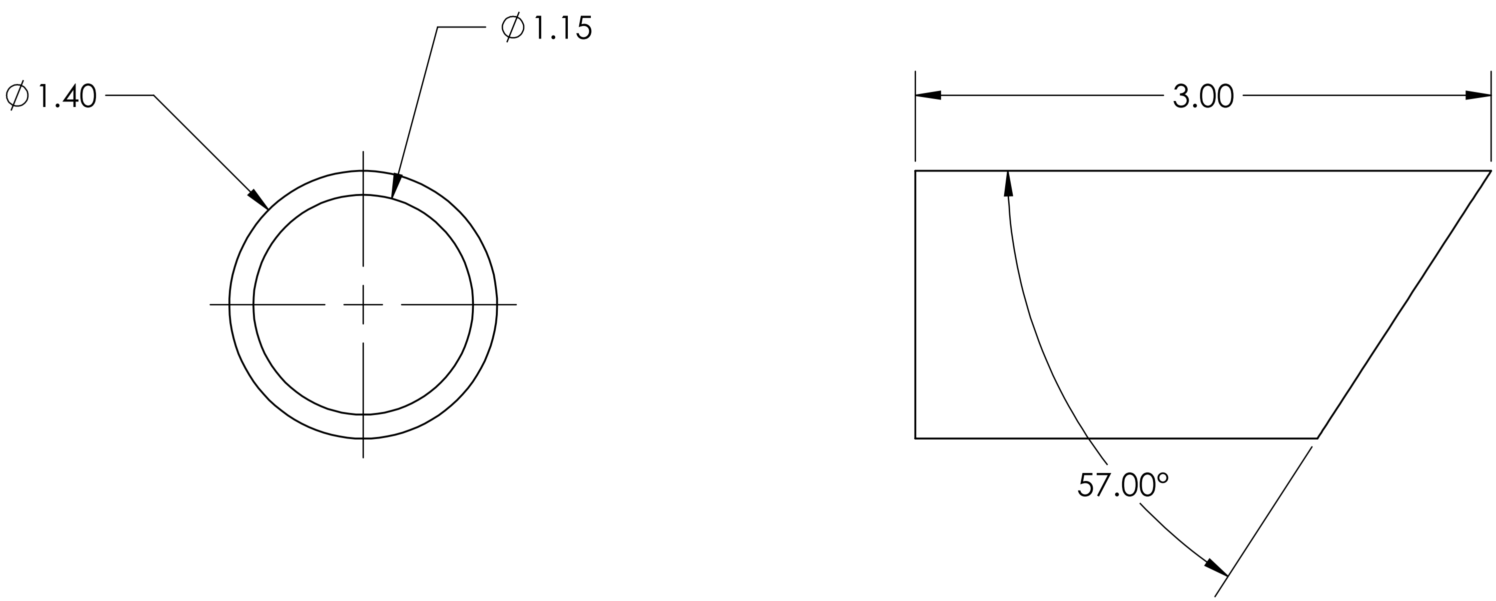
PROJECT: ELECTRIKE

TITLE:
ANGLED 1.40ODX4L SHAFT

SIZE	DWG. NO.	REV
A	ETLA-001	1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Electric Tandemonium

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
MACHINED ALUMINUM PIPE

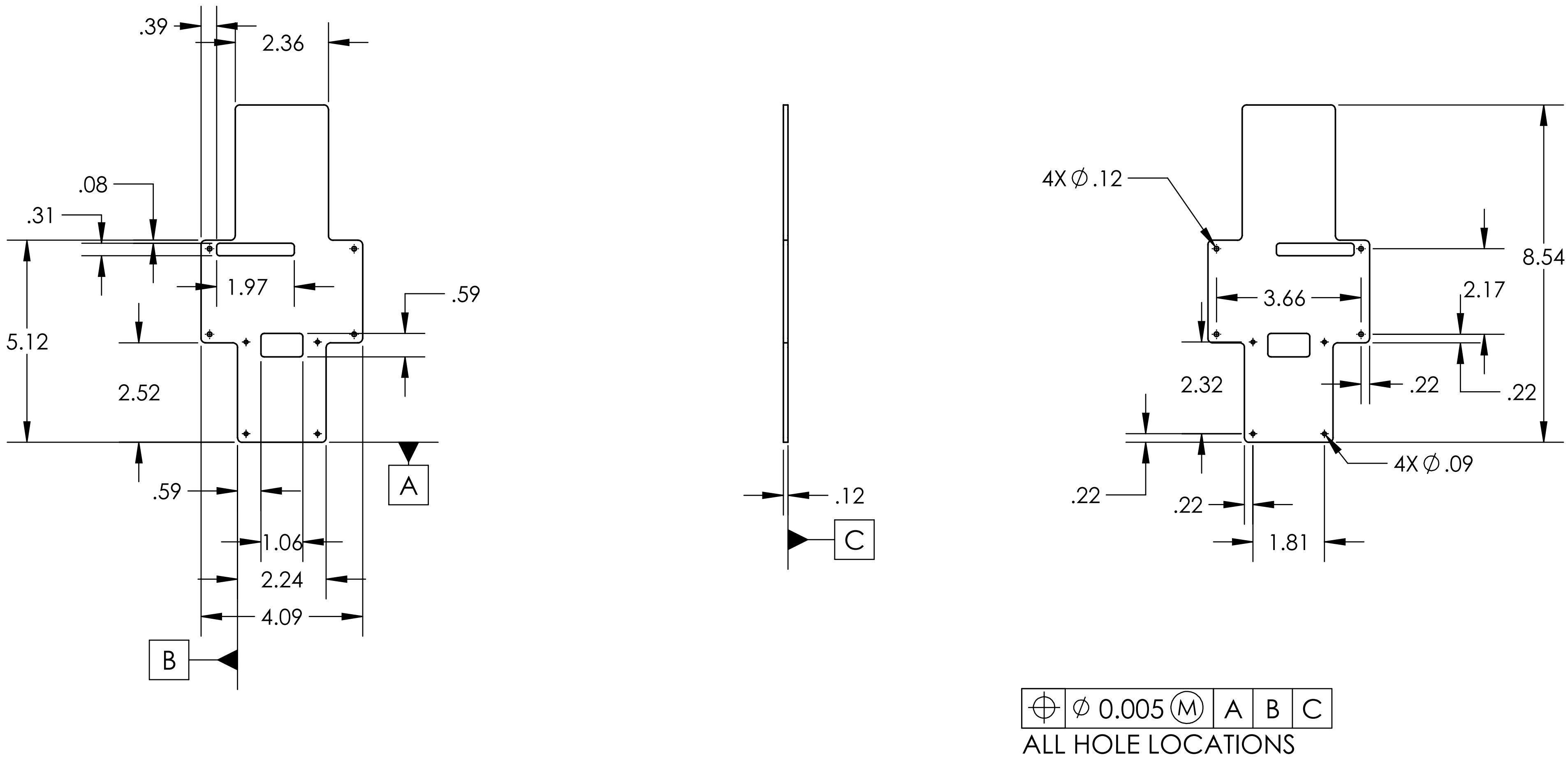
PROJECT: ELECTRIKE

TITLE:
ANGLED 1.45OD SHAFT

SIZE	DWG. NO.	REV
A	ETLA-002	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/8" ANGULAR: MACH ± 1 BEND ± 2 TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL 6061-T6 ALUMINUM
FINISH

	NAME	DATE
DRAWN	KIL	1/30/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
BENT ALUMINUM SHEET
ALL EXTERNAL FILLETS 3MM
ALL INTERNAL FILLETS 2MM
BEND RADIUS 2MM

__Electric Tandemonium__

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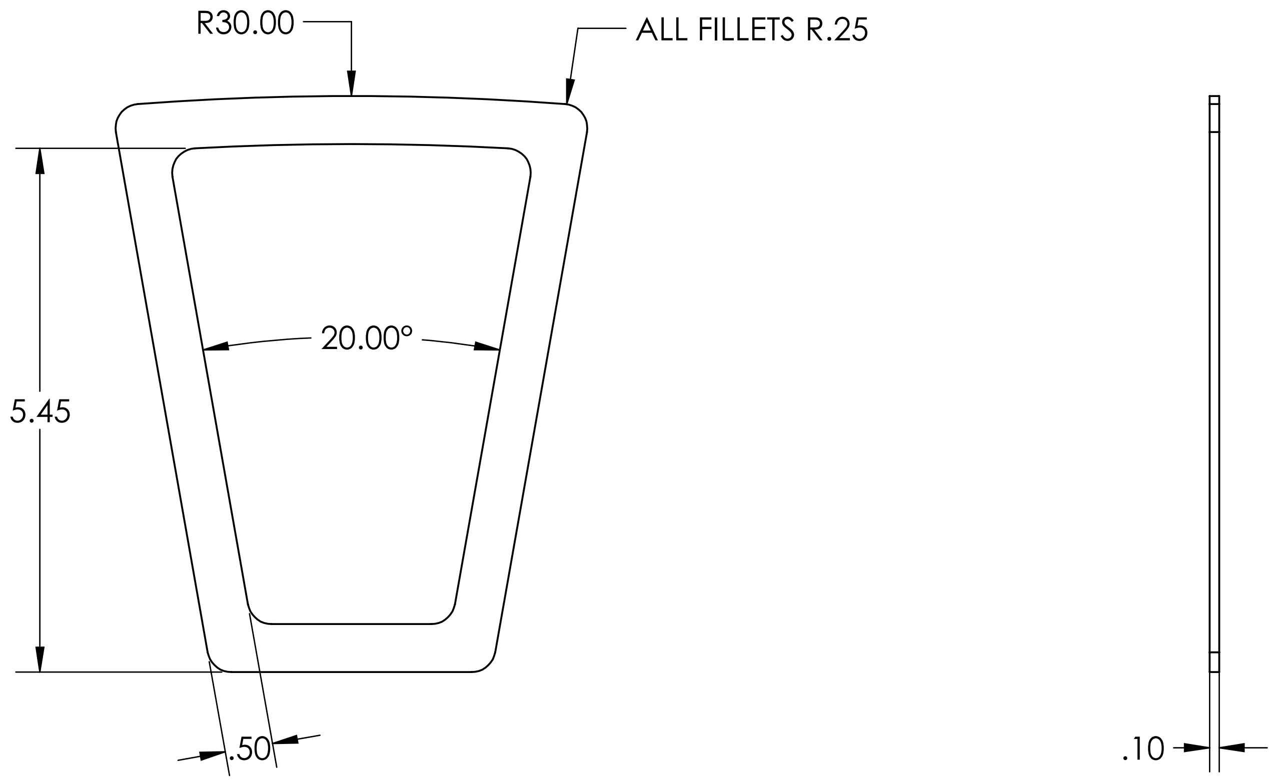
__PROJECT: ELECTRIKE__

TITLE:
BENT SHEET METAL ADAPTER

SIZE	DWG. NO.	REV
A	ETLA-003	1

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Electric Tandemonium

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/8"
ANGULAR: MACH ± 1 BEND ± 2
TWO PLACE DECIMAL ± .05
THREE PLACE DECIMAL ± .005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: ADD TO DRAWING THE HOLE DIMENSIONS FOR A TRUNK LATCH.

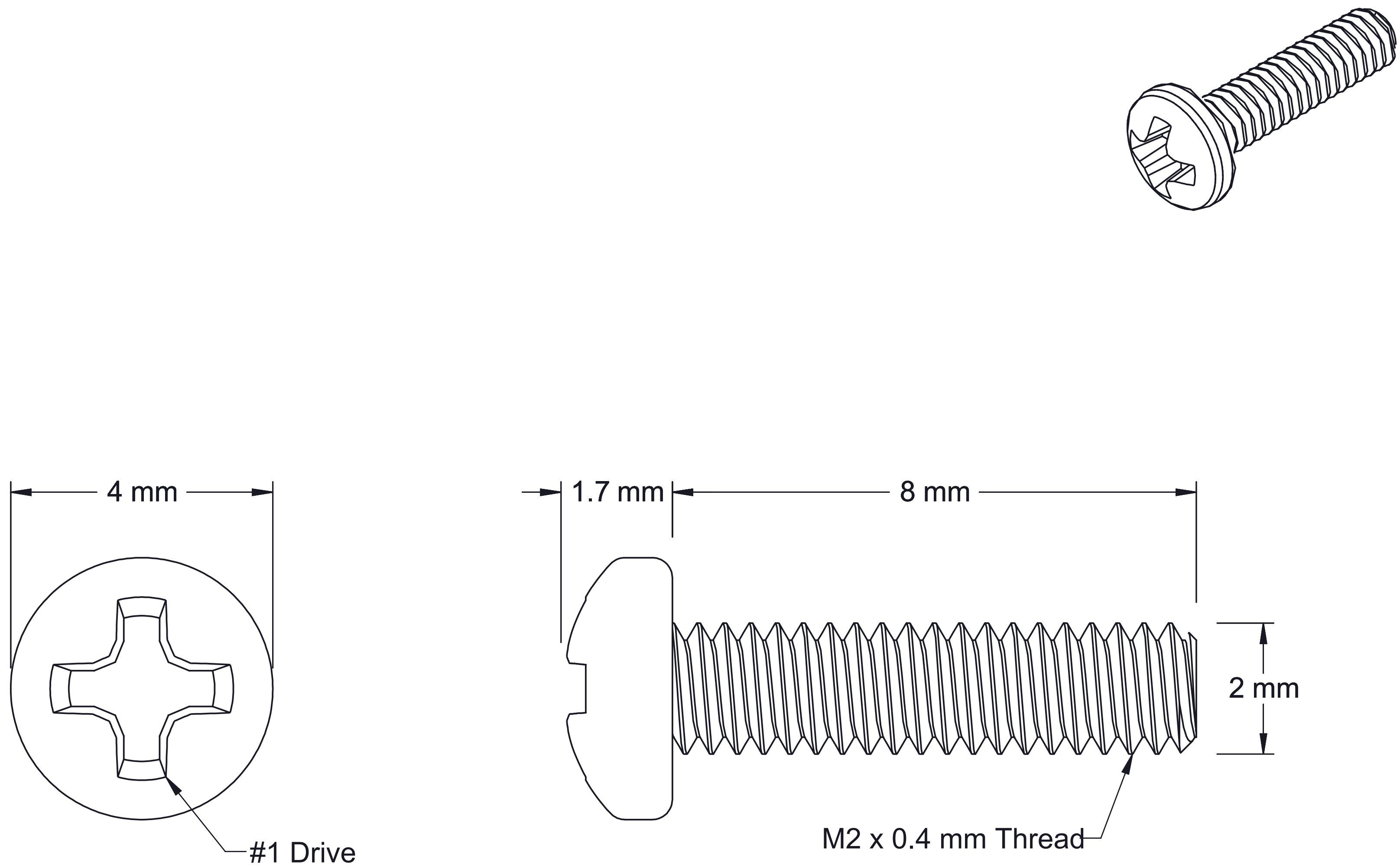
PROJECT: ELECTRIKE

TITLE:
Latch Plate

SIZE	DWG. NO.	REV
A	ETLA-005	1

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



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McMASTER-CARR® CAD	PART NUMBER	90116A015
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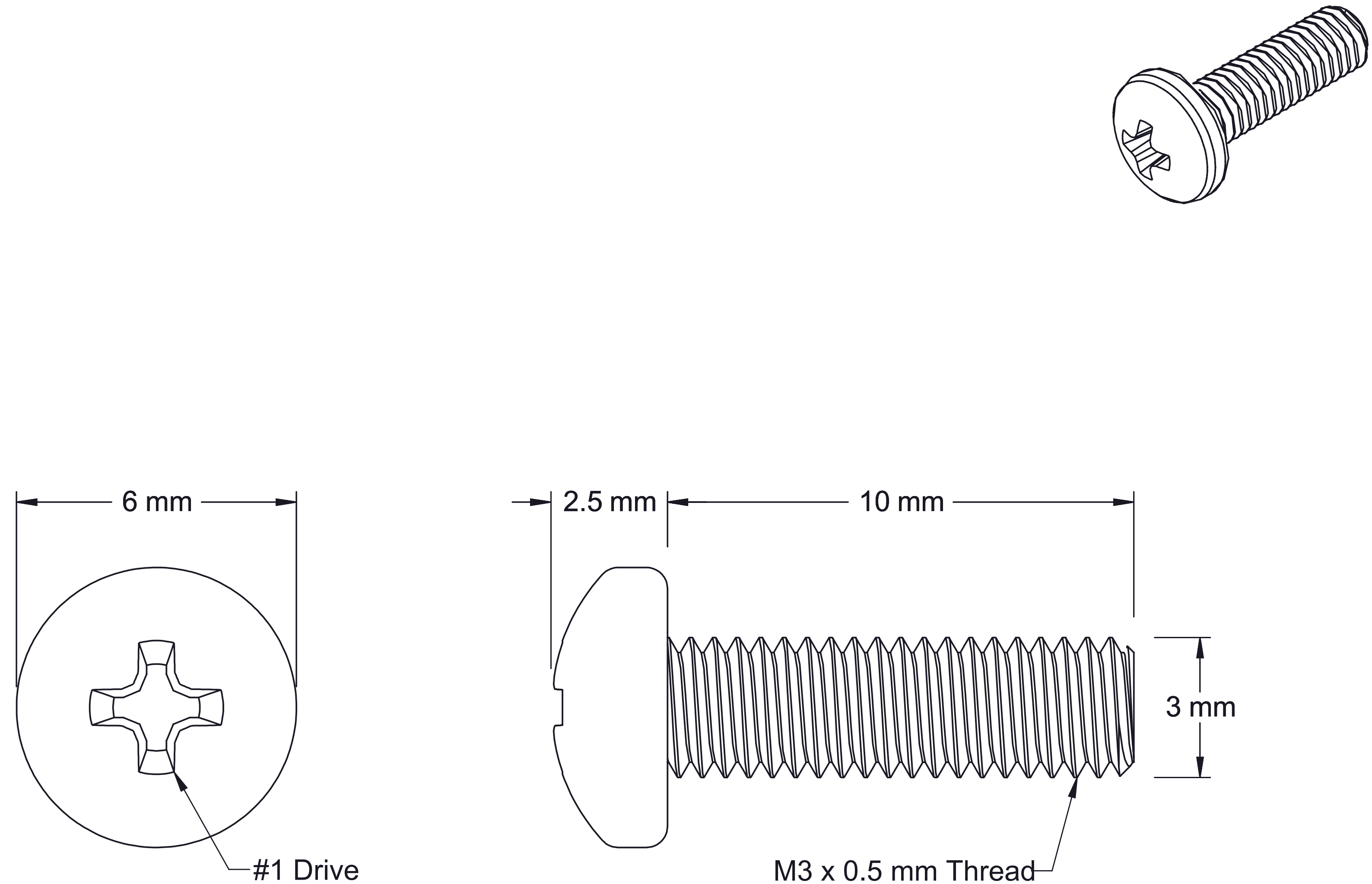

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McMASTER-CARR® CAD	PART NUMBER	90116A155
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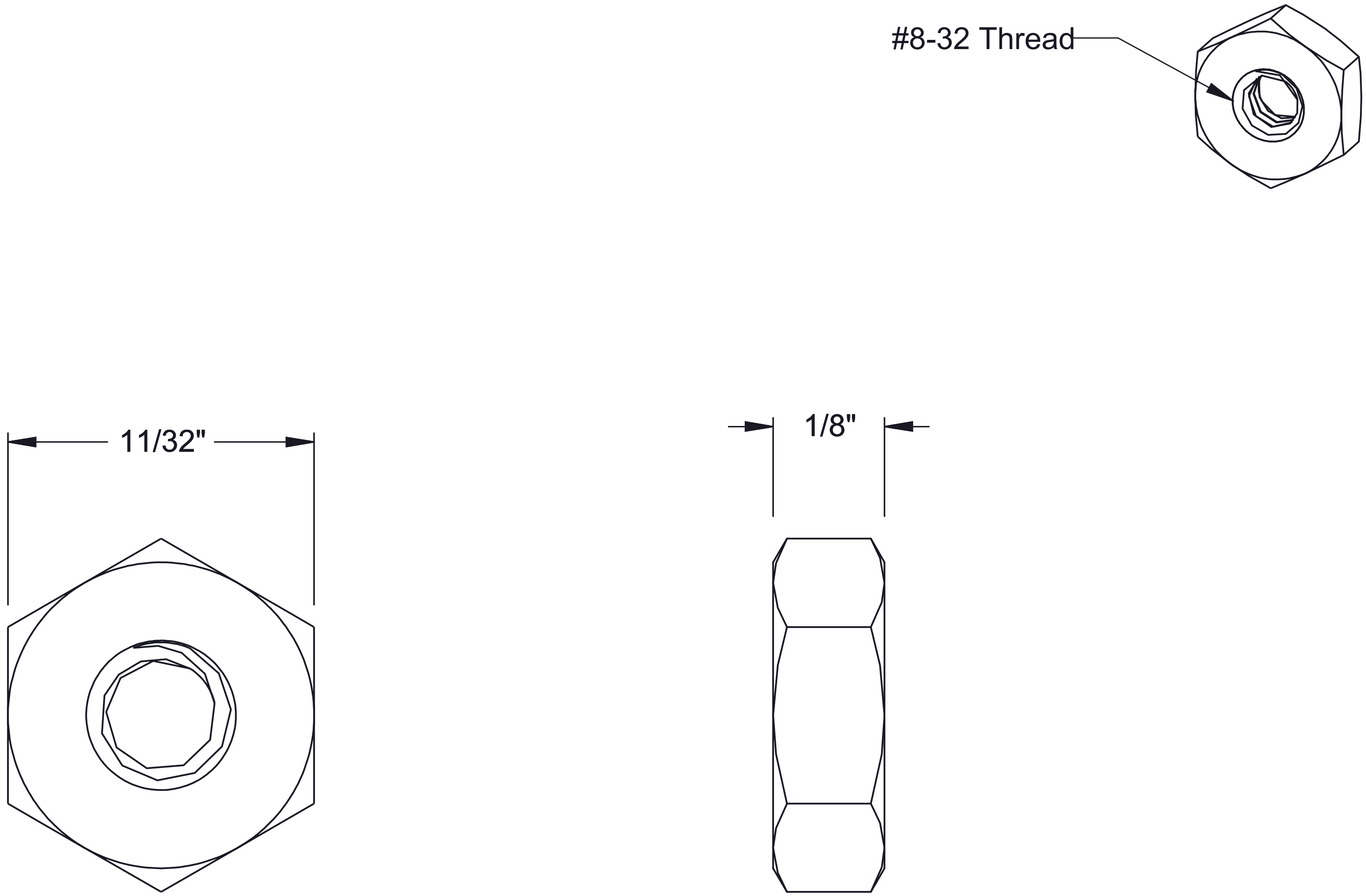

McMASTER-CARR® CAD	PART NUMBER	90545A009
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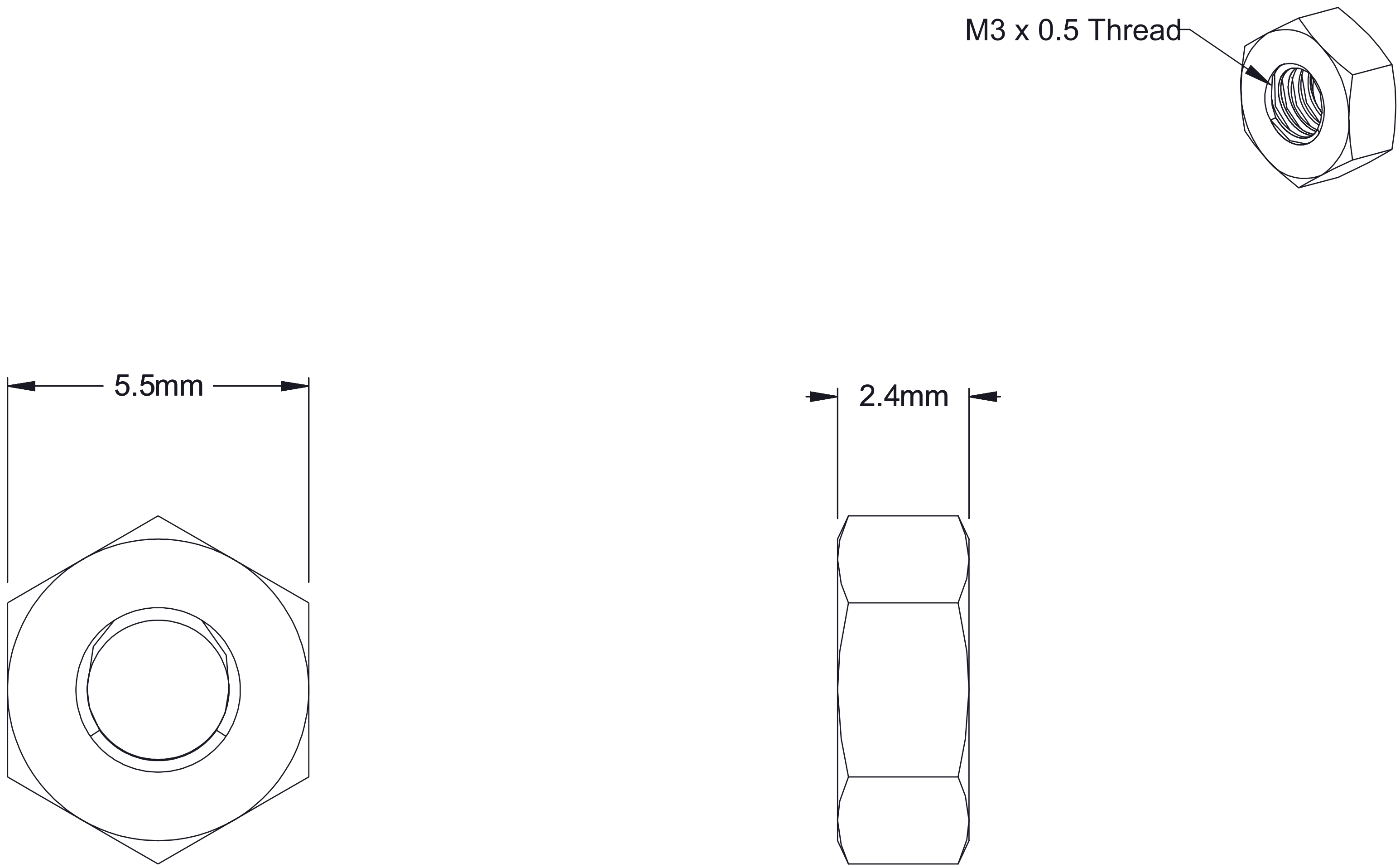

McMASTER-CARR® CAD	PART NUMBER	**90591A121**
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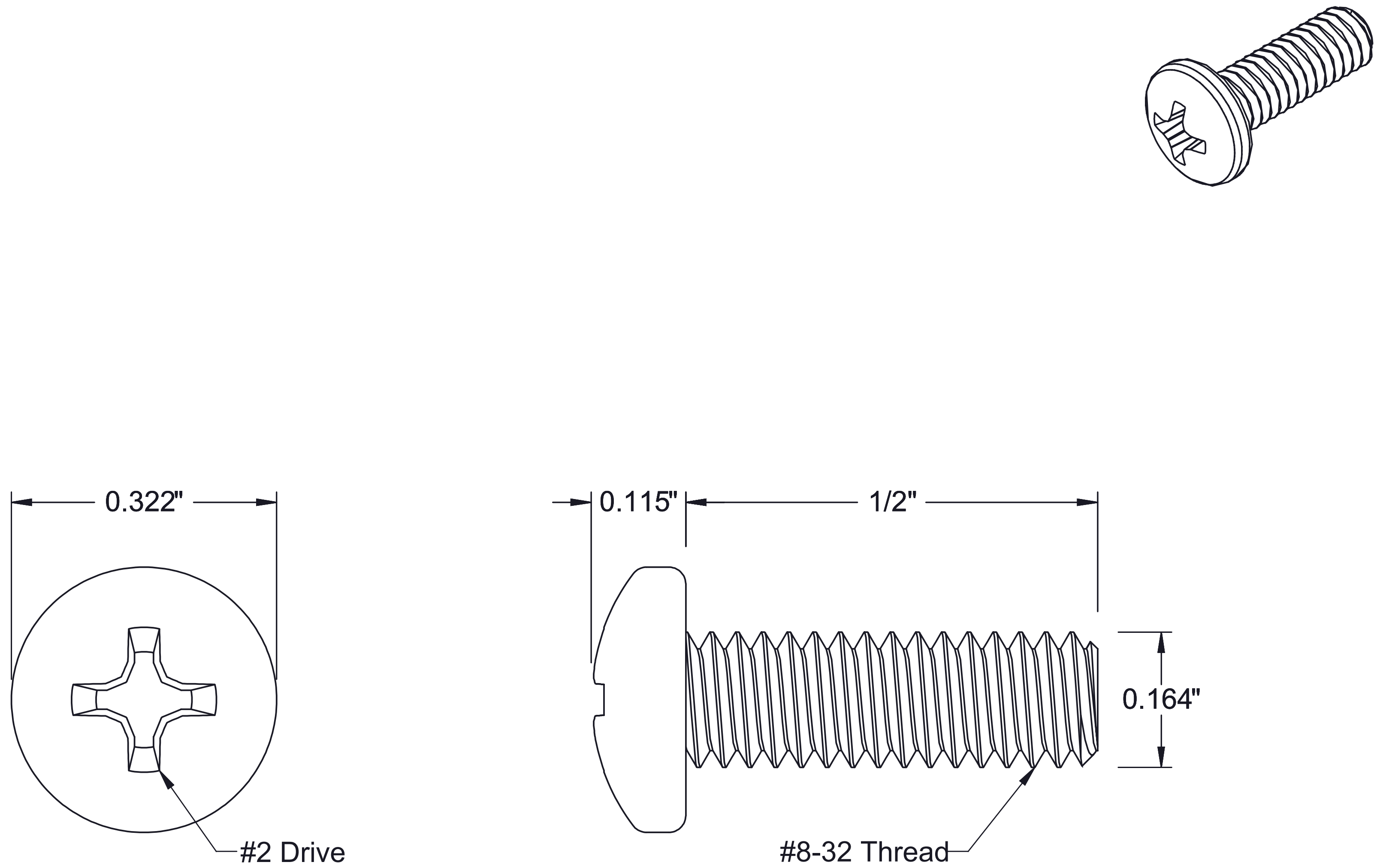

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McMASTER-CARR® CAD	PART NUMBER	91735A194
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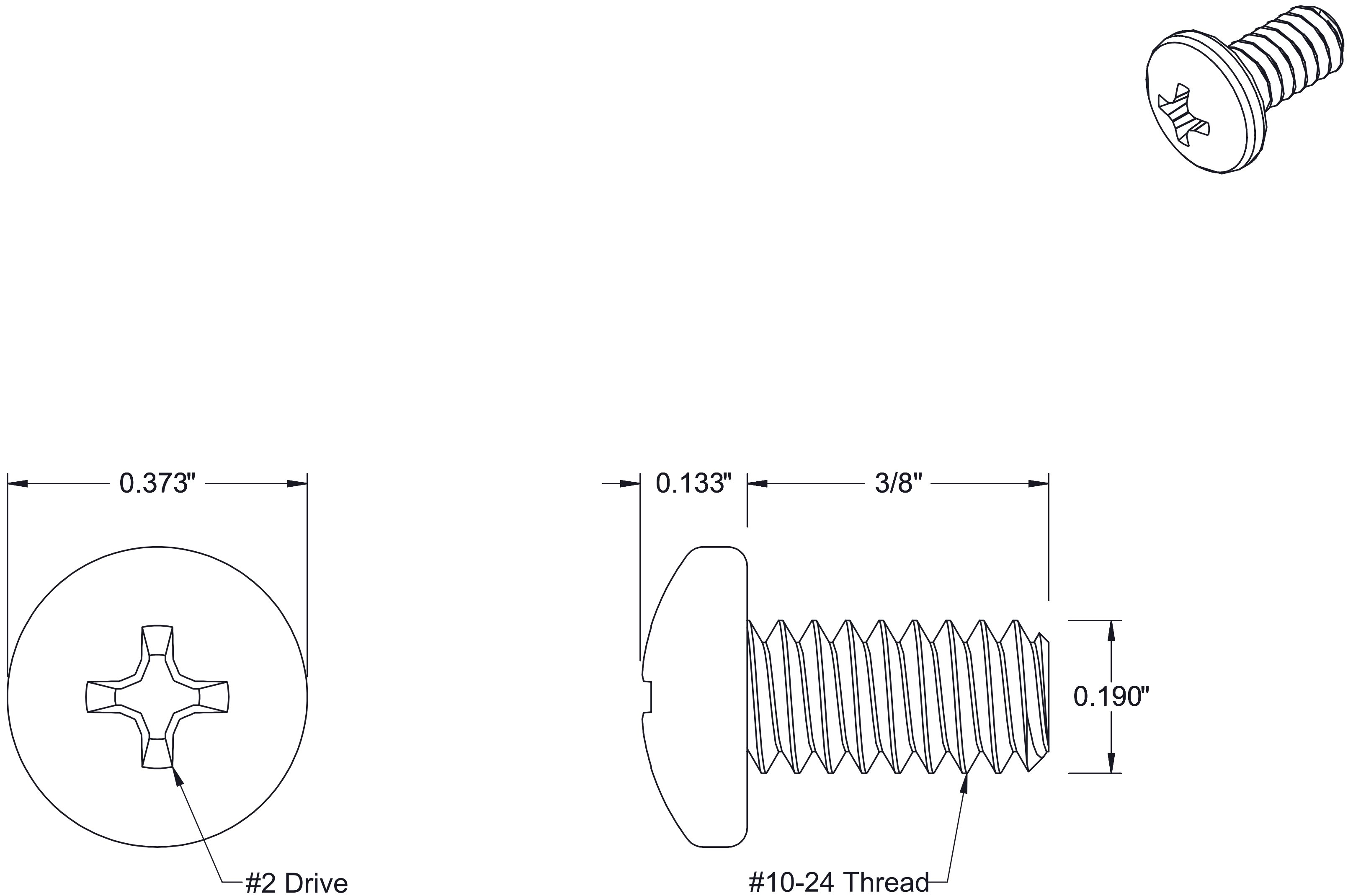

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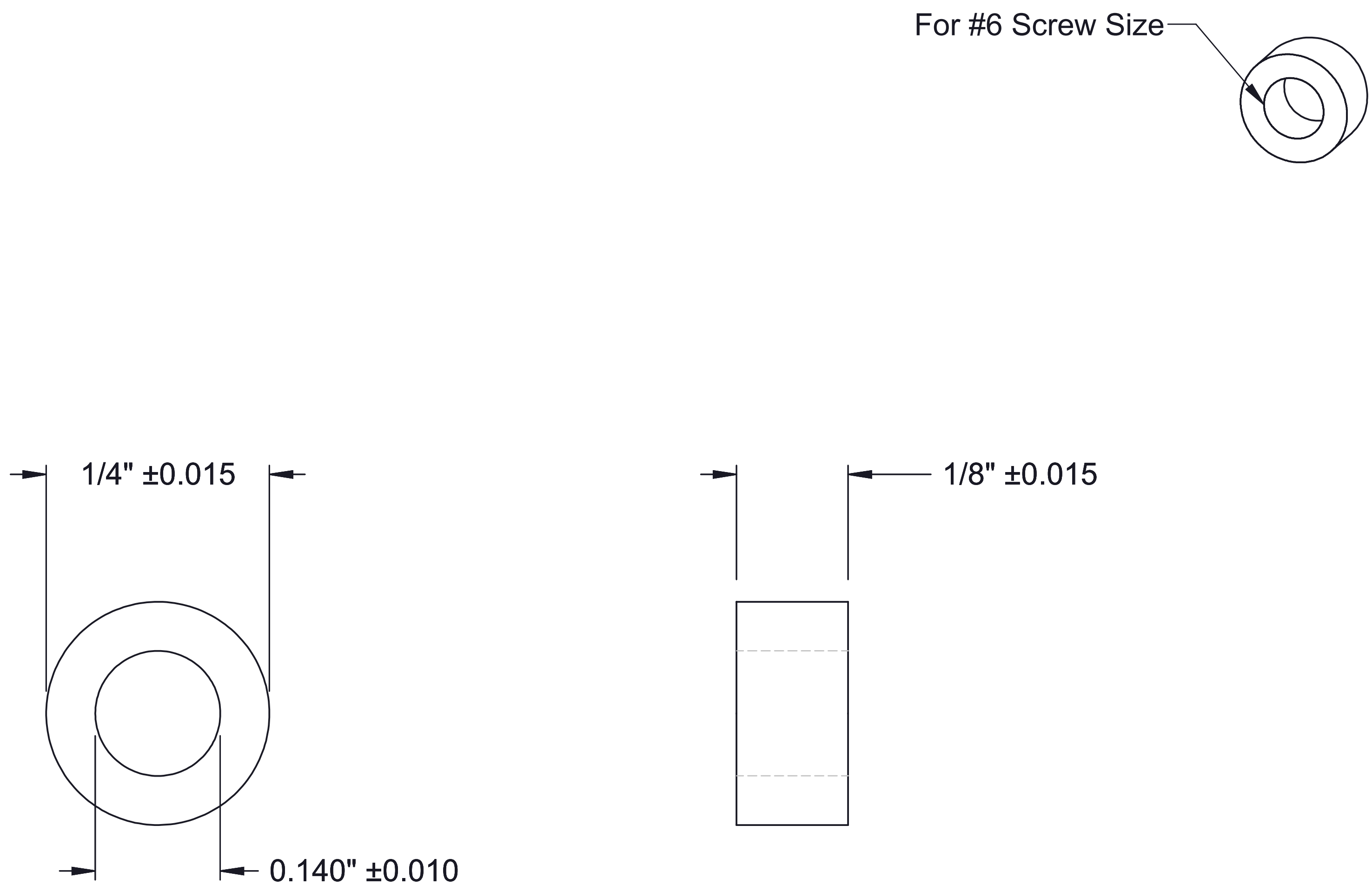
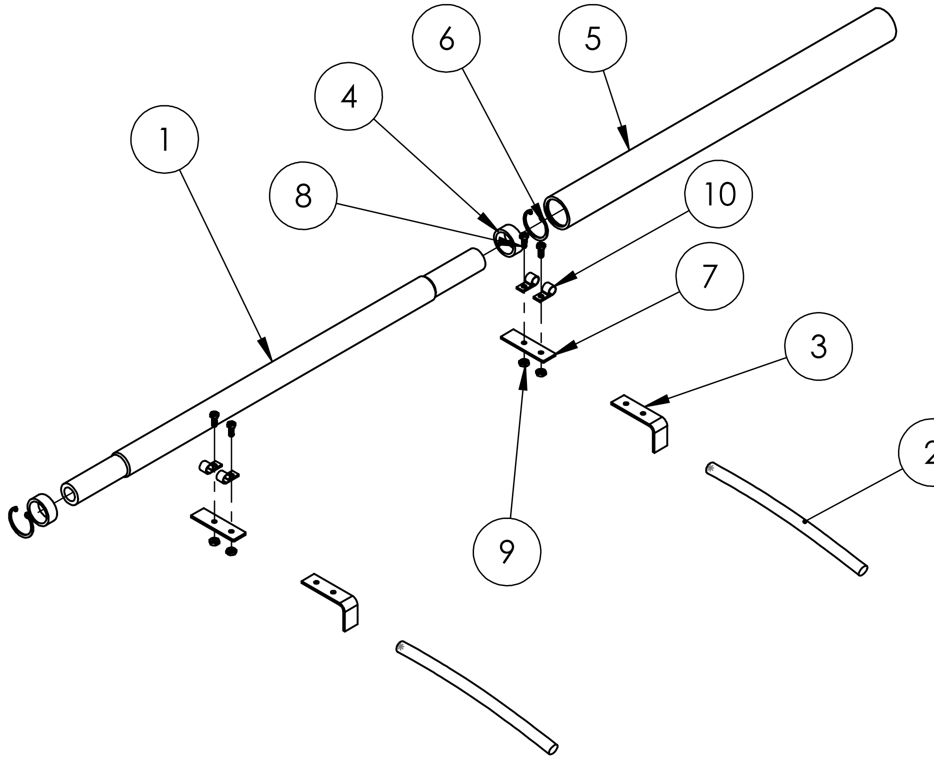
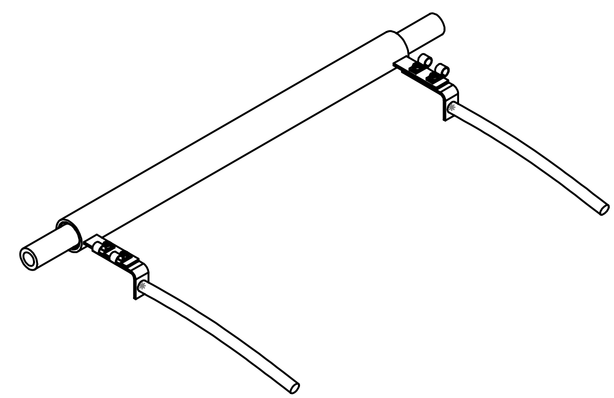
McMASTER-CARR® CAD	PART NUMBER 91735A240
http://www.mcmaster.com	Pan Head Phillips Machine Screw
Information in this drawing is provided for reference only.	



McMASTER-CARR® CAD	PART NUMBER	94639A299
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Off-White Nylon 6/6 Unthreaded Spacer	

ITEM NO.	PART NUMBER	DESCRIPTION	Material	QTY.
1	ETRA-001	INTERNAL STEPPED SHAFT	6061-T6 ALUMINUM	1
2	ETRA-002	BENT HANDLE	6061-T6 ALUMINUM	2
3	ETBR-009	FAIRING HANDLE BRACKET	6061-T6 ALUMINUM	2
4	6391K281	1" ID SLEEVE BEARING	SAE 841 BRONZE	2
5	ETRA-003	1.25IN ID ROTATING SHAFT	6061-T6 ALUMINUM	1
6	99142A500	1.25IN OD SNAP RING	1018 STEEL	2
7	ETBR-007	WELDED FAIRING BRACKET	6061-T6 Aluminum	2
8	92620A412	10-24X0.5L BOLT	1018 STEEL	4
9	90545A011	10-24 NUT	1018 STEEL	4
10	3177T51	.375IN LOOP CLAMP	303 STAINLESS STEEL	4





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
VARIED

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
SEE CDR FOR ASSEMBLY INSTRUCTIONS

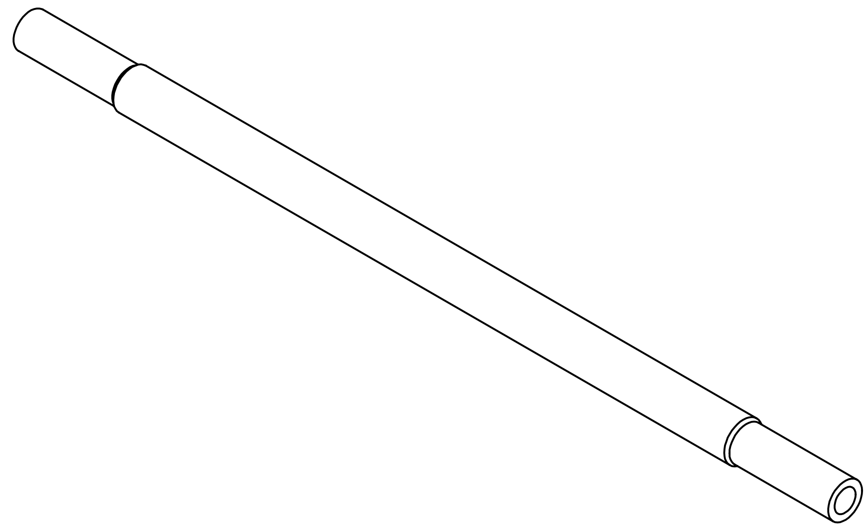
PROJECT: ELECTRIKE

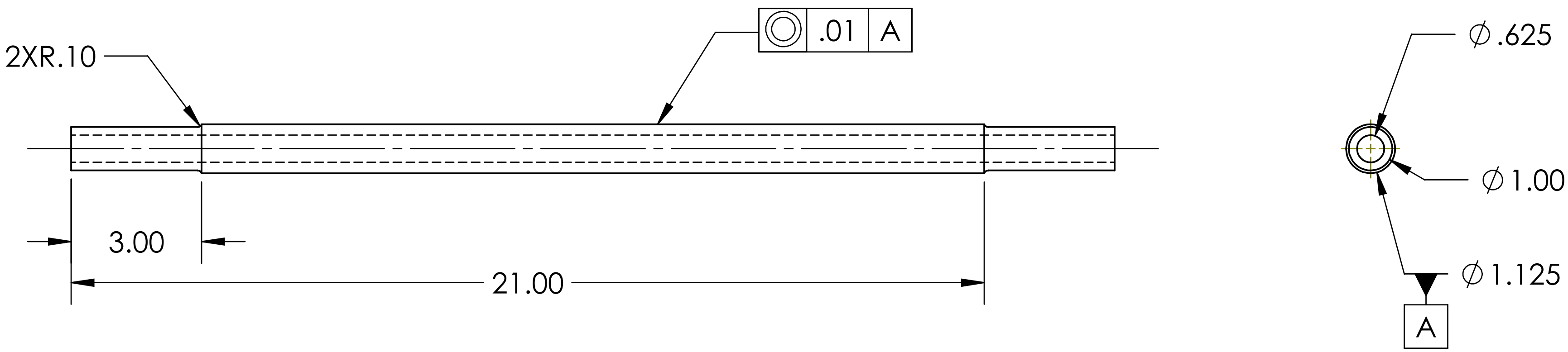
TITLE:
ROTATING ASSEMBLY

SIZE A | DWG. NO. ETRA-004 | REV 1

SCALE: 1:8 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	KIL	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
STEPPED DIAMETER SHAFT
BUILD ON LATHE

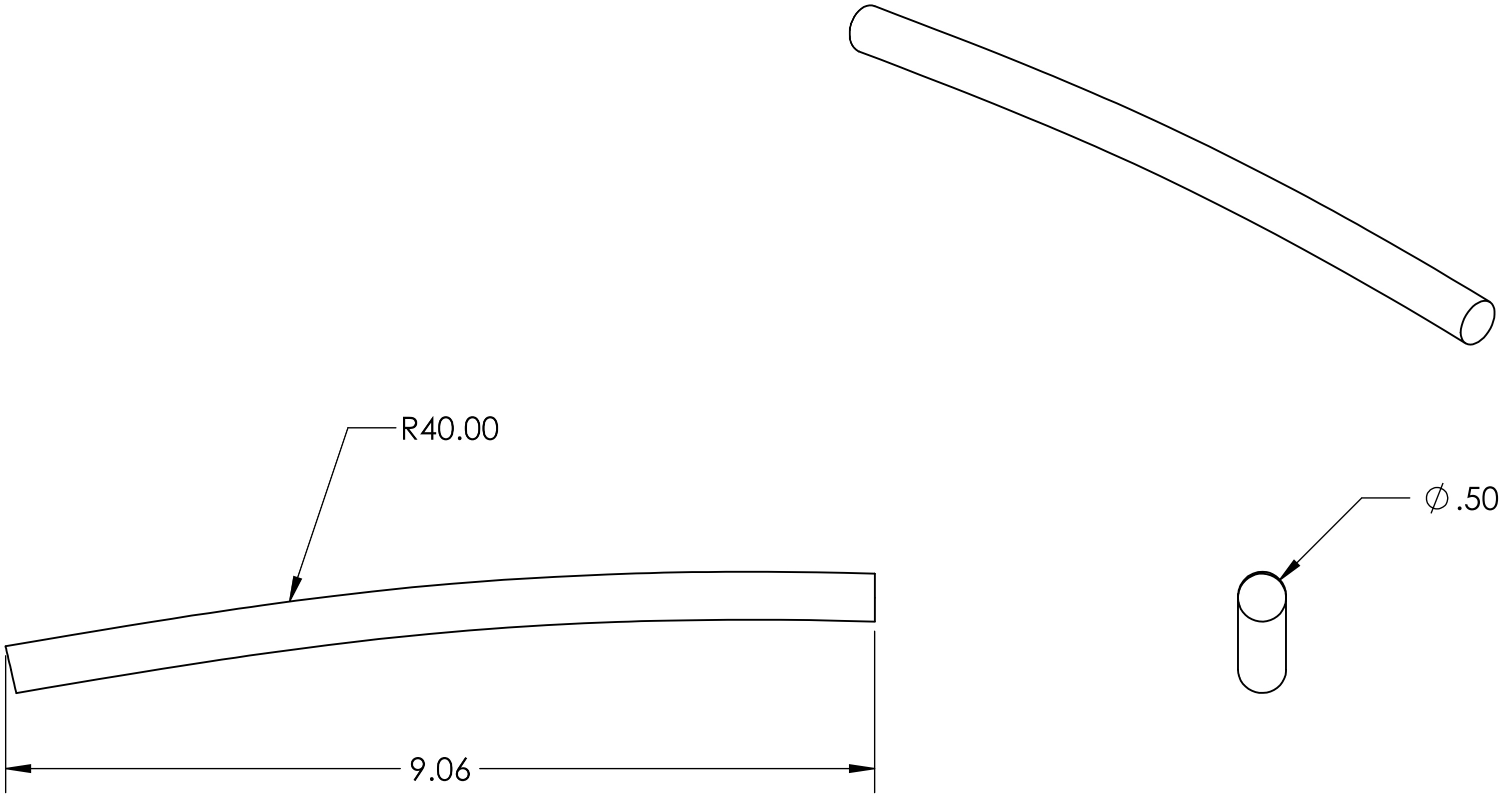
PROJECT: ELECTRIKE

TITLE:
STEPPED INTERNAL SHAFT

SIZE	DWG. NO.	REV
A	ETRA-001	1

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
RADIUS OF CURVATURE NOT CRITICAL - BEND 10IN ALUMINUM BAR TO ALLOW FOR EASY GRIP FROM BELOW

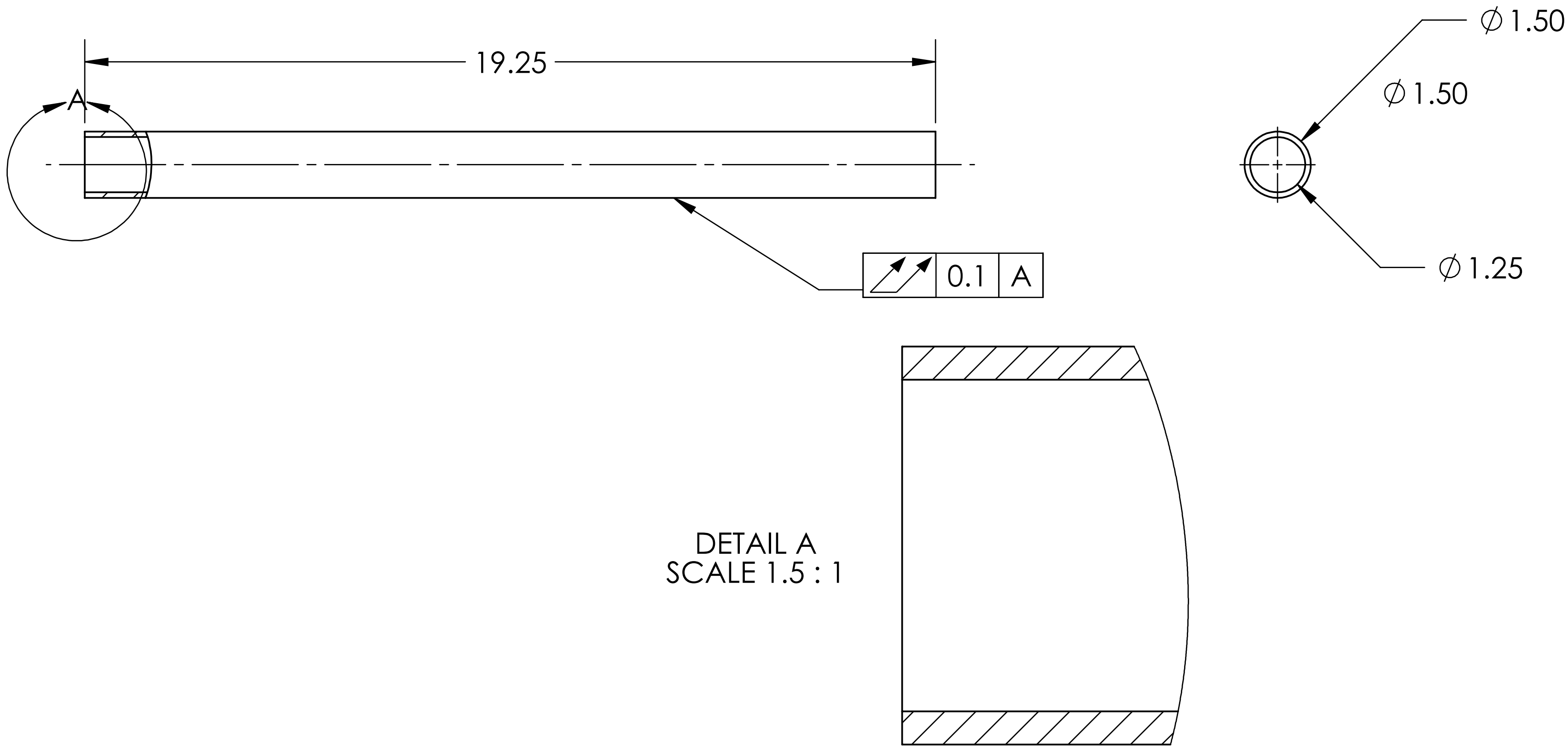
PROJECT: ELECTRIKE

TITLE:
BENT HANDLE

SIZE	DWG. NO.	REV
A	ETRA - 002	1

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 ALUMINUM

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
MACHINED ON LATHE
ID FOR FITTING AROUND 1.25IN BUSHING

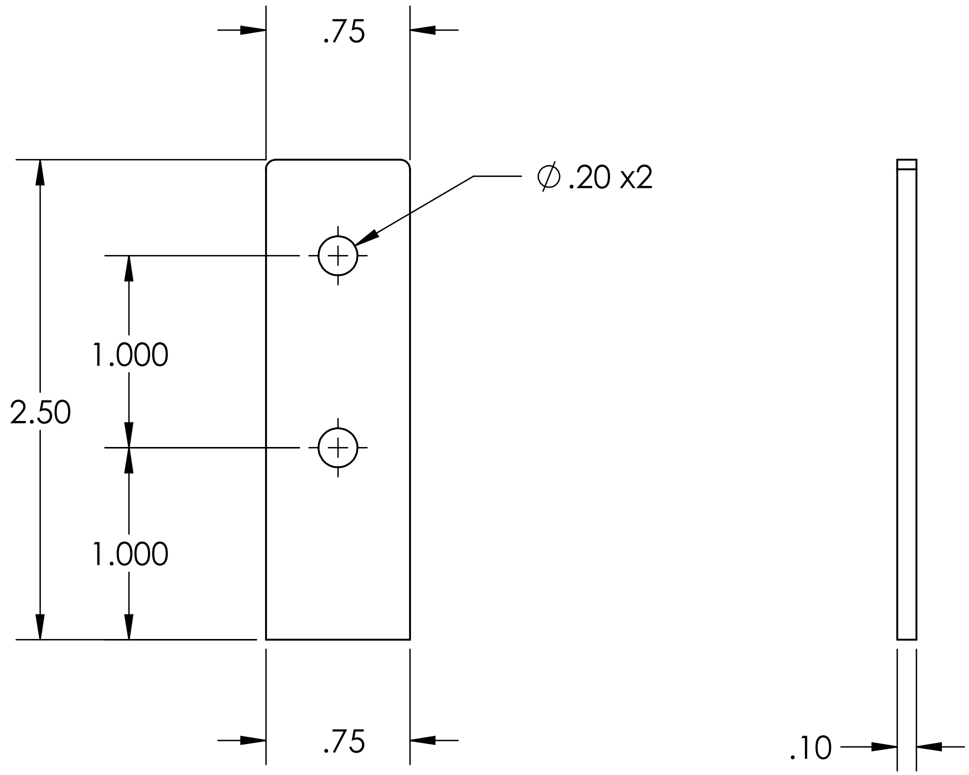
PROJECT: ELECTRIKE

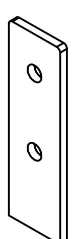
TITLE:
1.25IN ID ROTATING SHAFT

SIZE	DWG. NO.	REV
A	ETRA-003	1

SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1





Electric Tandemonium

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
6061-T6 Aluminum

FINISH

	NAME	DATE
DRAWN	PM	1/28/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
TAB TO WELDED TO TOP OF 2" ALUMIUM ROTATING PIPE

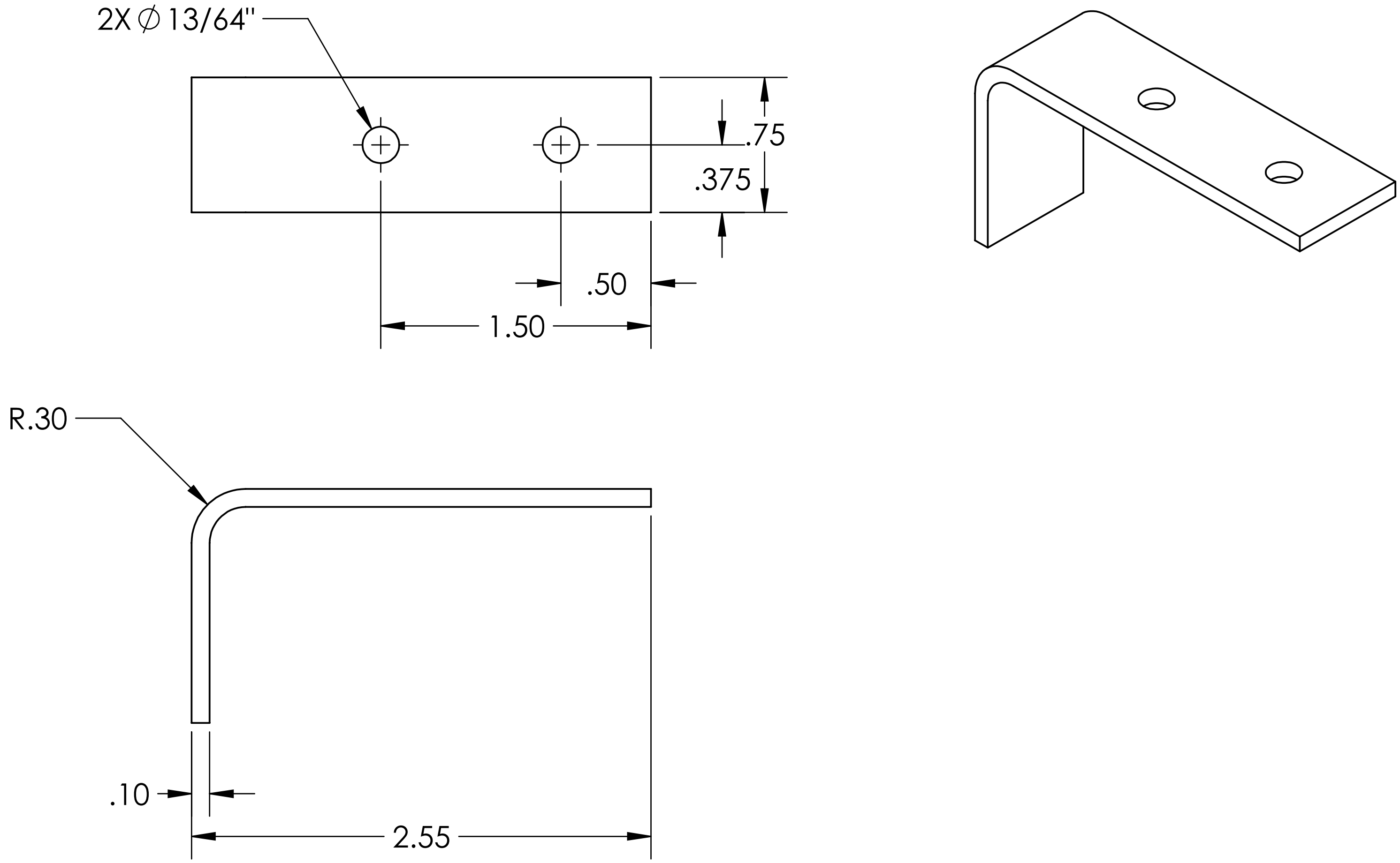
PROJECT: ELECTRIKE

TITLE:
BRACKET MOUNT FOR PLASTIC FAIRING

SIZE	DWG. NO.	REV
A	ETBR-008	1

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

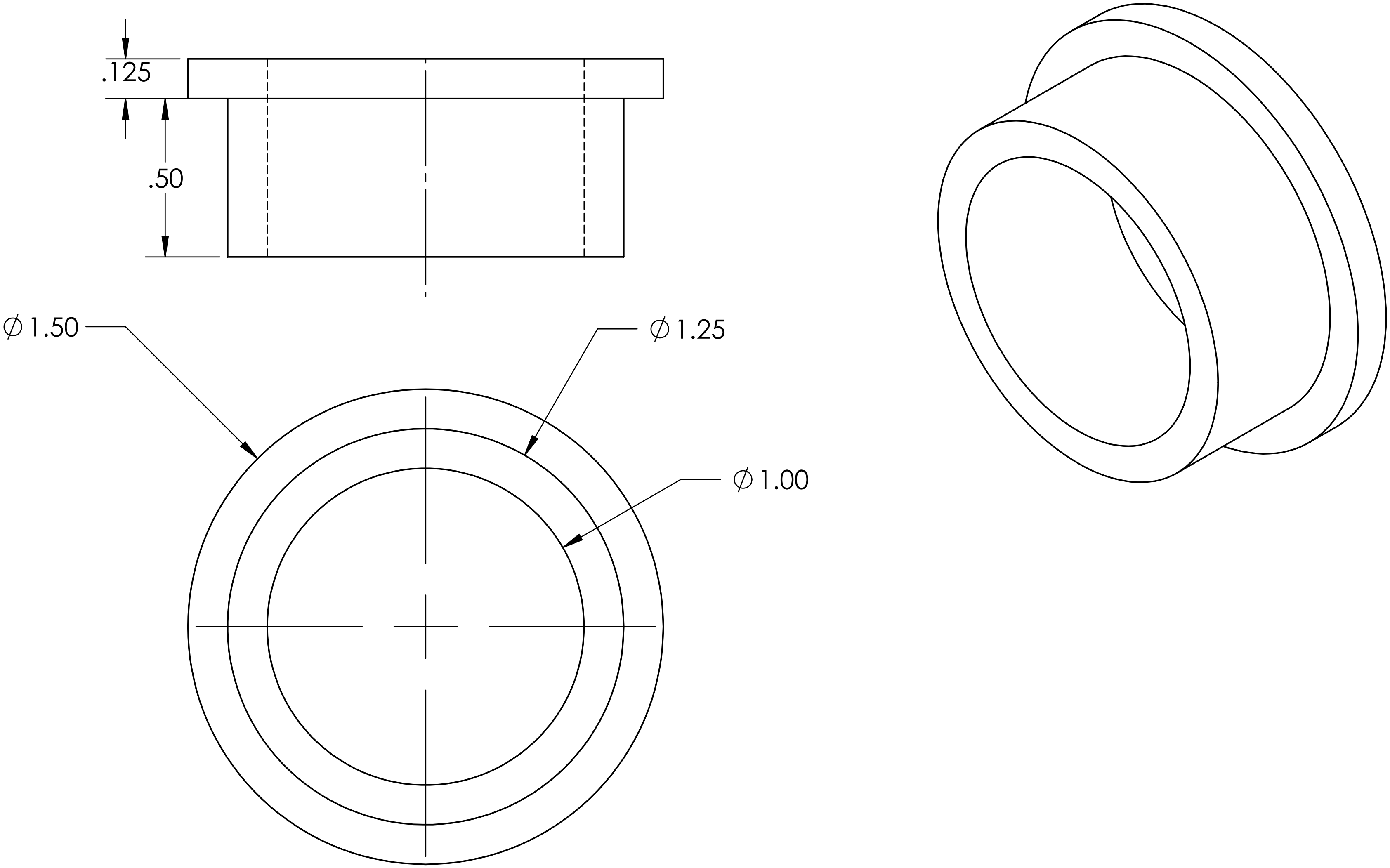
5 4 3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	*PROJECT: ELECTRIKE*
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/8" ANGULAR: MACH ± 1 BEND ± 2 TWO PLACE DECIMAL ± .05 THREE PLACE DECIMAL ± .005	DRAWN	KIL	1/29/15	TITLE: FAIRING HANDLE BRACKET
	CHECKED	KIL	1/30/15	
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL 6061-T6 ALUMINUM	COMMENTS: BENT SHEET METAL PART			SIZE A DWG. NO. ETBR-009 REV 1
FINISH				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

Electric Tandemonium

5 4 3 2 1



Electric Tandemonium

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/8"
ANGULAR: MACH ±1 BEND ±2
TWO PLACE DECIMAL ±.05
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
SAE 841 BRONZE

FINISH

	NAME	DATE
DRAWN	KIL	1/29/15
CHECKED	KIL	1/30/15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
PART PURCHASED AT MCMASTER.COM

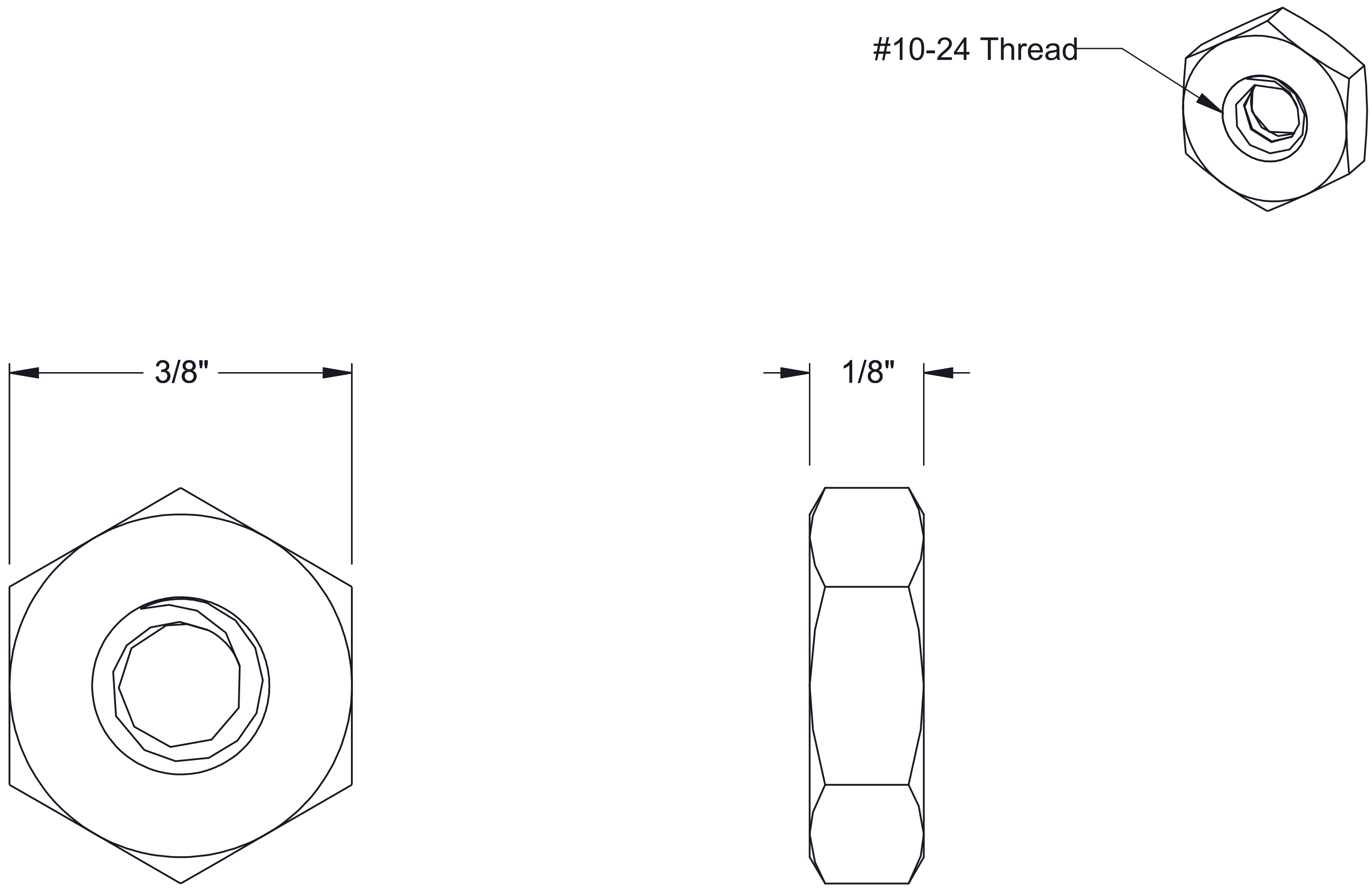
PROJECT: ELECTRIKE

TITLE:
1IN ID BUSHING

SIZE	DWG. NO.	REV
A	6391K281	1

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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McMASTER-CARR® CAD	PART NUMBER	90545A011
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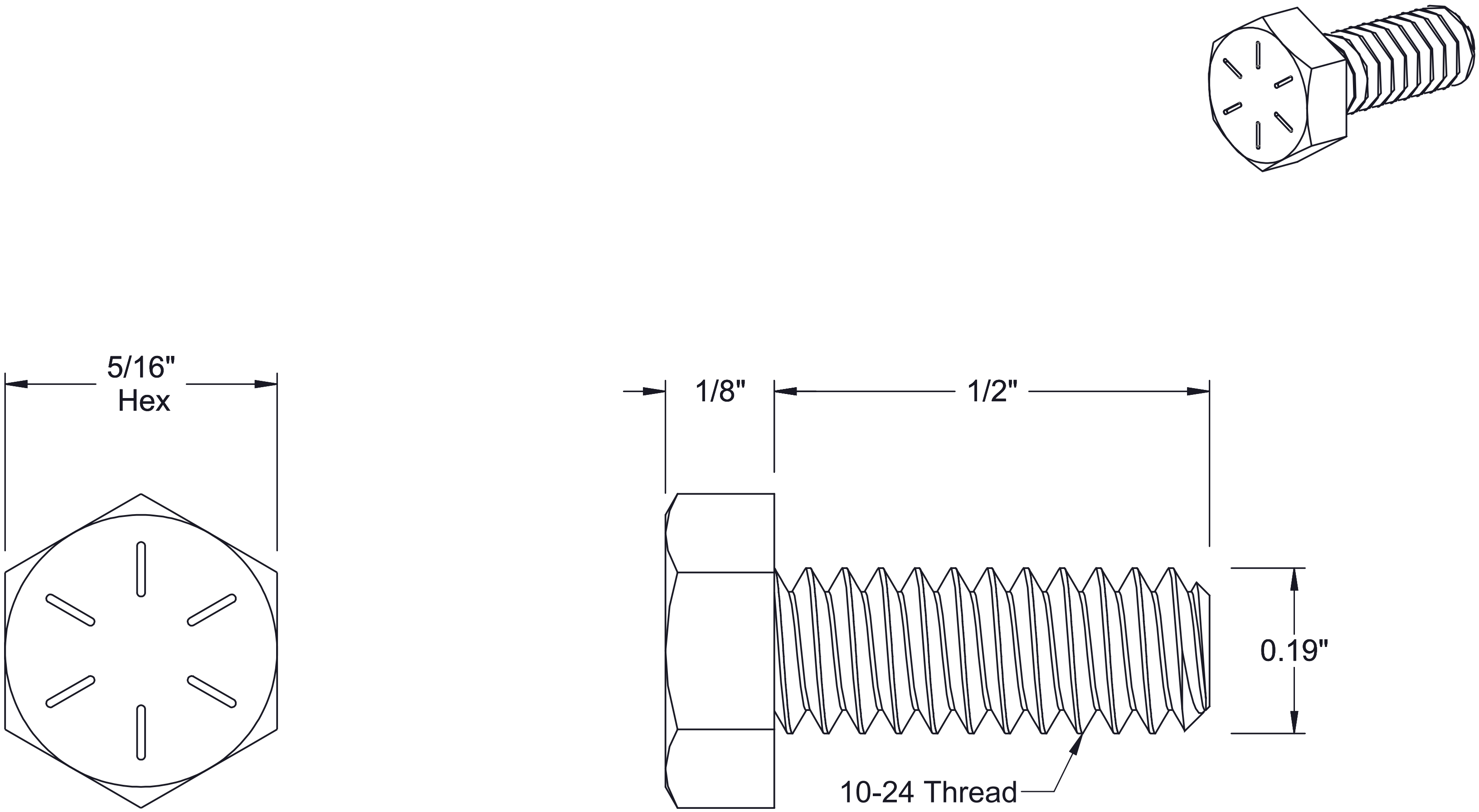

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McMASTER-CARR® CAD

PART NUMBER **92620A412**

http://www.mcmaster.com

High-Strength Steel
Cap Screw-Grade 8