7a2 - HandiTrike

Final Design Report

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The complete senior project report was submitted to the project advisor and sponsor. The results of this project are of a confidential nature and will not be published at this time.

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Abstract

This report covers the design and construction of the recumbent racing tricycle for Mr. Robert T. Kelly, a disabled veteran. Unfortunately Rob's right leg is five inches shorter than his left one and therefore is unable to properly operate standard cranks. Our team HandiTrike is composed of Sean Higginson, Kevin Howie, and Vinay Patel and our project requires us to come up with a design that is feasible to complete within the given three quarters, as well as allow Rob to gain full use of his tricycle. Currently Rob 's trike uses the standard crank set up found on most bicycles and tricycles today, but to overcome the five-inch difference a previous group attempted to solve this problem by adding an extension member to the right crank. The overall thought was that this rotating member would allow Rob to potentially gain full use of the crank system. However, there were several flaws in their design due to lack of communication between the group and sponsor.

Throughout this report you will find our various conceptual solutions to our problem, as well as our overall final design to solving this problem. Along with solving the crank issue, HandiTrike has been asked to also construct a completely new trike for Rob Kelly. Currently Rob is not satisfied with the performance he receives from his current GreenSpeed tricycle. Therefore, our group has been asked to solve the crank issue, as well as, design a rear suspension system, improve seat conditions, and include a collapsibility feature to allow for easier transportation in a vehicle. Along with these requested features, HandiTrike will also be including standard safety accessories, such as, lights, reflectors, and flags.

As you will read later in the report, there are no clear leaders in developing components for disabled riders. Therefore most of our problem solving will be based off of completely new and innovative ideas that will hopefully help benefit Rob and future riders as well. We believe that the solutions we come up with by the end of the report will fully satisfy Rob's needs out of a tricycle, thus allowing him once again to get back on the road and enjoy those long rides.

Introduction

From the beginning of Winter Quarter 2012, HandiTrike will be designing a comfortable, collapsible, human-powered recumbent racing tricycle for a disabled veteran, Robert T. Kelly, whose right leg is five-inches shorter than his left. HandiTrike is comprised of Sean Higginson, Kevin Howie, and Vinay Patel. Mr. Robert T. Kelly, a retired Navy diver, has requested this bike be constructed for his personal everyday use. Rob had an unfortunate accident during active duty that caused him to contract a severe case of decompression sickness, otherwise known as the "bends". Due to the severity of his condition, Rob has had to undergo multiple surgeries, during which he has had pieces of his femur, hip, and shoulders removed. With Rob having received multiple surgeries, it has left him with a five-inch difference between his right and left legs, thus limiting his everyday activity. Rob, being an avid cyclist, has informed us that he would like a recumbent racing tricycle that allows for him to properly operate with his condition.

The Quality of Life Plus (QL+) Program will be providing the funding for the

recumbent tricycle project. QL+ is a not-for-profit organization whose mission is to foster and generate innovations to aid and improve the quality of life of those injured in the line of duty. QL+ was founded by Jon Monett in an effort to assist wounded warriors whom are struggling with the daily challenges of returning to a civilian lifestyle.

Come Fall Quarter 2012, HandiTrike will have constructed a fully functioning recumbent racing tricycle with all the requested additions from Rob. As a team we have formulated three main goals we are hoping to achieve. Our main goal is to create a mechanical crank system that can replace Mr. Kelly's current set-up, and allow him to fully utilize his tricycle with his current physical condition. Additionally, our team hopes to provide a smoother and more comfortable ride than what is currently offered by Mr. Kelly's tricycle, which is extremely rigid due to the lack of suspension. To counteract this problem, our team has devised a set-up that will allow us to utilize a rear triangle from a set-up that currently uses a suspension system to help reduce any disruptive or uncomfortable forces Mr. Kelly will experience whilst out riding. Lastly, we want to create a tricycle that can be easily collapsed for transportation and storage. Mr. Kelly has stated that he currently has trouble with his current tricycle in these areas, and would like the trike to collapse in on itself via a quick-release hinge or a similar mechanism. Along with these main goals, we still want the final product to look and feel like a normal tricycle, with standard amenities including a wide range of gearing, disc brakes, and safety features (i.e. lights, flags).

Background

In today's market, there are a vast range of manufacturers of recumbent tricycles. Even though select manufacturers produce recumbent tricycles for disabled riders, no current manufacturer makes one that can fully satisfy Rob's needs. When starting our research, HandiTrike noticed that there are wide ranges in styles of recumbent tricycles. The model styles offered in today's market range from a sleek and light model intended for long road rides to large and bulky frames which are intended for off-road riding. HandiTrike has decided to focus our research towards a racing style of recumbent tricycle. This decision is based off of input received from Rob Kelly himself. Rob mentioned that he currently has a touring style recumbent tricycle and has requested for our team to construct a lighter, more mobile frame for him to use.

We have reviewed multiple manufacturers' current products that relate to a racing style frame, including companies such as GreenSpeed, ICE, and Catrike. All three of these companies currently produce a long distance road model frame for purchase. Based off of the three company's current production models, HandiTrike will be constructing a frame to satisfy the needs proposed by Rob Kelly.

Ian Sims started GreenSpeed in 1990, in the shed in his backyard. GreenSpeed will hopefully become one of our larger suppliers considering that Ian loves to create new products that help benefit people's daily lives. GreenSpeed has previously constructed models for people with various disabilities. Since Ian has mentioned to HandiTrike that he is open to modifying his currents models to benefit

our situation, we may be able to have him help us in our production of our crank system. GreenSpeed also produces the GT-3, which is a collapsible trike model. Rob has mentioned to our group that he would like for our final model to offer this feature. Due to his disability, it makes it difficult for Rob to get it his trike out of his apartment, but to also transport it to each ride location. If the final product is able to collapse, Rob will be able to maneuver and transport his tricycle on his own.

ICE began in 1998 in Cornwall, England by Chris Parker and Neil Selwood. They have continuously pushed the limits on traditional tricycles. In 2011 ICE designed and produced the Vortex, which is their ultimate long distance, high performance racing tricycle. One of the innovative features they offer on the Vortex is the Air-Pro seat. The Air-Pro seat is constructed from glass fiber or carbon fiber to help promote increased durability with minimal weight. Another benefit to the Air-Pro seat is that there is contoured padding added to the seat to help aid in comfort and help promote air-flow behind the back to keep the rider cool.

Design Development

The first step we took when approaching this problem was thoroughly defining it. Luckily for us, the end user of the project has been readily available to communicate his needs. Through multiple meetings with our client, we created a house of quality (Appendix A.1), and matched up the customer needs with engineering requirements. The next step was to perform multiple brainstorm session ideas to solve these engineering problems (Appendix A.2). We mainly

focused on a crank design, suspension system, and frame collapsibility during our brainstorming session. One of the methods our group utilized was the 6-3-5 method in which we each took one of the three main objectives, brainstormed for 5 minutes, passed to our left, and repeated until we were out of ideas. Through this process HandiTrike generated multiple concepts for each design and refined some of them further. We took these refined designs, and created a weighted average table (Appendix A.3) to decide on the best design for each subsystem. After that, we were able to start building a conceptual model of the trike.

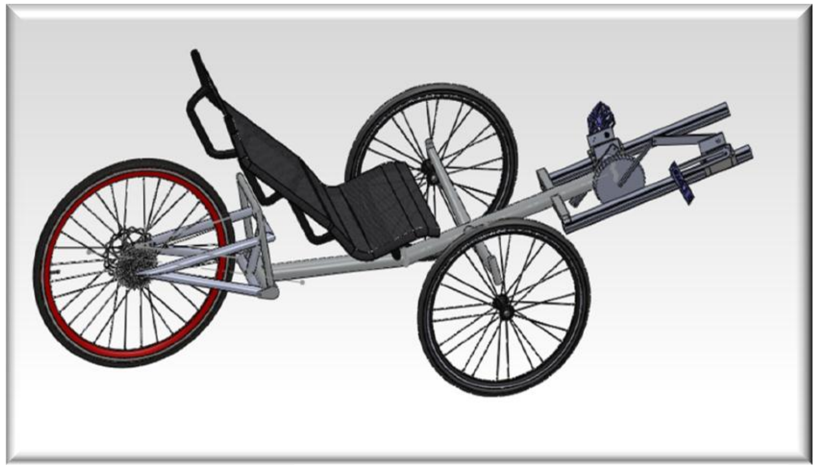


Figure 1. Tube Design

Our initial approach is to get the trike dimensioned and select materials for the subsystems. The first step is to create a 3-D model of the tricycle in SolidWorks to work out dimensions and clean up any interference issues. A standard 3 view drawing will be produced for communications purposes during any and all manufacturing and fabrication processes. Stress analysis and FEA will be performed on each subsystem for various materials using the dimensions from the SolidWorks model. The dimensions will be adjusted based on strength and yielding due to various loads. Materials will be selected based on strength, density, cost, and ease of manufacture. The SolidWorks model will be updated as needed throughout the project.

We will research and purchase parts that are readily available on the market while sizing the tricycle. Disc brakes, gearing system, seats, and spring/damper systems are readily available on the market and will be purchased based on performance, weight, cost, and compatibility with other parts. A rear triangle and steering system could possibly be purchased from current tricycle manufactures. Then we will purchase parts and material to start building the trike (Appendix B). Overall, HandiTrike will be focusing on designing and constructing the crank system, the rider's seat, and utilizing a rear triangle that includes a mounting point for a suspension system. Also, Rob has proposed that we attempt to design a collapsible frame that will allow him to transport the trike in an easier fashion. HandiTrike will attempt to incorporate this feature once the other three components of the tricycle are properly tuned.

The crank system will consist of two sliders mounted onto two rails that slide in a linear direction as the rider applies force. The sliders will be linked to eight-inch connecting rods that will be linked up to that 6.9-inch crank arms. The rest of the drive train is similar to other recumbent tricycles. The rails will be made out of 6061-T6 Aluminum because it has a reasonably high strength, but it is also light. The sliders will have ball bearing to help reduce friction and lower power loss. The connecting rods will be built out of 6061-T6 Aluminum as well. The crank arms will consist of standard crank arms found on road bikes today.

The seat will be constructed based off of an existing model produced by ICE Recumbent Trikes. They produce a model called the Air-Pro carbon fiber seat, which is constructed from carbon fiber and also includes shaped foam padding to provide

cushioning and air flow channels to keep the riders back cool and sweat free. This seat is extremely strong considering its overall lightweight design.

HandiTrike is planning to utilize a rear triangle from an existing mountain bike. This will allow for us to acquire a rear triangle that is large enough for a 700 cc tire and have the proper mounting points to allow for a suspension system to be attached. We would like to construct our own rear triangle for the trike, but due to time constraints and safety concerns, we have decided to use a proven rear triangle offered by Santa Cruz. This rear triangle will easily support a 700 cc tire as well as offer the mounting points we need for our suspension system. Also, the small angle for the rear triangle allows us to keep the center of gravity of the rider as low as possible, while in the trike. This will help reduce the amount of rollovers the rider could experience while going through a turn.

Assembly is the next step in the construction process. We will first mount the crank and suspension system using support brackets or welding. Then we'll add on the steering system and wheels. After that, the gearing and braking system will be added. Finally any other attachments like chain guard and wire brackets will be added to the frame.

At this point, the trike is complete and able to ride. Now, testing and tuning will take place to optimize each component and to see if all parts meet our objectives and required specifications. If not, parts will be redesigned until required specifications are met. The braking and gearing system will be tested and tuned to get the best possible performance while meeting our required safety specifications. We'll test the suspension system and adjust it to what Mr. Kelly finds comfortable.

The crank will be adjusted or redesigned if needed. We'll purchase a second set of tubing in case we need to redesign the frame for a better ride or to make it more ergonomic for Mr. Kelly.

Final Design

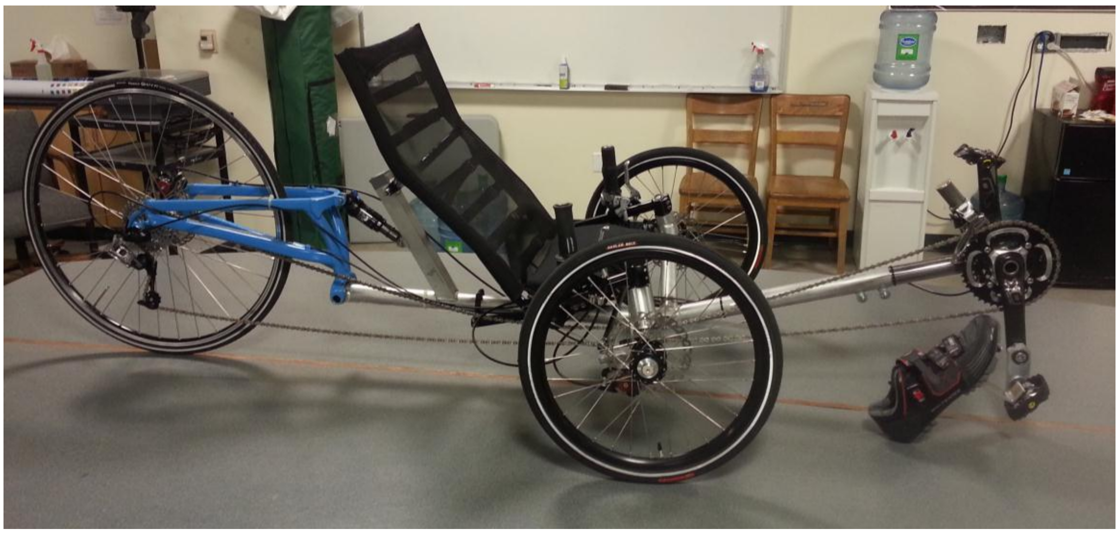


Figure 2. Final Design

Overall, Rob has expressed satisfaction with the trike that HandiTrike has designed and constructed for him. He stated that he enjoys the feel and control you get from the trike while riding in it. However, he felt there is room for improvement with the crank system. HandiTrike felt that this would be an issue considering we were required to construct the trike from the ground up. If the project was to focus our concentration on producing a fully functioning system to account for Rob's disability, we feel HandiTrike would have fully succeeded at the task presented to us.

For our final design, we have decided to utilize the previous groups' invention, as well as, use a fixed 3.5" long, 0.25 inch thick aluminum to construct a

part that will attach to both the bottom of Rob's shoe, as well as, to the SPD attachment on Rob's pedal. Initially, our group attempted to create a five-inch extension that would account for the missing 5 inches on Rob's right leg. However, since majority of Rob's surgery have been reducing his thigh bone, and not his shin bone, upon bring the crank towards you, Rob was unable to turn over the crank because of this issue. If his surgeries were to have removed a 5 inches from his shinbone, our product would have worked flawlessly.

For the rear suspension, HandiTrike utilized a rear triangle off of a Santa Cruz Super Light. Our group initially felt that this would be a satisfactory rear triangle. However, due to the pivoting point and the angle at which the chain goes under the rider's seat, contact between the chain and rear triangle became an issue once the trike was fully assembled. To account for this our group purchased a Bionicon Chain Guide to account for the contact. This part simply guides the chain away from the rear triangle thus getting rid of the contact issue.

For the seat, HandiTrike was unable to produce a seat comparable to that of the ICE carbon fiber seat. We had to resort to an existing seat model found through HostelShoppe, an online recumbent retailer. We were also able to get various components for the trike as well. The seat we found online was wider than Rob's current model and offered a padded bottom. Having the padded bottom proved very enticing for our group seeing as Rob's current seat is constructed of just mesh.

For the steering system, we used a direct knuckle steering adapted from a Catrike recumbent. Catrike was nice enough to give us a discounted rate on their steering column, and we were able to incorporate it into our design rather

seamlessly. Direct knuckle steering differs from Rob's previous under seat steering system. Instead of the handlebars pivoting at a point under the seat, the wheels are directly connected via a tie rod and the handlebars come directly out from the steering knuckle, hence the name.

Based off of group discussion and input from Rob himself, we have decided to use a 700 cc rear tire along with the rear suspension. The belief is that this will allow for a much smoother ride as well as less rolling resistance due to the smaller amount of tire being in contact with the road. We will also be able to use smaller chain ring for the rear tire which will allow for a higher top speed. However there are a few negative aspects to using the larger rear tire is that it has a much slower acceleration due to the increased rolling resistance of the larger diameter wheel. The 700 cc tire is also more prone to punctures due to pinching from debris on the side of the road.

Safety is of high concern for HandiTrike and we have implemented various components to help guarantee Rob's safety while he is out riding on the road. We have implemented a post behind the seat that allows the rider to place a rear facing light at head height for people driving motor vehicles to notice. We have also created a mounting point for a light on the front of the trike. Also, there are multiple components that make up the crank system that can easily fail due to clogged pivot points or prolonged fatigue. One solution to this is to use a dry lube on the chains and ball bearings, this way it will produce a waxy buildup and repel any dirt or debris that lands on these parts thus reducing the chance of increased friction in these critical components. Another issue arises when looking at the components

that fully make-up the crank system.. There are many moving parts on this feature of the tricycle and you can easily pinch body parts or get clothing caught on the parts. To reduce the risk of pinching, HandiTrike has devised a guard to go around the crank components. One last safety issue arises whenever Rob must enter or exit the tricycle. Currently his rear brake locks out to keep the bike from moving, however with enough force you can overcome the static friction load and cause the bike to skid. To prevent this we have decided to move the front wheel arms below the rider's seat to allow the rider to apply more of their weight over the front two wheels, thus reducing the skidding effect that Rob experienced before.

Standard repairs and maintenance are required for Rob's new trike. HandiTrike designed the trike so that standard tuning is all that is required for the trike. Even the attachments for the crank are comprised of very basic components (i.e. sealed bearings, aluminum). The more complicated repairs will be in the construction on the fixed 5-inch attachment. If this component gets disabled in any way, Rob will need to have someone construct a new part. However, HandiTrike has considered this complication and have designed the attachment to be constructed as simply as possible.

Product Realization

The overall final design of the trike has varied quite significantly from our conceptual design. The main differences are with the crank system as well as the

seat for the rider. With the crank, our group originally proposed a linear system to allow for the five-inch difference between Rob's left and right leg. However, after further analysis, our team has determined that the trike would be to heavy at the crank end, thus making it inoperable. The solution our group initially came up with was a fixed five-inch aluminum connection from the bottom of Rob's shoe to the SPD pedal. The main issue that arose with this attachment is that since Rob's surgeries have all been above his knee, the five-inch extension adds length on to the distance from his knee to the pedal, thus forcing Rob's knee to move back an additional 5-inches. Our attachment would have worked if Rob's surgeries were below the knee. After testing the 5-inch attachment, we considered utilizing the prior groups' rotating/adjustable attachment to our fixed 5-inch aluminum attachment. Upon combining both the prior groups' solution and our new attachment, Rob was able to generate what felt like three times more power than with just the prior groups' attachment. In the end, this is not the solution our group originally planned for. , however, due to the need to incorporate other factors into the design and construction of the tricycle, our group was unable to fully design the crank system past utilizing the prior groups' attachment.

For the seat, our group originally wanted to go with a carbon fiber seat that would be molded to Rob to ensure a comfortable and snug fit for him while out riding. However, over summer Rob proceeded to lose a significant amount of weight and HandiTrike and Rob decided it would be best to design a seat similar to the current style on his Greenspeed. We were lucky enough to find a similar version

through HostelShoppe, however, the new seat was much wider and offered a cushioned bottom to provide more comfort while out riding.

Another difference between the conceptual and final model of the trike is that there is no collapsibility feature for the trike. Due to complications in fabrication and parts organization, the collapsibility feature proved to be the last feature on our list. We informed Rob that this would be the case at the beginning of the project, due to the needed focus for the design of other components on the trike. Not having the collapsibility feature designed into the trike frame proves a constraint when dealing with the transportation of the trike.

For the future, we would recommend that the crank system be improved. The system is clearly not fully engineered to its highest efficiency; therefore, if this project has another go around, the next group should solely focus their attention to the crank system of the trike. Another needed addition is the collapsibility feature. Without this, there is no easy way to transport the trike unless you have a truck. Without this feature, the trike proves to be very difficult for Rob to transport from location to location.

The frame was manufactured from 6061 Aluminum tubes. The main and front tubes were cut to length using a horizontal band saw and notched using the tube notcher in Mustang 60. The notched tubes were then welded together by our welder, Simon. The rear shell for the rear suspension was made from a 6061 Aluminum tube and machined to hold the bearings in place with a lip and to the right length so that the rear doesn't sway too much. It was then welded on the back of the main frame.

The front crank assembly was made from 4130 Steel tubes. The main crank tube and the derailleur post were sized and notched in the same way the aluminum tubes were. The main crank tube was turned just enough so that it could slide in and out of the front tube of the main frame. This way Mr. Kelly could adjust how far the crank set will be from the seat. The derailleur post and the bottom bracket shell where then welded on to the main crank tube. We also cut a 4.5" long slot using a mill for the clamps into the bottom of the front tube of the main frame. Then we cut two 1.5" pieces of a ¾" aluminum tube and welded them perpendicular and centered to the slot. One was positioned near the front of the slot and the other was about 3" away from the first tube. We put the frame onto the mill again the cut a slot into ¾" aluminum tubes. That created our clamp so that the crank tube could be held securely to the main frame.

Figure 3. Turing Crank Tube

Figure 4. Milling Slot into Main Frame

The seat post was made from a 1.25" square aluminum tube and was cut, angled, and notched. The brackets that hold the seat onto the frame were made from

¼" aluminum plates. The plate was cut into the proper lengths so that they can fit inside the brackets on the seat. The sides had holes drill into them on the mill. The plates were then welded into brackets. The sides were grinded down enough to slide the seat into. The bottom seat bracket and seat post were welded to the frame and the top seat bracket was welded onto the seat post.

The front wheel arms were cut and notched and cut to the right lengths using the same method that we used for the frame. The arms had to be the right length so that the tie rod on the steering system could go over the frame and not interfere with the seat. We built two supporting posts out of spare square tubing to hold the trike in place. We tested out a few locations check the clearance. After setting it in the right location, we welded the arms onto the frame only a ¼ of the way around. The idea was to have Mr. Kelly test it out and see if he liked to location of the arms. If he didn't, we could cut off the weld and place the arms at another location. He accidentally tested it without the supporting posts and broke the left arm. Our welder was able to fix it by welding a supportive plate over the arms.

Figure 5. Arm Assembly

Figure 6. Rear shock Assembly

The mounting bracket for the rear shock was made from the same ¼" aluminum plate we used for the seat brackets. We cut two plates and, drilled two holes into them using the mill and welded them onto the seat post.

The frame is complete and then we assembled all the parts and tested out the trike. Everything fit and worked well. We took apart everything and then got it ready for paint. Once the bike is painted, all the parts go back on. The trike is complete.

Design Verification/Testing

HandiTrike performed multiple testing to verify that all components fell within the necessary range of projected values. For the stresses on the tubes we constructed a program in MATLAB to analyze the forces. The tubes are designed to withstand an impact force of 750 lbs. The full code and results can be found in Appendix E.

Since our group ultimately had to use the previous groups' solution we had to verify that their solutions are valid. In the end, it was determined that their attachment is suitable for the design due to the deflection of -3.756e-02 inches under a 200 lb_f load. We also performed the various testing scenarios they set up when they designed the attachment. Our group determined that all testing holds true to their original analysis.

The following figure illustrates the free body diagram used in the analysis of the shoe attachment:

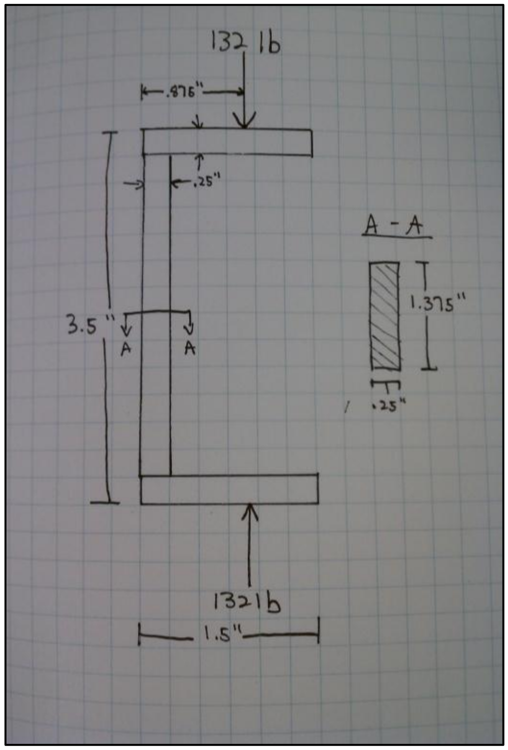


Figure 3. Free-Body Diagram of Attachment

Expected Forces

The expected forces on the attachment were calculated in the following way:

- Average Cadence of rider = 100 rpm = 10.5 rad/sec = **w**
- Crank arm length= 170mm=.17m = **r**
- Velocity of pedal = **r** * **w** = 1.78 m/s
- Continuous Power Output of elite cyclist = 350 W
- Power = F*V → Force = P/V
- Force applied to pedal = 44 lbs.

- Factor of safety of 3 → Design for 132 lbs. force

The values for the average cadence and max power output were found by researching the respective topics on the Internet. Having little prior knowledge in the subject, we assume them to be valid approximations. In addition to a temporary static load, we assume the load to be cyclic with stress amplitude of 132 lbs. and a mean stress of 0 lbs. This is due to the fact that the clipless pedals allow the rider to pull on the pedals during the return stroke. For the analysis, we expect the attachment to fail in one of two ways: eccentric buckling or cyclic fatigue.

Eccentric Buckling Analysis

The secant column formula was used for the analysis of the attachment:

$$\frac{P}{A} = \frac{S_{YC}}{1 + \left(\frac{ec}{k^2}\right)\sec\frac{l}{2k\sqrt{\frac{P}{AE}}}}$$

As long as $S_{yc} > P/A\left(1 + \left(\frac{ec}{k^2}\right)\sec\frac{l}{2k\sqrt{\frac{P}{AE}}}\right)$, then the column will not yield.

When the appropriate numbers are plugged into the figure above, and assuming that the compressive yield strength is the same as the tensile yield strength = 35 kpsi, we find that the max stress in the column is 8.5 kpsi. Since the max stress is less than the yield stress, the design will not fail. The factor of safety for yield is 4.12. A fully detailed version of this analysis can be found in Appendix f.

Cyclic Fatigue Analysis

Under normal circumstances, the Manson-Coffman relationship could be used in order to solve for the number of cycles until failure, but we were unable to find the fitting parameters for 6061-T6 Al. However, we were able to find an endurance limit for the metal for fully reversed loading with zero mean stress that is good up to 500,000,000 cycles. According to Aerospace Specification Metals, Inc., the endurance limit is 14 kpsi. The max stress, 8.5 kpsi, is less than the endurance limit, therefore it can be assumed that the design will not fatigue under that load for at least the specified 500,000,000 cycles.

Conclusion and Recommendations

HandiTrike feels confident with the tricycle that has been produced during the Winter '13 – Fall '13 Senior Project. In the end HandiTrike was able to produce a fully functioning recumbent racing tricycle. There were some aspects of the tricycle that could not be completed due to various complications. Out of the four main tasks to be completed throughout this senior project, HandiTrike was able to complete three of the tasks. We successfully produced a trike that utilized rear suspension, improved the comfort of the seat, and improved the power produced through the crank system.

HandiTrike is proud to have completed this recumbent tricycle for Robert T. Kelly. We have received strong thanks from Rob, as well as, Cal Poly staff and students, and the public in designing and constructing this trike for Rob. HandiTrike

is pleased to have worked with QL+ and Rob Kelly on this project from beginning to end. It gives us all great pleasure to give back to a veteran that has served our country and done so much for its citizens.

For the future, HandiTrike recommends that if this project gets picked up again, the focus of design should be on maximizing the efficiency of the crank system, as well as, incorporating a collapsibility feature to the trikes frame. Upon utilizing these two systems, HandiTrike believes that the trike will be what Rob was originally looking for at the beginning of the Senior Project. HandiTrike believes that the linear system, that was originally designed, would prove most efficient crank system for Rob. By offsetting the right pedal by five inches and keeping the pedaling motion to a linear direction, this would allow Rob to get very close to a natural feel of riding a trike.

References

1. "Catrike Recumbent Trikes." *Catrike Recumbent Trikes*. Web. 17 Feb. 2012. <http://www.catrike.com/>.
2. "GreenSpeed Recumbent Trikes - Tandem Bike - Comfort Bikes - Velomobile – Trike."*GreenSpeed Recumbent Trikes*. Web. 20 Jan. 2012. <http://www.greenspeed.com.au/>.
3. "ICE - Inspired Cycle Engineering Recumbent Trikes and Recumbent Bikes." *Recumbent Trikes*. Web. 24 Feb. 2012. <http://www.icetrikes.co/>.
4. "INTRODUCING QUALITY OF LIFE PLUS." *QL Plus*. QL Plus. Web. 01 Mar. 2012. <http://www.qlplus.org/>.
5. McLaren, Nicholas. "All About Decompression Sickness." *About.com Scuba Diving*. New York Times. Web. 25 Feb. 2012. <http://scuba.about.com/od/divemedicinesafety/a/dcs.htm>.
6. "Manitou Suspension Forks & Bicycle Components for Mountain Bikes." *Manitou Suspension Forks & Bicycle Components for Mountain Bikes*. Web. 03 Mar. 2012. <http://www.manitoumtb.com/index.php?page=shock>.
7. Welcome to Rohloff." *COMPANY: Www.rohloff.de*. Web. 16 Feb. 2012. <http://www.rohloff.de/en/>.
8. "Pilot Supplies, Avionics, and Homebuilt Aircraft Parts from Aircraft Spruce and Specialty Co." *Pilot Supplies, Avionics, and Homebuilt Aircraft Parts from Aircraft Spruce and Specialty Co.* Web. 14 Feb. 2012. <http://www.aircraftspruce.com/>.

9. "Schlumpf Innovations." *Alles Ueber Schlumpf Innovations: Wasserpumpe, Einradnaben, Fahrradantrieb. Hersteller & Entwickler.* Web. 16 Feb. 2012. <http://www.schlumpf.ch/hp/schlumpf/antriebe_engl.htm>.

10. "Airparts Inc. Aircraft Construction Supplies." *Airparts Inc.* Web. 14 Feb. 2012. <https://www.airpartsinc.com>.

11. "Tenecco Marzocchi Suspension - Air Shocks 2012." *Tenecco Marzocchi Suspension*. Web. 03 Mar. 2012. <http://www.marzocchi.com/Template/listProdotti.asp?LN=UK&idC=1629&IdFolder=552&uf=ST&idST=1>.

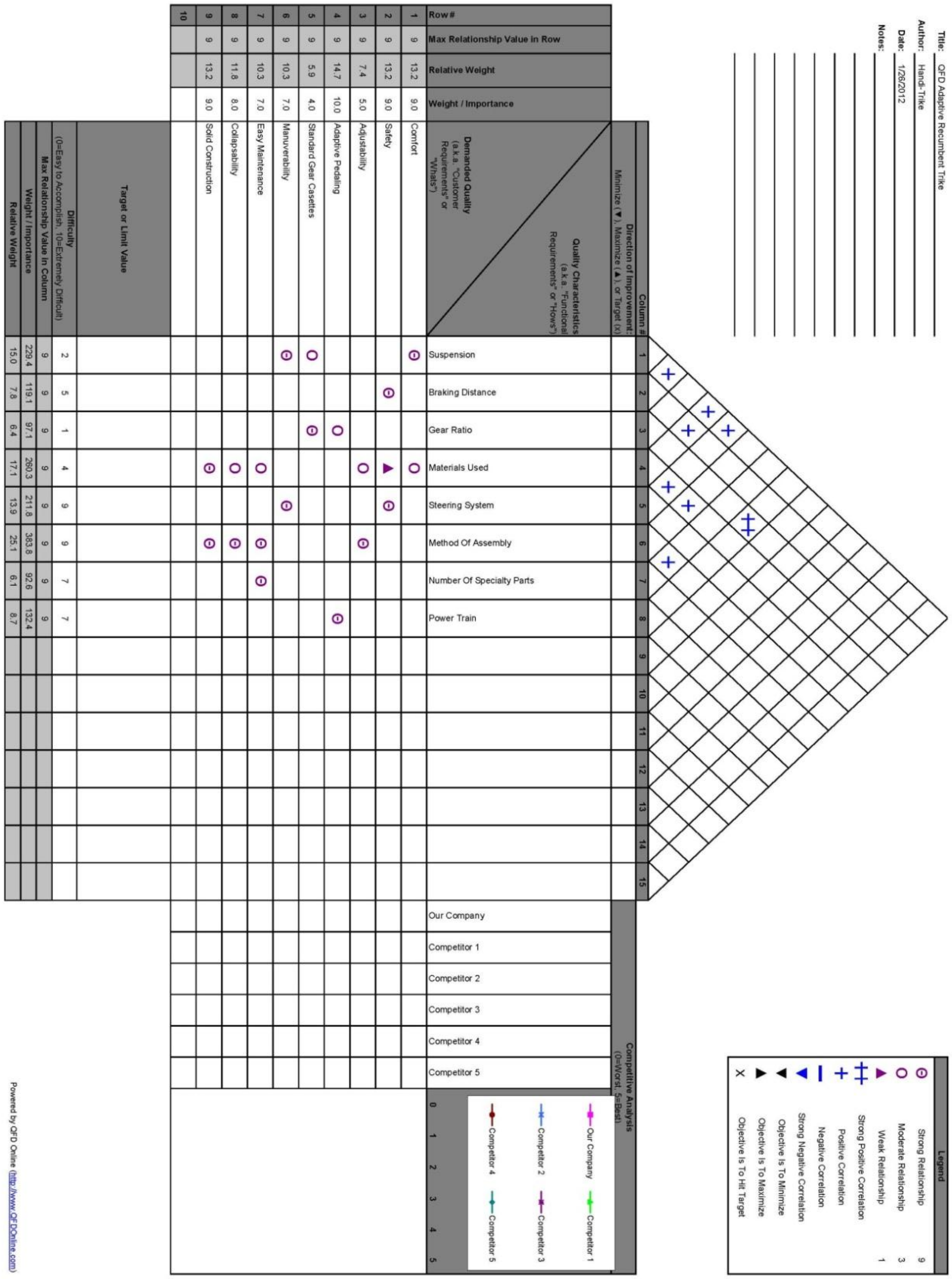
12. "DT Swiss - Shocks." *DT Swiss*. Web. 03 Mar. 2012. <http://www.dtswiss.com/Products/Suspension/DT-Swiss-Shocks.aspx>.

13. "2-Part Foam for Seat Fitting, Two Quart Kit." *Pegasus Auto Racing Supplies*. Pegasus. Web. 12 Apr. 2012. <https://www.pegasusautoracing.com/productdetails.asp?RecID=1038>.

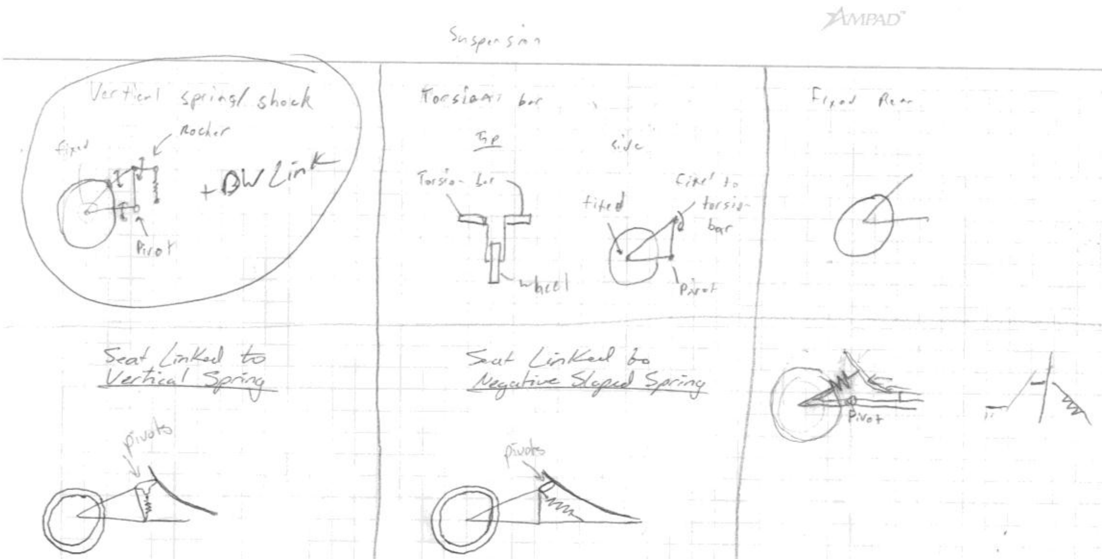
14. Astle, Seth. "Cadence Prosthetic". 2012. www.Isda.org.

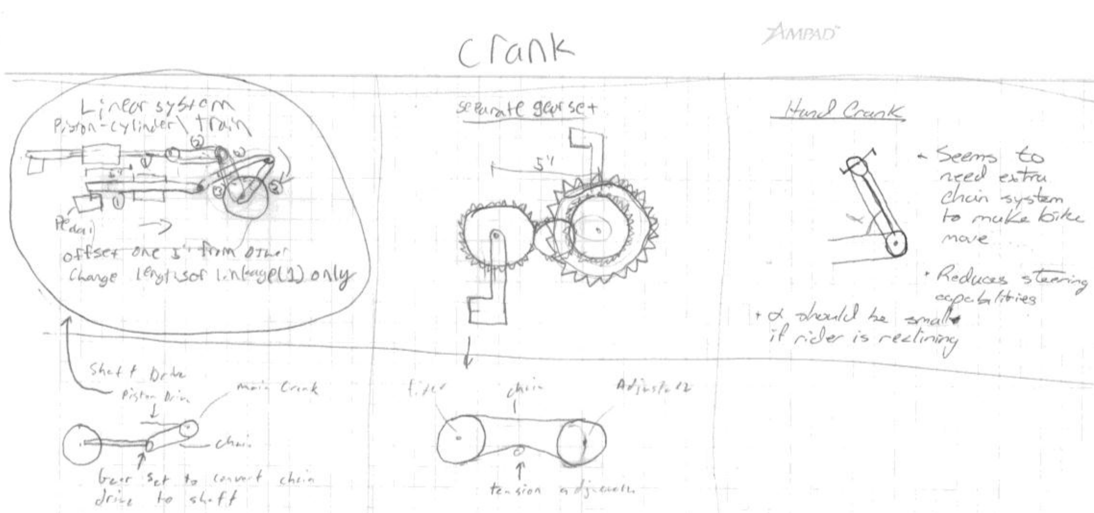
15. "Aluminum 6061-T6 Material Properties." Aerospace Specification Metals Inc. 2012. www.asm.matweb.com

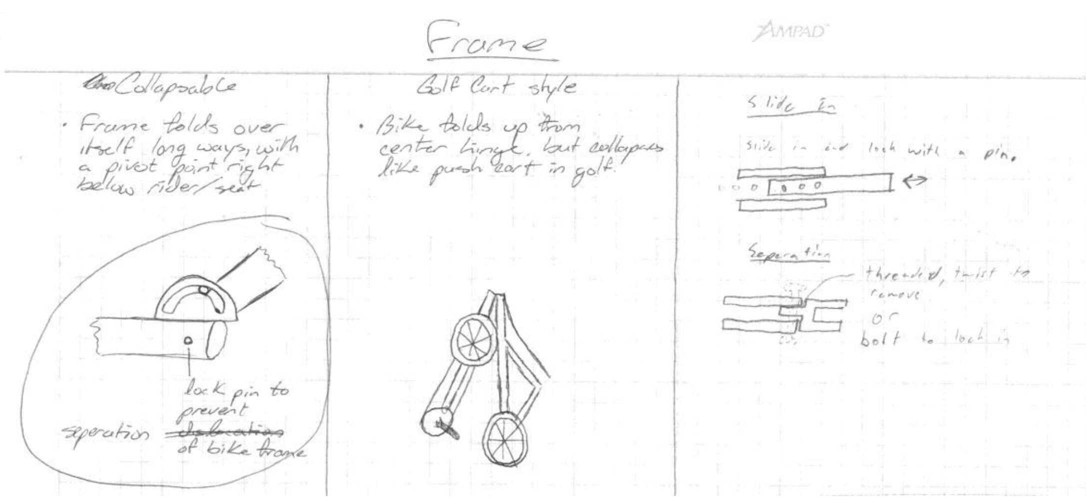
Appendix A.1—House of Quality



Appendix A.2—6-3-5 Method







Appendix A.3—Decision Matrix

	Weight	Linear Crank		Hand Crank		Tandem crank	
		Non- Weighted	Weighted	Non-Weighted	Weighted	Non-Weighted	Weighted
Functionality	.4	9	3.6	3	1.2	7	2.8
Cost (min)	.05	7	.35	4	.2	7	.35
Weight (min)	.2	6	1.2	3	.6	6	1.2
Aesthetics	.1	6	.6	6	.6	7	.7
Life	.15	6	.9	5	.75	8	1.2
Ease of Assembly	.1	4	.4	6	.6	5	.5
Total		38	10.2	27	3.95	40	6.75

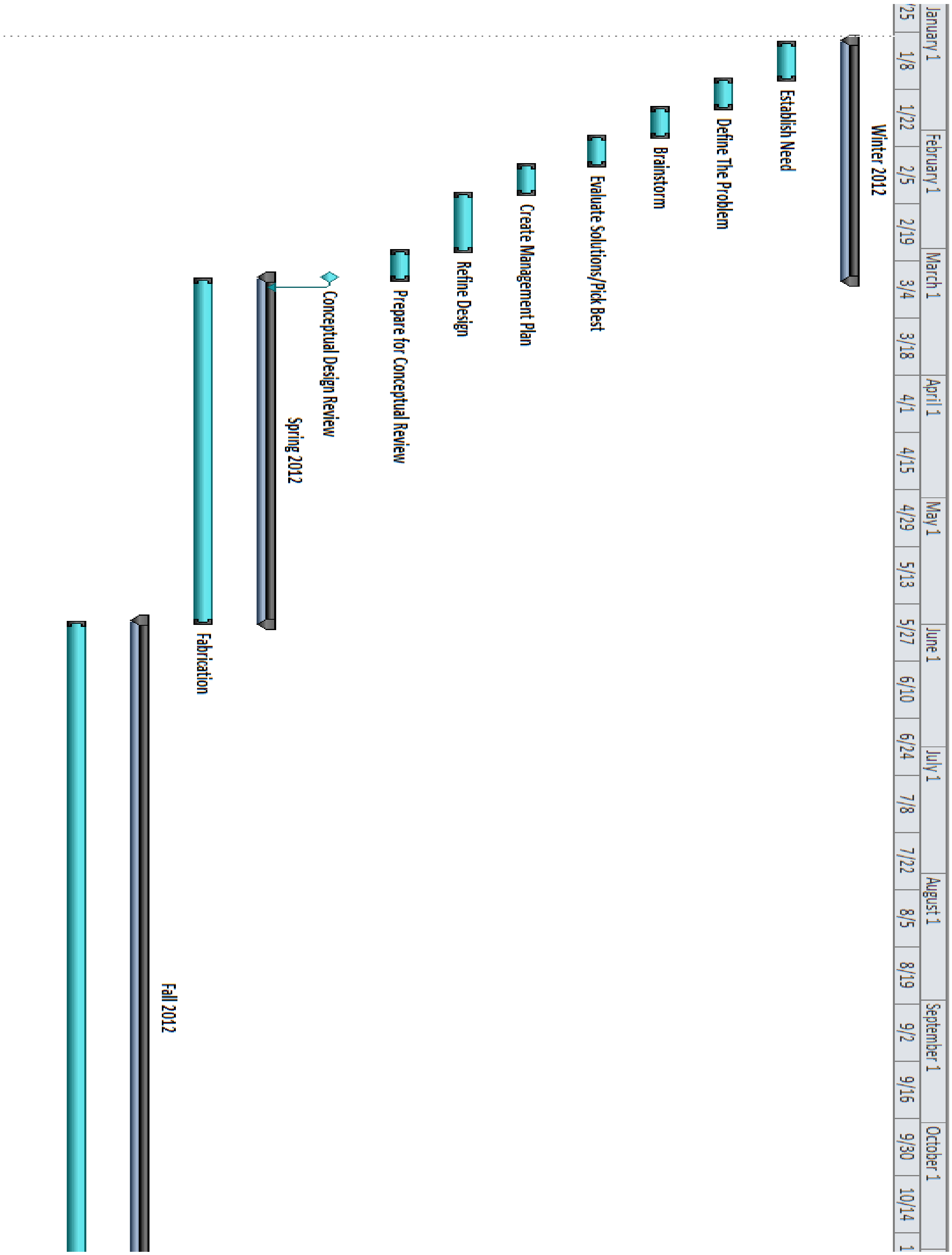
	Weight	Vertical Suspension		Positive Slope		Negative Slope	
		Non- Weighted	Weighted	Non-Weighted	Weighted	Non-Weighted	Weighted
Functionality	.4	9	3.6	6	2.4	6	2.4
Cost (min)	.05	5	.25	5	.25	5	.25
Weight (min)	.2	7	1.4	8	1.6	7	1.4
Aesthetics	.1	9	.9	8	.8	8	.8
Life	.15	7	1.05	7	1.05	7	1.05
Ease of Assembly	.1	6	.6	5	.5	5	.5
Total		43	7.8	39	6.6	38	6.4

	Weight	Golf Cart		Side Hinge		C-Hinge	
		Non- Weighted	Weighted	Non-Weighted	Weighted	Non-Weighted	Weighted
Functionality	.4	8	3.2	1	.4	7	2.8
Cost (min)	.05	4	.2	7	.35	7	.35
Weight (min)	.2	7	1.4	8	1.6	8	1.6
Aesthetics	.1	8	.8	3	.3	7	.7
Life	.15	6	.9	6	.9	6	.9
Ease of Assembly	.1	4	.4	1	.1	4	.4
Total		37	6.9	26	3.65	39	6.75

Appendix B—Bill of Materials

Project: 7a2 - HandiTrike	Design by: Sean Higginson, Kevin Howie, Vinay Patel		Date: 04 / 20 / 2012	
Item	Description	Cost each	Number required	Cost Total
1.75" Al 6061 T6 Round Tube	1.75" OD x 0.083" T x 3 L" Tubing	$25	3	$75
1.50" Al 6061 T6 Round Tube	1.50" OD x 0.083" T x 3 L" Tubing	$6	2	$12
1.25" Al 6061 T6 Round Tube	1.25" OD x 0.083" T x 3 L" Tubing	$7	2	$14
0.75" Al 6061 T6 Round Tube	0.75" OD x 0.100" T x 3L" Tubing	$4	2	$8
1.00" Al 6061 T6 Square Tube	1.00" OD x 0.065" T x 3 L" Tubing	$4	2	$8
0.25" Al 6061 Sheet	0.25" T x 12" W x 12" Sheet	$25	1	$25
Stainless Steel Ball Bearing	0.50" Shaft OD, 1.375 OD x 0.438" W	$35	4	$140
10 x M8 Socket Head Screws	M8, 12mm Length, 1.25mm Pitch	$10	1	$10
3" W Al 6061 U Channel	3" W x 1.5" H x 12" L	$15	1	$15
Ball Bearing Carriage	22mm Rail Width Carriage	$205	2	$410
Ball Bearing Guide Rail	760mm Length Rail	$335	2	$670
Shimano Avid 3	Disc Brakes	$105	3	$315
Shimano R453 Derailleur	Front Derailleur	$50	1	$50
Shimano Dura Ace Shifter	9-speed Shifters	$130	1	$130
Shimano Tiagra Aero Levers	Brake Lever	$50	1	$50
Shimano SPD A530	Pedal	$100	1	$100
Fox Float RL	Rear Shock Suspension	$300	1	$300
Green Speed Steering	Steering Mechanism	$100	1	$100
Yeti 575 Carbon Triangle	Rear Triangle	$700	1	$700
SKF Bottom Bracket	110mm Square Bottom Bracket	$130	1	$130
Velo-Orange Triple Crankset	110/74mm 3 Gear Crankset	$130	1	$130
Pegasus 2 part-foam	2-Part Foam for Seat Fitting	$65	1	$65
Ill Street Composite	5.7oz 3K 2x2Carbon Fiber Cloth	$35	10	$350
SeaDek Sheet Foam	Seat Foam	$45	1	$45
Rohloff Speedhub 500/14 DB	Rear Hub/ Gear set with disk brake	$1,700	1	$1,700
Other	Bolts, cable, washers, brackets, etc	$100	1	$100
Shipping	Total Estimated Shipping Cost	$300	1	$300
	Total with Tax			$6,443

Appendix C—Gantt Chart



Appendix D.1—Raw Material Costs

Steel 4130 Tube Cost

Tube #	O.D. [in]	I.D. [in]	Thickness [in]	Weight/ft	Price per ft	Length [in]	Length [ft]	Cost	Weight [lbf]
1 (round)	1 3/4	1.510	0.120	2.089	$8.60	42.25	3.521	$30.28	7.355
2a	1 3/8	1.135	0.120	1.608	$7.50	6.5	0.542	$4.06	0.871
2b	1 3/8	1.185	0.095	1.299	$5.20	6.5	0.542	$2.82	0.704
3a	7/8	0.685	0.095	0.791	$7.20	11.5	0.958	$6.90	0.758
3b	7/8	0.745	0.065	0.562	$4.25	11.5	0.958	$4.07	0.539
4	5/8	0.495	0.065	0.388	$3.75	10.5	0.875	$3.28	0.340

Frame	Cost	Shipping	Subtotal	Tax	Total	Total Weight
1-2a-3a-4	$44.52	$20.00	$64.52	$5.32	$69.85	9.32
1-2a-3b-4	$41.70	$20.00	$61.70	$5.09	$66.79	9.10
1-2b-3a-4	$43.28	$20.00	$63.28	$5.22	$68.50	9.16
1-2b-3b-4	$40.45	$20.00	$60.45	$4.99	$65.44	8.94

Aluminum 6061 T6 Tube Cost

Tube #	O.D. [in]	I.D. [in]	Thickness [in]	Weight/ft	Price per ft	Length [in]	Length [ft]	Cost	Weight [lbf]
1a (round)	2 1/4	2	0.125	0.999	$8.00	42.25	3.521	$28.17	3.517
1b (square)	2	1.750	0.125	1.120	$7.75	42.25	3.521	$27.29	3.943
2a	1 3/8	1.584	0.083	0.520	$9.25	6.5	0.542	$5.01	0.282
2b	1 1/2	1.26	0.125	0.635	$9.75	6.5	0.542	$5.28	0.344
3a	1	0.75	0.125	0.404	$6.00	11.5	0.958	$5.75	0.387
3b	7/8	0.635	0.12	0.335	$6.75	11.5	0.958	$6.47	0.321
4	3/4	0.62	0.065	0.164	$2.99	10.5	0.875	$2.62	0.144

Frame	Cost	Shipping	Subtotal	Tax	Total	Total Weight
1a-2a-3a-4	$41.54	$20.00	$61.54	$5.08	$66.62	4.33
1a-2a-3b-4	$42.26	$20.00	$62.26	$5.14	$67.40	4.26
1a-2b-3a-4	$41.81	$20.00	$61.81	$5.10	$66.91	4.39
1a-2b-3b-4	$42.53	$20.00	$62.53	$5.16	$67.69	4.33
1b-2a-3a-4	$40.66	$20.00	$60.66	$5.00	$65.67	4.76
1b-2a-3b-4	$41.38	$20.00	$61.38	$5.06	$66.45	4.69
1b-2b-3a-4	$40.93	$20.00	$60.93	$5.03	$65.96	4.82
1b-2b-3b-4	$41.65	$20.00	$61.65	$5.09	$66.74	4.75

http://www.aircraftspruce.com
https://www.airpartsinc.com

Steel 4130 Cost

Part #	O.D. [in]	I.D. [in]	Thickness [in]	Weight/ft	Price per ft	Length [in]	Length [ft]	Cost	Weight [lbf]
1 (Rods)	1/2	0.058	0.384	0.274	$3.50	24	2	$7.00	0.548
2 (Sheet Metal)	18 x 36		0.05	NA	NA	NA	NA	$35.74	NA

Cost	Tax	Shipping	Total	Total Weight
$42.74	$3.53	$20.00	$66.27	NA

Aluminum 6061 T6 Cost

Tube #	O.D. [in]	I.D. [in]	Thickness [in]	Weight/ft	Price per ft	Length [in]	Length [ft]	Cost	Weight [lbf]
1 (Rods)	5/8	0.495	0.065	0.1367	$3.45	24	2	$6.90	0.273
2 (Sheet Metal)	24	24	0.063	0.889	NA	NA	NA	$35.74	0.019

Cost	Tax	Shipping	Total	Total Weight
$42.64	$3.52	$20.00	$66.16	0.292

Appendix D.2—Component Cost Analysis

Frame			
	Material		
	Aluminum (Round)	Aluminum (Square)	Steel (Round)
Weight	4.26 lb (1930 g)	4.75 lb (2155 g)	8.94 lb (4060 kg)
Cost	$67.40	$66.74	$65.44
Ease of Collapsibility	Easy	Easy	Hard

Crank		
	Material	
	Aluminum	Steel
Weight	135 g	N/A
Cost	$42.64	$42.74

Seat			
	Material		
	Netting	NovoSport Carbon Fiber	ICE Seat
Weight	NA	1200 g	N/A
Cost	NA	$350	N/A

Planetary Gear		
	Brand	
	Sram HammerSchmidt	Schlumpf Speed Drive
Weight	1623 g	N/A
Cost	$475	N/A

Suspension							
	Brand						
	Fox		Marzocchi		DT Swiss		Manitou
	Float RL	Float RP2	Roco Lite	Roco Air Lo	XM 180	M 212 Remote	Radium Expert
Lockout	Yes	No	Yes	Yes	Yes	Yes	Yes
Weight	210 g	227 g	199 g	255 g	177 g	218 g	230 g
Travel (max)	57.15 mm	57.15 mm	38.1 mm	57 mm	37.5 mm	37.5 mm	N/A
Handle Control	No	Yes	No	No	Yes	Yes	Yes
Cost	$290	$470	$450	$325	$500	$330	$215

Appendix E.1—MATLAB Code

```
%% Vinay Patel
%  ME 441-03
%  Basic Frame Stress Analysis

clc
clear

%% Force Input
F = 250*3; % Unit Force [lbf]

%% Force Conversion
N_lbf = 0.2248; % Conversion from N to lbf [lbf/n]

%% Strength Properties
sig_y = 35e3; % AL Yield Strength [psi]
sig_u = 42e3; % AL Ultimate Strength [psi]
E = 10e10; % AL Modulus of Elasticity [psi]
nf = 3; % Safety Factor
sig_a = sig_y/nf; % Allowable Strength

%% Tube Length & angle
T_l1 = 29.75; % Main Tube Length [in]
T_l2 = 19.50; % Main Tube Length [in]
T_l3 = 11.50; % Arm Tube Length [in]
T_l4 = 12.00; % Seat Tube Length [in]
T_l5 = 12.00; % Crank Turned Tube Length [in]
T_l6 = 4.00; % Crank Unturned 6 Length [in]
T_l = [T_l1; T_l2; T_l3; T_l4; T_l5; T_l6]; % Tube Length Matrix [in]

T_a1 = 0.0; % Angle between Tube 1 and Force [deg]
T_a2 = 10; % Angle between Tube 2 and Force [deg]
T_a3 = 25; % Angle between Tube 3 and Force [deg]
T_a4 = 60; % Angle between Tube 4 and Force [deg]
T_a5 = 10; % Angle between Tube 5 and Force [deg]
T_a6 = 10; % Angle between Tube 6 and Force [deg]
T_asind = [sind(T_a1); sind(T_a2); sind(T_a3); sind(T_a4); sind(T_a5); sind(T_a6)]; % Sin
Angle Matrix [deg]
T_acosd = [cosd(T_a1); cosd(T_a2); cosd(T_a3); cosd(T_a4); cosd(T_a5); cosd(T_a6)]; %
Cos Angle Matrix [deg]

%% Tube Outer Diameter
T_od1 = 1.750; % Main Tube Outer Diameter [in]
T_od2 = 1.750; % Front Tube Outer Diameter [in]
```

Appendix E.1—MATLAB Code (cont)

```
T_od3 = 1.500; % Arm Outer Diameter [in]
T_od4 = 1.250; % Seat Tube Outer Diameter [in]
T_od5 = 1.610; % Crank Turned Outer Diameter [in]
T_od6 = 1.625; % Crank Unturned Outer Diameter [in]
T_od = [T_od1; T_od2; T_od3; T_od4; T_od5; T_od6]; % Tube Outer Diameter Matrix[in]

%% Tube Wall Thickness (use smallest thickness)
T_t1 = 0.083; % Head Tube Wall Thickness [in]
T_t2 = 0.083; % Top Tube Wall Thickness [in]
T_t3 = 0.083; % Down Tube Wall Thickness [in]
T_t4 = 0.083; % Seat Tube Wall Thickness [in]
T_t5 = 0.070; % Chain Stay Wall Thickness [in]
T_t6 = 0.085; % Seat Stay Wall Thickness [in]
T_t = [T_t1; T_t2; T_t3; T_t4; T_t5; T_t6]; % Tube Wall Thickness Matrix [in]

%% Tube Inner Diameter
T_id = T_od-2*T_t; % Tube Inner Diameter Matrix [in]

%% Tube Area
T_A = pi/4.*(T_od.^2-T_id.^2); % Tube Area Matrix [in^2]

%% Tube Moment of Inertia (along length axis)
T_I = pi/64*(T_od.^4-T_id.^4); % Head Tube Moment of Inertia [in^4]

%% Maximum Yield Compressive Stress unit
sig_c = F*T_A.^(-1) % Compressive Stress [psi]

n_c = sig_a*sig_c.^(-1) % safty factor check > 1 (ok)

%% Maximum Bending Stress unit
sig_b = F*T_acosd.*T_l.*T_asind.*T_od.*T_I.^(-1)/2 % Bending Stress [psi]

n_b = sig_a*sig_b.^(-1) % safty factor check > 1(ok)

%% Shear Stress
tau_s = 2*F*T_acosd.*T_A.^(-1) % Bending

n_s = sig_a*tau_s.^(-1) % safty factor check (ok)

%% Critical Loading Force
Pcr = pi^2*E*T_I.*T_l.^(-1) % Critical Loading > 1[lbf]

%% Combined Stress
```

```
sig_t = ((sig_c).^2+3*tau_s.^2).^(1/2) % Von Mises Stress

n_t = sig_a*sig_t.^(-1) % safety factor check > 1(ok)

F_a = n_t.*F % allowable force on part [lbs]
```

Appendix E.2—Stress Analysis Results

sig_c =

1.0e+03 *

1.7254
1.7254
2.0298
2.4647
2.2146
1.8238

n_c =

6.7616
6.7616
5.7476
4.7335
5.2681
6.3970

sig_b =

1.0e+04 *

0
1.4458
2.6626
4.6782
1.2315
0.3409

n_b =

Inf
0.8069
0.4382
0.2494
0.9473
3.4225

tau_s =

1.0e+03 *

3.4509
3.3984
3.6793
2.4647
4.3619
3.5921

n_s =

3.3808
3.4330
3.1709
4.7335
2.6747
3.2478

Pcr =

1.0e+10 *

0.5021
0.7661
0.7986
0.4282
0.8274
3.0172

sig_t =

1.0e+03 *

6.2211
6.1339
6.6883
4.9294
7.8729
6.4836

n_t =

1.8753
1.9020
1.7444
2.3668
1.4819
1.7994

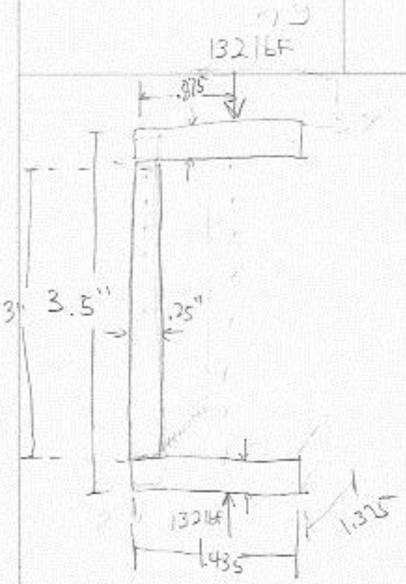
F_a =

1.0e+03 *

1.4065
1.4265
1.3083
1.7751
1.1114
1.3496

All Parts Pass

Appendix F—Shoe Attachment Analysis



$\sigma_y = 35$ kpsi   6061 Al

$E = 10.4$ Mpsi

$\left(\frac{l}{k}\right)^2 = 0.282\left(\frac{AE}{P}\right)^{1/2}$

$\frac{l}{k} = 0.282\left[\frac{(1.375)(.25)(10.4\times10^6 \text{ psi})}{132 \text{ lbf}}\right]^{1/2}$

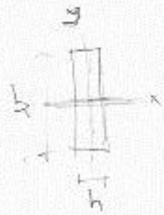
$\frac{l}{k} = 46.40$

$k = \sqrt{\frac{I_x}{A}} = \sqrt{\frac{(1.375)(.25)^3/12}{(1.375)(.25)}}$

$k = .07216$

$l = 46.40\ (.07216)$

$l = 3.35''$



Must use Buckling eq^n

$$\frac{P}{A} = \frac{\sigma_y}{1 + (ec/k^2)\sec\left[\frac{l}{2k}\sqrt{P/AE}\right]}$$

as long as $\sigma_y > \frac{P}{A}\left[1 + (ec/k^2)\sec\left[\frac{l}{2k}\sqrt{P/AE}\right]\right]$, won't buckle

$$35\text{ kpsi} > \frac{132\text{ lb}\left[1 + \left(\frac{.375(.125)}{.07216^2}\right)\sec\left[\frac{3.5}{2(.07216)}\sqrt{\frac{132}{(.25)(1.375)(10.4\times10^6)}}\right]\right]}{.25(1.375)}$$

35 kpsi > 8.5 kpsi, will not yield!

for 500,000,000 cycles

fatigue limit = 14 ksi > 8.5 ksi