Strider

A Senior Project

presented to

the Faculty of the Mechanical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

by

George Cummings
Brian Kreidle
Ricky Lee
Clark Steen

December, 2011

STRIDER

Senior Design Report

December 6, 2011

Team Members:

George Cummings – gpcummin@calpoly.edu

Brian Kreidle – bkreidle@calpoly.edu

Ricky Lee – rilee@calpoly.edu

Clark Steen – cnsteen@calpoly.edu

Strider4Nathan@gmail.com

Advisor:

Sarah Harding – sthardin@calpoly.edu

Sponsor:

Dr. J. Kevin Taylor – jktaylor@calpoly.edu

DISCLAIMER

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply 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 device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Table of Contents

List of Figures

LIST OF TABLES

ABSTRACT

Nathan Cooper is a young boy with Spinal Muscular Atrophy. He needs assistance for basic activities and movements and requires a device to help him exercise. More physical exercise can potentially improve his bone density, blood flow, and respiratory function. Our team took on the challenge of designing a device to meet this requirement. We created an apparatus that gives Nathan greater freedom than any of his current assistive devices. The Strider is the product we designed to meet Nathan's needs and improve his quality of life. The following is a report that details our work on this project.

Introduction

The primary goal of the Strider project was to improve the life of a five-year-old boy, Nathan Cooper, and his parents, Amy and Bob. Nathan was born with Spinal Muscular Atrophy, or SMA, a condition that results in degenerated motor neurons in the spinal cord. SMA causes Nathan's muscles to atrophy and grow extremely weak to the point that he cannot support his own body weight while standing. As a result, Nathan spends much of his life sitting or lying down, which may eventually cause other health problems such as low bone density and poor circulation.

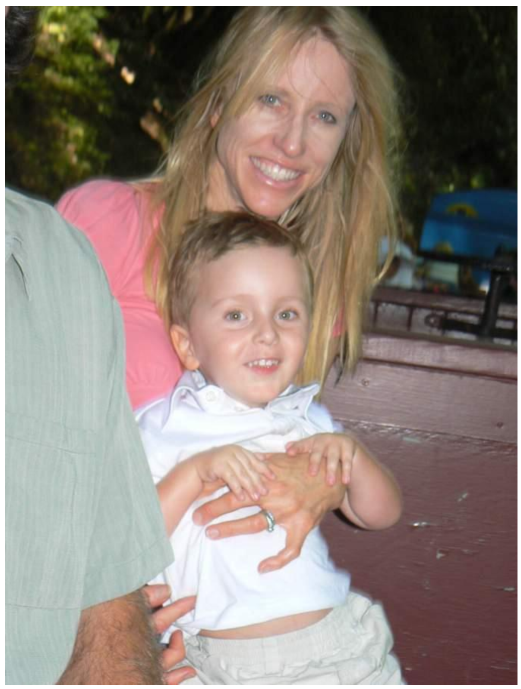


Figure 1. Nathan and his mother, Amy

A standing rider, or Strider, will give Nathan the opportunity to spend more time standing up and moving his body. Standing up more often will engage many of his muscle groups and in turn, possibly improve his health. Also, a standing rider will allow Nathan to interact with the world around him with fewer restrictions that result from SMA. This can greatly increase Nathan's quality of life as well as that of his parents.

Our team of mechanical engineering students consisted of George Cummings, Brian Kreidle, Ricky Lee, and Clark Steen and worked with a team of kinesiology students to develop a standing rider for Nathan as part of the Mechanical Engineering Senior Project program. This project is funded by a grant from the National Science Foundation (NSF) thanks to the efforts of Dr. Kevin Taylor who specializes in Adapted Physical Activity with the Kinesiology department at Cal Poly San Luis Obispo, and Dr. Brian Self and Dr. Jim Widmann of the Mechanical Engineering department at Cal Poly San Luis Obispo.

A strider can enhance Nathan's ability to live a more comfortable and healthy life, and other families and individuals affected by SMA may use a Strider device to better their own lives. Thus, the stakeholders of this project include Nathan Cooper and his mother and father, Bob and Amy, Dr. Kevin Taylor, Dr. Brian Self,

Dr. Jim Widmann, the National Science Foundation, and other families and individuals with similar conditions.

Background

Nathan currently owns a number of assistive devices that provide him with some mobility while he is in the upright position. Each device has features that Nathan and his parents enjoy and would like to see incorporated into the Strider. Undesirable features of these products were to be remedied or eliminated in our new design. This section includes a brief description of these currently used devices and their points of interest, as well as additional information about SMA.

Spinal Muscular Atrophy (SMA)

Spinal Muscular Atrophy is a relatively rare congenital disease that limits muscular development and function. Approximately 25,000 people in the United States live with the disease[1]. Many more live with the responsible recessive genetic trait.

The condition is the result of the absence or mutation of a gene known as Survival Motor Neuron 1 (SMN1). This gene encodes the "survival of motor neuron" protein, which in turn supports certain "α-motor" neurons, or nerve cells, located in the spinal cord. These α-motor nerve cells are responsible for the contraction of muscles. Therefore, the lack of the SMN1 gene results ultimately in a severely reduced ability to contract muscles. Eventually, the unused muscles atrophy and have little strength to support the body as it grows[1].

The muscles most affected by SMA are those in the trunk and neck area. These muscles are instrumental in supporting the spine and internal organs. People with SMA often develop spinal deformities and respiratory illness due to this lack of muscular support of the upper body. It is essential that these and other muscles are exercised on a regular basis with various forms of physical therapy in order to prolong the health of affected internal systems.

There are multiple types of SMA. Nathan has Type II, which is diagnosed in infancy and is characterized by the inability to stand and sometimes sit independently. People with Type II often require some type of assistive device throughout their lives and can usually benefit from physical therapy. A Strider

can give Nathan a much needed opportunity to exercise his muscles and enjoy an outdoor environment unhindered by his assistive device.

The Go-Bot

Figure 2. The Go-Bot by Mobility4Kids

The Go-Bot is a battery powered cart that Nathan can control with a joystick. It affords him some independence and a good deal of mobility. An added advantage of the electrical motor system is the increased stability of the cart due to the low center of gravity; a disadvantage is the decrease in transportability. Nathan is in no danger of tipping over, but limited transportability limits possibilities of fun outings.

The device holds Nathan in an upright position with a stiff, supportive harness. This gives Nathan some opportunity to bear weight with his legs, but a saddle supports the bulk of his weight. Unfortunately, this harness and saddle system is uncomfortable after extended periods of time because Nathan is forced to lean forward and bear some weight with his chest.

The most undesirable aspect of the Go-Bot is its lack of shock absorption. Nathan is jolted by every bump he rolls over and can become quickly fatigued. This is a major limiting factor of the Go-Bot.

Gait Trainer

Figure 3: A typical gait trainer

Nathan often uses a gait trainer similar to the device in Figure 3. His particular device secures him with soft neoprene pads in contact with his back, sides, and chest, and his weight is supported by a padded saddle. His distance from the ground can be increased so that he can swing his legs freely, which he enjoys, or decreased so that his feet make contact with the ground. The latter option allows Nathan to propel himself in any direction under his own power. The trainer offers very little resistance and can rotate and translate with minimal effort provided the polyurethane wheels are in contact with a smooth surface. An excellent feature of Nathan's current gait trainer is its harness suspension system. Nathan's

saddle and harness move collectively to damp any sudden shock to his feet or back. This makes for a much more comfortable and healthy experience overall and reduces fatigue.

While the trainer can glide smoothly over pavement, it does not travel well over rougher terrain such as dirt or gravel paths. This lack of continuity limits Nathan's mobility and is the primary drawback to the gait trainer.

The Original Strider

Figure 4. The original STRIDER

The original Strider for kids is pictured here with Nathan. It was developed by a Cal Poly senior project team to give Nathan the opportunity to travel on dirt paths and grass either under his own power or with his parents pushing from behind. It is stable, has large, all-terrain wheels, and a suspension system.

This device has a number of features that limit Nathan's mobility and comfort. Firstly, the spring suspension system does not function as intended and does not allow Nathan to bounce in place.

Secondly, the weight of the device (around 60 pounds) makes acceleration difficult for Nathan. Only with maximum effort can he move small distances on flat, smooth surfaces. Movement over variable terrain can only be accomplished with his parents pushing, which itself is somewhat difficult because of the Strider's lack of maneuverability. Also, like the Go-Bot, the Strider is difficult to transport. It does not collapse easily and its dimensions make it difficult to place in car to take to walking trails.

Lastly, the old Strider is less aesthetically pleasing than might be desired. This is understandable, considering the time and budget constraints involved. The design is more focused on safety and performance than appearance.

To summarize, the rarity of Nathan's condition has resulted in a sparseness assistive devices that accommodate his needs. No product currently on the market satisfies his needs completely. The Strider is intended to be a combination of the best points of the current products and fully meet Nathan's needs.

Problem Definition

Nathan is a young boy with SMA who requires assistance for basic movements. Exercise is critical in improving his quality of life and minimizing the effects of his condition. An assistive Strider device that meets these needs would greatly aid this cause.

Objective

Our team aimed to create a Strider device that combines the most desirable qualities of the aforementioned products to fulfill the needs of Nathan and his family. Through the use of a Quality Functional Deployment (QFD) matrix (App A.), which translates Nathan's needs into unambiguous engineering considerations, we were able to take the desires of the Coopers and of our sponsor, and turn them into specific design quality parameters. The Strider should encourage Nathan to increase his exposure to physical activity and allow him to access terrain he would not otherwise be able to cover. And, most importantly, it should allow him to do so safely. The following points highlight our main objectives and their risks.

The Strider should

- Enable Nathan to ride comfortably in multiple standing positions, including one that permits him to swing his legs freely and another that allows him to rest. These are high risk qualities because they represent some of the primary functions of the Strider.

- Have the possibility of being motorized and powerful enough for mild off-road conditions. This is a medium risk because a final design could function with or without a motor.

- Have some form of shock absorbency to increase the ease of use and comfort for Nathan. This is a medium risk accessory that would make the product more convenient for its user.

- Be adjustable to make the device usable for a wide range of body sizes and more convenient overall for primary and secondary users. This is a desirable, medium risk objective that is not necessary given the project's primary objective.

- Be a collapsible product for convenience of transportation and storage. This will make the product more appealing, but is not an essential quality, so is a medium risk.

- Include a drink holder or food tray. This is a low risk addition because it is not required to meet the main goals of the project.

- Be compatible with Nathan's Hip Knee Ankle Foot Orthosis (HKAFO), which is an orthopedic device that supports Nathan's legs. This objective is desirable but not essential given Nathan's desire to swing his legs, so it is a medium risk. Depending on the design and based on the wishes of Nathan and his family, the device could function properly regardless of the inclusion of Nathan's braces.

- Be safe. The most critical and highest risk criteria for this device involve safety. The Strider must be stable and dependable for its intended use. It should be designed such that it will not fail under its intended or more extreme operating conditions. The health and safety of Nathan is the primary concern of this project, so this objective will receive the most attention.

- Be relatively lightweight. Weight is a high risk objective that will substantially affect the final design and its overall usefulness and safety. The total loaded weight and how it is distributed will be given a high level of attention in the Strider design.

- Be sized to accommodate aesthetics, safety, transportability, and functionality. In other words, the size of the final product is critical for fulfilling its primary functions. The size with respect to safety will be given the most attention, but there is some room for variation, so it is a medium risk.

- Have a reasonable cost of manufacturing. The cost of the Strider will affect the accessibility of replication by other families. This is not an extremely limiting requirement and can be adjusted slightly if needed, so it is a medium risk.

Below is a compliance matrix showing the risks and importance of each objective and a table of preliminary specifications for main parameters. The compliance of each objective is presented to describe how design requirements will be met.

Table 1. Compliance matrix for some of the Strider objectives

Objective	Risk/Importance	Compliance	Specification
Access to varying terrain	M	A, T	8 in
Radius of free leg swing	H	A, T, I	1-2 ft
Horsepower (if motorized)	L	A, T	1-2 Hp
Suspension travel	M	A, T, S	6 in
Height adjustability	M	A, T, S	1 ft
Weight	H	A, T, S	10-30 lbs
Cost	M	A	< $1,500
Height	M	I, A	2-3 ft
Wheelbase	M	I	1-2 ft
Turn Radius	M	I,T	1-2 ft
Drink Holder	L	A, S	
HKAFO compatible	M	A, T	
Safety, dependability	H	A, T, S, I	
Comfort: head, arm, and	H	T, I	
Portable, collapsible	M	A, T, S	

Risk level: High (H), Medium (M), Low (L)

Compliance: Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)

Method of Approach

Our general plan for this project was to perform sufficient background research and design a product that achieves the set goals and objectives. Part of our approach included learning from the previous Strider. It was built for Nathan and his parents but failed to fully meet their needs. It was designed and built with safety and strength as isolated priorities. It did not address the proper needs of Nathan and did not take account of Nathan's size and physical ability. It also failed to be easily maneuverable for his parents. Most importantly, it did not serve its main purpose of giving Nathan weight-bearing exercise and mobility.

In order to address all of the requirements and produce a high-quality and effective product, we followed a simple and strict method of approach. We

began by creating a detailed problem statement as defined by the needs of our customer and the goals of our sponsor. After fully understanding what our customer wanted, we defined specific engineering requirements and specifications in addition to the preliminary specifications of Table 1. These specifications served to verify whether our design concepts, prototypes and final product satisfy the needs of our customer. Also, we regularly met and discussed designs with our kinesiology partners and the Coopers to ensure that our designs did not stray from our goal.

We continued to observe and understand our customer. The goal of the Strider was to give Nathan weight-bearing exercise, accessibility and some mobility. This product was designed specifically for Nathan and his family. We familiarized ourselves with the environment in which Nathan will use this product, his everyday practices and needs, and what kind of exercise or adaptive physical activity is required by Nathan specifically. We observed Nathan's current adaptive equipment and learned what he likes, dislikes and what he would enjoy to have in order to aid him in his everyday life. We also determined what was needed in the Strider in order to give him and his parents the assistance and freedom that they desire.

Once we completed an initial development of our best concepts, we presented them to Nathan and his parents for feedback. We then used this feedback to refine our designs and concentrate on one design to pursue.

Having picked our best design, we modeled the device in SolidWorks and performed the necessary engineering calculations early in spring quarter (see Gantt chart in App. B) to make the device both effective and safe for Nathan and his parents. Our final design concept was further refined and presented in detail in our concept design report.

A prototype was then built and tested. Once we determined that the prototype was safe, we asked Nathan and his parents to use it and give us further feedback.

Finally, after all testing concluded, we finished the final product for Nathan and his parents midway through fall quarter. The final product was displayed at the design exposition at the end of year.

Ideation & Concept Modeling

After completing our research on existing adaptive equipment and Nathan's needs and condition, we used various ideation techniques to generate design concepts. Each member, including our kinesiology partners, drew up design concepts and shared with the entire group. We then picked and combined the best concepts that met our requirements.

We started with a morphological attributes list to get an overview of the possible materials, modes of movement, harness types, and sources of propulsion (App C.). These ideas were narrowed down to include the most feasible options, which were then combined to create composite concepts during brainstorming sessions.

Our initial concepts focused on frame and suspension designs. We felt that these would be the most pivotal aspects of the new Strider. However, communication with the Cooper family at that time revealed that the harness design was the most important outcome of this project. As such, we planned to continue to generate ideas for Nathan's support system. The kinesiology members of our team took a very active role in the further development of the harness.

Concepts

Most of our drawings were done individually over a period of about two weeks. We wanted to create independent designs, so we refrained from sharing our ideas for a set time. We then collaborated and combined the best features of each design. Original drawings and their primary attributes are shown below.

the Jungle-gym

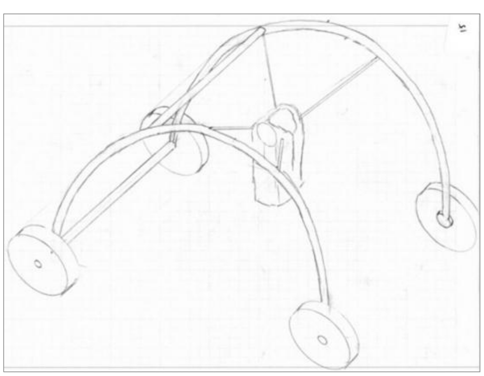


Figure 5. The Jungle-Gym Concept

This design is a departure from the common, clinical appearance that many assistive device process. It is simple, would not require much maintenance, and incorporates elastic bands for suspension.

The Jungle-gym would probably be too obtrusive for Nathan's liking. It would not allow his parents much access to him while he is in his harness. Also, this design might be difficult to collapse for transportation.

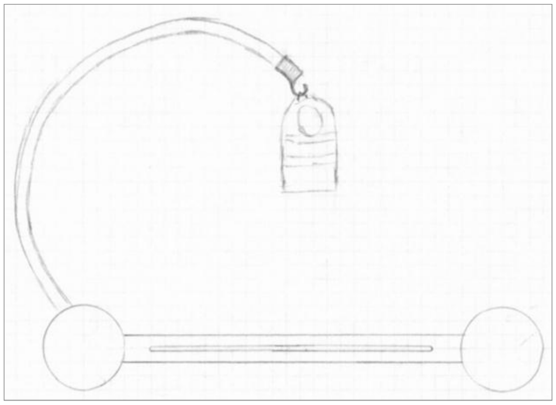


FIGURE 6. THE ARC CONCEPT

THE ARC

The Arc is a variation of the Jungle-gym. It improves parental access and decreases the feeling of enclosure. Suspension is provided by deflection of the curved beams extending from the rear axle.

This design lacks adjustability. Nathan would not be able to vary the amount of support the device provides. Also, he would quickly grow out of it.

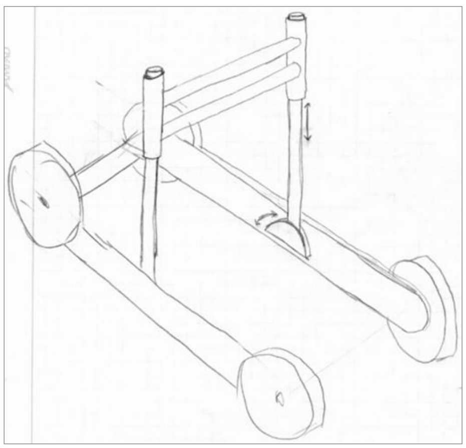


FIGURE 7. THE SLIDER CONCEPT

THE SLIDER

The Slider attempts to resolve the binding moment issue of the previous Strider by centering Nathan's weight over the sliding suspension system. It would have vertical and angular motion to prevent fatigue due to extended use. It is also very accessible and unobtrusive.

This device would be too constrictive. It would not allow Nathan to rotate left and right, and thus might restrict his ability to walk.

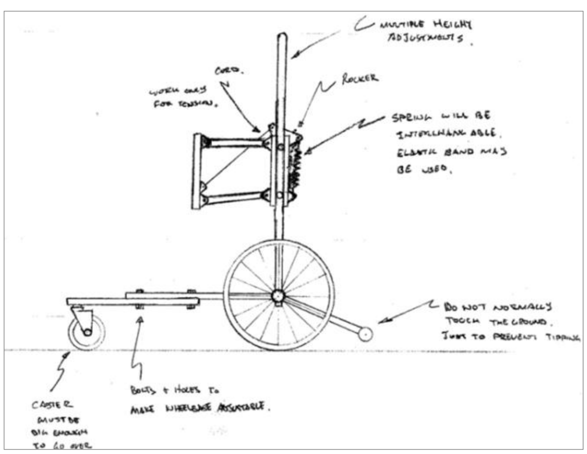


FIGURE 8. THE FOUR-BAR CONCEPT

THE FOUR-BAR

The Four-Bar design took its inspiration from assistive devices like the KidWalk (App. D). The Strider needs to give Nathan a wide range of freedom, but it must also guide his movements for proper gait and posture. The Four-Bar would regulate Nathan's movements while giving him multiple degrees of freedom.

The complexity of this design was considerably greater than that of our other designs. Also, it would be substantially heavier.

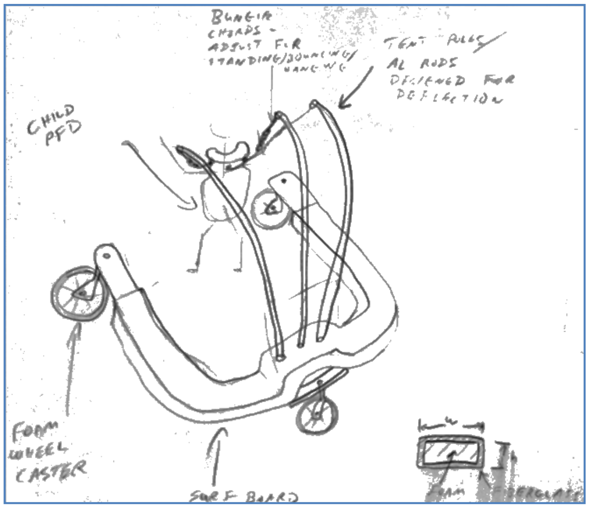


FIGURE 9. THE SURFER CONCEPT

THE SURFER

The Surfer suspension system consists of both deflecting rods and elastic cords. It has three wheels in order to increase maneuverability. The frame would be constructed with a lightweight fiberglass, epoxy, and foam composite.

The stability of the Surfer was questionable, especially in situations involving rough terrain. Safety bars would have to be installed to prevent the entire device from tipping over.

THE TRIKE & ELLIPTICAL

These two designs were intended to give Nathan a lot of exercise, but not necessarily from walking. The scope of Nathan’s strength and ambition would probably not cover the physical output the Trike and the Elliptical (not pictured) would require, so they were not incorporated into our final design.

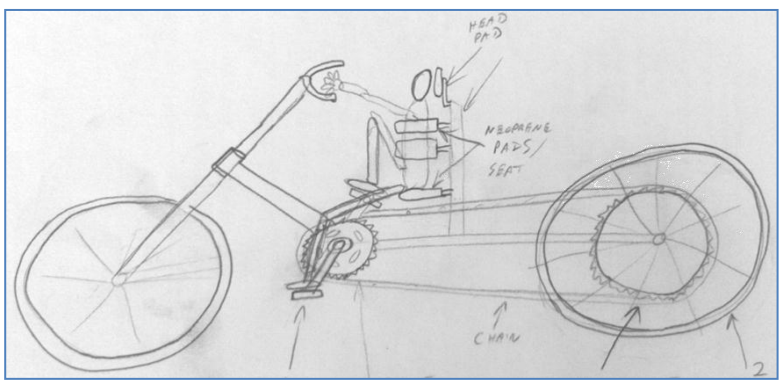


FIGURE 10. THE TRIKE & ELLIPTICAL CONCEPT

DECISION MATRIX

Decision Matrix

	Specifications	Weight (1-5)	Four-Bar	Surfer	Trike	Elliptical	Jungle	Slider
1	Weight	**4**	0	2	-1	-1	1	0
2	Dimensions (Upright)	**3**	0	-1	-1	-1	-1	0
3	Dimensions (Collapsed)	**2**	1	0	-1	-1	0	2
4	Adjustibility	**3**	1	0	-1	-1	-1	0
5	Shock Loading	**2**	1	1	0	-1	1	0
6	Elasticity	**5**	1	2	-1	-1	1	0
7	Cost of Materials	**3**	0	1	0	-1	1	1
8	Accessibilty	**4**	0	0	-1	-1	-1	0
9	Maneuverability	**5**	0	0	-1	-2	-1	-1
10	Loading and Fatique	**3**	0	-1	1	0	0	0
11	Maintainance	**3**	0	0	-1	-1	0	0
12	Stability	**4**	0	-1	0	0	0	0
13	Materials (Aesthetics)	**1**	1	1	1	1	0	0
14	Durability	**4**	0	0	1	0	0	0
15	Height of CG	**4**	-1	1	0	1	0	0
16	Level of Activity	**5**	1	1	0	1	1	0
17	Terrain Capability	**5**	2	1	2	0	1	0
18	Comfort	**5**	1	1	1	0	1	0
19	Safety	**5**	0	0	0	0	0	0
		Total:	**25**	**28**	**-3**	**-23**	**5**	**3**

Datum: KidWalk

DECISION

Specifications for our decision matrix (preceding page) were made based on the project requirements listed in our QFD. Weights were given to each based on their importance in the overall success of the project. We used a current product, the KidWalk, for comparison. Criteria relating to overall safety and effectiveness were given the highest weight. It was critical that the Strider allow Nathan to safely and comfortably improve his condition. Of somewhat lesser importance, but still a major focus, was our goal to allow Nathan access to varying terrain. In order to make the Strider an improvement on current products, Nathan should be able to access mild terrain such as dirt trails and footpaths. We also wanted the device to be convenient for indirect users in terms of portability and adjustability. We hoped to make this product easy to use for Nathan's parents. The Strider should be easy to transport and maintain. Cost is another consideration that we accounted for to make the Strider possible with our budget.

The results of our decision matrix helped in the selection of a design from initial concepts. To produce our totals, each member completed their own matrix and the results were averaged. Two designs stood out the most from our results. The Surfer and Four-Bar concept were given the most focus as potential final designs. We decided to mix some of the stronger components of each idea. We developed some basic ideas for the base, frame, and harness based on these concepts. After another meeting with Nathan and his family and receiving advice from our sponsor, we were able to create an initial proposed design.

This proposed design was lighter, more mobile, and more comfortable than the KidWalk. It was also much less complex than the KidWalk, so would cost less and require fewer custom manufactured parts.

FINAL DECISION ON MATERIALS

After testing the bending characteristics of aluminum tubing, we concluded that aluminum would not be a feasible material out of which to make the entire Strider. Once aluminum is deformed plastically, the material will continue to yield to loading and will not keep its shape. The only way aluminum could be used for this application is if it was hot worked into shape or annealed after it was bent. Neither of these methods were practical for our project, so it was not reasonable to make the Strider completely out of aluminum, but it was

determined that using it for the joints would provide the needed strength in critical areas and could be combined with other materials to maintain a low weight.

Steel was found to be an acceptable material in terms of strength with which to make the Strider. It can be cold worked into the bent shape we desire and still be able to hold its shape. Steel is also very cheap, reliable and safe for Nathan. However, it is very heavy. Our estimations indicated that making the frame out of steel would result in a frame weight of around 35 lbs. This did not meet our weight requirement and thus was not an option for frame material.

We were dedicated to making most of the frame out of composite materials. The joints would be machined out of aluminum and bonded with epoxy to carbon fiber tubes. This required some surface preparation for both surfaces. The aluminum had to be anodized and the carbon fiber sanded and cleaned to insure a secure bond. With carbon fiber, we could make a frame as strong and as reliable as one made out of steel, but much lighter. We planned to begin constructing the frame according to our calculations and final design. Testing for stability and strength were to be done as components were added. We planned to make any necessary changes if problems arose.

FIGURE 11. THE FINAL STRIDER CONCEPT

DESIGN DETAILS

The carbon Strider concept has four main subsystems that function both individually and collectively in the device in order for the Strider to meet the needs of the Coopers. The four main subsystems are the frame, wheels, harness, and suspension. The following sections provide details about the design of each subsystem as well as considerations for further design development.

Frame

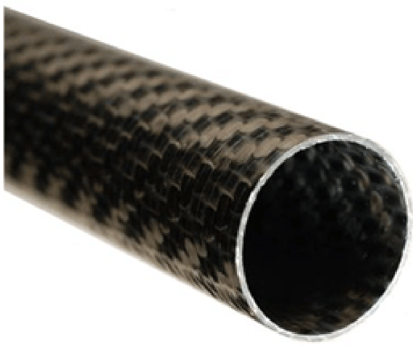


Figure 12. Carbon fiber tube for STRIDER frame

The frame of the Strider accounts for the majority of the weight and size of the device. For this reason, the frame needed to be lightweight yet durable enough to stand up to everyday wear and tear. Nathan weighed approximately 35 pounds, so the overall weight of the Strider had to be much less than this in order for him to be able to walk with the device. Also, Mr. and Mrs. Cooper planned to load and unload the Strider in and out of their car. The frame had to be light enough for either of them to easily lift and load it into a car trunk so that using the Strider out of the house would not be a hassle. It was also to be strong enough to withstand the outdoors and more rugged terrain. With these considerations in mind, we chose carbon fiber (see Fig. 12) with aluminum joints for the Strider frame. A carbon fiber frame can withstand repeated impacts and bending loads, and is light enough to be carried with one arm. Aluminum provides the necessary strength at critical locations. The frame has attachment points for the wheels and suspension system. The wheels and bungees are attached to the frame with karabiners that hook to aluminum inserts.

Finally, in order to make the frame collapsible, the four base joints and the wheels are attached with quick-release connections. This was accomplished using pins that fit through holes machined in the aluminum tubes. Carbon fiber components are adhered to the joints with epoxy and were tested to guarantee an acceptable bond was created between the two materials. The final frame is strong, lightweight, and has detachable parts for ease of use.

Wheels

Figure 13. Swivel wheels such asthis are ideal for dirt trails.

The wheels of the Strider had to allow Nathan to move and change direction easily so that he has the feeling that he is walking unconstrained. Also, if his parents are pushing him around on a trail or path, it should feel comparable to pushing a stroller. Since the Strider was designed with some off-road capability, to go on trails such as those in Poly Canyon, the wheels had to be able to go over rocks, sticks, and cracks without getting stuck and ideally without transmitting shock to Nathan. For these reasons, the wheels are somewhat large (over 10 inches in diameter) and the front wheels are able to change direction like casters. A quick release system in the rear wheels makes the

Strider more transportable and easier for Mr. and Mrs. Cooper to use. We used the wheels from the previous Strider for the rear wheels because they were readily available for immediate use. Also, they are ideal for off-road conditions because air can be added or removed from the tires and they have a quick-release mechanism. The front wheels are a durable foam material and are connected to a swivel fixture which can be attached via the quick-release mechanism to the frame.

Harness

Figure 14. The Kaye Suspension Harness is ideal for Nathan to use on the STIDER and in other applications.

The harness is the only subsystem that directly interfaces with Nathan by holding him in a standing position. It is therefore is a key component of the overall design. Nathan's comfort is a top priority because if this device makes him feel uncomfortable after only a few minutes of use, he will not want to use it. The harness distributes his weight so that he is not supported just between his legs like many of his current harness systems do. The harness supports Nathan's upper body as well since his core muscles are not strong enough to stabilize his torso in a standing position. Some possibilities for the harness we considered were a children's personal floatation device, or PFD, with added hip and lower body support sewn on, or a design similar to the TeraSuit (suittherapy.com), which is a therapeutic harness developed for children with Cerebral Palsy. A neoprene children's PFD with lower body support and attachments for support straps would provide comfortable upper and lower body support as well as give Nathan free use of his limbs to move about and exercise. The harness used for Strider is called the Kaye Suspension Harness. It is ideal for supporting Nathan in the critical points and appears to be very comfortable. This harness is versatile because it can be used on other devices that suspend Nathan.

Suspension

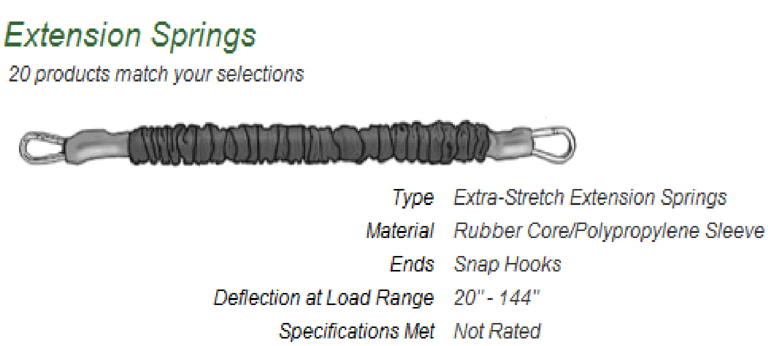


Figure 15. Bungee cords that could connect Nathan's harness to the support arches.

The Strider design may use as many as three suspension subsystems in order to provide Nathan with a comfortable ride and allow the Strider device to traverse trails and other off-road terrain. The first would be at the wheels

FIGURE 16. BUNGEES WITH KARABINERS OR RUBBER STRAPS COULD BE USED TO SUSPEND NATHAN.

FIGURE 17. CARBON FIBER POLES OR TUBES ARE IDEAL FOR PROVIDING NATHAN WITH THE SUPPORT HE NEEDS.

where the tire pressure provides a kind of spring for dampening vibration. The second are the carbon tubes over Nathan's head that hold him in a standing position. These are will be made from carbon fiber poles that deflect slightly and flex while still supporting Nathan's weight. Finally, bungee cords, or extension springs, are attached to Nathan's harness and to the overhanging tubes with karabiners. Many variations of these extension springs could be used, but the current design uses adjustable bungee cords with simple hooks. The extension springs help support Nathan's weight and allow him to walk, bounce, and stand with his weight supported. These extension springs can be purchased in a variety of lengths, stiffness's, and load capacities.

DESIGN ANALYSIS

Our initial stress and deflection analysis was performed on the simplified aluminum frame shown in Figure 18. We analyzed this simple model of 1" schedule 40 round tube to get a rough understanding of the reaction forces, moments and torques that would likely occur from loading. Iterations were performed in Matlab (App D) and compared deflection and weight for various tube sizes and loads for both steel and aluminum. The code utilized Castigliano's method of strain-energy to determine deflection. We gathered from this model that a frame made entirely of aluminum or steel would not satisfy our weight and strength requirements.

We modified our materials choice to reduce weight and improve overall strength. The profile shown in Figure 18 shows the points of interest. Point A is the hanging point of the bungees. B is the joint between the overhanging and the vertical carbon fiber tubes, and C is the connection of the arm system to the rear axle.

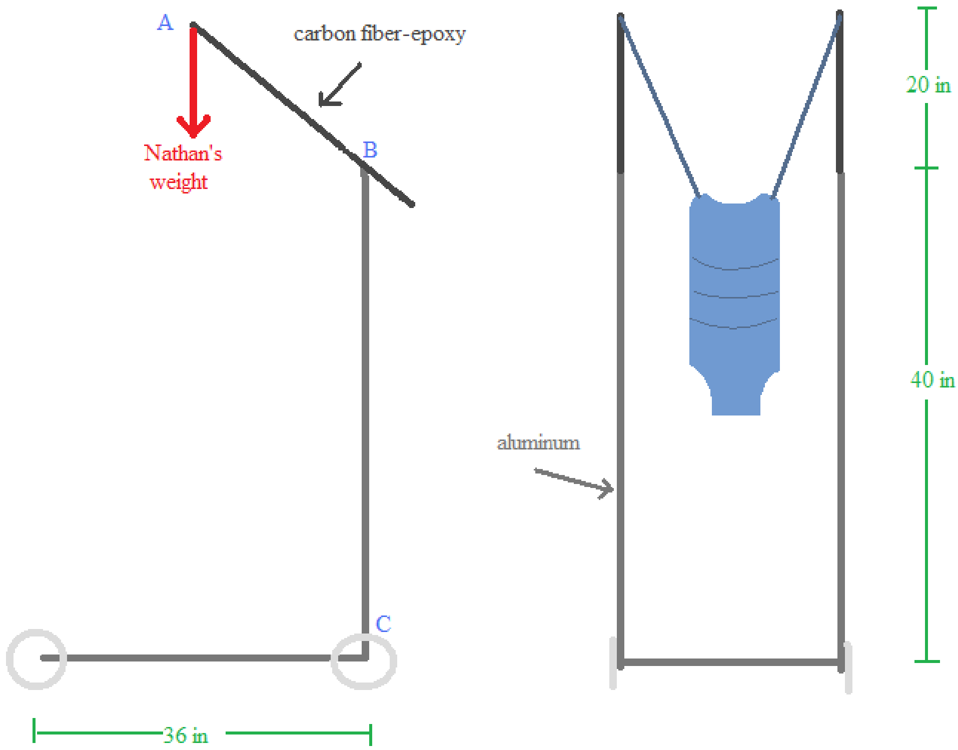


Figure 18. Simplified front and side views of the design.

The analysis took into account the vertical weight of Nathan, but the horizontal forces Nathan will exert to move forward and sideways were neglected because they will most likely be small compared to his weight. We plan to make the friction resistance of the Strider very small so that Nathan will not have difficulty moving.

The component sizes we picked for initial analysis were 2” schedule 40 round aluminum tube for the axle and 1.5 outer diameter, .07” thickness carbon fiber-epoxy tube.

However, the final stress analysis was performed on the exact materials and dimensions of the final design. Details of this analysis are discussed in a later section.

Deflection

The deflection analysis assumed that each arm would experience a 40 lb load, which is nearly the weight of Nathan. This conservative value was used in both deflection and stress analysis to anticipate Nathan's growth and the possibility of one arm failing with the device remaining safe.

The results (App. E) show that the carbon fiber tube will deflect vertically less than .1" at point A. The tubes are pulled together by about .1" because the load is not completely vertical. The smallness of these deflections is not surprising considering the stiffness (E = 32 mpsi) and relatively short length of the tubes. The vertical carbon tubes deflect at point B about .09" horizontally. The vertical displacement at B due to this horizontal deflection is negligible.

The axle does not bend from the vertical shear due to the proximity of the arm-axle connection and the wheel. There is a slight deflection of .05" at the center of the axle due to moment caused by Nathan's centrally located weight drawing the arms together.

Stress

The stress in the components of the Strider was analyzed to determine factors of safety for both static load and fatigue failure. The static analysis was relatively straightforward and considered Von Mises stress at critical locations and found that there was no likelihood of static failure.

Loading was determined by a dynamic analysis of Nathan's motion for expected deflections with a simple mass-spring analytical model. At his current weight, Nathan will provide a mean load of about 18 lbs and an alternating load of about 13 lbs per bungee support.

Fatigue analysis for aluminum is difficult to perform given the lack of readily available information regarding aluminum's fatigue properties. A conservative fatigue strength of 25 ksi for $500x10^6$ cycles was used in place of the endurance limit in a modified Goodman failure criterion

$$\frac{1}{n} = \frac{\sigma'_a}{S_e} + \frac{\sigma'_m}{S_U}$$

which also uses the Von Mises stresses for combined loading for both the mean and alternating load. The Von Mises stress incorporated normal and shear

concentration factors of 2. The lowest factor of safety was 1.8. This is very conservative considering the number of cycles the Strider will likely see (<<500 million). It is expected that Nathans weight can increase considerably before the Strider becomes unsafe.

An important issue of stress analysis of carbon fiber is that its ultimate strength is direction-dependent. The longitudinal strength of the tubes analyzed is as high as 180 ksi or greater, while the transverse strength can be much lower depending on the lay-up of the tube. It was assumed that strength of bending is subject to rated longitudinal strength (180 ksi) and strength in shear is subject to transverse strength (10 ksi). This resulted in factor of safety of 34 or greater for the carbon tubes. Detailed calculations are in Appendix E.

The strength of the epoxy is not considered to be an issue because the shear stresses in those joints are relatively small and the bond between anodized aluminum or carbon fiber and epoxy is very strong.

Safety Considerations

Among the many design factors considered, Nathan's safety as well as his parents' safety ranks highest on our list. The Strider should never put them in harm's way. To ensure that this will not happen, several safety features have been incorporated into the design of the Strider.

First of all, unlike the old Strider, there will be no sharp or pinch points. The old Strider has very sharp metal corners with tapered cantilever tubes protruding from the frame. Nathan and other people around him can easily be cut or stabbed by these sharp points. Also, the old Strider had a sliding mechanism that can pinch or crush someone's fingers. The new Strider will not have these problems. The frame will be made into a smooth shape so that nothing sticks out from it. Also, all endpoints will be rounded and capped with soft plastic. The new Strider also does away with all pinch points by eliminating the sliding mechanism on the old Strider.

To ensure that the frame do not sway and buckle under loading, such as at times when Nathan will be bouncing in it or when the Strider is moving over rough terrain, support bars could be placed between the top arches. This would add another level of safety by stabilizing the arches from sway side to side. Given the current safety factor, however, this feature is would not greatly increase safety. This could be added to a future model, but it was not included

in this prototype. There are other more critical locations to be reinforced to insure adequate safety.

Furthermore, the harness will be professionally made and bought with part of the project's funding. Since the harness will be holding Nathan in the Strider, it is critical that it is strong and durable. It should not break or rip anywhere and be able to hold Nathan comfortably. As a result, we have come to the conclusion that the best solution is to buy a harness made professionally for assistive devices.

Finally, the frame support must be strong enough to withstand any reasonable loading from Nathan, his parents, and the terrain. As a measure of safety, we will build several prototype parts and test them individually for strength and durability. These parts will be altered as needed. Our test plan, included in this document, will describe in detail how these parts will be tested.

Design Verification Plan and Report (DVPR)

Our design combines several different materials, including carbon fiber tubes, swivel wheels, and aluminum pipe. Analyzing and modeling methods of how these materials react to the loads being applied to them and the attachment methods used to join them together are lacking. To ensure a reliable, safe, and functional product, extensive testing and design verification of the Strider's individual subsystems and overall system was completed.

In general, the tests performed used the loads applied by Nathan during expected use of the device to evaluate the functionality of each subsystem of the device: the frame, harness, support arms, wheels, bungees, and the entire device as a whole. Table 2 below shows a brief description of the tests were performed. For a more complete and detailed list of the tests for the Strider, see Appendix F.

TABLE 2. SUBSYSTEM BREAKDOWN OF DESIGN VERIFICATION TESTS.

Subsystem	Test Types
Frame	Bending, Connections, Cycle
Arms	Bending, Connections, Cycle
Harness	Comfort, Fitting, Connections, Cycle
Bungee	Tension, Adjustability, Connections, Cycle
Wheels	Off-Road Capability, Connections
Main System	Off-Road Capability, Stability

MAINTENANCE

Several of the components of the Strider device will require maintenance due to the environment they are used in and the loads applied to the different materials. Bungee cords will need to be replaced because of the cyclic loading they experience and the UV radiation they will endure being used outside. Accordingly, the bungee cords used in the device are available at Home Depot or Ace Hardware and can easily be replaced by the Coopers.

Since the purpose of the Strider is to be used on bumpy trails while Nathan is bouncing, the device will undergo a great deal of cyclic loading. This may require that certain parts such as the wheels, support arms, or connections be replaced after or before they fail in order for the Strider to remain operational.

COST ANALYSIS

Through a federal grant from the National Science Foundation, NSF, the Strider project was given a budget of $1500. All material costs, assembly costs, and testing costs fit into this budget. Since the assembly and manufacturing were done by the engineers of the Strider project, there is no assembly and manufacturing cost. The majority of the budget money was spent on the materials that go into the Strider so that the device provides the best performance for Nathan.

The carbon fiber tubes, carbon cloth, and aluminum connections are all aspects of the design that are aimed to minimize weight while providing the maximum strength. For this reason, these items are expensive. The harness is a crucial part of the design since it is the only subsystem that directly contacts Nathan. Therefore, a significant amount of the overall budget was spent on the harness to ensure that Nathan is comfortable and supported. Table 3 provides details of the materials that were purchased, their individual costs, and vendor information. The total cost of the Strider came in about $250 under budget. A more exact breakdown of the cost of each purchase can be found in Appendix G.

TABLE 3. BILL OF MATERIALS INCLUDING INDIVIDUAL PARTS ORGANIZED BY SUBSYSTEM WITH THE COST AND VENDOR ASSOCIATED WITH EACH ITEM.

Item	Subsystem	Cost	Vendor
Composite Tubes	Frame	$200.00	McMaster
Epoxy	Frame	$150.00	McMaster
Aluminum Tube	Frame	$180.00	McCarthy Steel
Anodizing	Frame	$90.00	Pacific Anodizing
Nuts, Bolts, Pins	Wheels	$80.00	Home Depot
Wheels	Wheels	$175.00	Strider Sports
Harness	Harness	$315.00	Kaye Products
Bungees	Suspension	$35.00	Home Depot
Paint	Entire System	$25.00	Home Depot
Total		$1,250.00	

Product Realization

At the beginning of the spring quarter of 2011, in ME 430, the Strider team was divided into two sub-teams. Ricky and George took the task of developing and manufacturing the carbon fiber tubes used for the frame while Clark and Brian worked on designing and fabricating all the aluminum parts of the Strider.

Aluminum

The aluminum team had the challenge of designing and building all of the components of the Strider that are made from aluminum. Those parts include the inserts that are glued to the carbon fiber tubes, the bungee hangers, front wheel assembly, angled arm inserts and the Tri-Joint. Following is a detailed description of how those parts were constructed.

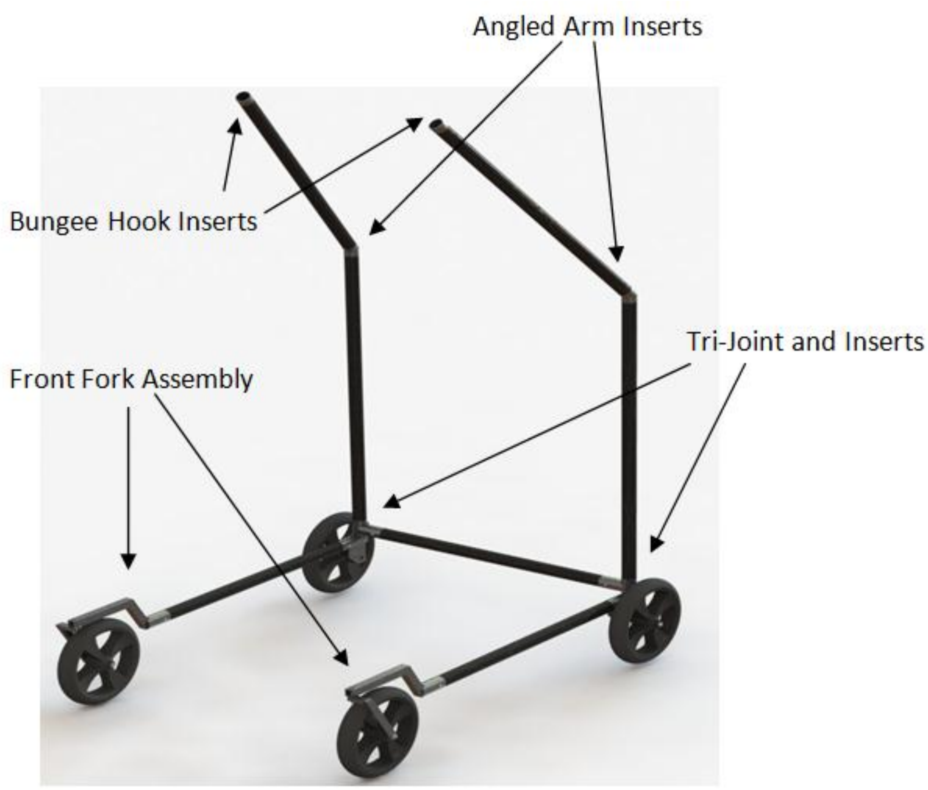


Figure 19. The Strider

Angled Arm Inserts

The angled arm inserts are the pieces that allow the support arms to jut out at an angle so that Nathan can be suspended in the center of the device. These parts started off as pieces of schedule 80 aluminum pipe. Many of the aluminum parts are made from schedule 80 pipe which is a 0.25 inch wall thickness pipe made from an aluminum alloy, designated 6061-T6, that is made for its high strength property.

Figure 20. The stock aluminum pipe used for the angled arm inserts and many other aluminum parts.

The two angled arm inserts were made identical. The first step in making the angled arm inserts was to turn down both sides of the pipe outer diameter so that the carbon fiber tubes can fit over them.

Figure 21. a), b) Here is Clark turning down the aluminum tube on the lathe.

The tubes were turned down to an outer diameter 0.02 inches smaller than the carbon fiber tube inner diameter. Then one fast pass was made at a shallow depth to scuff the surface so that the epoxy would bond better with the aluminum. We also sanded the outer surface with rough grit sand paper to put scratches on the surface to create an even better surface for the aluminum to bond to. Once the aluminum tubes were done on the lathe, it was time to cut them at an angle. We used the horizontal band saw and set the cut angle to 70 degrees so that the tubes would create a 140 degree angle when welded together.

Figure 22. a), b), c) The aluminum tube being cut on the horizontal band saw with the clamp set at an angle.

Once the tube was cut, we used the disk sander and wire wheel to take off the sharp edges. The tubes were now ready to weld. We used a vice to hold the tubes together at the angle we wanted. Welding aluminum requires using a TIG (Tungsten Inert Gas) welder because of the chemical properties of the metal under high heat causing it to easily oxidize.

Figure 23. a), b), c) Angled arm inserts before and after welding.

One drawback of welding aluminum is that it loses nearly 30 % of its strength because of the extreme heat. In order to regain that strength, we did a heat treatment process on all the parts that were welded by heating the parts to 970 degrees Fahrenheit for one hour, quenching them in water, and then heating them at 350 degrees Fahrenheit for 8 hours.

Figure 24. a) The angled arm inserts in the heat treatment chamber along with other parts being heat treated. b) An angled arm insert and a Tri-Joint after the heat treatment process.

The heat treatment process leaves the aluminum parts with a white oxide layer on the outer surface of the metal. The next step was to anodize the metal. Anodizing aluminum cleans off the oxide layer left from the heat treatment process and creates a deep oxide layer that that protects the metal from corrosion and provides an ideal surface for the epoxy to bond to. The angled arm inserts were then ready to be bonded to the carbon fiber tubes with a two part epoxy.

Tri-Joint

The Tri-Joint is an intricate and essential part of the design where the support arm, back cross beam, front wheel beams, and rear wheels all come together and are able to disconnect making the Strider able to collapse into several pieces for easy transport and storage. Many steps in the making of the Tri-Joint are the same as the Angled Arm Inserts; they started as schedule 40 aluminum pipe, were turned down on the lathe, TIG welded, heat treated and anodized. However, on two of the "axes" of the part, the inside diameter of the pipe was turned so that an insert could fit inside. Also, one of the tubes was notched so that one end had the shape of the outer diameter of the pipe so that three tubes could be welded orthogonally to each other. For this, a tube notcher was used that is very similar to a drill press and cuts out a semi-circular cut from one end of the tube.

Figure 25. The tri-joint after it had been welded. The outside diameter of the tube being held was turned to the inner diameter of the carbon fiber tubes but while the inside diameter of the other two tubes were turned to fit the aluminum inserts.

Once the tubes were welded together, the rear wheel bracket from the previous Strider model was welded to the bottom of the tube assembly. This way the rear wheels from the old Strider could be used. These wheels have a quick release axel and are off-road capable. The only drawback is that they are fairly heavy (about 3 pounds each). The tube that had the outer diameter turned was used as the vertical "axis" so that the support arms would have the maximum moment support of a direct epoxy bonded joint as opposed to a detachable joint.

FIGURE26. TRI-JOINT AFTER THE REAR WHEEL BRACKET WAS WELDED ON.

After welding, the two Tri-Joints were heat treated to increase the strength of the metal.

FIGURE 27. THE TWO TRI-JOINTS AND TWO ANGLED ARM INSERTS AFTER HEAT TREATMENT. THE DARK DISCOLORATION AROUND THE WELD IS DUE TO THE DIFFERENT ALLOY MAKEUP OF THE WELD FILLER METAL.

Then the Tri-Joints were ready to be anodized.

FIGURE 28. AN ANODIZED TRI-JOINT WITH THE CARBON FIBER TUBE INSERTS IN PLACE.

INSERTS

As shown in the above figure, aluminum inserts were made to connect the carbon fiber tubes to the Tri-Joints. These were simple pieces that started out as schedule 80 aluminum pipe, were cut to length, turned on one end to 0.002 inches smaller than the inner diameter of the carbon fiber tube and to the inner diameter of the Tri-Joint tubes on the other end, and then anodized. Schedule 80 pipe was used to since it adds 0.1 inches to the wall thickness of the tube and therefore makes a stronger part. Six aluminum inserts were made to connect to the Tri-Joints and front fork assembly. There was no need to heat treat the aluminum inserts since they were not welded.

BUNGEE HANGERS

The bungee hangers are the parts at the end of the support arms that connect the bungees to end of the support arm with a hole for a carabineer to loop through. These parts are made similar to the aluminum inserts except that they are much shorter, and the end that sticks out from the carbon fiber tube is not turned and has a hole drilled in it.

FIGURE 29. BUNGEE HANGER AFTER ANODIZING AND GLUING INTO THE CARBON FIBER TUBE.

The six aluminum inserts, two Tri-Joints, two angled arm inserts, and two bungee hook inserts were sent away to be anodized at Pacific Coast Anodizing in Fresno, California.

FIGURE 30. PACIFIC COAST ANODIZING TRUCK TAKING OUR PARTS AWAY TO BE ANODIZED.

After the anodized parts were returned, there was some final machining to do to make everything functional. The inserts were sanded and in some cases turned again to make them fit better in the Tri-Joints. The inserts were placed inside the Tri-Joints and then a hole was drilled though both tube walls on the mill. This hole allows the quick release pin to be installed into the aluminum insert which allows for a lockable yet detachable joint.

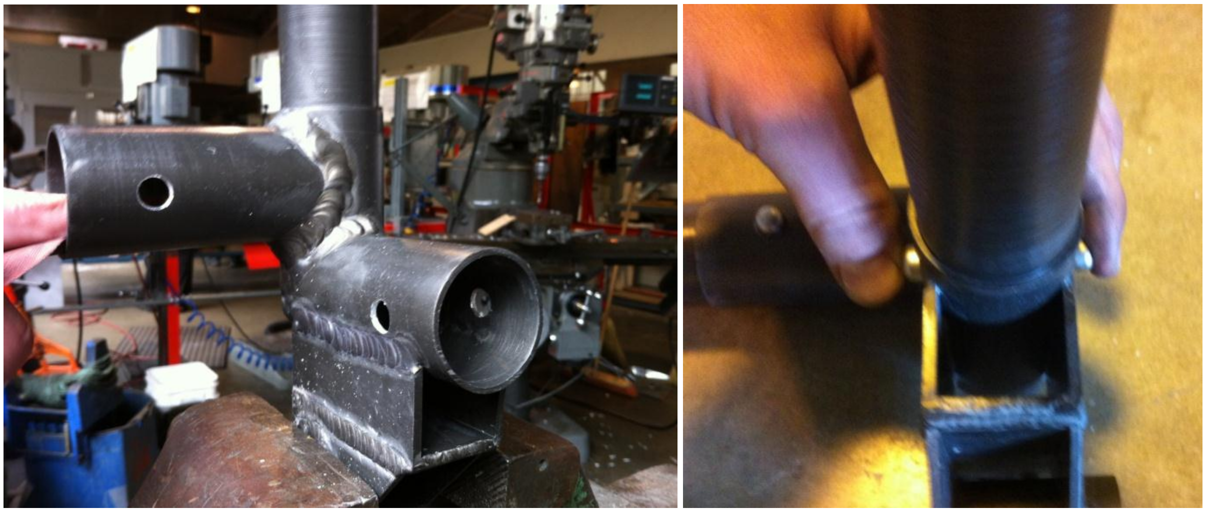


FIGURE 31. A) TRI-JOINT AFTER HOLES WERE DRILLED FOR THE QUICK RELEASE PINS. B) SHOWS HOW THE QUICK RELEASE PINS WORK. WHEN THE TWO PINS ARE EXTENDED, THE JOINT IS LOCKED IN PLACE. WHEN THEY ARE PRESSED IN, THE INSERT CAN SLIDE OUT OF THE TRI-JOINT.

FRONT FORK ASSEMBLY

The front fork assembly consists of an aluminum insert, a single sided fork, and extender. The single sided fork and extender are made from square aluminum tube. They were cut to the appropriate length and angle required for construction. The one sided fork is two pieces of square tube cut down the in half lengthwise and TIG welded at the appropriate angle. After they were welded, they were heat treated and drilled so that the front wheel axel and top bolt could be attached. The single sided fork and extender did not need to be anodized since they are not bonded to the carbon fiber tubes.

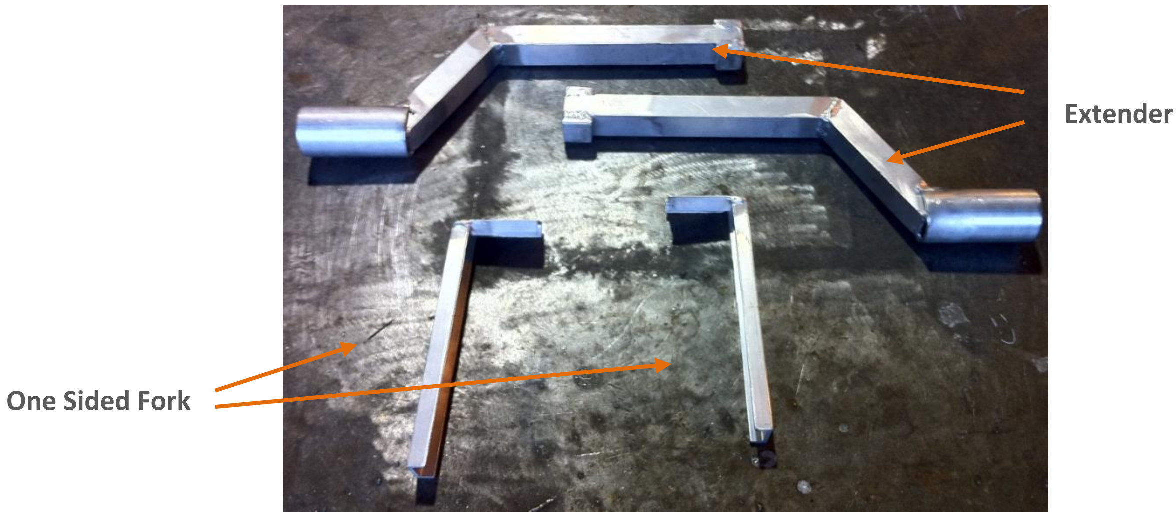


Figure 32. Two extenders and one sided forks.

Figure 33. A one sided fork clamped so that it could be welded.

The extender also includes a piece of schedule 40 pipe welded on one end so that the insert can attach to the fork assembly with quick release pins. The pipe part was notched with a pneumatic grinder to allow the square tube to fit into it at an angle to be welded.

FIGURE 34. NOTCHING OF THE PIPE FOR THE EXTENDER SECTION OF THE FRONT FORK ASSEMBLY.

FIGURE 35. A) WELDING AN EXTENDER. B) A FULLY WELDED EXTENDER BEFORE HEAT TREATMENT AND DRILLING.

Once the one sided forks and extenders were welded, they were heat treated in the furnace.

FIGURE 36. COLD WATER QUENCHING AN EXTENDER; A NECESSARY STEP IN THE HEAT TREATMENT PROCESS.

After heat treating the fork assembly parts, they needed to have a series of holes drilled in them for axel bolts going though the one sided fork, and connection bolts and quick release pins through the extender. The drilling was done on the mill.

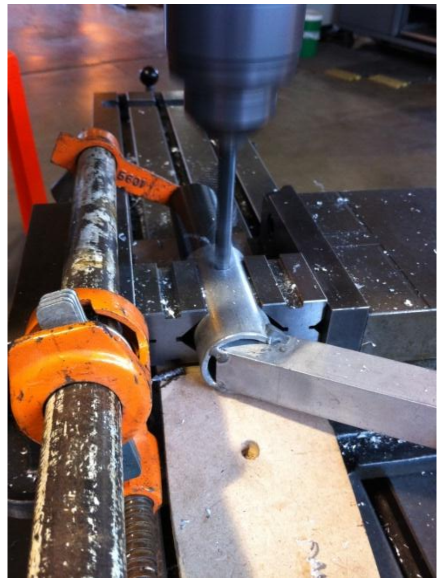


Figure 37. Drilling a hole for the quick release pin through the extender and aluminum insert.

With the holes drilled, the one sided fork and extender could be assembled. An oil impregnated brass bushing in the extender allows the one sided fork to rotate easily so the Strider can turn. A bolt with a series of nuts and washers keeps the fork assembly together and spaced correctly.

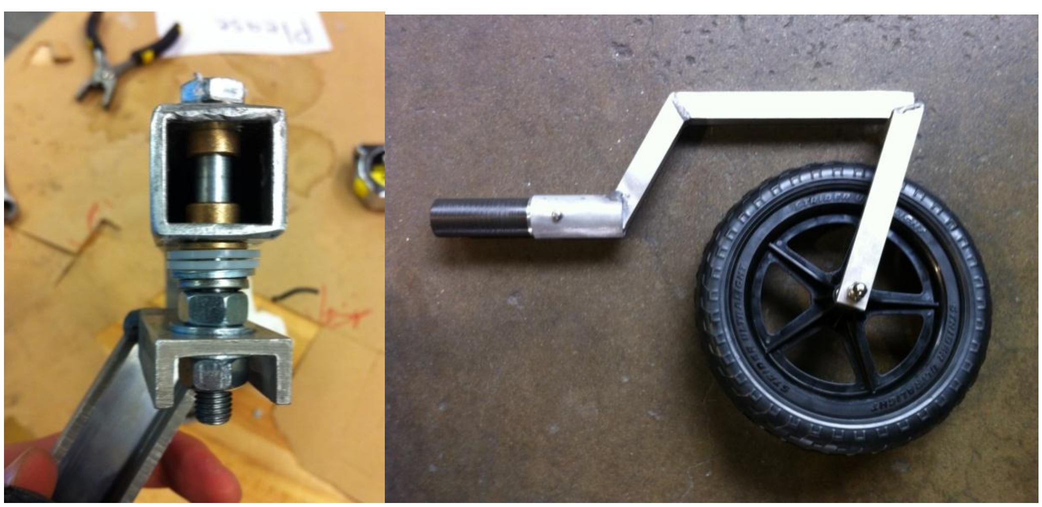


Figure 38. a) Bolt going through the brass bushing and held on with nylon and metal washers and nuts to hold the fork assembly together and allow it to rotate. b) A completed front fork assembly with foam wheel and aluminum insert attached.

Painting

Nathan wanted his Strider to be blue. The painting process consisted of masking the insert areas so that they do not get painted and ruin the clearance fit, spraying on a primer, and finally spraying on two coats of the final blue color.

FIGURE 39. A) SOME ASSEMBLED AND MASKED PARTS AFTER THE PRIMER WAS SPRAYED ON. B) PARTS HANGING TO DRY AFTER THEY WERE PAINTED WITH THE FINAL BLUE COAT.

Carbon Fiber

Ricky and George were responsible for designing and fabricating carbon fiber tubes for the Strider frame. The tubes had to meet the strength and dimension requirements specified in the design. Care had to be taken to insure that they were capable of withstanding all types of loading and wear during normal use. Both teams continued to work together on the sizing and epoxy connection between carbon fiber and aluminum. This was a somewhat new material for the group, so careful testing had to be performed and outside help had to be found whenever needed.

The Difficulty of using Carbon Fiber

Carbon fiber was chosen as the material for the tubes because of its light weight and high strength. These characteristics made it ideal for the Strider. However, carbon fiber tubes are very difficult to manufacture without prior experience; Ricky and George had to spend many hours modifying and improving the manufacturing process that is described below.

Carbon fiber is also very costly, both in time and money. Wrapping the tubes take a very long time because of the attention to detail needed in order to produce a high-quality finish. Curing of the tubes also take a very long time.

The Strider team was very lucky to have the Composites Lab and free carbon fiber to use. As a result, the extra cost of buying pre-manufactured carbon fiber tubes was eliminated. The Strider team would like to thank Cal Poly, Dr. Joseph Mello and Parker Drennan for their help.

Testing

The appropriate number of layers and orientation of the carbon fiber sheets had to be determined before a final product could be made. The strength of the epoxy connection between aluminum and carbon fiber also had to be tested. Two different weave designs were tested: 0-45-135 and 0-90-0. This nomenclature describes the direction of the each layer. For example, the 0-45-135 has a first layer with fibers going along the tube at 0°. The second layer is 45° offset from the first layer and the third layer is offset 135°.

From testing we found that a two-foot section the 0-90-0 held a static load of 185 lb and buckled with a dynamic load of 100 lbs dropped a foot off the ground. The 0-45-135 design buckled at a static load of 150 lb. Thus, we concluded that the 0-90-0 was the better design. However, since the '90' layer does nothing for bending and two '0' layers on the outside of the tube can hold more bending load, the design was changed to 90-0-0.

FIGURE 40. THE FRAME OF THE OLD STRIDER WAS USED AS A TESTING RIG FOR CARBON FIBER TUBES.

FIGURE 41. WEIGHT WAS SUSPENDED FROM THE STRIDER FRAME TO TEST FOR STRENGTH AND FLEXIBILITY.

MANUFACTURING OF TUBES

Manufacturing the carbon fiber tubes was broken up into five major steps. The first step was to wrap the mandrel with the desired weave. The second step was to cure the tubes in an oven at a specified temperature and pressure. Third, the cured tube was cut to length. Next, the aluminum inserts were bonded to the carbon fiber tubes. Finally, the tube was reinforced if needed. The following describes these steps in detail and highlight the lessons that Ricky and George learned while manufacturing these tubes. Recommendations for improvement are also included.

Wrapping the Mandrels

The quality of the finished tube is critically dependent on the quality of the wrapping; therefore, great attention was necessary in order to achieve a good result. For example, voids in the weave would carry through to the end product and would most likely be filled by excess resin, which does not react to loads in the same way as the carbon fiber. It was very important to keep an eye on how well the weave was wrapped.

The mandrel that the carbon fiber was wrapped on was bought to size (1.5 in diameter) from McMaster-Carr. The mandrel was made of polypropylene; this material was chosen because of its lower thermal expansion properties. This is important because the mandrel has to be placed in the oven along with the carbon fiber during the curing process. If the mandrel expanded too much, the internal diameter of the tube would be unpredictable.

With that said, we noticed that the mandrel had a slightly larger diameter after the first heat cycle. The initial diameter was measured to be 1.52 in. After one heat cycle, the average diameter was 1.53-1.54 in. While this difference seems negligible, the tolerance between the finished tube and the aluminum inserts varied widely, making quality control very difficult. For future development, we recommend that the mandrel be taken through one heat cycle before using it for tube production.

For our tubes, we used sheets of pre-pregnated, uni-directional carbon fiber. This type of carbon fiber was readily available to us for free in the composites lab and was very easy to use.

Before wrapping the first layer, the mandrel was sprayed with a dry silicon release, specifically, the LPS Dry Film Silicon Lubricant. This was used because this is not volatile and is rated up to 500 °F. When it is first applied, the spray stays wet for a while; so, the mandrel was left to dry for a few minutes before applying the carbon fiber. After the lubricant has dried, the first layer is applied. The following pictures shown were taken during the prototyping phase; the same concepts applied to the final tubes.

FIGURE 42. THE MANDREL WAS SPRAYED WITH SILICONE LUBRICANT AND WRAPPED WITH CARBON FIBER.

For every layer, the diameter was measured in order to cut out the correct amount of carbon fiber. From our prototype, we found that a little bit of overlap is desirable when wrapping a layer with fibers in the axial direction ('0' orientation). Overlap is very important when the fiber are oriented tangentially ('90' orientation). This is because the resulting seam tends to tear the fibers around it apart. This is especially crucial when the fibers around the seam are in the '0' orientation; the seam will cause cracks along the tube when bending occurs. When wrapping the '90' layer, an overlap length of 1/10 the circumference of that layer is recommended. These cracks occurred on our final tubes and we had to reinforce the tubes. Reinforcing the tube is covered later in the report.

FIGURE 43. MULTIPLE LAYERS OF CARBON FIBER WERE WRAPPED ON TOP OF ONE ANOTHER.

For the prototype tubes and reinforcements, a cross weave was used. The prototype tubes saw a weave orientation 45° and 135° from 0. A 30° orientation was used for the reinforcement. In order to figure out the appropriate length and width of carbon fiber sheet needed, the surface area of the previous layer was calculated using the measured diameter and length. This surface area is equivalent to the overall area of the sheet needed. The shape needed is a parallelogram. With this, we were able to calculate the length and width needed.

When wrapping these angled layers, it was very important to start the wrap well, with the edge of the sheet meeting up nicely as shown above. This is because a small imperfection magnifies as you continue to wrap down the mandrel. Some tugging and stretching of the sheet helped to get the edges to meet up nicely.

From prior testing, we found that the weave pattern of 90-0-0 was more effective at resisting the bending loads occurring in the Strider than the 0-45-135 pattern. Very little overlap was used in the '90' layer, thus, cracking became a problem later on. The seam on the first '0' layer was placed 180° apart from the seam of the '90' layer. The second '0' layer seam was placed 90° apart from the seam of the first '0' layer. As mentioned earlier, we learned that a little overlap on each layer is desirable.

Figure 44. Shrink tape was wrapped around the parts proir to curing.

After the layers are wrapped, a release-coated Hi-shrink tape, bought from McMaster-Carr, was used to bind the outer layer. This tape applies inward pressure on to the tube when is expands during the curing process. Scotch tape was used to hold the ends of the shrink tape on the mandrel. When wrapping the shrink tape, we made sure that the tape overlapped at least 1/8 the width of the tape to make sure that the resin would not leak out and that the pressure is roughly uniform.

CURING THE TUBES

Curing the tubes required the use of the Autoclave Oven in the Composites Lab. Because this is a dangerous and expensive machine, the lab assistant, Parker Drennan had to help turn on and set up the oven. Ricky and Parker took turns to monitor the oven while it ran.

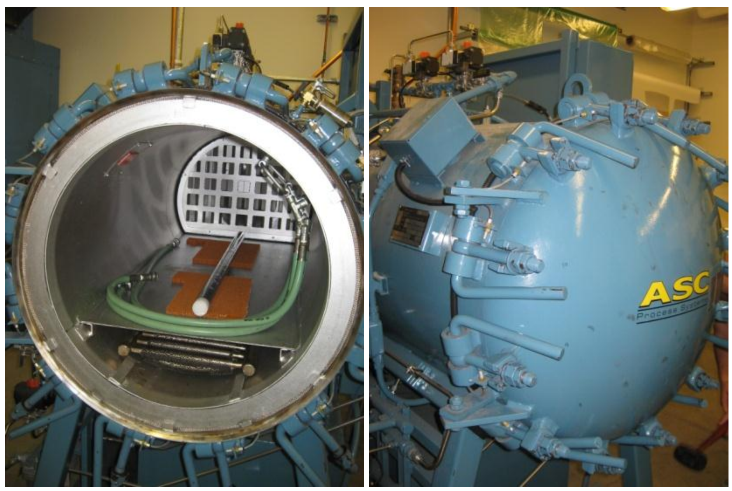


FIGURE 45. THE PARTS WERE PLACED IN THE AUTOCLAVE OVEN TO CURE.

The temperature and pressure was set to 275°F and 80 psig, respectively. The cook time was set at four hours at those setting. Because the oven requires a long time to heat up and cool down, the actual time required to produce one heat cycle was around six to seven hours. When closing and opening the Autoclave oven, it is crucial to following the specified steps outline in the oven's manual.

CUTTING THE TUBES

After the tubes have been cured and cooled to room temperature, the product slid off the mandrel with little effort and looked like the following:

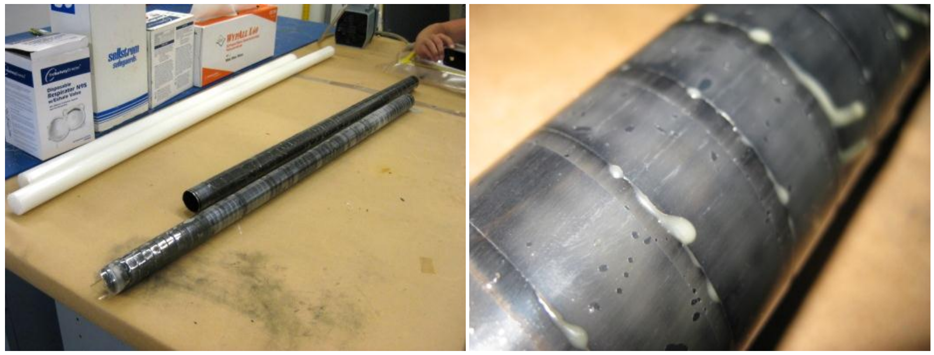


Figure 46. After curing, the carbon fiber tubes where slid off the mandrels.

The leftover resin was removed with a blade and the shrink tape was peeled off. Some of the shrink tape did not peel off as expected; the excess shrink tape was just neatly cut off on the final tubes.

Breathing in carbon dust is very harmful to ones health, so Ricky had to wear a respirator with a super-fine dust filter while cutting and sanding the carbon fiber. To minimize the amount of dust released into the air, the shop vacuum cleaner was turned on to suck up the dust while cutting. Cutting was done with a diamond blade Dremel rotary tool. High speed is necessary to avoid tearing and breaking off the fibers. Blue painters tape was used to guide the cut and protect the fibers from fraying.

Figure 47. Carbon fiber tubes where cut to length in the composites lab.

Bonding the Aluminum Inserts with the Carbon Fiber Tubes

After the tubes were cut to length, the inside of the carbon fiber, where contact is made with the aluminum insert, was sanded to create grooves for the epoxy to grab on to. Next, epoxy was applied to the inside of the carbon fiber and the outside of the aluminum and the parts were slid together according to the gluing schedule shown below. Tiny strips of pre-pregnated carbon fiber were used to line the aluminum inserts to maintain an equal gap between the carbon

fiber and the aluminum insert. This produced a more even distribution of epoxy.

FIGURE 48. OVERVIEW OF BONDING THE CABRON FIBER TUBE TO THE ALUMINUM INSERTS

A:

Angled Arms
Rear Cross Tube
Front Wheel Inserts

B:

Tri to "Leg"

C:

Bungee Hooks
Tri to Arms

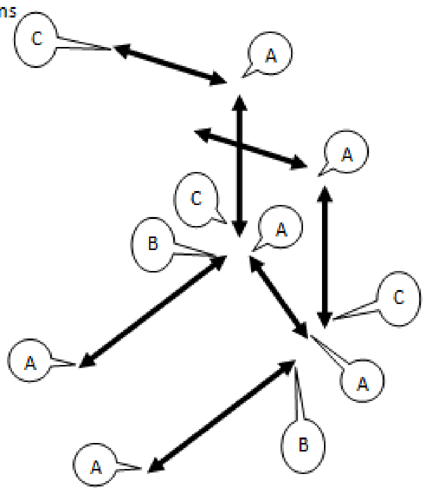


Figure 49. The order of joints to be glued together with epoxy.

Reinforcing the Tubes

After we used epoxy to connect the joints to the carbon fiber on our final product, we noticed that a few cracks that compromised the structural rigidity of the Strider. As mentioned before, this was because the short overlap on the '90' layer tore the '0' layers apart. As a result, we had to reinforce the tubes.

To do this Ricky and George sanded the tubes down till the naked carbon fiber was revealed. After carefully wiping off the excess dust, two to three additional layers were applied in the same manner as wrapping the mandrel. For the vertical tubes, a 10 inch long layer, with a '30' orientation, was wrapped locally near the connectors for added strengthening. Shrink tape was then used to bind the new layers.

The entire part, including aluminum and epoxy, was placed in the autoclave and cooked according to the required cycle. The oven was set at a lower temperature of 250°F and a longer cook time of 4.5 hours so that the new layers could cure without reaching the glass temperature of the existing tube.

Figure 50. More carbon fiber sheets were applied to the existing parts to reinforce the tubes.

Recommendations

Since carbon fiber was very new to our group, in the interest of safety we designed in an extremely high safety factor for all the parts. As a result, the tubes were very large and the design was not fully optimized in terms of cost and material use. The following are some recommendations for future improvements on the design of the Strider.

a. Smaller diameter (same thickness) tubes could be used and still maintain a reasonable safety factor.
b. Optimization of parts to minimize cost and material use.
c. Purchase professionally made tubes to improve uniformity and tolerances.
d. More precise tolerances for aluminum to insure better mating of parts.
e. Minimize material used to reduce cost and weight.
f. If manufacturing your own tubes:
    i. Don't leave un-cured tubes out overnight.
    ii. Give a good amount of overlap for carbon fiber strips.
    iii. Mind the change in diameter of the polypropylene mandrel.
    iv. Mandrel may change shape and not be straight.
    v. Consider using a different material for the mandrel.
g. More research on types and available qualities of carbon fiber to guarantee the best possible design.
h. Dependable access to shop equipment would speed the production process.

The "Nathan Factor" & The Importance of Proper Testing

Unlike many other projects, the Strider has a huge human factor that critically alters the effectiveness of the product. The Strider must not only work in conjunction with Nathan, but also assist him without additional hindrances. This is why we spent a lot of effort and time defining what we call the "Nathan Factor."

The "Nathan Factor" is a combination of typical human factors, such as ergonomics, and Nathan's enjoyment in using the Strider. These factors are extremely important and cannot be overlooked. The old Strider was well designed for strength and safety, but it was unable to properly cater to Nathan's other needs. As a result, it had a very high safety factor, but Nathan was unable to use or enjoy it. With the new Strider, we made sure to avoid the mistakes of the previous Strider by dealing carefully with Nathan's ability to enjoy using the final product.

Thus, properly designing and testing of test pieces was critical. Safety is the highest concern and an appropriate safety factor was chosen. Since we needed

to make the Strider as light as possible, the amount of stress and loading on the frame and the suspension was carefully designed and tested. We tested different carbon fiber layups with the same epoxy and aluminum tube sizes in our final design in order to create the lightest and safest frame structure possible within our budget.

As mentioned earlier, Nathan’s comfort is also very important. Even if the Strider does everything else perfectly, Nathan will not want to use it if it causes him discomfort. This is one of the main reasons why Nathan does not use his KidWalk—it is extremely uncomfortable and he cannot spend much time in it. Hence, the design of the harness, how the extension springs suspend him, and the connecting points on the harness and the frame are very significant. The connecting points must be placed so that he feels most natural in the upright position; the Strider should not constantly pull him into a position that is unnatural and uncomfortable.

One of our biggest concerns with the Strider lies with the harness design. The harness is the only component that physically connects Nathan to the Strider. This component is where we expect comfort to play the most critical role. With the help of our kinesiology partners, we researched many potential harness designs and tested the Kaye Suspension Harness used in our final design with Nathan. We suspended him in the harness from a rig and observed him to determine his level of comfort and the most effective locations for bungee cord connection points.

Once we found that our product was safe, we had Nathan try it out to see what he and his parents liked and disliked about it. We monitored his ability to walk while supported and gauged how much he enjoyed it in comparison to his other assistive devices. We received a very positive reaction from Nathan and his parents. It seemed, in their opinion, to be superior in comfort and ease of use to Nathans other devices.

In order to develop a great final product, we made some final modifications to guarantee the highest level of safety and the utmost satisfaction with the Coopers. The final iterations of the Strider included reinforcing the carbon fiber tubes and painting and labeling the frame according to Nathans preference. Properly testing our design for both the function and Nathan’s ability to enjoy using the Strider was extremely important. After preliminary testing and a final showing at the Design Expo, where Nathan used his Strider for the second time, it was clear that this will be a very useful device for Nathan and his family.

Conclusion

The ultimate purpose of the Strider is to help Nathan be healthier with better blood circulation and muscle development and happier with being more mobile and independent. This is why the success of the Strider was so important. This product is not just to give Nathan exercise, but to also give him the ability to explore, play, and enjoy life to the fullest. We worked to the best of our ability to use our engineering skill and knowledge to positively impact the life of child with a disability.

Nathan's condition, though it decreases muscle function, does not and should never decrease his ability to live an active and fulfilling life. Thanks to an NSF grant and the efforts of Dr. Kevin Taylor, Dr. Brian Self and Dr. Jim Widmann of the Kinesiology and Mechanical Engineering departments at Cal Poly San Luis Obispo, we had the opportunity to provide Nathan with some fun recreational and therapeutic equipment that he can enjoy. Good communication with the Coopers, our sponsor, and our advisor and the use fundamental problem solving techniques has allowed us to successfully complete this project. The purpose of the Strider was to help the condition of a young boy with a disability, but there is a much deeper meaning behind it. This project has shown how much a person is not defined by their disability. Despite the limitations caused by a disability, there is enormous potential for improvement with the use of assistive devices. These improvements help free a person from limitations and better their quality of life. Our hope is that Nathan will be able to enjoy the Strider for years to come.

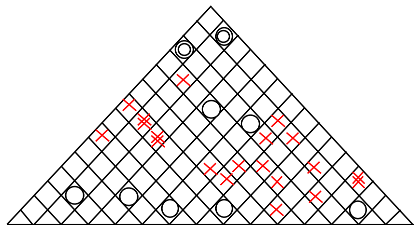
References

1) "Spinal Muscular Atrophy FAQ." *SMA Foundation | Spinal Muscular Atrophy*. Web. 03 Feb. 2011. <http://www.smafoundation.org/>.

APPENDIX A

Below is our Quality Function Deployment matrix which relates the importance of customer needs to their related engineering objectives.

Larger is Better
Nominal is Best
Smaller is Better



- Strong Positive Correlation
- Positive Correlation
- Negative Correlation
- Stong Negative Correlation

Customer Desciption:
1 = Nathan & Amy Cooper
2 = Dr. Taylor, Other Children with SMA and their parents & caretakers
3 = NSF, Disability Community, Companies that make equipment for people with SMA

Specifications (Hows): A = Weight, B = Dimensions (Upright), C = Dimensions (Collapsed), D = Adjustibility, E = Shock Loading, F = Elasticity, G = Cost of Materials, H = Accessibility, I = Maneuverabilty, J = Loading and Fatique, K = Maintainance, L = Stability, M = Materials, N = Durability, O = Height of Center of Gravity

Customer Requirements (Whats)	Item No.	Importance	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Customer Ratings 1 (Bad)	2	3	4	5 (Good)
Allow user to move in standing position via legs		5	9	3		3		9		3	9			9	3	3	3	BCEF		A		D
Lightweight		5	9			3			9	3	9	9	3	3	9	9	9	CA	F	B	D	E
User comfort		5	9	3	3	3	9	9	3	3	3	3	3	3	9	3	3	F	A	E	D	BC
Move over grass, gravel, pavement		4	9	3			3	3	3	3	9	3	3	3	3	9	3	EF	D	B	A	C
Have suspension and shock absorbing		5				3	9	9		3	3	3	3		9	3		A	F	B	D	CE
Be height and weight adjustable		5		3	3	9	9	3	3	3	3		3	9	3	3	9		E	D	C	AFB
Allow caretaker to move product		4	9	9	9				3	3	9		9	9	3	9	9	E			FB	ADC
Be compatible with HKAFO		5		9		9	3	3		9	9			3	3	3						
Size based on household standards		4	3	9	9	3			3	9	9			3	9		3	C	A		B	DFE
Durable and resistant to spills/puddles/mud		4							3	3	3	3	9	9	9	9		C	E		BDF	A
Easy to clean and sanitize		3		3	3	3			3	3			9		3	9			C	E	D	ABF
Have rest support for head and arms		5		9	3	9	3	3	9	3	3		3	3	9	9	3	AE	F	BD		C
Be collapsible and portable		4	9	3	9	9			3			3	3		3	9		AC		BD	F	E
Have a drink holder		5		3	3	3				9	3				3	9		AE				BCDF
Be lockable in place		4	9			3			3			3	9	9	3	9	9	A			E	BCDF
Allow user to bounce in place		5	3	9		9	9	9	9	3	3	9	9	9	9	9	9	ABCF			D	E
Be easy to maneuver and accelerate by user		5	9	9		3	3	3	3	3	9	3	3	9	9	3	9	ADEF		B		C
Be aesthetically pleasing		4		3	3	3	3		9	3					9	3		FA	C	BD		E
Tamper-Proof		4		3	3	9	3	3	9	3			9	3	9	9				D	B	ACEF
Attachable food tray		2	3	3	3	3				3	3		3	3	3	3	3	AE				BCDF
Collapsible seat		2		3	3	9			3	9	9	9	3	3	3	3	9	ADF			DC	B
No sharp/protruding points		5		3	3	3			3	9	3		3		3			A				BCDFE
No Pinch Points		5		3	3	9	3	3	3	3	3		9		3	3		A	B		C	DEF
Stable/ no tipping		5	3	3			3	3	3	3	9	3	3	9	3		9			BF	AC	DE
Low general end cost		3	3	3	3	3	3	3	9	3	3	9	9	3	9	3		CA		F	D	BE
Allow user to access others		5	3	9		9				9	9	3	3	9	3	3	9	F	B	D	C	EA
Easy to replace parts		3	9	3	3				9	9	3	9	9	3	9	9	3	CA	E		BFD	
Electric drive		2	9	3	9		3		9	9	9	9	9	9	9	9	9	EA	DF		B	C

Company Ratings

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Good	5	D,E		E	B.C	C	E	E		B	B,C,D	A,D,		D		D
	4	B	D,E	D	F	E	D	F	C,E	D	E,F	,D,	B,F	B,C	C,D	,C,D
	3	5	B	B	D			D	A,D	C		E	C	E,F	A	E,F
	2	C	F	F	E	B,D		A	B	F				A	E	
Bad	1	A	A,C	A,C	A	A,F	B,C	C	F	A,E		A,C				

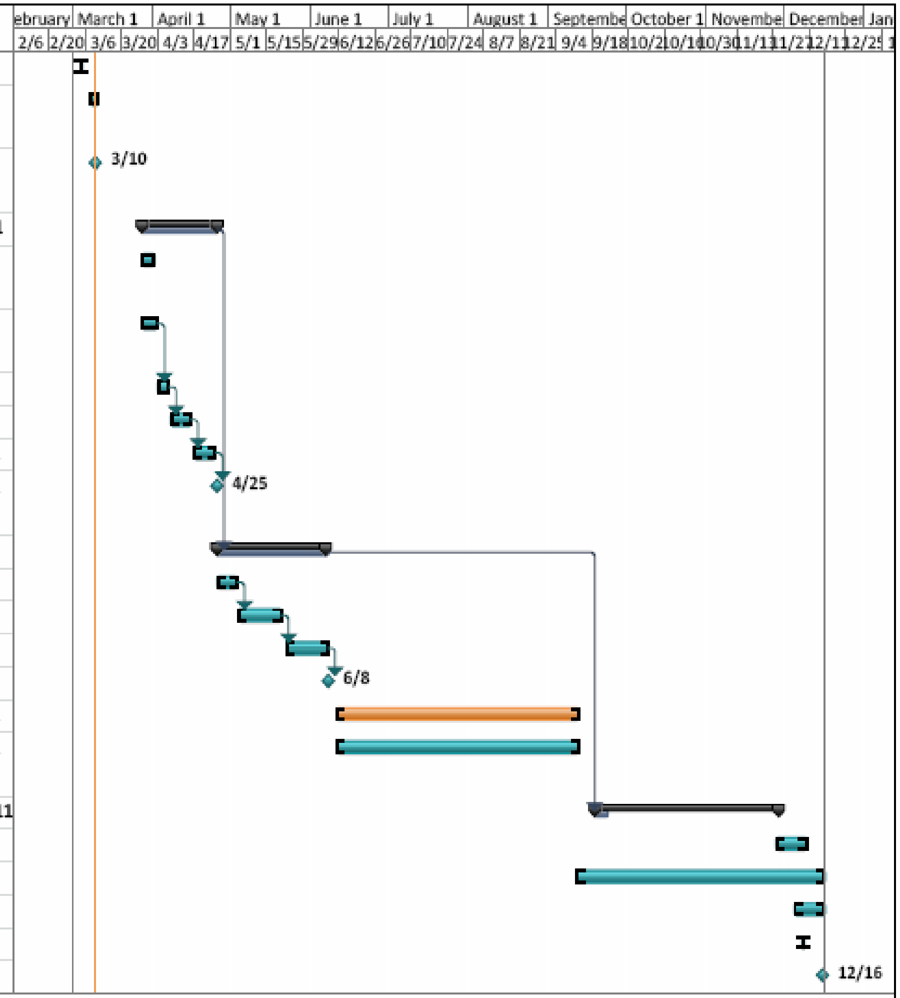
A STRIDER 1.0
B Dynamic Standers
C Mobility Scooters
D Gait Trainers
E Jimmy-Jump-Up
F Prone Stander

Strong - 9
Medium-3
Weak - 1

Relationship Strength

APPENDIX B

ID	Task Mode	Task Name	Duration	Start	Finish
1		Cooper Meeting	1 day	Fri 3/4/11	Fri 3/4/11
2		Present to Dr. Taylor - Preliminary	3 days	Tue 3/8/11	Thu 3/10/11
3		Preliminary Design Report Due	0 days	Thu 3/10/11	Thu 3/10/11
4		**Design**	**21 days**	**Mon 3/28/11**	**Mon 4/25/11**
5		Foam/Fiber glass testing	5 days	Mon 3/28/11	Fri 4/1/11
6		Develop Components and systems	6 days	Mon 3/28/11	Sat 4/2/11
7		Vendor Details	4.5 days	Sun 4/3/11	Thu 4/7/11
8		Design Analysis	6 days	Fri 4/8/11	Fri 4/15/11
9		Model/BOM	6.5 days	Sun 4/17/11	Mon 4/25/11
10		Critical Design Review with DR. T	0 days	Mon 4/25/11	Mon 4/25/11
11		**Build**	**30 days**	**Tue 4/26/11**	**Mon 6/6/11**
12		Buy Materials	6 days	Tue 4/26/11	Tue 5/3/11
13		Cut	13 days	Wed 5/4/11	Fri 5/20/11
14		Paste/Assemble	12 days	Mon 5/23/11	Tue 6/7/11
15		Status Report	0 days	Wed 6/8/11	Wed 6/8/11
16		Summer	67 days	Sat 6/11/11	Mon 9/12/11
17		Summer Building/Overflow	67 days	Sat 6/11/11	Mon 9/12/11
18		**Test**	**51 days**	**Mon 9/19/11**	**Mon 11/28/11**
27		Final Rebuild	10 days	Mon 11/28/11	Fri 12/9/11
28		Final report	70 days	Mon 9/12/11	Fri 12/16/11
29		Finalize design	10 days	Mon 12/5/11	Fri 12/16/11
30		Expo	1 day	Thu 12/8/11	Thu 12/8/11
31		Deliver	0 days	Fri 12/16/11	Fri 12/16/11



Project: Strider.mpp
Date: Thu 3/10/11

Task	External Milestone	Manual Summary Rollup
Split	Inactive Task	Manual Summary
Milestone	Inactive Milestone	Start-only
Summary	Inactive Summary	Finish-only
Project Summary	Manual Task	Deadline
External Tasks	Duration-only	Progress

Page 1

Appendix C

Below are the morphological attribute charts that we produced during our ideation phase to come up with different design concepts.

Terrain Transfer	Style	Source of Power	Hold Nathan	Source of Stability
wheels	batman	electricity (battery)	harness	base of support
legs	cars	recip engine	pfd	center of gravity
treds	lighting mcqueen	gasoline	straight jacket	training wheels
skills	aerodynamics	solar	bungie	tripod
bouncing ball	light-up wheel	nathan	saddle	quad
Felt "moving men"	not hospital	kicking	suit	5+ wheels
rollers	balanced	arms	baby bjorn	segway
walkers	color	parents	floaties	ipod
ball bearing	concealed	animal	velcro	gyro
slipping "banana"	ironman	turbine	elastic bands	big wheels
hovering	open	gears, chain, belt	kyack suit	protective
pogo stick	kidfriendly	elephant	climbing harness	independent axes
duck feet	age appropriate	biofuel	diper	designed falling
animals	spiderman	compressed air	sumo suit	bo-bo dolls
batmobile	utility belt	biofuel	base jumping	wheelie bars
lighting mcqueen	accessory	steam	trapeze	wheel angle
sled dogs	fisher price	jet pack	parachute	damping
animal adaptive		prop	PT pool	helmet
tripods		gravity	standing harness	neck rest
shocks		spring	arm rest	
springs		pumping	foam	
			neoprene	
			crotch straps	
			car seat	
			leach	
			pillow	
			hand	
			blanket	
			cocoon	
			baby board	
			body brace	
			ironman	

Adjustability	Nathan's Capability	Material	Mode of Movement
adaptable wheels	Kicking	Carbon Fiber	Robotic Legs
arm rest	sitting	Plastics/Polymer	Casters
height	standing	Surf Foam w/ Fiberglass	Tracks
weight	walking	Aluminum	Push
terrain	bouncing	Rubber	Sterling Engine
collapse	see-saw	Springs	Skis
color	tic-tac-toe	Bungie	Pedal
straps	arm exercise	Velcro	Bounce Ball
paint	grip	Tent Poles	Giant Wheel
cupholders	core	Wood	Full Body Movement
sound fx	amplified movement	Wire	Use Bounce
speakers	touch pad	Wool	Magnify Strength with Gears/Chains/Sprocket
flexibles	elevated arm rest	Foam	Perpetual/jet engine
seat	joystick	Cotton	Compressed air
foot rest	throwing		Bubble ball
harnmess angle	outside access		Skateboard
width of harness	out of field of view		reciprocating engine
interchangeable parts	trails		"Walk by Wire"
disassemble			"Walk by Cable"
tire pressure			Treads
speed			Hand Pedal
brakes			Fluild power/Aquatics
Direction			Duck Feet
lockability			
motor possibility			
elasticity			

Appendix D

```
%Arm Deflection
clear;clc;

%Materials
aluminum='aluminum';
steel='steel';
copper='copper';
PVC='PVC';
wood='wood';

disp ('Enter material:')
Material=input('','s');

%Dimensions
Ro=1.315;                              %Outer radius of tube
thickness=.109;             %Pipe thickness
Ri=Ro-thickness;                   %Inner radius of tube
rc=18;                                %Radius of curvature of
arm (centroidal axis)
L=40;

A=pi*(Ro^2-Ri.^2);                     %Area of cross-section
(in^2)
Vc=A*rc*(pi/2);                    %Volume of curve
I=(pi/4)*(Ro^4-Ri.^4);             %Moment of inertia

%Forces
Ay=1:1:100;                              %Total vertical load
Bx=0;                                           %Horizantal force
(forward)
Mz=Ay*rc;


%Curved portion



switch (Material)                      %Modulus of elasticity
(lbf/in^2) and unit weight(lbf/in^3)
    case {'aluminum'}
        E=10.4*10^6;
        w=.098;
    case {'steel'}
        E=30.0*10^6;
        w=.282;
    case {'copper'}
        E=17.2*10^6;
        w=.322;
    case {'PVC'}
```

```
        E=.5*10^6;
        w=.052;
%      case {'wood'}
%          E=
%          w=

end



rn=Ro^2/(2*(rc-sqrt(rc^2-Ro^2)));            %Radius of
curvature of arm (neutral axis)
e=rc-rn;


deltaAy=Ay.*rc^3*pi./(4*E.*I);
weightCurve=Vc*w;
%disp    (['Vertical    deflection    at    A    =    '
(num2str(deltaAy)) ' inches'])


%Vertical portion


Vs=A*L;
weightStraight=Vs*w;

deltaBx=Bx*L^3./(3*E.*I)...                         %Due to
horizantal force
        +Mz*L^2./(2*E.*I);                          %Due to
moment
deltaBy=L-sqrt(L^2-deltaBx.^2);                     %Change
in vertical height at B

weightTotal=weightCurve+weightStraight;
DeflectionAY=deltaAy+deltaBy;
%disp (['Forward deflection at B = ' num2str(deltaBx)
' inches'])
%disp(['Weight  of  arm  =  '  num2str(weightTotal)  '
lbs'])


%clear weightTotal thickness Vs Vc Ri A
%thickness=[0:.01:.5];
%weight=(Vs+Vc)*w;
subplot (212); plot (thickness,weightTotal)
xlabel('Load','FontSize',11)
ylabel(['Arm      Weight      (lb)      for      '
Material],'FontSize',11)
```

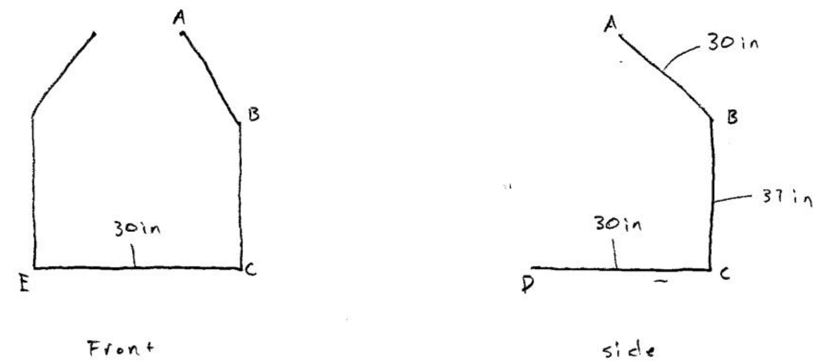
```
title(['Load=' num2str(Ay) 'lbs,R=' num2str(rc) 'in,
L='...
    int2str(L) 'in, OD=' int2str(Ro)])
% hold
subplot (211); plot (thickness,DeflectionAY)
ylabel(['Vertical deflection (in) for ' Material
],'FontSize',11)
%subplot (thickness,weightTotal,DeltaAy)
```

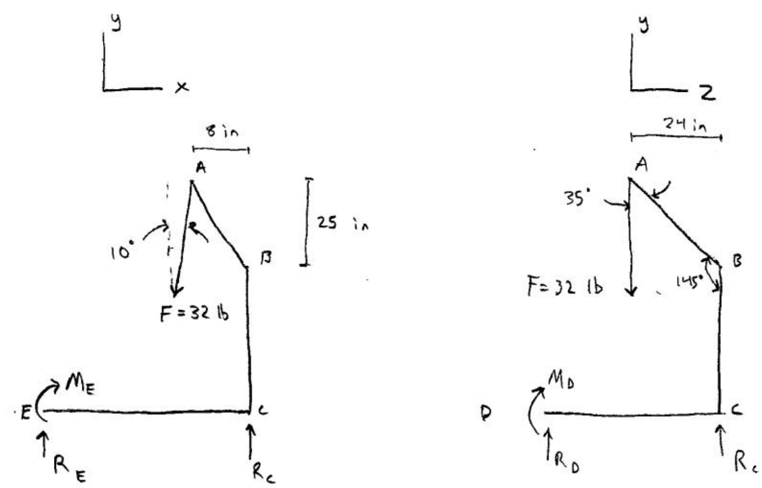
APPENDIX E

Hand calculations

E.1 Stress

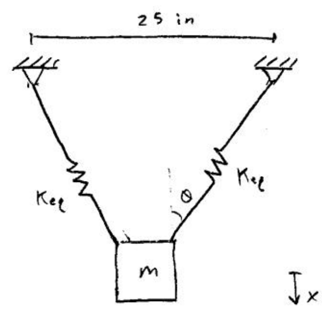
Stress Overview of Carbon tubes (not to scale)





Weight (Load) Fluctuation on a Single Bungee Connection

- neglect damping
- assume linear springs
- neglect structure stiffness

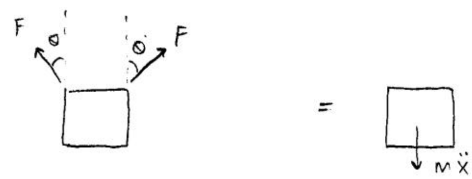


$K_{eq} = \left(\frac{2}{K}\right)^{-1} = \left(\frac{2}{5\frac{lb}{in}}\right)^{-1} = 2.5\ \frac{lb}{in}$

Static load

$mg = 2F\cos\theta$

$F_s = \frac{mg}{2\cos\theta} = \frac{35\text{ lb}}{2\cos 9} \approx 18\text{ lb}$



$-2F\cos\theta = m\ddot{x}$ (1)

$F = K_{eq}\frac{x}{\cos\theta}$ (2)

combining (1) and (2)

$m\ddot{x} + 2K_{eq}x = 0$

If initial displacement is 5 inches

$x(t) = 5\cos\left(\frac{2k_{eq}}{m}t\right)$

$x_{max} = 5$

$F_{max} = K_{eq}\frac{x_{max}}{\cos\theta} = \left(2.5\frac{lb}{in}\right)\frac{5\text{ in}}{\cos 9^{\circ}} \approx 13\text{ lb}$

Total load : $F_s + F_{max} = 31\text{ lb}$

Stress in Carbon Fiber tube AB

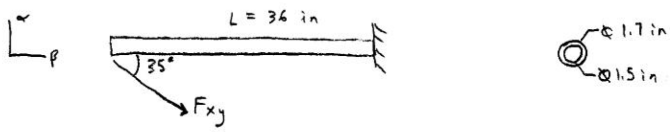
$F_y = F\cos 10 = 32\cos 10 = 31.5$ lb

$F_x = 32\sin 10 = 5.6$ lb

$F_z = 0$ (neglected)

$F_{xy} = \sqrt{F_x^2 + F_y^2} = 32$ lb $= F$

Treat AB as cantilever beam



$F_\alpha = F_{xy}\sin 35 = 18.4$ lb

$F_\beta = F_{xy}\cos 35 = 26.2$ lb

$$\sigma\big|_{tension} = \frac{Mr}{I} - \frac{F}{A} = \frac{F_\alpha L \frac{D}{2}}{\frac{\pi}{64}(D^4 - d^4)} - \frac{F_\beta}{\frac{\pi}{4}(D^2 - d^2)}$$

$$= \frac{(18.4\text{ lb})\left(\frac{1.7\text{ in}}{2}\right)(36\text{ in})}{\frac{\pi}{64}(1.7\text{ in}^4 - 1.5\text{ in}^4)} - \frac{(26.2\text{ lb})}{\frac{\pi}{4}(1.7^2\text{ in} - 1.5^2\text{ in})}$$

$$= 2.85 \text{ ksi}$$

$$\sigma\big|_{compression} = \frac{Mr}{I} + \frac{F}{A}$$

$$= 2.96 \text{ ksi}$$

$\tau = \frac{VQ}{Ib}$ for tube $\tau = \frac{2V}{A} = \frac{2F_{a}}{\frac{\pi}{4}(D^2 - d^2)}$

$= \frac{2(18.4 \text{ lb})}{\frac{\pi}{4}(1.7^2 \text{in} - 1.5^2 \text{in})} = .073 \text{ ksi}$

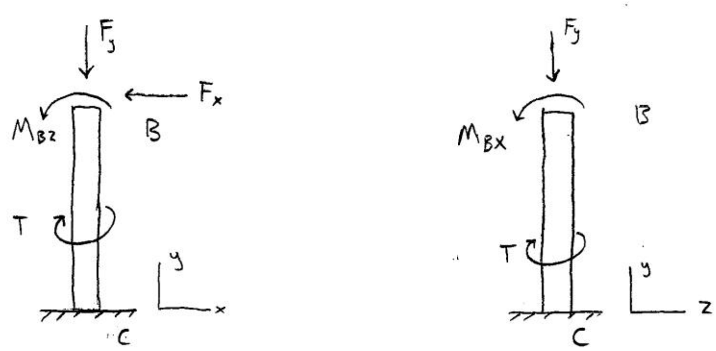
Von mises stress, plane stress

$\sigma' = \sigma$ at top of tube
$\sigma' = \tau$ at side of tube

For carbon fiber $S_{ut} = 180$ ksi

$FS = \frac{S_{ut}}{\sigma'} = \frac{180 \text{ ksi}}{2.96 \text{ ksi}} = 61$

Stress in carbon fiber tube BC



$F_x = 5.6$ lb

$F_y = 31.5$ lb

$M_{BZ} = (5.6\ \text{lb})(25\ \text{in}) + (31.5\ \text{lb})(8\ \text{in}) = 392\ \text{in lb}$

$M_{BX} = (31.5\ \text{lb})(24\ \text{in}) = 756\ \text{in lb}$

$M_{CZ} = M_{BZ} + F_x L = (392\ \text{in lb}) + (5.6\ \text{lb})(37\ \text{in}) = 600\ \text{in lb}$

$M_{CX} = M_{BX} = 756\ \text{in lb}$

$M_C = \sqrt{M_{CX}^2 + M_{CZ}^2} = \sqrt{756^2\ \text{in}^2\text{lb}^2 + 600^2\ \text{in}^2\text{lb}^2} = 965\ \text{in lb}$

$T_C = 135\ \text{lb in}$

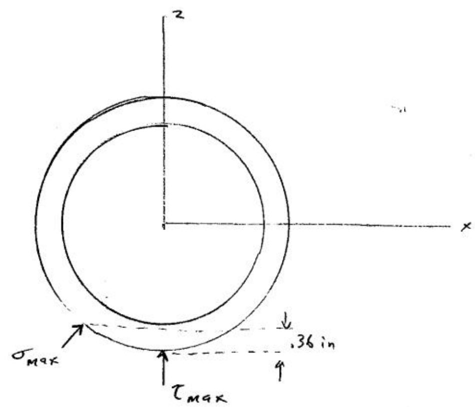
Stress:

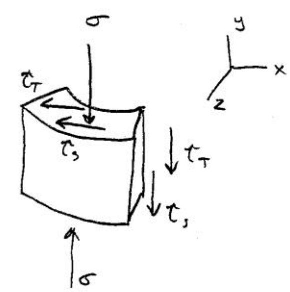
$$\sigma\Big|_{tension} = \frac{M_C r}{I} - \frac{F_y}{A} = \frac{(965\ \text{in lb})\left(\frac{1.1\ \text{in}}{2}\right)}{.16148\ \text{in}^4} - \frac{31.5\ \text{lb}}{.503\ \text{in}^2} = 5.02\ \text{ksi} \ @ \ -52°$$

$$\sigma\Big|_{compression} = \frac{M_C r}{I} + \frac{F_y}{A} = 5.14\ \text{ksi} \ @ \ 128° \text{ from x axis}$$

$$\tau_s = \frac{2V}{A} = \frac{2\,(5.6\ lb)}{.503\ in^2} = .022\ ksi \quad @\ 90^\circ \text{ from x axis}$$

$$\tau_T = \frac{T_c r}{J} = \frac{(135\ lbin)\left(\frac{1.7\ in}{2}\right)}{\frac{\pi}{32}\left(1.7\ in^4 - 1.5\ in^4\right)} = .355\ ksi$$





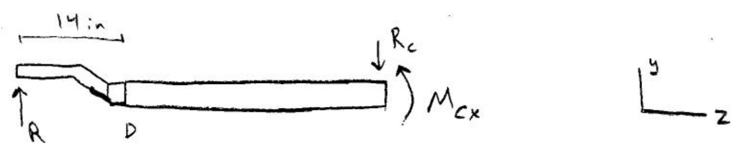
$$\sigma\Big|_{@\ \tau_{max}} = \frac{-5.14\ ksi}{1.7\ in}(.36\ in) + 5.14\ ksi = 4.1\ ksi$$

$$\sigma' = \frac{1}{\sqrt{2}}\left[2\sigma^2 + 6\left(\tau_s + \tau_T\right)^2\right]^{1/2} = 5.2\ ksi$$

$S_{ut} = 180\ ksi$

$FS = \frac{180}{5.2} = 34$

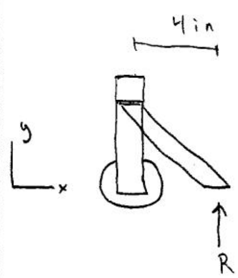
Stress in carbon fiber tube CD



$$R_D = \frac{M_{cx}}{L} = \frac{756 \text{ in lb}}{30\text{in} + 14\text{in}} = 17 \text{ lb}$$

$$\sigma_c = \frac{(756 \text{ in lb})\left(\frac{1.7\text{ in}}{2}\right)}{I} = 3.98 \text{ ksi}$$

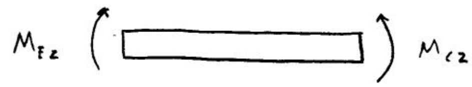
$$\tau_s = \frac{2\,(17 \text{ lb})}{A} = .068 \text{ ksi}$$



$$T_D = (17 \text{ lb})(4 \text{ in}) = 68 \text{ lb in}$$

$$\tau_T = \frac{(68 \text{ lb in})\left(\frac{1.7\text{ in}}{2}\right)}{J} = .179 \text{ ksi}$$

Stress on Carbon fiber tube CE



$M_{cz} = M_{Ez} = 600$ in lb

$\sigma = \frac{M_{cz}\, r}{I} = 3.2$ ksi

Fatigue stress at point C

Mean load : 18 lb
Alternating load: 13 lb

Moments:

Mean

M_{cm} : $\vec{r}_{cA} \times \vec{F}_{Am}$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ -8 & 62 & 24 \\ -3.2 & -17.7 & 0 \end{vmatrix} = 425\,\hat{i} - 77\,\hat{j} + 218\,\hat{k}$$

$$M_{cm} = \sqrt{425^2 + 218^2} = 478 \text{ in lb}$$

$$T_{cm} = 77 \text{ lb in}$$

Alternating

M_{ca} : $\vec{r}_{cA} \times \vec{F}_{Aa}$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ -8 & 62 & 24 \\ -2.3 & -12.8 & 0 \end{vmatrix} = 307\,\hat{i} - 55\,\hat{j} + 158\,\hat{k}$$

$$M_{ca} = \sqrt{307^2 + 158^2} = 346 \text{ in lb}$$

$$T_{ca} = 55 \text{ lb in}$$

$$I = \frac{\pi}{64}\left(1.5^4_{in} - 1.38^4_{in}\right) = .070478 \text{ in}^4$$

$$A = \frac{\pi}{4}\left(1.5^2 - 1.38^2\right) = .2714 \text{ in}^2$$

$$J = 2I$$

Mean stress

$$\sigma_m = \frac{M_{cm}}{I} + \frac{F_{ym}}{A} = \frac{(478 \text{ in lb})(\frac{1.7 \text{ in}}{2})}{I} + \frac{(17.7 \text{ lb})}{A} = 5.2 \text{ ksi}$$

$$\tau_{sm} = \frac{2V_m}{A} = \frac{2(3.2 \text{ lb})}{A} = .013 \text{ ksi}$$

$$\tau_{Tm} = \frac{T_m r}{J} = \frac{(77 \text{ lb in})(\frac{1.5 \text{ in}}{2})}{J} = .41 \text{ ksi}$$

$$\sigma_m' = \left((K_f\sigma_m)^2 + 3K_{fs}^2(\tau_{sm} + \tau_{Tm})^2\right)^{1/2} = 10.5 \text{ ksi}$$

use $K_f = K_{fs} = 2$

Alternating stress

$$\sigma_a = \frac{M_{ca}}{I} + \frac{F_{ya}}{A} = 3.71 \text{ ksi}$$

$$\tau_{sa} = \frac{2V_a}{A} = .009 \text{ ksi}$$

$$\tau_{Ta} = \frac{T_a r}{J} = .293 \text{ ksi}$$

$$\sigma_a' = \left((K_f\sigma_a)^2 + 3K_{fs}^2(\tau_{sa} + \tau_{Ta})^2\right)^{1/2} = 7.5 \text{ ksi}$$

use $K_f = K_{fs} = 2$

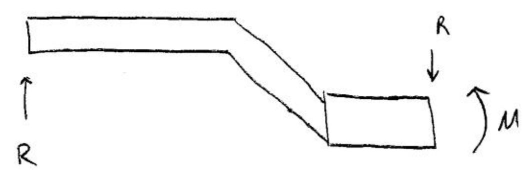
Using Modified Goodman failure criteria assuming

S_f @ 10×10^6 cycles is about 25 ksi

and $S_u = 38$ ksi

$$\frac{1}{n} = \frac{\sigma_a}{S_f} + \frac{\sigma_m}{S_u} \qquad n = 1.7$$

Fatigue of Z bar



Square cross section

$I = \frac{1}{12}(1 \cdot 1^3 - .75 \cdot .75^3)$

$= .056966 \ in^4$

$A = 1 - .75^2 = .4375 \ in^2$

$R_m = \frac{M_{cm}}{44 \ in} = \frac{478 \ in \ lb}{44 \ in} = 11 \ lb$

$R_a = \frac{M_{ca}}{44 \ in} = \frac{346 \ in \ lb}{44 \ in} = 9 \ lb$

$M_m = (11 \ lb)(14 \ in) = 154 \ in \ lb$

$M_a = (9 \ lb)(14 \ in) = 126 \ in \ lb$

$\sigma_m = \frac{(154 \ in \ lb)(.5 \ in)}{I} = 1.35 \ ksi$

$\sigma_a = \frac{(126 \ in \ lb)(.5 \ in)}{I} = 1.11 \ ksi$

$\tau_{sm} = \frac{Vc^2}{2I} = \frac{(11 \ lb)(1 - .75 \ in)^2}{2I} = .006 \ ksi$

$\tau_{sa} = \frac{(9 \ lb)(1 - .75 in)^2}{2I} = .005 \ ksi$

$\tau_{Tm} = \frac{T}{2A_m t}$ $\qquad A_m = (1 - .125)^2 = .7656 \ in^2$

$= \frac{(44 \ lb \ in)}{2(.7656 in^2)(.125 \ in)} = .23 \ ksi$

$\tau_{Ta} = .188 \ ksi$

Fatigue of Z bar 2/2

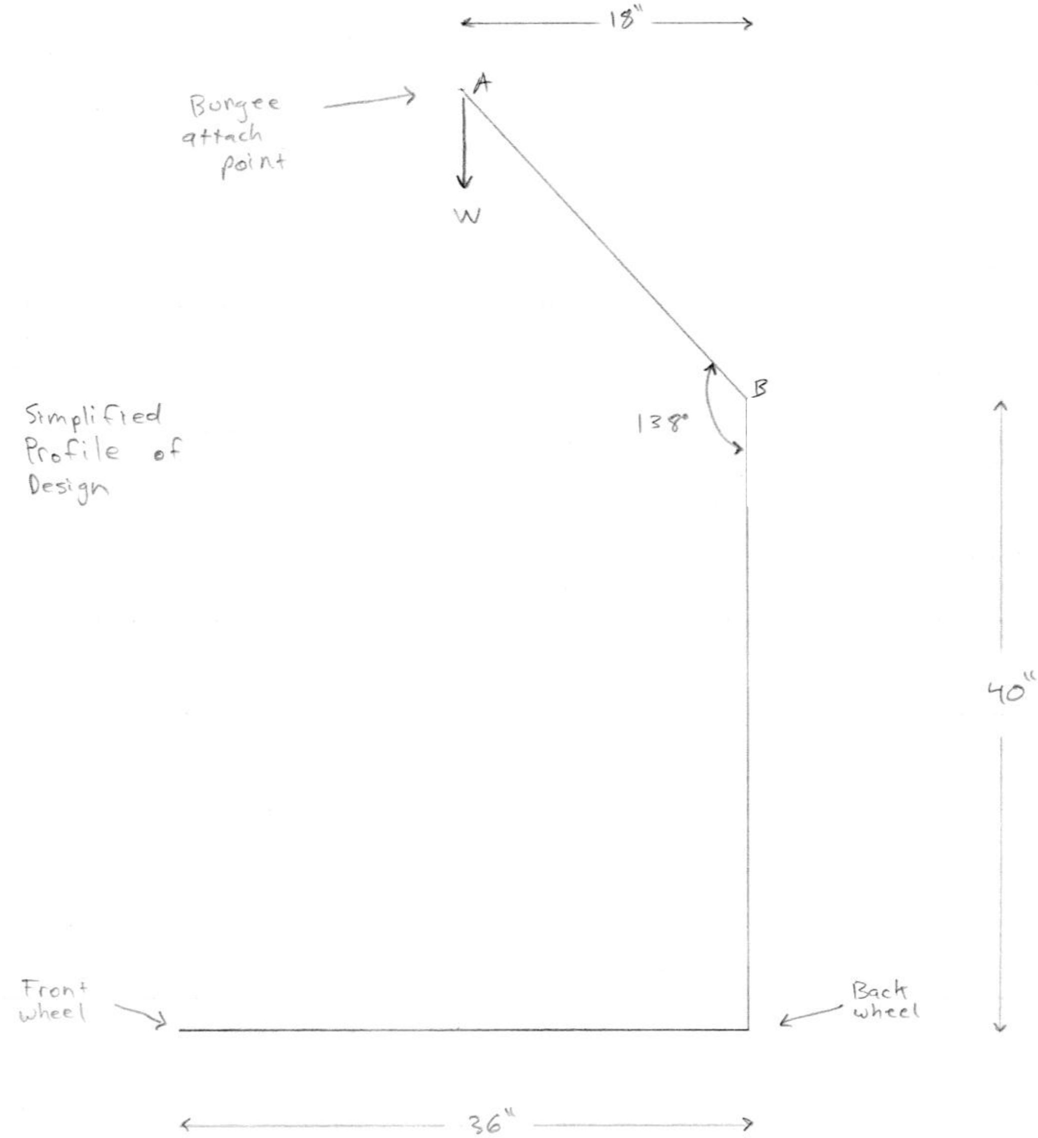
$$\sigma_m' = \left((K_f \sigma_m)^2 + 3K_{fs}(\tau_{sm} + \tau_{Tm})^2 \right)^{1/2} \qquad K_f = K_{fs} = 2$$

$$= 2.8 \ ksi$$

$$\sigma_a' = 2.32$$

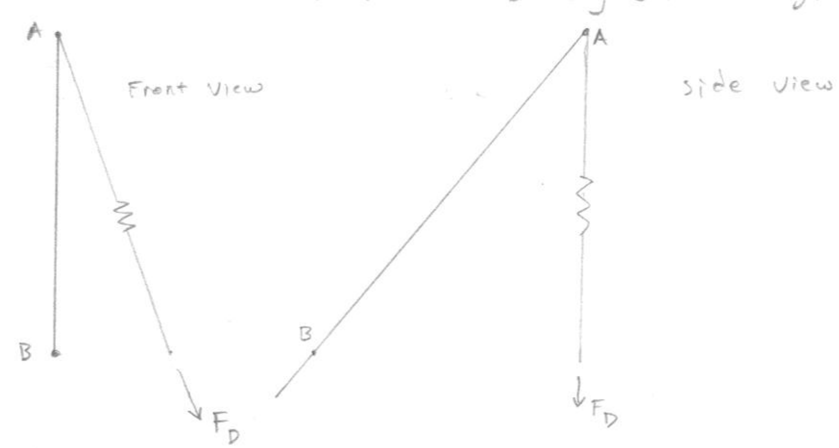
$$\frac{1}{n} = \frac{\sigma_a}{S_f} + \frac{\sigma_m}{S_u} \qquad n = 6$$

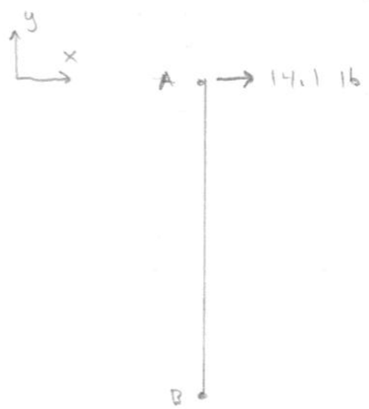
AMPAD


18"
A
Bungee attach point
W
B
138°
Simplified Profile of Design
40"
Front wheel
Back wheel
36"

Carbon Fiber Rod Front View

Horizontal Bending Deflection analysis





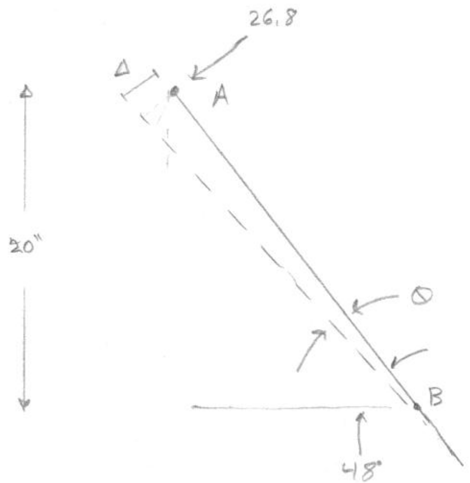
$$F_D = \frac{40}{\sin 70^\circ} = 42.6 \text{ lb}$$

$$\delta_{A-x} = \frac{F_x L^3}{3EI}$$

$$= \frac{(14.1 \text{ lb})(25 \text{ in})^3}{3(19{,}000{,}000 \text{ psi})(.043 \text{ in}^4)}$$

$$= .09 \text{ in}$$

Carbon Fiber Rod vertical deflection



$$\theta = \sin^{-1} \frac{\Delta}{26.9"}$$

Δ assumed small

$$\delta_{A-y} = 20" - 26.9" \sin(48° - \theta)$$

$$\Delta = \frac{F_A L^3}{3EI}$$

$$= \frac{(26.8\ lb)(27\ in)^3}{3(33{,}000{,}000\ psi)(.043\ in^4)}$$

$$= .12\ in \qquad \theta = \sin^{-1} \frac{.12}{27"} = .25°$$

$$\delta_A = 20" - 26.9 \sin(48° - .25°)$$

$$= .09"$$

The following pages contain calculations for a preliminary design that would have been made entirely out of aluminum.

Schedule 40 2" aluminum tube (circular)

Alloy 6061 Yeild strength $\sigma_y = 40$ Ksi

$$\sigma = \sigma_m + \sigma_a$$

$$= \frac{M r_o}{I} + \frac{F}{A}$$

$$I = \pi \left(2.375^4 - 2.067^4\right) \frac{1}{64}$$

$$= .6657 \text{ in}^4$$

$$A = \frac{\pi}{4}\left(2.375^2 - 2.067^2\right)$$

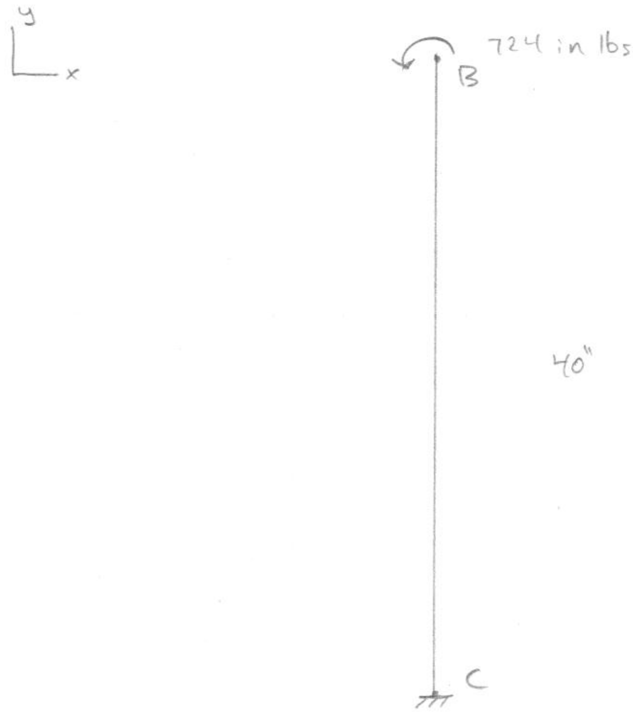
$$= 1.075 \text{ in}^2$$

$$\sigma = \frac{(724 \text{ in lb})(2.375)}{.6657} + \frac{40 \text{ lb}}{1.075}$$

$$= 2620 \text{ psi}$$

$$FS = \frac{40{,}000}{2620} = 15.3$$

Aluminum Tube Deflection

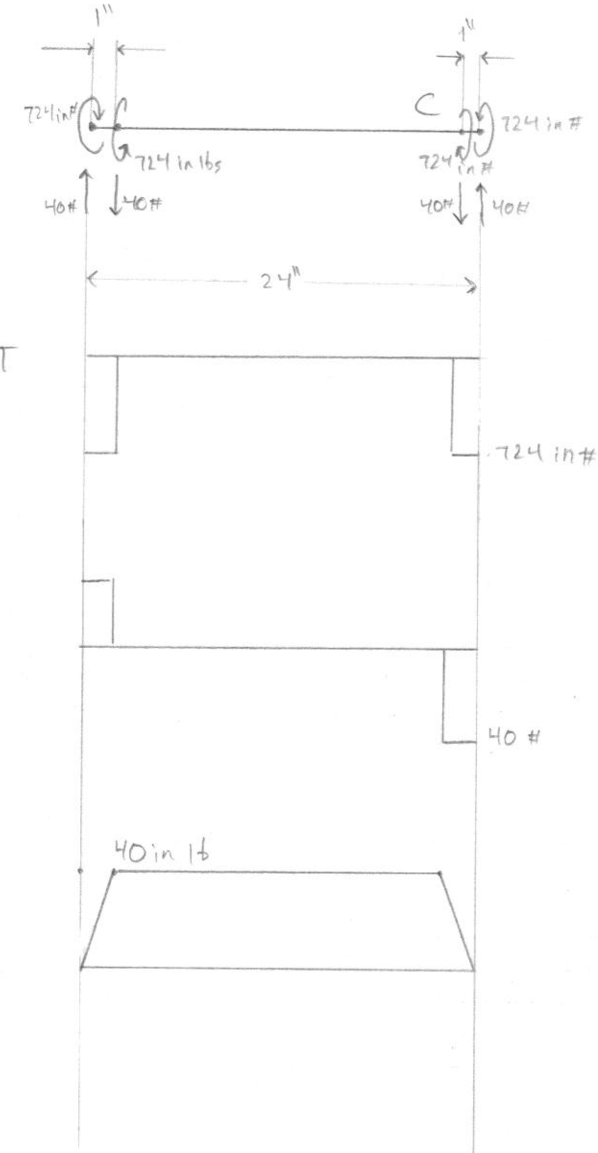


$$\delta_{B-x} = \frac{M\ L^2}{2\ E\ I}$$

$$= \frac{(724 \text{ in lbs})(40 \text{ in})^2}{2(10{,}000{,}000 \text{ psi})(.6657 \text{ in}^4)}$$

$$= .087 \text{ in}$$

Rear Axle stress (2" sch. 40 aluminum)



Critical Point : C

$T = 724 \text{ in lbs}$

$V = 40 \text{ lbs}$

$M = 40 \text{ in lbs}$

$$\tau_{max} = \tau_T + \tau_V$$

$$= \frac{T r_o}{J} + \frac{4V}{3A}\left(\frac{r_o^2 + r_o r_i + r_i^2}{r_o^2 + r_i^2}\right)$$

$$J = \frac{\pi}{32}\left(2.375^4 - 2.067^4\right)$$

$$= 1.33 \text{ in}^4$$

$$\tau_{max} = \frac{(724 \text{ in lb})\left(\frac{2.375}{2} \text{ in}\right)}{1.33 \text{ in}^4} + \frac{4(40 \text{ lb})}{3(1.075 \text{ in}^2)}\left(\frac{2.375^2 + (2.375)(2.067) + 2.067^2}{2.375^2 + 2.067^2}\right)$$

$$= 718 \text{ psi}$$

$$FS = \frac{40{,}000}{718(2)} = 28$$

13

Critical Point : C

$$\sigma = \frac{M r_o}{I}$$

$$= \frac{(40 \text{ in lb})\left(\frac{2.375}{2}\right)}{.6657 \text{ in}^4}$$

$$= 71.4 \text{ psi}$$

$$\sigma << \sigma_y$$

Angular Deflection

$$\phi = \frac{TL}{GI}$$

$$= \frac{(724 \text{ in lb})(1 \text{ in})}{(3.76 \times 10^6 \text{ psi})(.6657 \text{ in}^4)}$$

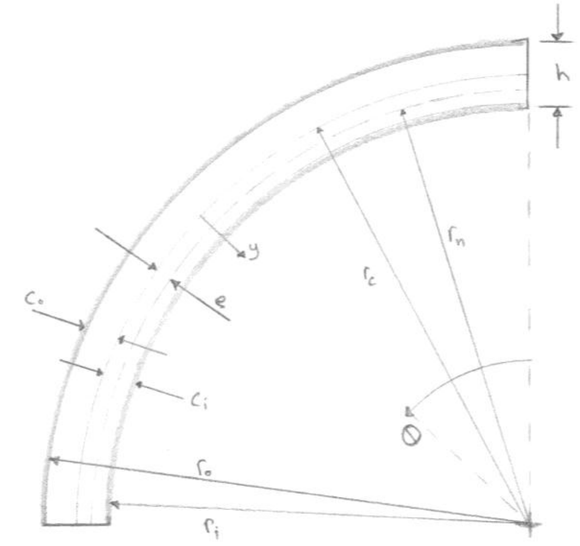
$$\approx 0^\circ$$

$$G = \frac{E}{2(1+\nu)}$$

$$= \frac{10{,}000{,}000}{2(1+.33)} = 3.76 \times 10^6$$

Shcematic

Curved Aluminum Tube



$R_o = h/2$

$r_c = r_i + R_o$

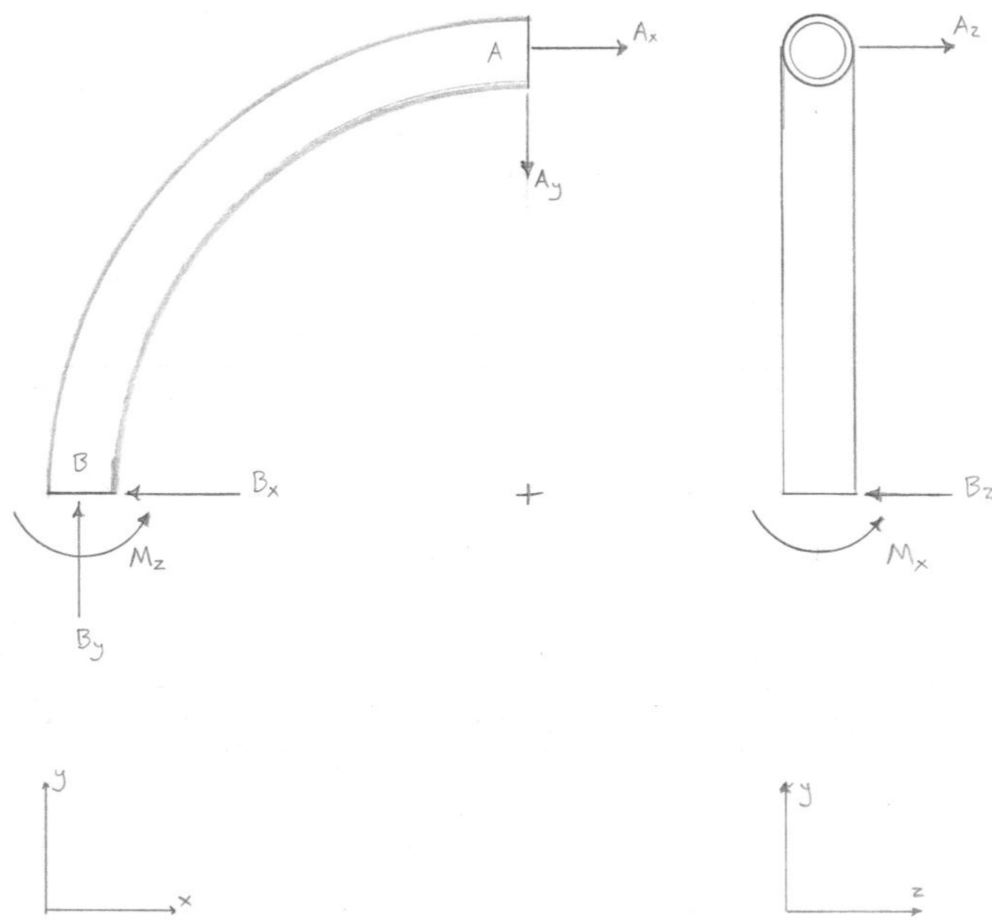
$$r_n = \frac{R_o^2}{2\left(r_c - \sqrt{r_c^2 - R_o^2}\right)}$$

$e = r_c - r_n$

$c_o = r_o - r_c$

$c_i = r_c - r_i$

Schematic



Deflection For Curved Aluminum Tube

$$U_{M_z} = \int \frac{M_z^2}{2EI}\, ds$$

Castigliano's method

$$M_z = A_y \left(r_c \sin\theta \right)$$

$$U_{M_z} = \int_0^{\pi/2} \frac{A_y^2\, r_c^2 \sin^2\theta}{2EI}\, r\, d\theta$$

$$= \frac{A_y^2\, r_c^3}{2EI} \int_0^{\pi/2} \frac{1}{2} - \frac{1}{2}\cos(2\theta)\ d\theta$$

$$= \frac{A_y^2\, r_c^3}{2EI} \left[\frac{\theta}{2} - \frac{1}{4}\sin(2\theta) \right]_0^{\pi/2}$$

$$= \frac{A_y^2\, r_c^3\, \pi}{8EI}$$

$$\delta_{A_y} = \frac{\partial U_{M_z}}{\partial A_y}$$

$$= \frac{A_y\, r_c^3\, \pi}{4EI}$$

APPENDIX F

DV&R test plan

ME428/ME481 DVP&R Format

Report Date		4/22/2011	Sponsor	NSF					Component/Assembly		STRIDER	REPORTING ENGINEER:	
TEST PLAN										**TEST REPORT**			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Frame Bending	Apply expected bending loads to the frame. The fame must not yield under the expected bending load.	No Failure under bending moment created by suspending 40 lbs.	Brian	CV	1	A						
2	Frame Compression	Apply compressive loads to the frame, particularly at the connection areas and observe the frame material for permanent deformation	No permanent deformation.	Brian	CV	1	A						
3	Frame Connections	Apply expected forces to the wheel and arm connections and observe the frame material for permanent damage	No Failure under loads created by suspending 40 lbs.	Brian	CV	1	A						
4	Frame Cycle	Apply cyclic loads to the frame components and observe for failures	10000 cycles	Brian	CV	1	A						
5	Arm Bending	Apply expected bending loads to the support arms. The arms must not yield under the expected bending load.	No Failure under bending moment created by suspending 40 lbs.	Brian	CV	2	A						
6	Arm Connections	Apply expected bending, axial, and torsional loads to the arm connections - carbon to metal and metal to foam.	No Failure under loads created by suspending 40 lbs.	Brian	CV	2	A						
7	Arm Cycle	Apply cyclic loads to the arm components and observe for failures	10000 cycles	Ricky	CV	2	A						
8	Harness Comfort	Suspend Nathan in the harness and observe his comfort level. Compare to other harnesses to gage his comfort.	Nathan's reaction/ approval	Ricky	CV	1	C						
9	Harness Fitting	Does the harness fit as it is designed to.	Not constricting, loose, unevenly secured to Nathan, or obstructive.	Ricky	CV	1	C						
10	Harness Connections	Apply tensile and shock (impulse) loads to rings, straps, and carabiners.	No Failure under loads created by suspending 40 lbs.	Ricky	CV	1	C						
11	Harness Cycle	Apply cyclic loads to the harness components and observe for failures	10000 cycles	Ricky	CV	1	C						
12	Bungee Tension	Apply tensile and shock (impulse) loads to bungee cords.	No Failure under loads created by suspending 40 lbs.	Clark	CV	4	B						
15	Bungee Adjustability	Can the bungees be adjusted as Nathan's body changes (grows, becomes tired, weaker of stronger)	Pass or fail	Clark	CV	4	B						
16	Bungee Connections	Apply expected forces to the bungee connections and observe the bungee material for permanent damage	No Failure under loads created by suspending 40 lbs.	Clark	CV	4	B						
17	Bungee Cycle	Apply cyclic loads to the harness bungee and observe for failures	10000 cycles	Patrick	CV	4	B						
18	Wheel Connections	Apply expected forces to the wheel connections and observe the wheel assembly for permanent damage	No Failure under loads created by suspending 40 lbs.	Patrick	CV	2	A						
19	Wheel Off-Road	Can the wheels traverse trails with relative ease	Test on Poly canyon trail	Patrick	CV	2	A						
20	System Stability	Set the entire system on a inclined surface and raise the angle of inclination until tipping.	No tipping on 30° surface	Patrick	CV	1	A						
21	System Off-Road	Can the entire system traverse trails with relative ease	Test on Poly canyon trail	Patrick	CV	1	A						

Appendix G

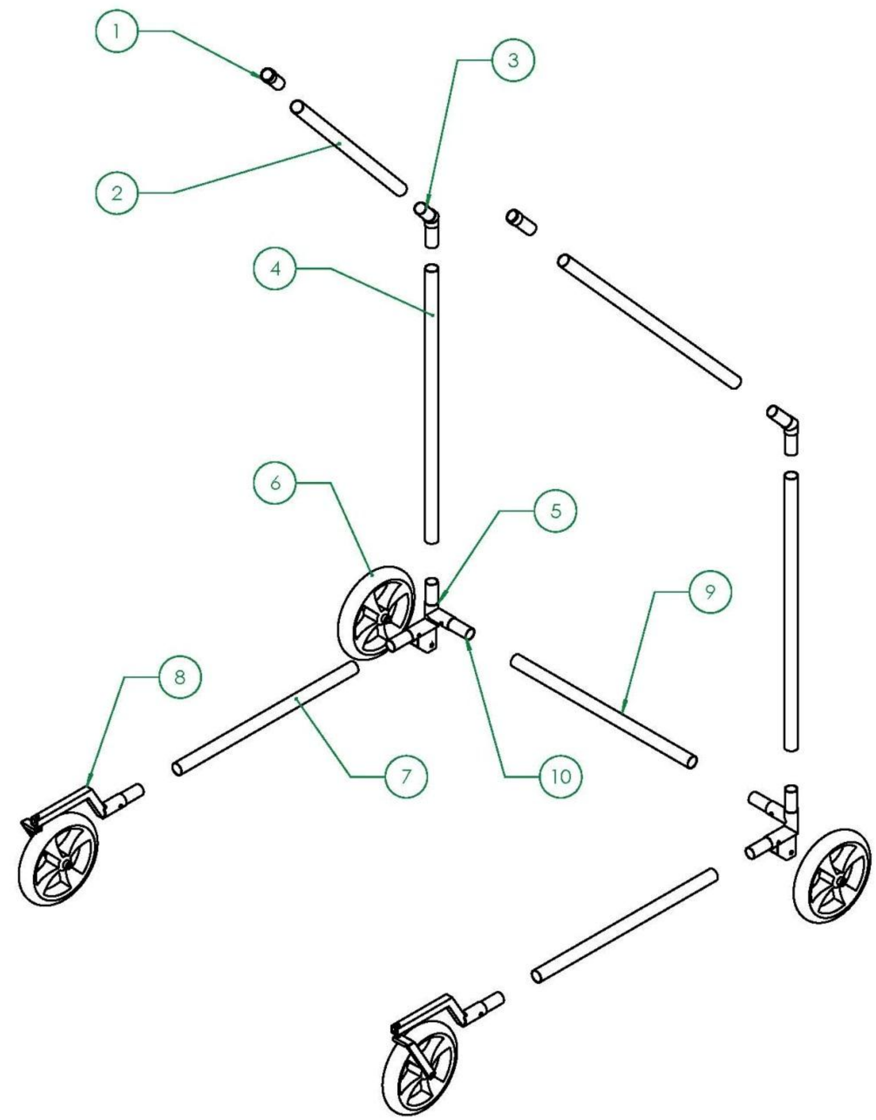
Cost Breakdown

Brian Kreidle					
Amount	Vendor	Item	Payment type		
$ 9.15	Home Depot	Bungees	Visa Credit		
$ 315.15	Sears	Harness	Visa Credit		
$ 6.46	Home Depot	Bungees	Visa Credit		
$ 16.21	McCarthy Steel	Al pipe	Visa Credit		
$ 23.95	Online Metals	Al pipe	Visa Credit		
$ 17.00	My Strider Bike	Wheel	Visa Credit		
$ 67.86	McMaster	Mandrill	Visa Credit		
$ 66.15	McMaster	Mandrill	Visa Credit		Budget used
$ 24.31	McCarthy Steel	Al pipe	Visa Credit		$ 1,208.19
$ 14.82	McMaster	Pins	Visa Credit		
$ 19.39	McMaster	Pins	Visa Credit		Budget Remaining
$ 23.95	Online Metals	Al pipe	Visa Credit		$ 291.81
$ 68.65	K-9 Cart Company	Wheels	Visa Credit		
$ 103.67	Enable your life	Forks	Visa Credit		
$ 91.42	Strider Sports	Wheels	Visa Credit		
$ 12.01	McCarthy Steel	Al pipe	Visa Credit		
$ 90.00	Pac Anod	Anodizing	Check		
$ 14.50	CC Bearings	Bushings	Cash		
$ 4.68	Home Depot	Nuts and bolts	Visa Credit		
$ 68.00	Strider Sports	Wheels	Visa Credit		
$ 11.37	Ups Store	Shipping	Visa Credit		
$ 6.22	Home Depot	Foam Padding	Visa Credit		
$ 4.77	El Corral Bookstore	Letters	Visa Credit		
$ 4.77	El Corral Bookstore	Cardboard	Visa Credit		
$ 22.98	Home Depot	Paint	Visa Credit		
$ (93.72)	Enable your life	Forks	Visa Credit		Returned
$ 6.63	McCarthy Steel	Al pipe	Visa Credit		
Ricky Lee					
Amount	Vendor	Item	Payment type		
$ 25.36	McMaster	Epoxy	Visa Credit		
$ 23.78	McMaster	Shrink Tape	Visa Credit		
$ 24.95	Aircraft Spruce	Silicone Spray	Visa Credit		
$ 76.00	McMaster	Epoxy	Visa Credit		
$ 6.75	Ace Hardware	Bungees	Visa Credit		
Clark Steen					
$ 31.00	Big Bearing Store	Bearings	Credit		

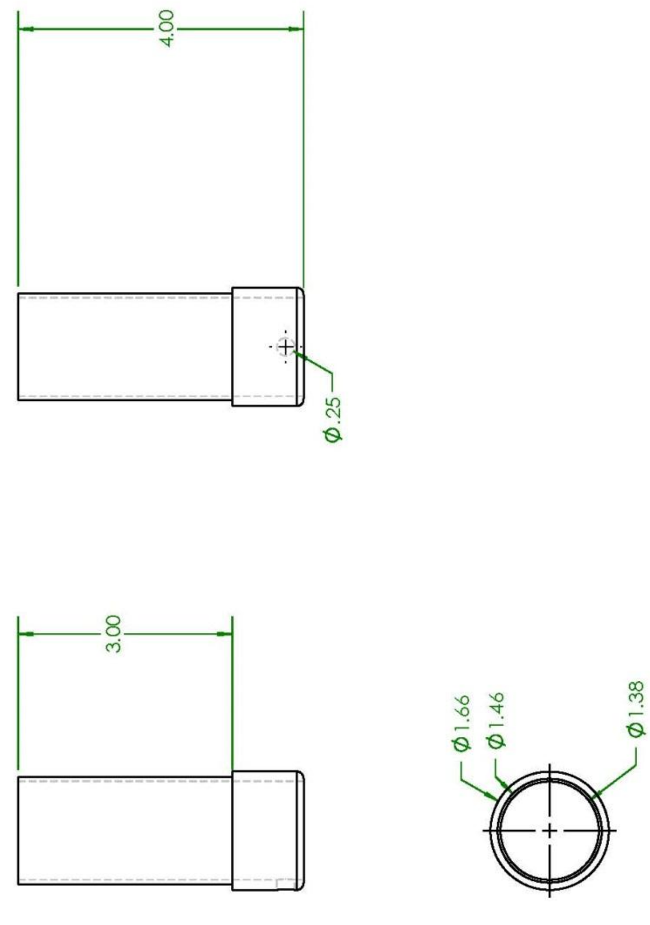
APPENDIX H

Strider drawings

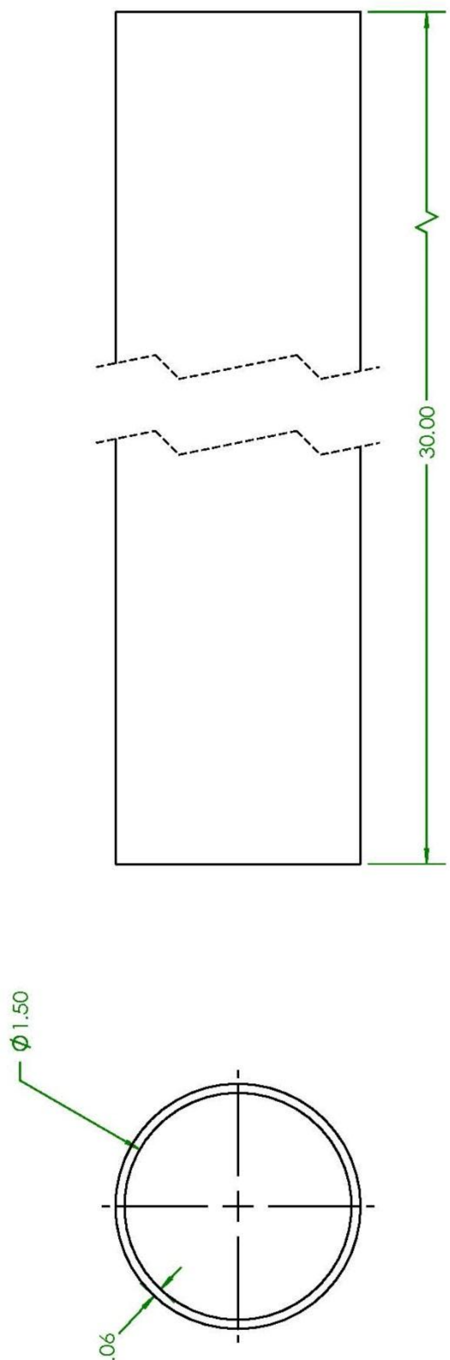
ITEM NO.	PART NAME	QTY.
1	Hanger	2
2	30in carbon fiber tube	2
3	Angle joint	2
4	37in carbon fiber tube	2
5	Tri joint	2
6	Previous STRIDER wheel	2
7	30in carbon fiber tube	2
8	Front Wheel/Fork assembly	2
9	30in carbon fiber tube	1
10	Insert	6



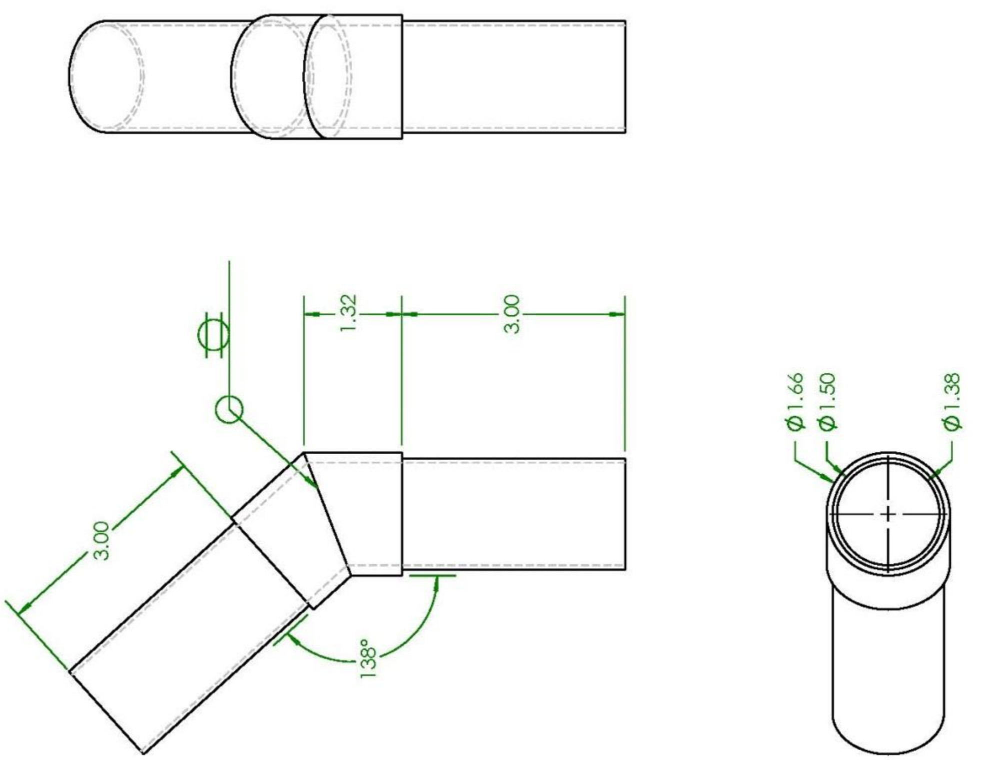
NAME	Strider assembly



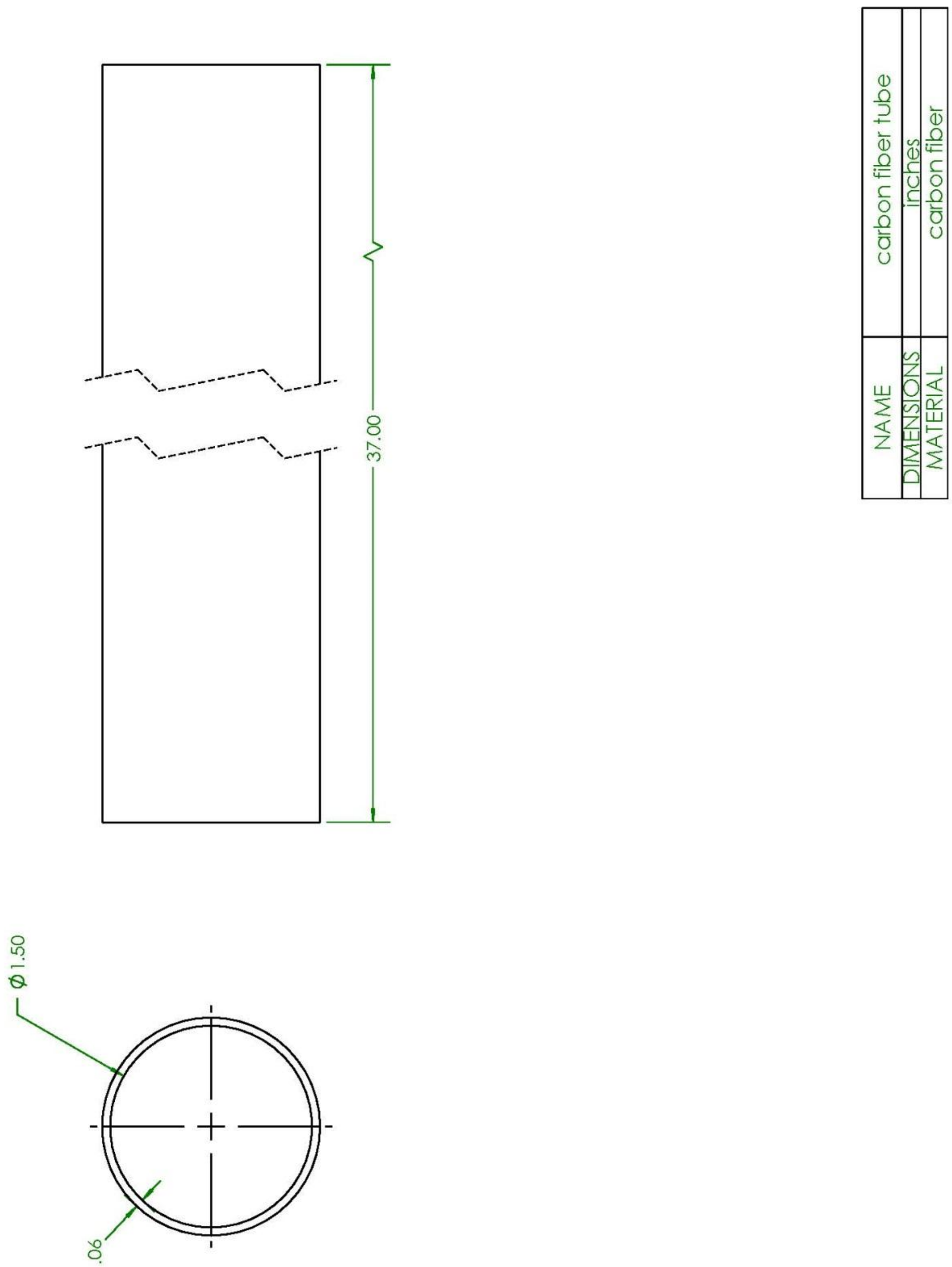
NAME	Hanger
DIMENSIONS	inches
MATERIAL	Sch 40 aluminum pipe

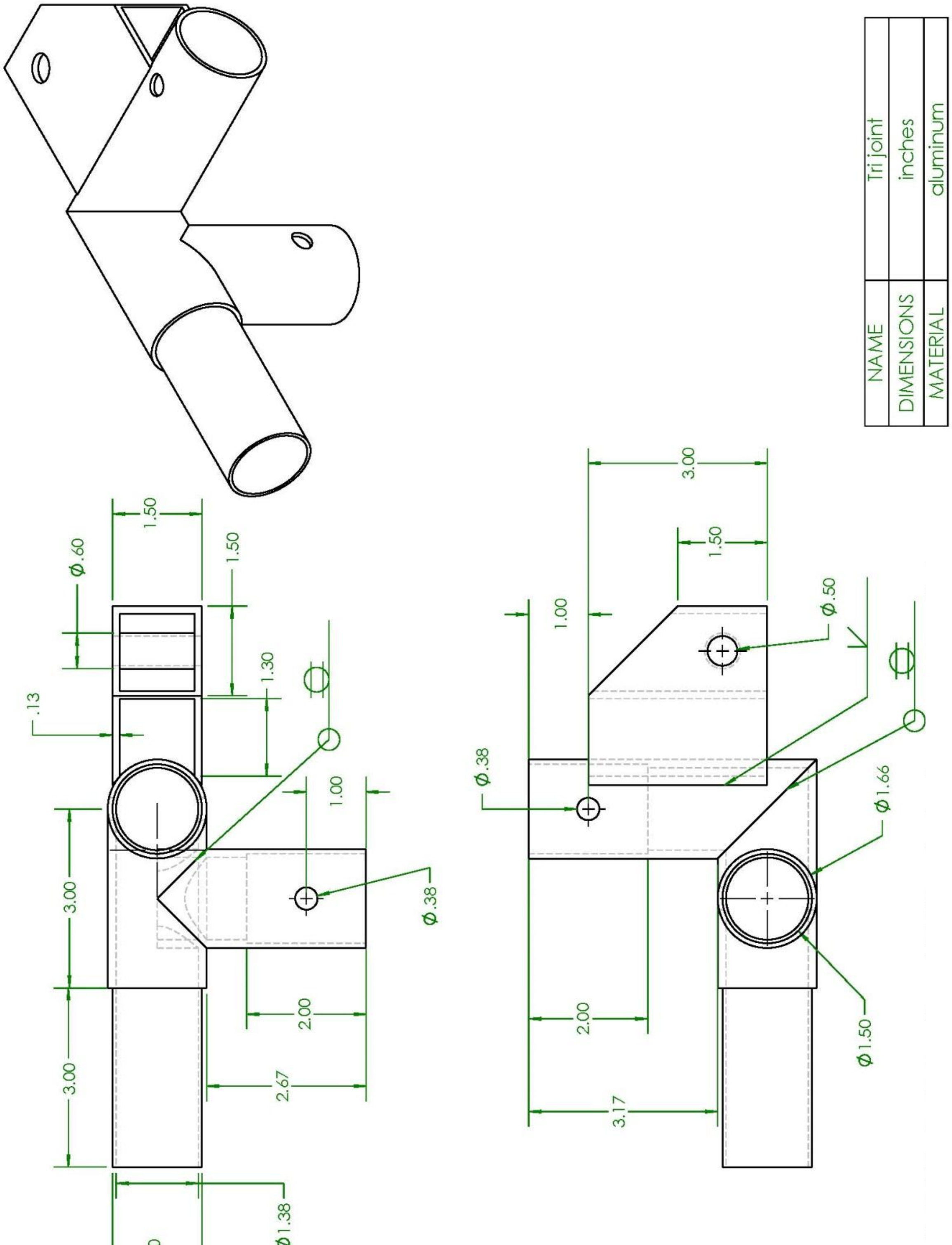


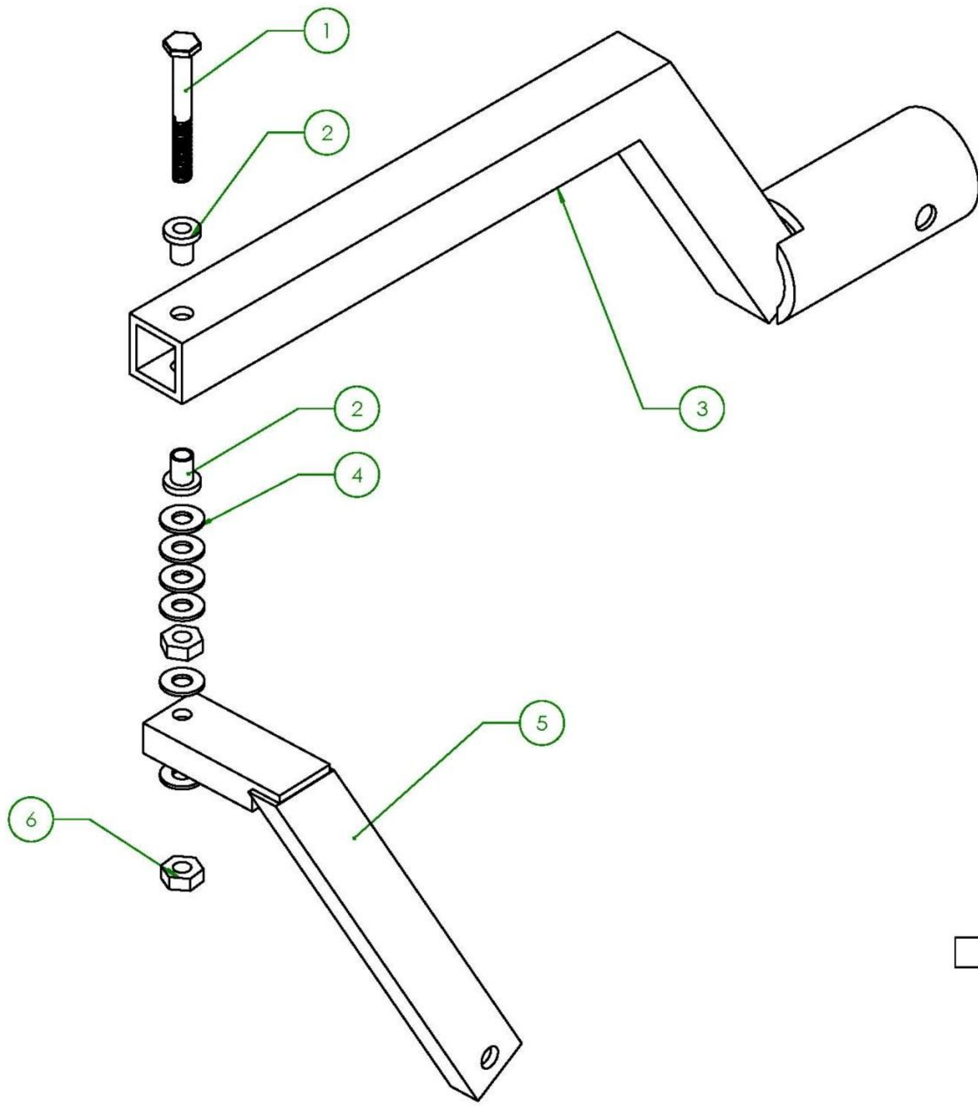
NAME	carbon fiber tube
DIMENSIONS	inches
MATERIAL	carbon fiber



NAME	Angle joint
DIMENSIONS	inches
MATERIAL	Sch 40 aluminum pipe

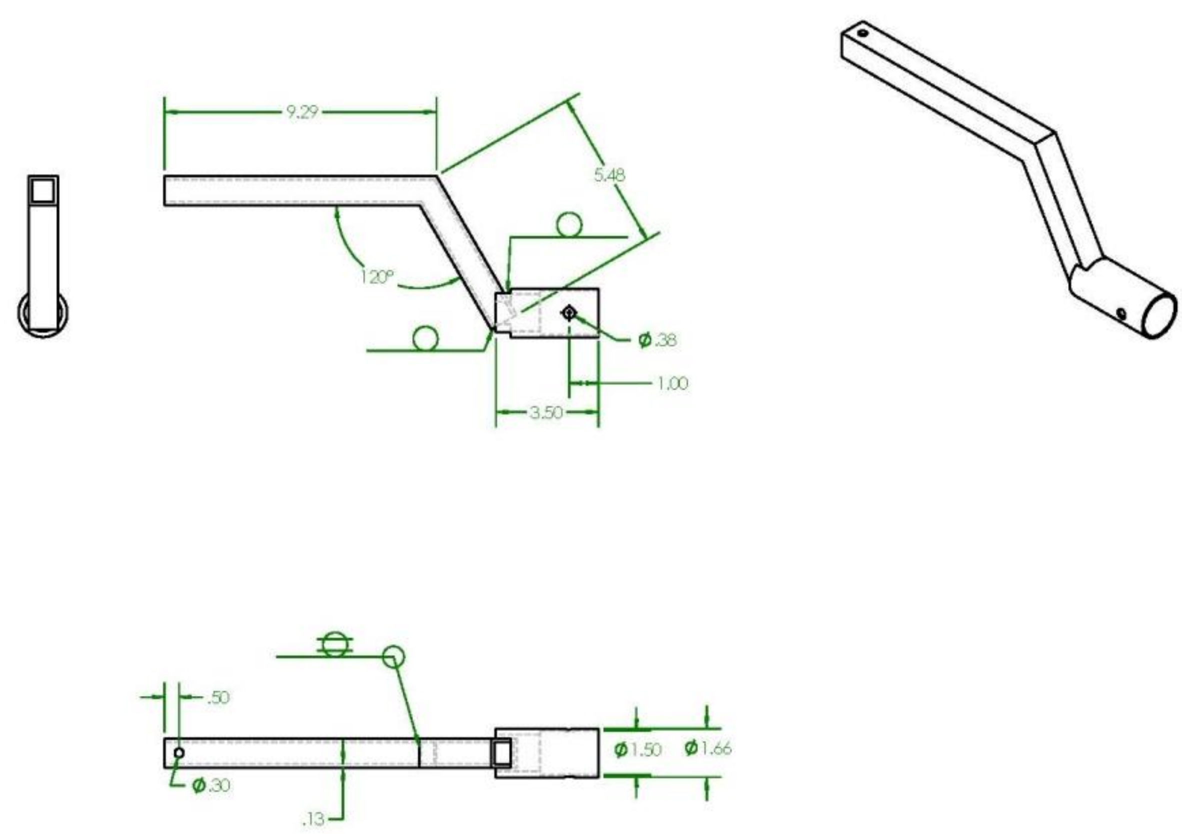

37.00
Ø1.50
.06
NAME
carbon fiber tube
DIMENSIONS
inches
MATERIAL
carbon fiber


NAME
Tri joint
DIMENSIONS
inches
MATERIAL
aluminum
1.50
1.50
Ø.60
.13
1.30
1.00
3.00
3.00
Ø.38
2.00
2.67
Ø1.38
Ø1.50
3.00
1.50
1.00
Ø.50
Ø.38
Ø1.66
2.00
3.17
Ø1.50

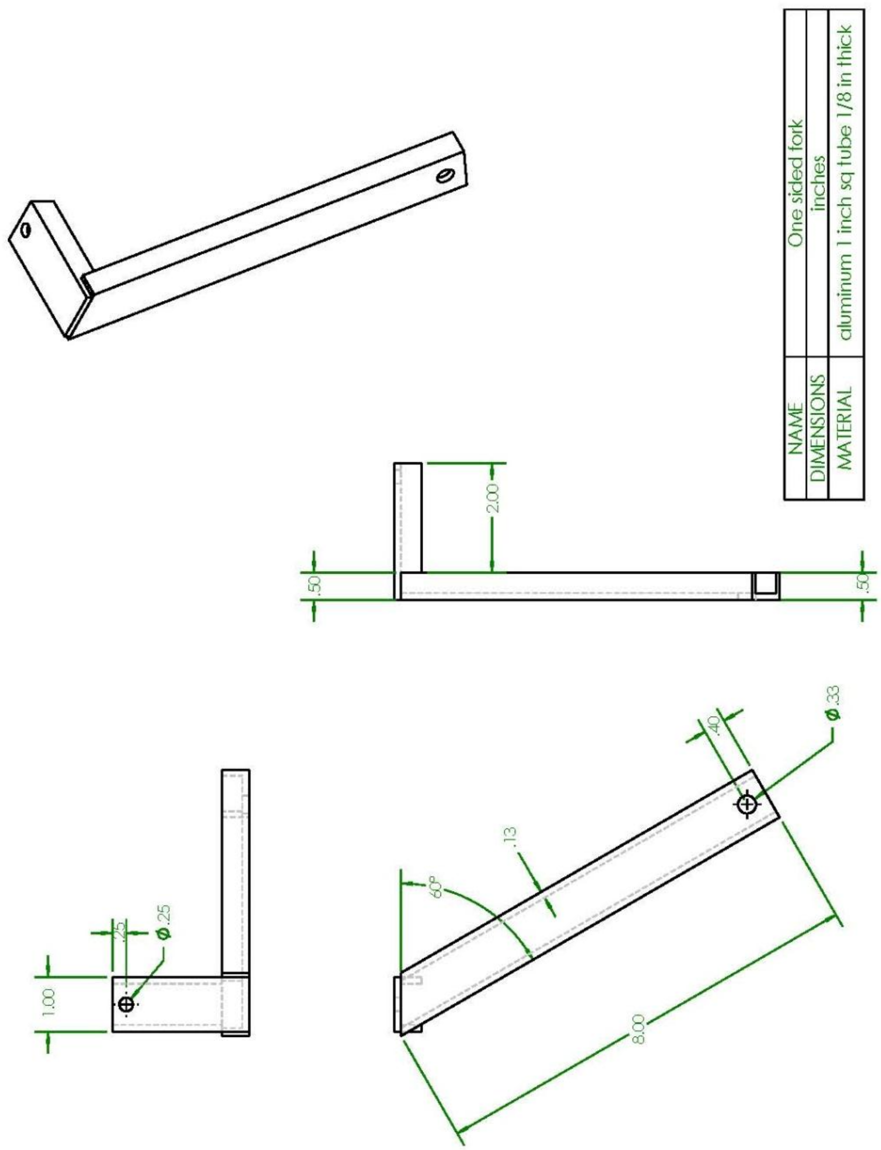


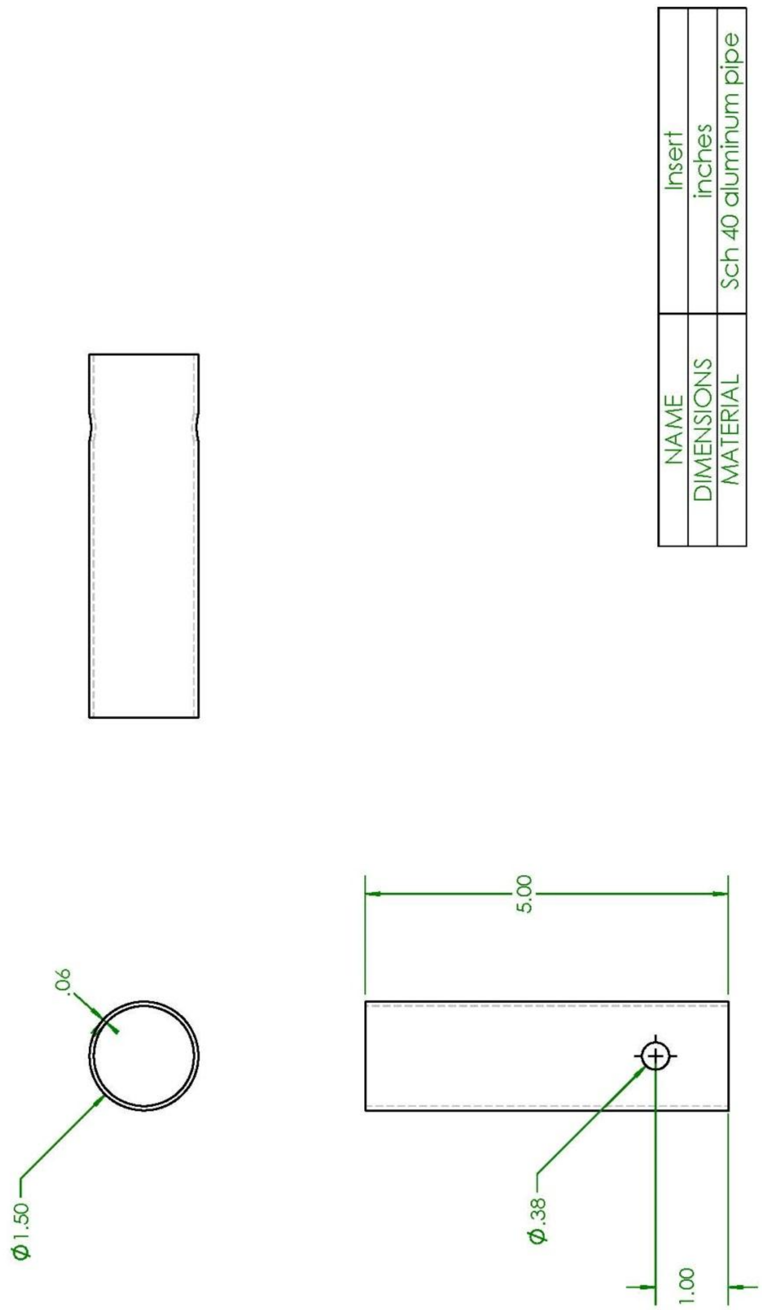
ITEM NO.	PART NAME	QTY.
1	1/4 in hex bolt	1
2	1/4 inch brass bushing	1
3	Extender	1
4	1/4 in washer	6
5	One sided fork	1
6	1/4 in nut	2

NAME	Wheel assembly



NAME	Extender
DIMENSIONS	inches
MATERIAL	Aluminum 1/8 sq tube & sch 80 pipe


NAME
One sided fork
DIMENSIONS
inches
MATERIAL
aluminum 1 inch sq tube 1/8 in thick
2.00
.50
.50
Ø.33
.40
.13
60°
8.00
1.00
.25
Ø.25


NAME
Insert
DIMENSIONS
inches
MATERIAL
Sch 40 aluminum pipe
5.00
.06
Ø1.50
Ø.38
1.00