HOLY WALKAMOLIE

NEXT GENERATION WALKER

CONCEPT DESIGN REPORT

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Table of Contents

Table of Figures

Table of Tables

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Abstract

Parkinson's disease is a progressive debilitating disorder that leads to poor posture and balance, slow movement, tremors, and freezing of gait. Jack Brill, a Korean War Veteran who suffers from Parkinson's disease, noticed that most walkers that are available do not adequately meet the needs of users afflicted with Parkinson's disease, so this team (Holy Walkamolie) was tasked with designing and building a walker could meet these needs. In order to do this, the walker needs to be lightweight, foldable, it must have a small turning radius, large wheels, a forward-facing seat, and brakes that are locked by default and must be actively released to move.

The following paper outlines the design process the team went through to create this walker. First, the team researched the walkers currently on the market. While researching the walkers, the team started to brainstorm solutions for the issues Mr. Brill has with the current walkers. The team brainstormed both overall walker ideas as well as ideas for specific components. After building the first prototype, the team realized how important the weight requirement was for Mr. Brill and went back to the drawing board to discuss better options. The team decided a change in materials would help keep the overall weight down, and started designing with new materials in mind. The final design focuses on the use of composites (carbon fiber) for the base material with metal tubing as the connecting material. It should be noted that the team has created a prototype at the time of this report.

Chapter 1: Introduction

Background

Parkinson’s disease is a progressive disorder of the nervous system that occurs when the brain cells that produce dopamine breakdown or die. The subsequent decrease in dopamine levels causes abnormal brain activity which can lead to impaired posture and balance, general slowness of movement, lower voice volume, tremors, and loss of automatic movements. Another symptom of Parkinson’s disease is freezing of gait, which occurs when the brain sends signals to the legs to move, but the legs do not receive the message and become locked in place.

Mr. Brill suffers from Parkinson’s disease, and has noticed that current walkers on the market do not fit the needs of users who suffer from this disease as well as they could. The team was introduced to Mr. Brill through the Quality of Life Plus Lab (QL+ Lab) and Cal Poly. The QL+ Lab is a not-for-profit lab on Cal Poly’s campus that was developed by Scott and Jon Monett in order to improve the lives of veterans who have suffered trauma. Mr. Brill is a veteran of the Korean War. He came to the QL+ lab with a challenge to help him and others with Parkinson’s disease be more mobile. This team’s walker helps to achieve that goal.

Project Definition

The purpose of this project is to develop a walker that better fits the needs of users with Parkinson’s disease. The walker presented in this report needs to be lightweight, foldable, and it must have a small turning radius, large wheels, a seat that the user does not have to turn around to sit on, and brakes that are locked by default and must be actively released to move. Other objectives and requirements are included below.

Objectives

Although there are many walkers on the market, there is not a single walker that incorporates all the features that will help Mr. Brill and others with similar mobility limitations. After discussing the project requirements with Mr. Brill, the team decided that the most important objective of this project is to keep the weight of the walker under 10 pounds. This is important because Mr. Brill and his wife are elderly, and they struggle to lift any of the walkers that Mr. Brill currently owns. This presents a problem when they need to put a walker in the trunk of a car. Another important requirement is the ability of the user to walk upright when using the walker, which will decrease stress on the user’s back and thus increase comfort. Below is a list of additional requirements that were taken into account during the design process:

- The seat must move out of the way
- The seat must be behind the user at all times
- The user must be able to sit and walk or stand and walk.
- The seat should not be shaped like a bicycle seat.
- The walker must be able to hold 300 lb.
- The walker must weigh under 10 lb.
- The walker must be collapsible, folding flat so it can fit in the trunk of a car.
- The walker must have large wheels in order to roll on carpet or grass.

- The walker must have a small turning radius to be able to turn in hallways.
- The walker's height must be adjustable in order to accommodate many users.
- The walker handle placement must improve the user's posture compared to other walkers.
- The walker must contain at least 4 wheels.
- The user must be able to step up on a curb with the walker.

The team created a Quality Function Deployment (QFD) to assess and rank how the above requirements relate to each other and their importance toward the final design. The QFD also compares the requirements listed above to existing products on the market. This matrix can be found in Appendix A: Charts.

Parameters

The four most important requirements that could be expressed as quantities are listed in the table below. These parameters were chosen due to the importance Mr. Brill placed on them during the initial meeting.

Table 1: Design Parameters

Parameter	Requirement	Tolerance
Weight	10 lbs	MAX
Weight Capacity	300 lbs	±10 lbs
Fold Flat	47 x 42 x 22 in.	±2 in.
Large Wheels	8 in. (diameter)	±2 in.

The weight parameter/requirement was the most important because Mr. Brill is primarily looking for a lightweight alternative to the current walkers on the market. As stated above, Mr. Brill and his wife are elderly and would like to own a walker they can easily transport on their own. This weight requirement was a main focus throughout the design process.

The weight capacity requirement was a result of the research the team completed. Most walkers on the market have a 300 lb weight capacity, so the team chose to match this value.

Mr. Brill expressed that he would like the walker to fold flat so it can fit in a car trunk for transportation. The team decided to design for a smaller car trunk (dimensions above in table) for the folded walker. This is an important parameter because Mr. and Mrs. Brill need to be able to transport the walker without the help of others.

The final parameter the team decided to focus on was the size of the wheels. Mr. Brill made it very clear that he desired a walker that could be used on different surfaces within the house as well as outside. Since 6 inch wheels are typical for rolling walkers, the team chose to increase the size to 8 inches.

The following chapters discuss, in detail, the process the team went through to design a walker that fit the requirements set forth by Mr. Brill.

Chapter 2: Background Information

Currently, Mr. Brill uses a few different walkers to fit his everyday needs. He owns a cane, a U-Step Walker, a common rollator walker, and a scooter. He has also led previous QL+ Lab projects that have aimed to modify the walkers he currently owns. There are both positive and negative features of each of the walkers that Mr. Brill uses. These features were kept in mind throughout the design process.

Existing Products

The walker that Mr. Brill most often uses is the U-Step Walker, (Figure 1) which was created specifically for people who suffer from Parkinson's disease. The U-Step Walker is equipped with self-locking brakes. These brakes are locked by default, and the user must squeeze one or both of the hand brakes to release the brakes and begin walking. With this design, the user doesn't have to worry about the walker rolling away from him or her when walking up or down a hill. Additionally, the U-Step has a small turning radius that is accomplished by placing caster wheels on the front of the walker and regular wheels directly to the user's sides. This allows the user to turn in place. The U-Step also has a raised bar behind the two main, non-caster wheels. This acts as a Class 1 lever that can be stepped on to raise the front of the walker to move over small obstacles such as street curbs.

Figure 1: U-Step Walker

The primary drawback of the U-Step Walker is its weight. The walker weighs 22 pounds, which makes it difficult for Mr. Brill or his wife to lift it and place it in a car. Furthermore, the U-Step's seat is in the front of the walker, so the user must turn around to sit down. This can be dangerous especially if the user cannot stand up without the walker.

The second walker that Mr. Brill talked about was the Merry Walker (Figure 2). The main feature relevant to the team's design goals is that the seat is always behind the user, allowing the user to sit down at any time without turning around. One of Mr. Brill's favorite features in this walker is that it has a single handlebar in the front instead of two separate handles. Additionally, the user can sit down and still move around by pushing off the ground with his or her legs. The wheels on the Merry Walker are all caster wheels which allow the user to make point turns;

however, this eliminates the possibility of having simple brakes. Furthermore, the small size of the wheels makes it unsuited for moving over grass or carpet.

Figure 2: Merry Walker

A unique walker concept on the market is the Alinker R-volution (Figure 3). The main feature of this walker is that it allows the user to walk while sitting. This walker resembles a tricycle without pedals; the device's height and the gap between the front and back wheels allow the user to sit on the seat while pushing themselves forward with his or her legs. This allows users to use their legs to move even if they do not have the strength to stand up. The Urban Flyer design (Figure 4) uses this concept as well.

Figure 3: Alinker R-Volution

Figure 4: Urban Flyer

Both the Alinker R-Volution and the Urban Flyer act like tricycles with handlebars to turn and bike-like seats to rest on while walking. While this is a good idea for elderly people to be able to use while walking, Mr. Brill wants a seat that is more comfortable than a bike seat and can also act as a solid, flat surface to put items on. The Alinker R-Volution cannot make point turns due to the steering mechanism, which is a concern as well.

After meeting with Mr. Brill and researching the existing walkers, the team was able to come up with a list of objectives and requirements with which to start brainstorming.

Current State of the Art

Currently, there is no walker on the market that contains all of the specifications that Mr. Brill has set forth. Every existing walker weighs significantly more than 10 pounds, which is Mr. Brill's primary concern.

List of Applicable Standards

The Americans with Disabilities Act (ADA) states that walkways and doorways should be 32 inches in order to fit standard walkers and wheelchairs. This means that the walker presented in this report must be no more than 32 inches wide.[1]

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[1] ADA website for walkways and doorways: http://www.ada.gov/reg3a.html#Anchor-94210

Chapter 3: Design Development

The QL+ Lab owns a standard rollator that the team used to explore different pushing and pulling options during team meetings. This was useful to see how the walker folded, how much it weighed, how it turned, and how much force it took to move the walker with the brakes applied. The team also used Mr. Brill's walkers during the initial meeting with him in early February 2015. After seeing and experimenting with the walkers, the team was able to incorporate desirable features into all ideas and sketches.

Concept Designs

The team started out with a range of ideas that either incorporated the overall structure of the walker or focused on specific components of the walker. A major design consideration from the beginning was how to have a seat behind the user at all times. The team discussed if the walker should be situated in front of the user (how most current walkers are made) or behind the user. The team discussed iterations that utilize both designs.

The initial designs were created using features of the existing walkers to which the team was introduced. A square shaped structure (Figure 5) was considered because it has a large space for the user to move in while walking. Additionally, with the structure's shape, the walker could be used in both positions, behind or in front of the user.

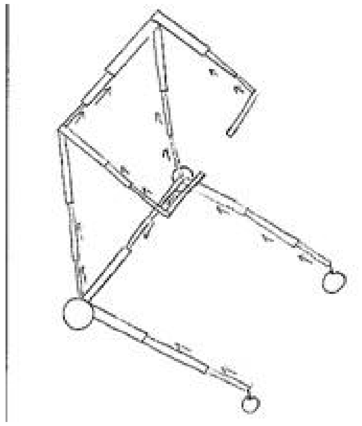


Figure 5: Square/Box Sketch

The second structure discussed was an X-shape (Figure 6), which uses a connection bar connecting two X-shapes at their intersection points. In this design, the user walks with the walker behind them.

Figure 6: X-Shape Walker

The second iteration of the X-shape (Figure 7) was designed so that the top part of the bars holding the caster wheels could be eliminated to further reduce the material needed for this structure. The shape of this new design looks like an upside down “Y”. With this design, users still walk with the walker behind them. Forward facing seats were added on the connecting bar to keep the standing and sitting positions facing the same direction.

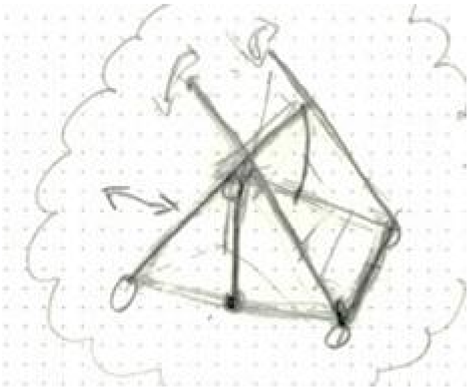


Figure 7: Y-Shape Sketch

Both the X- and Y-shape handles would rotate 180 degrees to allow the user to enter and exit the walker without being blocked by the handles. This design option also allows the handles to be a handle bar across the whole walker.

The third structure idea that the team discussed was N-shaped (Figure 8). The motivation for this design came from the desire to make the folding process easier and to position the handle supports vertically so it would be better at supporting the user’s weight. This design uses diagonal linkage bars to connect two vertical bars. One vertical bar supports the handles while the other supports the seat. The N-shape design places the walker behind the user, similar to the X- and Y-shaped designs. The wheels in this design are also set up the same as the X- and Y-shaped designs. To fold, the two vertical bars are pushed toward each other, and the diagonal linkage bars bring the vertical bars together in one motion.

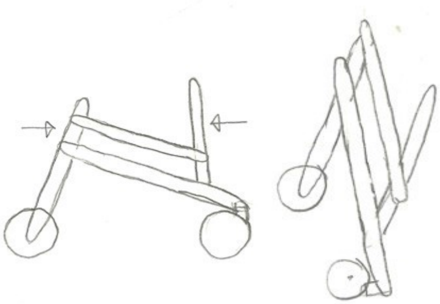


Figure 8: N-Shape Walker

The three designs, X-, Y-, and N-shape, were designed with aluminum tubing in mind.

After comparing the four designs above, the team decided to move forward with the N-shape design due to its foldability. The team decided to build a prototype in order to test how much support the design offers and to make sure that the folding mechanism would work. The team created a full scale model from Schedule 40 PVC pipe and connected the pipe using ¼” screws. The full prototype can be seen below (Figure 9).

Figure 9: Prototype 1

The user would be positioned facing the camera and standing in the area over the blue rectangle on the ground seen above.

While the construction of the first prototype was beneficial towards troubleshooting the N-Shape design, the team found that if they were to manufacture the walker out of aluminum tubing it would not meet the weight requirement. The team went back to the drawing board to look at lighter options. The team originally chose aluminum tubes due to the high strength and low density, however the need for a lighter material led the team to explore the possibility of using carbon fiber.

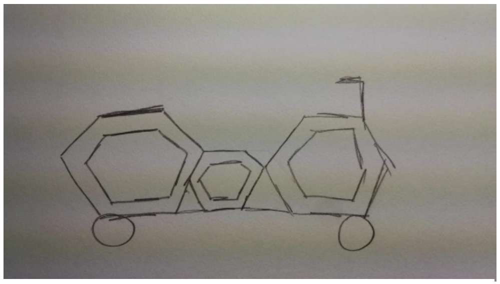


Figure 10: Hexagon Carbon Fiber Panel Design

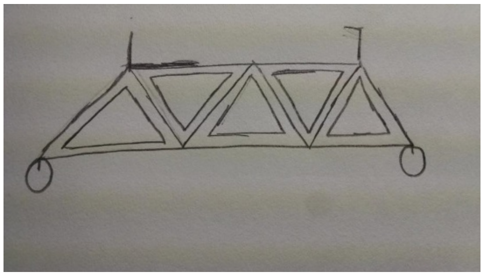


Figure 11: Triangular Carbon Fiber Panel Design

The structure of the walker would need to be different if this new material were to be used, so the team brainstormed designs of panels made of carbon fiber (Figure 10 and Figure 11).

Component Ideas

Folding Mechanism:

Within each structure design, several design concepts as to how the walker would move and fold were explored. The first concept used telescoping bars to reduce the walker to the minimum possible size when it folds. The structure (Figure 12) could telescope in three dimensions, allowing the walker to be compacted to the smallest possible size.

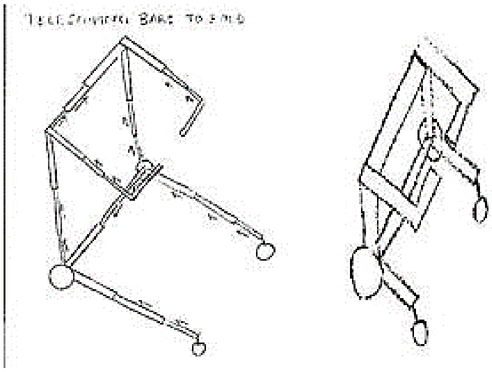


Figure 12: Telescoping Mechanism

The second folding mechanism (Figure 13) would use two interlocking horizontal bars that could be pulled on to force the walker to collapse on itself. This concept is safer that the telescoping bars because the user does not have to lean over to collapse the walker, thereby minimizing the danger of falling over. Eliminating the need to lean over also prevents putting extra stress on the user's joints.

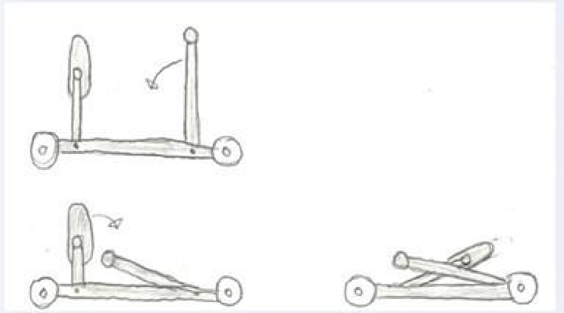


Figure 13: Folding Mechanism Design

The PVC prototype the team built had a folding mechanism designed off of this idea. The idea used in the prototype was further developed to fit with the base N-shape structure. The team found that both the idea sketched in Figure 13 above and the folding mechanism built in the prototype required two motions, and kept designing to find a mechanism that would be able to fold the walker with only one motion. This decrease in activity to use the walker was important to the team due to the limited movement abilities of Mr. Brill. This led the team to design the third folding mechanism.

This third folding mechanism mimics the folding ability of a scissor lift. To unfold the walker, the user would push the handlebar down forcing the linkages outward thereby forcing the sides of the walker outward. To fold the walker, the user would simply reverse the motion by lifting up on the handlebar forcing the linkages inward. The advantage of this folding mechanism over the previous two is that the user can be complete it in one motion. This makes it much simpler to use. This idea was also superior to the others because it was designed with the composite material base structure in mind. The folding mechanism could also double as a way to connect the two side structures together (Figure 14).

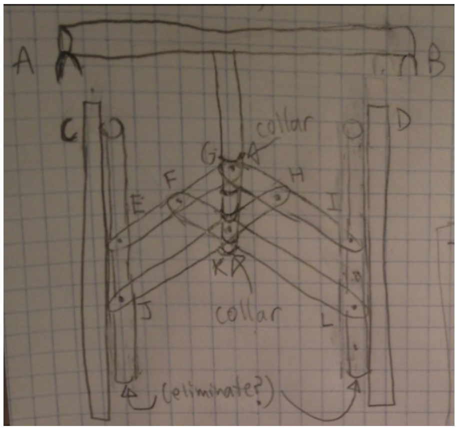


Figure 14: Scissor Lift Folding Mechanism

Seat:

The second design concept explored was a seat that moves. Mr. Brill stressed that it was important to him to have a walker where he did not need to turn himself or the walker around when he needs to sit down.

This component could be implemented within every structure that the team discussed. Within this design component, there were many options discussed. The first was a seat located on a locking-track mechanism (Figure 15). In this design, the seat would be able to help the user in multiple ways. The seat could be fully horizontal, allowing the user to use the walker more like a wheelchair. The second option was an angled seat to help support and push the user along as they walk. Here, the two bars holding the seat would slide along the track underneath the seat as the back of the seat slides up the vertical bars in the back of the walker. Finally, the seat could be folded out of the way completely. To do this, the user would slide the two support bars farther back than the bottom of the seat as the back of the seat slid further up the vertical bars in back. Here, the seat would hang vertically and out of the way.

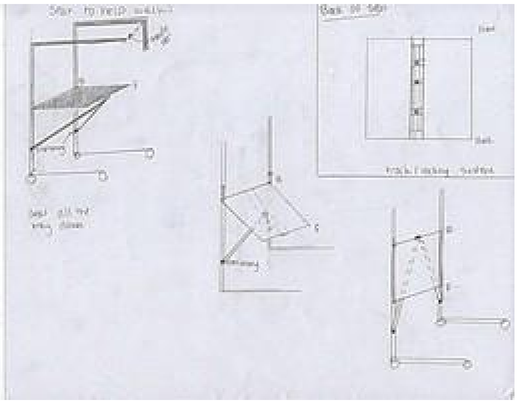


Figure 15: Seat Design 1

However, this design still required the user to turn around to change the seat location, or required the help of another person.

The second seat idea (Figure 16) was for a walker that is located in front of the user, or a "front walker." In this design, the seat is placed on the side of the structure when the user enters or exits the walker. If the seat is needed, the user enters the walker, and the seat can be rotated behind the walker. The seat then rotates from a vertical position to a horizontal position so the user can sit on it.

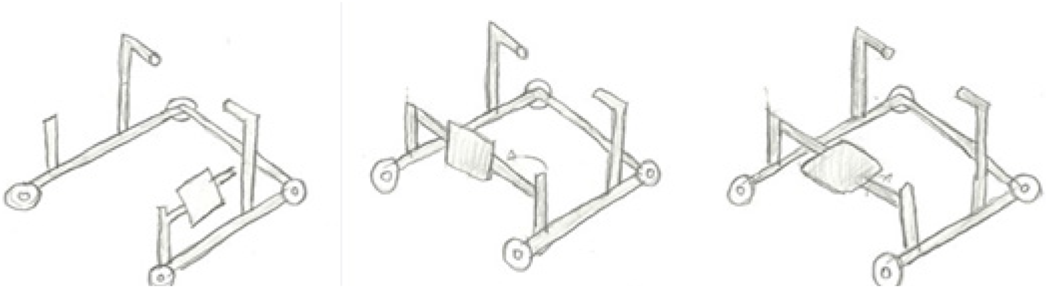


Figure 16: Seat Design 2

This idea sparked the discussion of a lever or some kind of mechanism that would allow options like this one and the one above (Figure 15) to work while the user stays facing forward.

Another seat folding mechanism that the team explored is based off of a storage box top. The concept incorporates two equally sized parts. The way the two halves mate together allows them to be opened when pulled up, but they stay closed when pushed down. This allows the user to easily open the seat to walk, and it ensures the user's safety when they are sitting down (Figure 17).

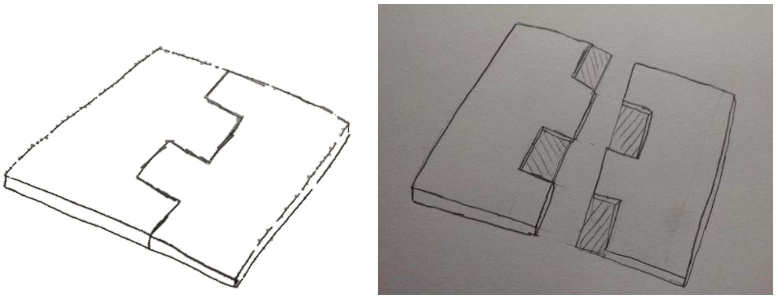


Figure 17: Seat Design 3

The team further designed this idea to be paired with a lever-wire system to allow the use to not turn around when raising or lowering the seat.

The system involves a cable in tension with one end attached to a lever and the seat halves attached to the other ends. When the lever is ‘locked’, the cable is pulled taught and the seat raises. When the user wants to lower the seat, the lever is pushed to ‘unlock’ and the seat falls 90 degrees to allow the user to sit. In addition, one side of a spring is attached to the seat half and the other side of a spring is attached to the side panel. When the lever is unlocked, the spring ensures that both seat halves rotate at the exact same time. This is necessary in order for the seats to lock properly.

Handlebars:

During the initial meeting, Mr. Brill stated that he preferred a handlebar that went all the way across the walker, instead of two separate handles like in the standard rollator. The team brainstormed ideas that allowed for two separate handles to connect into one long handle (Figure 18).

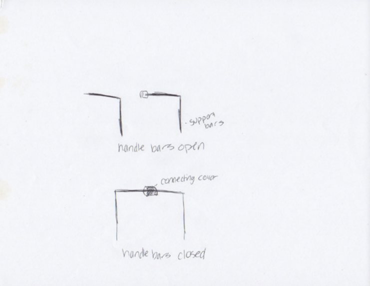


Figure 19: Connecting Handlebar

The team also designed walkers with one solid handlebar (Figure 19).

Figure 18: Long Handlebar

Wheels:

The team decided from the beginning that they would not design new wheels. The team did have to decide on what size to choose for the final design, however. Mr. Brill requested the wheels on the walker be able to move across many different terrains, both indoors and outdoors such as carpet and grass. The team started with the sizes of the wheels that Mr. Brill currently owns, and moved up from there. The U-Step walker, for example, has 4" castor wheels. The team compared existing walker wheels for both the back 'stable' wheels, as well as the front caster wheels:

Table 2: Wheel Comparison - Stable Wheels

Stable Wheels	Weight	Cost
	[lbs]	[$]
6"	1	$19.95
8"	1	$19.95
Double (8")	5	$33.00

Table 3: Wheel Comparison - Caster Wheels

Caster Wheels	Size	Weight	Cost
	[in]	[lbs]	[$]
Ultra Light Freedom	6"	4	$30.95
Medline Economy	8"	4	$30.95
Medline Heavy Duty	8"	4	$22.95
Nova Rolling Walker	8"	1	$19.95

The team experimented with all the walkers available to them to see how different wheels worked with different terrains.

Concept Selection

After many brainstorming and discussion sessions, the team decided to focus on one design with a compilation of all the component and structure ideas talked about during meetings. As mentioned above, the team originally decided on a design that focused on using aluminum tubes but realized after building a prototype that weight was an issue. The team discussed the other aluminum ideas, but once they added in the weight of the handlebars and the wheels, the team decided the only way to keep the overall weight down was to reduce the amount of metal in the design. The team decided to move forward with a carbon fiber design.

In order to eliminate the unnecessary weight from the previous designs, the team decided to focus on structures that could incorporate more composite materials and less metal tubing. The team started with the sketches of the base structures from above and came up with an initial design (Figure 20).

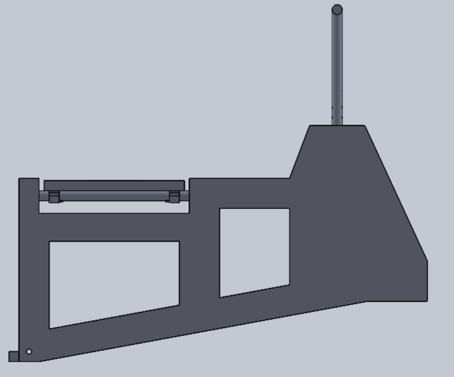


Figure 20: Original Carbon Fiber Design

After reviewing the original design, it was found that a more triangular design would be more structurally sound due to the way the load is supported by the location of the wheels on the walker (Figure 21).

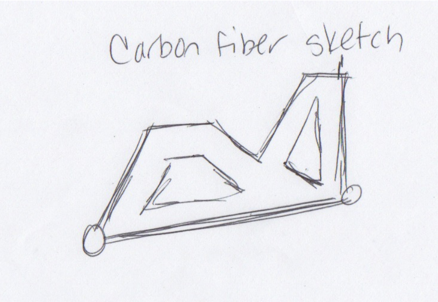


Figure 21: Sketch of Carbon Fiber Panels

Once the composite layout was better suited for the loads, the team chose the design for the folding mechanism. The scissor lift was the best design for the composite panels due to the way it connected the panels. This layout focuses on being able to fold easily and support weight on the handles better than some alternatives. Here, two composite sides are connected by the handlebars and folding mechanism. As the team worked on the design for the folding mechanism, the panels had to be adjusted. The brackets attaching the folding mechanism to the side panels were overlapping with some of the holes in the panels. The triangular holes were then moved to ensure the folding mechanism brackets could be completely attached to the panels (Figure 22).

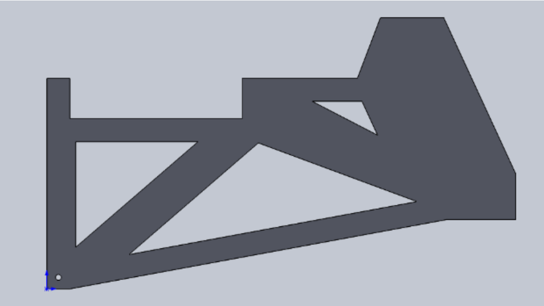


Figure 22: Final Iteration of Carbon Fiber Panels

The scissor lift folding mechanism is utilized in order to ensure ease of use. It also guarantees that the walker remains open when the user is putting force on it. When the user wishes to fold the walker, he or she pulls up on the handlebar. This moves the collars on the middle bar up, which in turn pulls the two composite sides together. The collars will be described in more detail in the following sections.

The seat is modeled after the storage box top mentioned above. The seat rotates within a 90° angle between horizontal (for sitting) and vertical for when the user doesn't want to utilize the seat. The team also decided on the locking-lever system to raise and lower the seat when the user so chooses. Both sides of the seat are attached to each other by way of a cable in tension, so they can move at the same time. There is a lever that controls this mechanism on the right-hand side of the walker.

The final two design components the team looked at were the orientation of the handlebars and the wheel selection. As mentioned above, Mr. Brill was very specific in his requirements about having a horizontal bar. The handlebar in the final design is height adjustable and have one horizontal bar for the user to place their hands.

The wheel setup has two caster wheels in the front and two stable wheels in the back. All four wheels have a diameter of 8 inches. The team decided the larger wheels would be a much better option for the terrain parameter Mr. Brill wanted. This setup also allows for a smaller turning radius. During the team's brainstorming phase at the beginning of the project, it was found that walkers were easier to push and maneuver when the caster wheels were located under the handlebars.

Chapter 4: Description of Final Design

After many brainstorming sessions and design iterations, the team decided to pursue a design incorporating carbon fiber panels. This change in material helped decrease the overall weight of the walker, which was the main concern for Mr. Brill's. The following section describes the final design in more detail.

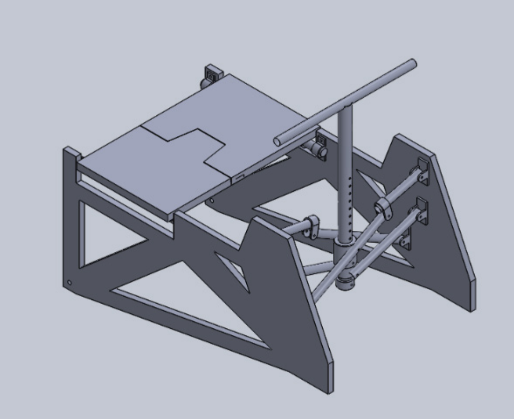


Figure 23: Overall Final Design

Detailed Design Description

Base Shape

Due to the nature of building with carbon fiber, the walker has two matching panels (Figure 24), one on each side of the user, as the 'base'. The sides are attached by the handlebar and folding mechanism, which is placed in front of the user. These will be described in detail in later sections.

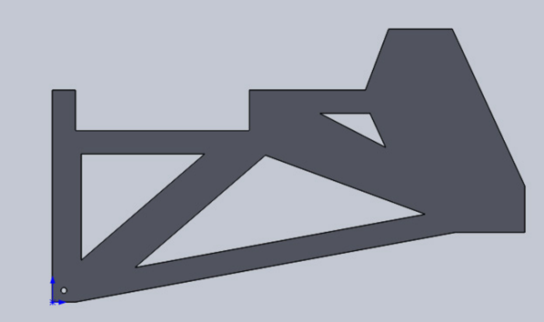


Figure 24: Final Design of Carbon Fiber Panels

Folding Mechanism

The folding mechanism was designed to minimize the amount of work the user would have to do to fold the walker. To fold the walker with the carbon fiber design, the user simply has to unlock and lift the handle bars up to bring the two carbon fiber sides together. A major design priority that the team had to keep in mind was to make sure the walker would not fold in on itself while in use. The handlebar and folding mechanism set up eliminates this hazard with the locking collars on the handle bar. The user's weight on the handle also forces the walker to stay open because it forces the folding mechanism to push out, which keeps the walker open.

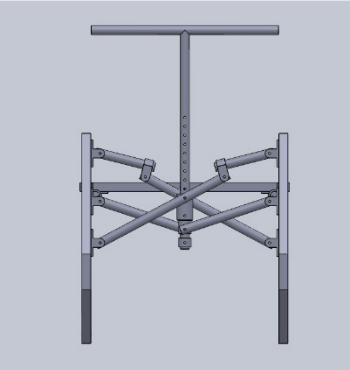


Figure 25: Walker fully extended

Figure 25 above shows the walker fully extended. The handlebars lock at the bottom of the T-bar to keep the handles from rotating as well as moving up and down. Figure 26 below shows the walker being folded.

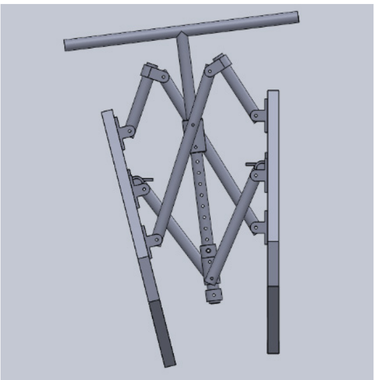


Figure 26: Folding mechanism in action

Seat

As mentioned above, current rollator seats are just a flat, padded bench that the user can rest on. In order to sit down, the user must turn the rollator around or walk around the rollator without support. It can be dangerous for the user to maneuver without any support. Therefore, this walker eliminates the need of the user to move around the walker by placing the seat behind the user as opposed to in front of him or her. The seat will also be made out of carbon fiber to minimize the weight.

Although some walkers on the market do place the seat behind the user, they typically use seats shaped like bicycle seats. This can be very uncomfortable if used for long periods of time. Therefore, the seat in this design is flat and more like a chair, and it allows the user to place various items on it to carry them over short distances.

As mentioned above, the seat is designed to be behind the user. The user has the option to walk with the seat up or down; however, there is more legroom when the seat is open. In order for the seat to be in use, the two sides interlock with each other to ensure that it doesn't fold past 90 degrees (parallel with the floor) (Figure 27).

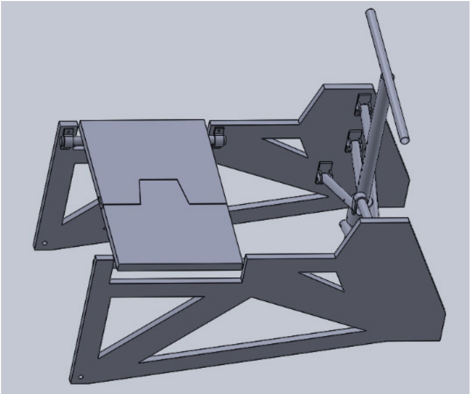


Figure 28: Seat down for sitting

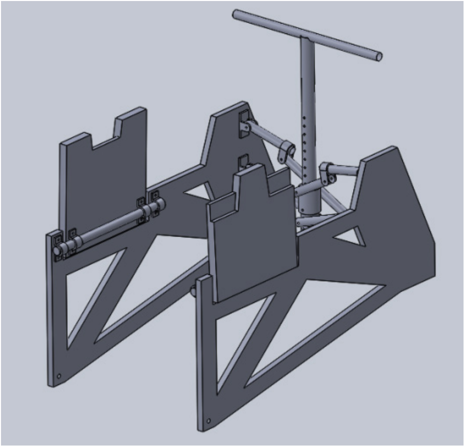


Figure 27: Seat up for walking

The seat in the carbon fiber opens and closes behind the user. The seat interlocks with itself to ensure that it does not fold past 90 degrees so the user can sit on it (Figure 28).

The seat has a lever and cable mechanism that allows the user to open and close it without turning around._This system consists of a cable in tension with one end attached to a lever and the seat halves attached to the other ends. When the lever is 'locked', the cable is pulled taught and the seat raises. When the user wants to lower the seat, the lever is pushed to 'unlock' and the seat falls 90 degrees to allow the user to sit and rest if they need to without having to turn around or have another person help them.

Handlebars

One very important ergonomic consideration in the design of this walker was the orientation of the handlebars. Mr. Brill has noticed that the standard handlebar orientation is detrimental to the user's posture. Currently, walker handlebars are parallel to the user's feet (Figure 29). Since the handlebars are to the sides of the user's body, the walker does not provide the maximum possible support to the user in front of his or her body, causing him or her to hunch over. The height of the handlebars also affects the user's posture.

Figure 29: Current Walker Handlebar Locations

A better configuration for the handlebars is to create a horizontal handlebar that is not only perpendicular to the user's feet, but located higher up relative to the user's body. This would create more support in front of the user, and help him or her stand upright (Figure 30).

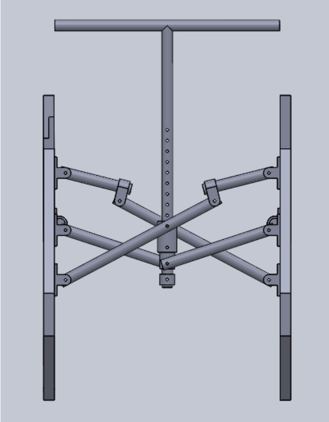


Figure 30: Finale Handlebar Design

The handlebars on the carbon fiber design are height adjustable to fit each user specifically. Depending on the user, the height of the handlebars allows users to stay upright and discourage them from hunching over while walking.

The handlebars are located 21 inches above the seat, which is approximately 18 inches above the ground. These dimensions correspond to the highest possible handle height and the lowest possible seat height. The height of the handle bars helps tall users stay upright and discourage them from hunching over while walking.

Materials

Although the side panels are made out of carbon fiber, the interlocking folding bars must be made out of metal because it is much easier to manufacture. Important characteristics of the metals under consideration include weight, cost, yield strength, and weldability (Table 4).

The metals under consideration were aluminum, steel, titanium, and composite materials such as carbon fiber. The following table is a first look at the comparisons among the materials.

Table 4: Material Comparison

	Yield Strength	Nominal Density	Weldability
	[psi]	[lbs/in^3]	[poor, good, excellent]
Aluminum			
2024	42,000	0.101	good
6061	35,000	0.1	good
Steel			
4130	70,000	0.283	excellent
Titanium			
Grade 9	90,000	0.162	good-excellent
Carbon Fiber			
Unidirectional	132,000	0.000205	poor

It was also important to consider price of the materials (Table 5 and Table 6).

Table 5: Metal Material Comparison

	Al-2024	Al-6061	Steel
Length (3 ft)			
OD - 0.25"	$19.78	$12.11	$14.09
OD - 0.5"	$22.60	$15.46	$14.98
OD - 0.75"	$24.08	$18.44	$16.27
OD - 1"	$35.05	$21.67	$18.00
OD - 1.5"	$54.44	$31.46	$32.25

Table 6: Aluminum and Carbon Fiber Comparison

	Ti-Grade 9	Carbon Fiber
Length (4 ft)		
OD - 0.5"	$176.03	--
Length (5 ft)		
ID - 0.25"	--	$36.80
ID - 0.5"	--	$54.00
ID - 0.75"	--	$72.00

The team decided on a final material by analyzing the characteristics above in conjunction with budget constraints and overall aesthetics of the walker.

As mentioned above, the team has decided to move forward with carbon fiber for the material. This was decided primarily because of the weight requirements set by Mr. Brill. The team switched designs and materials after finding the total weight of the walker made with aluminum, plus all of the components mentioned below, was much higher than the 10 pound weight requirement. The team has decided to go with carbon fiber for the final material due to its much lower nominal density.

Components

Wheels:

A major concern of current walker users is the ease of use on rough surfaces. Most current walkers are especially hard to use on carpeted floors. In order to fulfill Mr. Brill's requirement that the walker be able to roll on non-smooth surfaces, the team compared existing walker wheels and chose 8 inch diameter wheels, which are capable of rolling over a greater variety of surfaces than the typical 6 inch wheels.

The wheels in Table 5 and Table 6 above are comparison tables of the options the team reviewed when choosing the wheels size for the final prototype.

Handlebars

Another one of Mr. Brill's requirements is to be able to stand upright and not be hunched over while using the walker. As mentioned above, this is accomplished by rotating the handles to be perpendicular and higher up from the ground than existing walkers. The handlebars are made out of aluminum tubing.

Analysis Results

Since the walker needed to support 300 pounds in the handlebars or the seat, it was important to do a force analysis on both the side panels and the folding mechanism. The team used a Finite Element Analysis program, Abaqus, to complete the force analysis.

Side Panels

Since the carbon fibers can be laid out in the direction of the force, an axial stress analysis was used to determine the necessary thickness of the side panels. It was determined by initial hand calculations that a core thickness of ¾ inches and three plies of fiber (0.006 inchesthick each) on each side would be sufficient to support the 300 pound load. The composite-foam core-composite layering can be seen below in Figures 31 and 32.

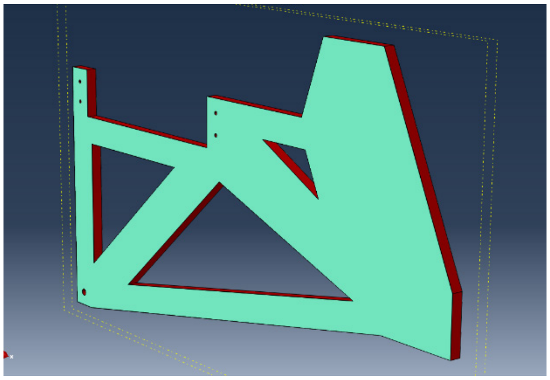


Figure 32: Carbon fiber side 1

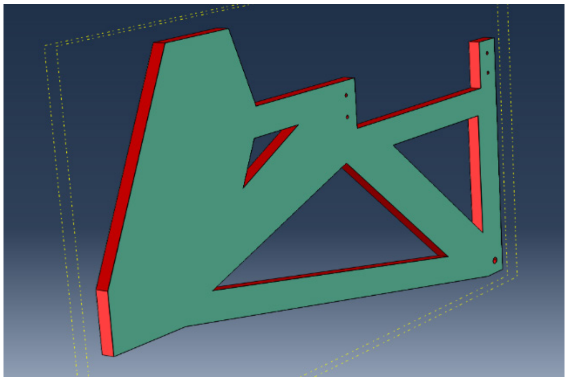


Figure 31: Carbon fiber side 2

The green sections represent the carbon fiber plies and each have a thickness of 0.018 inches. The red section in the middle represents the PVC foam core and has a thickness of 0.75 inches. Each of the three sections were assigned the following material properties (Table 7):

Table 7: Material Properties

Material	Young's Modulus	Poisson's Ratio	Thickness
	[psi]	[ ]	[inches]
Carbon Fiber Composite	19,580,000	0.32	Each ply = 0.006
			Total (each side) =0.018
PVC Foam Core	20,300	0.3	0.75

Originally, the model was only going to represent the carbon panel plies, which has a total thickness of 0.036 inches. When the model was run, it was found that Abaqus needed the full thickness of the panels (including the PVC foam core) in order to get accurate results. With a thickness of only 0.036 inches, the results showed extreme deformations that the team knew were wrong due to the nature of carbon fiber. The model was then reanalyzed with the correct thickness of both the carbon fiber and the foam core and the corresponding material properties (seen above in Table 7).

The team wanted to analyze the panels for a worst-case scenario of the user putting 300 pounds of force on the seat. This way, the walker would support the user if they needed to be fully supported by only the seat. The seat is attached to a tube which is then attached to the carbon fiber panels by brackets (Figure 33).

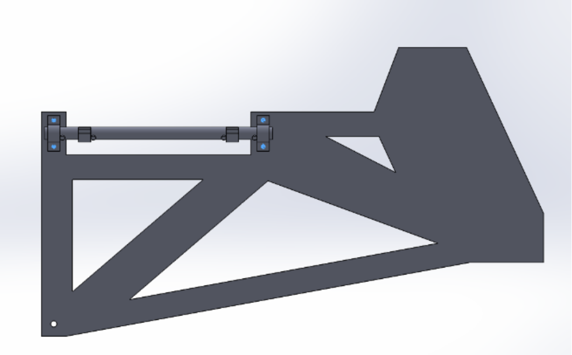


Figure 33: Location of Loads for Analysis

The loading was applied at the four holes, highlighted blue in the figure above, as a pressure throughout the thickness. The 300 pound load was split so the front part of the seat saw 150 pounds and the back part received 150 pounds. These loads were then cut in half again so each bracket hole received 75 pounds. In order to be analyzed in Abaqus, the 75 pounds were distributed over half of the area of the thru hole (0.31 in^2). The pressure seen by each of the four bracket holes is 242 psi.

The boundary conditions in Abaqus represented how the wheels react with the physical model. The back wheels are attached by a screw at the hole highlighted in Figure 34. This hole has boundary conditions that do not allow for any displacement in all directions or rotation. The front wheel is attached on the vertical part on the front of the panel. This is also highlighted below in Figure 34. The same boundary conditions applied for the back wheel are applied for the front wheel.

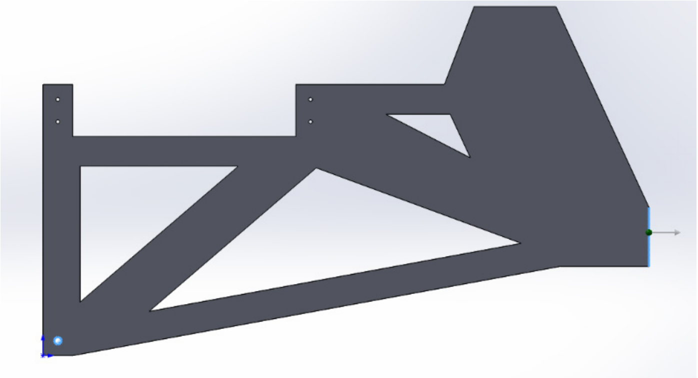


Figure 34: Location of Boundary Conditions for wheels

Figure 35 shows the complete loading and boundary condition setup for the model.

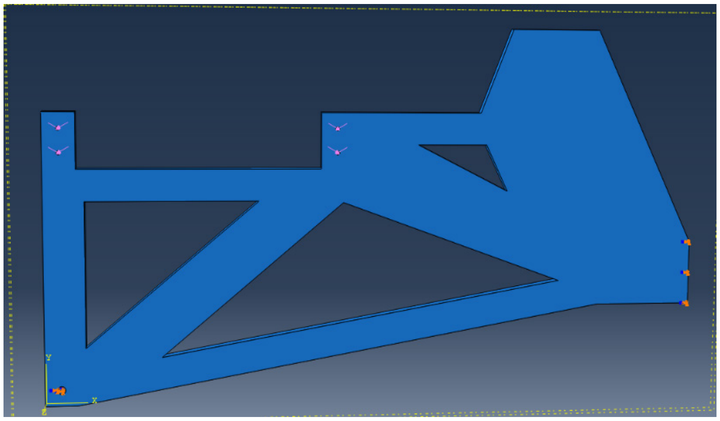


Figure 35: Complete Loading and Boundary Condition Setup

The mesh created for this model was a standard, linear, 3D stress, wedge element (C3D6 element). This mesh setup was chosen because it resulted in no warnings of distorted elements or errors when the model was run. The mesh size was changed and run multiple times to make sure the mesh converged and to see what the maximum stress and vertical deflections were on the model. The purpose of this Abaqus analysis was to see the locations and values of maximum stress as well as the vertical deflections on the panels. With the results of this analysis, the team will be able to make changes to the prototype to improve the design.

Figures of the stress on the panel with each seed size used can be found in Appendix D. The figures showing the vertical deflections can be found in Appendix E.

The results of the stress analysis showed that the panels will be experiencing around 6,000 psi when the full loading is applied. This was not a concern for the team because the carbon fiber panels will fail at about 180,000 psi. The results did show the team that, if needed, extra plies of carbon fiber could be added around the holes where the loading is applied, as well as where the wheel is attached for extra support.

The results also showed a maximum vertical deflection where the front of the seat is attached. Again, this told the team that, if needed, extra plies of carbon fiber could be applied here for extra support. However, the max deflection seen by the model is $2.47*10^{-3}$ inches so the team is not concerned about the design failing due to the loading.

Folding Mechanism

Because the folding mechanism consisted of many interlocking components, a force analysis on it was much more complicated. If the force on the folding mechanism were to cause the walker to break, the crossbars of the folding mechanism would be forced completely horizontal. Therefore, the team decided to analyze the force that would cause this to happen with various thicknesses of aluminum tubing. It was found that aluminum tubing with a thickness of 0.035 inches, would be more than strong enough to support the 300 pound load.

Cost Breakdown

Below is a table outlining the individual costs of each component of the prototype walker (Table 8).

Table 8: Cost Breakdown for Prototype

Component	Item	Quantity	Supplier	Unit Price	Total Price
Handlebar					
	1” diam. 6061 Al Tube	25.25” length	McMaster Carr	$15.90	$15.90
	1.5” diam. 6061 Al Tubing	25” length	McMaster Carr	$31.26	$31.26
Folding Mechanism					
	2.5” diam. 6061 Al bar stock	1’	McMaster Carr	$38.14	$38.14
	2” diam. 6061 Al bar stock	1’	McMaster Carr	$25.34	$25.34
	¼”-20 Threaded Rod	1’	Home Depot	$1.97	$1.97
	1” diam. 6061 Al Tubing	5.66’	McMaster Carr	$35.33	$35.33
	4 ft 1.25”X1.25”X 1/8 ” Al U-Channel	18”	Metals Depot	$19.48	$7.30
	Stainless Steel Pin with Wire Lock	1	McMaster Carr	$6.76	$6.76
	#8-¾” Wood Screws	12	Home Depot	$4.65	$4.65
	¼”-20 1” Bolts	8	Home Depot	$1.18	$9.44
	¼”-20 Nuts	6	Home Depot	$1.18 (10 pack)	$1.18
Wheels					
	8” Walker Wheels	2	Nova Medical Products	$19.95	$39.90
	8” Caster Wheels	2	Nova Medical Products	$13.17	$26.34
	1.5”X1.5”X 24”	6”	McMaster	$27.13	$6.78
Side Panel (For Prototype)	¼” Thick Plywood	4’X2’	Home Depot	$6.20	$6.20
Total (for prototype)					$256.49

Safety Considerations

There are many important safety considerations with this project, most of which involve preventing the user from falling down. First, the walker must not break under normal loading conditions, since doing so could result in the user falling and possibly injuring him or herself. In addition, the wheels must be set up in a stable configuration that supports the user on various inclines. Furthermore, the user must not lose his or her balance when adjusting the seat. In order to ensure this, our design allows the user to hold onto the handlebars while adjusting the seat. It is also important to consider the brake and friction force on the wheels because the walker should not be able to roll away from the user. This consideration is especially important on hills because if the user needs to stop on a hill, the walker should stay with the user at all times.

Maintenance and Repair Considerations

It is important to make sure that there are extra parts that users can buy to replace worn down wheels or handlebars.

Chapter 5: Product Realization

Description of Various Manufacturing Processes Employed

When manufacturing the prototype, the team decided to begin with the locking mechanism and work outward to the side panels. This way, the team could verify that the folding mechanism would work before moving forward.

T-bar

The main part of the folding mechanism is the middle vertical bar that connects all the components (Figure 36). To create this, the team began with a 1.5 inch diameter aluminum tube with a wall thickness of 0.049 inches. The team needed to drill holes exactly 1 inch apart along a 1 foot length of the tube. In order to ensure that the holes were exactly 1 inch apart and completely perpendicular, the team used a mill to drill 11, ¼ inch diameter holes.

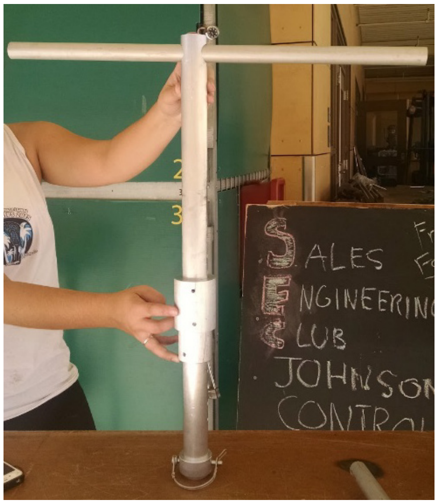


Figure 36: Handlebars with collars

Crossbars

Another component of the folding mechanism are the crossbars (Figure 37). These bars connect the side panels to the middle T-bar. These bars were made out of 1 inch diameter aluminum tubing with a 0.035 inch wall thickness. Since the hole placement on these bars was crucial, the team decided to use a mill to drill the ¼ inch holes.

Figure 37: Connecting bars

Collars

The next important component of the folding mechanism were the collars that limited the movement of the other components (Figure 38 and 39). In order to create these collars the team started out with 3 inch diameter aluminum bar stock. This 3 inch diameter collar is the outer collar which is attached to the cross bars. This collar has two inside diameters. One side of the collar has an inside diameter of 2.01 inch that is 2 inch deep, and the other side has an inside diameter of 1.51 inch. Then the team used a drill press to drill two, ¼ inch holes in the side of the collar where it is attached to the cross bars. The team then tapped those holes with a ¼-20 tap so that there would not be interference with a nut on the other side of the collar.


Figure 38: Top Collar

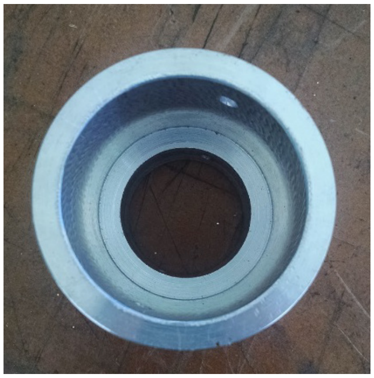


Figure 39: Inside of Top Collar

The other three collars were made on a CNC machine. The first collar made was the stopper (Figure 40). This collar was made by milling out a 1.51 inch hole from at 2 inch round stock bar. Two holes were then drilled though the middle. A locking pin is placed here once the stopper is on the T-bar. The purpose of the stopper and locking pin is to keep the other collars from sliding off the T-bar.


Figure 40: Stopper

The second collar made in the CNC was the height adjustment collar (Figure 41). This collar was made the same way as the stopper, but with an added contour cut to add grooves into the bottom.

The two holes seen in the figure above were tapped, and they line up with the holes drilled into the vertical bar of the handlebar. A set screw is screwed into the collar and then through the T-bar at a height that allows the user to walk with the handlebars at a comfortable level. This was set at a height reasonable for Mr. Brill in the prototype.

The final collar, bottom collar, made fits into the middle collar (Figure 42). This collar was made the same way as the middle collar, expect the grooves made are opposite so the middle collar and bottom collar fit into each other.

Fi ent

Figure 42: Bottom Collar

The bottom collar is attached to the connector bars and slides up and down the T-bar when the walker is being folded or unfolded. When folded, the bottom collar and middle collar fit together (Figure 43) and keep the walker extended. When unfolded, the bottom collar slides to the bottom of the T-bar and the connector bars bring the carbon fiber panels together.

Figure 43: Middle and Bottom Collars Together

Side Brackets

In order to attach the crossbars to the side panels, the team needed to manufacture brackets (Figure 44). The team used a band saw to cut 1.25 in. X 1.25 in. X ⅛ in. aluminum c-channel into 3 inch long sections. Then the team used a drill press to drill ¼ inch holes into the walls of the c-channel as well as two holes in the base of the c-channel. The team then used wood screws to attach the brackets to the side panels.

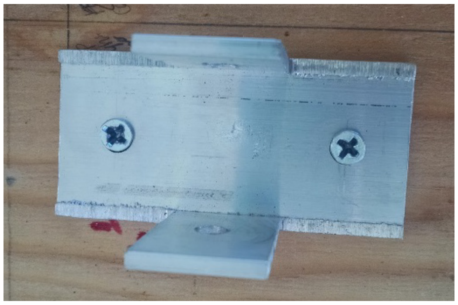


Figure 44: Side Bracket

Side Panels

For the prototype, the side panels were made out of ¾ inch thick plywood (Figure 45). The outline of the panels was drawn onto the plywood. Then the team used a jigsaw to cut the panels down to size and to cut out the holes in the panels. The side panels were then painted black.

Figure 45: Side panels before painting

Wheel Brackets

Since the shafts of the caster wheels are vertical and not horizontal, the team needed to manufacture brackets to attach the caster wheels to the side panels (Figure 46). This bracket was made out of 1.5 in X 1.5 in X 24 in. aluminum bar stock. The team cut two, 2.75 inch pieces off of the bar stock, and they drilled a 1 inch diameter hole into both pieces. The shaft of the wheel fits into this hole. Then, another ¼ inch hole was drilled perpendicular to the 1 inch hole. When a bolt is placed into this hole, it acts as a stopper so that the wheel cannot be removed. Then, a 0.75

inch wide channel was milled out of both brackets, and the plywood side panel was placed into this channel and secured with epoxy.

Figure 46: Wheel attachments

Description of How Prototype Differs from Planned Design

Because the side panels and the seat were made out of plywood in this iteration of the prototype, the ten pound weight requirement was not met. Additionally, since the seat raising mechanism was designed based on the weight of the carbon fiber seats, it was not able to lift or lower the plywood seats. Furthermore, the original design included press fit pins in each of the collars to connect the folding mechanism to the T-bar. However, the team decided that it would be easier to manufacture the collars with tapped holes and use threaded aluminum rods to attach the collars to the T-bar.

Recommendations for Future Manufacturing of Design

Due to the timeline and the scope of the project, the team was unable to see the manufacture of the design to completion. In the next prototype, the seat and the side panels would be made out of carbon fiber. Furthermore, some of the dimensions of various components will need to be updated in order to aid in the manufacturing process.

Chapter 6: Design Verification

Test Descriptions

The first step in testing the walker was to make sure that it is easy to use. By the nature of the requirements, the walker is much larger than a standard rollator. This means that it is important to make sure that the user can walk through hallways and doorways with the walker. Additionally, it is important to make sure that the walker can roll on all types of flooring including hardwood floors, carpet, grass, and concrete. Furthermore, the user must be able to fold the seat up while facing forward, so the team needed to use the walker with the seat to make sure this is possible. It was also necessary to fold the walker and place it inside different car trunks to make sure that it fits inside any user's car.

In addition to usability testing, strength testing was also be necessary. Through research, the team found that the walkers currently on the market can hold up to 300 pounds. In order to make sure that this walker is compliant with this standard weight limit, the team placed different loads on parts of the walker in order to ensure that it can withstand 300 pounds.

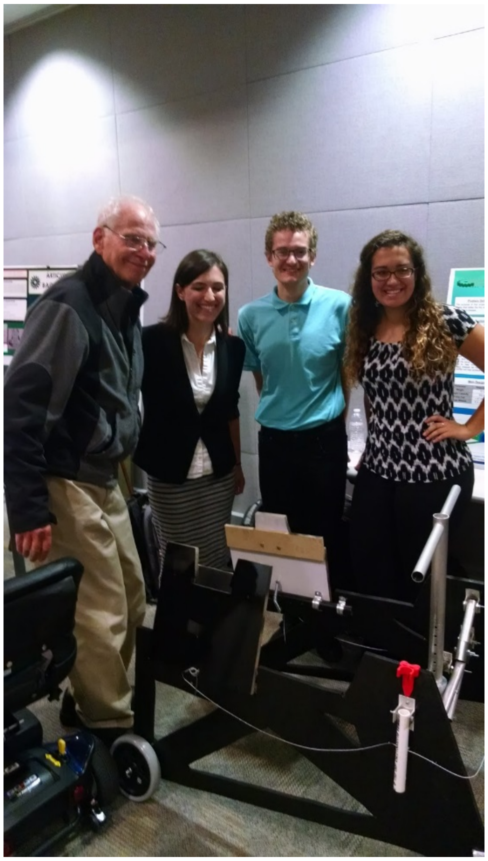
Specification Verification Checklist

Table 9: Specification Verification Checklist

Spec #	Parameter	Requirement	Tolerance	Actual Value Tested
1	Weight	10 lbs	MAX	Prototype - NA
2	Weight Capacity	300 lbs	±10 lbs	300 lb
3	Fold Flat	47 x 42 x 22 in.	±2 in.	Yes
4	Large Wheels	8 in. diameter	±2 in.	8 in
5	Sit and Walk and Stand and Walk	--	--	Yes
6	Small Turning Radius	--	--	No
7	Adjustable Height	--	--	Yes
8	Curb Step Up	--	--	No
9	Seat Moves out of the Way	--	--	Yes

Chapter 7: Conclusions and Recommendations

Upon the completion of this senior project, it is clear that there is more work to be done to improve this prototype. The carbon fiber still needs to be implemented, and testing still needs to be done in order to verify that the carbon fiber will be sufficient to support the necessary loads. However, when Jack Brill saw the prototype he really appreciated the way that the seat would fold behind the user as well as the handlebar orientation. If this project were to continue, it is recommended to use carbon fiber to achieve the weight restriction of 10 pounds.



Appendix A

QFD

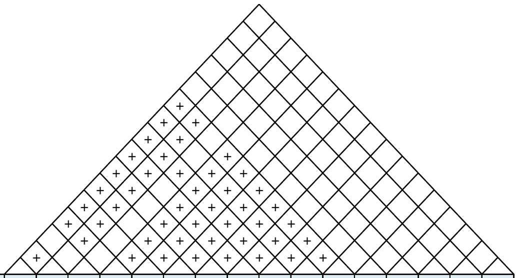
QFD: House of Quality

Project: Next Generation Walker
Revision: 1
Date: 2/10/2015

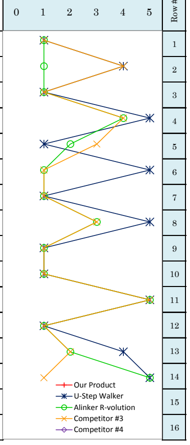
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

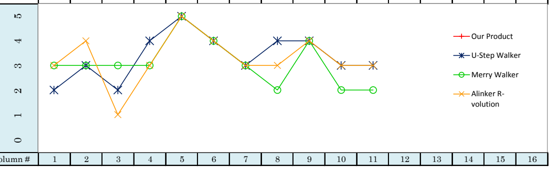


	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Current Product Assesment - Customer Requirements					
								Direction of Improvement	▲	▼	◇																			
Row #	Weight Chart	Relative Weight	Jack Brill	Parkinson's Disease Patients			Maximum Relationship	HOW: Engineering Specifications WHAT: Customer Requirements (explicit & implicit)	Measure wheels' static friction coeff.	Measure force to push walker	Weigh the walker	Measure force to turn	Perform force analysis on compnents	Compare against US criteria	Measure force to step up curb	Breaking force on all terrain	Only need one person for all functions	Measure force to squeeze brakes	Force requried to make brakes slip						Our Current Product	U-Step Walker	Merry Walker	Alinker R-volution		Row #
1		7%	6	6			9	Stand Upright		●		▽	●			○										1	1	1		1
2		2%	2	2			9	Sit and walk and stand and walk	○	●		○	●			○										4	1	4		2
3		5%	4	4			9	Seat gets out of the way					●				●									1	1	1		3
4		2%	2	2			9	Standard user weight limit	○	○		○	●	●	○	●										5	4	4		4
5		7%	6	6			9	Collpasible					●				●									1	2	3		5
6		6%	5	5			9	Lever to step up curb	○				●		●				○							5	1	1		6
7		7%	6	6			9	All-terrain	●			●	●			●		○	○							1	1	1		7
8		8%	7	7			9	Height Adjustable		○			○	●												5	3	3		8
9		9%	8	8			9	Bar in front instead of handles		●		●	●			○		○								1	1	1		9
10		9%	8	8			9	10 pounds maximum	○	●	●	○	●		○	○										1	1	1		10
11		7%	6	6			9	Durable materials	○	●	●		●						●							5	5	5		11
12		9%	8	8			9	Front-facing seat				▽	●													1	1	1		12
13		8%	7	7			9	Not modular					●				●									4	2	2		13
14		6%	5	5			9	More than 3 wheels	●			○	●													5	5	1		14
15		7%	6	6			9	Hand brake	●	○		▽				●		●	●											15
16		0%																												16



Current Product Assesment - Engineering Specifications

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	xxx (unitless)**	xxx lbs**	10 lbs	xxx lbs**	xxx lbs**	fulfills all requirements	xxx lbs**	xxx lbs**	1 person							
Max Relationship	9	9	9	9	9	9	9	9	9	9	9					
Technical Importance Rating	258.14	366.28	146.51	229.07	788.37	94.186	87.209	230.23	177.91							
Relative Weight	11%	15%	6%	10%	33%	4%	4%	10%	7%							
Weight Chart																
Our Product																
U-Step Walker	2	3	2	4	5	4	3	4	4	3	3					
Merry Walker	3	3	3	3	5	4	3	2	4	2	2					
Alinker R-volution	3	4	1	3	5	4	3	3	4	3	3					



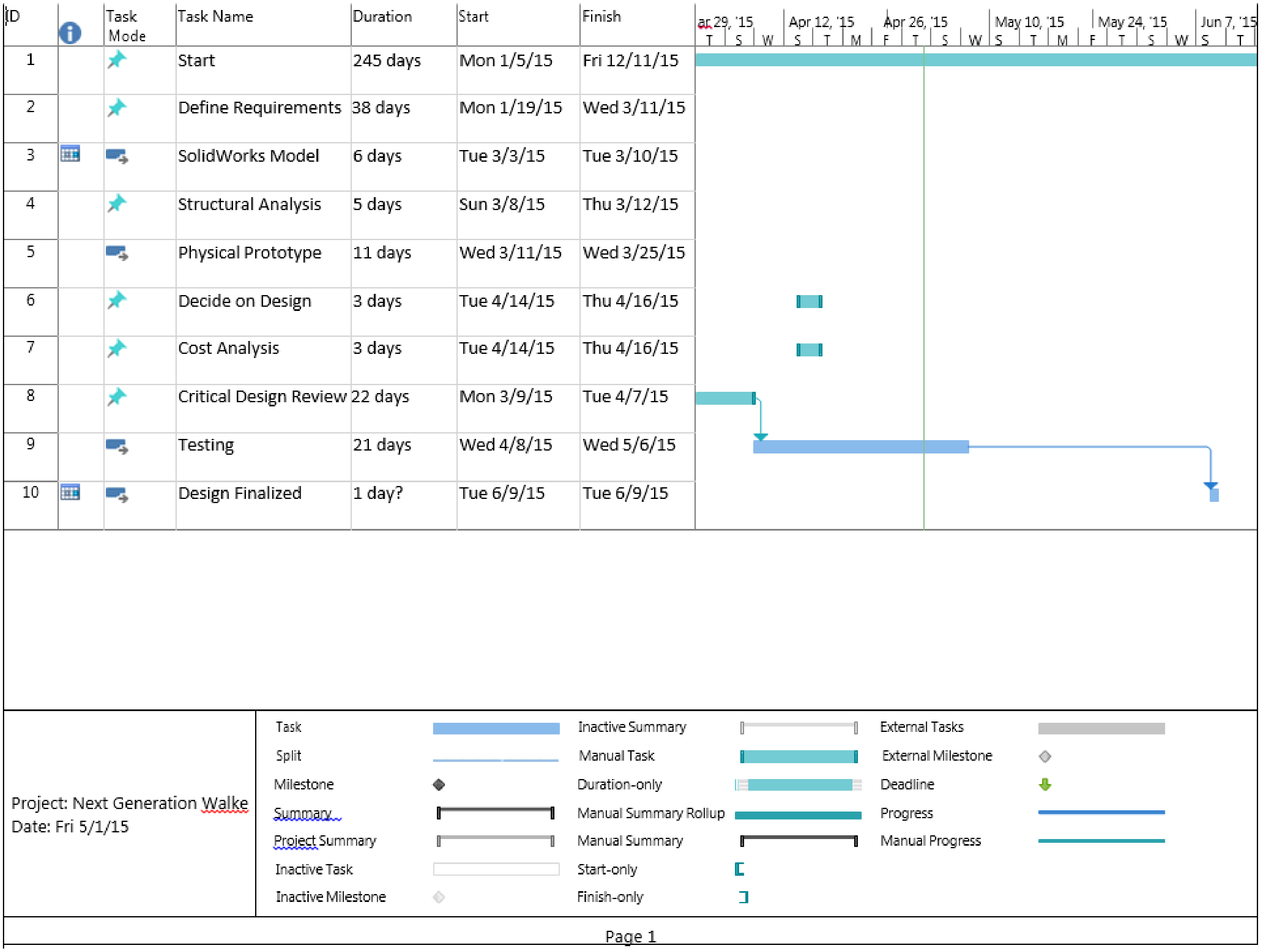
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Appendix B

Gantt Chart

Gantt Chart



ID	ℹ	Task Mode	Task Name	Duration	Start	Finish
1		📌	Start	245 days	Mon 1/5/15	Fri 12/11/15
2		📌	Define Requirements	38 days	Mon 1/19/15	Wed 3/11/15
3	📅	➜	SolidWorks Model	6 days	Tue 3/3/15	Tue 3/10/15
4		📌	Structural Analysis	5 days	Sun 3/8/15	Thu 3/12/15
5		➜	Physical Prototype	11 days	Wed 3/11/15	Wed 3/25/15
6		📌	Decide on Design	3 days	Tue 4/14/15	Thu 4/16/15
7		📌	Cost Analysis	3 days	Tue 4/14/15	Thu 4/16/15
8		📌	Critical Design Review	22 days	Mon 3/9/15	Tue 4/7/15
9		➜	Testing	21 days	Wed 4/8/15	Wed 5/6/15
10	📅	➜	Design Finalized	1 day?	Tue 6/9/15	Tue 6/9/15

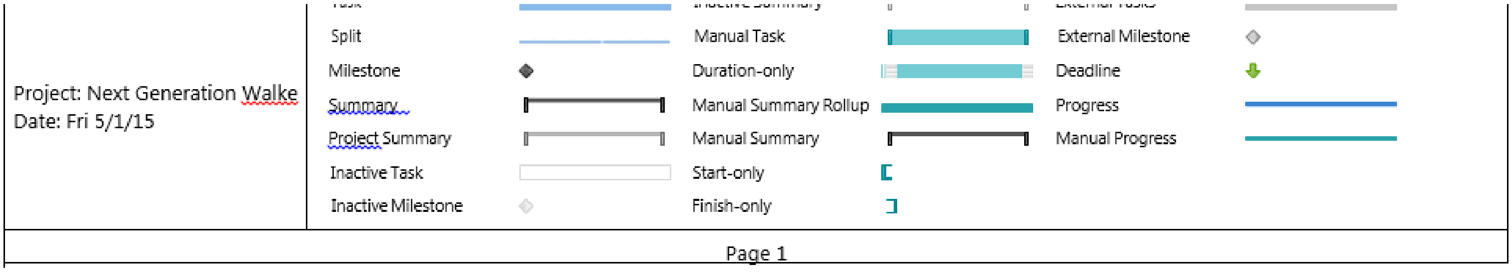
Project: Next Generation Walke
Date: Fri 5/1/15

Task
Split
Milestone ◆
Summary
Project Summary
Inactive Task
Inactive Milestone ◇

Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only [
Finish-only]

External Tasks
External Milestone ◇
Deadline ⇩
Progress
Manual Progress

Page 1



Task
Split
Milestone ◆
Summary
Project Summary
Inactive Task
Inactive Milestone ◇

Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only [
Finish-only]

External Tasks
External Milestone ◇
Deadline ⇩
Progress
Manual Progress

Project: Next Generation Walke
Date: Fri 5/1/15

Page 1

Appendix C

SolidWorks Model

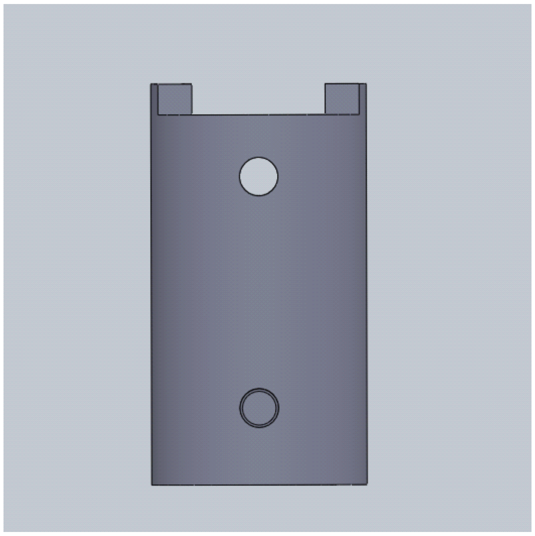


Figure 47. Bottom Collar on locking mechanism.

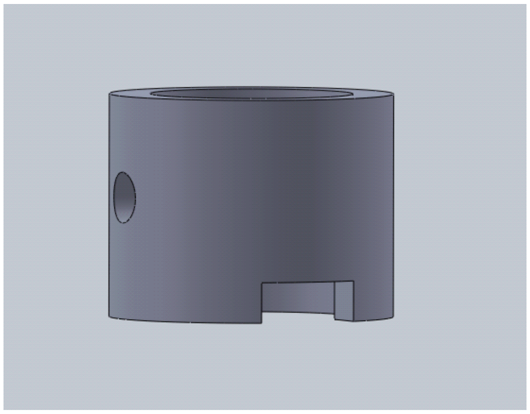


Figure 48. Top collar on locking mechanism.

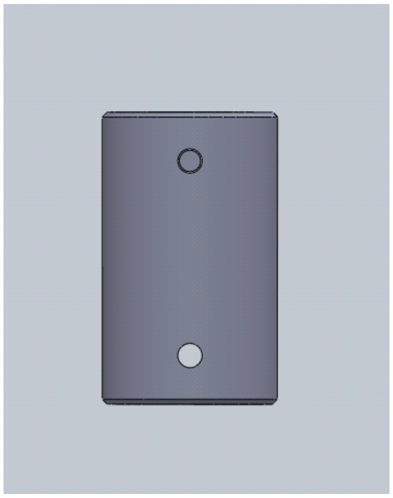


Figure 49. Large collar on locking mechanism.

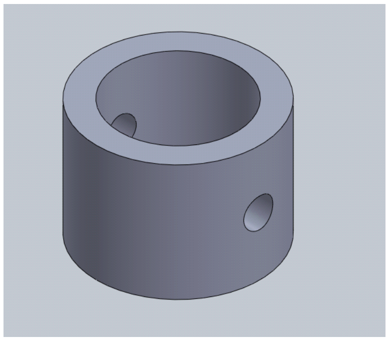


Figure 50. Bottom stopper collar.

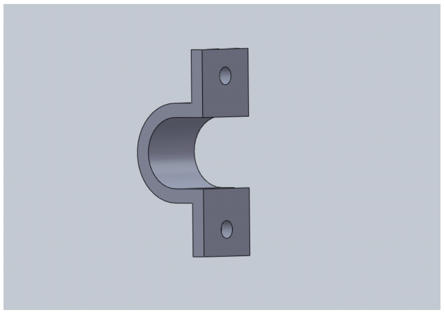


Figure 51. Seat bracket.

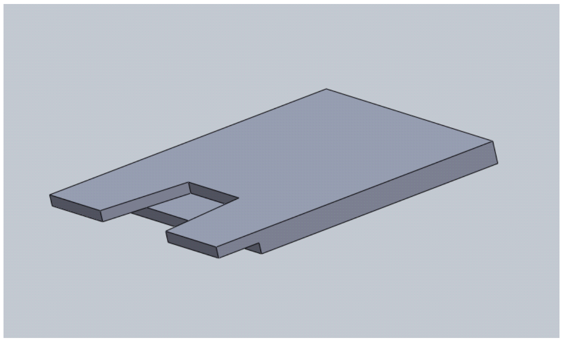


Figure 52. Left side of seat.

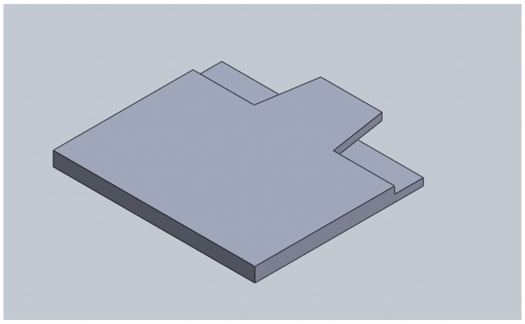


Figure 53. Right side of seat.

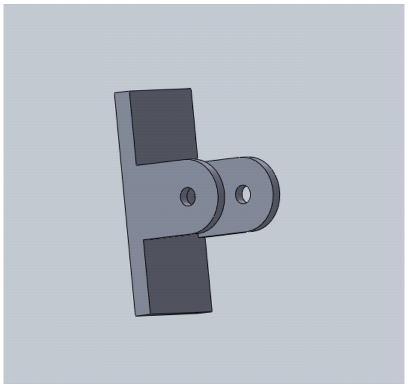


Figure 54. Side bracket.

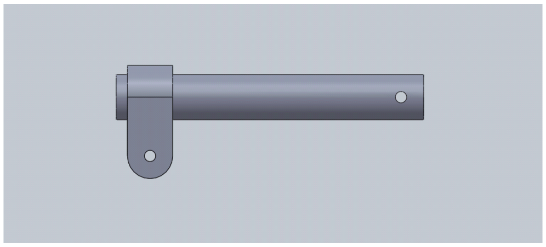


Figure 55. Top crossbar linkage.

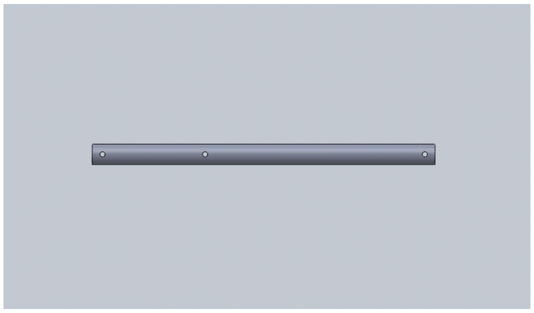


Figure 56. Bottom bar of crossbar linkage.

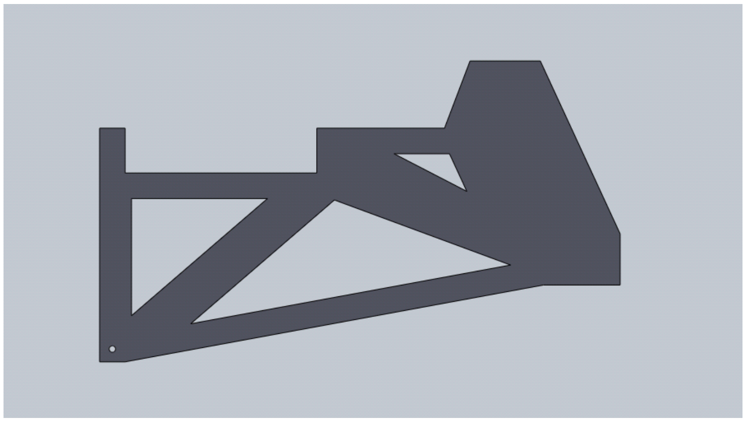


Figure 57. Carbon Fiber side panel

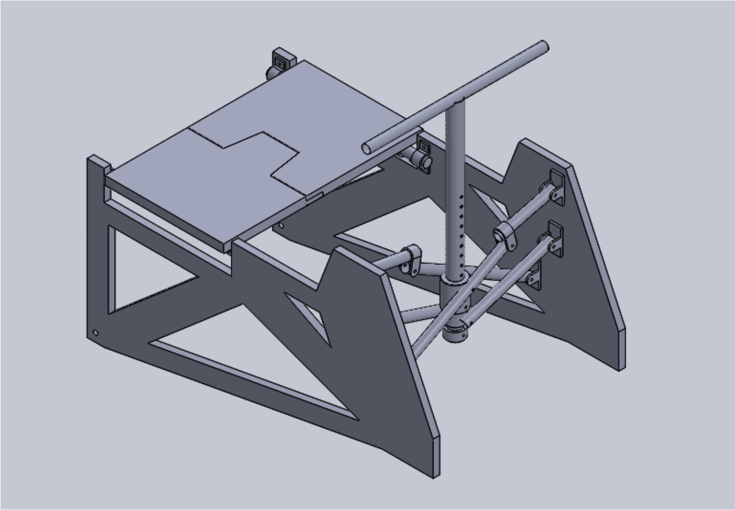


Figure 58: Isometric View of Final Design

Appendix D
FEA Results – Stress

Table 10: Max stress values panels

Seed Size	Stress
[inches]	[psi]
1	7410
0.5	4550
0.25	4595
0.175	5682
0.125	6595

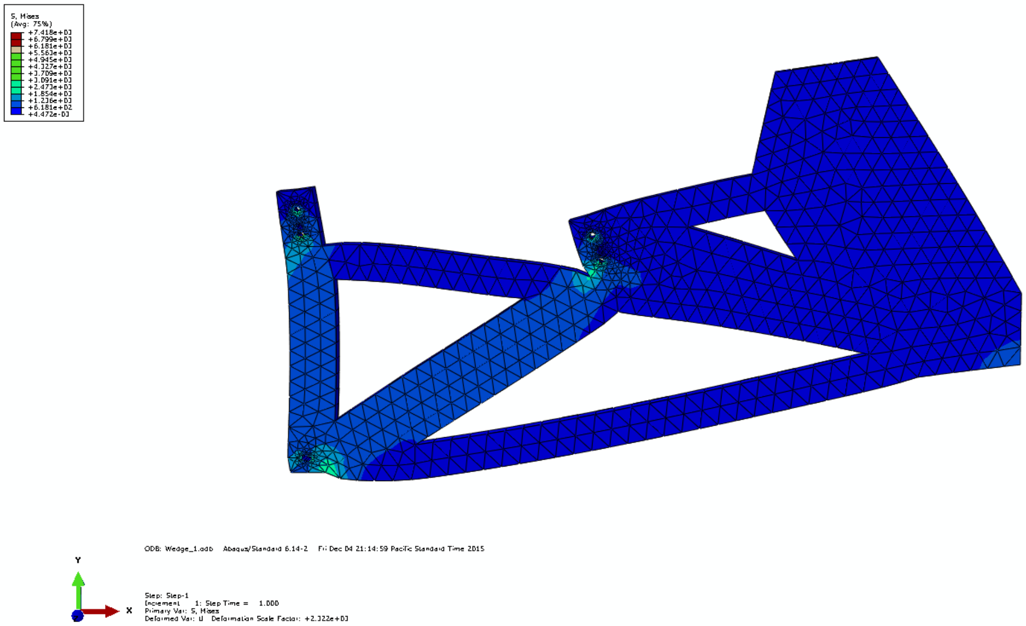


Figure 59: Mises stress on model with element seed size of 1"

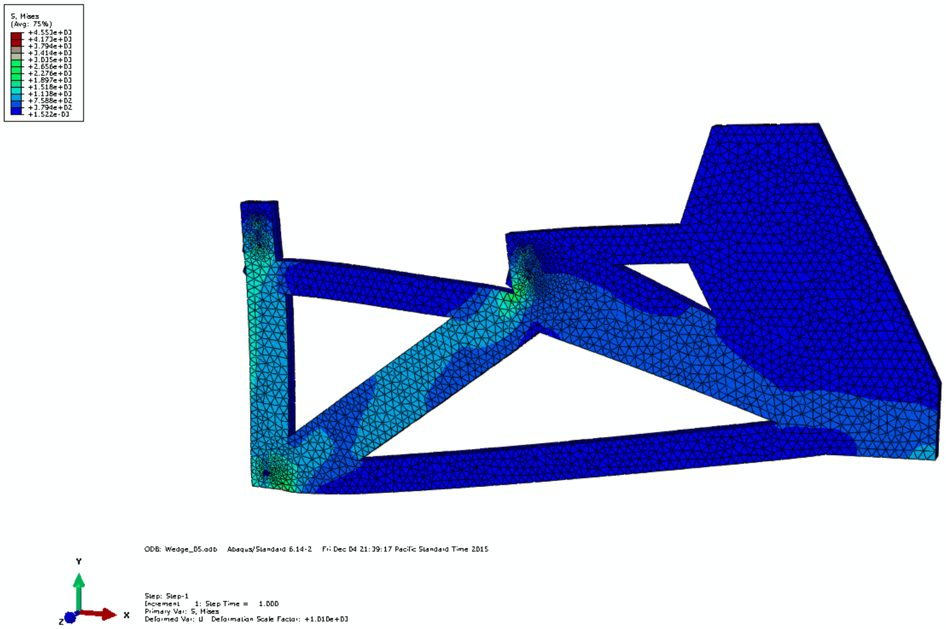


Figure 60: Mises stress on model with element seed size of 0.5"

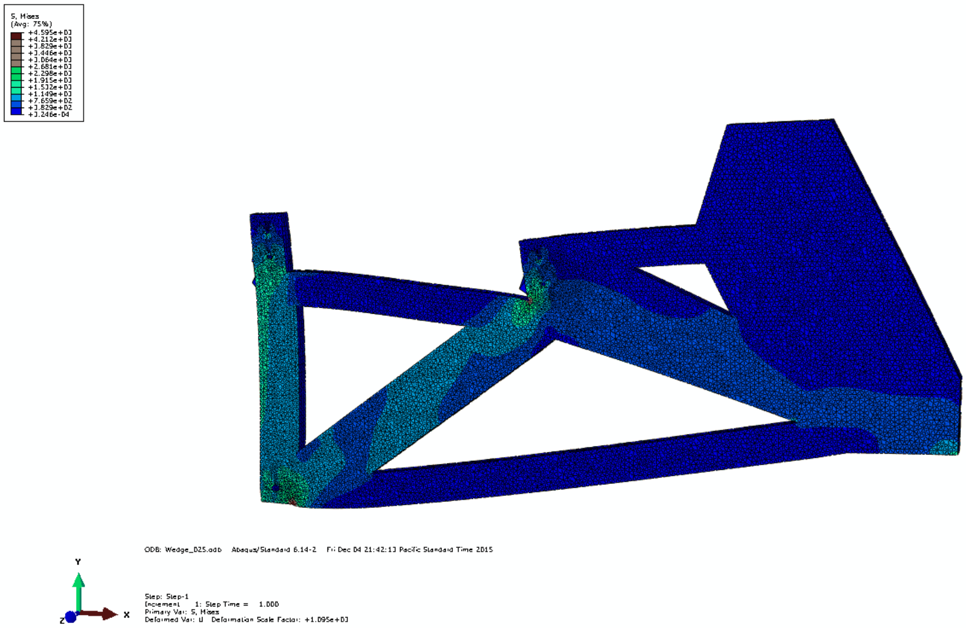


Figure 61: Mises stress on model with element seed size of 0.25"

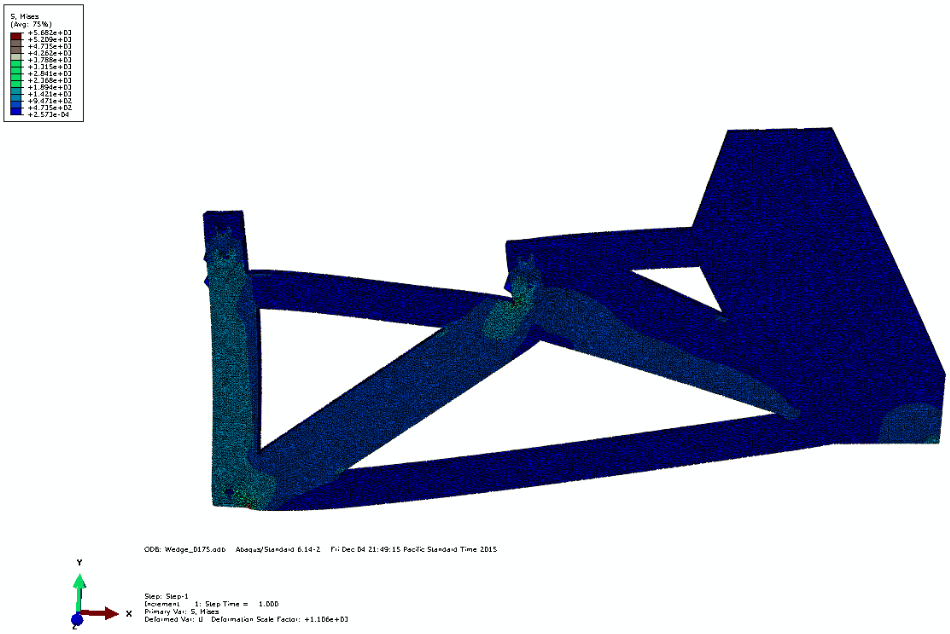


Figure 62: Mises stress on model with element seed size of 0.175"

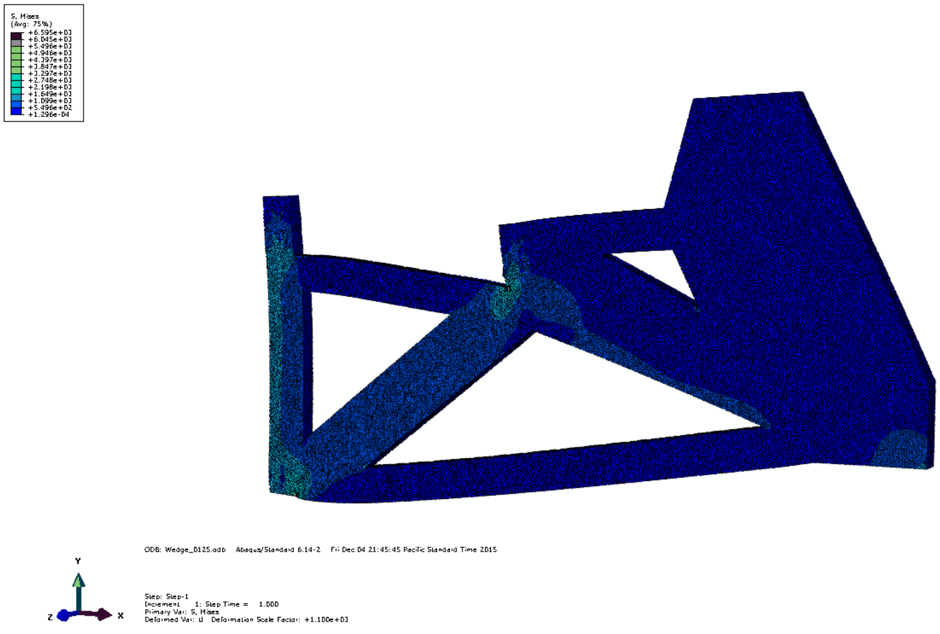


Figure 63: Mises stress on model with element seed size of 0.125"

Appendix E

FEA Results – Vertical Deflection

Table 11: Max displacements in the Y-direction

Seed Size [inches]	Displacement [inches]
1	-0.001755
0.5	-0.002689
0.25	-0.002482
0.175	-0.002456
0.125	-0.00247

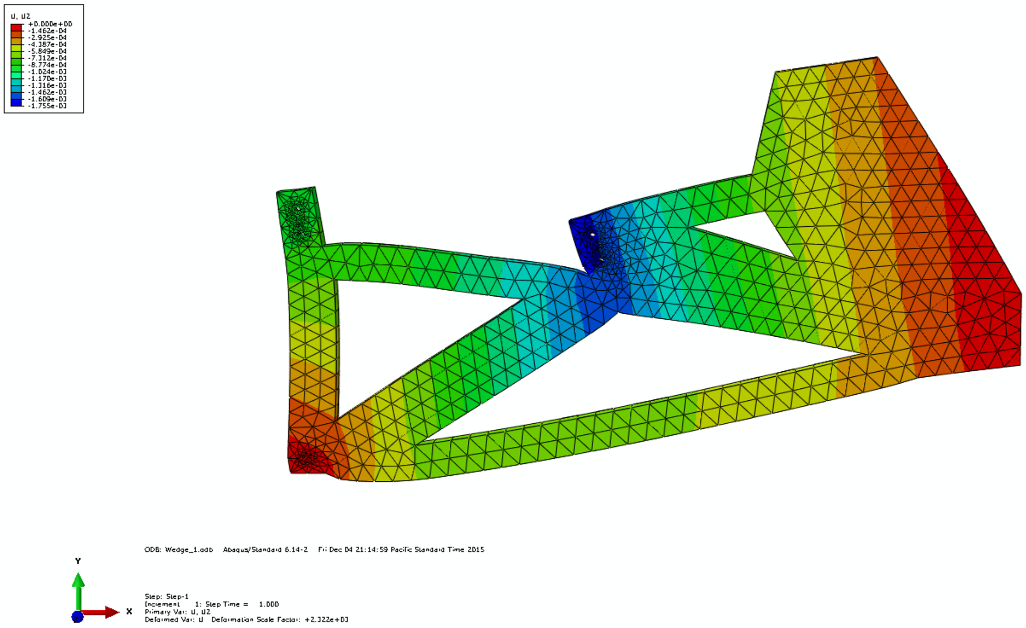


Figure 64: Vertical Displacements with element seed size of 1"

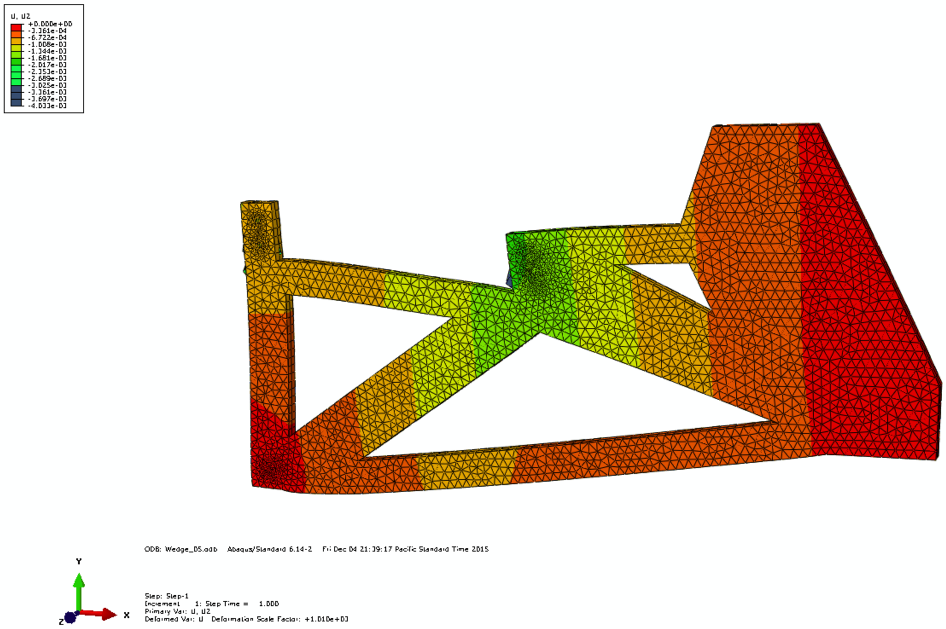


Figure 65: Mises stress on model with element seed size of 0.5"

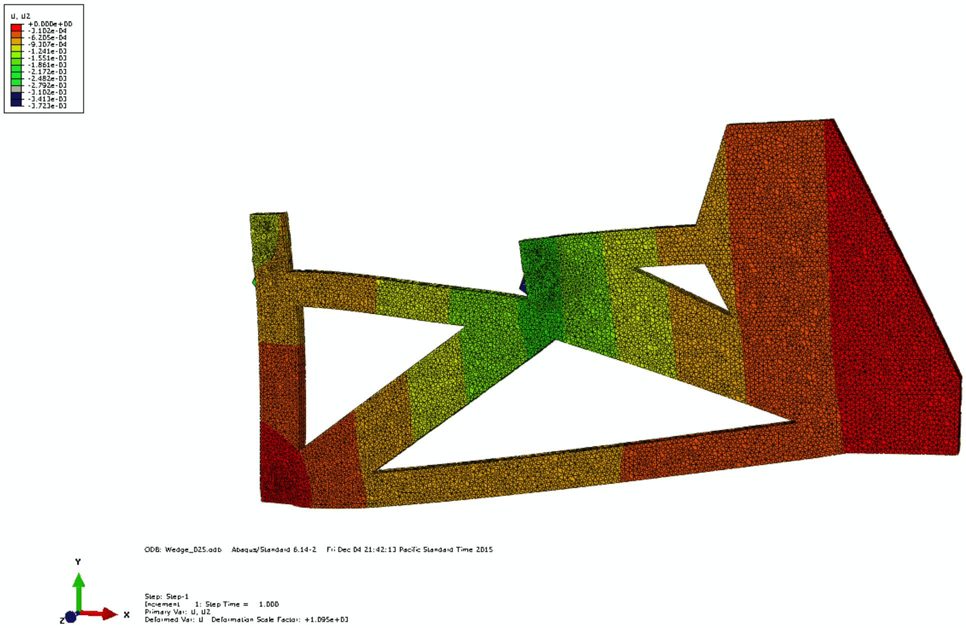


Figure 66: Mises stress on model with element seed size of 0.25"

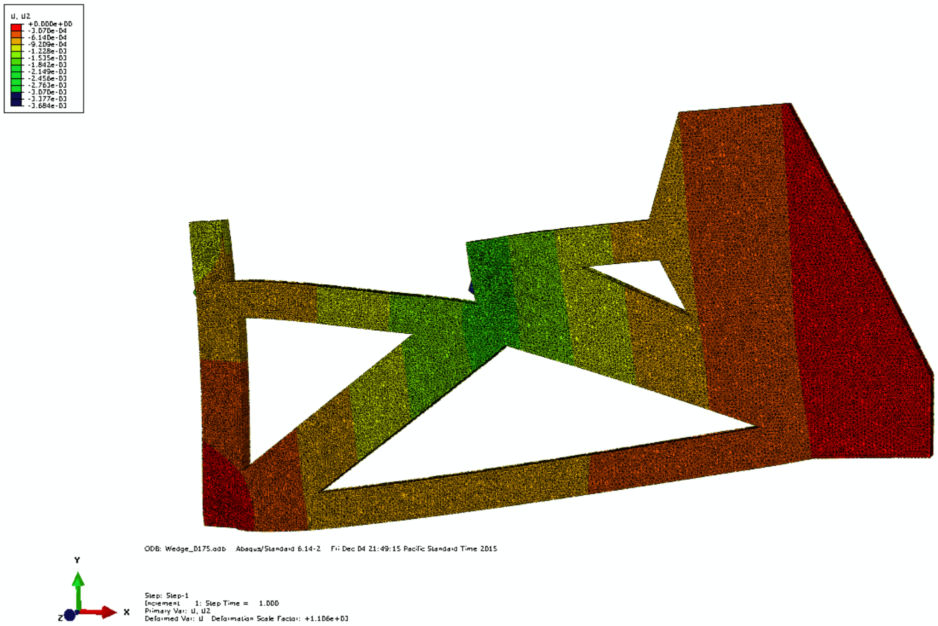


Figure 67: Mises stress on model with element seed size of 0.175"

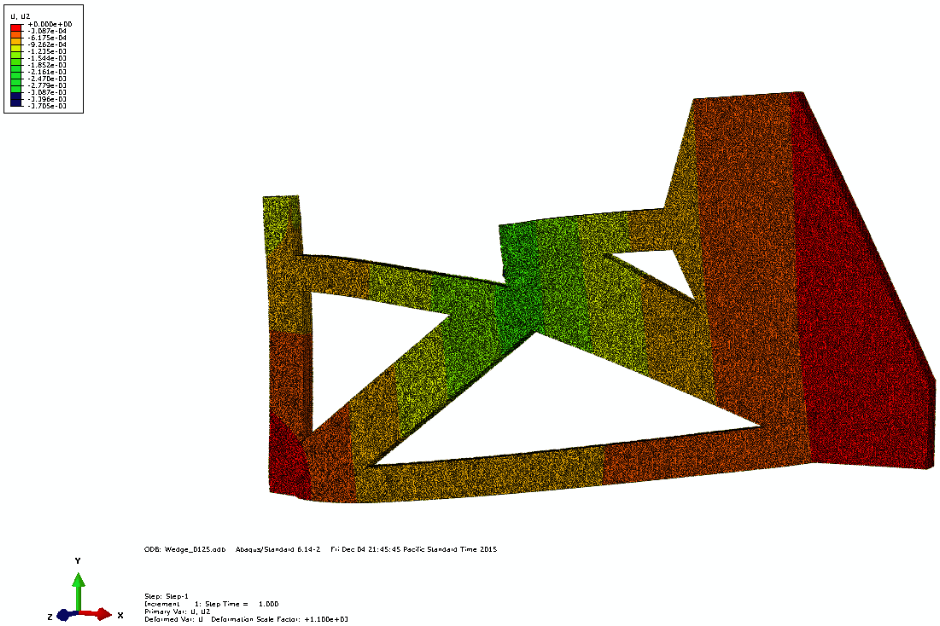
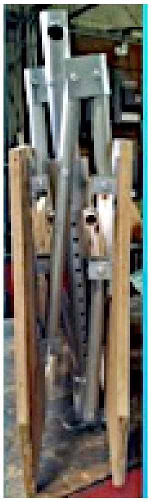


Figure 68: Mises stress on model with element seed size of 0.125"

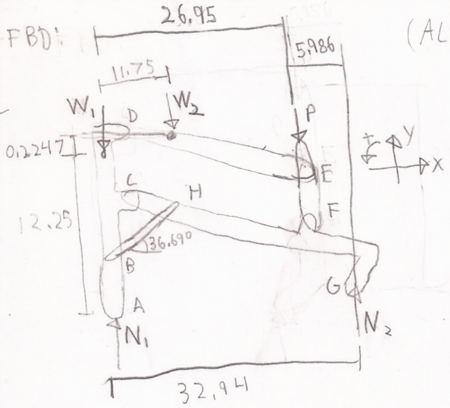
Appendix F
Final Prototype Pictures



Appendix G

Hand Calculations

FBD:



(ALL DIMS IN INCHES)

$\Sigma M_A = 0$

$-11.75W_2 - 26.95P + 32.94N_2 = 0$

$$\boxed{N_2 = \frac{11.75W_2 + 26.95P}{32.94}}$$

$\Sigma M_G = 0$

$5.986P + 21.236W_2 + 32.986W_1 - 32.986N_1 = 0$

$$\boxed{N_1 = \frac{5.986P + 21.19W_2}{32.986} + W_1}$$

DE:

$\Sigma M_D = 0$

$-11.75W_2 + 26.95E_y = 0$

$$\boxed{E_y = 0.436W_2}$$

$\Sigma M_E = 0$

$15.2W_2 - 25.95D_y = 0$

$$\boxed{D_y = 0.5857W_2}$$

EF:

$\Sigma F_y = 0$

$F_y - E_y - P = 0$

$F_y = E_y + P$

$$\boxed{F_y = 0.436W_2 + P}$$

CHFG:

$\Sigma M_C = 0$

$7.017BH\sin(36.69°) + 0.775BH\cos(36.69°)$
$-25.95F_y + 32.05N_2 = 0$

$4.814BH = 25.95F_y + 32.05N_2$

$4.814BH = 25.95(.436W_2 + P)$
$+32.05(.3567W_2 + .8182P)$

$$\boxed{BH = 4.725W_2 + 10.838P}$$

$\Sigma F_x = 0$

$-C_x + BH\cos(36.69°) = 0$

$C_x = BH\cos(36.69°)$

$C_x = (4.725W_2 + 10.838P)\cos(36.69°)$

$$\boxed{C_x = 3.789W_2 + 8.691P}$$

$\Sigma F_y = 0$

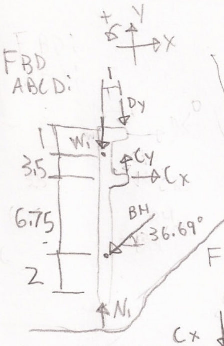
$C_y + BH\sin(36.69°) - F_y + N_2 = 0$

$C_y = -F_y + N_2 + BH\sin(36.69°)$

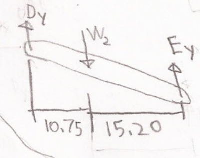
$C_y = -0.436W_2 - P + .357W_2 + .818P$
$+ (4.725W_2 + 10.838P)\sin(36.69°)$

$$\boxed{C_y = 2.744W_2 + 6.294P}$$

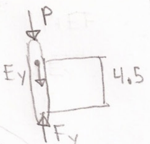
FBD ABCD:



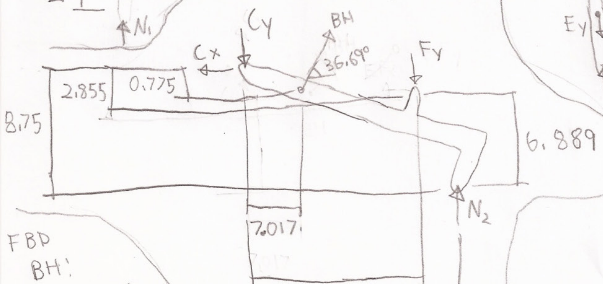
FBD DE:



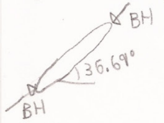
FBD EF:



FBD CHFG:



FBD BH:



This gives the

Max σ of 180,000 PSI

Carbon Fiber Panels

$$\sigma = \frac{P}{A}$$

$A = (\text{width})(\text{thickness})$

$$\sigma = \frac{P}{(\text{width})(\text{thickness})}$$

$P = 300$ lbs

$\sigma = 180{,}000 \ \frac{\text{lbs}}{\text{in}^2}$

$t = 0.012$ in (2 plys @ $\overset{0.006}{\cancel{0.00}}$")

$$\text{width} = \frac{P}{\sigma\,(\text{thickness})}$$

$$= \frac{300 \text{ lbs}}{(180{,}000 \ \frac{\text{lbs}}{\text{in}^2})(0.012 \ \cancel{\text{in}})}$$

width $= 0.139$ in → minimum width of carbon fibers

---

3 plys:

$t = 0.006" \times 3$

$= 0.018"$

$$\text{width} = \frac{300 \ \cancel{\text{lbs}}}{(180{,}000 \ \frac{\cancel{\text{lbs}}}{\text{in}^2})(0.018" \ \cancel{\text{in}})}$$

width $= 0.093$ in → minimum width w/ 3 plys

75A1

suggested 2" width
w/ 3 plys

$$\sigma = \frac{P}{(\text{width})(\text{thickness})}$$

$$\sigma = \frac{300\text{ lbs}}{(2\text{ in})(0.018\text{ in})}$$

$$\sigma = 8{,}333\ \frac{\text{lbs}}{\text{in}^2}$$

width 2.5"

$$\sigma = \frac{300\text{ lbs}}{(2.5\text{ in})(0.018\text{ in})}$$

$$\sigma = 6{,}667\text{ psi} < 180{,}000\text{ psi}\ \checkmark$$

- This does not include the core thickness.

---

6 plys total
- core - 0.5" thick
  - 0.75" thick

~

$$\sigma = \frac{300\text{ lbs}}{(2\text{ in})(}$$