MULTI-TERRAIN WHEELCHAIR

A Major Qualifying Project Report:
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Abstract

Many disabled people struggle to traverse outdoor terrain without specialized equipment. To tackle the outdoors, users have to spend money, time, and sacrifice usability and indoor capability by using bulky assistive devices. This project was carried out by a group of four WPI students to design and construct an assistive device for a fellow student who is paralyzed from the waist down. After initial brainstorming and research, the choice was made to create a multi-terrain wheelchair. Using organizational, financial, manufacturing and design methods, the group was able to design and construct a prototype wheelchair consisting of separate subsystems. Each subsystem attempts to solve a different facet of the overarching problem being addressed. This wheelchair design and prototype aims to not only assist disabled persons, but also serve as a basis for future projects to improve upon and help solve the issue.

Acknowledgements

We would like to thank WPI for giving us the usage of their machine shop and tools to create our test-bench and prototype. We would also like to thank our outsourced manufacturers Charles, Frank, Ben, Doug from AMT, and especially Dylan for offering his services for free. The completion of this project would not have been possible in the time frame without their work.

We extend our gratitude to Sharon, Donna, and all the other employees at WPI's Corporate Engagement and Donor Relations Office. Without their help we would never have found the very generous Kaneb family, who we also thank, for their donation. The project in its completion would also not have been possible without these funds. Many thanks to Barbara and Glorie-Ann in the Mechanical Engineering offices for guiding us with the financial requirements, advice, and means to purchase and fund our project. They were a great help.

We would also like to thank InMotion for their donation of some of their motors, as well as valuable insight and professional knowledge of motors and related specifications. The company Bikes + Life also provided great resources and advice for our suspension design, as well as promptly re-spoking our wheels.

We would like to thank Jared for his cooperation and help throughout the project, and we hope that this assists you to its full extent, as well as giving you a good potential MQP. Lastly, we thank Professor Bergstrom, Toby, for his invaluable guidance and support for driving us through the projects completion, and making sure that it gets done.

Contents

1 Introduction

1.1 Objective

Design and construct a safe, lightweight, electrically powered assistive vehicle that excels in traversing outdoor terrain while maintaining the ability to maneuver easily indoors.

1.2 Rationale

The inspiration for our project comes from one of our fellow students at WPI Jared Grier, who was injured in an accident in 2015 and is now paralyzed from the waist down. Jared along with an estimated 5.4 million other Americans suffer from some sort of paralysis which makes up roughly 1.7% of the United States population[1]. On top of that, according to the Center for Disease Control, 2.2 million Americans rely on wheelchairs for day to day mobility[2]. More specifically, in a survey done in 2015 by the National Spinal Cord Injury Statistical Center at UAB, it is approximated that 240,000 to 337,000 Americans suffer from spinal cord injuries with 56% of the injuries occurring between the ages of 16 and 30 with the average being at the age of 31[3].

With this many people in need of ways to get around, there are naturally many wheelchairs available to the general public ranging between manual, power assisted and fully powered. Unfortunately, most of the wheelchairs available today do not handle operating outdoors very well, and those that do are quite expensive costing somewhere between 10,000 - 20,000 dollars. Along with the large price tag, these chairs are large and heavy and cannot be used indoors effectively, making them inefficient for a normal consumer to purchase. Many streets, even in Worcester, are laden with people driving their wheelchairs on the dangerous roads because they cannot get over the curb onto the sidewalk. By building a compact and lightweight wheelchair that can handle both the outdoors and the indoors, not only would we be helping Jared, but we can potentially be helping millions of other people who have the same needs.

1.3 State of the Art

Before beginning the design of our assistive vehicle, we researched five of the leading competitors in the field of electric wheelchairs. Our research was centralised on DEKA, Suzuki, Arcatron Mobility, Ottobock, and Whill. Out of the top five companies we found, DEKA has the most comprehensive design with its iBot wheelchair and meets most of our design goals.

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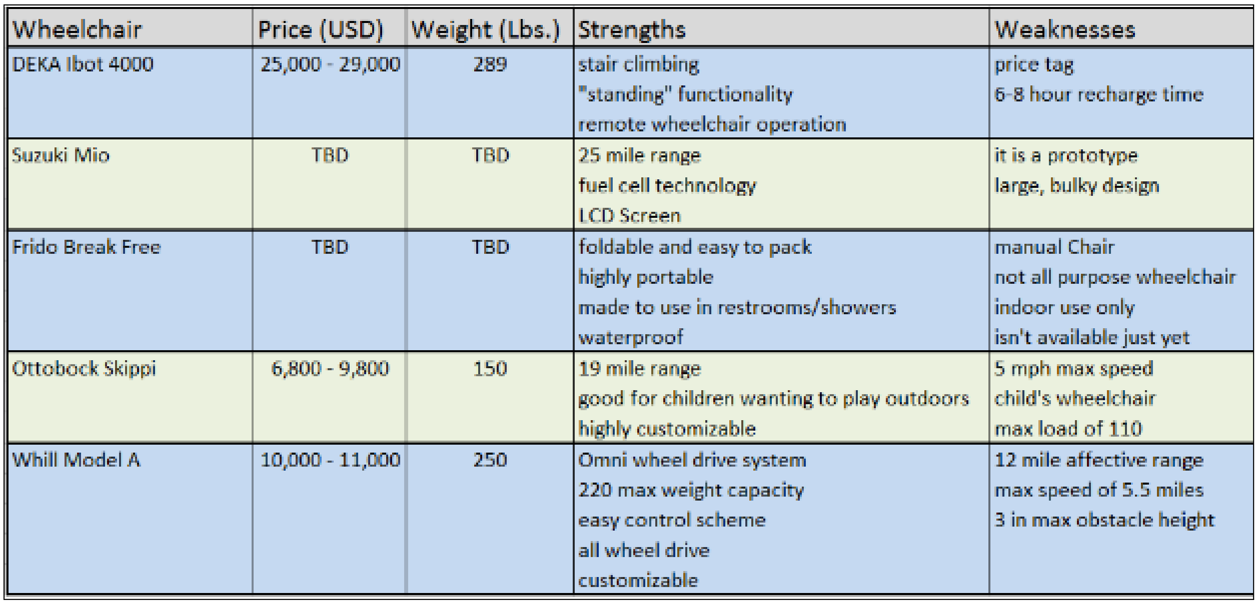
[1] Paralysis statistics. Reeve Foundation, Reeve Foundation, www.christopherreeve.org/living-with-paralysis/stats-about-paralysis.

[2] How many people use assistive devices? Eunice Kennedy Shriver National Institute of Child Health and Human Development, U.S. Department of Health and Human Services, www.nichd.nih.gov/health/topics/rehabtech/conditioninfo/Pages/people.aspx.

[3] Spinal Cord Injury Facts & Statistics. Spinal Cord Injury Facts & Statistics, SCI-INFO-PAGES, www.sci-info-pages.com/facts.html

The iBot allows users to drive through grass, up stairs, and can even bring the user to standing height by rotating its wheel structure and effectively standing on its rear wheels. With such technological advancements comes a large price tag which can be seen as the original iBot cost $25,000. The subsequent companies we researched all offered electric wheelchairs with varying degrees of off-road capability, but none approached the iBot in versatility or functionality. Traditional electric power chairs cost anywhere between $1500 - $3500 depending on their features and can weigh between 150 - 400 lbs[4]. Specifically designed off-road power chairs cost an average of $5000 - $18000 with a weight of 250 - 500 lbs[5]. Figure 1 below displays a visual comparison between the top five competitors in the wheelchair industry. Consequently, our project will attempt to incorporate the aforementioned benefits of the existing wheelchairs while trying to minimize the weight and the price.



Wheelchair	Price (USD)	Weight (Lbs.)	Strengths	Weaknesses
DEKA Ibot 4000	25,000 - 29,000	289	stair climbing "standing" functionality remote wheelchair operation	price tag 6-8 hour recharge time
Suzuki Mio	TBD	TBD	25 mile range fuel cell technology LCD Screen	it is a prototype large, bulky design
Frido Break Free	TBD	TBD	foldable and easy to pack highly portable made to use in restrooms/showers waterproof	manual Chair not all purpose wheelchair indoor use only isn't available just yet
Ottobock Skippi	6,800 - 9,800	150	19 mile range good for children wanting to play outdoors highly customizable	5 mph max speed child's wheelchair max load of 110
Whill Model A	10,000 - 11,000	250	Omni wheel drive system 220 max weight capacity easy control scheme all wheel drive customizable	12 mile affective range max speed of 5.5 miles 3 in max obstacle height

Figure 1: Commercially Available Wheelchairs Table

Ibot: Independence Technology, L.L.c Ibot 4000 (Power Wheelchairs) - USA Techguide. USA TechGuide Banner., United Spinal Association , www.usatechguide.org/itemreview.php?itemid=1467

Suzuki : Filipponio, Frank. Suzuki unveils MIO: the fuel-Cell powered wheelchair. Autoblog, Autoblog, 29 Sept. 2006, www.autoblog.com/2006/09/29/suzuki-unveils-mio-the-fuel-cell-powered-wheelchair/.

Frido: Breakfree. Frido, Frido, myfrido.com/.

Ottobock :Ottobock Skippi. Ottobock, Ottobock, professionals.ottobockus.com/Mobility/Wheelchairs/Pow

Whill:Model A is More Than Just Mobility-It's Freedom. WHILL, WHILL, 5 Jan. 2018, whill.us/model-a-personal-mobility-device-personal-ev/.

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[4] Wheelchairs & Medical Supply Shop. 1800wheelchair.Com, www.1800wheelchair.com/.

[5] GRIT Freedom Chair Offroad Wheelchair. GRIT Freedom Chair, www.gogrit.us/.

1.4 Approach

Jared currently uses a manual wheelchair with an electric power assist attachment to help him get around campus by reducing the amount of manual work that he must provide. This augmented manual chair is effective under average conditions, but struggles in inclement weather and challenging terrains such as hills, curbs, snow, or sand. He also owns a standard power chair, however it weighs roughly five hundred pounds, and is cumbersome to operate. Due to its large size, the power chair has a large turning radius which reduces maneuverability in tight spaces and makes it difficult to transport.

With this in mind, our goal is to construct a power chair that is purposefully built for off road conditions while keeping the weight and size of the chair at a minimum in order to increase his overall mobility and allow for indoor operation. We plan on creating a four wheel drive system, with each wheel being independently powered along with a custom built suspension system. The combination of these two features will determine the overall comfort and performance of the chair.

In addition to comfort and performance, Jareds mobility and dexterity, especially in his hands are a key focus. As such, the controls of the chair will all have simple functions and executions, including easily accessible buttons, and an intuitive LED display system. These general, yet critical, parameters are the foundation of our design. To produce the best possible design, we researched wheelchairs with similar traits and then used axiomatic design to narrow down and help focus our thoughts.

2 Methods

The methods section below is intended to detail the process we went through to achieve the result of building a prototype wheelchair. Our methods, however, weren't a linear process, meaning that we did this process multiple times. Brainstorming, budget development and final design where iterated through many times until we reached our desired final outcome.

2.1 Axiomatic Design

The first step of our process for designing and fabricating Jared's chair was using axiomatic design to figure out what we wanted to build. Axiomatic design is a system design method that uses a matrix system to split up key features into functional requirements and design requirements[6]. Following axiomatic design allows for a more complete design as it takes into account all variables associated with whatever system you are designing. This process ensures that all variables are independent and are given a hierarchy of importance.

2.2 Initial Brainstorming

Armed with our axiomatic design parameters, we sat down as a group in the living room and brainstormed. Our process was having one member of the team write all of our ideas on a large white board and generating as many ideas as possible. We repeated this as many times as was necessary for us to feel that we had enough ideas to move forward.

2.3 Budget Development

After establishing some concepts that we could possibly build, our next step was to formulate a budget. To formulate our budget, we took the lowest common denominator objects from each design and found rough price points for each part. An example of a lowest common denominator part would be DC motors or a wheelchair frame.

2.4 Fund Raising

The fourth step of our process was to acquire funds for our project. To increase our chances of getting a sponsor or donor we used four different steps. The first step was using family contacts for advice and information. The second step was contacting companies that might be interested in our project directly. Our third step was contacting wheelchair foundations

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[6] Axiomatic Design Technology. Functional Specs, Inc., www.axiomaticdesign.com/technology/axiomatic.asp.

and various disability foundations looking for funding. Our final step was using WPI and their donor relations and public outreach departments to help spread the word of our project and to help us find funding.

2.5 Final Design

The final step of our methods was to decide upon a final design and move forward with modeling and construction. To decide on a final design, we took into account how expensive a design was, how complex and hard to machine it was along with how well it would satisfy our axiomatic design parameters.

3 Results

Throughout the the three-term project our goal was to design and fabricate a wheelchair that Jared could use. This section details the results of building our prototype wheelchair.

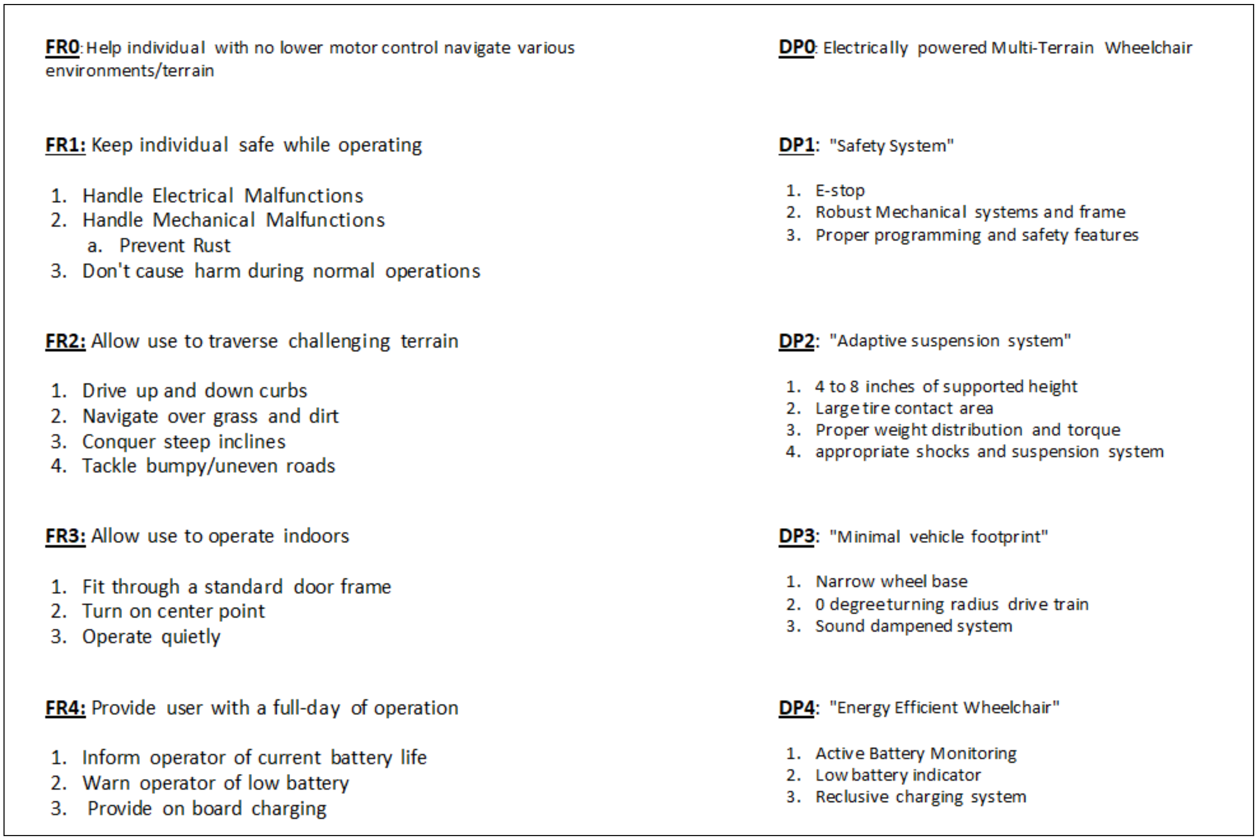
3.1 Design Requirements

3.1.1 Customer Need

Before we started brainstorming actual design ideas, we first wanted to make sure that we were building something that Jared could and would want to use. To do this, we met with him several times and compiled a list of key features that he wanted in a wheelchair. This list helped us grasp the functional needs of an outdoor and indoor assistive vehicle which helped to narrow our focus for key features. Some of the more important key features that Jared was looking for were manual control of the wheels, an easy, usable control system that was close to his reach, handlebars for stability and a thinner leg holster for comfort. Anything that was to be included also would need to be simple in its operation as his dexterity is very limited. His current design also includes poor functioning casters in the front, of which constantly get stuck or jammed. The current add on electric drive system he has is affective under normal circumstances, however, on malleable ground the system tends to drive the casters into the ground.

3.1.2 Axiomatic Design & Project Goal

As described above, and shown below (Figure 2), the features that were stressed the most from Jared were lightness and all-terrain capabilities with a slim profile so the device could still be used indoors. Not all of Jareds design parameters could be taken into account due to the duality of what we were trying to accomplish. That being said, we feel we came together and produced the most effective and feasible result. After many revisions and team meetings we were able to come up with the design matrix show below in Figure 2. The matrix allowed us to establish our project goal and mission statement: to design and construct a safe, lightweight, electrically powered assistive vehicle that excels in traversing outdoor terrain while maintaining the ability to maneuver easily indoors.



FR0: Help individual with no lower motor control navigate various environments/terrain	**DP0**: Electrically powered Multi-Terrain Wheelchair
FR1: Keep individual safe while operating 1. Handle Electrical Malfunctions 2. Handle Mechanical Malfunctions a. Prevent Rust 3. Don't cause harm during normal operations	**DP1**: "Safety System" 1. E-stop 2. Robust Mechanical systems and frame 3. Proper programming and safety features
FR2: Allow use to traverse challenging terrain 1. Drive up and down curbs 2. Navigate over grass and dirt 3. Conquer steep inclines 4. Tackle bumpy/uneven roads	**DP2**: "Adaptive suspension system" 1. 4 to 8 inches of supported height 2. Large tire contact area 3. Proper weight distribution and torque 4. appropriate shocks and suspension system
FR3: Allow use to operate indoors 1. Fit through a standard door frame 2. Turn on center point 3. Operate quietly	**DP3**: "Minimal vehicle footprint" 1. Narrow wheel base 2. 0 degreeturning radius drive train 3. Sound dampened system
FR4: Provide user with a full-day of operation 1. Inform operator of current battery life 2. Warn operator of low battery 3. Provide on board charging	**DP4**: "Energy Efficient Wheelchair" 1. Active Battery Monitoring 2. Low battery indicator 3. Reclusive charging system

Figure 2: Axiomatic Design Matrix

3.2 Project Iteration & Design Methods

Given our preliminary functional requirements, we sought to decide on a device capable of achieving our project goal. These ideas ranged from various assistive devices, along with wheelchairs. This method lead to various iterations of our design over the course of the project, broken up into five main subsections. These sections are organized logically from our functional requirements, and not as a direct train of thought. The design elements are broken up into the following subsystems: the total assistive device, suspension, back wheels, front wheels, and electric drive train.

3.2.1 Design of Assistive Device

After generating the design parameters using axiomatic design, the next decision to be made was what system would let us reach our goal in the most effective way. The two different types of systems that were discussed where an additive device versus a new device. Our first idea to ensure indoor and outdoor capability would be to keep the current indoor system he uses now, while creating an all terrain attachment that would allow him to take his current wheelchair outside and then detach when he needs to go back inside. Our second idea was to purposefully build a new system that was capable of handling outdoor terrain without being large and cumbersome. If we could design something that can handle the rigors of the outdoors while still maintaining a minimal footprint then that would fulfill our design parameters. After deliberating and making a pros and cons list, we decided to go with the second option and purposefully build a wheelchair so that we could cover as many of Jared's preferences as possible.

Even after making the decision to build a wheelchair there were still many details that needed to be decided on and custom tailored to fit our goal. Some of the more important details include: the number and type of wheels, the suspension system, the drive system, the frame layout and dimensions along with form factor, general sizing and durability. With many wheelchair designs commercially available we had plenty of inspiration and ideas to draw from. After rating and judging many designs, including Jareds manual chair, we decided on a wheelchair with four tires and an active suspension system. Below shows the initial measuring of Jareds chair. We disassembled it to make it easier for us, as well as the frame design we were able to design from the measurements (Figure 3a and Figure 3b). Along with the suspension system, we also wanted to have the chair be electrically powered. One of the more limiting constraints of any design decision that we went with was the ability to fit within a standard door frame. Operating indoors was an integral part of our design and thus anything that we came up with needed to be able to fit through a doorway without hitting. This was quite limiting when it came to balancing outdoor power and fine motor control. While we were able to draw upon our past experiences from class we also relied heavily on our engineering judgments and limited resources.

(a) CAD Model of Wheelchair Frame

(b) Jared's Disassembled Wheelchair

Figure 3: Information Gathering for the Wheelchair Frame

3.2.2 Design of Suspension System

3.2.2.1 Design Iterations After the system type and the general structure of the wheelchair were decided upon, the next most important aspect of our chair was the suspension system. The suspension for our chair was sought out to be the most unique part of our project as well as a selling point for our particular design.

It not only reinforces the outdoor capability and functionality of the wheelchair, but it also determines the comfortability for the user. While brainstorming possible suspension concepts, the most promising idea was the rocker-bogie system that NASA employs for their off world rovers. The basic concept of the rocker-bogie suspension is to have three sets of wheels in a unique setup of linkages that allow the main body of the system to never change its orientation as can be seen visually in Figure 4 to the left[7]. Along with the ability to keep the main body of the system parallel with the ground at all times, the rocker-bogie system also allows the user to traverse large obstacles with a relatively small suspension footprint. While this concept seemed very promising in the initial research, we decided that it was too complex of a design to try and implement into our chair for various reasons, the most important being its complexity of machining and cost along with the difficulty in balancing out the main system. The main body of the system only stays parallel to the ground if it is made the center of mass of the system which isnt feasible for a wheelchair. Without making the main body the center of mass, an active balancing system would have needed to be created and implemented which was greater than the scope of our project.

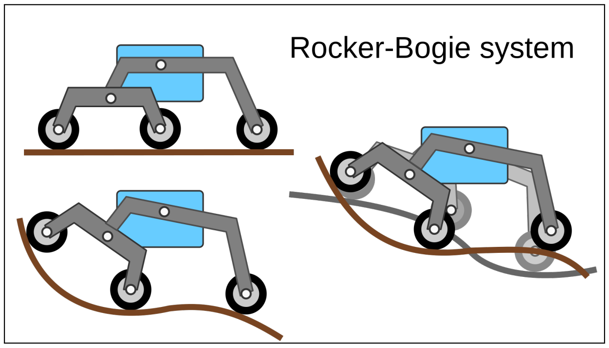


Figure 4: Example of Rocker-Bogie System

Our second most prominent design incorporated horizontal shocks that would be housed underneath the seat and would take advantage of custom A-arms to deliver a compact suspension system that was effective and low profile. The general concept of horizontal shocks and A-arms can be found in high speed Formula 1 cars and RC cars that mimic them like in Figure 5a below[8].

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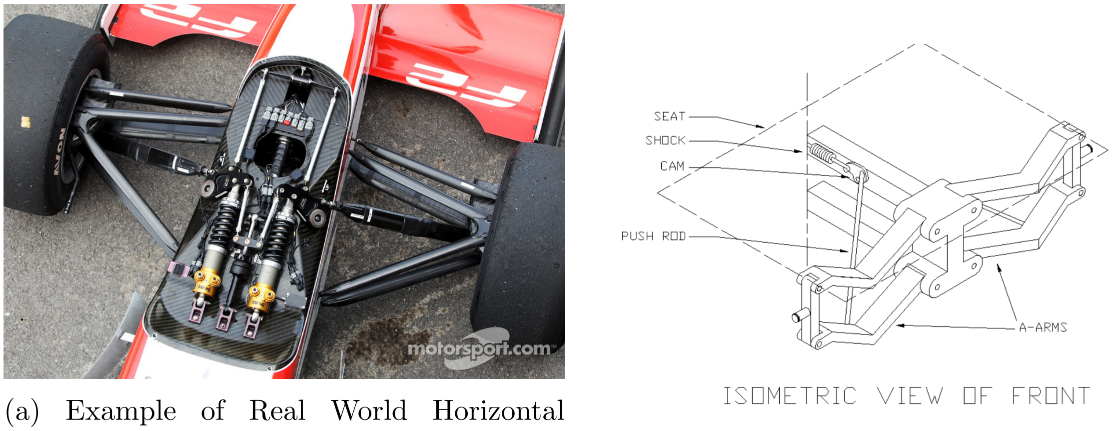
[7] Rathore, Abhijeet . What are the reasons behind using rocker bogie suspensions in mars curiosity rover? Quora, Quora, 23 Oct. 2015, www.quora.com/What-are-the-reasons-behind-using-rocker-bogie-suspensions-in-mars-curiosity-rover.

[8] PerformanceTrucks.net Forums. PerformanceTrucksnet Forums RSS, www.performancetrucks.net/forums/gm-drivetrain-suspension-22/advantage-re-locating-rear-shocks-513215/.

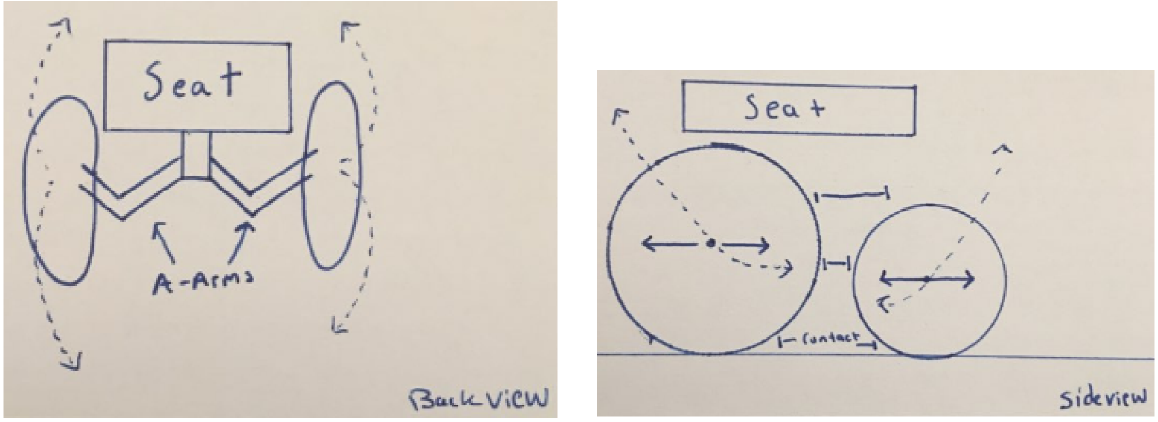


(a) Example of Real World Horizontal Shocks

(b) CAD Sketch of Horizontal Shocks

Figure 5: Horizontal Shocks

We adopted the idea of this system to fit underneath the wheelchair and generated a preliminary concept of the design illustrated in Figure 5b. The unique cam system coupled with the A-arms would give a vertical, semi-circle motion to the back wheels whenever they would encounter an obstacle to go over (Figure 6a).



(a) Back view of horizontal suspension system

(b) front view of horizontal suspension system

Figure 6: Horizontal suspension system

The reason for this vertical motion on the outside of the wheels was to avoid any chance of contact between the front and rear wheels which is common in horizontally traveling suspension systems, as is detailed in Figure 6b. Contact between the front and the rear wheel would cause the system to lock up and potentially buck the user out of the chair, making our system unreliable and unsafe. While this “hidden suspension” system added a bit of flare to our project, we discovered that it wasnt the best design because we were losing out on potential damping from the shocks and it widened our wheelbase which was counter intuitive to our preferred slim design. With this configuration, when a obstacle is encountered, the wheel would move outwards to the side perpendicular to the shock. When this happens, the complete force of the obstacle isn't channeled directly into the shock since it isn't in parallel. In addition to these design flaws, it would have been difficult to find and machine the correct parts to make the very specific shock and cam requirements needed to make the complete system.

For our third and applied design we decided to use four vertically dampened shocks. We combined the best aspects of our first two designs making the current system independently dampened and compact. The third design takes advantage of four bar linkages and vertical shocks to create obstacle forces that act in parallel with the shocks to get the most efficiency possible. While this design can be dangerous, as previously mentioned, precise measurements and calculations can prevent anything bad from happening which makes the risk versus the reward beneficial.

3.2.2.2 Research and Field Advice

With the general design of the suspension agreed upon, the next most integral part was the shocks, which give the system its damping. The shocks where the only part of the subsystem that no one on our team had personal experience with. Our initial thoughts where to go with mountain bike spring shocks as they handle much more stress than would be felt by our device in a semi-comparable application. In order to get the best damping possible from the shocks we needed to calculate the load that would be applied to each shock along with the pre-load position and sag of the system when it was at rest[9]. Our research showed us that we could expect a sag of 30% and a compression ratio of the shock of around 2.2 : 1. Unfortunately, after looking at available shocks online it became apparent that nothing was sold with these specific specifications at the desired length. Standard bike shocks are larger than what we needed. On top of the length discrepancy, bike shocks are made to take the weight of the rider on one shock compared to our design taking the weight of the rider on all four shocks. As a work around to our problem we looked into trying to re-coil bike shocks to the right size and coefficient, but the entire process would be expensive, dangerous and we wouldnt be able to guarantee the quality of the re-coiled spring.

Since spring shocks werent going to be easily implemented we started looking into air shocks. The concern with air shocks is that they have a high threshold of force for when the shock actually starts to dampen. Since we are trying to make a wheelchair, we would need shocks that activate immediately and then taper out, not the other way around. Unsure of the capability of air shocks in this application, we contacted a local bike shop (Bikes + Life[10]) for their opinion. According to their repair staff, air shocks would work great for our application, especially dual chambered air shocks as they lower the input force required to get the shock dampening initially. On top of their endorsement for using air shocks, they helped us choose what size and type of air shocks would be best suited for our application. With dual chambered air shocks, you can adjust the amount of air in each chamber to change how much and when the shock activates which allows for calibration of how smooth the chair performs. This capability is helpful for fine tuning the system to Jareds preferences.

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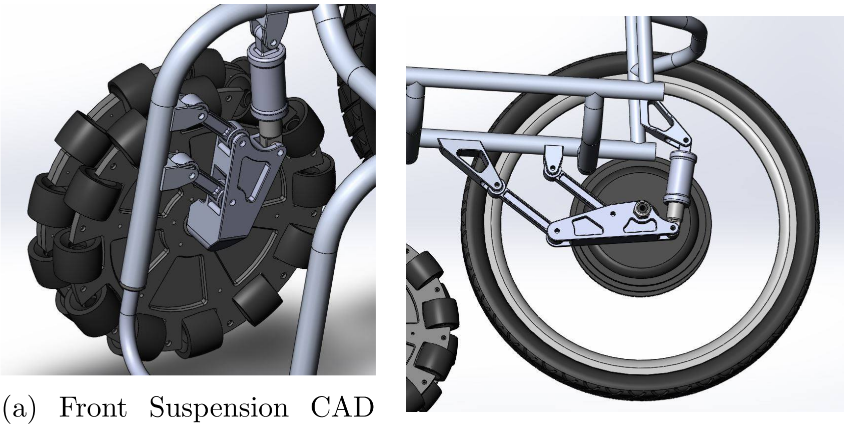
[9] Thede, Paul. Technicalities: Spring Rate and Preload. Sport Rider, www.sportrider.com/technicalities-spring-rate-and-preload.

[10] https://www.bikesandlife.com/pages/worcester-ma

3.2.2.3 Final Suspension Design As was mentioned in a previous section, our third and final design for the suspension system uses vertical shocks so that we can get the most efficiency out of our shocks as possible. Figures 7a and 7b represent our final iteration of the suspension.



(a) Front Suspension CAD Model

(b) Rear Suspension CAD Model

Figure 7: Final Suspension CAD Model

We decided to go with this design because it allowed us to channel more of the force from the obstacle into the shocks by keeping the shocks parallel with the force. With the horizontal shocks, we were losing out on some performance since the force of the obstacle was perpendicular to the shocks. This means we only get the y vector of the force instead of the total force.

In a different class at WPI (Mechatronic systems ME4322), our final project was to analyze some sort of subsystem and do static and dynamic analysis on it. We were lucky enough to be able to use our suspension system as our subsystem for that class. We included pictures from our dynamic analysis in this report, however, the ME4322 report will be included in the submission of this MQP report as a reference[11] and should be read for more details.

The force of the obstacle is applied at the bottom of the knuckle link which is the triangular link that acts as our coupler (Figure 7a). The mass distribution for Jareds wheelchair is 1:6 from the front to the rear. The total mass of the chair is 180 lbs, therefore 30 lbs is present in the front and 150 lbs in the rear.

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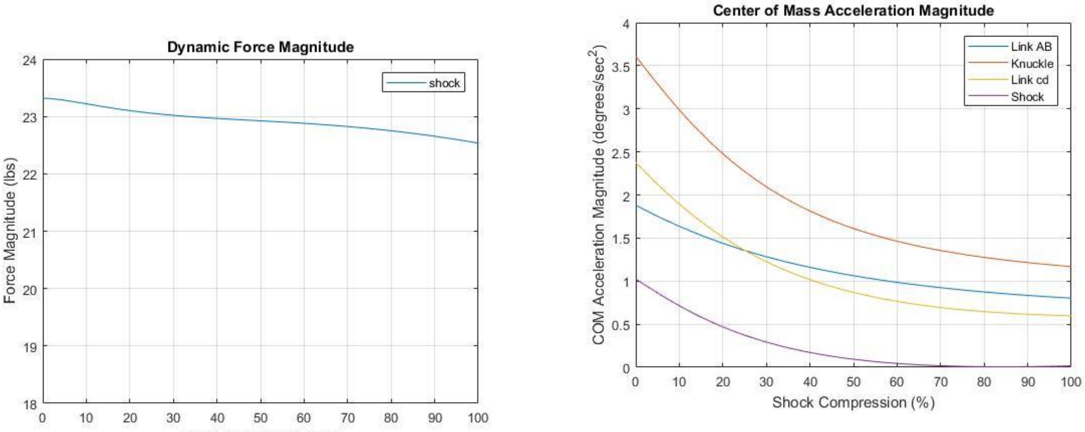
[11] ME4322 Final Report



(a) Force vs Shock Compression

(b) COM Acceleration vs Shock Compression

Figure 8: Dynamic Response and Analysis

Performing the dynamic analysis over the entire range of our suspension system, assuming a 20lb vertical input at the bottom joint of the knuckle, resulted in the force response seen in Figure 8a. This type of response is ideal since the shock we are using has a linear response. As the force applied to the shock is shown to be roughly linear, the shock should compress smoothly over its entire range. Figure 8b shows the joints will accelerate quickly when Jared first encounters an obstacle, and slow down as the shock is compressed. Such a response ensures the shock will compress quickly at the beginning of the stroke, allowing the wheelchair to deal effectively with small bumps, but move slowly at the end of the stroke to avoid bottoming out.

After proving to ourselves that vertical shocks were the most efficient, we had to make sure that we didn't have our set of wheels contact each other as detailed in section 3.2.2.1. To counter the danger of having both sets of wheels contact each other while encountering obstacles, we carefully plotted out the trajectory of both the front and rear wheels. Using geometry and the radius of each wheel, we were able to calculate the max travel of each wheel. With that information and with the wheels at max length, we moved them together as closely as possible while leaving a one inch gap for tolerance. With this design, there is no physical way that the wheels can contact and buck the user out of the chair.

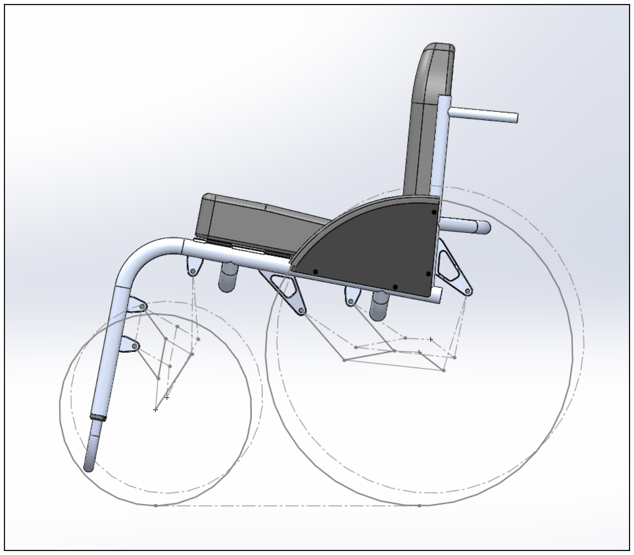


Figure 9: Wheel Tolerance Calculations

As you can see in Figure 9, we constrained each wheel to its point on the frame. Then using the linkages, we where able to plot out the wheels course of movement. The dotted line for each wheel represents the farthest the wheel can move backwards, and the solid line represents the farthest the wheel can move forward. We made sure that the dotted line for the front wheel never crossed the solid line for the rear wheel. If these lines never intersect, then the wheels will never touch. To be extra careful, not only did we make sure that they didn't touch, but we made the gap in between the lines equal one inch.

Our final decision on air shocks where four 165mm dual chamber air shocks. We went with these shocks because they gave us the most efficiency for their size (Figure 10). Using our engineering judgment along with measurements taken from Jareds current manual chair, these were the appropriate size while still having the dual air chamber. This feature was important for us since it not only helped to reduce the input force needed to get the shocks to dampen, but it allowed us to change the air ratio in the different compartments so that we could fine tune and adjust the ride of the chair.

Figure 10: Dual Air Chamber Shocks

3.2.3 Design of Rear Wheels

As a group we decided immediately to outfit the back of our wheelchair with off road mountain bike tires. When it comes to traversing obstacles outside, mountain bikes are efficient and do a very good job of tackling most terrains. By adding them to the back of our chair, where most of the force will be located, we hoped to make our design that much more robust.

Initially when we ordered our hub motors (details in a later section) our plans where to buy 24" hybrid mountain bike treads and construct our own hand rims to be attached along the outside of our rims. After receiving our hub motors in the mail, the rims on the tires were too small to accommodate any traditional mountain bike tires along with the metal being too thin to be able to mount hand rims affectively. To get around this we found standard size tires with hand rims already attached and re-spoked our hub motors to fit the new tires. The difference between the tires can be seen in Figure 11a and Figure 11b below.

(a) Re-spoked Hub Motor (b) Original Hub Motor

Figure 11: Difference in Hub Motor Rims

The mountain bike tread that we attached to the tires is a combinational tread that is supposed to allow for better gripping in all situations. As can be seen in Figure 12[12], the center of the tire is flatter and smoother for standard terrain while the edges have the traditional knobby texture.

Figure 12: Hybrid Tire Tread

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[12] https://www.bikerumor.com/2013/06/06/new-schwalbe-thunder-burt-xc-mountain-bike-tire-unveiled/

The reason behind getting the hybrid tires is because when driving on flat ground, having a completely knobby tire will make the ride more bumpy and noisy. The hybrid tire design allows us to have the best of both worlds, with some textured tire and some smooth tire.

3.2.4 Design of Front Wheels

3.2.4.1 Design Iterations We decided to use Omni wheels for the front wheels almost as quickly as we decided to use mountain bike tires in the back. Most commercially available wheelchairs use casters in the front, however these wheels where unacceptable for our design as they have flimsy construction and cannot handle rigorous treatment. Our team chose omni wheels for their compact design, versatility and durability.


Figure 13: Standard Omni Wheel

The basic idea of an omni wheel is that it is a set of smaller, offset wheels aligned sideways that come together to form a bigger wheel that moves forward (Figure 13[13]). The offset wheels of the omni wheel provide it a circular shape so that it can roll as a normal wheel while still maintaining the ability to be steered sideways. When pushed sideways, the mini wheels take over and drive the system sideways which allows for turning without actually moving the omni wheel. This provides a huge advantage when it comes to turning in place as you dont need the wheels to physically move before you can complete a turn. When turning with casters, first they must rotate on their bearings before they can roll normally. In tight spaces or stressful environments, the time and space needed for the casters rotation isn't the type of performance we are looking for. The only problem with using omni wheels is that they aren't available in large sizes, which means we had to design and fabricate our own.

3.2.4.2 Omni Wheel Research While the general concept of omni wheels was well known, there were multiple factors that went into designing the right omni wheel for our application. While designing the omni wheel from scratch everything had to be taken into account from the height of the wheel to what materials the rollers would be made out of. In order to make wheels that where both capable of indoor and outdoor travel we researched the best material for the rollers, the ratio of height versus obstacles of the wheels and how roundness affects the wheels coefficient of friction and the overall travel for the chair.

The most important metric of our design of the omni wheel was the ratio of the

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[13] https://www.vexrobotics.com/omni-wheels.html

height of the wheel to the height of the obstacle. This number was the most important because we needed to know how big to make the omni wheel. The size not only dictates the height of the obstacle that we can go over, but also how many rollers are needed on the wheel to make it circular enough to roll smoothly on flat ground. We modeled our design based on what we expected to be normal outdoor terrain.

$$r = \frac{(h_0 + h_{\mathrm{zs}})\sqrt{1 + \left(\mu_{\mathrm{p}} W_{\mathrm{w}} + F_{\mathrm{frame}}/W_{\mathrm{w}} - \mu_{\mathrm{p}} F_{\mathrm{frame}}\right)^2} - h_{\mathrm{n}}}{\sqrt{1 + \left(\mu_{\mathrm{p}} W_{\mathrm{w}} + F_{\mathrm{frame}}/W_{\mathrm{w}} - \mu_{\mathrm{p}} F_{\mathrm{frame}}\right)^2} - 1}.$$

Figure 14: Wheel Height Ratio Equation

Our target obstacle for the outdoors was a sidewalk curb which range anywhere from 4 to 12 inches. Once our target obstacle was set, we conducted more research into wheel height ratios versus obstacle size and came up with a credited relationship shown in Figure 14. This equation accounts for the vertical forces of the wheelchair, the obstacle height, and the friction coefficient of the wheel. With the weights and forces of the chair already known, and the height of the obstacle being whatever we set as standard, the only factor left to come up with an accurate and valid height for our front omni wheels would be the material properties.

The next decision needed for the construction of our omni wheel is the material of the rollers. We decided on aluminum construction for the wheel itself, as it is lightweight, strong, easily machinable, and cost effective. However we needed a high friction coefficient material for the rollers, as this would be the surface touching the ground, getting over obstacles, and overall determining the grip and traction of the wheels. At first we searched for premade omni wheel rollers, but to no avail as we could not find them big enough for our application. The only premade rollers that might have worked had bushings instead of actual bearings, which would not only hinder the quality of the roll, but also decrease the lifespan and impact the wheels would make on questionable terrain. Instead of buying rollers, we decided to machine them ourselves and insert our own bearings. We needed the roller material to be easily machinable, maintain a high friction coefficient and be readily available to be purchased in bulk.

The last key factor for the omni wheels was the smoothness of travel. Since the omni wheel are made up of multiple contact points, it has the chance of making the wheelchairs ride not smooth. This has to do directly with the number of rollers, and the shape at which they touch the ground. The rounder the rollers are, the more comfortable the ride.

Another factor is the more rollers that are present on the wheel means that there is less distance between each one. More rollers makes the total wheel larger, which effects not only the travel distance of the wheel, but it increases the amount of money required to fabricate it. To address this issue we created a parametric model of a generic omni wheel (Figure 15). This allowed us to measure the distances in height between each roller, test the curvature, and see how these factors af-

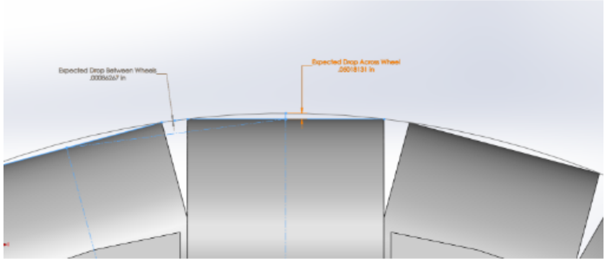

Figure 15: Parametric Omni Wheel Model

fect cost. This gave us a way to efficiently choose the number of rollers at the best price point and best ride conditions. After knowing the height of our front wheels, the material at which to make the rollers, and the number and shape of the rollers around the wheel, we were able to accurately design and construct an efficient and working omni wheel.

3.2.4.3 Final Omni Wheel Design Our final Omni wheel design looked very similar to Figure 16a with the important pieces being made out of urethane, aluminum and steel. The final dimension of the omni wheel was a wheel with 15 inch diameter and 12 rollers per plate, with a total of 24 rollers per wheel. After using our roundness methods from above, we figured 12 rollers on each side was optimal.

(a) Final Omni wheel CAD Model (b) Turned Down Urethane Wheel

Figure 16: Omni Wheel Construction

We chose to go with urethane for the rollers because of our past experience using the material, its ability to be bought in bulk and its friction coefficient. Our plan was to buy skateboarding wheels and turn them down on a lathe to make rollers out of them. After testing the machine-ability of urethane using an old skateboard wheel, Figure 16b, we were confident that we could make 48 rollers out of similar wheels.

The plate and the shafts where going to be made out of aluminum and steel respectively since those are both industry standard materials and we were confident that we wouldnt have any issues making our desired parts. The only problem with making our omni wheels was the physical amount of parts that we needed. Omni wheels in general are complex parts with many smaller parts. Making one requires a lot of attention to detail and time to make sure you have all of the correct parts. In total, we needed 48 rollers, 4 plates, 48 shafts and 96 spacers which is both time consuming and repetitive. In Figure 17 below, you can see a small part of our inventory of stock materials before it was sent out to be machined.

Figure 17: Omni wheel Parts

We assumed any obstacles encountered to be around six inches. With this standard obstacle height, it made 15 inches the largest wheel that satisfied our equations and fit on the chair model with enough safe clearance. It was the optimal size for the performance that we were aiming for.

3.2.5 Design of Electric Drive Train

3.2.5.1 Design Iterations Like many of the other design sections, there wasnt much brainstorming required when it came to the design of the drive train. We as a group already knew it as going to be electrically powered, we just needed to figure out how we actually wanted to do it while staying within the parameters of the project. Being the most straightforward part of the design, the electric drive is at the bottom of our functional requirements. Even with the simplicity of this subsection, our design still went through iterations which required adjustments and redesigning.

Toward the beginning of the project, the brainstorming stage, we discussed the many different drive systems that were available to us. The idea of the design being wireless powered or including a security system was talked about, however after serious thought and discussion those ideas were omitted because of the level of difficulty it takes to actually implement them. The first concrete design we had was four wheel drive, powered by four independent motors. We wanted four wheel drive for the traction and power increase, which would allow the front wheels to better get over obstacles. This design was consistent overall, but due to money and time constraints, we had to adjust and only power the back wheels in our prototype.

The next design decision was the motors themselves. We were at first looking at brushless motors and incorporating a gearbox to decrease the speed down to the appropriate RPM for a wheelchair. However, we decided that the gearbox would be too cumbersome in its design, taking too much physical space on the wheelchair. Additionally, it would also have been complicated to design and manufacture. On top of the issues with making a gearbox, using brushless motors would have required us to make and design a fitting and axle system for for the wheels so that we could mount them properly. Instead, we chose to go with hub motors, similar to those used on electric bikes. These motors allowed us to not worry about creating an axle or fitting, as the motor is built in to the wheel (figure 18[14]).

Figure 18: Standard Hub Motor

Not only were hub motors simpler to implement, but it was also the most low-profile option which satisfies our functional requirements. After deciding on using hub motors, there were still a couple of parameters that needed to be figured out. Most hub motors are dual shafted, or in other words, the shaft protrudes out from both sides of the wheel. This is because of their widely used application in electronic bikes. We needed to find a hub motor that was only one sided, or we would have to cut one of the axles that stuck out the other end. The second and more complicated design decision was how we were going to step down the motor's RPM. Since these hub motors were originally intended to be used on bicycles, the speed was much higher than what we wanted which required us to find a way to slow them down. This stepping down of the RPM is essential to our design as the chair needs to perform indoors. We would need to adequately pick a motor controller, test it with the motors we choose, and implement that into our code. This would require a test bench to ensure that the wheels and motor controller can perform under load, and to ensure that the controllers can allow the wheels to be controlled simultaneously.

The other main section of our drive system was our control electronics. We needed a user-friendly and effective way to enable Jared to control the wheelchair. There also needed to be safety features implemented within in the control scheme so that we could minimize any accidents. Aside from the motor controllers for each wheel, we needed a micro-controller, joystick, buttons, a battery, and a led screen for a display. The battery would be responsible for running both the wheelchair and all of the electronics required to drive the system. The battery life of the wheelchair would need to include an average days use along with any extra conditions that Jared would encounter. An important feature that we need to keep in mind with our electronic design is ability to for Jared to spin the wheels manually. Not only did he stress this feature a few times in our meetings with him, but it is also integral for fine control indoors. The ability to electrically power your chair outside and manually control it inside gives the user power for outdoors and control for indoors.

After figuring out all of the hardware, we still needed a way to control everything. Our general design included some form of Jared-friendly joystick, navigation buttons for the

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[14] 20 Inch 36v 750w E-Bike Hub Motor Conversion Kit Front. The DIY Outlet, thediyoutlet.com/products/20-inch-e-bike-hub-motor-front-fat-tire-conversion-kit-36v-750w

LED screen, an emergency E-stop buttons, a custom PCB and a waterproof housing. The joystick will be responsible for controlling the speed and direction of the chair along with navigating through menus with the help of the LED navigation buttons. The E-stop button is included in case anything goes wrong with the chair or Jared simply wants to stop the function of the chair.

3.2.5.2 Research and Field Advice

Although the concept of motor control, wattage, torque, and RPM was known from experience and our classes, we wanted to be sure that our design was not only going to work but also perform efficiently to ensure safety and low-cost. Our first step was reaching out to local motor companies for their input on our design. One company, InMotion, gave us a better insight on the relationship between torque, RPM, and energy loss by sending us a very useful chart (Figure 19). This information was crucial in our calculations and decisions of motors. It gave us insight on the battery usage for our application, and gave us a direction as too making it efficient depending on the voltage and wattage requirements of our hub motors. This chart also allowed us to visualize the amount of torque and speed within our application in relation to motor efficiency.

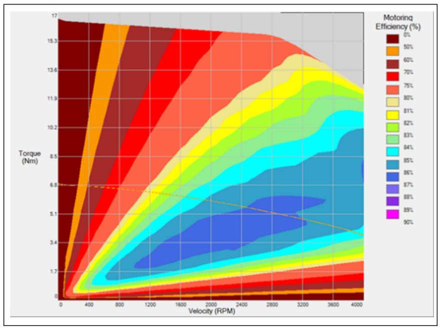
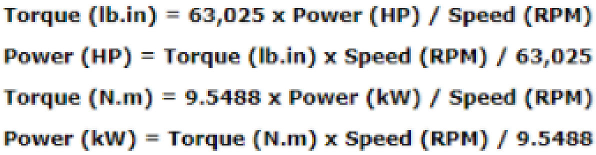


Figure 19: Standard Hub Motor

Knowing our design ideas for the motor, as well as given experience and field advice from companies, we needed to calculate the required wattage needed for our estimated torque values in our application. From the field advice and research, we found a general equation relating power and torque (Figure 20). We implemented this heavily in our calculations. We were able to take into account each wheels estimated weight, diameter, angular velocity, estimated speed, friction coefficient, and environment grade angle to derive an accurate min and max wattage for our motors. This gave us the confidence to choose a hub motor that would perform not only efficiently, but effectively in our design.



Torque (lb.in) = 63,025 x Power (HP) / Speed (RPM)

Power (HP) = Torque (lb.in) x Speed (RPM) / 63,025

Torque (N.m) = 9.5488 x Power (kW) / Speed (RPM)

Power (kW) = Torque (N.m) x Speed (RPM) / 9.5488

Figure 20: Power and Torque Relationships

3.2.5.3 Final Drive Layout and Control Scheme

To prove to ourselves that we were able to control the hub motors we went through a series of tests. We first used a spare VESC motor-controller to prove that we could run a motor at the desired speed that we needed. To do this, we mounted a motor on the side of a table and used a pre-made control scheme to power the motor at a low RPM (Figure 21).

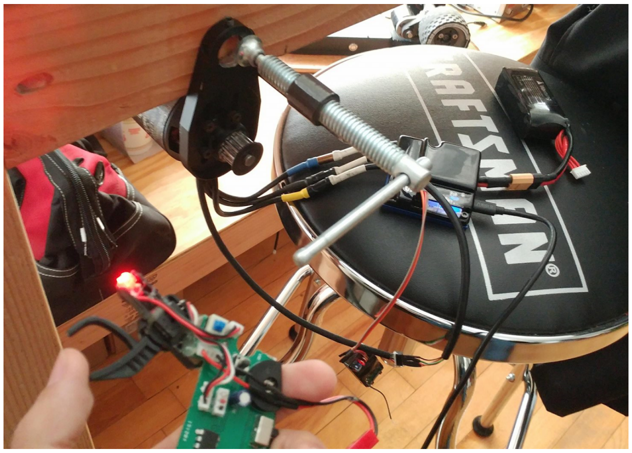
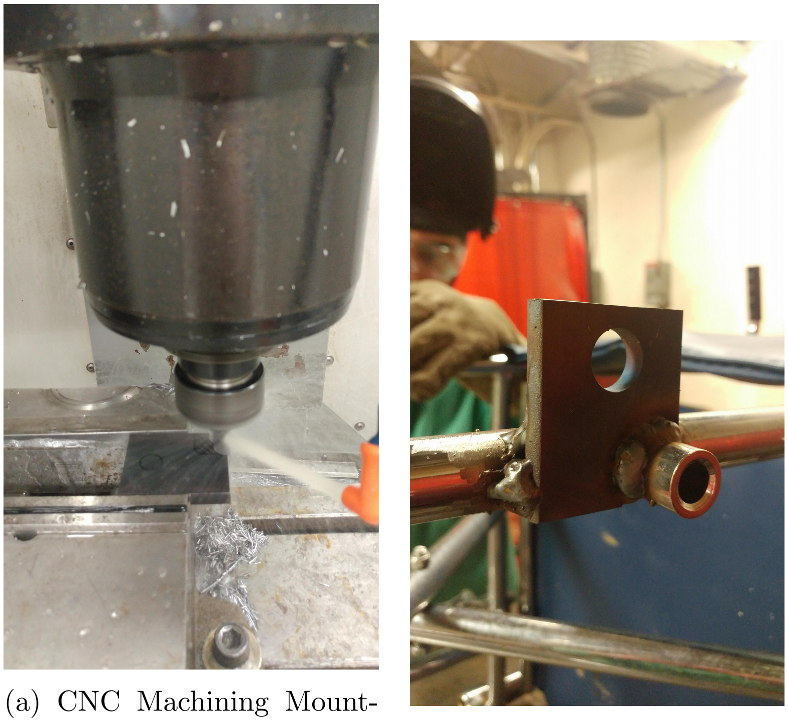


Figure 21: Motor-Controller Testing

After we proved that the motors could be controlled at a low speed, we got an old beat up hospital wheelchair and welded on tabs in the back so that we could attack our hub motors and begin to program them. Testing continued with this set up for a while since we were waiting on the frame and linkages to be machined and assembled. In Figures 22a , 22b and 22c you can see the process of machining and welding the tabs on the back of the disposable chair.



(a) CNC Machining Mounting Plate

(b) Mounting Plate Welding

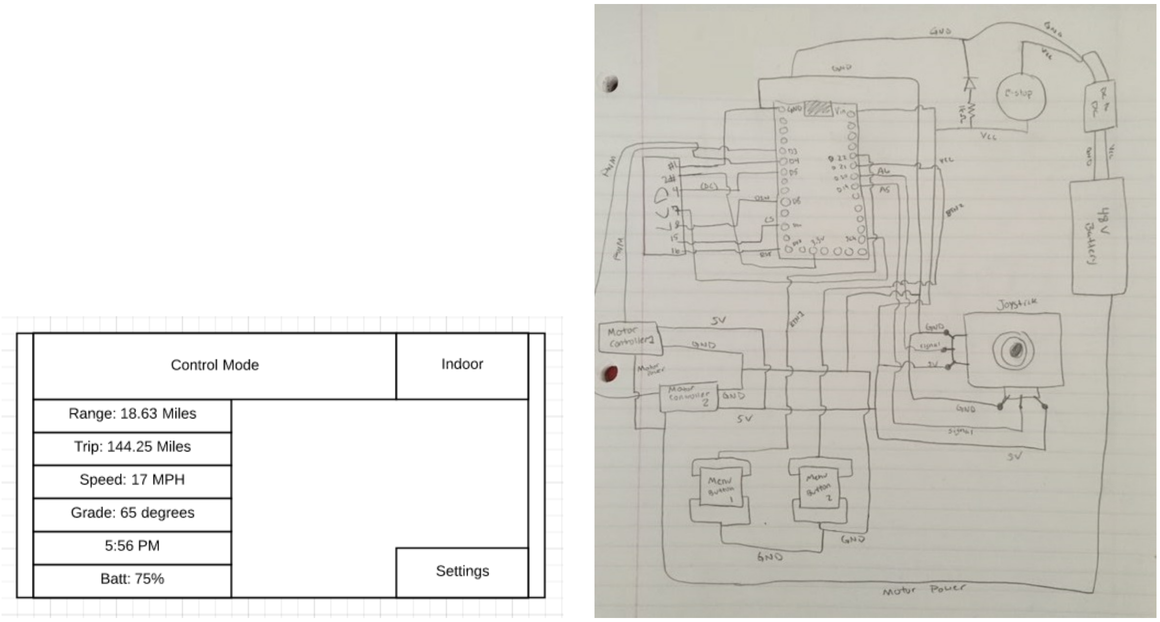
(c) Completed Test Wheelchair

(d) Motor Testing Setup

Figure 22: Machining Process for Test Wheelchair

After the tabs where installed on the chair we were then able to begin testing in the chair with the setup shown above in Figure 22d.

While the motors were being tested and programmed, we were simultaneously designing the circuit and custom PCB that would power and control everything. On top of the PCB we also were creating a programming flowchart for how the UI of the LED display would work. A sample of the menu screen is shown in Figure 23a. The total circuit diagram can be seen below in Figure 23b.



(a) Proposed UI Interface (b) Hand Drawn Control Scheme Schematic

Figure 23: Control Scheme

As the diagram describes, the chair will be powered by a simple joystick and three buttons. There will be an interface including three navigation buttons and an emergency stop. Two of the buttons will allow Jared to enter and exit menus of the included LED screen, and the third button will allow him to enter and exit drive and control mode. This function will only run if the chair is stopped, and it will ensure that Jared, since the LED screen will be controlled by the joystick as well, can quickly move if need be while in control mode. This interface will be fitted into one combined service incorporated into his arm rest. For testing purposes we came up with the testing platform shown below in Figure 24.

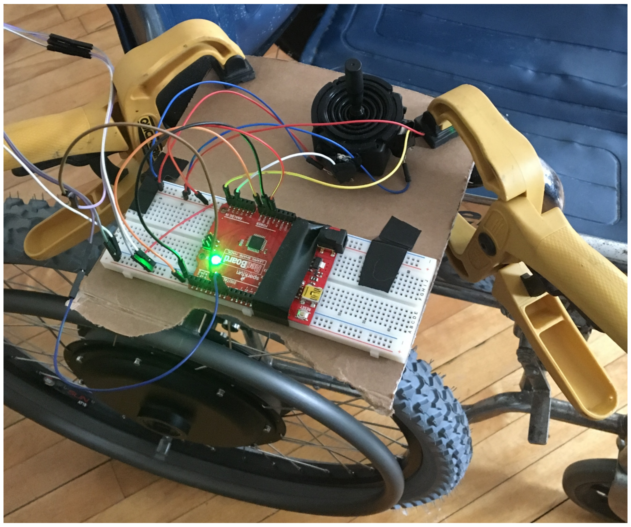


Figure 24: Prototype Control Scheme

4 Discussion

This section is an analysis of our results and the problems that we were able to overcome during this project. The layout of this section mimics the results section to keep things consistent.

4.1 Axiomatic Design

Axiomatic design was an integral part of our design process as it allowed for us to focus our thoughts and gave us a solid starting point in the form of the functional and design requirements. One of the more important skills that we learned while developing our axiomatic design was the art of being "vaguely specific". While performing axiomatic design it is important to be precise in your functional requirements, but you can't make it too precise otherwise you will limit yourself further down the line of functional requirements. Axiomatic design was an exercise in both system design and technical language because what was said specially mattered. Inaccurate words and phrases would lead to conflicting design parameters and would ruin your design matrix.

The big takeaway point from our experience using axiomatic design was the importance of not getting caught up in specific wording. As a group, we spent more time debating wording and phrases than we should have. It is very easy to get caught up in the wording and forget to focus on what the words represent. To take advantage of using axiomatic design it is important to have the discipline and knowledge of when to move on to the next requirement instead of sticking on one and debating its wording.

4.2 Design of Assistive Device and Frame

The frame functioned just as we expected. It was sturdy and able to support all of our subsystems, while still leaving room for improvement and on the fly adjustments. The frame is welded out of rigid, lightweight aluminum with a sturdy design which incorporates as many of our axiomatic functional needs as possible. On top of making sure the frame functioned the way we designed it, it was also important to us to allow room for some minor upgrades and adaptations. In our past experiences in engineering, no matter how well designed a product is, it always needs some adjustments once it is fabricated. We designed our frame in such a way that it had room for changes which was very helpful when we were troubleshooting.

One of the important lessons that we learned from designing the frame is the difference between a finished model and a perfect model. When we were designing our model we spent a significant amount of time making sure that everything was perfect and had extra detail in the model. To accomplish making our perfect models we put other tasks such as searching for funding on hold. A more time efficient method would be to work on modeling in tandem with other smaller tasks. If that isn't possible then it is important to know the difference between usable and perfect. Looking back, if we stopped when we reached a usable model instead of working constantly to make that perfect model, we would have been able to manage our time slightly better.

One difficulty that we had with the frame was the complexity and specialty of the parts that we designed. Most if not all parts of the frame had to be outsource manufactured due to their complexity. Specifically, we did not possess the tools required to bend the frame at our required angles. While outsourcing all of the parts increased our production time, it reduced the amount of hands on experience we got manufacturing the wheelchair. Additionally, the cost of manufacturing the wheelchair went up as we had to pay machine shops for the construction of our parts. Regardless of the difficulties we faced in producing the parts, our frame design turned out to be solid in terms of manufacturing, even though it had to go through multiple steps and vendors from bending, welding, and eventually powder coating.

4.3 Design of Suspension system

The suspension system started out as the selling point of our design, so it went through many iterations as described above in the report. Because of this, it was the most taxing on us in terms of researching, designing, and generally figuring things out. A lot of engineering judgment was used as well because of time constraints and overall lack of experience. The suspension was one of the first subsystems created in our design process making it an effective combination of research, experience, and engineering judgment.

What was unique about our experience with our suspension system was the fact that almost all of our interaction with it was virtual. This was the first time anyone in our group designed a suspension system so we had no real world experience to rely upon. On top of that, getting all of the parts fabricated took the whole of three quarters so when we finally got the parts we didn't have much time to test them in real life. It was definitely a cool process to see something you designed become a real object, but it was also eerie since we didn't get much face time with the parts to test them as thoroughly as we wanted.

One difficulty that we faced while making the suspension system was keeping the shocks completely parallel. As explained in section 3.2.2.3, if the shocks aren't parallel you lose performance to the splitting of the force into the X and Y direction. The suspension system was designed according to the path of travel of the front and rear wheels, however, the front suspension turned out to be more perpendicular than we would have liked. This is because we felt it would be more rigid and easy to machine at the spot they are mounted currently. Even with the slight deviation into the perpendicular direction, the shocks still compensate the force as intended.

While the suspension system wasn't as parallel as we would have liked, it was perhaps the most custom and intricate part of the chair. It still remains as one of the highlights of the project, and gives the chair arguably the most functionality toward our requirements. In addition to being the most interesting subsystem we designed, we also feel it offered something new to the wheelchair market. After doing some patent research, we realized that there wasn't anything quite like our design out on the market, so we decided to file for a patent on our design.

4.4 Design of Rear Wheels

The rear wheels of the chair we felt turned out to be the most solid and best functioning subcomponent with the least amount of troubleshooting required. We were able to maintain the needed size of the wheel, have good outdoor tires, and have a hand rim to meet most of our functional requirements and Jareds needs. Because of our multiple iterations, we ended up with two types of tires. One set of tires came with the hand rim wheels, and we also took the liberty of ordering outdoor tires and inner tubes. Both sets of tires are viable and it offers Jared just a little bit more customization and flexibility.

The only real difficulty we had with the rear wheels was the size discrepancy in the rims which led them to needing to be re-spoked. The spokes that came with our hub motor were fairly large in terms of diameter, and too large for our local bike shop to re-spoke them onto our hand rim wheel. Therefore they had to use their own, shorter diameter, and less rigid spokes. This worked for a short term solution, however, not only are the spokes less rigid but they also give less clearance into the hub motor spoke hole itself. In other words, the hub motor was designed for bigger spokes, so smaller spokes have more of a chance to slip out. Because of these reasons, over a long term the chair might need to be designed with more rigid spokes and perhaps new tires under extensive use and torque loading. Especially when hitting strong obstacles head on, or many consecutive movements. We could not replace them at this point because of our time constraints and current dimensions of our hub motors. That being said, our rear wheels function very nicely on our test bench and as a fully designed subcomponent.

4.5 Design of Front Wheels

The front wheels, along with the rear wheels, contributed the least issues to our design. However, this may be because of the fact that they are yet to be manufactured, constructed, and tested. Along with the suspension system, they were very involved in terms of research, engineering judgment, and mechanical design and fabrication. Just like the frame components, the omni wheel components where a challenge to machine. While we were able to get them outsourced, the complexity of their design showed in the expensive quote price.

Another difficulty with the front wheels was the physical assembly. Putting the wheels together involves a lot of bearings, shafts and rollers which need to fit together precisely. Tackling difficult terrain will test not only the machining precision of the parts, but also the accuracy of how we put them together. An interesting note about the wheels is that they weigh more than we expected. While this is a benefit because it helps to keep the chair grounded and sturdy, it technically goes against one of our functional requirements of being lightweight. This was interesting to us because while it contradicted our design parameters, it had an unforeseen bonus to technically violating our parameters.

4.6 Design of Electric Drive Train

Being the most research intensive and involved subsystem, designing the electric drive system was the subsystem that had the highest learning curve and amount of growth. There were many issues, adaptations, changes, and sacrifices made to produce our final prototype. Overall however, this subsystem alone drives the chair and was quite rewarding to get working. It involved the most testing, safety, and fine tuning to get it ready to be used normally.

The first discussion point involves our choice of hub motors to power the back wheels. Based on the chart given to us by InMotion and our current knowledge, our motors are certainly not the most energy efficient in terms of torque and wattage. However, that functional requirement was low, and we sacrificed it to fully utilize other more important requirements.

With such a complex system it was only natural that we were having some difficulties getting the controls to do what we wanted. We were able to tune the controllers to our desired speeds along with controlling the motors simultaneously, however we were having some difficulty in reading the speed values for display. Additionally, we decided to take out the reverse functionality along with reducing the sensitivity of the joystick. This not only added to our safety requirements, but prevented the chance of mechanical sensitivity issues. In other words, because of Jareds dexterity and how the joystick is constructed, the resting position of the joystick may been counted as a command to move in forward or reverse. This would cause Jared to dangerously move without meaning too. The omission of the reverse seemed to be the right decision since Jared also has manual control of the chair when he isn't using the joystick due to the hand rims.

The second discussion point involves our emergency stop button. Currently, the E-stop isn't a true emergency stop button as it doesn't cut the power from the battery to every component. The current E-stop button is a logic E-stop, meaning that it kills the power to the micro-controller and the logic of the motor-controllers, but it doesn't disconnect the motors from the battery. We could not find a device capable of handling our large current as well as being able to interface with the small 5V logic. The switches that could handle our diverse power range were large, expensive and not practical. The chair will still stop as the motor signals through the board will cease, however, it is important to clarify that the button isn't a true emergency stop button.

5 Future Work

This section describes the steps a following MQP team could take to complete our vision. Most of our shortcomings were the direct result of not being able to find funding until the last stages of our project. The direction of the project changed from a theoretical work, to a physical creation as a consequence of the late-stage funding, providing insufficient time to re-plan and purchase components. This section goes in detail of each sub component design to mimic the structure of the report. Each section talks about advancements that could be made regarding the respective component.

5.1 Frame

The frame needs to be analyzed and tested physically as we have only performed cursory theoretical calculations and the most basic physical tests. Additionally, the arm rests specifically need to be reconsidered. We did not add the armrests as part of the initial design, opting to instead create a user control panel and then make an armrest to fit the control panel. The armrest should be reconsidered to account for greater comfort and adaptability.

5.2 Suspension

After performing additional theoretical analyses of the force application on the shock after contracting the frame to be machined, we found some of our assumptions may not be as accurate as we first anticipated. After performing a static analysis of the front suspension system at multiple points across the entire travel of the suspension, we discovered the force vector is expected to point fairly perpendicularly to the shock during the last third of its travel. This behavior should be thoroughly tested on the completed wheelchair. Specifically, the shock should be tested to see if any binding occurs during this expected region.

The travel of the wheel could also be further analyzed. Currently the front wheel strictly follows a circular path, although testing should be performed to find if a more exponential travel better allows for traveling over obstacles. Also, the travel should be optimized as to ensure the wheel moves the most at the beginning of the stroke, and slows movement at the end of the stroke. Such a velocity profile will help to better handle small obstacles without bottoming out the shock during large impacts. The motion and travel of the rear wheel must also be analyzed. Currently the same shock is used for the front and rear suspension for uniformity, however the amount of compression needed in the rear of the wheelchair should be analyzed to determine if more compression is necessary.

The shock itself needs to be tested to ensure it provides the expected linear response. Our research indicated air shocks tend to offer a high actuation force that ramps up in a fairly parabolic curve, but can be flattened out somewhat with proper tuning. We purchased low end shocks to fit within our budget, which may have sacrificed the linearizing effects of proper tuning. While this isn't guaranteed, this is something that should be tested before drawing conclusive results for future shocks. As the static and dynamic force analyses both indicate the current suspension will exert a fairly uniform force profile regardless of the shock position, the shock response must be linear to optimize ride comfort.

5.3 Rear Wheels

The rear wheel requires fairly minimal future work outside of standard testing. Most significantly, custom spokes should be ordered to provide a more robust solution, as the current spokes are undersized.

5.4 Front Wheels

The front wheels require more thorough testing as they are a completely custom solution. Firstly, the wheels must be tested on a variety of surfaces and conditions to determine if there are any environments they are poorly suited to operate in. Primarily, testing on soft grass and dirt should occur to examine if the rollers sink into the dirt to cause sufficient difficulties while driving. The durability of the machined rollers must be tested as we have no experience with the wear pattern the rollers may experience during use.

The omni wheels must also be modified to accommodate hub motors. Such a modification will enable four wheel drive, which will enhance the off-road capabilities of the wheelchair. During the modification, the weight of the omni wheel should be minimized, as the wheels will contribute the largest un-sprung mass to the front suspension which will reduce the responsiveness of the suspension.

5.5 Electric Drive

The electric drive requires the most testing and has the greatest potential for improvement. As with the other subsystems, the drive system requires significant testing to ensure operation behaves as we anticipated. The two largest components of the drive system that require consideration are the hub motors and the control scheme.

The hub motors are currently assumed to match a variety of criteria that require real-world testing. Namely, the motors are expected to be fairly efficient at their operating torques and speeds; however, no data is available for their specific operating ranges. They should be tested first to see if they are fully capable of hitting the low-speed, high-torque operation required by the wheelchair, and then tested to see if they are still reasonably efficient. In the event the hub motors fail in any criteria, new hub motors should be sought out. Heinzmann offers one hub motor that appears to match the torque, speed requirements better than the current hub motors, but we were unable to establish contact with the German company.

The control scheme itself also requires testing, as well as optimization. Currently, the control scheme works adequately on our prototype chair, however its behavior on the final wheelchair has yet to be evaluated. Additionally, there are some immediate improvements that could be made. Currently, when turning, we are unable to slow the wheels, only cause them to coast. This causes turns at even moderate speeds to have a tremendously large radius. This could be remedied by altering the VESC firmware to allow for coasting and braking capabilities. Currently the firmware only allows for either braking of coasting. We opted for coasting as this allows manual operation of the wheelchair, where braking would provide smaller radius turns, but would sacrifice any manual intervention. Ideally, these two functions would both be achieved. This could be done by modifying the firmware as previously noted or by choosing a new speed controller with more suitable operation enabled by default. InMotion offers a potentially suitable motor controller, and provided a list of the following companies which also offer speed controllers, although we were unable to initialize contact with any of the companies. The companies noted by InMotion are, ZAPI, Curtis, Schwarzmuller, PG Drives, and Sevcon. If possible, their motor controllers could be considered as support will likely be more prevalent than the hobby oriented motor controllers currently in use on the wheelchair.

5.6 Safety

Although we planned on incorporating a number of safety features, our budget and time constraints did not allow for their full implementation. The current emergency stop button is the first feature that requires reconsideration. Currently the emergency stop cuts the logic of the speed controllers, but is not able to cut power directly as we are dealing with a large current range as well as 5 volt logic. Emergency stops for such a range proved to be unaffordable; however, transitioning to a true emergency stop would be a beneficial safety feature. Secondly, we wanted to implement speed oriented safety features which would limit the possible turning radius at high speeds. This feature was not able to be implemented due to time constraints, but would ensure the wheelchair would be far less likely to tip over at higher speed operation. To further increase safety, force sensors could be implemented in the seat to determine the riders weight, and use their weight and the speed of the wheelchair to determine the tightest turn possible within a certain safety factor.

6 Conclusion

We believe that the prototype that was produced will meet Jared's goals and allow him greater mobility. Our prototype includes:

- A compact and robust frame which integrates all subsystems seamlessly
- A custom made suspension system which was tailor made for outdoor use, while maintaining the ability to be used indoors
- Custom made 15" omni wheels to avoid caster whip and allow for in place turning
- Dual purpose rear wheel tires that give the user multi terrain functionality
- An electrically powered wheelchair that maintains the ability to be controlled manually without any extra strain to the user physically
- A simplistic electronic control scheme that allows for driving and menu navigation

References

[1] "Paralysis Statistics" Reeve Foundation,Reeve Foundation, www.christopherreeve.org/living-with-paralysis/stats-about-paralysis.

[2] "How many people use assistive devices?" Eunice Kennedy Shriver National Institute of Child Health and Human Development, U.S. Department of Health and Human Services, www.nichd.nih.gov/health/topics/rehabtech/conditioninfo/Pages/people.aspx.

[3] "Spinal Cord Injury Facts & Statistics." Spinal Cord Injury Facts & Statistics, SCI-INFO-PAGES, www.sci-info-pages.com/facts.html

[4] "Wheelchairs & Medical Supply Shop." 1800wheelchair.Com, www.1800wheelchair.com/.

[5] "GRIT Freedom Chair Offroad Wheelchair." GRIT Freedom Chair, www.gogrit.us/.

[6] "Axiomatic Design Technology." Functional Specs, Inc., www.axiomaticdesign.com/technology/axiomatic.asp.

[7] Rathore, Abhijeet . "What are the reasons behind using rocker bogie suspensions in mars curiosity rover?" Quora, Quora, 23 Oct. 2015, www.quora.com/What-are-the-reasons-behind-using-rocker-bogie-suspensions-in-mars-curiosity-rover.

[8] "PerformanceTrucks.net Forums." PerformanceTrucksnet Forums RSS, www.performancetrucks.net/forums/gm-drivetrain-suspension-22/advantage-re-locating-rear-shocks-513215/.

[9] Thede, Paul. "Technicalities: Spring Rate and Preload." Sport Rider, www.sportrider.com/technicalities-spring-rate-and-preload.

[10] https://www.bikesandlife.com/pages/worcester-ma

[11] https://www.bikerumor.com/2013/06/06/new-schwalbe-thunder-burt-xc-mountain-bike-tire-unveiled/

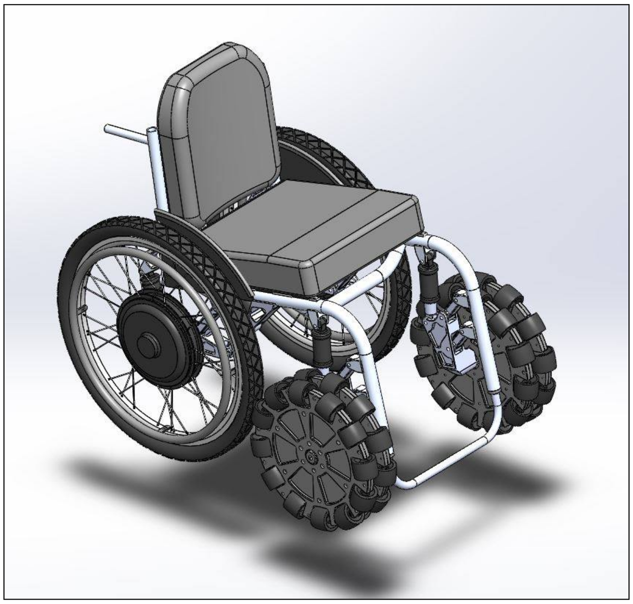
[12] https://www.vexrobotics.com/omni-wheels.html

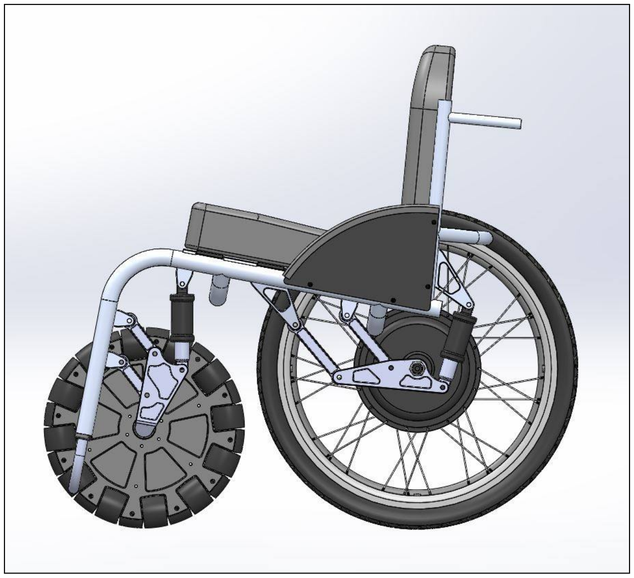
[13] "20 Inch 36v 750w E-Bike Hub Motor Conversion Kit Front." The DIY Outlet, thediyoutlet.com/products/20-inch-e-bike-hub-motor-front-fat-tire-conversion-kit-36v-750w

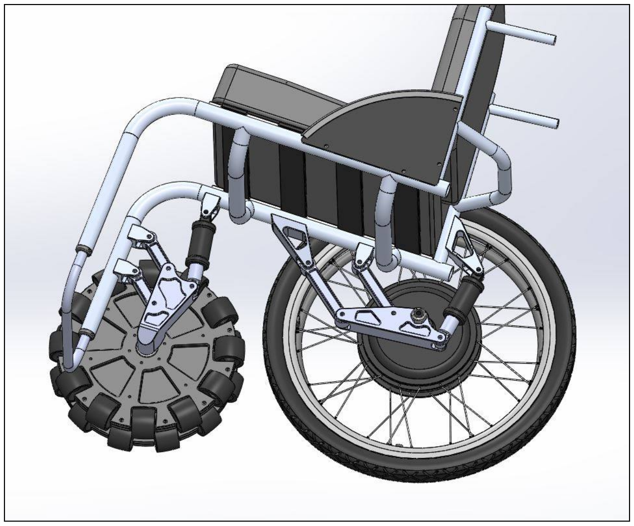
[14] ME4322 Final Report

Appendix A: Completed Wheelchair CAD Models

This appendix shows the finished total CAD model of our wheelchair. Three different views are provided so that every aspect of the design can be displayed.







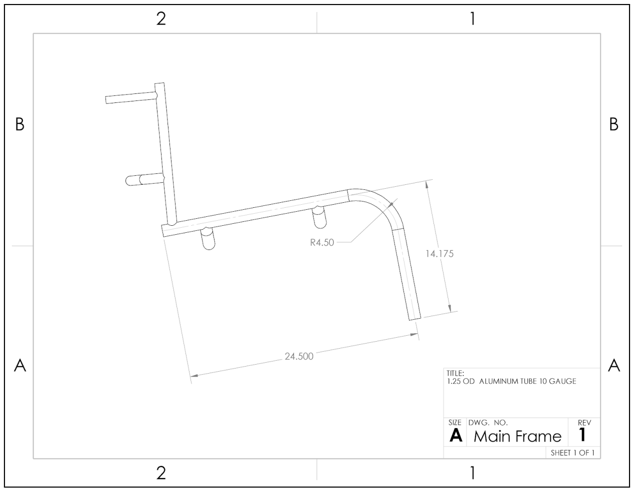
Appendix B: Component List and Drawings

Below in this appendix shows all the parts used, designed, and manufactured in this project. They are shown as schematics, models, and pictures based on how they were obtained or designed. Not every item and piece used on the chair is mentioned, for example miscellaneous thing bought such as accessories or specific electronic parts. We felt that it would be sufficient and worthwhile to include only the items that we needed to figure out ourselves and design. Some accessories or specific products are shown in the report. The parts are grouped into our main subsystems of the wheelchair, for which they were either used directly in or helped provide for, to mimic consistency with the report. Only the subsystems in which had parts designed for them are mentioned.

6.1 Frame Parts

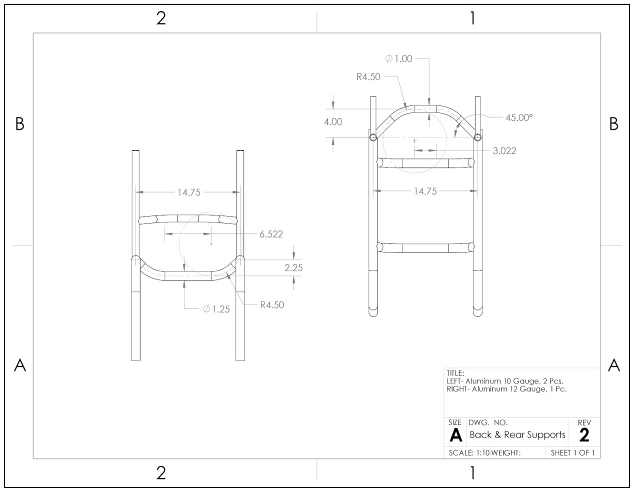
6.1.1 Base Wheelchair

This is our base frame design as based off of Jareds current chair to be bent, welded, and powder coated so that we can start putting things together.



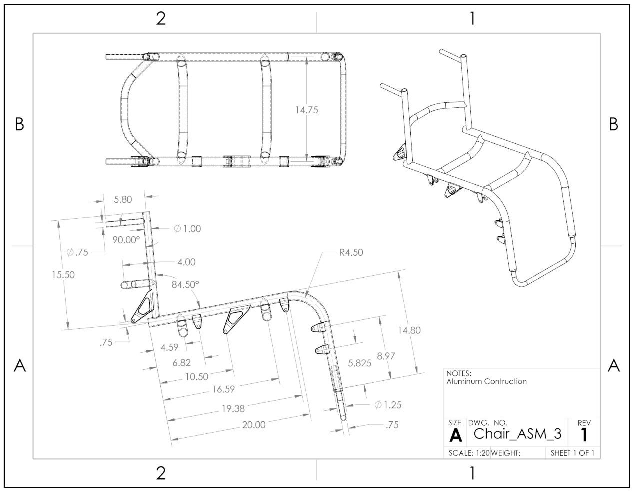
6.1.2 Base Wheelchair Frame with Support Bars

Here is our wheelchair frame including support bars. We measured them to be able to fit our specified cushions, to be sturdy enough, and as well to effectively house our suspension parts and electronic enclosure and components.



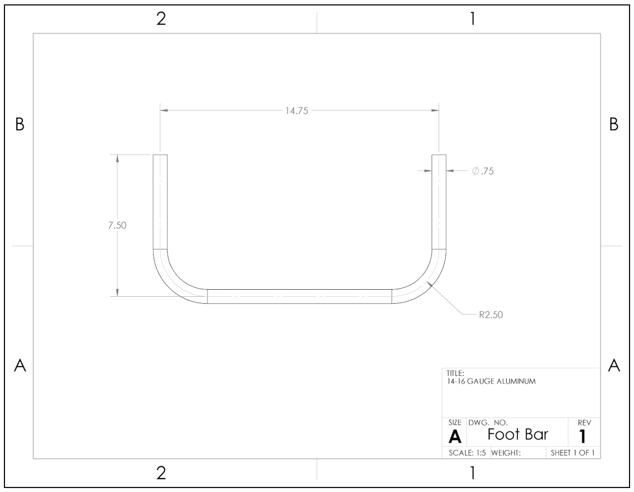
6.1.3 Base Wheelchair Frame with Suspension Mounting Tabs

Below is our more complete wheelchair frame design to include the mounting tab locations for our suspension system and its components.



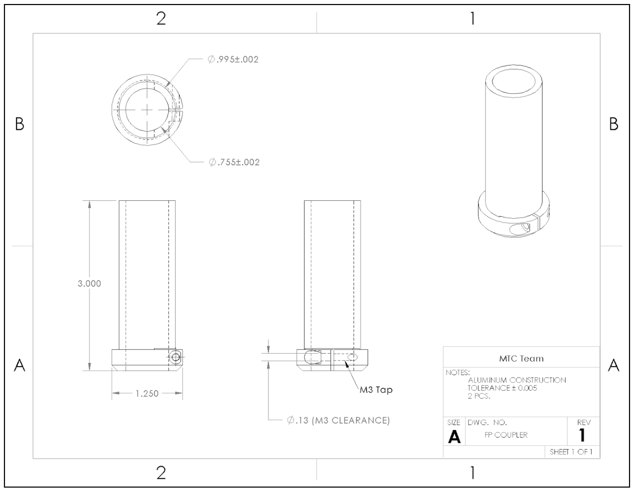
6.1.4 Foot Bar

Our foot bar in which will be adjustable, also based off of Jareds current chair and our design requirements.



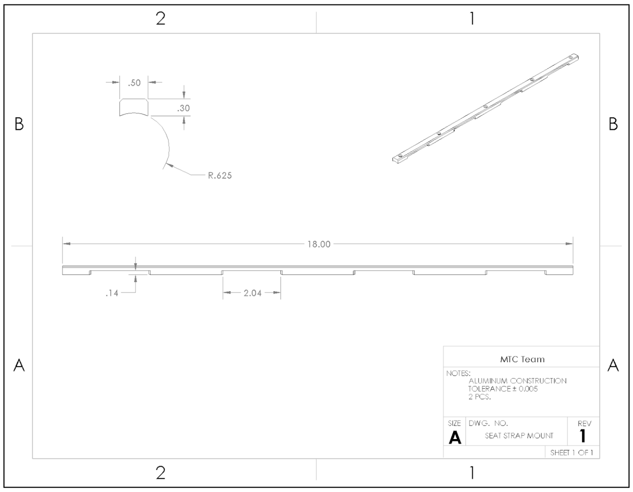
6.1.5 Foot Bar Coupler

This is the coupler in which will allow the foot bar to be adjustable, customized to fit on our main wheelchair frame. There will be two in total, one on each end of the foot bar.



6.1.6 Seat Strap Mount

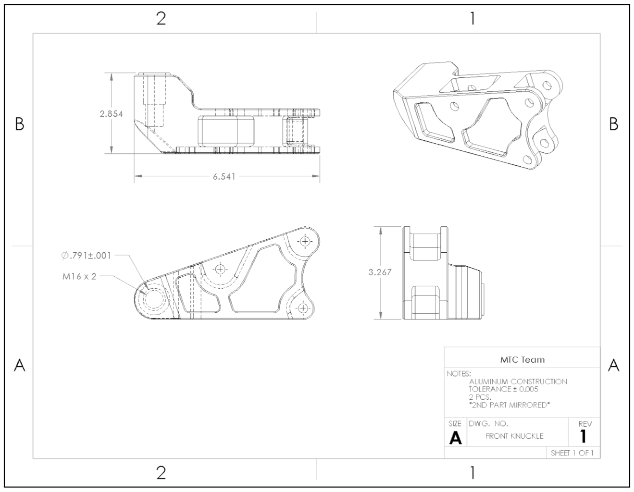
Below is our seat strap mount in which allows us to safely harness our seat cushion using velcro straps. As for our back cushion, we made sure it came with adjustable clamps in order to affix on to our frame on each end. There is one seat strap mount on each side of the frame.



6.2 Suspension Parts

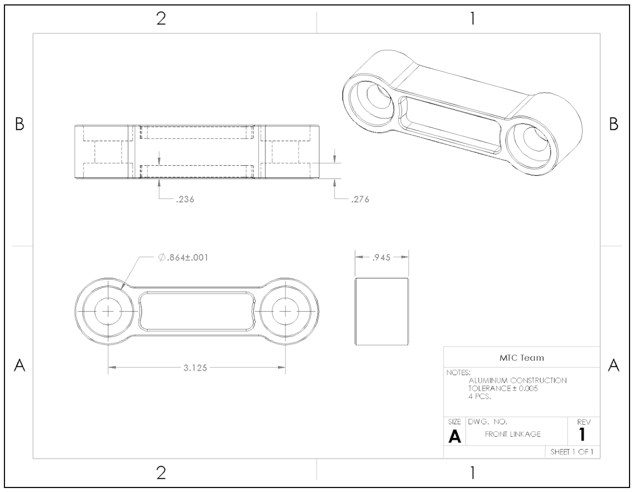
6.2.1 Front Knuckle

Below shows our front knuckle component in our suspension system. This will hold the front linkages within the four-bar in our chair. There is one on either side in the front.



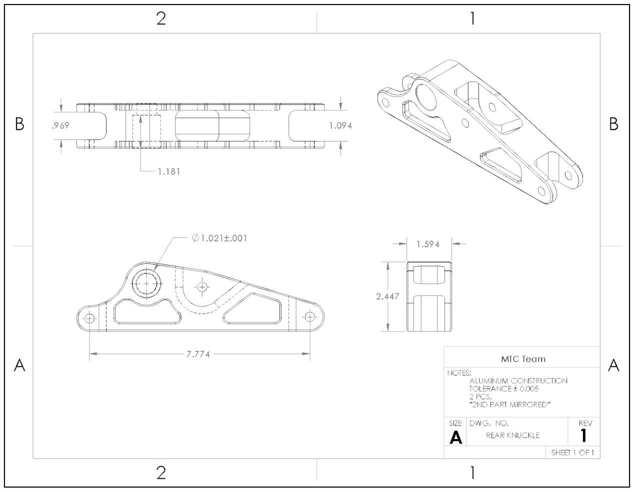
6.2.2 Front Linkage

The front linkage is responsible for connecting the front knuckles and the frame, and therefore connecting the front shocks. There are two on each side, making four in total.



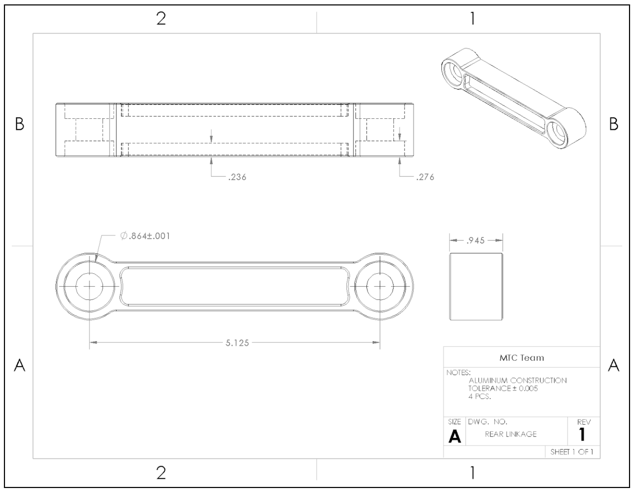
6.2.3 Rear Knuckle

Much the same as the front knuckle, the rear knuckle will hold the rear linkages within the four-bar in our chair. There is one on either side in the front. It is designed a little differently than the front knuckle to fit in our design.



6.2.4 Rear Linkage

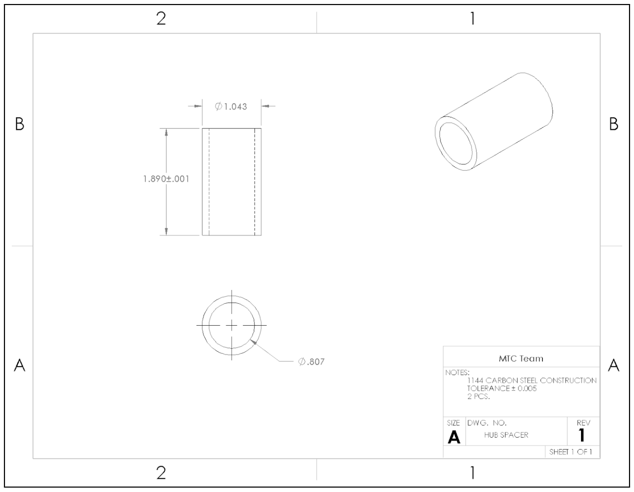
The rear linkage is a bit longer than the front linkage, and does the same effect to connect the rear shocks and rear knuckle to the wheelchair frame via the mounting tabs.



6.3 Rear Wheel Parts

6.3.1 Hub Spacer

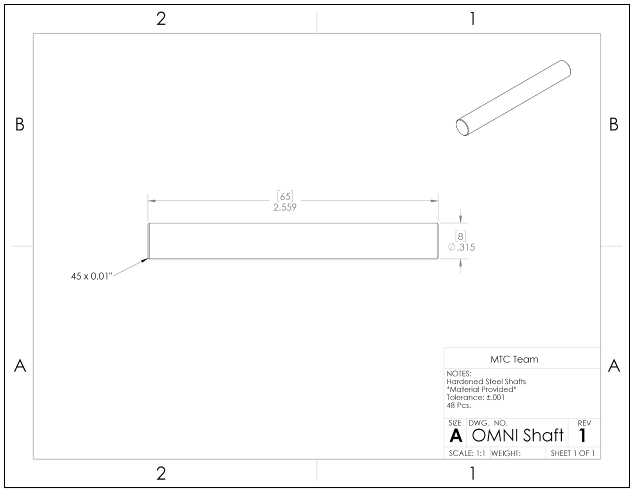
Below is the hub spacer in which aligned our one-sided hub motors on the chair. There is one for each motor.



6.4 Front Wheel Parts

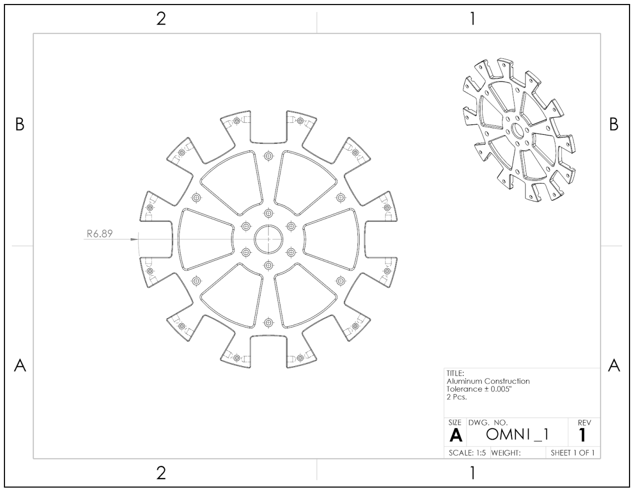
6.4.1 Omniwheel Shaft

The omniwheel shaft is based on a bought stock of case hardened steel, however we needed to cut them into the correct lengths we needed in order to connect the rollers and bearings to the omniwheel plate design.



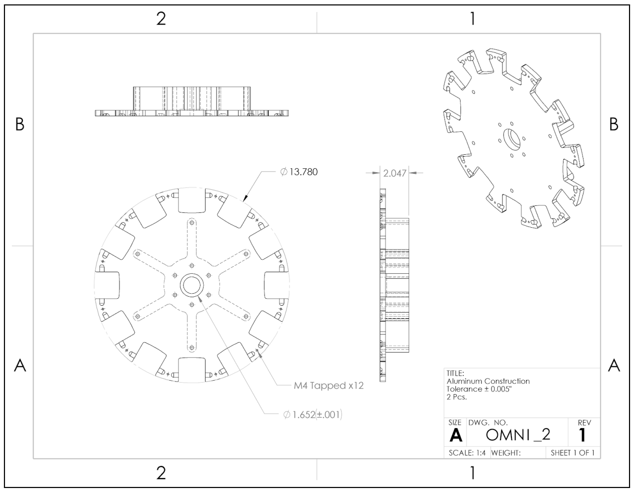
6.4.2 Omniwheel Plate 1

Our omniwheel design consists of four plates for our main wheel, bolted together concentrically. Below is the first outermost plate. There is one for each wheel.



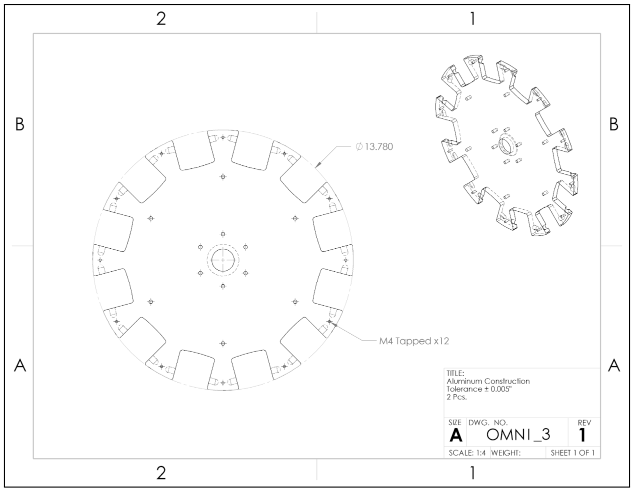
6.4.3 Omniwheel Plate 2

The second plate includes the spacing to hold the rollers and the other side of the wheel, it also includes holes for the shafts and bearings. There is one for each wheel.



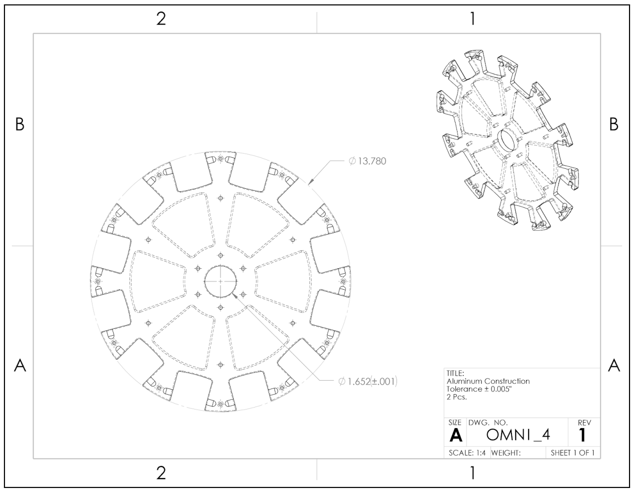
6.4.4 Omniwheel Plate 3

The third plate attaches on to the second, and there is one for each wheel.



6.4.5 Omniwheel Plate 4

The fourth is very much like the second, but without the spacer. There is one for each wheel.

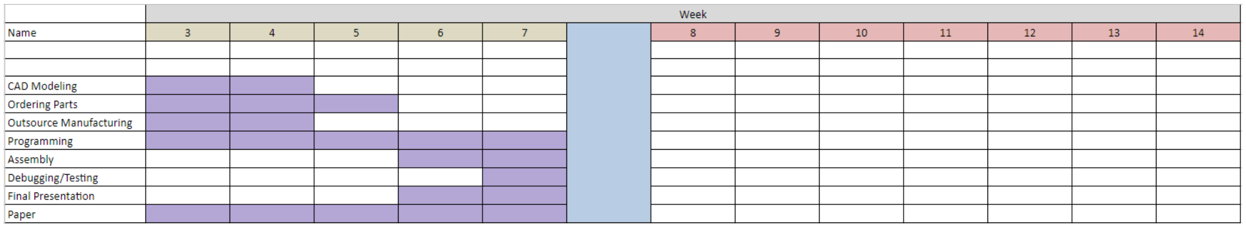


Appendix C: Documentation Iterations

Much like our design methods, our organizational and documenting methods went though much the same iterations. For these reasons, we have numerous different versions of gantt charts and budgets which are included in this report for the sake of a complete record. Below, are the current versions and iterations with descriptions of how they were use and how they benefited us. Our evolution of these ideas, charts, and plans are cited. We used various organizational methods to not only reference our actions, but also keep on track.

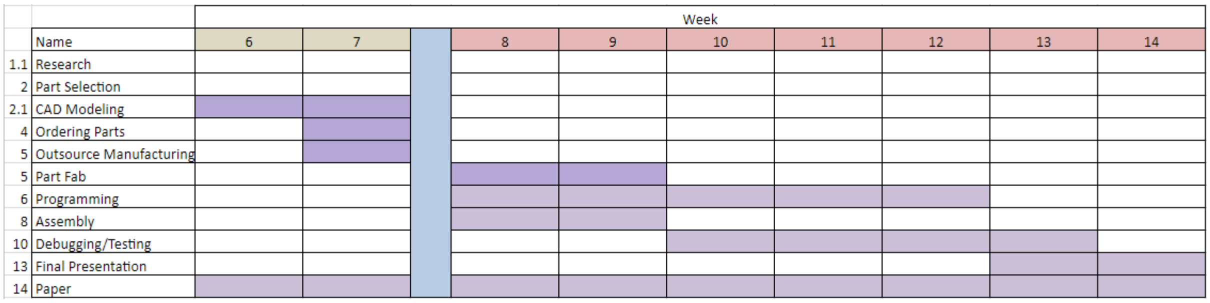
6.5 Gantt Charts

We used Gantt charts as planning our next course of action was essential, especially in the scope of our project and situation. Below first is our current chart and final, using only C-Term as this is the third iteration made after we were given external funds post-christmas break. It includes D-term as we were not sure what would carry over into it, if anything.



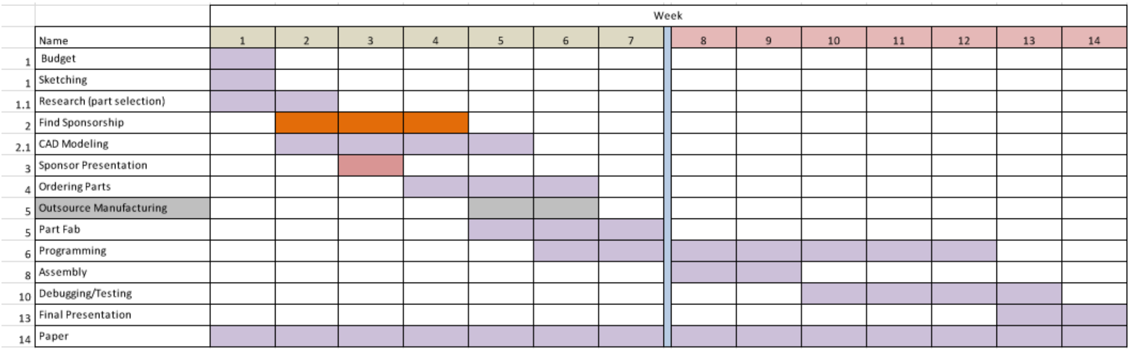
	Week												
Name	3	4	5	6	7		8	9	10	11	12	13	14
						🟦							
						🟦							
CAD Modeling	🟪	🟪				🟦							
Ordering Parts	🟪	🟪	🟪			🟦							
Outsource Manufacturing	🟪	🟪				🟦							
Programming	🟪	🟪	🟪	🟪	🟪	🟦							
Assembly				🟪	🟪	🟦							
Debugging/Testing					🟪	🟦							
Final Presentation				🟪	🟪	🟦							
Paper	🟪	🟪	🟪	🟪	🟪	🟦							

The next version was the point in time at which we decide to only construct test benches for our components using what we could afford from WPI and the used wheelchair that we had. As at this point we decided that we were going to continue the project without external funds. It describes the middle of B-term up until project completion.



		Week									
	Name	6	7		8	9	10	11	12	13	14
1.1	Research			🟦							
2	Part Selection			🟦							
2.1	CAD Modeling	🟪	🟪	🟦							
4	Ordering Parts		🟪	🟦							
5	Outsource Manufacturing		🟪	🟦							
5	Part Fab			🟦	🟪	🟪					
6	Programming			🟦	🟪	🟪	🟪	🟪	🟪		
8	Assembly			🟦	🟪	🟪					
10	Debugging/Testing			🟦			🟪	🟪	🟪	🟪	
13	Final Presentation			🟦						🟪	🟪
14	Paper	🟪	🟪	🟦	🟪	🟪	🟪	🟪	🟪	🟪	🟪

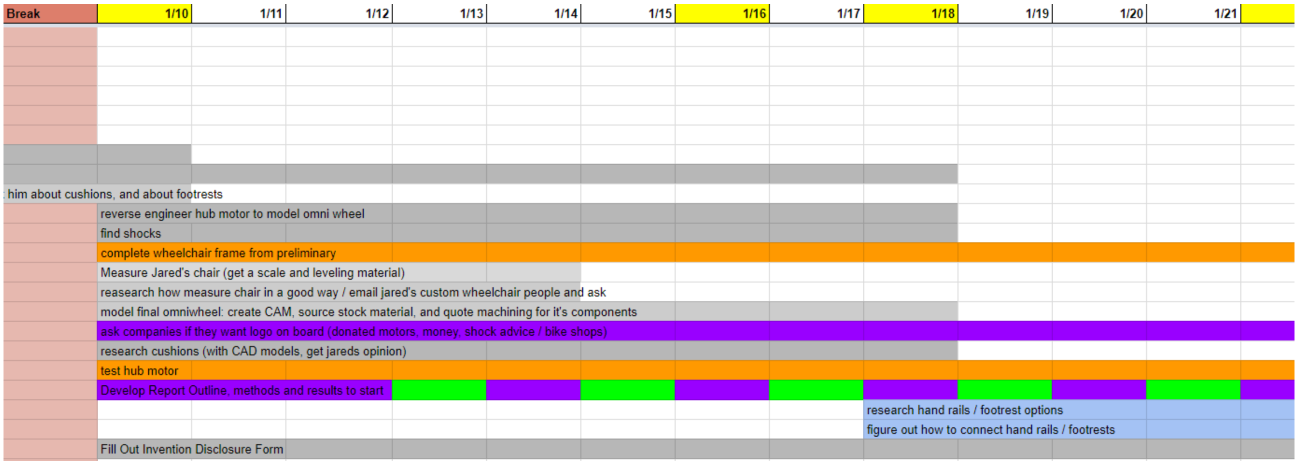
Our first iteration of the Gantt chart was us planning the entire project, assuming external funds could be obtained. It includes the entirety of B and C term until project completion, as we needed to refocus our ideas in A term.



		Week														
	Name	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Budget	🟪							🟦							
1	Sketching	🟪							🟦							
1.1	Research (part selection)	🟪	🟪						🟦							
2	Find Sponsorship		🟧	🟧	🟧				🟦							
2.1	CAD Modeling		🟪	🟪	🟪	🟪			🟦							
3	Sponsor Presentation			🟥					🟦							
4	Ordering Parts				🟪	🟪	🟪		🟦							
5	Outsource Manufacturing					▨	▨		🟦							
5	Part Fab					🟪	🟪	🟪	🟦							
6	Programming						🟪	🟪	🟦	🟪	🟪	🟪	🟪	🟪		
8	Assembly								🟦	🟪	🟪					
10	Debugging/Testing								🟦			🟪	🟪	🟪	🟪	
13	Final Presentation								🟦						🟪	🟪
14	Paper	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟦	🟪	🟪	🟪	🟪	🟪	🟪	🟪

6.6 Task Documentation

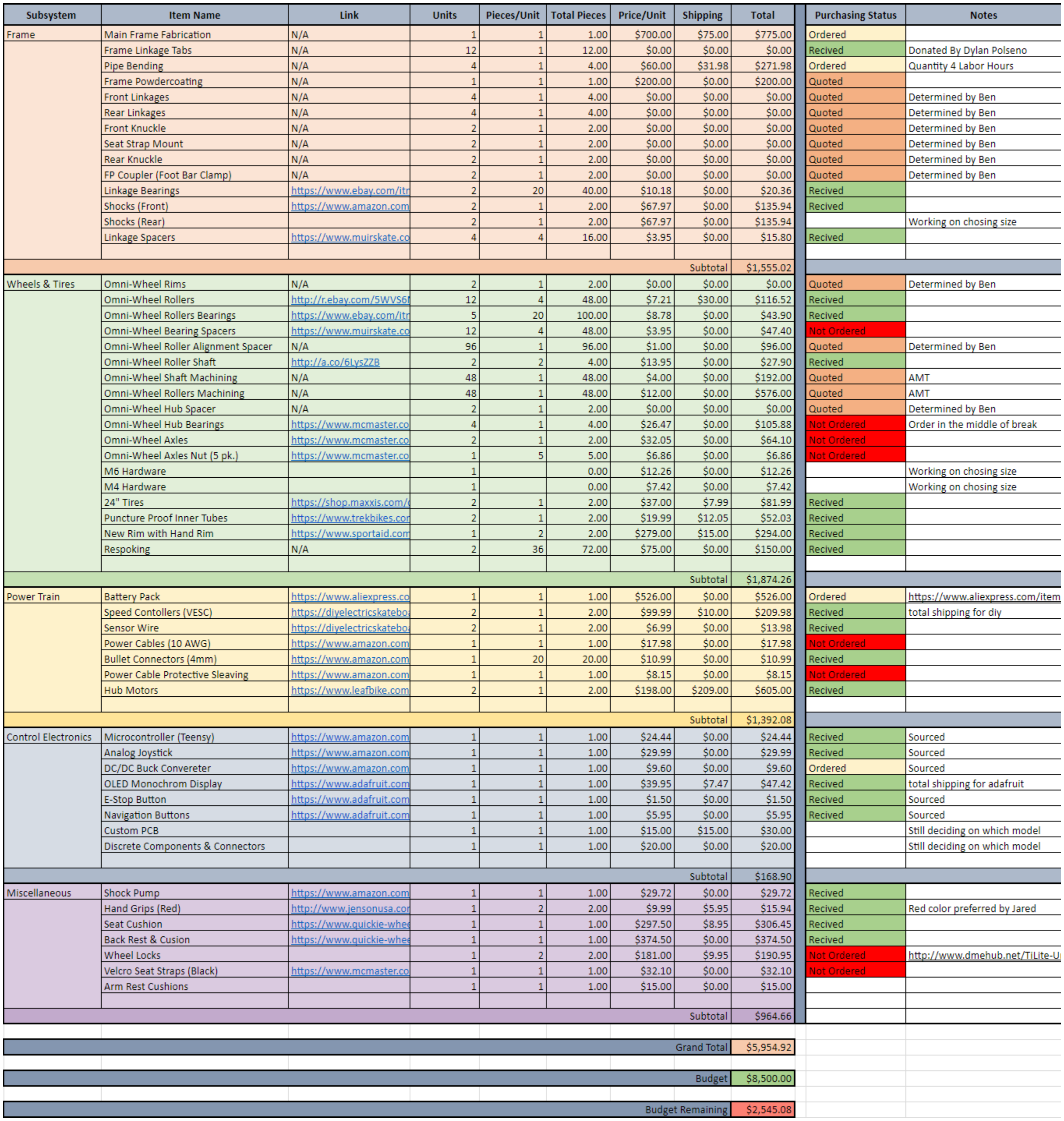
To establish a sense of accountability, and to keep all our project tasks in order, we utilized the method shown in the excerpt below. Each task was given a color, or multiple, depending on who was working on the specific task. Generally these are followed up on a weekly basis, and greyed out when completed. The dates in yellow were meeting days and the task generally started or ended there. We followed through with this method the entire course of the project.



Break	1/10	1/11	1/12	1/13	1/14	1/15	1/16	1/17	1/18	1/19	1/20	1/21
: him about cushions, and about footrests												
	reverse engineer hub motor to model omni wheel											
	find shocks											
	complete wheelchair frame from preliminary											
	Measure Jared's chair (get a scale and leveling material)											
	reasearch how measure chair in a good way / email jared's custom wheelchair people and ask											
	model final omniwheel: create CAM, source stock material, and quote machining for it's components											
	ask companies if they want logo on board (donated motors, money, shock advice / bike shops)											
	research cushions (with CAD models, get jareds opinion)											
	test hub motor											
	Develop Report Outline, methods and results to start											
									research hand rails / footrest options			
									figure out how to connect hand rails / footrests			
	Fill Out Invention Disclosure Form											

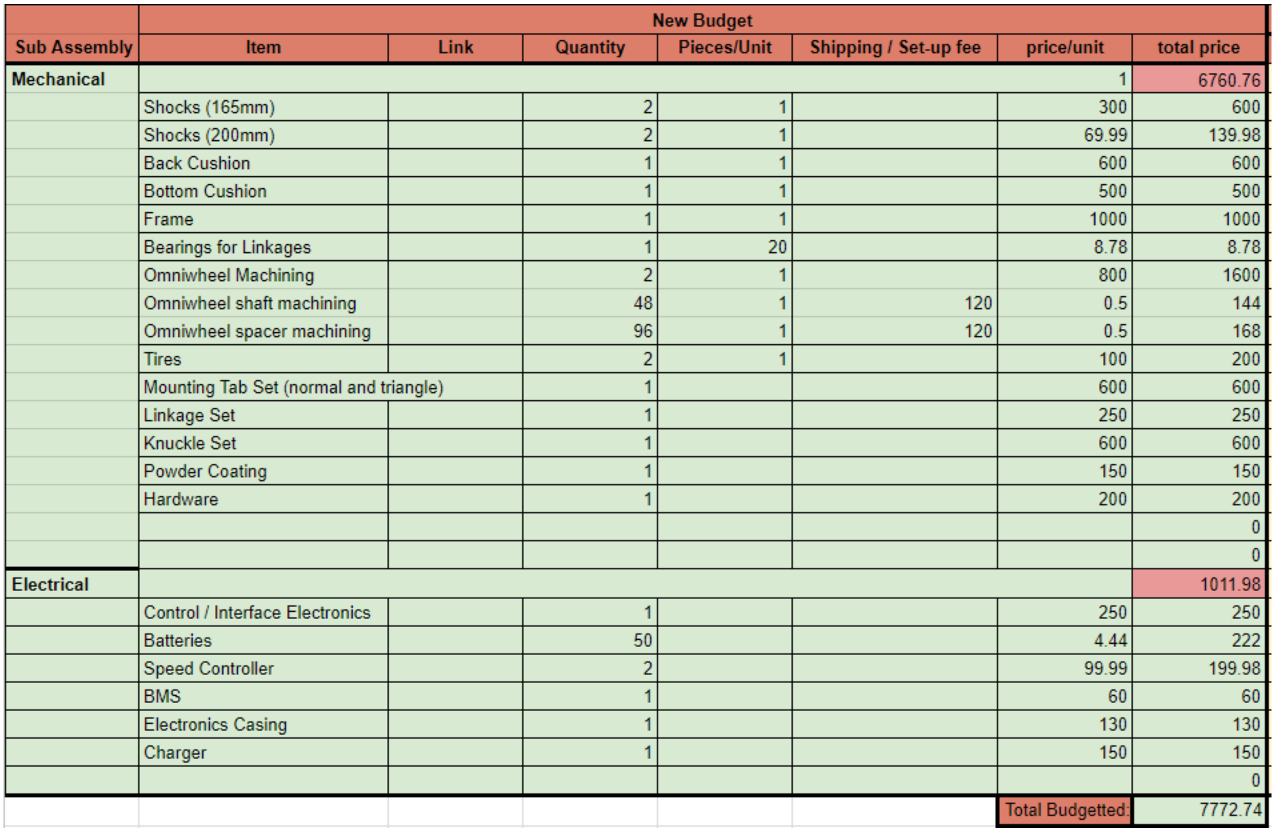
6.7 Budget

Below is our budget used based on the money allocated to us by WPI and by our generous donors. It is an ongoing list that also calculates how under or over we are with our budget as we continue with the project, as well as current status of each item. This was an essential resource for us. Below shows our current iteration for this method, labeling each subsystem of our design and detailed pricing. It is our second and final budget that we went in full detail as we were making sure we did not go over our total funding.



Subsystem	Item Name	Link	Units	Pieces/Unit	Total Pieces	Price/Unit	Shipping	Total	Purchasing Status	Notes
Frame	Main Frame Fabrication	N/A	1	1	1.00	$700.00	$75.00	$775.00	Ordered	
	Frame Linkage Tabs	N/A	12	1	12.00	$0.00	$0.00	$0.00	Recived	Donated By Dylan Polseno
	Pipe Bending	N/A	4	1	4.00	$60.00	$31.98	$271.98	Ordered	Quantity 4 Labor Hours
	Frame Powdercoating	N/A	1	1	1.00	$200.00	$0.00	$200.00	Quoted	
	Front Linkages	N/A	4	1	4.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Rear Linkages	N/A	4	1	4.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Front Knuckle	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Seat Strap Mount	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Rear Knuckle	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	FP Coupler (Foot Bar Clamp)	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Linkage Bearings	https://www.ebay.com/itr	2	20	40.00	$10.18	$0.00	$20.36	Recived	
	Shocks (Front)	https://www.amazon.com	2	1	2.00	$67.97	$0.00	$135.94	Recived	
	Shocks (Rear)		2	1	2.00	$67.97	$0.00	$135.94		Working on chosing size
	Linkage Spacers	https://www.muirskate.co	4	4	16.00	$3.95	$0.00	$15.80	Recived	
							Subtotal	$1,555.02		
Wheels & Tires	Omni-Wheel Rims	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Omni-Wheel Rollers	http://r.ebay.com/5WVS6I	12	4	48.00	$7.21	$30.00	$116.52	Recived	
	Omni-Wheel Rollers Bearings	https://www.ebay.com/itr	5	20	100.00	$8.78	$0.00	$43.90	Recived	
	Omni-Wheel Bearing Spacers	https://www.muirskate.co	12	4	48.00	$3.95	$0.00	$47.40	Not Ordered	
	Omni-Wheel Roller Alignment Spacer	N/A	96	1	96.00	$1.00	$0.00	$96.00	Quoted	Determined by Ben
	Omni-Wheel Roller Shaft	http://a.co/6LysZZB	2	2	4.00	$13.95	$0.00	$27.90	Recived	
	Omni-Wheel Shaft Machining	N/A	48	1	48.00	$4.00	$0.00	$192.00	Quoted	AMT
	Omni-Wheel Rollers Machining	N/A	48	1	48.00	$12.00	$0.00	$576.00	Quoted	AMT
	Omni-Wheel Hub Spacer	N/A	2	1	2.00	$0.00	$0.00	$0.00	Quoted	Determined by Ben
	Omni-Wheel Hub Bearings	https://www.mcmaster.co	4	1	4.00	$26.47	$0.00	$105.88	Not Ordered	Order in the middle of break
	Omni-Wheel Axles	https://www.mcmaster.co	2	1	2.00	$32.05	$0.00	$64.10	Not Ordered	
	Omni-Wheel Axles Nut (5 pk.)	https://www.mcmaster.co	1	5	5.00	$6.86	$0.00	$6.86	Not Ordered	
	M6 Hardware		1		0.00	$12.26	$0.00	$12.26		Working on chosing size
	M4 Hardware		1		0.00	$7.42	$0.00	$7.42		Working on chosing size
	24" Tires	https://shop.maxxis.com/	2	1	2.00	$37.00	$7.99	$81.99	Recived	
	Puncture Proof Inner Tubes	https://www.trekbikes.cor	2	1	2.00	$19.99	$12.05	$52.03	Recived	
	New Rim with Hand Rim	https://www.sportaid.com	1	2	2.00	$279.00	$15.00	$294.00	Recived	
	Respoking	N/A	2	36	72.00	$75.00	$0.00	$150.00	Recived	
							Subtotal	$1,874.26		
Power Train	Battery Pack	https://www.aliexpress.co	1	1	1.00	$526.00	$0.00	$526.00	Ordered	https://www.aliexpress.com/item
	Speed Contollers (VESC)	https://diyelectricskatebo	2	1	2.00	$99.99	$10.00	$209.98	Recived	total shipping for diy
	Sensor Wire	https://diyelectricskatebo	2	1	2.00	$6.99	$0.00	$13.98	Recived	
	Power Cables (10 AWG)	https://www.amazon.com	1	1	1.00	$17.98	$0.00	$17.98	Not Ordered	
	Bullet Connectors (4mm)	https://www.amazon.com	1	20	20.00	$10.99	$0.00	$10.99	Recived	
	Power Cable Protective Sleaving	https://www.amazon.com	1	1	1.00	$8.15	$0.00	$8.15	Not Ordered	
	Hub Motors	https://www.leafbike.com	2	1	2.00	$198.00	$209.00	$605.00	Recived	
							Subtotal	$1,392.08		
Control Electronics	Microcontroller (Teensy)	https://www.amazon.com	1	1	1.00	$24.44	$0.00	$24.44	Recived	Sourced
	Analog Joystick	https://www.amazon.com	1	1	1.00	$29.99	$0.00	$29.99	Recived	Sourced
	DC/DC Buck Convereter	https://www.amazon.com	1	1	1.00	$9.60	$0.00	$9.60	Ordered	Sourced
	OLED Monochrom Display	https://www.adafruit.com	1	1	1.00	$39.95	$7.47	$47.42	Recived	total shipping for adafruit
	E-Stop Button	https://www.adafruit.com	1	1	1.00	$1.50	$0.00	$1.50	Recived	Sourced
	Navigation Buttons	https://www.adafruit.com	1	1	1.00	$5.95	$0.00	$5.95	Recived	Sourced
	Custom PCB		1	1	1.00	$15.00	$15.00	$30.00		Still deciding on which model
	Discrete Components & Connectors		1	1	1.00	$20.00	$0.00	$20.00		Still deciding on which model
							Subtotal	$168.90		
Miscellaneous	Shock Pump	https://www.amazon.com	1	1	1.00	$29.72	$0.00	$29.72	Recived	
	Hand Grips (Red)	http://www.jensonusa.cor	1	2	2.00	$9.99	$5.95	$15.94	Recived	Red color preferred by Jared
	Seat Cushion	https://www.quickie-whee	1	1	1.00	$297.50	$8.95	$306.45	Recived	
	Back Rest & Cusion	https://www.quickie-whee	1	1	1.00	$374.50	$0.00	$374.50	Recived	
	Wheel Locks		1	2	2.00	$181.00	$9.95	$190.95	Not Ordered	http://www.dmehub.net/TiLite-U
	Velcro Seat Straps (Black)	https://www.mcmaster.co	1	1	1.00	$32.10	$0.00	$32.10	Not Ordered	
	Arm Rest Cushions		1	1	1.00	$15.00	$0.00	$15.00		
							Subtotal	$964.66		
							Grand Total	$5,954.92		
							Budget	$8,500.00		
							Budget Remaining	$2,545.08		

The next budget it formatted a little more generally, it was made after we got the external funding and gave us an idea of how we could move forward.



	New Budget						
Sub Assembly	**Item**	**Link**	**Quantity**	**Pieces/Unit**	**Shipping / Set-up fee**	**price/unit**	**total price**
Mechanical						1	6760.76
	Shocks (165mm)		2	1		300	600
	Shocks (200mm)		2	1		69.99	139.98
	Back Cushion		1	1		600	600
	Bottom Cushion		1	1		500	500
	Frame		1	1		1000	1000
	Bearings for Linkages		1	20		8.78	8.78
	Omniwheel Machining		2	1		800	1600
	Omniwheel shaft machining		48	1	120	0.5	144
	Omniwheel spacer machining		96	1	120	0.5	168
	Tires		2	1		100	200
	Mounting Tab Set (normal and triangle)		1			600	600
	Linkage Set		1			250	250
	Knuckle Set		1			600	600
	Powder Coating		1			150	150
	Hardware		1			200	200
							0
							0
Electrical							1011.98
	Control / Interface Electronics		1			250	250
	Batteries		50			4.44	222
	Speed Controller		2			99.99	199.98
	BMS		1			60	60
	Electronics Casing		1			130	130
	Charger		1			150	150
							0
						Total Budgetted:	7772.74

Our first budget we made in order to find a sponsor. This was a rough estimate of the parts and subsystems in which we would need, as well as estimating machining cost and baked by a little research of components.

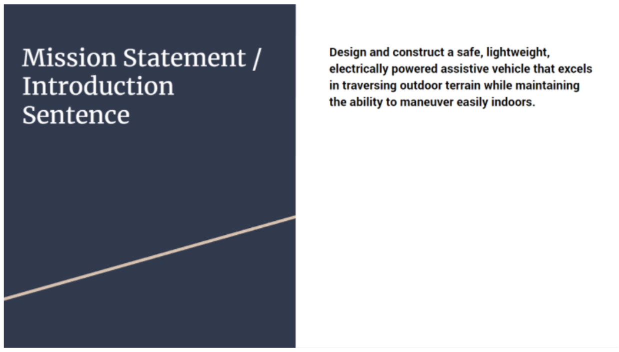
Part	Quantity	Unit Price	Low Cost	High Cost	Details
Wheelchair	1	1000 to 2000	1000	2000	Quickie GP Wheelchair
Hub Motor	4	100 to 300	660	1200	48W 1000V
Back Tires	2	30 to 40	60	80	TBD, 24"
Batteries	72	4 to 8	400	500	LG He4 18650's
Motor Controller	4	100	400	400	Arduino compatible
Shocks	2	100 to 200	200	400	TBD when frame is sized
Processor board	1	20 to 40	20	40	Teensy/Arduino Mega
Suspension Hardware		500 to 1000	500	1000	
Misc Electrical			50	100	Wires, Connectors, LEDs, ect
Misc Mechanical			100	150	Raw Materials, rubber, metal, ect.
Omni Wheel Hardware	2	120 to 200	240	400	Omni Wheel fabrication, bearings, custom rollers
	Total:		3630	6270	

6.8 Meeting Slides

Throughout the project we participated in weekly adviser meetings. They were essential in keeping us on track, as well as giving us insight and guidance. In each meeting we prepared a power point presentation of our status and things completed for the following week. The slides began to follow a similar structure of project goal, design and manufacturing updates, other financial and report updates, and then goals for the next week. Perhaps the most valuable part of these, additionally, was that they not only gave us an idea of our project growth but also a resource for any pictures, ideas, and designs that we used in the report. Below an example meeting that follows the general structure explained above.

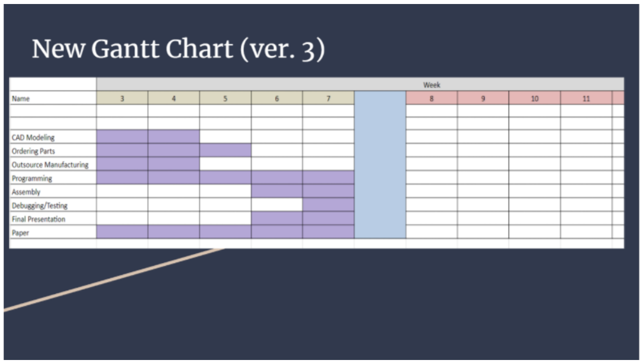
Advisor Meeting 18
5 February 2018

MTC Team



Mission Statement / Introduction Sentence

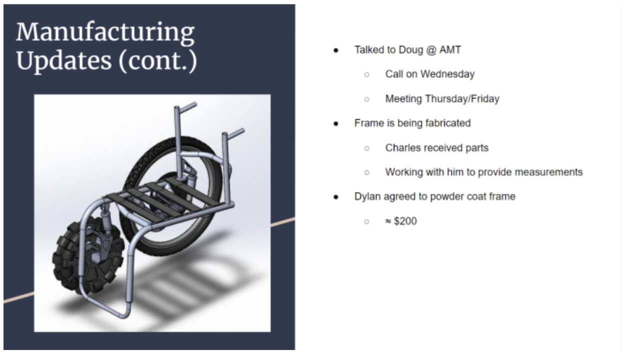
Design and construct a safe, lightweight, electrically powered assistive vehicle that excels in traversing outdoor terrain while maintaining the ability to maneuver easily indoors.



New Gantt Chart (ver. 3)

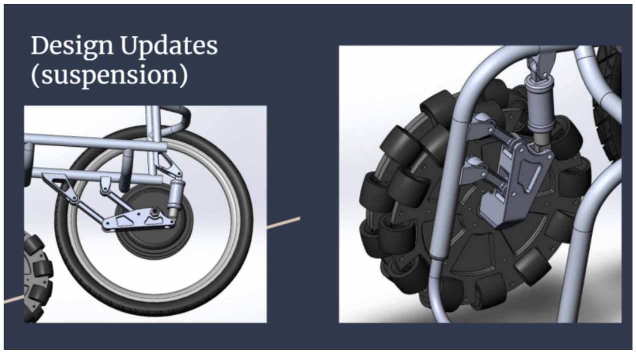
	Week									
Name	3	4	5	6	7		8	9	10	11
CAD Modeling	▨	▨								
Ordering Parts	▨	▨	▨							
Outsource Manufacturing	▨	▨								
Programming	▨	▨	▨	▨	▨					
Assembly				▨	▨					
Debugging/Testing					▨					
Final Presentation				▨	▨					
Paper	▨	▨	▨	▨	▨					

Manufacturing Updates (and hub motors)

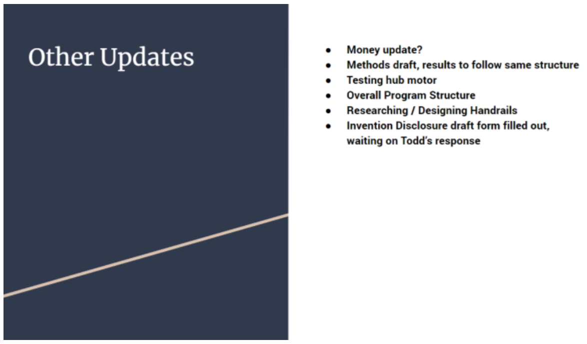


Manufacturing Updates (cont.)

- Talked to Doug @ AMT
  - Call on Wednesday
  - Meeting Thursday/Friday
- Frame is being fabricated
  - Charles received parts
  - Working with him to provide measurements
- Dylan agreed to powder coat frame
  - ≈ $200

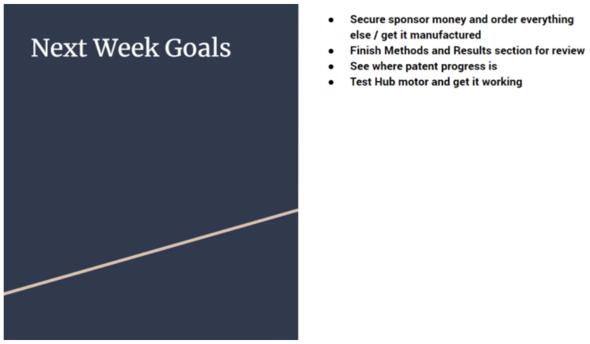


Design Updates (suspension)



Other Updates

- Money update?
- Methods draft, results to follow same structure
- Testing hub motor
- Overall Program Structure
- Researching / Designing Handrails
- Invention Disclosure draft form filled out, waiting on Todd's response



Next Week Goals

- Secure sponsor money and order everything else / get it manufactured
- Finish Methods and Results section for review
- See where patent progress is
- Test Hub motor and get it working

Appendix D: Mechatronic Systems Final report

As previously mentioned, three of the members of our MQP group took a separate class here at WPI, RBE/ME 4322 Modeling and Analysis of Mechatronic Systems. This class went into detail about how to model and represent mechanical, electrical and electro-mechanical systems in 2D and how to analyze them. For our final term project we were required to come up with bond graphs and system equations along with the static and dynamic response of a subsystem. We were allowed to use our MQP as a valid subsystem, so we used our suspension system as our subsystem. Excerpts from our term report where used above in section 3.2.2.3. In addition to the excerpts, we will include the full report with the submission of this report so that anyone who is interested can learn about the dynamic response of the suspension system in more detail.