NATHAN'S MOBILITY DEVICE

FINAL DESIGN REVIEW REPORT

Sponsored by: CPConnect

Mechanical Engineering Department
California Polytechnic State University, San Luis Obispo
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Statement of Disclaimer

Table of Contents

List of Figures

List of Tables

List of Nomenclature

SMA – Spinal Muscular Atrophy
QFD – Quality Function Deployment
OSHA - Occupational Safety and Health Administration
ADA - Americans with Disabilities Act
CAD - Computer Aided Design
FEA - Finite Element Analysis
WDM - Weighted Decision Matrix

Executive Summary

Nathan's Mobility Device is a California Polytechnic State University senior project composed of a team of four mechanical engineering students that designed, built and implemented a specialized seat on an existing mobility device. Nathan, the sole beneficiary of this project, is an 11-year-old boy afflicted with a condition known as Spinal Muscular Atrophy (SMA) which causes him extreme muscular weakness. In this report, the team discussed the problem at hand, provides preliminary research and product benchmarking (evaluation and comparison to specific criteria), and described the ideation, prototyping, testing, and iteration plan. In addition, the team explored the final design in detail while confirming that each component was within the specified budget, meets Nathan's required criteria, and functions safely and appropriately. This final design review discusses the final design choices incorporated into the mobility device and the manufacturing and testing procedures done to achieve the final product. Manufacturing and testing were divided into mechanical and electrical subgroups and have their respective risk assessments and critical tests outlined in the sections six and seven.

In the first two months of receiving this project, the team was undecided between modifying an existing power scooter that either focused on comfort or building a mobility device from scratch that focuses on aesthetics at the expense of reliability. In analyzing the hierarchy of Nathan's needs and collaborating with his mother, Amy, team members decided to forfeit the latter idea and settle on a mobility base to build upon. This report spans the period before, during, and after this choice was made.

The report also identifies the constraints that will be considered for the design to ensure that the project is within the scope of the team's expertise. Some of these constraints include: budgeting, working within the scope of work, and modifying the mobility base without damaging existing components.

1. Introduction

The Cal Poly senior project is a year-long class where a team of students are assigned a task to research, analyze, and build a product while providing detailed documentation throughout the progression of the project. Nathan's mobility device is a senior project sponsored by Special Olympics whose sole benefactor is Nathan Cooper. Matthew Brenholdt, Steven deCsesznak, Lansen Eto, and Moulay Salahdin will be working on this project as Team Nathan during the 2017/2018 academic school year under the advisory of Professor Sarah Harding and Special Olympics' sponsor, Michael Lara.

Nathan is an intelligent, young boy, who has limited mobility in his arms and legs requiring him to use a mobility device to commute. His current mobility device, the Standing Dani as seen in Figure 1, makes it difficult for him to breathe and causes him pain and fatigue. The Standing Dani is an upright electric device that is operated with a joystick. The device is equipped with a chin rest to support Nathan's head and chest braces to lock him into the device and keep his back straight. These features, however, compress Nathan's body and cause discomfort. Also as shown in Figure 1, the Standing Dani is not equipped with functional footrests, forcing Nathan to lay his feet on the battery box, which gets hot and uncomfortable for Nathan.


Figure 1. Nathan on the Standing Dani

The project has three main stakeholders who the team will be periodically checking in with to ensure that the goals are coinciding with the team's progress. Amy Cooper, Nathan's mother, and Nathan are the main stakeholders of this project since the final prototype will directly affect the family. The third stakeholder, Michael Lara, Head of the Special Olympics division in San Luis Obispo, is contributing time, resources, and money to assist with this project.

The purpose of this project is to design, test, and build a new mobility device that will overcome the Standing Dani's design flaws and be suitable for Nathan's health conditions. To accomplish this, the team first conducted background research on existing mobility devices which included compiling relevant patents and applicable technologies such as different types of adjustable seats. With an understanding of the technology and costs behind mobility devices, the team sat down with Amy and Michael to gain a better understanding of the problem. From here, a problem statement was defined, and a quality function deployment (QFD) matrix, shown in Appendix A, was developed to correlate Nathan's needs and wants to the engineering specifications of the new device.

Using different selection matrices that will be discussed later in section four of this report, ideas for the main functions of the mobility device were evaluated, reduced, combined, and selected. Ultimately, one combination of the team's ideas was deemed the best. After consulting with Stan at A1 Mobility, the team's final design was revisited and ultimately changed to better suit Nathan's needs. The main objective of this final design review is to outline the final proposed design for Nathan's mobility device. This report will document the team's thought process in choosing the final design while providing the necessary documentation for design development and documenting the full manufacturing and fabrication process.

2. Background

Background research is necessary to the design and understanding of the project. For this project, the research collected can be categorized into four major sections illustrated below in Figure 2.

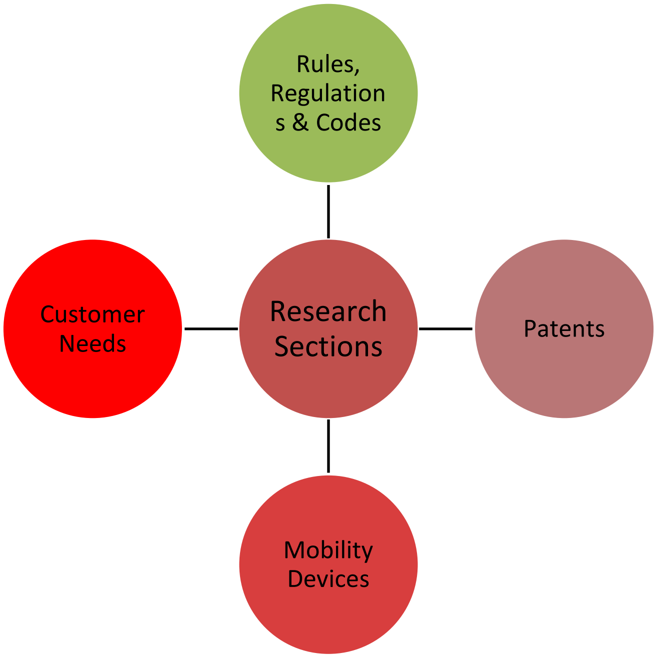


Figure 2. Team Nathan's major research sections

2.1 Customer Needs

In the initial meeting with Amy and Mr. Lara, the team discussed the customer's problems with the current mobility device. After learning about the customer's needs and wants, the team took note of them (shown in Appendix B), so they would be included in the design and fabrication of the new mobility device. Additionally, Nathan's favorite aspects of the Standing Dani, most notably maneuverability, were accounted for in order to integrate them into the design. These requirements are as follows:

- Comfort
- Safety
- Transportability
- Maneuverability
- Aesthetics

2.2 Benchmarking Mobility Devices

Team Nathan benchmarked a variety of mobility devices (four-wheeled and three-wheeled devices, adjustable seating, and kid's powered vehicles) to develop an understanding of the types of mobility devices currently on the market. From the sponsor interview, the team was told to include an adjustable seat that would recline to help Nathan breathe more easily and a joystick input system so that he would have more control over the device. From the list of benchmarked products, specifications were developed to help narrow down the number of the possible choices, which can be seen in the attached QFD (Appendix A).

2.3 Rules, Regulations, & Codes

In order to move forward, accessibility and transportation regulations needed to be addressed. In regard to applicable industry codes and regulations determined by the Occupational Safety and Health Administration (OSHA), it is required for exit routes to be at least 28 inches in width at all points, cannot decrease in the direction of the exit route, walkways must have guardrails for protection from unenclosed sides and be reasonably straight, smooth, and level [1]. This is relevant to people who use wheelchairs or other mobility device so they do not have restricted exit route access in case of emergency. For Nathan, this is mandatory for when he is in school and must be able to fit and maneuver through the exit route. The Americans with Disabilities Act (ADA), provides accessibility laws that lead to additional design criteria for mobility devices and wheelchairs, such as requiring ramps to have a slope ratio of one foot of wheelchair ramp for each inch of rise, a minimum width of 36 inches across the wheelchair ramp, and handrails on each side with a rise greater than six inches [2].

2.4 Patents

The team did a patent search for any relevant or helpful products that could be incorporated in the design of the product. The focus was on reclining mechanisms that would adjust the foot position as the back support changes. The Modular Wall Proximity Reclining Chair Patent, as seen in Figure 3, encompasses the idea of having the foot position as a function of the back support angle [3]. This idea was later prototyped as an eight-bar linkage but deemed too complicated to move forward with. A complete list of all the relevant patents can be found in Appendix C.

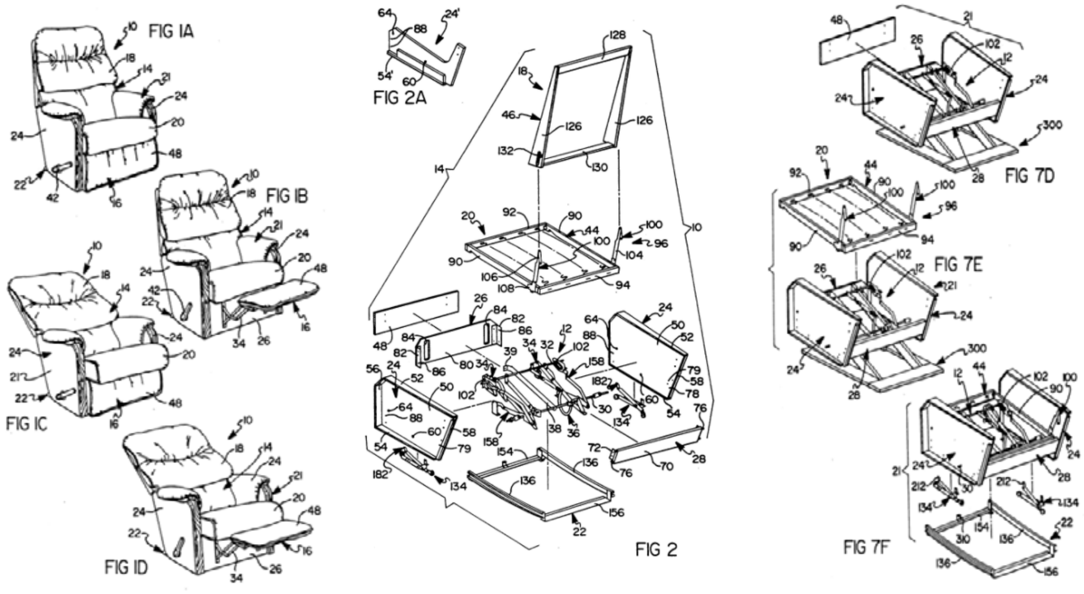


Figure 3. The modular wall proximity reclining chair patent

3. Objectives

The objectives' section describes the desired outcomes of the project. In this section, updated project goals will be discussed based on Nathan's feedback and the new information about his needs. It will also describe the detailed QFD process and will outline the device engineering specifications the team took into consideration. While many aspects of this project have changed from conception to the Final Design Review, the overall objectives of the project outlined in this section have remained the same.

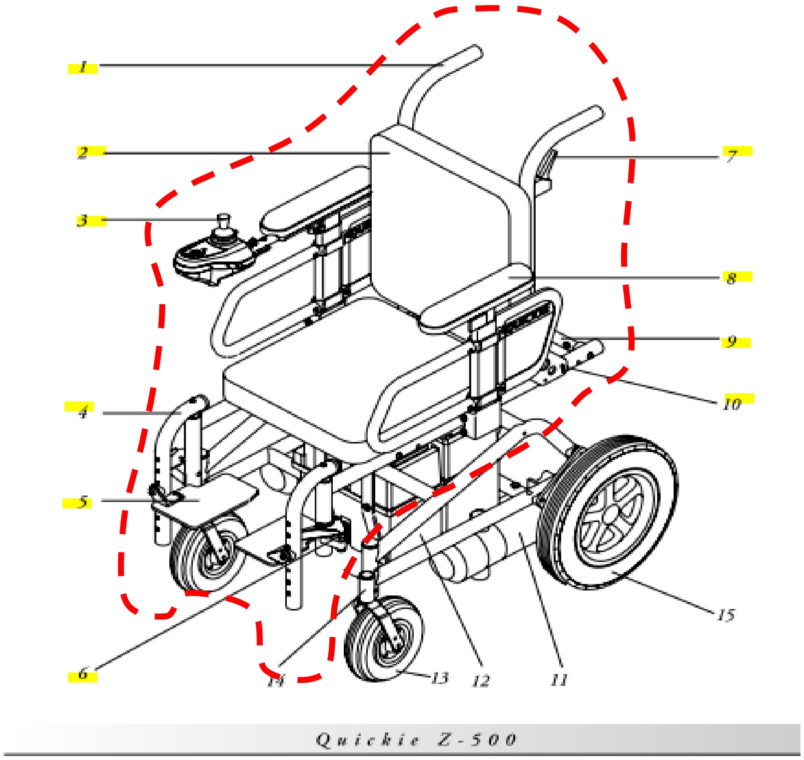
3.1 Project Goals for Current Scope

The objective of this project is to design a mobility device suited to Nathan's needs and health conditions. As previously stated, due to Nathan's movement restrictions and associated discomfort, Nathan's parents need to adjust his position on the Standing Dani frequently which can be seen in Figure 4. Additionally, he cannot spend more than 45 minutes to an hour on the device, as he will begin to experience debilitating chest pain. This limits the time they can spend participating in family activities. As one can imagine, this hindrance puts enormous amounts of stress on not only Nathan but also the family, as they are limited in where they can go and what they can do.

Figure 4. Nathan being helped by his mother into a comfortable position after extended use

3.2 Project Scope and Boundary Sketch

To create a mobility device that satisfies the end user's needs, Team Nathan explicitly outlined the scope of the project. In other words, Team Nathan defined what is within the realm of the project and what is out of reach. A boundary diagram was used to illustrate the team's project focus: the seat element of the mobility device. This means that the project will not include redesigning the powertrain of the mobility device or anything outside the dotted red lines. The boundary diagram can be seen in Figure 5.



1. Stroller handle
2. Solid back
3. Joystick
4. Swing-away hanger
5. Footplate
6. Swing-away release latch
7. Tilt-in-space mechanism release lever
8. Armrest
9. Strut tube
10. Backrest pivot plate
11. Motors
12. Battery boxes
13. Caster tire
14. Caster housing
15. 12" Drive wheels

Figure 5. Scope of Work Boundary Diagram

Based on the team's conversation with Nathan and Amy, the team developed a list of customer requirements along with other items that Nathan would like if possible. These items are ordered from high priority to low priority as summarized in Figure 6 below.

Comfort
- The main objective of our project, is for Nathan to be comfortable in the mobility device
- This specification takes precedence and is our top priority

Safety
- The mobility device and reclining seat will not present a hazard for Nathan and will be designed in a manner to keep Nathan safe
- This includes designing the seat for sturdiness and stability

Transportability
- The mobility device needs to be lightweight so Amy is able to lift the device into her vehicle without special assistance.
- This will complement customer requirement # 4 as weight has a direct relationship to acceleration and handling

Maneuverability
- Nathan's current mobility device is very quick and sensitive to the joystick input control
- Nathan specifically mentioned this is one of his favorite features of the Standing Dani

Aesthetic
- The design will be pleasant to the eye and closely resemble a Batmobile
- The design will not impede or hinder the overall intended look

Figure 6. Hierarchy of customer needs

3.3 Quality Function Deployment

The quality function deployment (QFD) chart is an engineering tool used in design to better understand and identify the needs of the customer from their perspective. It is also used as a strategy to stay competitive in industry through collecting information about competitor products and benchmarking them. The team used this tool to determine the appropriate specifications for the new mobility device based on previous benchmarked products and Nathan's predetermined needs.

3.3.1 Overview

After identifying Nathan's needs and wants, the QFD was created. Customer requirements were listed on the left side of the matrix. The customer priorities were then rated using a one to five scale for each requirement. Competitor products were listed on the right side of the matrix and given ratings from one to five based upon their compliance with the customer's requirements. The correlations between customer's requirements and product requirements were then developed by indicating their strengths.

Based on the QFD Current Product Assessment section in Appendix A, The Air Hawk from Discover My Mobility and the PWWT from Mattel had the highest rating, both with scores of 2.5 out of five points. The Lexis from Discover My Mobility scored second with 2.3 points.

3.3.2 Results

Another portion of the QFD used in rating the specifications of multiple devices was the Target Section. The QFD Target Section indicates that both the Air Hawk and the Lexis from Discover My Mobility scored 3.67 points. The PWWT from Mattel scored 3.5 points followed by the Polaris from Peg Pergo with 3.33 points.

This assessment gives us a clear idea of the products to consider while designing Nathan's mobility device. Products with the highest scores are the ones that best satisfy the needs of the customer. The features of these products might be copied or improved upon to achieve the best performance of the new mobility device. In this case, The Air Hawk and the PWWT features will be strongly considered in the team's designs.

3.3.3 Engineering Specifications

Table 1 depicts Nathan's mobility device engineering specifications. This table was developed based upon benchmarked products and the customer's requirements discussed during the sponsor interview.

Table 1. Engineering specifications

Spec. #	Parameter Description	Requirement on Target (units)	Tolerance	Risk	Compliance(1)
1	Weight Capacity	50 lb	Max	L	A,T
2	Length	42 in	Min	M	I,A
3	Width	24 in	Min	M	I,A
4	Height	36 in	Min	M	I,A
5	Ground Clearance	3 in	±1in	L	I,A
6	Battery Life	20 miles	Max	M	T
7	Max. Speed	5 mph	±1mph	M	S,T
8	Cost	$3000	±$500	M	A

Compliance methods include: Analysis (A), Test (T), Similar to Existing Designs (S), Inspection (I)

The size specifications of the device are most pertinent to the design due to their direct relation to accessibility and safety. On the other hand, the risk of the weight capacity is rated low due to the industry standard of mobility devices accommodating for a high weight limit.

3.4 Project Budget

As the senior project did not have inherent funding, the team applied for both the Baker Koob endowment and CPConnect grant. Fortunately, the team received the CPConnect grant totaling a sum of $3,000. A breakdown of the funds allocated to specific components will be outlined in greater detail in section 5.7 Cost Analysis.

4. Concept Design Development

The concept development outlined below did not change but it is important to note that the final design did. This change was the result of multiple consultations with an expert at A1 mobility. Although some of the calculations and analysis were ultimately deemed irrelevant to the final design, the thinking process of each was essential to coming up with the final design. These changes are the fruition of the thinking processes described in this section, they represent a large shift in the project and should be kept in mind when reading this section.

This section documents the development process and the results of the conceptual design. It depicts the methodology used to select the appropriate concept design and provides a quantitative analysis and evidence of its components' functionality. The section also outlines the risks associated with concept design. These steps are outlined in Figure 7 below.

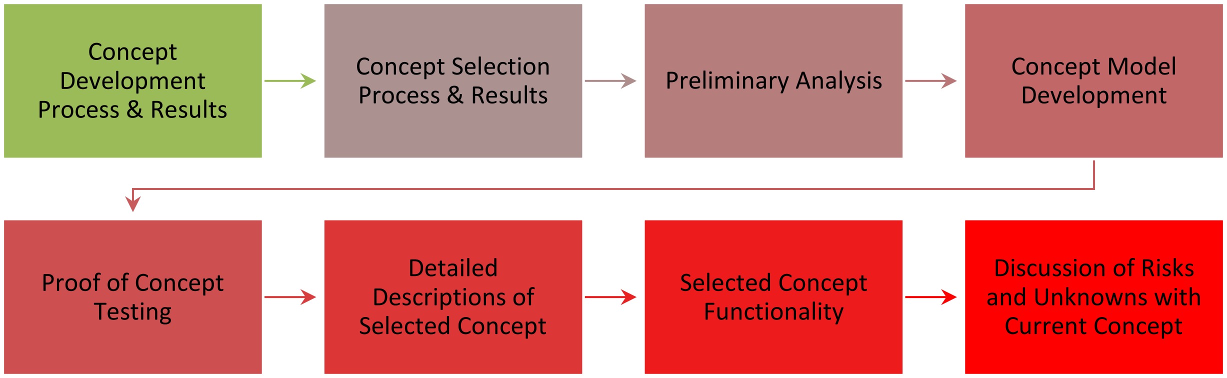


Figure 7. Concept development road map

4.1 Concept Development Process & Results

To begin the design phase of the project, four idea generation sessions were conducted to come up with an optimal number of ideas for different functions. These sessions were designed to create, develop, and communicate ideas in various mediums to maximize creativity output.

4.1.1 Idea Generation for Aesthetics

In the first idea generation session, team members decided to draw their own personal interpretation of what Nathan's mobility device would look like, focusing on the aesthetics factor. Each Batmobile drawing had its own distinct features. Some had sleek, race car-like exteriors while others had more jagged exteriors closely resembling a bat which can be seen in Figure 8 and 9. This session made clear what each team member was thinking and also helped facilitate the selection of the aesthetic aspects of the project.

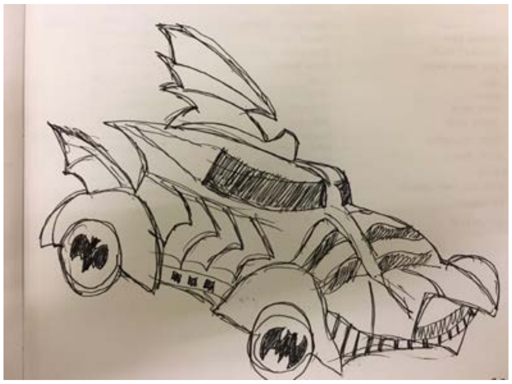


Figure 8. Batmobile with jagged exterior

Figure 9. Batmobile sketch with sleek exterior

4.1.2 Idea Generation for Seating Actuation

During the second idea generation session, team members came up with different method to actuate the seat. These ideas included electric linear actuators, pneumatic and hydraulic actuation mechanisms, spring-loaded systems, rack and pinion assemblies, and many others. A pulley system, slider, rack and pinion and a linear actuator sketches are shown below in Figures 10, 11, 12, and 13, respectively.

Figure 10. Pulley system sketch

Figure 11. Slider system sketch

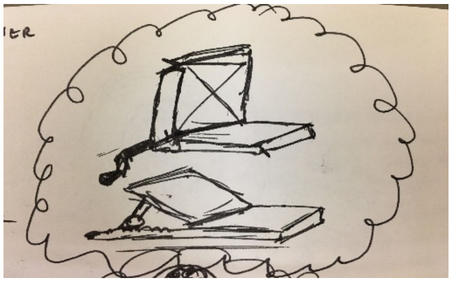
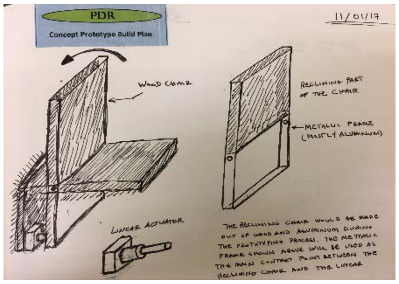


Figure 12. Rack and pinion system

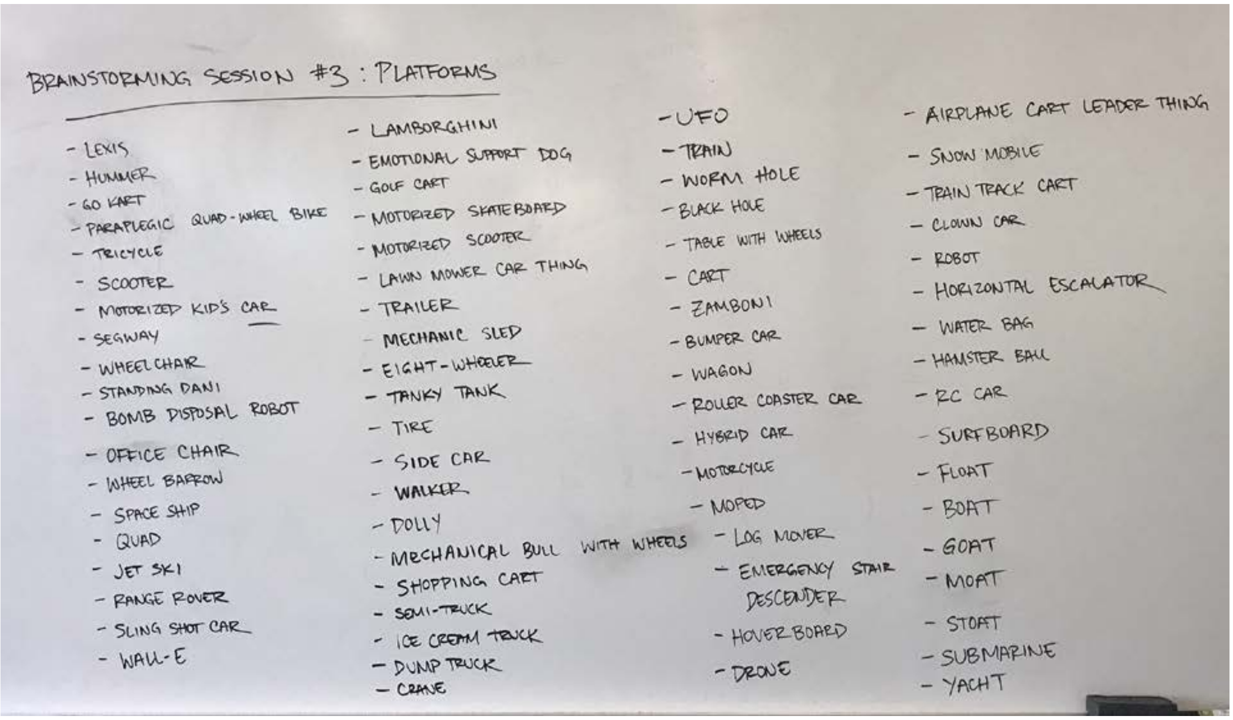


THE RECLINING CHAIR WOULD BE MADE OUT OF WOOD AND ALUMINUM DURING THE PROTOTYPING PROCESS. THE METALLIC FRAME SHOWN ABOVE WILL BE USED AS THE MAIN CONTACT POINT BETWEEN THE RECLINING CHAIR AND THE LINEAR

Figure 13. Linear actuator sketch

4.1.3 Idea Generation for Mobility Platform

In the third idea generation session, team members came up with potential platforms for the mobility device. The full list compiled during the brainstorming session can be seen in Figure 14.



BRAINSTORMING SESSION #3 : PLATFORMS

- LEXIS
- HUMMER
- GO KART
- PARAPLEGIC QUAD-WHEEL BIKE
- TRICYCLE
- SCOOTER
- MOTORIZED KID'S CAR
- SEGWAY
- WHEEL CHAIR
- STANDING DANI
- BOMB DISPOSAL ROBOT
- OFFICE CHAIR
- WHEEL BARROW
- SPACE SHIP
- QUAD
- JET SKI
- RANGE ROVER
- SLING SHOT CAR
- WALL-E

- LAMBORGHINI
- EMOTIONAL SUPPORT DOG
- GOLF CART
- MOTORIZED SKATEBOARD
- MOTORIZED SCOOTER
- LAWN MOWER CAR THING
- TRAILER
- MECHANIC SLED
- EIGHT-WHEELER
- TANKY TANK
- TIRE
- SIDE CAR
- WALKER
- DOLLY
- MECHANICAL BULL WITH WHEELS
- SHOPPING CART
- SEMI-TRUCK
- ICE CREAM TRUCK
- DUMP TRUCK
- CRANE

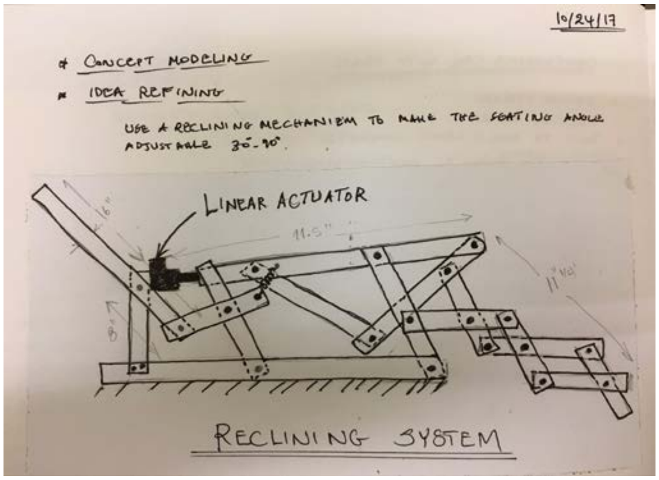
- UFO
- TRAIN
- WORM HOLE
- BLACK HOLE
- TABLE WITH WHEELS
- CART
- ZAMBONI
- BUMPER CAR
- WAGON
- ROLLER COASTER CAR
- HYBRID CAR
- MOTORCYCLE
- MOPED
- LOG MOVER
- EMERGENCY STAIR DESCENDER
- HOVER BOARD
- DRONE

- AIRPLANE CART LEADER THING
- SNOW MOBILE
- TRAIN TRACK CART
- CLOWN CAR
- ROBOT
- HORIZONTAL ESCALATOR
- WATER BAG
- HAMSTER BALL
- RC CAR
- SURFBOARD
- FLOAT
- BOAT
- GOAT
- MOAT
- STOAT
- SUBMARINE
- YACHT

Figure 14. Mobility platform idea generation session

4.1.4 Idea Generation for Adjustable Seating

The fourth idea generation session involved broaching ideas for adjustable seating. The ideas generated are as follows: eight-bar linkage recliner, simple-hinge recliner, window crank recliner, and tilt-in-space mechanism. The eight-bar linkage recliner is demonstrated in Figure 15.



10/24/17

* CONCEPT MODELING
* IDEA REFINING

USE A RECLINING MECHANISM TO MAKE THE SEATING ANGLE ADJUSTABLE 30°-90°.

Figure 15. Eight-bar reclining mechanism sketch

4.1.5 Idea Generation for Input Control

In the fifth and final idea generation session, all possible input controls were listed. The list included joysticks, steering wheels, levers, buttons, and pedals.

4.2 Concept Selection Process & Results

This subsection describes the process used to reduce the list of ideas generated during the team's idea generation sessions by eliminating the ones that were not feasible. Appendix E shows examples of selected concept ideas.

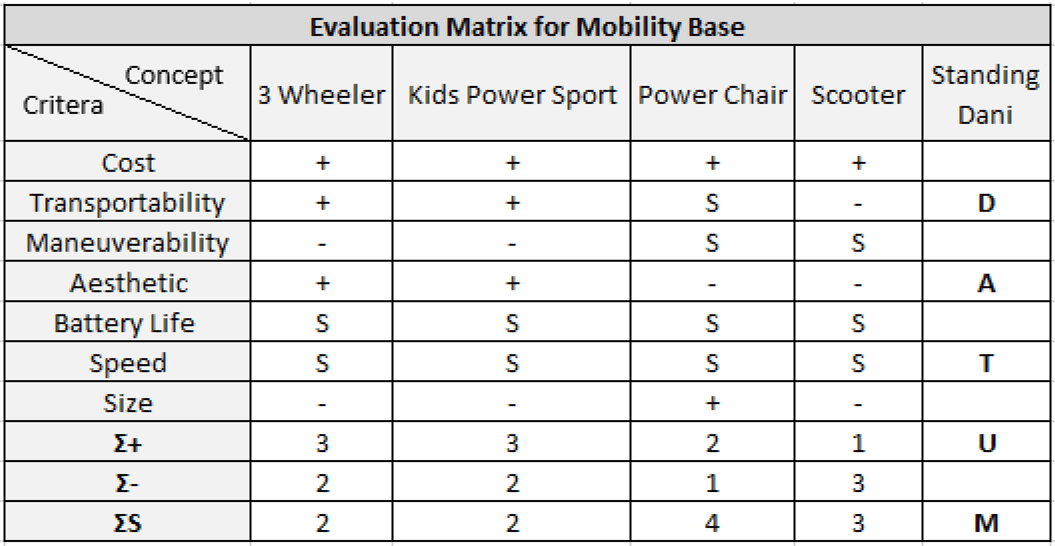
4.2.1 Project Direction

At this point in the project, the team was faced with a fundamental choice in the project's direction. On the one hand, Nathan wanted an aesthetic mobility device that did not take the form of a typical mobility chair. This would mean designing a device that would look good but had no guarantees of working or actually relieving Nathan's discomfort. On the other hand, the team could use a mobility chair as the powertrain platform and focus on the reclining seating. In assessing the hierarchy of Nathan's needs and collaborating with Amy, the team decided on the latter option.

4.2.2 Pugh Matrices

When compiling all of the generated concepts, team members came up with four critical functionalities for the mobility device. For each of the four critical functionalities, a Pugh matrix was used to filter down ideas that did not meet predefined standards. A Pugh matrix is a tool that compares concepts to specific criteria. Four Pugh matrices were created for mobility bases, user input, adjustable seating, and seating actuation. The Standing Dani was selected as the datum with which the other concepts were compared. A positive sign "+" signified that the concept performed better than the Standing Dani for the given criterion. A negative sign "-" indicated that the concept was worse than the Standing Dani for the given criterion. The letter "S" meant that the concept was on par with the Standing Dani. Table 2 depicts the generated Pugh matrix for the mobility base.

Table 2. Pugh matrix for the mobility base



Evaluation Matrix for Mobility Base					
Concept Critera	3 Wheeler	Kids Power Sport	Power Chair	Scooter	Standing Dani
Cost	+	+	+	+	
Transportability	+	+	S	-	**D**
Maneuverability	-	-	S	S	
Aesthetic	+	+	-	-	**A**
Battery Life	S	S	S	S	
Speed	S	S	S	S	**T**
Size	-	-	+	-	
Σ+	3	3	2	1	**U**
Σ-	2	2	1	3	
ΣS	2	2	4	3	**M**

For the mobility base Pugh matrix, three-wheel scooters, kid's powered sports vehicles, power chairs, four-wheel scooters, and go-karts were compared against cost, transportability, maneuverability, aesthetics, battery life, max speed, and overall size. The power chair and the scooter scored significantly higher than the rest of the mobility platform concepts.

The second Pugh matrix evaluated user input. Joysticks, steering wheels, levers, buttons, and pedals were compared against cost, sensitivity, ease of use, aesthetics, durability, and manufacturability. Similar to the first Pugh matrix, the joystick and steering wheel concepts outscored the rest of the input control concepts.

In the third Pugh matrix, five different adjustable seating options were evaluated. The team compared simple hinge, recliner mechanism, tilt-in-space, futon slider, and sliding recliner against cost, manufacturability, maintenance, safety, comfort, reclining range, and weight. Both the simple hinge and recliner mechanism scored highest in this Pugh matrix. As seen in Figure 16, Amy is reclining Nathan to a comfortable position, which Nathan can relax in. The position uses a stationary seat with Nathan's mom acting as a pivoting backrest.

In the fourth and final Pugh matrix, five different seating actuation options were compared. Spring-loaded actuator, hydraulic, pneumatic, rack and pinion, and linear actuator were compared against cost, size, complexity, safety, time to response, durability, and maintenance. The linear actuator was by far the highest scoring option. All Pugh matrices are in Appendix F.

4.2.3 Morphological and Weighted Decision Matrices

Using the results from the four Pugh matrices, a morphological matrix that encompasses eight potential ideas for the mobility device was generated. The morphological matrix can be seen in Table 4 below.

Table 3. Morphological matrix of the device functions

Mobility Base	User Input	Adjustable Seating	Seating Actuation
Power Chair	Joystick	Simple Hinge	Linear Actuator
Scooter	Steering Wheel	Recliner Mechanism	Rack and Pinion

Eight different combinations of the selected concepts were then generated and evaluated through a Weighted Decision Matrix (WDM). A WDM is a matrix that quantifies each combination based on a series of criteria. Each criterion is assigned a weight based upon its importance in the design. These weights were based on the customer's hierarchy of needs and the team's own interpretation of the design priorities. Each combination is compared against a criterion and given a value between one and five with one being the worst and five being the best. Finally, the values assigned to each combination are multiplied by the weight of each criterion and summed up. The highest score identifies the best concept combination based on the given criteria and corresponding weight. The combinations are as follows:

- Concept 1: Power chair, joystick, simple hinge, and linear actuator
- Concept 2: Power chair, joystick, recliner mechanism, and linear actuator
- Concept 3: Power chair, steering wheel, simple hinge, and linear actuator
- Concept 4: Power chair, steering wheel, recliner mechanism, and linear actuator
- Concept 5: Scooter, joystick, simple hinge, and linear actuator
- Concept 6: Scooter, joystick, recliner mechanism, and linear actuator
- Concept 7: Scooter, steering wheel, simple hinge, and linear actuator
- Concept 8: Scooter, steering wheel, recliner mechanism, and linear actuator

In order to evaluate each combination, a list of factors was established. These factors were chosen based on the conducted research and customer needs. Team Nathan originally picked 20 factors to grade the combinations but filtered them down based on its relevance to the project. They are as follows:

- Cost
- Size
- Comfortable
- Aesthetics
- Safety
- Durability
- Maintenance
- Manufacturability
- Speed
- Ease of Use

With the criteria established, corresponding weights from one to five, with one being the least important, were assigned based on their importance to the customer and relevancy to the design process. Figure 16 summarizes different criteria, their weights, and why they were assigned their specific weight.

Cost	5	The Project has a limited budget. The team plans to be very conservative with the finances due to the team's limited resources.
Safety	5	Nathan will be using this device every day and safety will be paramount to his wellbeing.
Size	4	The device is used in different environments including school, restaurants, etc. which requires small dimensions.
Comfortable	4	This is important for Nathan to avoid discomfort and trouble breathing.
Durability	3	The device is used and relied upon extensively. High durability ensures a more reliable device for Nathan.
Aesthetic	3	This is the most important factor to Nathan.
Manufactuability	3	Since the platform is already available, manufacturability is not of very critical importance
Maintenance	2	The device should not require extensive maintenance.
Ease of Use	2	Nathan is very comfortable driving a mobility device
Speed	1	This is not the priority of the project given the environment Nathan will use it in.

Figure 16. Design criteria weights and descriptions

The results of the weighted decision matrix yielded Concept 1, the power chair, joystick, simple hinge, and linear actuator, as the best combination with 137 points. This combination scored 5/5 in the Cost, Comfortable, Speed, and Ease of Use categories. It also scored 4/5 in the Size, Safety, Durability, Maintenance and Manufacturability categories. Aesthetics criteria was the lowest with a score of 3/5. In order to bring up the Aesthetics score, Team Nathan plans on designing adds-on features purely for aesthetic pleasure. This coupled with adding decals and painting the frame of the device will be sufficient to avoid the aesthetics deficiency. The decision matrices can be seen in Appendix G.

4.3 Preliminary Analysis

The following analysis was the Center of Gravity calculations. The body system was simplified by splitting it into two parts, the lower body and the upper body. It is assumed that multiples of body parts (arms, legs, hands, and feet) move together as one body in order to further simplify the system. The origin of system is where parts two and six meet. The positive x-axis direction is to the right, and the positive y-axis direction is down. This information will be used to do stability and rollover analysis for this mobility device as well as developing load cases for the linear actuator. Body part percentage data was pulled from *Human Body Dynamics: Classical Mechanics and Human Movement* and adjusted based on Nathan’s unique body type [4] and shown in Table 4 below.

Table 4. Body part percentage data

Mass Data for Nathan							
Upper Body System *(25.9lb)*					Lower Body System *(9.1lb)*		
1	2	3	4	5	6	7	8
Head	Torso	Upper Arm	Forearm	Hand	Thigh	Lower Leg	Foot
12%	53%	2%	1.5%	1%	6%	5%	2%
4.2lb	18.55lb	0.7lb	0.525lb	0.35lb	2.1lb	1.75lb	0.7lb
Disclaimer: All percentage and mass values given for individual body parts, not doubles							

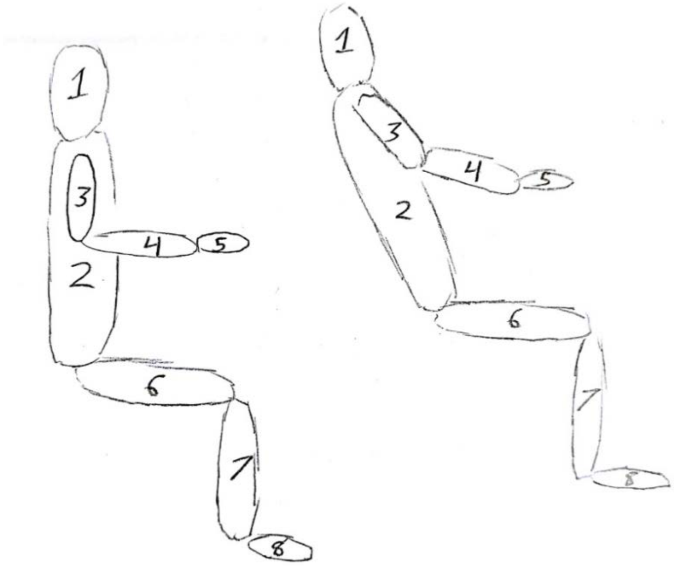


Figure 17. Center of gravity body distribution

$$x_{cg} = \frac{\sum m_i x_i}{\sum m_i}$$

$$y_{cg} = \frac{\sum m_i y_i}{\sum m_i}$$

$$x_{cg\ of\ legs} = \frac{\sum m_{legs} x_{legs}}{\sum m_{legs}}$$

$$y_{cg\ of\ legs} = \frac{\sum m_{legs} x_{legs}}{\sum m_{legs}}$$

$$x_{cg\ of\ upper\ body} = \frac{\sum m_{upper} x_{upper}}{\sum m_{upper}}$$

$$y_{cg\ of\ upper\ body} = \frac{\sum m_{upper} y_{upper}}{\sum m_{upper}}$$

$$x_{cg\ of\ upper\ body} = \frac{(0in)(4.2lb+18.55lb+2*0.7lb)+(6.25in)(2*0.525lb)+(9.25in)(2*0.35lb)}{25.9lb}$$

$$x_{cg\ of\ upper\ body} = 0.5in$$

$$y_{cg\ of\ upper\ body} = \frac{(-8in)(18.55lb)+(-5.25in)(2*0.525lb+2*0.35lb)+(-20.5in)(4.2lb)+(-10.625)(2*0.7lb)}{25.9}$$

$$y_{cg\ of\ upper\ body} =- 10in$$

$$x_{cg\ of\ legs} = \frac{(6.5in)(2*2.1lb)+(13in)(3.5lb)+(16.875in)(2*0.7lb)}{9.1lb}$$

$$x_{cg\ of\ legs} = 10.6in$$

$$y_{cg\ of\ legs} = \frac{(0in)(2*2.1lb)+(6.25in)(2*0.525lb)+(9.25in)(2*0.35lb)}{9.1lb}$$

$$y_{cg\ of\ legs} = 1.5in$$

4.4 Concept Model Development

This section introduces two different prototypes that have been developed and tested in order to learn more about limiting factors for their functionality and manufacturability.

4.4.1 First Concept Model

Team Nathan's first tangible prototype explored the mechanics of the reclining mechanism. Although the reclining mechanism scored second behind the simple hinge, the team was curious about its application. More specifically, the reclining mechanism simultaneously adjusts the backrest and footrest, which is what the team was trying to achieve. Using foam core, wood skewers, and hot glue, team members built a half-scale model as seen in Figure 18 below.

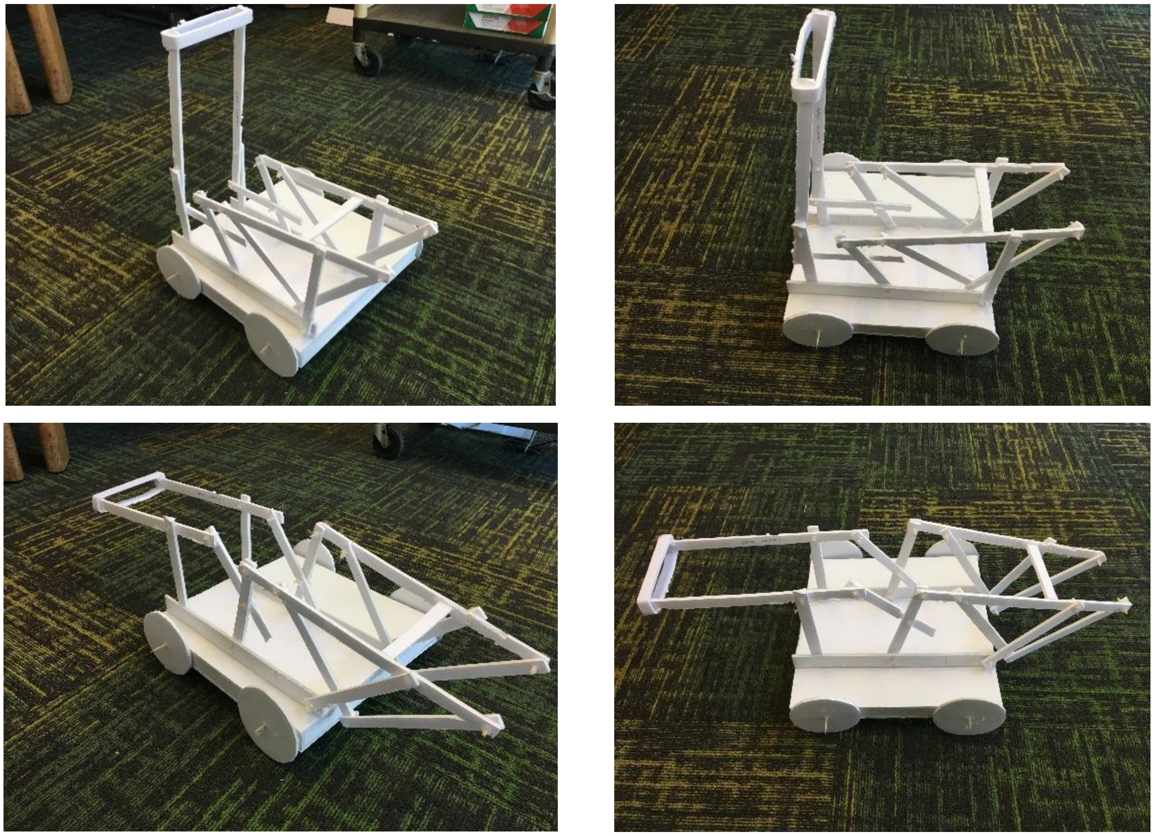


Figure 18. Recliner mechanism prototype shown at different angles

After careful consideration, Team Nathan concluded that this eight-bar mechanism was too complicated to manufacture and too heavy for Nathan's mobility chair. Also, the mechanism required very precise, interlinked dimensions that would raise the cost of manufacturing. With many dynamic parts, the adjustable seating system would not be very reliable due to the amount of maintenance that it would require in the future.

4.4.2 Second Concept Model

The purpose of the second concept model was to build the concept combination that scored the highest in the Weighted Decision Matrix. This concept was composed of a power chair, joystick, simple hinge, and a linear actuator. Out of the four components, the power chair, simple hinge and linear actuator were able to be incorporated within the prototype, as seen in Figure 19. Prototyping a joystick on a concept with no electrical powertrain was unnecessary.

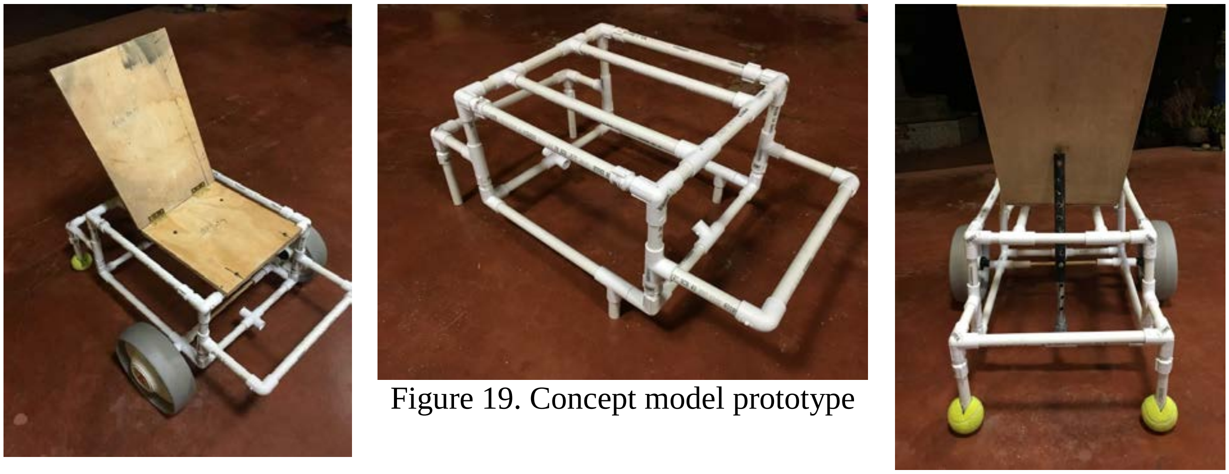


Figure 19. Concept model prototype

In assessing the effectiveness of the prototype, Team Nathan concluded that the components were compatible. While this prototype was a good representation on the team's direction, two key factors were not addressed. The most pressing issue was this prototype did not incorporate Nathan's feet position within the design. Secondly, the positioning of the telescoping pipe used to represent the linear actuator on the base and seat recliner was merely based on convenience. The actual positioning of the linear actuator will be based on the mobility frame, the stroke of the actuator, and the amount of load it can handle as shown later in section 4.5. A concept layout drawing can be seen in Appendix H.

4.4.3 Prototype Reflections

By modeling two completely different concepts, Team Nathan was able to compare and contrast the advantages and disadvantages of each. To begin with, the recliner mechanism incorporates a dynamic change in position for both the backrest and the foot position which the simple hinge lacked. This functionality comes at the price of reliability and manufacturing costs. The simple hinge and linear actuator, on the other hand, is minimalistic and can be more easily integrated onto an existing mobility platform.

4.5 Proof of Concept Testing

In order to test the validity of the concept design, the first step is to model it in a Computer Aided Design (CAD) software such as SolidWorks. By modeling the system, an initial understanding of how the system may look and operate can be determined. Maximum load cases are then determined based around system usage parameters. From there, failure analysis will be conducted to validate the strength of the design. Load cases and failure analysis will be discussed in greater detail in section five of the report. Once the design has been validated electronically, physical testing can begin. Manufacturing techniques will have to be tested before being implemented in the final design. Stress testing materials will be important in verifying the results of failure analysis. Before attempting to integrate electronic components into the physical system, they should be tested to verify their function.

In order to determine the exact location and the minimum load capacity of the actuator, the following analysis was conducted. Figure 20 shows the reclined and the upright positions of the seat with its specifications.

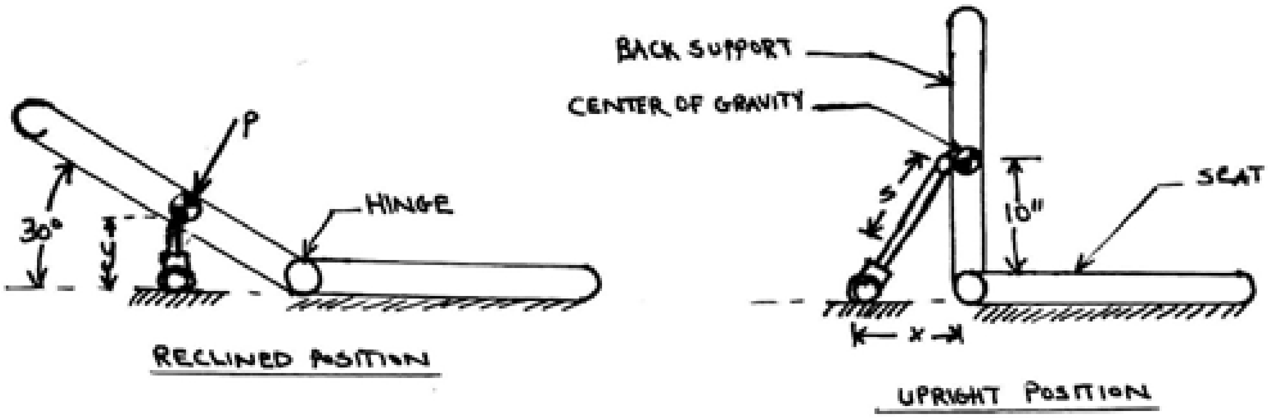


Figure 20. Two different seat positions with specifications

- <u>Linear actuator position:</u>

$$x = y_{CG} \cos(30)$$

$$= 10 \cos(30)$$

$$\mathbf{x = 8.66''}$$

- <u>Actuator length when retracted</u>:

$$y = y_{CG} \sin(30)$$

$$= 10 \sin(30)$$

$$\mathbf{y = 5''}$$

- <u>Actuator minimum required stroke</u>:

$$(s+y)^2 = y_{CG}^2 + x^2$$

$$s = (y_{CG}^2 + x^2)^2 - y$$

$$\mathbf{s = 8.23''}$$

- Actuator load capacity:

The minimum load occurs when the seat is inclined, so the load will be calculated at this position.

- Nathan’s upper body weight: $P_1 = 25.9\ lb_f$
- Back support weight: $P_2 = 5\ lb_f$

$$P_y = P\cos(30)$$

$$= 30.9\cos(30)$$

$$\mathbf{P_y = 26.76\ lb_f}$$

Based on this analysis, the system requirements for linear actuators fall within industry standards for currently existing products.

4.6 Detailed Description of Selected Concept

After determining the power chair to be the best mobility platform option, the team researched potential purchasing options. Team Nathan’s advisor, Sarah Harding, recommended a mobility device on eBay that met the customer requirements. The mobility base that was purchased is a used, but well-maintained Quickie Z-500 Pediatric power chair (Appendix I). More specifications on this product can be found in the user manual available on the Sunrise Medical website. Since the power chair will only be used as the base of the device, all components not directly related to user input and device motion will need to be removed. Once the device has been stripped down to only the essential components, the team will be free to implement the rest of the design onto the mobility base. The team’s initial concept uses a PVC representation of a mobility base mainly because the power chair was recently purchased. Upon receiving the power chair, a 3-D SolidWorks model of the device stripped down to its base was created as shown in Figure 21. The platform’s CAD drawing is shown in Figure 21. Attached to the mobility base will be a custom-hinged reclining chair operated with two linear actuators, one for reclining the back rest and the other for the tilt-in-space motion as shown in Figure 22. The mobility base will be controlled by the joystick included with the power chair and an additional button pad that will be separately purchased and included in the design.

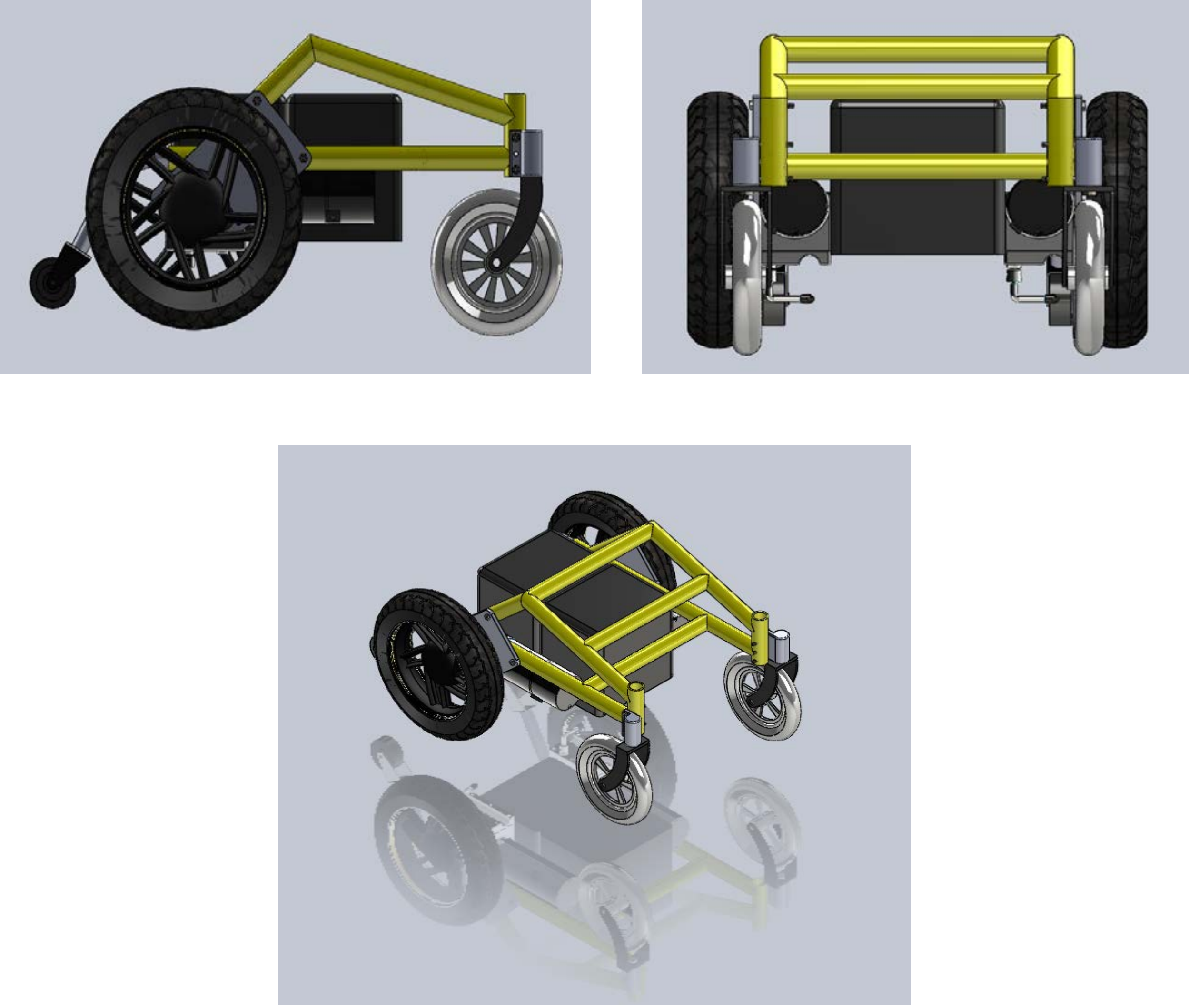


Figure 21. CAD model of the device base

By using a power chair that is driven by two powered wheels, the concept design is able to feature a similar turning radius to the Standing Dani. The reclining seat will provide a wide range of seating positions and will move with minimal user input due to the linear actuator providing the mechanical energy required. By giving Nathan such a wide range of seating angles, he will be able to determine what he feels is his most comfortable position. By using an existing power chair as the base, the team eliminates any size and stability concerns, as this device has already been tested for everyday use by its designers and customers. This specific power chair has been certified to meet all OSHA and ADA requirements.

Figure 22. Old version of mobility device solid model

4.6.1 Seat Design Details

With a mobility platform purchased, the seat design can be moved from simply a set of selected ideas to a concept. The driving ideas behind this chair design are its use of two linear actuators to drive the chairs reclining and tilt-in-space motion as well as a simple hinge mechanism that allows the chair to recline. The concept chair will be broken down into four main categories: frame, support, padding, and actuation. The frame is the primary weight bearing part of the chair system. The support is the part of the chair that Nathan’s body will be resting on and the padding will be what does over the support to make it comfortable. Actuation is how mechanical energy to move the chair will be inputted into the system. An inspiration for this design breakdown comes from a plastic and metal folding chair you might find at a school or in an office. The frame of these types of chairs is constructed out of a strong material such as metal and is usually composed of just the bars along the outside edge of the chair. The back support and seat of these chairs are typically constructed out of plastics or sheet metal. No actuation method or padding is usually included in these chairs.

4.6.2 Seat Design: Frame

The concept model developed utilizes 6061 Aluminum ½” round tubing as the frame of the chair. This material has a high strength-to-weight ratio and can be purchased while staying within budget. Round tubing is easy to work with and will have no sharp edges that could cause potential safety concerns. Other frame options such as steel or carbon fiber were considered but were ultimately not chosen for the initial concept. Steel, while strong and relatively easy to manufacture, is too heavy for the purposes of this project. Carbon fiber is strong and very lightweight, but is expensive and difficult to manufacture.

4.6.3 Seat Design: Support

For the backrest and seat of the chair, 3D printed plastic wrapped in composites was the selected design choice. By 3-D printing the backrest and seat, there is a lot of flexibility in terms of redesign as well as eliminating the need for an outside source for manufacturing. These parts will be printed in pieces and then glued together due to limitations in 3D printer size. The plastic components will serve as the shape of the backrest and seat but not the structure, so they can be printed hollow to minimize the weight. The composite wrapped around the plastic shape will serve as the structure. Currently, carbon fiber is the composite material selected for use in this concept design. This material is lightweight and very strong, making it ideal for this application. Fiberglass was another composite considered for use in this design due to its reduced cost compared to carbon fiber, but its reduced strength and lack of aesthetic appeal lead to it not being selected for use. Nathan requires more than just a backrest and a seat; he requires additional support in the form of lateral head supports, a crotch support, and a footrest.

4.6.4 Seat Design: Padding

Since comfort is the most important design criterion, padding is necessary in the seat design to allow for prolonged use. The cushioning material selected for use is a high density, closed cell, upholstery foam. This material is durable, waterproof, and meant for extended use in outdoor conditions. This foam will be shaped and then covered in a waterproof nylon cloth. This upholstered padding will be removable to allow for changes to be made as well as easy cleaning. The padding will be attached with industrial strength Velcro to the seat panel for easy removal.

4.6.5 Seat Design: Actuation

The actuation of the reclining part of the chair will be controlled using a linear actuator. How this actuator attaches to the system will be determined through extensive analysis and testing. A linear actuator is a self-contained system that utilizes the rotation of a shaft on an electric motor to create linear motion. Linear actuators have a wide range of force outputs and ranges of motion. The linear actuator will be controlled via a two-button control system (up and down option).

4.6.6 Foot Position

In the analysis conducted thus far, a reclining foot position has not been included. While Team Nathan acknowledges that is has been an overlooked problem, incorporating a mechanism that changes the foot position may not be necessary. As seen in Figure 22, the angle of Nathan’s feet while he is in a reclined state is very small.

This begged the question whether Nathan’s foot position needs to be manipulated to increase his comfort. This question was answered by Nathan and a moving footrest was included in the final design

4.7 Selected Concept Functionality

Through the use of idea selection techniques, a concept design was determined. It is important to then verify that the selected concept will meet the customer needs as well as function according to designer specifications. Prototyping was carried out to verify the initial viability of the concept design. From the prototypes, the team was able to identify potential problems with the concept and adjust the design to solve these issues. After prototyping, analysis was required to further validate the concept design. The first type of analysis performed was center of gravity analysis on Nathan. After determining the distribution of Nathan's mass as well as how it shifts when the chair reclines, load cases were developed to determine stresses and strains on system components. This analysis was done to make sure components would not fail under maximum loading conditions. The next step for determining concept functionality is physical component testing. Components such as the linear actuator will be tested for functionality before being integrated into the system. Manufacturing technique will also have to be tested before use in the final product.

4.8 Discussion of Risks and Unknowns with Current Concept

With this concept design, there were still some potential risks and unknowns. The most apparent risks are outlined and addressed in Appendix D. One potential risk in the team's design was the condition of the purchased mobility device. While there are no discernible issues with the device, the team decided to have the device inspected by A1 Mobility, a mobility device sales and repair shop. One of the biggest unknowns in this project deals with the issue of how the linear actuator will be powered and controlled. The mobility base uses two 12-volt batteries linked in series to power its movement. This is a problem since the system runs on 24 volts while most linear actuators require a 12-volt source to operate. Either the voltage from the system batteries need to be stepped down in order to power the actuator or a different power source will have to be implemented to use a 12-volt actuator. Twenty-four volt linear actuators exist, but they tend to be more expensive than their 12-volt counterparts and less relevant to the team's design needs.

Team Nathan was able to get the mobility base checked out at A1 Mobility and was told that everything was functioning well. This eliminates the unknowns and concerns about the mobility base's safety and performance. Additionally, it was determined that the linear actuators will be powered using two 12-volt batteries in series so the system would run on the required 24 volts.

5. Final Design

Through extensive concept design development and trial and error, a final design was agreed upon. By consistently comparing this design to the customer needs previously stated in section 2.1, the team is optimistic in satisfying Nathan's requirements.

It is important to note that Team Nathan made sure not to compromise the original integrity of the purchased mobility device.

5.1. Overall Description & Layout

The final design of Nathan’s mobility device utilizes three linear actuators with independent controlling. By using three linear actuators, the three other sub-assemblies - footrest, seat base, and backrest - can be moved and positioned. By controlling each component independently, Nathan can find his optimal position of comfort. This is a significant change from the team’s previous design with one actuator. Moreover, the controller will be positioned on the right armrest alongside the joystick.

Figure 23. Isometric view of CDR design

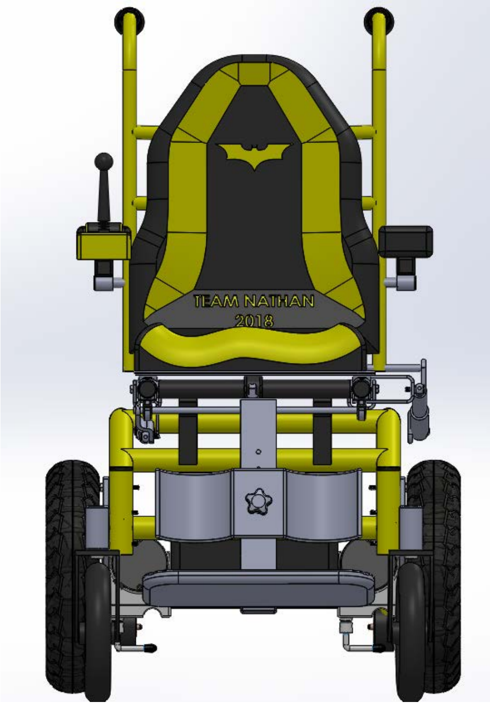


Figure 24. Front view of CDR design

This final design can be broken down into subassemblies: linear actuator subassembly, backrest subassembly, backrest subassembly and the footrest subassembly.

5.2. Detailed design description

Seen below is an exploded assembly of the final designed mobility chair. This exploded view is a good representation of how the mobility chair components are interlinked.

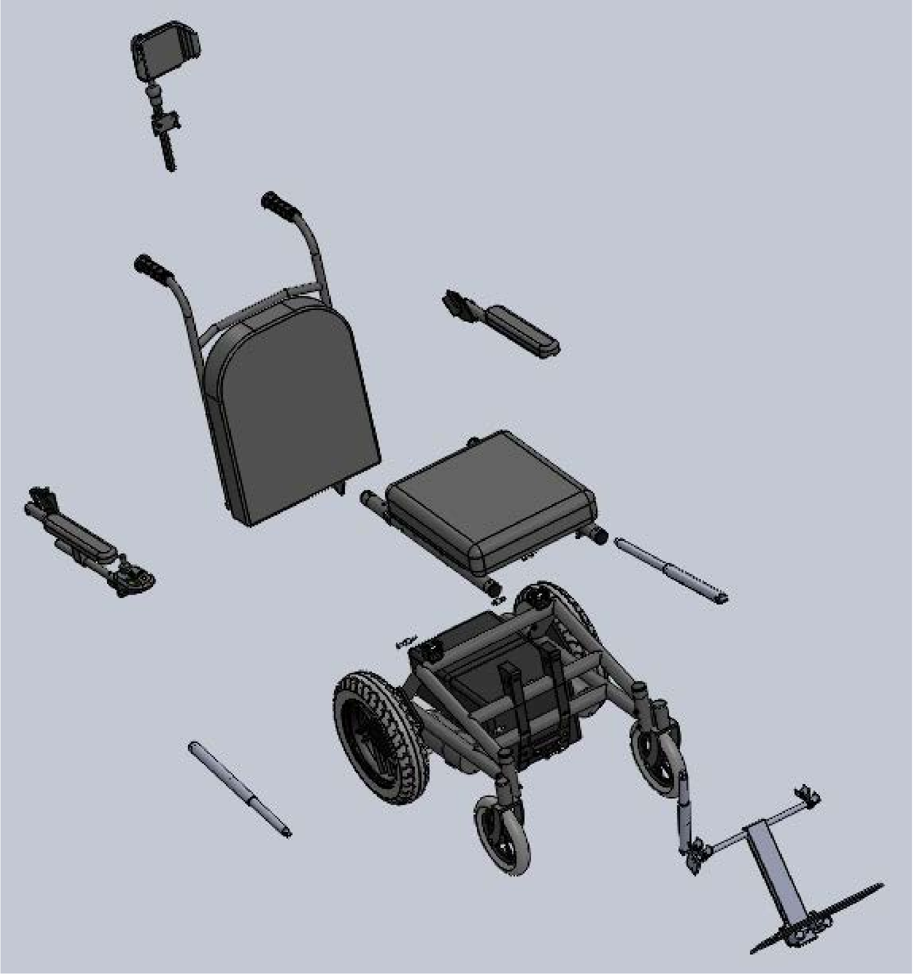


Figure 25. Exploded view of mobility chair

While the subassemblies are broken up into four categories- actuation, seating, backrest, and footrest – the actuation assembly will be interconnected to the other three assemblies. The actuation assembly will provide the dynamic motion to move the tilt-in-space (seating), backrest, and footrest. By creating a separate subassembly category for just the actuation, the electronic components and their associated analysis can be emphasized and focused on.

5.3 Linear Actuators

Linear actuators are used within the system to generate motion from electrical power stored within batteries. Using a set of switches, Nathan will be able to control each linear actuator independently. Each linear actuator will control of the motion of a different subsystem.

5.3.1 Selection Analysis

In order to choose a suitable linear actuator, Team Nathan created selection criteria in which the actuators would be chosen. These criterions are outlined and explained below.

Actuation speed	Rate at which actuator length changes
Stroke length	Max change in length of the linear actuator
Retracted length	Shortest length of the linear actuator
Static load capacity	Max load the actuator can hold stationary
Dynamic load capacity	Max load the actuator can drive

Figure 26. Linear actuator selection criteria factors

Using these criterions, analyses were performed to determine the appropriate metrics needed to filter the linear actuator selection.

5.3.2 Analysis

Linear actuators are essentially electric motors attached to a threaded rod that move via the spinning of the motor. Actuation speed is a function of the rotational velocity of the motor and the pitch of the threads. The steeper the pitch the greater the actuation speed but lower the dynamic load capacity. For these applications, actuation speeds can be low and desired load capacities need to be high. A slower moving system is inherently safer and easier to operate and is usually able to support more mass. In order to determine the appropriate dynamic load capacity, a simple static beam analysis was performed like the one seen below in Figure 27.

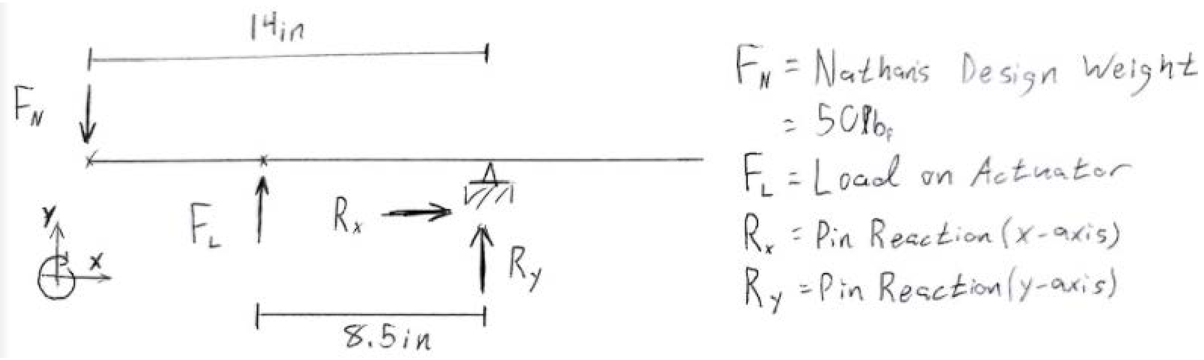


Figure 27. Hand calculations depicting the sum of forces

This figure represents a simplified 2-D model of the maximum load case for the linear actuator selected to operate the tilt-in-space feature of the power chair. Under normal conditions the system should not see loads this high, but this represents the maximum expected loading. By reducing all applied loads to point loads and changing the seat into a simple rigid beam, the system becomes manageable to analyze with hand calculations. By summing all forces in both the X and Y directions respectively as well as summing moments about the pin, and then setting them to all to zero, a maximum required dynamic load for the system can be determined. These calculations are seen below.

$$\text{Sum of forces in Y-direction} = \sum F_y = R_Y + F_L - F_N = 0$$

$$\text{Sum of forces in X-direction} = \sum F_x = R_X = 0$$

$$\text{Sum of clockwise moments about pin (R)} = \sum M_R = F_L * (8.5\text{in}) - F_N * (14\text{in}) = 0$$

$$F_L = 83.33\text{lb}$$

At this point, F_L represents the smallest max dynamic load an actuator can have in order to work within the system, assuming all parts behave exactly as designed. While theoretically this is fine, for real world applications a linear actuator capable of a higher dynamic load capacity than required should be selected to make up for potentially inefficiencies ignored in the system. This process is achieved using a Factor of Safety. A factor of safety is a constant numerical value, typically greater than one, which you multiply the calculated load by to get the minimum allowable actuator dynamic load. After a factor of safety is applied, F_L becomes the lower limit of possible manufacturer specified maximum dynamic load capacities.

$$\text{Factor of Safety} = 1.3$$

$$\text{Minimum allowable Actuator Dynamic Load} = \text{Factor of Safety} * F_L$$

Minimum Allowable Actuator Dynamic Load ≈ 110 lb_f

A similar process was used to determine the max dynamic load capacity of both the recliner and footrest linear actuators. Using the structural prototype along with 3D modeling techniques, linkage geometries for the moving systems were determined. Knowing the geometry of these linkages, linear actuator stroke lengths and retracted lengths can be solved. Once this data has been determined, all necessary design parameters for linear actuator selection have been determined and products can be selected. Firgelli Automation Bullet Actuators were selected for use in the team's designs due to their small size, high dynamic load capacities, and wide variety of stroke lengths. The small size of these actuators made them ideal for fitting in the constrained areas under the seat of the power chair. Traditional actuators like the one in Figure 28 are difficult to use in our design due to their large cross-sectional area. The free space under the seat of our power chair is minimal and so actuator size needs to be kept small. The bullet actuators selected for this design seen in Figure 29 have the motor built into the actuation rod to minimize cross-sectional area, making them ideal for our purposes. After analysis, all three linear actuators had allowable dynamic load capacities under 110 lbs, so the Firgelli Automation 110-lb Bullet Actuators of varying stroke lengths were selected for all three systems. This reduces system complexity as well as making part replacement and maintenance easier on the user.

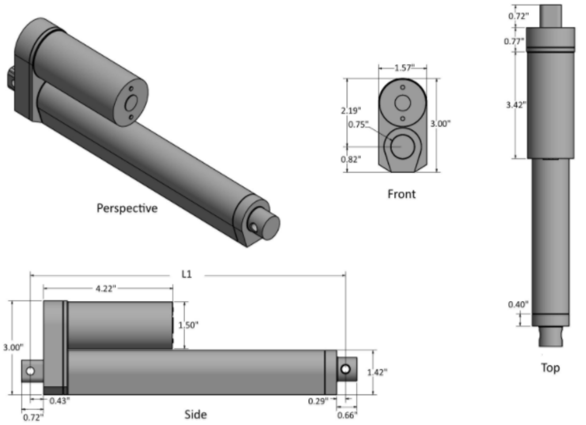
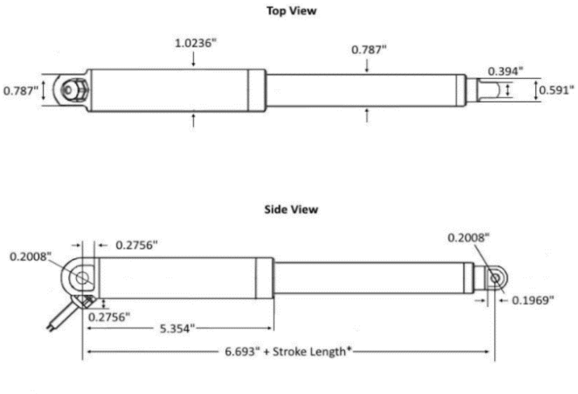


Figure 28. Regular Linear Actuator



*Stroke length tolerance is ± 0.0787"

Figure 29. Bullet Linear Actuator

All three of the actuators selected are Firgelli Automation Bullet Series Actuators of varying stroke lengths. The design parameters of each linear actuator selected for this build are detailed in Table 5.

Table 5. Design parameters for each linear actuator

Actuator	**Stroke [in]**	**Dynamic load [lbf]**	**Static Load [lbf]**	**Speed [in/s]**	**Retracted Length [in]**	**Voltage [V]**
Tilt-in-Space	4	110	500	0.183	10.693	24
Recline	4	110	500	0.183	10.693	24
Footrest	2	110	500	0.183	8.693	24

Using these actuator metrics, the appropriate actuators have been selected which are found in section 6.1 Procurement.

5.3.3 Actuator Controller

The three linear actuators are controlled independently using an appropriate seat control switch unit. There are three switches within the control box for the corresponding three linear actuators. Switches were requested by Nathan as he is comfortable with that control system. The control did not need an ON/OFF switch because each switch is off in the resting middle position.

The button control unit will provide Nathan with an easy to use system interface for which the optimal position can be used. Nathan can move each actuator separately or can do multiple motions simultaneously. The linear actuators have a preprogrammed hard stop on the fully retracted and extended length. At first, it might take Nathan a couple seconds to realize that the linear actuator threshold has been met, but over time Nathan should become accustomed to the motion and limits of the actuators.

The circuit diagram of the schematic can be found in Appendix J. This schematic was based on the existing circuit diagram of the Quickie Z-500 with the linear actuators and controls integrated. Although Team Nathan had some experience in circuit building and analysis, the team was not comfortable in their ability to ensure the safety and functionality of the system. For this reason, an appointment was set up with Ben Carr, a Cal Poly technical support staff member, to discuss the accuracy and overall safety of the diagram.

5.4 Backrest

The backrest sub-assembly was composed of a metal support frame, backrest padding, lateral support straps and a head support unit. This whole unit is moved using a bullet linear actuator. Information about the selected linear actuator can be found in 5.3 Linear Actuators. Due to a lack of available 3D models of the chosen headrest and the complicated nature of its shape, the head support system is not featured in Figure 30. Exploded view of backrest. The team decided to use the same head rest that came with the preexisting mobility device, but reupholstered the head cushion.

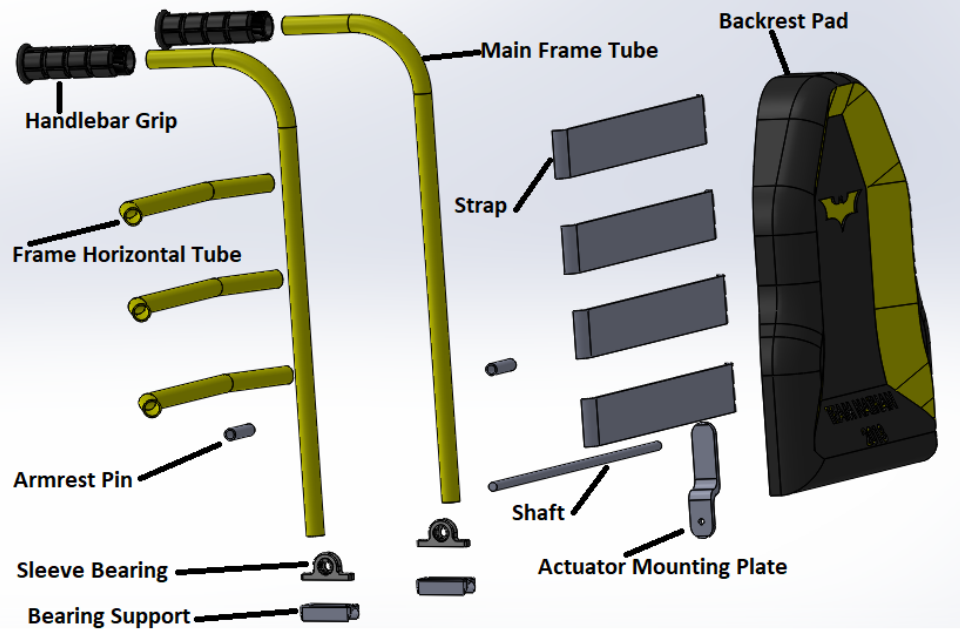


Figure 30. Exploded view of backrest

5.4.1 Frame

Designing the backrest was about making a system that comfortably supported Nathan while making it strong enough to be safe but not too heavy. The overall design of the backrest section of the power chair consists of a metal frame that composes the structure, an upholstered foam cushion for Nathan to rest against, and a set of nylon straps to separate the cushion from the frame. Velcro was applied to the front of the nylon straps as well as the back of the cushion in order to non-permanently fix the cushion to the backrest.

Frame Material Selection

In designing frames for motor vehicles, whether they be rally cars or power chairs, metal tubing is the most common build material, more specifically, aluminum or steel. Aluminum is a stiffer, lighter, and weaker material than steel. Since the loading in this backrest frame design was considered to be fairly small, the frame did not require the additional strength that steel could provide over aluminum. Having selected aluminum as the frame material type, a specific variant of aluminum was selected. After considering a many variants of aluminum alloy, 6061-T6 was selected for the frame build. 6061-T6 aluminum alloy has a relatively high stiffness and strength compared to other aluminum alloy variants. It is also easy to weld compared to other variants of aluminum. While some of the strength was lost through the welding process, the applied load was small enough to the point where the decreased strength had no significant effect on the overall safety of the design. 6061-T6 is also very machinable and has great surface finishing characteristics.

Backrest Frame Analysis

The initial design was done using 1-in diameter aluminum tubing for the frame of the backrest. This choice was made because the frame tubing on the power chair that was purchased also featured 1in diameter tubing. The team believed that interfacing 1-in diameter tubing together would be easier than trying to interface different sized tubes. Simple beam bending analysis was conducted to make sure the loading would not be too extreme. The analysis below shows simple bending stress in a 1-in diameter tube.

$$Bending\ Stress = \frac{My}{I}$$

$$M = Bending\ Moment = (force)(length) = (50lb)(16in)$$

$$I = Moment\ of\ Inertia = \frac{(pi)\left(d_{outer}{}^{4} - d_{inner}{}^{4}\right)}{64} = \frac{(3.14)(1^4 - 0.87^4)}{64} = 0.021in^4$$

$$y = distance\ to\ neutral\ axis = 0.5in$$

$$\boldsymbol{Max\ Bending\ Stress} = \frac{\boldsymbol{(50lb)(16in)(0.5in)}}{\boldsymbol{0.021}} = \boldsymbol{19050\ psi}$$

$$Aluminum\ 6061 - T6\ Ultimate\ Stress = 42000\ psi$$

$$\boldsymbol{Factor\ of\ Safety} = (\boldsymbol{ultimate\ stress})/(\mathbf{max}\,\boldsymbol{bending\ stress})$$

$$\frac{42000\ psi}{19050\ psi} = \mathbf{2.21}$$

After the SolidWorks model of the frame was constructed, FEA was done to verify the results of the hand calculations. This analysis showed the frame to be much stronger than necessary for our final design. Since the analysis occurs at the maximum load case, we do not expect the load on the system to ever get this high. Due of this, a factor of safety over two is higher than we need for this application. This led to a decision to reduce the tube diameter to a smaller size. In consulting with our project advisor, we determined a common tube diameter used in projects such as this one was 0.5 inches. Repeating the above calculations using the new tubing diameter, it was determined that the frame would fail in this max load case situation. With that in mind, we upped the tube diameter to 0.75 inches in the model and reran FEA calculations. The new tube diameter tubing had an acceptable factor of safety while being significantly lighter than the 1-inch diameter tubing.

5.4.2 Straps

The team decided to use nylon straps placed perpendicular to the two backrest poles on each side of the seat. The backrest needed support for the backrest cushioning to attach to so that Nathan could lean back into the seat without feeling like he was falling in between the two poles. The strap supports were equally spaced along the length of the back rest for optimum positioning. Doing so added very little weight while providing sufficient back rest support. How the straps attach to the frame backrest frame can be seen in Figure 31.

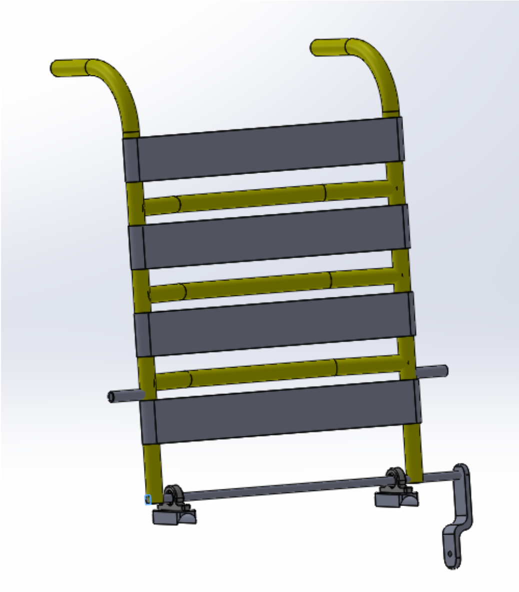


Figure 31. Drawing of Backrest frame with straps

Having straps rather than a full back rest support plate allowed for more flexibility and comfort. The straps would form better around the back seat and Nathan while he was upright and in a reclined position. With a plate instead of the straps, the seat would provide more structure, but the seat would feel more rigid. By not including a backrest support plate in the design, the overall weight of the system was reduced.

Material selection

Team Nathan chose to use nylon as the material for the strap supports. Nylon is inexpensive and flexible yet rigid enough to maintain structure. These straps used Velcro along the front to attach the backrest cushion to as well as adjust the position and tension of the straps. Other materials such as vinyl and polyester were considered for the straps but were ultimately not chosen due to manufacturing concerns

The four nylon straps were cut into approximately 46-inch strands with approximately eight inches of overlap. On each strap at both ends, seven inches of Velcro were sewn. The Velcro allowed the straps to be tightly secured. However, after fabricating these nylon and Velcro straps, the team discovered that the belts could not be tightened to the appropriate tension. Since the Velcro didn't work, the team decided on buckles which turned out to work great.

5.4.3 Padding

Arguably one of the most important features relating to Nathan's comfort was the padding used for the backseat. With this in mind, Team Nathan designed a backseat cushion that was uniquely designed to Nathan's body measurements.

Foam selection

The selection of foam directly impacted the comfort of Nathan. Team Nathan explored multiple foam types as seen in Table 6.

Table 6. Weighing out advantages versus disadvantages for various types of cushion foams

Type of Cushion Foam	Advantages	Disadvantages
Compressed Polyester	● Will not disintegrate ● Inexpensive option	● It will compress over time
Polyester Fiberfill	● Resistant to mildew ● Inexpensive	● Predisposition to bunch up ● Formless shape
Anti-Microbial Polyurethane Foam	● Resistant to mildew ● Resistant to compression over time	● Soaks up water
High Density Polyurethane Foam	● Lasts up to 12 years ● Resistant to compression over time	● Soaks up water
Open Cell Foam	● Fast drying ● Resistant to mold and mildew	● Expensive ● Large amounts of knock offs that are hard to spot
Closed Cell Foam	● Resistant to moisture absorption	● Expensive ● Very firm
Ensolite Foam	● Excellent for impact absorption ● Low heat retention	● Expensive

**All information collected from sailrite.com*

These foams were researched using online resources such as sailrite.com and carrscorner.com. After visiting Fine Touch Upholstery in San Luis Obispo and talking to Randy, the owner, the team came to an agreement to use High Density Polyurethane Foam with a super soft rating. This Polyurethane Foam was purchased at Quality Fabrics and Foam Supplies located in San Luis Obispo. After a consultation with a manager, a 10% discount was promised upon for a 2" x 24" x 96" sheet of super soft foam at a price of $67. This sheet provided more than enough foam to customize and build upon the 14" x 20" backseat. The manufacturing plan for the back rest is outlined in detail in 6.2.2 Backrest Sub-Assembly Manufacturing.

Design Layout

In determining the design of the backrest padding, multiple considerations were taken into account. At the top of the list was ease of manufacturing since Team Nathan cut and shaped the foam themselves.

The backrest cushion assumed a minimalist form at the beginning of shaping. Multiple consultations with Nathan were conducted to ensure that this was comfortable for Nathan along with seeing if the lower back support would be beneficial. On the sides of the foam, removable triangular cuts of foam were placed to align Nathan with the center of the seat.

With a simpler design for the backrest cushion, the cost for upholstery was minimized as well as gave Nathan flexibility in personal positioning.

Upholstery selection

In choosing a suitable upholstery for the backseat padding, the team narrowed the fabric choices to Nylon and Vinyl. The team then weighed out the pros and cons of each shown below in Figure 32.

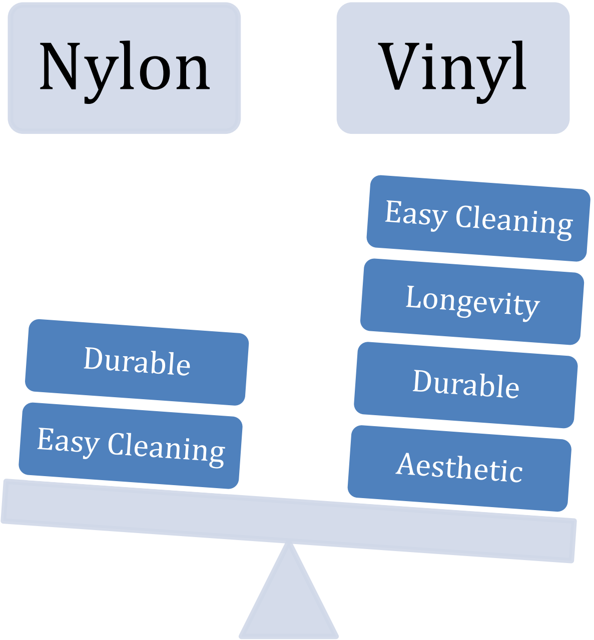


Figure 32. Comparing benefits of nylon versus vinyl

Vinyl was chosen because it included all of nylon’s benefits along with longevity and aesthetics. In talking with Randy at Fine Touch Upholstery, this choice was confirmed as the best option with the given environment it will be used in.

Attachment

The backrest padding was attached to the nylon straps using industrial strength Velcro.

5.4.4 Armrest

The purpose of the armrest was to support Nathan's arms and to serve as a mounting point for the steering joystick and linear actuator switches. Meeting these requirements while also making the system comfortable, easy to use, lightweight, and aesthetically pleasing was the team's goal. Figure 33 below shows an exploded view of the mechanical components of the armrest assembly.

Figure 33. Armrest exploded view drawing

5.5 Seating

The seat sub-assembly shown in Figure 34 is composed of a carbon fiber plate and a seat cushion. The seat cushion will distribute Nathan's weight on the carbon fiber panel which will be supported by the tilt-in-space frame.

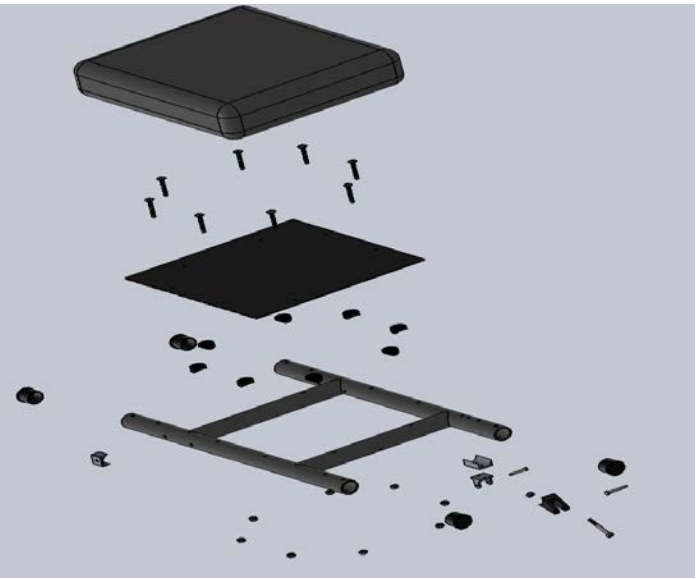


Figure 34. Exploded schematic of seating subassembly

5.5.1 Plate

The function of the pad support plate was to provide a flat surface for the seat cushion to rest on while acting as a distributive medium for which the load will be applied.

Design Choices and Function

A seat plate was needed to provide support underneath the seat cushioning. Without the seat plate, the foam padding would sit directly onto the mobility base, which would provide uneven support for Nathan considering that the seat would sink into the holes between the base bars.

The team also wanted to have a seat plate that was lightweight to ensure that the total weight of the mobility device is as low as possible. Since Nathan is not very heavy, the strength of the material chosen for the seat plate was not as important as the weight.

Attachment

The seat plate was attached to the base of the mobility device and seat padding with nuts and bolts.

Material selection

The team initially wanted to use aluminum but ultimately carbon fiber was chosen due to its excellent strength to weight ratio, material compatibility, and its unique appearance.

Carbon Fiber Analysis

A composite (carbon fiber) analysis was done on the seat base plate to determine how much load an twelve-ply $[0^{o}/90^{o}]_{6S}$ carbon-epoxy (AS4/3501-6) laminate, or twelve layers of carbon fiber with various angles, could support given that the max allowable strain would be on the scale of microns. Using the carbon fiber's engineering parameters, a stress analysis was conducted first. Since the load would be in the normal direction (straight down on the plate face), only this stress component was analyzed to see what the max load would be in this direction. Once the stress value was obtained, the max load was calculated from the stress value and the area of the plate and came out to a value that is well above 50 lb_f. From here, a factor of safety was determined and came out much higher than expected. The calculations can be found in Appendix K.

While the calculations outlined above yield a high safety factor with a low weight assumption, the team investigated using aluminum instead. This idea was a natural extension of a Matt Steensma's recommendation to use aluminum for the back seat support. Matt Steensma is a Cal Poly Shop Technician who performed the team's manufacturing review. During the review, the team intended to use an aluminum plate as a support frame. Since the team initially thought they would be working with aluminum for the frame, it would be favorable to use the same material. After conducting more research including detailed investigation on Josephs Jogger, an old Cal Poly senior project, the team decided to replace the aluminum frame with nylon straps. This idea was confirmed by the Senior Project Advisor, Professor Sarah Harding.

Table 7. Comparing seat base material options

Criteria	Carbon Fiber	Aluminum 3003-H14	Aluminum 5052-H32
Weight [lb_f]	2.69	4.12	4.05
Price [$\$/\text{ft}^2$]	$59.99	$18.23	$29.26
Vendor	RockWest Composites	Metals Depot	Metals Depot
% Difference compared to Carbon Fiber	---	42.0%	40.35%

**Carbon Fiber data collected from Rockwest Composites and Aluminum from MetalsDepot.com*

Ultimately, the team decided on using carbon fiber due to its high strength-to-weight ratio. This was a trade-off for the expensive price, but weight was a main concern. With the team not using aluminum for the backseat frame, carbon fiber was determined to be the ideal choice. Additionally, with the help of Dr. Elghandour, the head composites professor at Cal Poly, the team was able to obtain unidirectional carbon fiber for free and save the money to use on other parts.

5.5.2 Seat Cushion

Initially, Team Nathan intended on shaping and upholstering the seat cushion themselves; however, a table was created, shown below, to compare the advantages and disadvantages of building a seat cushion from scratch versus buying one.

Table 8. Comparing do-it-yourself upholstery vs. purchased seat cushion

Criteria	Custom Made Seat Cushion	Vendor Bought Cushion (Low End)	Vendor Bought Cushion (High End)
Price [$]	Estimation ~ $150 - $200	$40 + S&H	$305 + S&H
Weight [lbs]	3 lbf – 5 lbf	3 lbf	4 lbf
Time Involved [hr]	10 hrs	0	0
Rated Comfort (1-5)	4	2	5
Vendor	Upholstery Supplies & Fine Touch Upholstery	Ebay	1800Wheelchair.com
Dimensions [in]	Custom	3” X 14” X 11”	Custom

Weight of the cushion was an excluded factor since each vendor-purchased cushion is different, and the weight of a “do-it-yourself” cushion was dependent on the foam and upholstery cloth used. In comparing the price, rated comfort, and time involved for a custom-made seat cushion to two vendor-purchased cushions, the purchased cushions were the better option. A custom-made seat costed between $150-$200 (soft foam + outsourcing upholstery), while a high-end seat cushion costed around $300. Given that a bought seat cushion costed more, the comfort rating would naturally be higher as reflected in Table 8. With this, a medium-end vendor-bought cushion would have the same rated comfort, cost around $200 (roughly medium of low and high-end cushions), and have no assembly time. After researching the seat cushion that came with the Quickie Z-500, however, the team discovered it was very high quality with a retail price of $400.

Attachment

Similar to how the backrest cushioning was attached to the vinyl outlined above, the seat padding was attached to the seat base plate utilizing industrial strength Velcro. Figure 35 below shows the positioning of the two Velcro straps where the strips ran parallel to the direction of travel.

Figure 35. Velcro placement on seat cushion

The placement of the Velcro was not as important as the consistency of placement between the cushion and the carbon fiber plate. The motion of the tilt-in-space will put a load on the Velcro, so lining up the seat cushion and plate while also running the strips parallel would distribute the force along the length of the strip.

5.6 Footrest

The footrest sub-assembly is composed of the foot plate, frame, and pin on which the frame rotates. This subassembly was responsible for supporting Nathan’s lower extremities with the added benefit of having an adjustable position. Figure 36 below shows the exploded view of the footrest sub-assembly design.

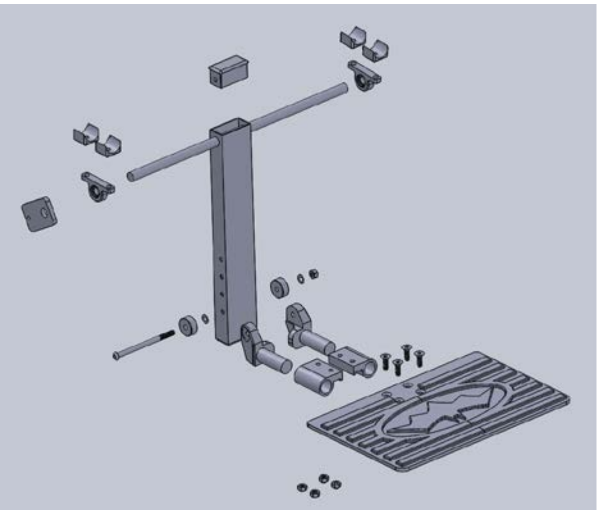


Figure 36. Exploded layout of footrest sub-assembly

5.6.1 Foot Plate

The foot plate was designed to provide Nathan with a designated resting area to put his feet to support his legs. Nathan's Standing Dani did not have a footplate to put his legs on, so this addition will improve leg room comfort.

Design Choices

The foot plate is the part of the footrest system where Nathan's feet will actually sit. In designing this part of the system, it was important to balance comfort, aesthetic appeal, and safety in order to create the best possible product. A good foot plate must comfortably and safely support the user's feet while also not detracting from the overall aesthetic of the system. A single footrest plate for both feet was chosen rather than one for each foot in order to both reduce system complexity as well as contribute to the overall aesthetic of the device. Many common footrest designs incorporate surface texturing in order to increase contact friction between foot and support. This was a design detail that the team wished to incorporate into the design. In order to make an aesthetically appealing footplate that has a surface texture and fits Nathan's very specific geometric requirements, it was determined that 3D printing was the most effective solution in terms of cost and time. Later in the design process, however, the team realized that the 3D-printed foot plate would be too hard to print and would take up too much time. Resultantly, the team decided to create the foot plate out of aluminum which is discussed again later in the chapter in section 5.10.

Material Selection

Due to the nature of the selected manufacturing process, the list of materials available for use was limited to whatever can be printed on the Cal Poly campus. The two most common types of 3D printers on campus are Fused Deposition Modeling (FDM), which prints in layers of plastic fused to a build plate and Stereolithography (SLA) which is resin cured to a build plate using a laser. SLA printing is a very expensive process that is typically reserved for parts that must have very small tolerances or need to be perfectly waterproof. The foot plate for this system requires neither of those characteristics and so SLA printing and its associated resins can be removed from the list of potential materials. This leaves the various thermoplastics that are common in FDM 3D printing. Of these, the most readily available for use on campus are Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), and Polyvinyl Alcohol (PVA). Of these, PVA is water soluble and typically used as a support material when printing. This makes it unsuitable for structural use. In comparing PLA and ABS, each has benefits and concerns. The material properties of both materials are outlined in Table 9 below.

Table 9. ABS and PLA material properties

Material	**Cost [$/kg]**	**Modulus, E [GPa]**	**Density, ρ [g/cm^3]**	**Ultimate Tensile Strength [MPa]**	**Melting Temperature [°C]**
ABS	22	1.1-2.9	1.01-1.21	33-110	88-128
PLA	22	3.5	1.25	35	160

At first glance, it is apparent that ABS is typically both lighter and stronger than PLA. Melting temperature is not a concern for this project as the lowest recorded melting temperature is 88°C, or 190°F, which is well above the temperatures this device is expected to operate in. One thing to consider in deciding between the two materials is that ABS tends to be harder to print with than PLA and has a higher chance of print failure. Since part strength is important and the team has significant 3D printing experience, ABS was selected as the material of choice for this part. The foot plate can be seen in Figure 37 below.

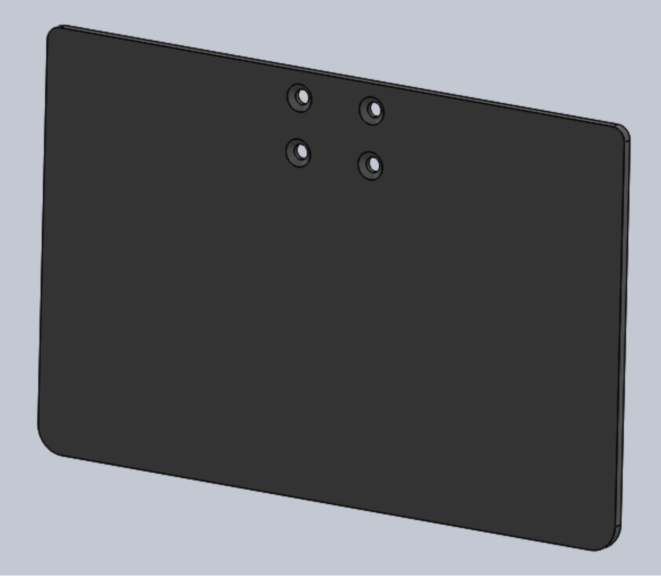


Figure 37. Footplate design

5.6.2 Frame

The footrest frame was made to provide the structural integrity for the foot plate to be attached to. The linear actuator moves the footrest frame via a welded-on shaft and attachment plate.

Design Choices

This design uses a rectangular tube for the main part of the footrest frame. A contributing factor to this selection of design is the simplicity of the design. By keeping the footrest design simple, the minimalistic aesthetic goal that Nathan expressed interest in was met. Another driving force in this design decision was other power chairs on the market. Power chairs such as the Permobil C300 featured a center-mounted footrest using rectangular tubing as the primary frame member. Part dimensions were selected based on supplier availability and then analysis was performed to verify the selected part would function as designed.

Material Selection

The three primary types of materials considered for making this part are aluminum, steel, and carbon fiber. Steel was the strongest material but also the heaviest. The main benefit of steel was that it was easily welded and machinable. Aluminum was significantly lighter than steel, stiffer, and easier to machine. Its primary shortcomings were that it was more expensive and very difficult to weld. Carbon fiber was a difficult material to classify because while it was lighter than both aluminum and steel, its strength and stiffness depended on the fiber orientation and number of layers. It was also expensive and depending on how it was made, could have been very difficult to machine as well. Due to the minimal loading this part was going to experience, strength was not the driving characteristic of this design. This, therefore, made aluminum the clear favorite over steel in terms of material properties and more useful than carbon due to its simpler manufacturing and lower cost. The selected beam cross-section is seen in Figure 38.

Analysis

The below set of equations represented the hand calculations for simple beam bending on the foot rest bar used in the design. This analysis represented bending in the weak axis assuming that beam was fixed on one end and the loading was a point load at the end of the beam. This analysis uses 6061-T6 aluminum as the material. This represented the maximum loading that the system could potentially see, not a typical load expected on the system. Figure 38 represents the important values in inertia analysis on this particular bending plane.

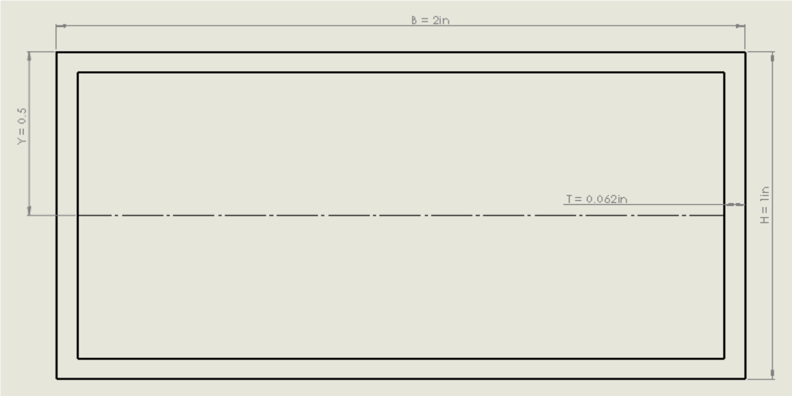


Figure 38. Cross-section of Beam for Inertia Analysis

$$Bending\ Stress = My/I$$

$$M = Bending\ Moment = (force)(length) = (50lb)(12in)$$

$$I = Moment\ of\ Inertia = (BH^3 - (B - 2T)(H - 2T)^3)/12 = 0.061\ \text{in}^4$$

$$Y = distance\ from\ neutral\ axis = 0.5\ in$$

$$Max\ Bending\ Stress = (50\ lb)(12\ in)(0.5\ in)/(0.061\ in^4)$$

$$\boldsymbol{Max\ Bending\ Stress = 4918\ psi}$$

Aluminum 6061-T6 ultimate stress = 42000 psi

$$\boldsymbol{Factor\ of\ Safety} = (\boldsymbol{ultimate\ stress})/(\boldsymbol{max\ bending\ stress})$$

(42000 psi)/(4918 psi) = **8.54**

From this analysis, it was apparent that the selected beam was strong enough in the analyzed bending plane. Even though the factor of safety from hand calculation was quite high, finite element analysis was done on the beam in the same bending plane under similar loading. FEA was performed due to the number of drill holes put into the part. The simple beam approximation does not account for holes in the beam and so could skew data. The results show similar stress, thus verifying the hand calculations. Similar calculations and FEA were done analyzing the beam on other planes of bending. FEA and hand calculations for this system can be found in Appendix L.

5.7 Cost Analysis

Team Nathan was fortunate enough to receive a grant of $3,000 from CPConnect. This section is dedicated to outlining how the team will budget the remaining balance of the CPConnect fund.

Team Nathan has spent $1195.52 on the various items summarized in Table 10. The full spreadsheet of the budget analysis can be found in Appendix M. This table tabulates initial costs (pediatric chair) and ideation development purchases.

Table 10. Project budget analysis

Name	Cost	Date	Company	Description
Pediatric Chair	$657.27	11/8/2017	Sunrise Medical	Purchase of the Quickie Z 500 Mobility Base
Pediatric Chair Batteries and Charger	$492.54	11/28/2017	A1 Mobility	Purchase of cell batteries and 5 Amp Charger
PVC Tubing Supplies	$65.05	11/5/2017	Home Depot	PVC supplies used to build prototype
Supply Return	$(28.94)	12/2/2017	Home Depot	½-inch PVC returned b/c not needed
Hinge	$9.60	1/19/2018	Home Depot	Hinge used for structural prototype
Sum	**$1195.52**			

With the purchases outlined above, the remaining money, $1804.48, was allocated to building upon the mobility chair that was purchased.

Combining the complete bill of materials and the outsourced cost for professional services yielded a nominal value of $2309.01. This table can be found in Appendix N. However, Team Nathan spent $2752.96 overall on the project which comes to $443.95 above the bill of materials total cost. This can be attributed to buying parts in bulk where not all the parts are used. The total budget breakdown can be found in Appendix M.

5.8 Flowcharts, Schematics, Pseudo-code, Wiring Diagrams

As previously stated in the linear actuator sub-assembly section, the ORCAD circuit diagram of the schematic is found in Appendix J. This wiring diagram was built upon the wiring diagram included in the Quickie Z-500 User's Manual which is attached as Appendix I.

In terms of altering the pseudo code, A1 Mobility took care of the coding for the joystick control system. Editing the software required equipment that Team Nathan does not have access to on campus.

5.9 Safety, Maintenance, & Repair Considerations

To account for safety, maintenance, and repair, the team had to perform an FMEA, or failure modes and effects analysis. In the team's FMEA, seven different systems were analyzed: backrest, seat, foot rest, headrest, seat actuation, general mechanical parts, and general aesthetic parts. The potential failure modes of each system/function, potential causes and effects of each failure mode, and current preventative and detection actions were analyzed to see what could go wrong and how these failures could be mitigated or avoided. Once this was done, the severity, frequency of occurrence, and ease of detection were analyzed on a scale from one to ten with one being the least severe, frequent, and difficult to detect and ten being the most severe, frequent, and difficult to detect. Once all the potential failure modes were scaled, an RPN, or risk priority number, was calculated by multiplying all three categories (severity, occurrence, and detection) together. The higher the RPN, the more care and attention that failure mode requires. The analysis showed that the highest RPN was 25, so none of the failure modes required extreme attention and caution.

Table 11. Critical dangers and mitigation plan from FMEA

Danger	**RPN**	**Mitigation Plan**
Actuator Breaks	21	Place actuators under seat away from exposure to outside harm
Power Source Does Not Provide Enough/Too Much Power	24	Consult with EE professors and Stan at A1 Mobility to have everything checked out and approved
Circuit Wired Incorrectly	21	Get wiring checked out at A1 Mobility
Fasteners Break/Corrode	21	Research best corrosion resistant metal and use lightest weight fasteners

From Table 11, the most critical dangers associated with the fabrication of the mobility device dealt with the actuator breaking, the power source either supplying too much or not enough power to the mobility device, the circuit being wired wrong, and the fasteners corroding or failing. These potential failures scored among the highest in terms of risk priority number, thus making them very important in the team’s manufacturing of the mobility device.

In order to prevent or reduce the possibility that the linear actuators break during operation, they were placed in areas that would not expose them. By placing the actuators under the seat of the mobility device, the number of pinch points was decreased and was far away enough from exposure for any accidents from happening.

To mitigate the possibility of the power source providing too little or too much power, the team’s best option was to go to A1 Mobility to make sure that the electronics were all functional and that no electronic part was defective.

For the circuit wiring, it was also best to visit A1 Mobility to get the wiring looked at and confirmed to be safe for operation. Going to a professional was the smartest and fastest way to determine whether or not the circuit wiring was correct.

Finally, the best plan to deal with corrosion and failure in fasteners was to use the best or one of the best corrosion resistant metals. Understanding the typical weather and climate that the client lived in would help with research on what would be considered a sufficient enough metal that would last long and perform well. Additionally, using the lightest weight metal fasteners would have been best just to keep the overall weight of the mobility device low. Anti-corrosion coatings also could have been applied to parts at risk for corrosion.

The full FMEA table can be found in Appendix O. This includes a full breakdown of each identified risk, rating, and mitigation technique planned to be deployed.

Additionally, three of the same bullet series mini actuators from Firgelli Automation were purchased to make maintenance and repair easier since they could be sent back to the same place for repair. The actuators have different length strokes and are pretty powerful in terms of force generation.

An operator's manual and a technical manual are attached in the appendices labeled Appendix P.

5.10 Final Design Changes

Following CDR, the team has made some significant changes in regard to the physical layout of the mobility device. The team opted to reuse some of the materials used in the old mobility device to save on money and mainly because of their quality. Rather than buy a new occipital headrest, the team reused the already existing head rest because of its low-profile nature and the approval of Nathan's family. The only changes that were done to the headrest involved upholstering the padded headrest with a new fabric to give it a newer and sleeker look.

For the user input sub-assembly of the mobility device, Team Nathan decided that rocker switches would be easier to use than buttons that were scattered on a pad near the joystick. After broaching the idea to Nathan and his family, they added that the rocker switches were also difficult to operate. Taking this into account, the team brainstormed and came up with the idea to include a lever that rests on top of the rocker switches than could be pushed forward and backward to push the switches forward and backward, respectively.

Also, for the foot rest sub-assembly, the idea of using a 3D printed foot plate ultimately turned out to be too difficult to carry out as the 3D printer used to create the foot plate could only print in small pieces which would take up too much time and be difficult to attach together to form one solid foot plate. Rather, the team agreed to reuse the existing footplate stop mechanism on the mobility device mainly because of its unique feature of being able to fold up and down along with a larger flat plate made of aluminum. It provided more structure and will have a longer life-span than a 3D-printed part. Additionally, the team decided to go in a different path and felt that it was best to not include a calf support in the final design. After speaking with Nathan, he told the team that a calf support would be unnecessary.

The armrest mechanism sub-assembly has also been altered. The armrest sub-assembly was also taken from the preexisting mobility device and slightly changed to fit a smaller diameter rod. Since the load will be mainly in compression, the team has created 3D-printed "rod adapters" to fit inside the larger diameter armrest connecter to then attach to the smaller diameter backrest frame more easily. The intricate, yet unique design of this armrest subassembly was very easily implemented into the new mobility device.

The team also encountered some problems with the previous design for the backrest straps, which incorporated just Velcro as the main means of attaching the straps to the backrest. With just Velcro as the means of attaching the straps to the back rest, there was noticeable slack, which prevented the straps from having a firm and tight hold on the back rest. To remedy this issue, the team decided on a new design that involved buckles to tighten the straps, so they did not fall down. The straps had to be cut slightly longer than the intended length to account for the extra length needed to wrap around each buckle end. Once this was completed, the Velcro was stitched on facing the backrest cushion to attach the backrest frame to the backrest cushion. To avoid the buckles from getting in the way of attaching the backrest cushion to the frame, the buckles were oriented in a way such that they faced toward the back of the mobility device. In addition, this provides a more convenient way to detach and attach the buckles from the backrest frame. The team got the idea of buckles from another senior project “Joseph’s Jogger” that also used buckles for straps in their design.

6. Manufacturing Processes

During the design phase, the team was careful to make every part on the device either purchasable or manufacturable. Outlined in the chapter below is the process the team followed in order to make or acquire all of the individual components of the system.

6.1 Procurement

The materials outlined in the bill of materials have been sorted by vendor. These parts were ordered by filling out the Pre-Authorization Pro-Card Purchase form.

Table 12. Amazon purchasing list

Amazon			
Name	**Quantity**	**Cost**	**Sub-System**
Hatchbox ABS 3D printer filament, 1kg	2	$21.99	Footrest Sub-Assembly Actuation Sub-Assembly
Industrial Velcro 2" X 15'	1	$25.99	Backrest Sub-Assembly Seating Sub-Assembly
Nylon Straps 2” X 20’	1	$23.99	Backrest Sub-Assembly
Neoprene XCEL 54" X 12" X 0.25"	1	$18.97	Footrest Sub-Assembly
-	Total	$112.93	-

Table 13. Firgelli purchasing list

Firgelli			
Name	**Quantity**	**Cost**	**Sub-System**
24 V Linear Actuator	3	$160	Actuation Sub-Assembly
Rocker Switch for Linear Actuator	3	$9	Actuation Sub-Assembly
Wiring Harnesses	3	$8	Actuation Sub-Assembly
-	Total	$531	-

Table 14. Home Depot purchasing list

Home Depot			
Name	**Quantity**	**Cost**	**Sub-System**
Aluminum Dowel 36" X 0.375"	1	$6	Footrest Sub-Assembly
Bushing	2	$2	Backrest Sub-Assembly
10 Amp Fuses	3	$1.50	Actuation Sub-Assembly
Bushing Enclosure	2	$2	Backrest Sub-Assembly
-	Total	$18.50	-

Table 15. McMASTER-CARR purchasing list

McMASTER-CARR			
Name	**Quantity**	**Cost**	**Sub-System**
Clevis Pin 3/16" X 1"	2 X [10]	$5.63	Actuation Sub-Assembly
Aluminum Tubing 6061-T6 X 1"X 6' X 0.065WT*	1	$53.10	Seating Sub-Assembly
1/8" X 1 1/2" X Bolts	4	$0.15	Seating Sub-Assembly
1/8" Nuts	4	$0.10	Seating Sub-Assembly
Knob Screw	1	$1.50	Footrest Sub-Assembly
Fasteners	6	$1.50	Footrest Sub-Assembly
Sleeve Bearings	4	$5	Footrest Sub-Assembly
Aluminum Tubing 6061-T6 X 3/4"X 6' X 0.065WT*	2	$53.10	Backrest Sub-Assembly
Aluminum Bar 1" X 1" X 12"	1	$7.44	Footrest Sub-Assembly
Aluminum Plate 2" X 24" X 1/8"	1	$5.84	Actuation Sub-Assembly
Aluminum Plate 1" X 12" X 1/4"	1	$2.70	Seating Sub-Assembly Backrest Sub-Assembly
-	Total	$218.04	-

Table 16. Miscellaneous vendors purchasing list

Miscellaneous Vendors			
Name / Vendor	**Quantity**	**Cost**	**Sub-System**
Vinyl Cloth X 54" / Fabric.com	2	$7.98 per yd	Backrest Sub-Assembly
Rectangular Aluminum Tubing 1" X 1" X 12" / Metals Depot	1	$10.90	Backrest Sub-Assembly
Rectangular Aluminum Tubing 2" X 1" X 1' X 0.062WT* / Online Metals	1	$3.10	Footrest Sub-Assembly
Super Soft Foam 2” X 24” X 96” / Quality Fabrics and Foam Supplies	1	$67	Backrest Sub-Assembly
Occipital Pad / Sunrise Medical	1	$135	Backrest Sub-Assembly
Solution 1 Seat Cushion / Walmart	1	$160	Seating Sub-Assembly
Armrest Pad / Enable your life	2	$8.99	Backrest Sub-Assembly
-	Total	$409.94	-

6.2 Manufacturing

The manufacturing was divided into six major sub-assemblies which are outlined and explained in detail below.

6.2.1 Actuation Sub-Assembly Manufacturing

The actuation sub-assembly consists of the linear actuators and their corresponding brackets and clevis pins. The linear actuators, brackets, and clevis pins were purchased components. The tilt-in-space mechanism actuator was the one that would support most of the loads, therefore the team decided to use the reinforced brackets that came up with the wheelchair. The backrest actuator bracket was slightly modified. The mounting hole-diameters were made larger (3/16”) to make sure that the clevis pins would fit. Two flat-to-round spacers were manufactured out of aluminum so that the flat parts of the assembly will be mounted to the round tubes of the chair. Figure 39, Figure 40, and Figure 41 depict the three linear actuators when mounted to the wheelchair.

Figure 39. Backrest linear actuator

Figure 40. Footrest linear actuator

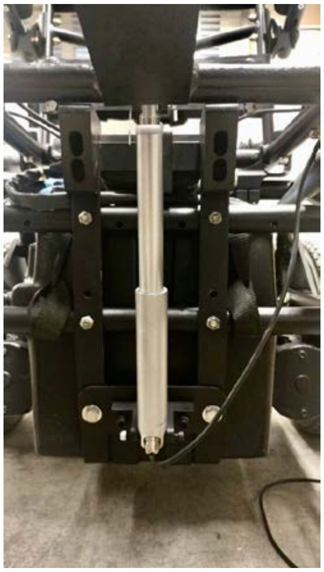


Figure 41. Seat linear actuator

6.2.2 Backrest Sub-Assembly Manufacturing

The backrest sub-assembly consists of the two main parts, the backrest and its contained parts as well as the arm rests. The backrest is composed of a frame, upholstered cushion, occipital pad, nylon straps, bearings, a push bar, and Velcro. The armrests consist of arm pads, armrest frames, bushings, plastic end caps, and bolts. The backrest frame was made out of ¾-in diameter 6061-T6 aluminum tubing cut and welded into shape with the help of Gentry Welding. The frame rotates on a 5/8-in diameter by 17-inch-long 6061-T6 Aluminum rod that sits on two 5/8-inch pillow block bushings. The bushings sit on round-to flat-adaptors which are machined out of blocks of 6061-T6 aluminum. These bushings are bolted to the tilt-in-space frame bar. A push bar made out of bent ¼-inch-thick aluminum plate was welded onto the end of the rod at a 30° angle to serve as the mounting point for the linear actuator. The cushioning was shaped out of a super soft rating foam. This foam was cut and shaped by Team Nathan but outsourced for the upholstery. The arm rests used 1-inch by 0.75-inch aluminum rectangular tubing as the structure with purchased arm pads bolted onto the structure. The armrests used 3D printed diameter adapters to fasten the smaller diameter arm rest subsystem to the backrest frame. End caps for the armrest structure were 3D printed out of ABS plastic and inserted into the ends of the structure. Figure 42, Figure 43, and Figure 44 document the process of constructing the backrest sub-assembly.

Figure 44. Backrest frame tubing being cut to length

Figure 43. Backrest frame being notched

Figure 42. Backrest frame cut to length and shaped before welding

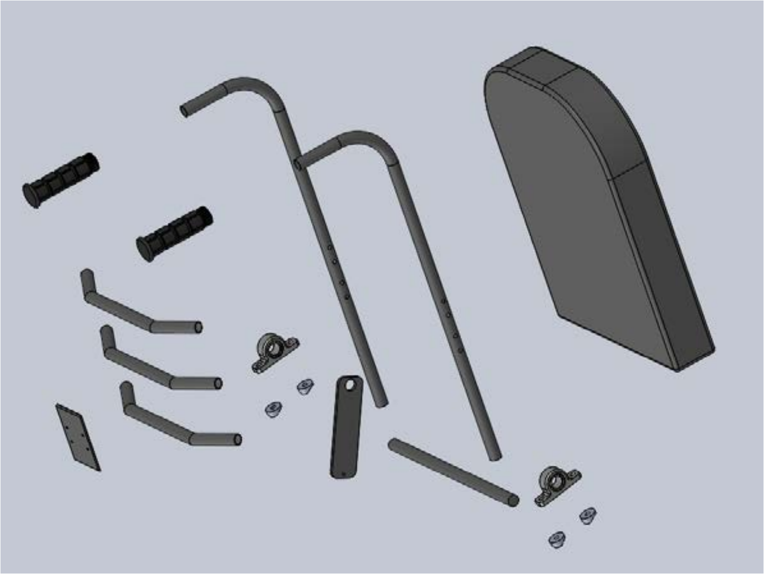


Figure 45. Backrest sub-assembly exploded view

With the frame materials cut for the backrest, the cushioning needed to be fabricated. Spray adhesive glued the low and high density foam together. This foam was cut to a size of roughly 16” x 28” with the top chamfered. From here, the foam along with the vinyl was taken to Fine Touch Upholstery for professional upholstery.

Bolsters were added to give Nathan a more upright position. Initially the team had trouble cutting the foam at an angle but Steven perfected the art of using an electric turkey saw and cut some nice slices of foam.

6.2.3 Seating Sub-Assembly Manufacturing

For the seating sub-assembly, the seat base plate was manufactured out of carbon fiber. The seat base plate (12” x 13”) is comprised of twelve plies of carbon fiber (AS4/3501-6) pre-impregnated with epoxy resin as the matrix. The team completed a lay-up of twelve unidirectional layers of carbon fiber one on top the other with a stacking sequence of [0/90]s, which means that the fiber orientation angles for each layer from bottom to top will be 0º, 90º, 0º, 90º, 0º, 90º, 90º, 0º, 90º, 0º, 90º, and 0º.

Figure 46. Carbon fiber seat plate setup before cure

After laying up the carbon fiber on a metal base plate, plastic film, breather mats, and a vacuum bag were placed on top of the carbon fiber laminate (multiple plies or layers). Tacky putty was used to stick the vacuum seal film to the metal plate beneath the carbon fiber laminate. Once this was finished, a vacuum connector with tubing connected to the vacuum was attached above and beneath the vacuum seal film on the carbon fiber laminate to suck out the air and any bubbles present. An air leak test was then conducted by listening for any air seeping out to make sure that the vacuum seal was sufficient for curing. Once this step was completed and everything was prepped correctly, the carbon fiber laminate was then placed in an autoclave to cure for several hours. Figure 46 above shows the finished setup.

Once the curing process was complete, the laminate was incorporated into the mobility base and attached using bolts and holes. The seat base plate was attached to the seat cushion with industrial Velcro for easy removal and maintenance.

The main challenges for this process dealt with being able to accurately lay up the carbon fiber so that the laminate came out to a near perfect square with no layers protruding from the general square shape of the laminate. Additionally, making sure that the vacuum seal was sufficient and ready to be put into the autoclave was a little difficult because the tacky putty did not entirely create a perfect seal for the vacuum bag around the carbon fiber and metal plate. The carbon fiber curing process itself took a long time to cure, making it difficult for the team to find a perfect time such that the team could wait for the cure to finish and retrieve the carbon fiber plate once it was done curing. The team was able to find a time during the work week to lay-up the composite laminate and then come back the next day to cure the laminate.

The tilt-in-space base bar attached to the seat base plate was replaced with one-inch diameter aluminum rods to reduce the weight of the mobility device. Holes were drilled into the bars using a mill so that the seat plate and backrest support bars had a place to be fastened and bolted. The tubes were cut and notched and then welded to mirror the look like the old tilt-in-space base bars.

Once this process was completed, the bar was cleaned, grinded, and then surface finished to enhance its appearance.

Figure 47. Tilt-in-space frame before welding

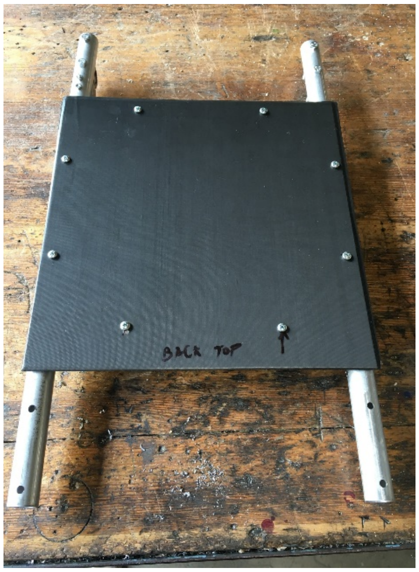


Figure 48. Carbon fiber plate on top of the tilt-in-space frame

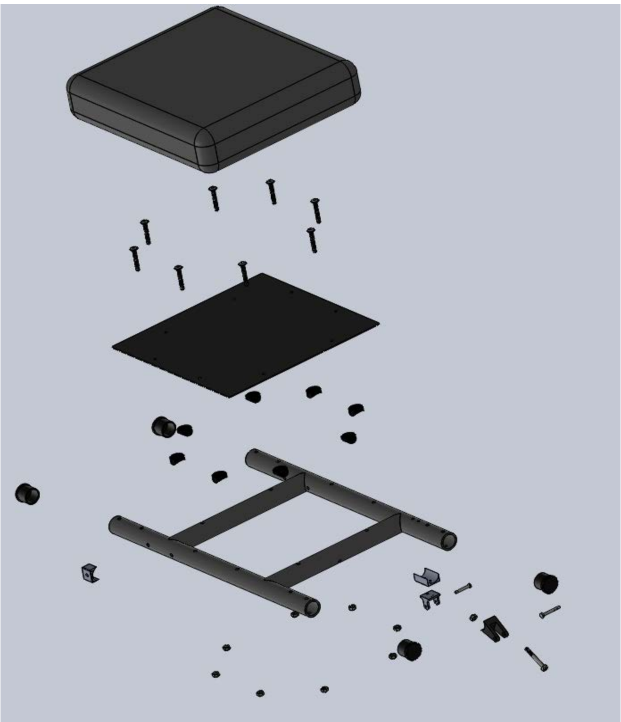


Figure 49. Seating sub-assembly Exploded View

6.2.4 Footrest Sub-Assembly Manufacturing

The footrest sub-assembly was manufactured in two different ways. A 3D printer was used to create the Batman-themed footplate grip while the footplate, linear actuator mounting plate, center bar, and cross pin were made out of aluminum. The previous design did include a calf support; however, because the inclusion of such a part was deemed unnecessary, the team agreed to leave it out of the final design as mentioned earlier.

The footplate, center bar that connects the crossbar and foot plate, cross bar that connects the center bar to the tilt-in-space frame to allow for the footrest reclining, and mounting brackets were purchased and fabricated out of 6061-T6 Aluminum mainly because of its strength and low cost. The foot plate was cut out of ¼” thick plate and is 12” long by 6” wide. Four ¼” counter-sink holes were drilled to attach the plate to the bottom connectors as shown in Figure 50.The connectors are squeezed using a 3” long bolt to allow the plate to be foldable.

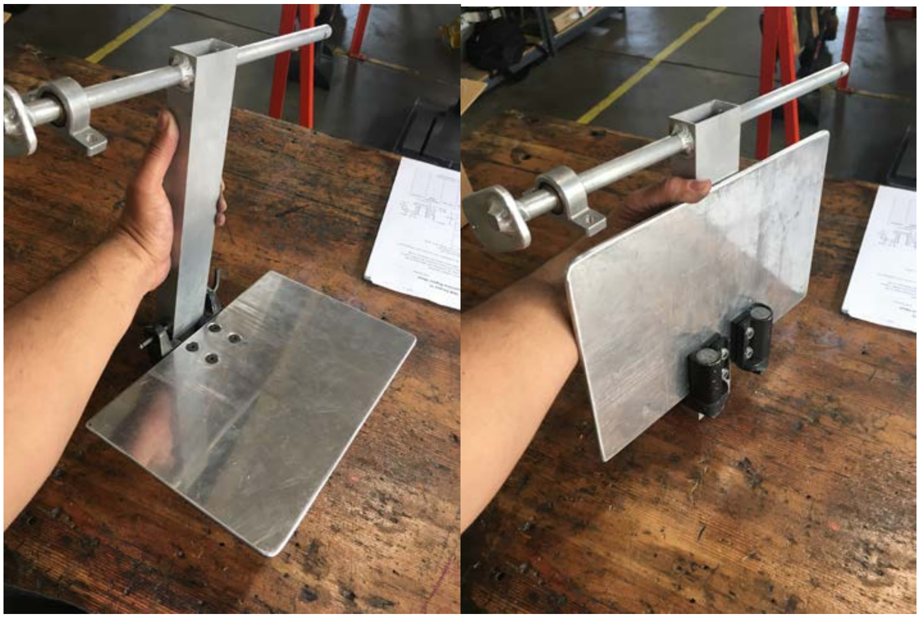


Figure 50. Foldable footplate

To complete the center bar piece, a mill was used to press holes for the foot plate and cross bar to attach to in the subsystem. The center bar was not cut since the purchased aluminum bar was already at the correct dimensions. The linear actuator mounting plate was made out of the same type of aluminum and shaped as small as possible to reduce weight yet allow for the linear actuator to function properly. The center bar was welded to the crossbar in the middle, and the plate for the footrest linear actuator was welded on one end of the cross bar at a 60° angle from vertical.

The aluminum cross bar was faced to length using a lathe. This bar was clearance fit into the top holes in the center bar so that the rotation of this bar about the cross bar was free and unrestrictive.

The mounting brackets that connect the cross bar to the mobility base was milled in a two-part process mainly because the thru holes in the brackets were too deep for the end mills. The brackets were also cut to length using the mill.

The end caps were constructed with a 3D printer that the team had access to. Once all the parts were fabricated, they were cleaned, grinded, and then surface finished to improve the overall appearance of them to suit Nathan's taste.

Nuts and bolts were used to connect the non-welded parts together to form the footrest subsystem assembly as shown in Figure 51 below.   A couple of clamp collars were used to fix the shaft locations relative to the bushings.

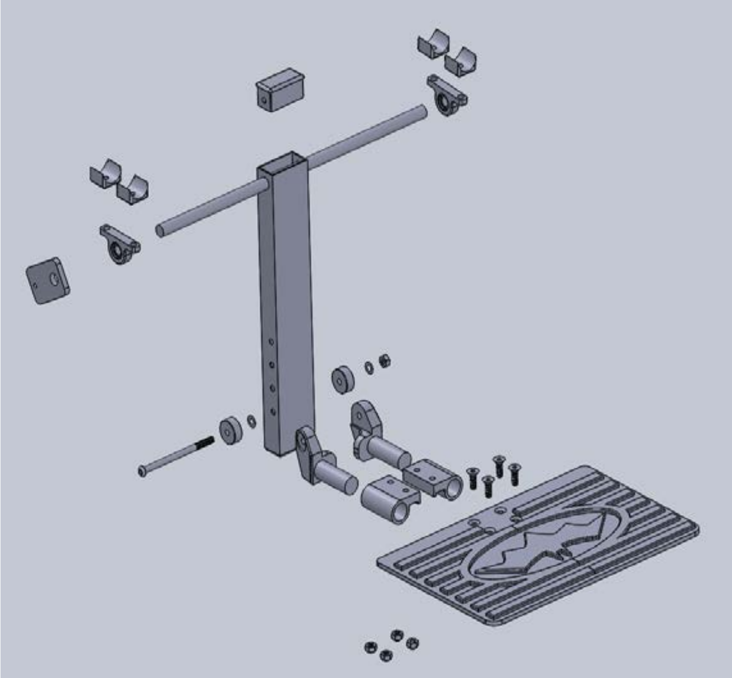


Figure 51. Footrest sub-assembly exploded view

6.2.5 Armrest Sub-Assembly Manufacturing

The armrest main support is made out of 1"-diameter Aluminum tube and was taken from the purchased wheelchair. Two 3/16" counter-sink holes were drilled on the main support to attach the armrest pad. The holes were drilled using a 7/32" drill bit and then counter-sinks were drilled with ¼" drill bit. In order to adapt the 1" diameter connector to the ¾" diameter backrest frame, an insert was 3D-printed and fitted between the backrest side tube and the armrest connector. The joystick holder tube was adjusted to length so that Nathan can operate the device comfortably. To attach the armrests to the chair, four 3/16" holes were drilled on the side tubes of the backrest frames as shown in Figure 52.

Figure 52. Backrest frame hole drilling to attach armrests

The armrest pad has dimensions of 12” x 2.5” x 1”. It has four imbedded 3/16” nuts that can be used to attach it to the armrest main support tube. Armrest components were then painted and assembled as shown in Figure 53.

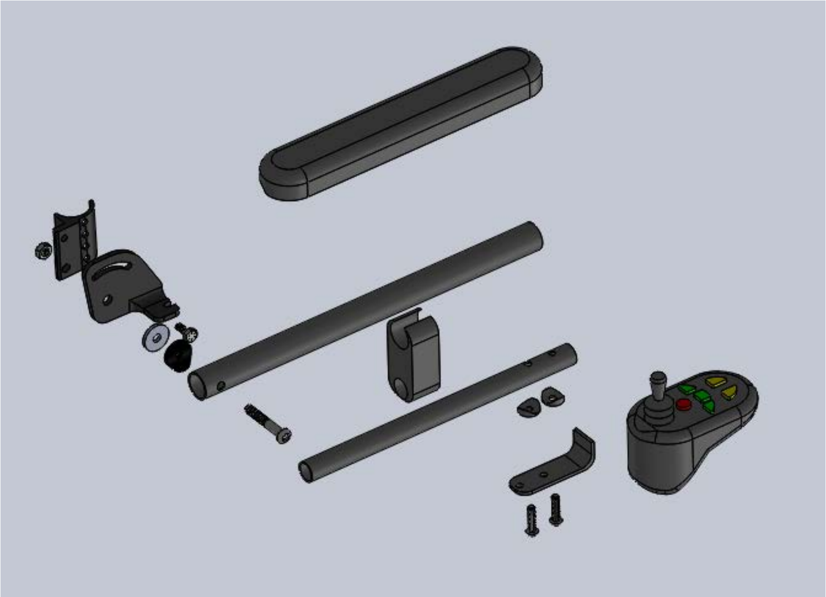


Figure 53. Right armrest sub-assembly exploded view

6.2.6 Electrical Systems Manufacturing

When designing an electrical system, the first things to consider are the systems sinks and sources. In this case, the systems source is two 12-volt batteries wired in series, which is effectively a 24-volt source. The sinks for this system were the three linear actuators used to adjust the chair positioning. Linear actuator selection was outlined in section 5.3.1.

Once the sinks and sources were determined, a form of user input needed to be selected to control the system. Since the linear actuators needed to both extend and contract, the user needed to be able to control the direction of current flow through the DC motors within the linear actuators. This can be accomplished with a Double Pole Double Throw (DPDT) toggle switch for each linear actuator. A DPDT toggle switch is a three position toggle switch that at forward position allows current to flow in one direction and a back position that allows current to flow in the opposite direction. Center position opens the circuit to prevent any current flow. The switch is spring-loaded such that after the user stops applying input, the switch naturally returns to center position.

The remaining decisions to be made in designing the electrical circuit were wire sizing, connector selection, and circuit protection elements. These three decisions were made iteratively. In order to simplify maintenance and assembly, crimp connectors were decided on as the connector of choice so that soldering was not needed. As seen in the circuit diagram (Appendix J), the secondary power wires running from the source to the toggle switches are connected in parallel to primary power wires on the battery. The sizing of the primary power wires was based on what size wires could connect to the ring terminals used to attach to the battery terminals. The battery has a 5/16-inch terminal and the wires that can connect to a 5/16 ring connector range between 10 and 14-American Wire Gauge (AWG). Since the current requirements for this circuit was fairly small, the 14-AWG wire was selected as the primary power wire because it was the smallest wire that could be selected. The secondary power wires were sized based on the maximum current requirements of the linear actuators, which are listed as 1.4 amps**.** Under normal operating conditions, 22-AWG wire can withstand up to three amps of current. By upsizing the wiring, a large factor of safety was achieved.

In order to prevent damage to the system or potential electrical fire in the event of a short circuit or system damage, in-line fuses were wired into the primary power wires as close to the source as possible to protect as much of the circuit as possible. The main goal behind fuse selection was picking a fuse that would burn out before the current limit of the wire is exceeded. Based on Appendix J, the current limit of 14-AWG wire was 15 amps under normal operating temperatures, so 10 amp fuses were selected for this circuit. The linear actuators already have wiring attached so wire selection for that circuit element was not required. Quick connectors were used to connect wiring to switches to allow for easy toggle switch replacement. The complete circuit diagram can be seen in Figure 54.

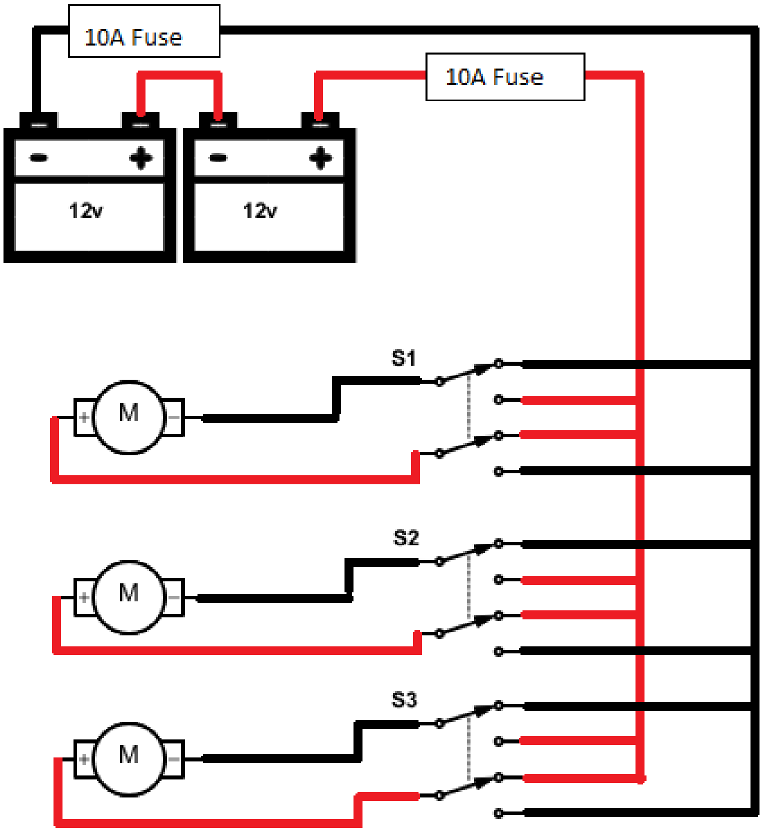


Figure 54. Circuit schematic

7. Design Verification Plan

During and after the manufacturing portion of the project, Team Nathan conducted tests on the major components of the mobility device. These include qualitative comfort testing, electrical testing, carbon fiber failure testing, center of gravity testing, and high side roll testing. Each test was given its own section below. The full plan can be seen in Appendix Q.

7.1 Qualitative Comfort Testing

One of the biggest objectives of this project was to ensure that Nathan was comfortable sitting in the chair. While engineering tests are usually quantitative and purely data driven, the sole beneficiary of this project Nathan determines whether or not he is comfortable. For this reason, comfort testing was conducted by asking Nathan to rate various foams, padding, and material types on a scale of 1 to 10. Also during this testing, the most comfortable arm and foot locations were determined as well as the appropriate shape and dimensions of the backrest cushion. For the duration of seven weeks, Team Nathan regularly met with the family roughly once a week. The two data tables below represent the consolidated data collected from the team’s weekly trips to Nathan’s house. The last two visits were conducted to ensure that Nathan felt comfortable on the seat and backrest.

Table 17. Foam type comfort testing

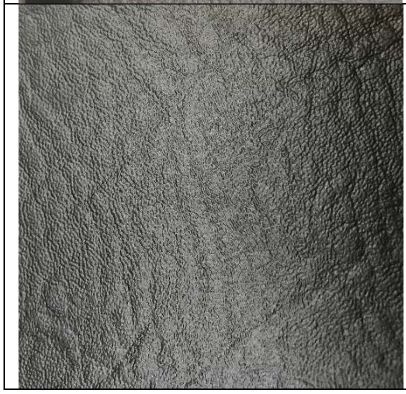
Description	Rating (1-10)	Comments
High density foam	8	Really liked how sturdy this foam was
Low density foam	6	Liked how soft it was but not how “flimsy” it was
Compressed Polyester	4	Did not like this foam

With this data outlined in Table 17, the team decided to use high and low-density foam together to create a synergy between the structure provided from the high density foam and the softness of the low-density foam.

During the third visit, the idea of incorporating bolsters was thrown around by the team. This idea was confirmed to increase Nathan’s comfort level in the fourth visit which is why it was incorporated within the final design.

For the fifth visit, nine samples of black nylon in various textures, softness, and shades were brought to Nathan. Table 18 illustrates the nine vinyl’s which Nathan picked from.

Table 18. Black Vinyl Visualization Table

With these nine samples in front of him, Nathan had no hesitation picking the bottom left sample as his favorite. From here, the team moved forward and started the electrical testing outlined in the next section.

7.2 Electrical Testing

Testing of the electrical system began at the component level. Before parts could be integrated into the system, they had to be verified to function under conditions similar to what they may see within the system. The linear actuators were the first component that needed testing. In order to verify that they function, the negative and positive leads had to be touched off to the terminals of a proper voltage battery. This allowed the actuator to move normally. When the actuator was at maximum or minimum extension and did not move when touching the battery terminals, the terminal contacts were switched. When the actuator still did not move, there was either a problem with the actuator or the battery.

For initial linear actuator testing, a 24-V lithium-polymer RC car battery was used. While this battery was not the wheelchair batteries used in the final design, it was far lighter and more portable, making testing easier. Once the actuators were verified as functional, the same test was performed using the wheelchair batteries in order to verify that the wheelchair batteries could power the actuator.

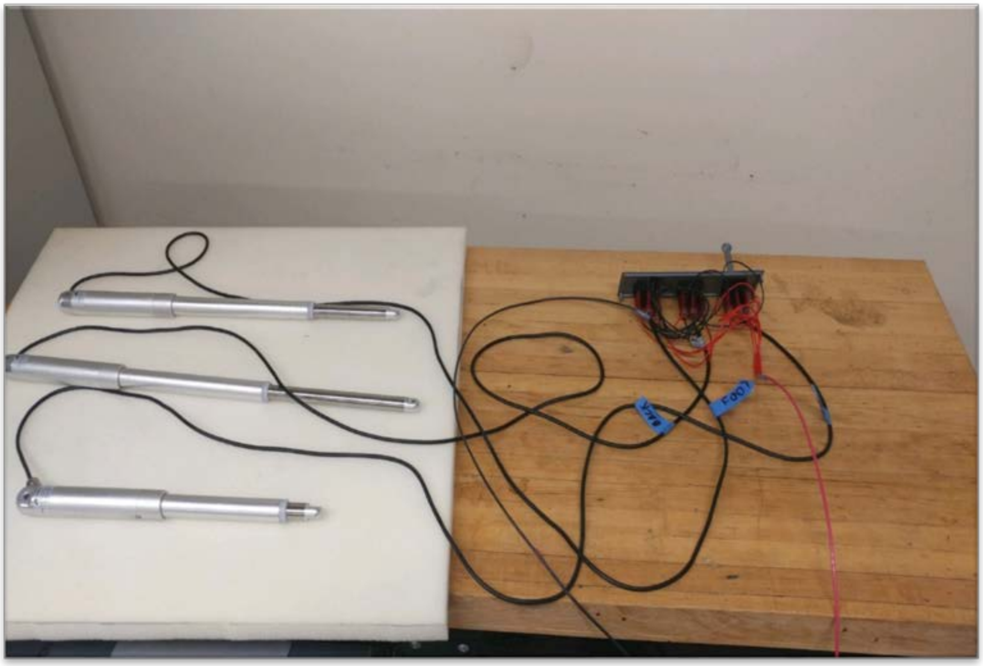


Figure 55. Electrical testing of the linear actuators and rocker switches

The next component test to perform was on the rocker switches. A rocker switch was wired to a linear actuator and then to the battery. In the resting middle position of the rocker switch, nothing happened, but once pressed in either direction, the linear actuator functioned.

In order to protect the circuit from damage or electrical fire in the event of short circuit, 10-amp in-line automotive fuses were wired into the system as close to the power source as possible. The goal of the fuses was to burn out before wiring or components burned. In order to test the function of the fuses, a short circuit was created with the fuse wired into the system. This was a destructive test and a spare fuse was on hand to replace the one being tested. In this case, personal protective equipment was worn at all times and care was taken to verify that there was no way for the path of current to flow through the tester's body. A short circuit was created and a short popping noise was heard. The fuse was checked for signs of scorch marks. The fuse was damaged and the flow of current stopped, so the fuse did its job and was replaced.

At this point, all major electrical components had been tested and the final circuit was built. After building the circuit, all functions performed as expected. No problems were found, so the electrical system was ready to be installed into the overall device. Figure 54 represents the completed circuit before installation into the final design of the mobility device.

7.3 Carbon Fiber Failure Testing

After completing the layup of the carbon fiber seat plate, testing was done to verify that it would not break under load. Since the strength of carbon fiber is highly dependent on the quality of the layup, testing was necessary before the part could be used in the final product. Based on initial analysis, the seat plate had a factor of safety of $1.44*10^{23}$. With this in mind, it was decided that doubling Nathan's design weight (50 lb_f) during testing would effectively determine if the part would be strong enough for use in the final design. The seat plate was mounted in position on the power chair, and then a 100-lb_f weight was placed on the center point of the plate. After about a day of testing this, the carbon fiber plate did not flex or show any signs of nearly failing. The carbon plate proved that it was strong enough to withstand much more than twice Nathan's weight.

7.4 Center of Gravity Testing

One of the first types of analysis performed for this design was center of gravity analysis on Nathan's body. By knowing where his center of gravity was located, the team was able to determine how his weight would be applied to the system. Center of gravity analysis also was performed in order to perform the high side roll test later. The equipment needed for this test were two identical weight scales, a measuring tape, and block of known height. The first step in this test was measuring the wheelbase. The wheelbase was the distance from the ground contact point of the rear wheels to the ground contact point of the front wheels. One scale was placed under the rear wheels and another under the front wheels. Using the recorded data from each scale, the mass distribution between the front and rear wheels was determined. This allowed for calculation of the center of gravity location in relation to the x-axis seen in Figure 56. The next step was to place either the front or rear scale on the block of known height and place the power chair on the scales in the same orientation as in step one.

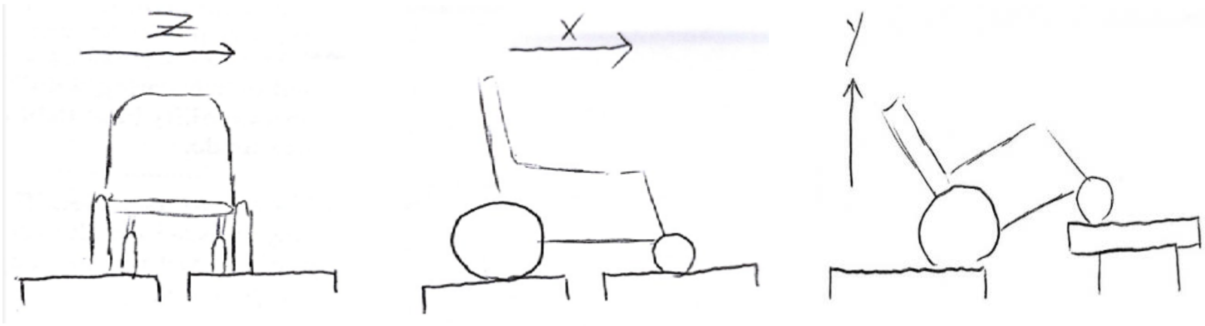


Figure 56. Center of gravity from the X, Y and Z axis

Uncertainty analysis showed that using a block less than five inches in height greatly increased uncertainty. This uncertainty analysis can be found in Appendix L. Using the new scale data and trigonometry, the center of gravity location in relation to the y-axis was found. A similar process to the first step was performed to find the z-axis center of gravity location. A scale was placed under the left set of wheels and the other scale was placed under the right set of wheels. Scale data provided the distribution of weight between the left and right and analysis using known geometry yielded a center of gravity location in the z-axis. With the x, y, and z axis' center of gravity locations known, the exact center of gravity of the device were found.

7.5 High Side Rollover Testing

This test is at its core, a test to determine if and when the mobility device will flip during turning. An increasing lateral load was applied at the center of gravity point until the device tips up onto its inside wheels. This force allowed us to determine the angular acceleration required to flip from chair. From here, a series of velocity and turning radii that could cause such an angular acceleration was developed. In practice, the center of gravity point is so low that on all but the roughest surfaces, the device slips sideways before any kind of rolling occurs. When blocks were placed behind the wheel to prevent sliding, it was determined that the amount of force required to tip the device far exceeded anything the system could encounter during any operating condition, extreme or otherwise.

7.6 Results

After completing the qualitative comfort test, the team discovered the most suitable type of cushion Nathan wanted to have integrated into the backrest design.

After the electrical system test was completed, the team was able to prove that the components in the electrical system worked well and were safe to use. The batteries connected to the user input was able to power the linear actuators, which provided the reclining motion for their respective subsystems. The integrated inline fuses were incorporated to provide added safety to the system and serve as indicators when the system is about to fail. With the 50-pound applied load, the linear actuators were able to recline the backrest, leg rest, and tilt-in-space base with little to no problems.

For the carbon fiber failure test, the seat base plate was able to withstand much more than the expected applied load. The composite analysis seen in Appendix K agrees with the results found from the applied load test. With such a high factor of safety and high weight capacity, the carbon fiber plate did not flex or experience any type of failure. The seat plate expectedly served its job and is safe for use.

For the center of gravity test, since most of the mobility device's weight came from the battery boxes located at the bottom of the device, the center of gravity was estimated to be closer to the bottom of the base. Additionally, with respect to the length of the device, the center of gravity was closer to the back of the chair, so the team was able to deduce that the chair would not be able to tip over while going at a top speed of five miles per hour and being subjected to a 50-pound load applied perpendicular to the seat cushion.

8. Project Management

This section describes the project design process and the steps Team Nathan completed in order to achieve the best possible design from start to finish.

8.1 Process Overview

As designers, Team Nathan was able to come up with a solution to a problem by implementing a process called "Design Thinking," developed by David Kelley from Stanford University. "Design Thinking" uses the following five steps to solve problems: empathize, problem definition, ideation, prototyping, and testing.

8.1.1 Empathize

By empathizing with the clients, Team Nathan was better able to approach the problem from an objective standpoint. Since the problem was viewed as though the team was the client, a complete and thorough list of customer requirements that catered to Nathan's needs was developed.

8.1.2 Problem Definition

Once Team Nathan approached the problem from the point of view of the user, a problem definition was developed. During the problem definition stage of the design process, the team compiled and analyzed all of the information collected during the empathize stage. Using all of this information, the core of the client's problem was defined in order to determine the best way to solve it. During this part of the design process, features, functions, and other key design elements were determined that were needed to solve the problem. Once the client-centered problem statement was developed, the team began to think about how the problem was going to be solved.

8.1.3 Ideation

After defining the problem, the team entered the ideation phase and began brainstorming design ideas and potential solutions to the problem. The goal during this stage was not necessarily to come up with the best idea and ignore all others, but rather to come up with a wide variety of potential solutions, ranging from industry standard to completely original. Once a large list of potential ideas was generated, non-practical ideas were eliminated to narrow the list down. The team did not entirely count out any idea since the team thought it wise to keep each idea in the case the designed product did not satisfy the customer.

8.1.4 Prototyping

After developing a list of potential design ideas and narrowing it to the current best, different options were tested out and prototypes of each concept were created. Like ideation, prototyping is iterative so the level of detail that went into the prototype depended on how far along the team was in the design process.

8.1.5 Prototype Testing

Once the final stage of prototyping was completed and the best design ideas were picked for the final product, detailed design and manufacturing were begun. The main components of the prototype were manufactured and fastened together, and a complete CAD model of the prototype was generated.

8.1.6 Manufacturing

Once prototype testing was finished, the team went on to complete the final design of the mobility device. Each subsystem and sub-assembly was designated to one person and each person was responsible for their respective subsystem. Each team member took time to go to the machine shops to make sure that their parts were finished and team-made deadlines were met on time.

8.1.7 Final Design Testing

Once the manufacturing was completed for the final assembly, the team conducted their own tests. Weight capacity/center of gravity, electrical/linear actuators, cushion compression, and maneuverability tests were done to see whether or not the final design met the criteria set by Nathan and his family. Each member was assigned to their own test and conducted them completely and thoroughly.

8.2 Gantt Chart

In addition to the design process followed, a Gantt Chart was created to assist with managing time and seeing what needed to be done, what was currently being worked on, and what had been completed. A Gantt Chart is a detailed scheduler for tasks needed to be completed over a period of time. The Gantt Chart laying out the tasks to be complete can be seen in Appendix R.

8.3 Plan Deviations

The project experienced a lot of changes in the design over the course of this past year. From PDR to CDR to FDR there have been many different setbacks that have affected the scheduling of the project. The team, however, managed to overcome these setbacks very professionally and did a decent job ensuring that everything was completed. Oftentimes as well, certain machines in the shop were undergoing maintenance, which delayed and affected the team’s scheduling. With the help of people outside of Cal Poly like Chris Gentry from Gentry Welding, the team was able to keep on track and achieve each weekly manufacturing goal to ultimately finish the mobility device in a timely manner.

Initially, the team planned to 3D print the footplate. After discussing this subject, however, Team Nathan decided that the plate might be subject to large loads that might be caused by running through static objects when operating the wheelchair. The footplate was manufactured out of aluminum to be able to withstand shocks and large loads. A batman grip was 3D-printed and was attached on top of the aluminum plate for aesthetic reasons.

One of the major changes of the initial design was the new location of the backrest actuator. Initially, the actuator was outside the base platform frame. This location made the actuator interfere with the back wheel when it was fully extended. In the new design, the actuator was installed inside the base platform frame in a location where it did not touch the battery and the frame.

The backrest and footrest actuators were initially designed to be mounted to bending plates. The plate being ¼”-thick made bending them a big challenge. The team members decided to utilize straight plates to ensure that the actuators had a reduced moment arm at the mounting points. This new design resulted in less complicated manufacturing processes, which saved the team time and effort. It also helped reduce the overall width of the wheelchair and minimized the pinch hazards that were associated with linear actuators.

9. Conclusion

The goal of this report was to provide detailed documentation on how the team went about building and designing the final product for Nathan’s mobility device. To start the project, the team interviewed the sponsors to gain an understanding of their wants and needs. From there, the team transitioned into idea generation. Once a suitable amount of ideas was formulated, the best ideas were selected using idea refinements tools such as a QFD and Pugh matrices. Initial prototyping was carried out at this stage to test the viability of certain ideas. After idea refinement and prototyping took place, a design concept was developed. This concept design used a stripped-down power chair as its base with a custom-made seat utilizing a hinge and a linear actuator to adjust seating angle. A joystick will be used to operate the device. After verifying the feasiblity of this concept design, Team Nathan began trying to find a viable power chair to purchase. Many options were considered before selecting the Quickie Z-500 pediatric power chair. After multiple iterations of design builds, a final design was chosen based on its functionality. After confirming the final design, the team researched and investigated the sub-assemblies and components necessary to complete the design. In particular, the team made sure that each component was manufacturable and within the given budget. By focusing on these two areas, manufacturing and cost, Team Nathan was able to confirm the plausibility of fully building the chair assemblies. After weeks of manufacturing and finalizing the design to Nathan’s liking, the mobility device was completed and handed over to Nathan and his family to take home.

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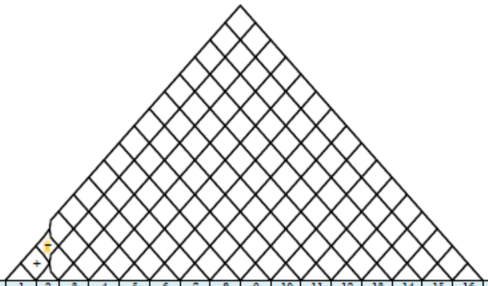
Appendix A – Quality Function Deployment

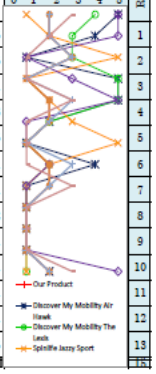
Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▾

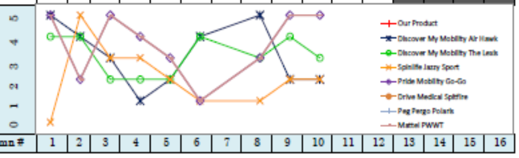
rection of Improvem	
Maximize	▲
Target	◇
Minimize	▼



					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	NOW: Current Product Assesment - Customer Requirements								
	WHO: Customers				Direction of Improvement	▼	◇	◇	◇	◇	◇	◇	▲	◇	▼	◇	▼													
Row #	Weight Chart	Relative Weight	Nathan	Maximum Relationship	HOW: Engineering Specifications / WHAT: Customer Requirements (explicit & implicit)	Weight (lb)	Capacity (lb)	Length (in)	Width (in)	Height (in)	Ground Clearance (in)	Frame Material	Battery Life	Max Speed (mph)	Cost ($)	Torque (lbf-in)	Turning Radius (in)					Our Current Product	Discover My Mobility Air Hawk	Discover My Mobility The Lexis	Spinlife Jazzy Sport	Pride Mobility Go-Go	Drive Medical Spitfire	Peg Pergo Polaris	Mattel PWWT	Row #
1	▮	8%	3	9	Light Weight	●	●	○	○	○	▾	●	○	▾	○	○	▾						5	4	1	2	2	3	5	1
2	▮▮	10%	4	9	Small Footprint	○	○	●	●	●	▾	▾	▾	▾	○	▾	▾						4	3	2	2	2	2	5	2
3	▮▮▮	13%	5	9	Adjustable Seating	○	▾	●	▾	●	▾	▾	▾	▾	○	▾	▾						1	3	5	3	3	1	1	3
4	▮▮▮	13%	5	3	Joystick Controls	▾	▾	▾	▾	▾	▾	▾	▾	○	○	○	○						5	5	1	1	1	1	3	4
5	▮	8%	3	9	Transportability	●	○	●	●	●	▾	●	▾	▾	○	▾	▾						5	5	2	2	3	3	5	5
6	▮▮▮	13%	5	3	Comfortable for Nathan	▾	▾	○	○	○	○	▾	▾	▾	○	○	▾						2	2	3	2	2	1	1	6
7	▮	8%	3	3	Has a head support	○	▾	▾	▾	○	▾	▾	▾	▾	○	▾	▾						1	1	5	1	1	1	1	7
8	▮▮	10%	4	3	Adjustable Feet support	○	▾	○	▾	▾	▾	▾	▾	▾	○	▾	▾						4	2	2	2	3	1	2	8
9	▮	5%	2	9	Safety Features	○	▾	▾	▾	▾	●	○	▾	○	○	○	○						1	1	1	2	2	3	1	9
10	▮	5%	2	3	Batman aesthetic	▾	▾	▾	▾	▾	▾	○	▾	▾	○	▾	▾						1	1	1	1	1	1	1	10
11	▮	3%	1	9	Interchangeable batteries	●	▾	▾	▾	▾	▾	▾	●	▾	●	▾	▾						1	1	1	1	1	1	1	11
12	▮	5%	2	9	Powered Reclining	○	▾	▾	▾	▾	▾	▾	▾	▾	●	▾	▾						1	1	1	1	1	1	1	12
13	▮	3%	1	9	Multi-terrain	▾	▾	▾	▾	▾	●	▾	▾	▾	▾	●	▾						2	1	1	2	2	3	5	13

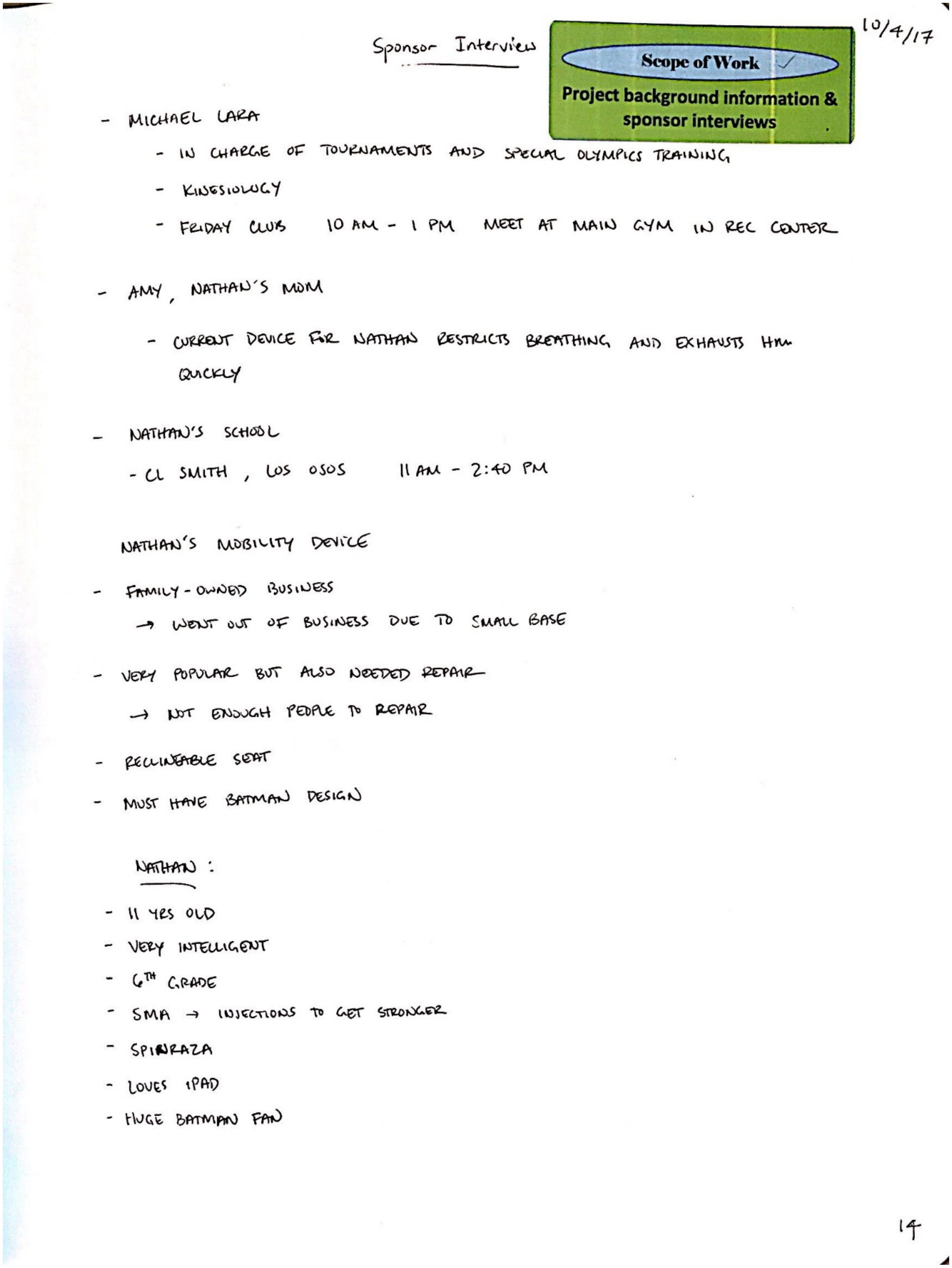


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target	50 lbs	50 lbs	42 in	24 in	36 in	3 in	NA	20 mi	5 mph	$3,000	NA	NA				
Max Relationship	9	9	9	9	9	9	9	9	3	9	9	3				
Technical Importance Rating	340	##	400	280	395	185	240	135	135	340	195	135				
Relative Weight	11%	7%	13%	9%	13%	6%	8%	5%	5%	11%	7%	5%				
Weight Chart	▬▬	▬	▬▬	▬▬	▬▬	▬	▬▬	▬	▬	▬▬	▬	▬				
Current Product Assessment - Engineering Specifications: Our Product																
Discover My Mobility Air Hawk	5	4	3	1	2	4		5	2	2						
Discover My Mobility The Lexis	4	4	2	2	2	4		3	4	3						
Spinlife Jazzy Sport	0	5	3	3	2	1		1	2	2						
Pride Mobility Go-Go	1	5	2	5	3	1		2	2	4						
Drive Medical Spitfire	1	5	5	3	3	2		1	3	4						
Peg Pergo Polaris	2	2	3	3	2	3		3	5	5						
Mattel PWWT	5	2	5	4	3	1		3	5	5						
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16



Template Revision: 0.9
Christopher Battles

Appendix B - Sponsor Interview Notes



Sponsor Interview

10/4/17

Scope of Work ✓

Project background information & sponsor interviews

- MICHAEL LARA
    - IN CHARGE OF TOURNAMENTS AND SPECIAL OLYMPICS TRAINING
    - KINESIOLOGY
    - FRIDAY CLUB 10 AM - 1 PM MEET AT MAIN GYM IN REC CENTER
- AMY, NATHAN'S MOM
    - CURRENT DEVICE FOR NATHAN RESTRICTS BREATHING AND EXHAUSTS HIM QUICKLY
- NATHAN'S SCHOOL
    - CL SMITH, LOS OSOS 11 AM - 2:40 PM

NATHAN'S MOBILITY DEVICE

- FAMILY-OWNED BUSINESS
    - → WENT OUT OF BUSINESS DUE TO SMALL BASE
- VERY POPULAR BUT ALSO NEEDED REPAIR
    - → NOT ENOUGH PEOPLE TO REPAIR
- RECLINEABLE SEAT
- MUST HAVE BATMAN DESIGN

NATHAN:

- 11 YRS OLD
- VERY INTELLIGENT
- 6TH GRADE
- SMA → INJECTIONS TO GET STRONGER
- SPINRAZA
- LOVES IPAD
- HUGE BATMAN FAN

14

Appendix C – Patent Search

Patent	Date	Number	Description
Modular Wall Proximity Reclining Chair	11/05/1996	US5570927	The modular wall proximity reclining/tilt chair has an actuation mechanism that reduces system complexity and weight while improving seat comfort. The actuation mechanism is suspended from and interdependent with the box-like modular frame components.
Seating Furniture Component with Coupled Backrest and Seat Adjustment	01/19/1999	US5860701	A seating furniture component with coupled backrest and seat adjustment has a support chassis, backrest and seat adjustably attached to the support chassis while being movably joined to one another in the area of the vertex of the angle between them, backrest coupled to a pivot axis on the support chassis at a distance above the vertex of the angle, and seat movably attached to the support chassis near the front of the sesat by a support mechanism. The backrest reclines while the seat simultaneously slides and lifts. The backrest and seat connection has two connecting axes on each side which run in two slotted cranks as connecting axis and slotted crank pairs.
Foldable Personal Mobility Vehicle	11/18/2008	US7451848B2	A foldable personal mobility vehicle is disclosed comprising first and second units having first and second wheels rotating about the first and second axles. A drive unit rotates the second wheel for moving the foldable mobility vehicle. A pivot disposed parallel to the first and second axles connects the first and second unit for folding the mobility vehicle.

Patent	Date	Number	Description
Traction Control in a Maneuverable Motorized Personally Operated Vehicle	08/23/2006	US20070045022A1	A personal mobility vehicle has a frame, ground engaging front wheel connected to the frame and configured to simultaneously drive and steer the personal mobility device, drive motor connected to the front wheel, steering mechanism connected to the front wheel, and rear suspension including two or more ground engaging rear wheels mounted to support the frame. One or more rear anti-tip wheels are mounted to the frame. A mechanism for distributing the weight away from the rear wheels and on the rear anti-tip wheels is used to prevent backwards tipping.
Lightweight Motorized Wheelchair	02/06/2001	US6183002B1	The lightweight motorized wheelchair includes a seat bottom and foldable seat back pivotally coupled to the seat bottom. A motor coupled to the rear wheels and control stick is in communication with each motor to operate each motor to drive and steer the wheelchair.
Motor Vehicle Adjustable Seat	01/07/1999	DE19726680C2	The seat has a front part that is longitudinally and vertically adjustable and adjustable in relation to the seat base part. The seat base part has a longitudinal guide which cooperate with the counterparts in the seat base part. The front part of the seat moves as a function of the seat height so that seat depth is greatest at minimum seat height and smallest at maximum seat height.

Patent	Date	Number	Description
Collapsible Vehicle	06/28/2011	US7967095B2	A powered vehicle has rear and front frame assembly attached to one another and can be pivoted from a fully-extended position to a folded position, reducing overall vehicle length to half. One or more latch members lock the front and rear frame assemblies in the fully-extended position and may be used to lock the frame assemblies in the folded position. The seat support may be integrated with the front or rear frame assemblies so the seat support can pivot and collapse. The steering tiller can collapse to the front frame, and the rear wheels may be mounted on a transaxle pivotally mounted on the rear frame assembly. An extended handle can also help with collapsing the vehicle and tow it on the anti-tip rollers.

Appendix D – DESIGN HAZARD CHECKLIST

Team: _Team Nathan__ Advisor: __Sarah Harding____ Date: __November 15, 2017__

Y N

☑ ☐ 1. Will the system include hazardous revolving, running, rolling, or mixing actions?

☐ ☑ 2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?

☐ ☑ 3. Will any part of the design undergo high accelerations/decelerations?

☑ ☐ 4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?

☐ ☑ 5. Could the system produce a projectile?

☐ ☑ 6. Could the system fall (due to gravity), creating injury?

☐ ☑ 7. Will a user be exposed to overhanging weights as part of the design?

☐ ☑ 8. Will the system have any burrs, sharp edges, shear points, or pinch points?

☑ ☐ 9. Will any part of the electrical systems not be grounded?

☐ ☑ 10. Will there be any large batteries (over 30 V)?

☐ ☑ 11. Will there be any exposed electrical connections in the system (over 40 V)?

☐ ☑ 12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?

☐ ☑ 13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?

☐ ☑ 14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?

☐ ☑ 15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?

☐ ☑ 16. Could the system generate high levels (>90 dBA) of noise?

☑ ☐ 17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?

☐ ☑ 18. Is it possible for the system to be used in an unsafe manner?

☑ ☐ 19. For powered systems, is there an emergency stop button?

☐ ☑ 20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.☑

Appendix D – Continued

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The systems castor wheels and powered wheels will rotate	The wheels will most likely be out of reach of the user. In the event they are close, wheel covers can be used		
The system itself will be a large moving mass	As long as proper stability calculations are done and max speed is limited, this shouldn't be a big issue.		
Because of the systems rubber wheels, it cannot be grounded	The entirety of the electric system will be covered in non-conductive material to protect the user from shock		
The system could be exposed to extreme weather conditions.	A suggested usage guide will be given to the user telling them not to operate the device in extreme weather		
The user could drive this device unsafely	A suggested usage guide will be given to the user telling them not to operate the device unsafely		
The system, is powered	A stop button is present on the device		

Appendix E - Concept Ideas List

Concept 1: Power chair, joystick, simple hinge, and linear actuator

Concept 2: Power chair, joystick, recliner mechanism, and linear actuator

Concept 3: Power chair, steering wheel, simple hinge, and linear actuator

Concept 4: Power chair, steering wheel, recliner mechanism, and linear actuator

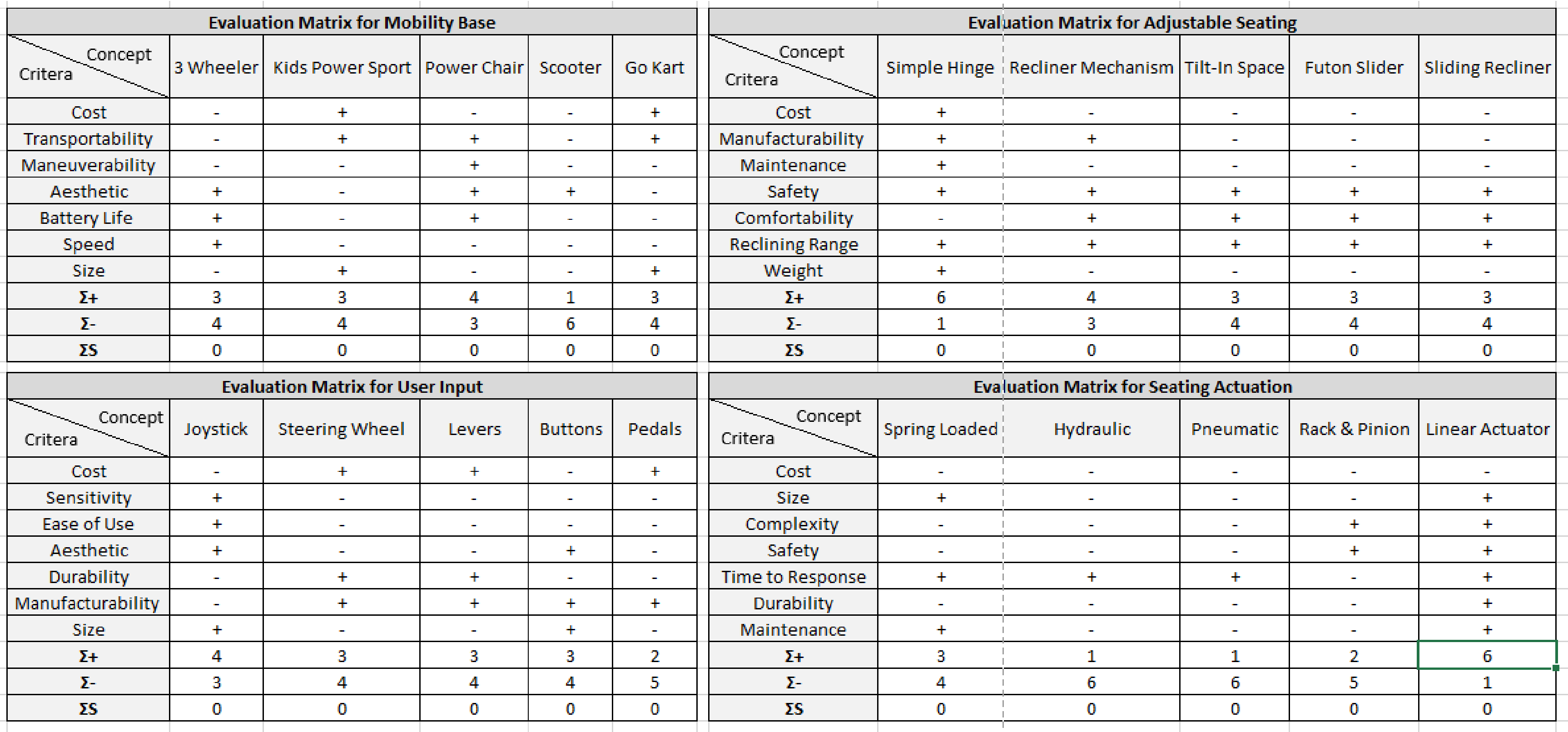
Concept 5: Scooter, joystick, simple hinge, and linear actuator

Concept 6: Scooter, joystick, recliner mechanism, and linear actuator

Concept 7: Scooter, steering wheel, simple hinge, and linear actuator

Concept 8: Scooter, steering wheel, recliner mechanism, and linear actuator

Appendix F – Pugh Matrices



Evaluation Matrix for Mobility Base

Concept Critera	3 Wheeler	Kids Power Sport	Power Chair	Scooter	Go Kart
Cost	-	+	-	-	+
Transportability	-	+	+	-	+
Maneuverability	-	-	+	-	-
Aesthetic	+	-	+	+	-
Battery Life	+	-	+	-	-
Speed	+	-	-	-	-
Size	-	+	-	-	+
Σ+	3	3	4	1	3
Σ-	4	4	3	6	4
ΣS	0	0	0	0	0

Evaluation Matrix for Adjustable Seating

Concept Critera	Simple Hinge	Recliner Mechanism	Tilt-In Space	Futon Slider	Sliding Recliner
Cost	+	-	-	-	-
Manufacturability	+	+	-	-	-
Maintenance	+	-	-	-	-
Safety	+	+	+	+	+
Comfortability	-	+	+	+	+
Reclining Range	+	+	+	+	+
Weight	+	-	-	-	-
Σ+	6	4	3	3	3
Σ-	1	3	4	4	4
ΣS	0	0	0	0	0

Evaluation Matrix for User Input

Concept Critera	Joystick	Steering Wheel	Levers	Buttons	Pedals
Cost	-	+	+	-	+
Sensitivity	+	-	-	-	-
Ease of Use	+	-	-	-	-
Aesthetic	+	-	-	+	-
Durability	-	+	+	-	-
Manufacturability	-	+	+	+	+
Size	+	-	-	+	-
Σ+	4	3	3	3	2
Σ-	3	4	4	4	5
ΣS	0	0	0	0	0

Evaluation Matrix for Seating Actuation

Concept Critera	Spring Loaded	Hydraulic	Pneumatic	Rack & Pinion	Linear Actuator
Cost	-	-	-	-	-
Size	+	-	-	-	+
Complexity	-	-	-	+	+
Safety	-	-	-	+	+
Time to Response	+	+	+	-	+
Durability	-	-	-	-	+
Maintenance	+	-	-	-	+
Σ+	3	1	1	2	6
Σ-	4	6	6	5	1
ΣS	0	0	0	0	0

Appendix G – Decision Matrices

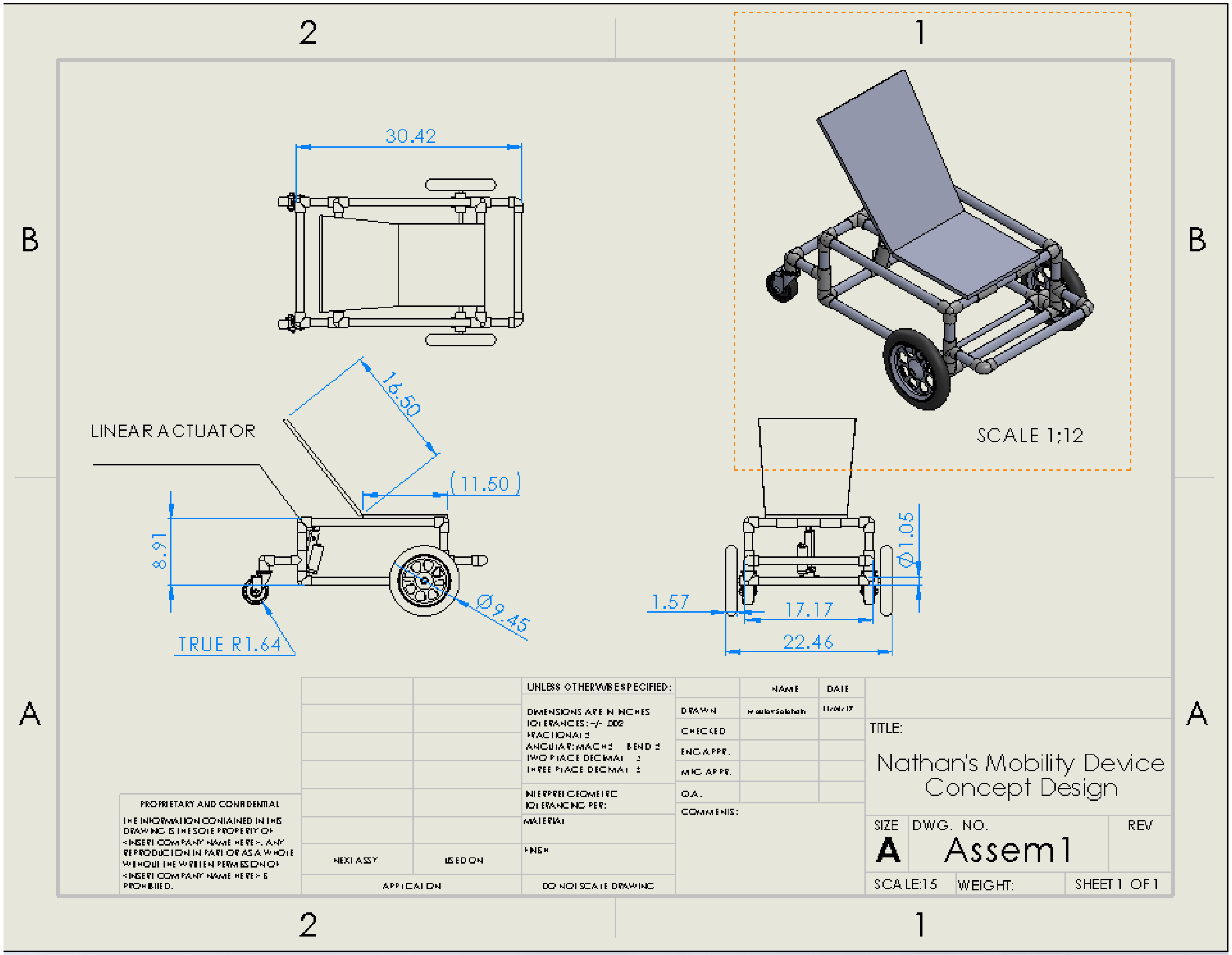
Morphological Matrix

Mobility Base	Power Chair	Scooter
User Input	Joystick	Steering Wheel
Adjustable Seating	Simple Hinge	Recliner Mechanism
Seating Actuation	Linear Actuator	Rack and Pinion

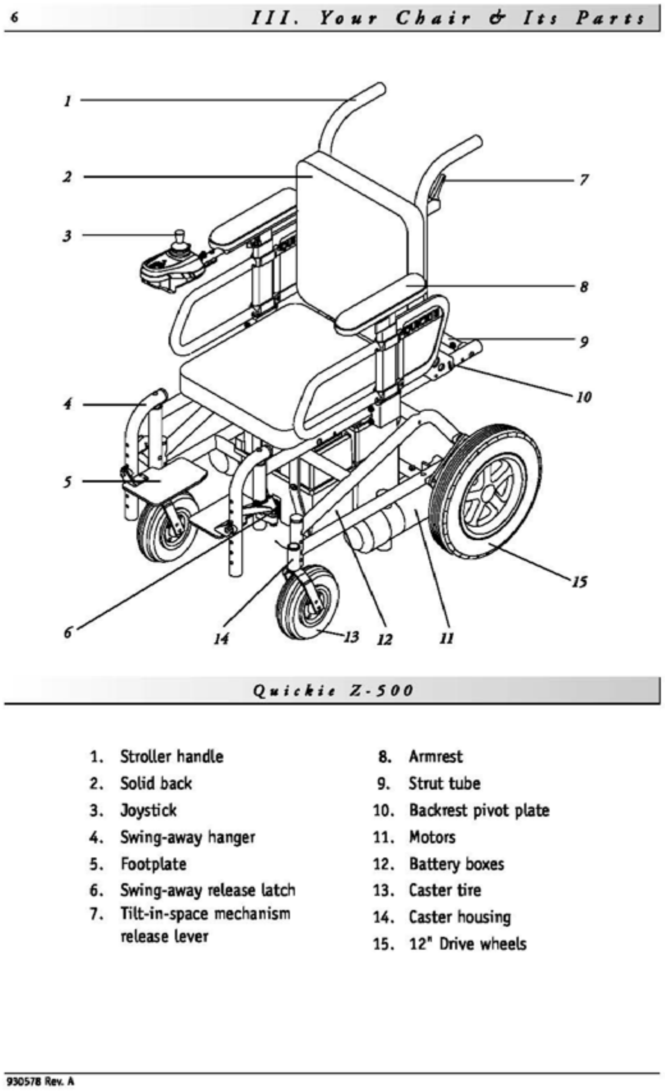
Weighted Design Matrix

	Cost	Size	Comfortable	Aesthetic	Safety	Durability	Maintenance	Manufacturability	Speed	Ease of Use	Total
Weight	5	4	4	3	5	3	2	3	1	2	
Power Chair/Joystick/Simple Hinge/ Linear Actuator	5	4	5	3	4	4	4	4	5	5	137
Power Chair/Joystick/Recliner Mechanism/ Linear Actuator	4	3	5	3	4	2	3	2	5	5	114
Power Chair/Steering Wheel /Simple Hinge/ Linear Actuator	5	4	5	3	4	4	4	4	5	3	133
Power Chair/Steering Wheel /Recliner Mechanism/ Linear Actuator	4	3	5	3	4	2	3	2	5	3	110
Scooter/Joystick/Simple Hinge/ Linear Actuator	4	3	5	4	4	4	4	4	5	5	131
Scooter/Joystick/Recliner Mechanism/ Linear Actuator	3	2	5	4	4	2	3	2	5	5	108
Scooter/Steering Wheel /Simple Hinge/ Linear Actuator	4	3	5	4	4	4	4	4	5	3	127
Scooter/Steering Wheel /Recliner Mechanism/ Linear Actuator	3	2	5	4	4	2	3	2	5	3	104

Appendix H – Concept Layout Drawing

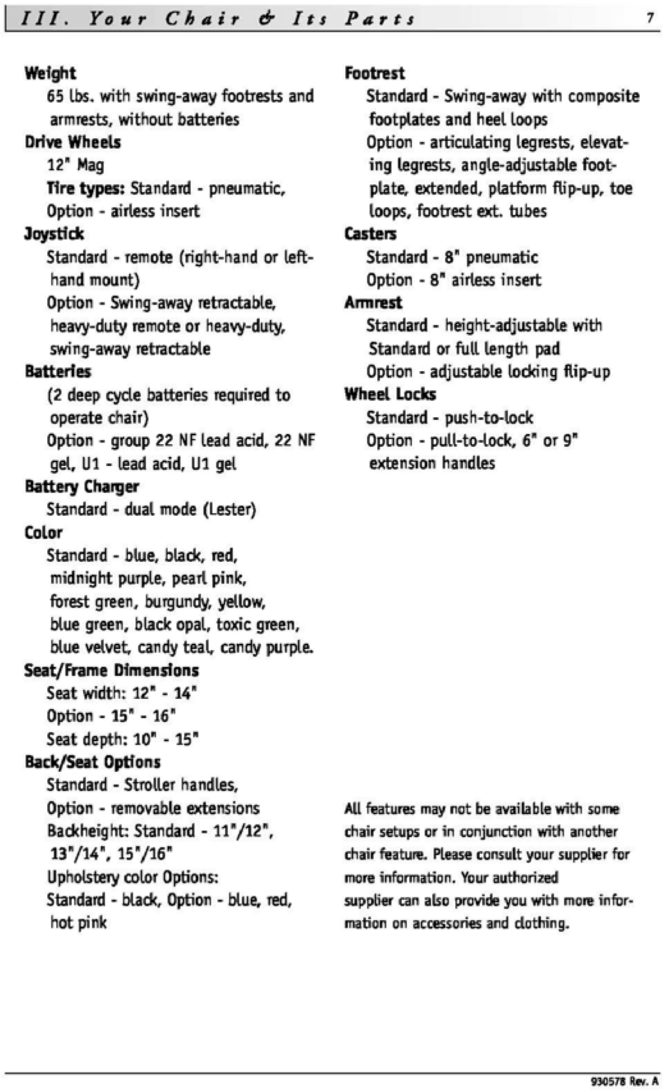


Appendix I – Quickie Z-500 User Manual



Quickie Z-500

1. Stroller handle
2. Solid back
3. Joystick
4. Swing-away hanger
5. Footplate
6. Swing-away release latch
7. Tilt-in-space mechanism release lever
8. Armrest
9. Strut tube
10. Backrest pivot plate
11. Motors
12. Battery boxes
13. Caster tire
14. Caster housing
15. 12" Drive wheels



Weight
65 lbs. with swing-away footrests and armrests, without batteries

Drive Wheels
12" Mag
Tire types: Standard - pneumatic, Option - airless insert

Joystick
Standard - remote (right-hand or left-hand mount)
Option - Swing-away retractable, heavy-duty remote or heavy-duty, swing-away retractable

Batteries
(2 deep cycle batteries required to operate chair)
Option - group 22 NF lead acid, 22 NF gel, U1 - lead acid, U1 gel

Battery Charger
Standard - dual mode (Lester)

Color
Standard - blue, black, red, midnight purple, pearl pink, forest green, burgundy, yellow, blue green, black opal, toxic green, blue velvet, candy teal, candy purple.

Seat/Frame Dimensions
Seat width: 12" - 14"
Option - 15" - 16"
Seat depth: 10" - 15"

Back/Seat Options
Standard - Stroller handles,
Option - removable extensions
Backheight: Standard - 11"/12", 13"/14", 15"/16"
Upholstery color Options:
Standard - black, Option - blue, red, hot pink

Footrest
Standard - Swing-away with composite footplates and heel loops
Option - articulating legrests, elevating legrests, angle-adjustable footplate, extended, platform flip-up, toe loops, footrest ext. tubes

Casters
Standard - 8" pneumatic
Option - 8" airless insert

Armrest
Standard - height-adjustable with Standard or full length pad
Option - adjustable locking flip-up

Wheel Locks
Standard - push-to-lock
Option - pull-to-lock, 6" or 9" extension handles

All features may not be available with some chair setups or in conjunction with another chair feature. Please consult your supplier for more information. Your authorized supplier can also provide you with more information on accessories and clothing.

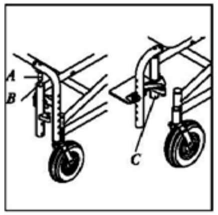
CHECK-OUT

Be sure this chair performs to your chosen operational settings. If it does not, turn the chair off immediately and reprogram with the Quickie QTRONIX Programmer. If you do not own a Quickie QTRONIX Programmer have your supplier reprogram your wheelchair as needed. Or, you can order a Quickie QTRONIX Programmer for your own use, from your supplier.

NOTE– Repeat this procedure until the chair performs to your specifications

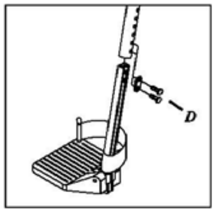
⚠WARNING

When properly set-up, this chair will operate smoothly. Check to see that all components work properly. If you detect a problem, be sure to correct it before use.

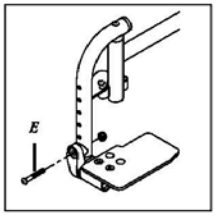


A. SWING-AWAY FOOTRESTS

1. **Installation**
   a. Place swing-away pivot saddle (A) into the receiver (B) on front frame tube with the footrest facing outward from the frame.
   b. Rotate the footrest inward until it locks into place on locking bolt.
2. **Removal**
   a. To remove footrest, push release latch (C) toward the frame.
   b. Rotate footrest outward, and lift.

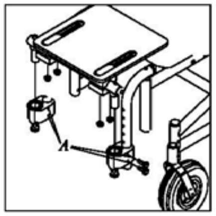


3. **Height-Adjustment**
   a. Loosen set screws (D).
   b. Slide footrest extension up or down inside frame tube to desired height.
   c. Tighten set screws.

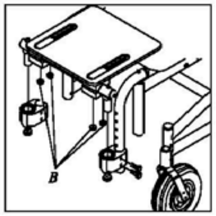


4. **Footplate Angle-Adjustment**
   a. Loosen the retaining bolt (E) in the frame tube.
   b. Reposition footplate to desired angle.
   c. Tighten bolt.

B. 90° FOOTBOARD

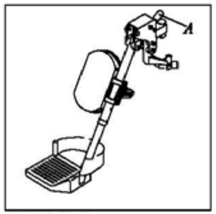


1. **Height-Adjustment**
   a. Loosen the four clamp bolts (A) underneath the footboard assembly.
   b. Position footplate at desired height.
   c. The adjustment on each side of the footrest should be of equal height.
   d. Tighten nuts.



2. **Angle-Adjustment**
   a. Loosen the four nuts (B) underneath the footboard assembly until the mounting tubes rotate freely.
   b. Adjust mounting tube length, by sliding the tubes inward or outward so it slides easily into the sleeves.
   c. Adjust the angle of the footboard.
   d. Slide it forward or backward for correct placement.
   e. Tighten nuts.

C. ARTICULATING LEGREST (OPTIONAL)



Articulating Legrests

1. **Installation**
   To install or remove Articulating Legrest (ALR) see instructions for Swing-away Footrest installation on page 28.
2. **Adjustment**
   a. To raise legrest, lift to desired position. Legrest will automatically lock in place.
   b. To lower legrest, while seated in chair, first lift slightly then lift release lever (A) up and lower legrest to desired position. Legrest will automatically lock in place.

D. ELEVATING LEGREST (OPTIONAL)

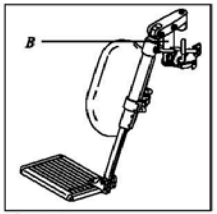
1. Installation

To install or remove Elevating Legrest (ELR) see instructions for Swing-away Footrest installation on page 28.

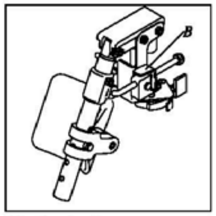
2. Adjustment

a. To raise legrest, lift to desired position. Legrest will automatically lock in place.

b. To lower legrest, while seated in chair, lift legrest slightly while pressing release lever (B) down and lower legrest to desired position. Legrest will automatically lock in place.



Elevating Legrests



90° Elevating Legrests

E. REMOTE JOYSTICK INSTALLATION

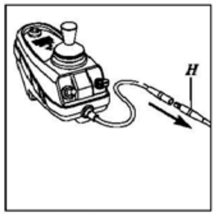
1. To Connect

a. Line up small cylindrical connector with its receptacle on the rear of the joystick.

b. Push in firmly.

2. To disconnect

Pull back on the retaining ring (H) of the cylindrical connector until it disconnects from the joystick box.



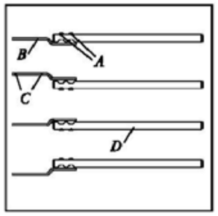
Remote Joystick

F. TO ADJUST THE HEIGHT OF THE REMOTE JOYSTICK

a. Remove the two pan-head screws (A), securing the angle bracket mount (B).

b. Remove the Joystick from the mount by unfastening the two screws (C) on the underside of the mount.

c. Position angle bracket mount such that you achieve the desired joystick height. Four positions are available by relocating the mount either on the top or bottom of the mounting bar (D) and/or by rotation of the angle bracket mount.



G. REMOTE JOYSTICK SWING-AWAY RETRACTABLE MOUNT (OPTIONAL)

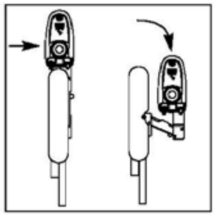
The remote joystick is mounted with a mechanism which allows the control to be locked in a forward or retracted position using magnets.

Adjustment

a. To retract joystick, push outward on the inside of joystick.

b. Push joystick away from front of armrest until it locks into retracted position.

c. To return to forward position, push joystick forward until it locks into place.



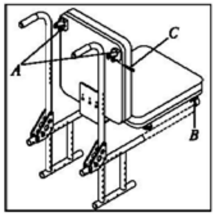
H. SOLID BACK AND SEAT INSERT

1. Installation

a. Place the solid back hook clamps (A) on the push handles.

b. Position solid seat on the top of front frame and press down until the saddles (B) are secured on the frame.

c. Insert the quick-release pins (C) through the mounting hole on the hook clamps.



I. WHEEL LOCKS

Quickie wheelchairs are shipped with high-mount wheel locks. Wheel locks are installed at Sunrise unless you have requested otherwise.

Use a torque setting of 100 in./lbs when setting-up wheel locks.

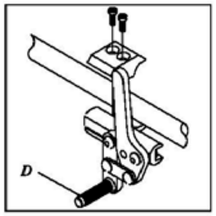
1. High-Mount Wheel Lock:

a. Loosen the screws on the top of each clamp. Do not attempt to remove one screw at a time.

b. Slide assembly toward rear wheel until clamp (D) embeds into tire to prevent wheel movement when in locked position.

c. Adjust angle position.

d. Tighten screws.



J. HEIGHT-ADJUSTABLE ARMRESTS (OPTIONAL)

1. Installation

a. Slide the outer armpost into the receiver mounted to the wheelchair frame.

b. The armrest will automatically lock into place.

2. Height Adjustment

a. Rotate release lever to second stop.

b. Slide armrest pad up or down to desired height.

c. Return lever to locked position against armpost.

d. Push arm pad until upper armpost locks firmly into place.

3. Removing Armrest

a. Rotate release lever to first stop and remove the armrest.

4. Replacing Armrest

a. Slide armrest back into receiver.

b. Return release lever to locked position against armpost.

5. Adjusting Armrest Receiver Fit

To tighten or loosen the fit of the outer armpost in the receiver:

a. Loosen the four bolts on the sides of the receiver.

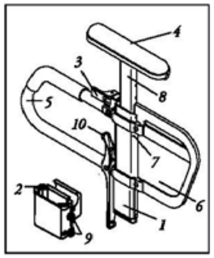
b. With the armrest in the receiver, squeeze the receiver to achieve the desired fit.

c. Tighten the four bolts.

6. Adjusting Inner Armpost Fit

a. Two set screws are installed in the outer armpost.

b. Turn the set screws in or out until the desired fit is achieved.



Height-Adjustable Armrest Key

1. Outer armpost
2. Standard receiver
3. Release lever
4. Armrest pad
5. Transfer bar
6. Side panel
7. Outer armpost tension adjustment set screws
8. Inner armpost
9. Receiver adjustment bolts
10. Release Lever

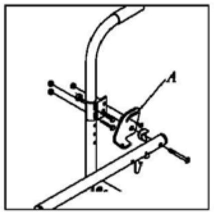
K. ADJUSTABLE LOCKING FLIP-UP ARMREST (OPTIONAL)

1. Adjustment

a. Loosen clamp bolts.

b. Move clamp up or down backrest posts to desired position.

c. Tighten bolts.

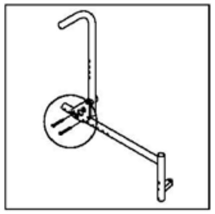


2. Angle-Adjustment

a. Loosen bolt.

b. Set armrest at desired angle using preset holes in armrest angle (A) plate.

c. Tighten bolt.



L. SEAT DEPTH

The solid back has an adjustment range of 6".

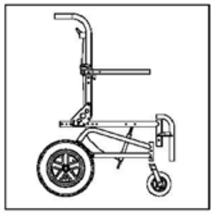
1. Adjustment

a. Remove the two bolts securing the backrest pivot onto the seat frame.

b. Position the backrest pivot plate in the pre-drilled holes on the frame.

c. Replace bolts and tighten securely.

NOTE– This adjustment may also require repositioning the seat-to-back bracket (underneath the solid seat) into the second set of mounting holes.



M. TILT-IN-SPACE MECHANISM

The tilt-in-space mechanism is installed at Sunrise. A cable trigger mechanism positively locks in place from 90° to 145°.

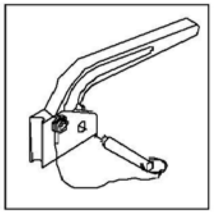
1. Adjustment

a. Loosen jam by turning it clockwise.

b. Turn the cable adjuster piece until looseness is removed from cable.

c. Tighten jam nut.

NOTE– With 15" and 16" frames two tilt-in-space mechanisms are required.



N. NONTILT

A 15" angle-adjustment is standard on all Quickie Z-500 wheelchairs with a nontilt option.

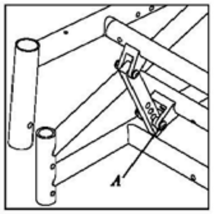
1. Nontilt Bracket Adjustment

a. Remove the lower securing bolt (A) on the nontilt bracket.

b. Set at desired angle. There are five holes (in 3" increments) to choose from.

c. Reinstall the bolt and tighten securely.

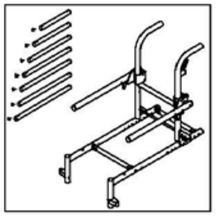
IMPORTANT NOTE– Do not position the front seat height lower than the rear.



O. STRUT TUBES

1. Width Adjustment

a. Replace the three strut tubes and release bar with larger or smaller sizes. Strut tubes and release bars are available from your authorized supplier.



NOTE ON WIDTH ADJUSTMENT– Size changes may require a larger seat insert and footplates. 15" and 16" widths receive adult hangers.

P. CHECK-OUT

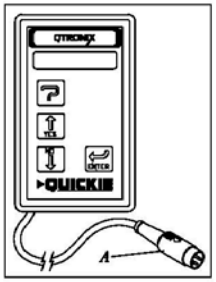
After the wheelchair is assembled and adjusted, it should roll smoothly and easily. All accessories should also perform smoothly. If you have any problems, follow these procedures:

1. **Review Set-up, Adjustment & Use sections to make sure chair was properly prepared.**
2. **If your problem persists, contact your authorized supplier. If you still have a problem after contacting your authorized supplier, contact Sunrise customer service. See the introduction page for details on how to contact your authorized supplier or Sunrise customer service.**

A. PERFORMANCE CONTROL SETTINGS

1. It is vital to match control settings to your level of function and ability.
2. Consult your health care professional and your supplier to select the best control settings for you.
3. Check and adjust the settings every six to twelve months (or more often, if needed).
4. Adjust the control settings **immediately** if you notice any change in your ability to:
   - •Control the joystick.
   - •Hold your torso erect.
   - •Avoid running into objects.
5. Control Settings are adjusted through the use of the Quickie QTRONIX Programmer. See your supplier if you do not own a Quickie QTRONIX Programmer pad.

B. QTRONIX PROGRAMMING PAD (OPTIONAL)



⚠WARNING

Program settings beyond the ability of the rider can result in serious injury. Consult your health care advisor before you alter settings.

1. Notes:

The Qtronix Programmer lets you adjust the control settings of the Z-500. You can customize a program for yourself or select the standard program.

- acceleration rate
- deceleration rate
- turn acceleration
- turn deceleration
- forward speed (max & min)
- reverse speed (max & min)
- turn speed (max & min)
- steer correct
- 4-axis joystick throw
- sleep timer

2. To Program Your Chair:

a. Turn **off** power to the chair.

b. Insert Qtronix Programmer plug (A) into the Programmer/Charger socket on the front of the remote joystick.

c. Turn **on** power to the chair; program as needed.

d. Remove plug and cycle ON/OFF switch to drive chair.

NOTE– Review the Qtronix Programmer Owner's Manual for more details on how to program your chair.

NOTE– Program settings that are not matched for the capabilities of the rider can result in serious injury. Do not alter settings without the advice of your health care professional.

C. THERMAL ROLL-BACK

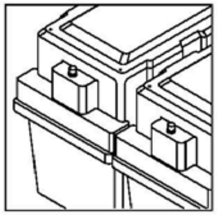
Your chair has a thermal roll-back circuit. This protects the controller from damage due to overheating. In extreme conditions (such as repetitive hill climbing) the circuit will decrease the power to your motors. This allows the chair to operate at a reduced speed. When the controller cools, the chair will return to normal speed.

D. CIRCUIT BREAKERS

1. Notes:

Your Quickie Z-500 has two battery boxes, with a circuit breaker on each box.

- In the unlikely event of a short circuit or heavy overload, all power to your chair will be shut off.
- To reset your chair, depress the circuit breaker button(s) on the front of the battery boxes. A few minutes wait is required before the circuit breaker(s) will reset.

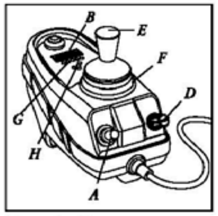


2. Repeated Shutdown

If the chair continues to shut down after resetting, have it serviced by a supplier.

E. JOYSTICK ASSEMBLY

The joystick connects to a controller, which controls the chair's performance. The joystick assembly consists of the following parts:



Remote Joystick

1. Speed Control Knob (A)

Use the speed control knob to adjust the maximum speed of your chair. Turn it counter-clockwise to reduce speed; turn it clockwise to increase speed.

2. Battery Charge Indicator (B)

- Green lights indicate that batteries are fully charged.
- Yellow lights indicate that batteries need recharging.
- When the lights stay in the red band, the batteries must be recharged.

---

3. On/Off switch (D)

The on/off/mode switch is located on the rear face of the joystick housing. It is a toggle switch. Turning the chair on or off is accomplished by pressing the switch downward. The switch will automatically return to the center point. Alternate locations exist for this switch. Please see your supplier in the event that you wish to relocate or re-orient this switch.

4. Mode Switch (D)

The on/off/mode switch allows you to select from 5 (five) different programmable drive profiles or actuator mode sets.

- Push up the on/off/mode select toggle switch to index among the five drive and actuator modes. The selected mode indicator will flash.
- Push joystick either left or right to select one of the five drive profiles. To select the actuator modes, push the mode select switch twice.
- The drive profiles are indicated by the mode indicators (G) and the actuators are indicated by the four actuator lights (H).
- To exit drive or actuator mode select, simply push the on/off/mode toggle up one or more times until the indicator no longer flashes, or push the joystick forward or reverse to begin driving.

5. JOYSTICK (E)

The joystick controls the direction and speed of your chair. Turn the chair on and move the joystick in the direction you want to go.

- Moving the joystick from the neutral (center) position disengages the motor locks, allowing the chair to move.
- The chair will move faster the more you move the joystick away from neutral.
  NOTE– If your speed becomes hard to manage, release the joystick and the chair will come to a complete stop.
- When you release the joystick it will return to neutral; the chair will slow to a stop and the motor locks will reengage.
- We recommend that you switch the chair off if you stop for any length of time. This will conserve battery power.

NOTE– Once the chair stops, switching the chair off will not affect the motor locks.

6. Joystick Boot (F)

Make sure the boot is not torn or cracked (this could allow debris, water or moisture to enter). If the boot is torn or cracked, replace it as soon as you can.

7. Remote Switch Jacks (optional) (I)

Two 1/8" mono jacks are optional to provide remote switch control of the on/off power function and the mode select function. Any of the single switches offered by Sunrise Medical can be used to connect to either or both of these jacks (except the single zero touch switch).

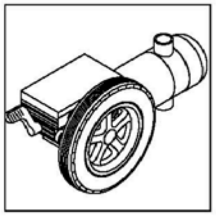
⚠WARNING

1. Never use the ON/OFF switch to stop your chair except in an emergency. This will result in an abrupt stop and may cause you to fall.

2. To slow or stop your chair, return the joystick to neutral.

F. MOTOR LOCKS

Disconnect the motor locks when you need to manually push the chair. (For example, in an emergency, or if batteries fail).



⚠WARNING

1. Do not disengage motor locks unless power to the chair is off.

2. Be aware that the chair will not have brakes in the free-wheel position.

3. Make sure that the person pushing the chair has full control when motor locks are disengaged.

1. Disengage Motor Locks

a. Turn the levers (both left and right side) inward to the free wheel position.

2. Engage Motor Locks

a. Turn the levers (both left and right side) outward into the drive position.

A. INTRODUCTION

1. Notes:

- Batteries supply the power for your chair. They contain a finite amount of energy and have limits on how long they can store and supply energy.
- You can charge batteries only a certain number of times before they will fail and no longer hold a charge.
- For answers to questions about batteries, consult your supplier.

2. Use Proper Batteries:

Your chair operates on two 12 volt batteries.

- They should be 22 NF or U1 size with a minimum of 30 ampere hour rating. Only **deep cycle sealed case** construction should be used in this device.
- When you buy a replacement, insist on a deep cycle sealed case type. Do not use a car starter battery.

3. Breaking In:

- A battery requires "breaking-in" for the first 6 to 12 charges. It will not accept a full charge for this period.
- It is best to limit the length of your trips until you break the batteries in and you know the range of your chair.

4. Discharged Batteries:

- **Never** allow a battery to completely discharge. If you operate your wheelchair until it has almost stopped, you will greatly reduce the life of your batteries.
- **Never** let a battery sit in a discharged condition. Give unused or stored batteries a full charge once per month.
- **Always** fully charge the batteries. **Avoid** "topping off" with frequent charges.

⚠WARNING

Never connect a life support or auxiliary device to a wheelchair battery. The electrical system may fail and result in severe injury to or death of rider.

B. BATTERY CHARGER

A battery charger produces a direct current (DC). When applied to a discharged battery, this reverses the chemical reaction that led to its discharge.

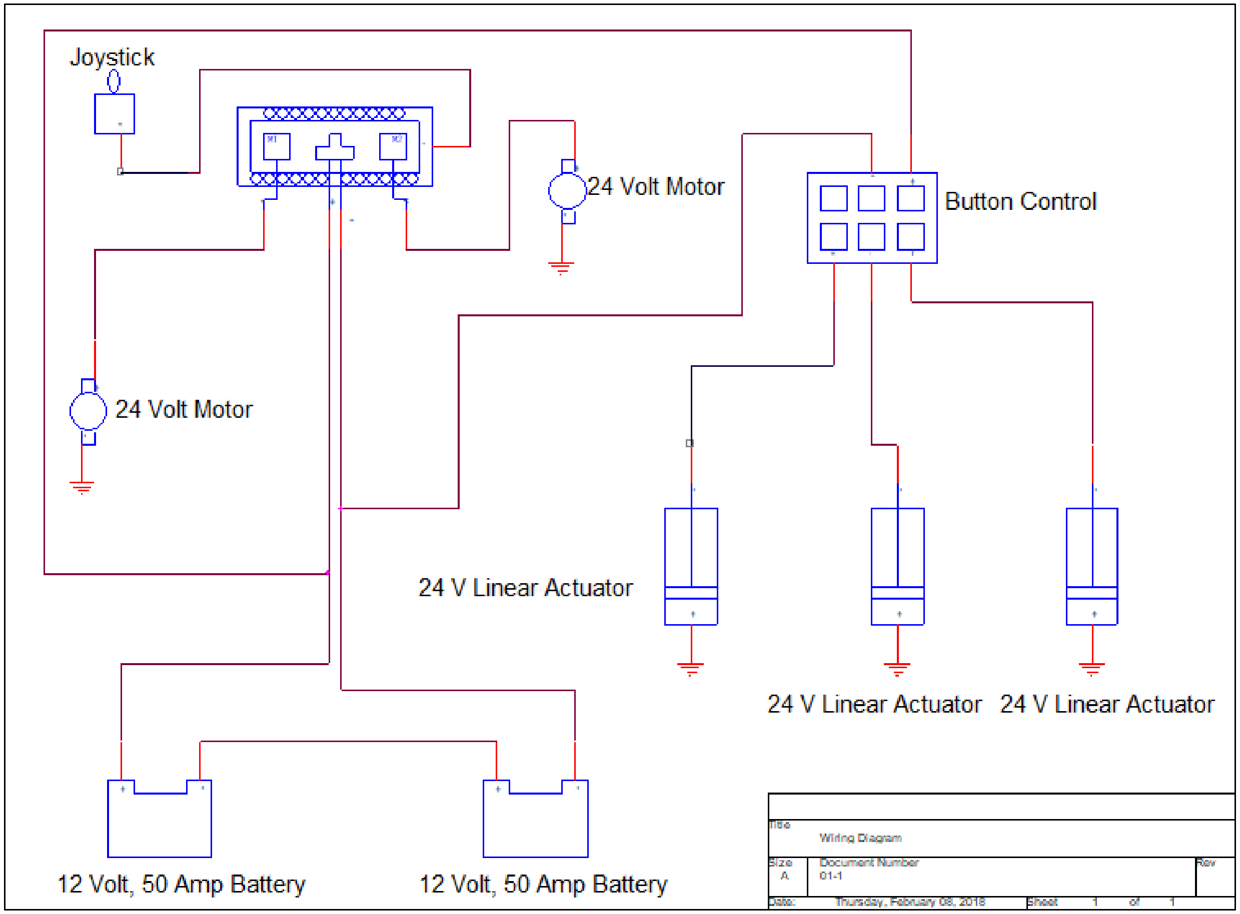
1. Charge Rate. How fast a battery will charge depends on:

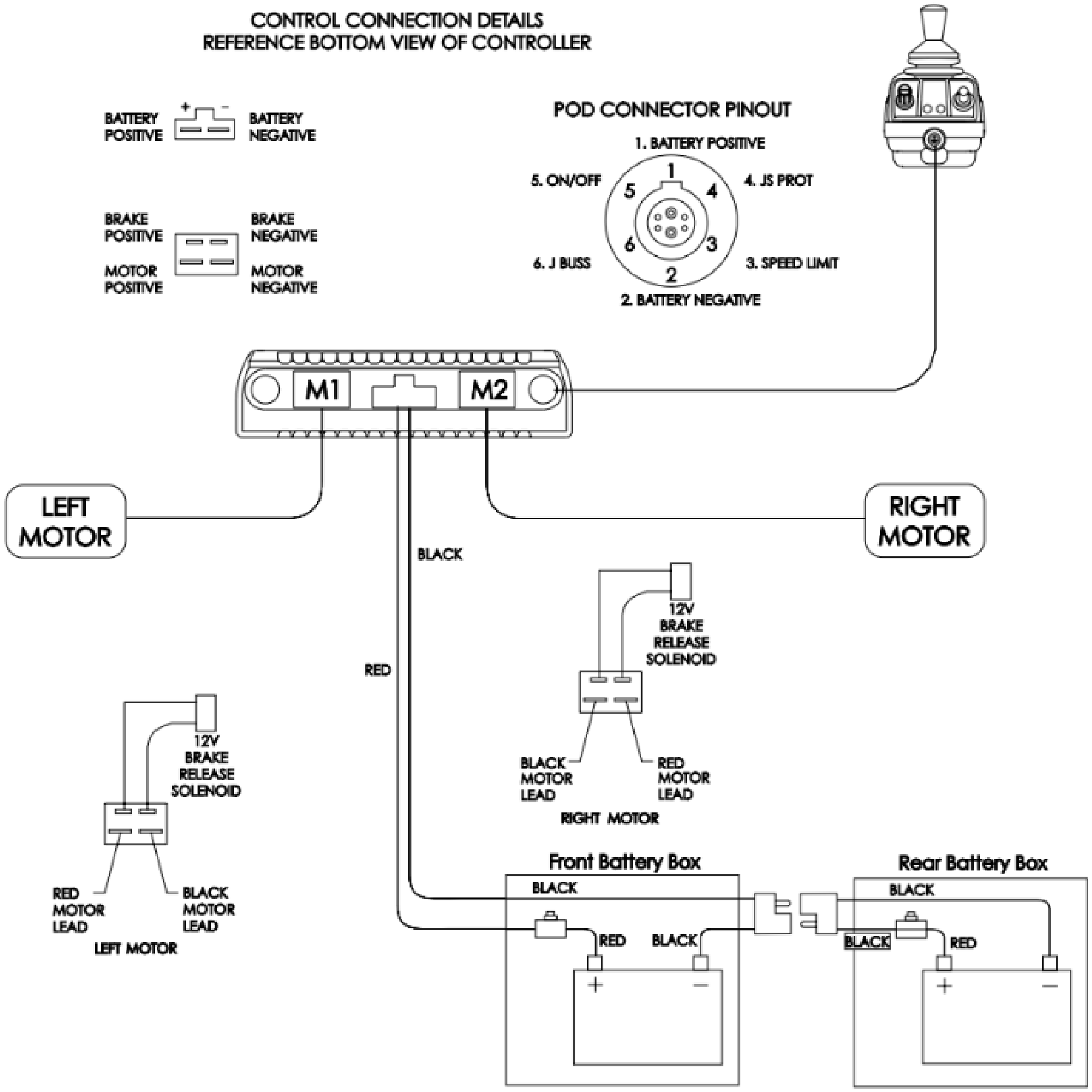
- Its electrical capacity; state of charge; electrolyte temperature; and internal condition.
- The DC output of the charger. (The charge rate will vary if the alternating current (AC) supply is higher or lower than 110 volts).

2. Caution — To Avoid Damage to the Charger:

- **Never** place the charger on top of a battery during charging. (Gases from the battery can damage the charger and may lead to an explosion or fire).
- **Never** place a battery on top of the charger.
- **Never** expose charger to rain or snow.

Appendix J – Circuit Diagram




CONTROL CONNECTION DETAILS
REFERENCE BOTTOM VIEW OF CONTROLLER
BATTERY POSITIVE
+
-
BATTERY NEGATIVE
BRAKE POSITIVE
BRAKE NEGATIVE
MOTOR POSITIVE
MOTOR NEGATIVE
POD CONNECTOR PINOUT
1. BATTERY POSITIVE
5. ON/OFF
4. JS PROT
1
5
4
6
3
2
6. J BUSS
3. SPEED LIMIT
2. BATTERY NEGATIVE
M1
M2
LEFT MOTOR
RIGHT MOTOR
BLACK
RED
12V BRAKE RELEASE SOLENOID
BLACK MOTOR LEAD
RED MOTOR LEAD
RIGHT MOTOR
12V BRAKE RELEASE SOLENOID
RED MOTOR LEAD
BLACK MOTOR LEAD
LEFT MOTOR
Front Battery Box
BLACK
RED
BLACK
+
−
Rear Battery Box
BLACK
BLACK
RED
+
−

Appendix K - Final Carbon Fiber Analyses

Table of Contents

Seat Plate Carbon Fiber/Epoxy Resin (Prepreg) Analysis

```
format short;
format
compact clc;

clear
;
```

Given Engineering Parameters

```
E1 = 147*10^9;         % Pa
E2 = 10.3*10^9;        % Pa
E3 = E2;               % Pa
G12 = 7.0*10^9;        % Pa
v12 = 0.27;

v21 = (v12/E1)*E2;

tply = 0.0002921;      % m

alpha1 = -0.5*10^-6;  % in/in/degF
alpha2 = 15.0*10^-6;  % in/in/degF
deltaT = 20;           % degF

beta1 = 0.01;
beta2 = 0.20;
deltaC =
0.01;
```

Q bar Matrices

```
Q11 = E1/(1-(v21*v12));
Q22 = E2/(1-(v12*v21));

Q12 = (v21*E2)/(1-(v12*v21));
Q21 = Q12;

Q66 = G12;


Q0 = [Q11  Q12   0 ;
      Q21  Q22   0 ;
```

```
       0    0   Q66 ];   %  2-D Stiffness matrix for zero degrees


theta1 =  0;         % degrees
theta2 = 90;         % degrees


m1 = cosd(theta1);

n1 = sind(theta1);


m2 = cosd(theta2);

n2 = sind(theta2);



Tstress90 = [ m2^2  n2^2    2*m2*n2;

              n2^2  m2^2   -2*m2*n2;

            -m2*n2  m2*n2  m2^2-n2^2 ];  % Transform stress for 90
 degrees


Tstrain90 =  [ m2^2    n2^2     m2*n2;

               n2^2    m2^2    -m2*n2;

            -2*m2*n2 2*m2*n2  m2^2-n2^2 ];  % Transform strain using
 90 degrees



Qbar90 = inv(Tstress90)*Q0*Tstrain90;
```

A Matrix

```
A1 = Q0*tply;

A2 = Qbar90*tply;
A3 = Q0*tply;

A4 = Qbar90*tply;
A5 = Q0*tply;
```

```
A6  = Qbar90*tply;
A7  = Qbar90*tply;
A8 = Q0*tply;

A9 = Qbar90*tply;
A10 = Q0*tply;

A11 = Qbar90*tply;
A12 = Q0*tply;


A = A1+A2+A3+A4+A5+A6+A7+A8+A9+A10+A11+A12;  % N/m
```

B Matrix

```
B1 = Q0*((5*tply)^2-(6*tply)^2);

B2 = Qbar90*((4*tply)^2-(5*tply)^2);
B3 = Q0*((3*tply)^2-(4*tply)^2);

B4 = Qbar90*((2*tply)^2-(3*tply)^2);
B5 = Q0*(tply^2-(2*tply)^2);

B6 = Qbar90*(-(tply)^2);
B7 = Qbar90*((tply)^2);

B8 = Q0*((2*tply)^2-(tply)^2);

B9 = Qbar90*((3*tply)^2-(2*tply)^2);
B10 = Q0*((4*tply)^2-(3*tply)^2);

B11 = Qbar90*((5*tply)^2-(4*tply)^2);
B12 = Q0*((6*tply)^2-(5*tply)^2);


B = (1/2)*(B1+B2+B3+B4+B5+B6+B7+B8+B9+B10+B11+B12);  % N
```

D Matrix

```
D1 = Q0*((5*tply)^3-(6*tply)^3);

D2 = Qbar90*((4*tply)^3-(5*tply)^3);
D3 = Q0*((3*tply)^3-(4*tply)^3);

D4 = Qbar90*((2*tply)^3-(3*tply)^3);
D5 = Q0*(tply^3-(2*tply)^3);

D6 = Qbar90*(-(tply)^3);
D7 = Qbar90*((tply)^3);
```

```
D8 = Q0*((2*tply)^3-(tply)^3);

D9 = Qbar90*((3*tply)^3-(2*tply)^3);
D10 = Q0*((4*tply)^3-(3*tply)^3);

D11 = Qbar90*((5*tply)^3-(4*tply)^3);
D12 = Q0*((6*tply)^3-(5*tply)^3);


D = (1/3)*(D1+D2+D3+D4+D5+D6+D7+D8+D9+D10+D11+D12);  % N*m
```

a Matrix

```
Bstar = -(pinv(A))*(B);
Cstar = (B)*(pinv(A));

Dstar = (D) - [((B)*(pinv(A)))*(B)];


a = (pinv(A)) - ((Bstar)*(Dstar))*Cstar;  % m^2/N
```

b Matrix

```
b = Bstar*pinv(Dstar);  % m/N
```

c Matrix

```
c = -(pinv(Dstar))*(Cstar);  % 1/N
```

d Matrix

```
 d = pinv(Dstar);  % 1/(N*m)
```

CTE

```
alpha12 =
[alpha1;alpha2;0];
Strain12 =
(alpha12)*deltaT;



Strainxy1T = Strain12;

Strainxy2T =
inv(Tstrain90)*Strain12; Strainxy3T
= Strain12;

Strainxy4T =
inv(Tstrain90)*Strain12; Strainxy5T
= Strain12;

Strainxy6T                         =
inv(Tstrain90)*Strain12; Strainxy7T
=          inv(Tstrain90)*Strain12;
Strainxy8T = Strain12;

Strainxy9T =
inv(Tstrain90)*Strain12;
Strainxy10T = Strain12;

Strainxy11T =
inv(Tstrain90)*Strain12; Strainxy12T
= Strain12;



alphaxy1 = Strainxy1T/deltaT;
alphaxy2 = Strainxy2T/deltaT;
alphaxy3 = Strainxy3T/deltaT;
alphaxy4 = Strainxy4T/deltaT;
alphaxy5 = Strainxy5T/deltaT;
alphaxy6 = Strainxy6T/deltaT;
alphaxy7 = Strainxy7T/deltaT;
alphaxy8 = Strainxy8T/deltaT;
alphaxy9 = Strainxy9T/deltaT;
alphaxy10 =
Strainxy10T/deltaT; alphaxy11
= Strainxy11T/deltaT;
alphaxy12 =
Strainxy12T/deltaT;
```

Thermal Resultant Forces

```
sum = ((Q0)*(alphaxy1)*tply) + ((Qbar90)*(alphaxy2)*tply)

 + ((Q0)*(alphaxy3)*tply) + ((Qbar90)*(alphaxy4)*tply)

 + ((Q0)*(alphaxy5)*tply) + ((Qbar90)*(alphaxy6)*tply)
 + ((Qbar90)*(alphaxy7)*tply) + ((Q0)*(alphaxy8)*tply)
 + ((Qbar90)*(alphaxy9)*tply) +
 ((Q0)*(alphaxy10)*tply) + ((Qbar90)*(alphaxy11)*tply)
 + ((Q0)*(alphaxy12)*tply);

NxyT = deltaT*sum
```

```
NxyT =

   1.0e+03
      *

    2.95
     33

    2.95
     33
```

```
sum2 = ((Q0)*(alphaxy1)*((-5*tply)^2-(-6*tply)^2))

 + ((Qbar90)*(alphaxy2)*((-4*tply)^2-(-5*tply)^2))

 + ((Q0)*(alphaxy3)*((-3*tply)^2-(-4*tply)^2)) +
 ((Qbar90)*(alphaxy4)*((-2*tply)^2-(-3*tply^2)))
 +

 ((Q0)*(alphaxy5)*((-tply)^2-(-2*tply)^2)) +
((Qbar90)*(alphaxy6)*(0- (-tply)^2)) +
((Qbar90)*(alphaxy7)*((tply)^2))

 + ((Q0)*(alphaxy8)*((2*tply)^2-(tply)^2)) +
 ((Qbar90)*(alphaxy9)*((3*tply)^2-
 (2*tply)^2))

 + ((Q0)*(alphaxy10)*((4*tply)^2-(3*tply)^2)) +
 ((Qbar90)*(alphaxy11)*((5*tply)^2-(4*tply)^2))
 + ((Q0)*(alphaxy12)*((6*tply)^2-(5*tply)^2));

MxyT = deltaT*sum2
```

```
MxyT = 3.1780
```

```
   -1.4527

         0
```

Mid-Plane Strains and Curvatures of Laminate

```
NxyTB = NxyT;                                % lbs
Midstrainxy = (a)*(NxyTB) + (b)*(MxyT)   %
in/in Curvaturexy = (c)*(NxyTB) + (d)*(MxyT)
% in/in
```

```
Midstrainxy =

    0.00
     00

     -
   0.001
     4

         0

Curvaturexy =

   1.0e+18 *

     -
   5.456
     7

     -
   0.085
     9

         0
```

Mid-Plane CTE of Laminate

```
alphaxyeff = Midstrainxy  % in/in
```

```
alphaxyeff =

    0.00
     00

     -
   0.001
     4
```

0

Total Strains For Each Lamina

```
TotalStrain01 = 2*Midstrainxy + (-6*tply)*(Curvaturexy) - Strainxy1T

        % Total strain for 0 deg layer 1
                    (in/in)

TotalStrain902 = 2*Midstrainxy + (-5*tply)*(Curvaturexy) -
Strainxy2T

        % Total strain for 90 deg layer 2
                     (in/in)

TotalStrain03 = 2*Midstrainxy + (-4*tply)*(Curvaturexy) - Strainxy3T

        % Total strain for 0 deg layer 3
                    (in/in)

TotalStrain904 = 2*Midstrainxy + (-3*tply)*(Curvaturexy) -
Strainxy4T

     % Total strain for 90 deg layer 4 (in/in)

TotalStrain05 = 2*Midstrainxy + (-2*tply)*(Curvaturexy) - Strainxy5T

     % Total strain for 0 deg layer 5 (in/in)

TotalStrain906 = 2*Midstrainxy + (-1*tply)*(Curvaturexy) -
Strainxy6T

     % Total strain for 90 deg layer 6 (in/in)

TotalStrain907 =  2*Midstrainxy + (tply)*(Curvaturexy) - Strainxy7T

     % Total strain for 90 deg layer 7 (in/in)

TotalStrain08 = 2*Midstrainxy + (2*tply)*(Curvaturexy) - Strainxy8T

     % Total strain for 0 deg layer 8 (in/in)

TotalStrain909 = 2*Midstrainxy + (3*tply)*(Curvaturexy) - Strainxy9T

     % Total strain for 90 deg layer 9 (in/in)

TotalStrain010 = 2*Midstrainxy + (4*tply)*(Curvaturexy) -
Strainxy10T

     % Total strain for 0 deg layer 10 (in/in)

TotalStrain9011 = 2*Midstrainxy + (5*tply)*(Curvaturexy) -
Strainxy11T

     % Total strain for 90 deg layer 11 (in/in)
```

```
TotalStrain012 = 2*Midstrainxy + (6*tply)*(Curvaturexy) -
Strainxy12T

       % Total strain for 0 deg layer 12 (in/in)
```

```
TotalStrain01
      =

   1.0e+15
      *

    9.56
     34

    0.15
     05

        0

TotalStrain902 =

   1.0e+15
      *

    7.96
     95

    0.12
     54

        0

TotalStrain03
      =

   1.0e+15
      *

    6.37
     56

    0.10
     03

        0

TotalStrain904 =

   1.0e+15
      *

    4.78
     17

    0.07
     53

        0
```

```
TotalStrain05
      =

   1.0e+15
      *

    3.18
     78

    0.05
     02

         0

TotalStrain906 =

   1.0e+15
      *

    1.59
     39

    0.02
     51

         0

TotalStrain907 =

   1.0e+15
      *

     -
   1.593
     9

     -
   0.025
     1


TotalStrain08
      =

   1.0e+15 *

   -3.1878

   -0.0502

         0

TotalStrain909
       =

   1.0e+15 *

   -4.7817

   -0.0753
```

```
         0

TotalStrain010
      =

   1.0e+15 *

   -6.3756

   -0.1003

         0

TotalStrain9011 =

   1.0e+15 *

   -7.9695

   -0.1254

         0

TotalStrain012
      =

   1.0e+15 *

   -9.5634

   -0.1505

         0
```

Stress-Induced Elastic Strains In Each Lamina

```
SIEStrainxy1 = TotalStrain01 - Strainxy1T      % Stress-
 induced elastic strain for 0 deg lamina 1 (in/in)

SIEStrainxy2 = TotalStrain902 - Strainxy2T     % Stress-
 induced elastic strain for 90 deg lamina 2 (in/in)

SIEStrainxy3 = TotalStrain03 - Strainxy3T      % Stress-
 induced elastic strain for 0 deg lamina 3 (in/in)

SIEStrainxy4 = TotalStrain904 - Strainxy4T     % Stress-
 induced elastic strain for 90 deg lamina 4 (in/in)

SIEStrainxy5 = TotalStrain05 - Strainxy5T      % Stress-
 induced elastic strain for 0 deg lamina 5 (in/in)

SIEStrainxy6 = TotalStrain906 - Strainxy6T     % Stress-
 induced elastic strain for 90 deg lamina 6 (in/in)

SIEStrainxy7 = TotalStrain907 - Strainxy7T     % Stress-
 induced elastic strain for 90 deg lamina 7 (in/in)
```

```
SIEStrainxy8 = TotalStrain08 - Strainxy8T      % Stress-
 induced elastic strain for 0 deg lamina 8 (in/in)

SIEStrainxy9 = TotalStrain909 - Strainxy9T     % Stress-
 induced elastic strain for 90 deg lamina 9 (in/in)

SIEStrainxy10 = TotalStrain010 - Strainxy10T   % Stress-
 induced elastic strain for 0 deg lamina 10 (in/in)

SIEStrainxy11 = TotalStrain9011 - Strainxy11T  % Stress-
 induced elastic strain for 90 deg lamina 11 (in/in)

SIEStrainxy12 = TotalStrain012 - Strainxy12T   % Stress-
 induced elastic strain for 0 deg lamina 12 (in/in)
```

```
SIEStrainxy1 =

    1.0e+15
       *

     9.56
      34

     0.15
      05

          0

 SIEStrainxy2
      =

    1.0e+15
       *

     7.96
      95

     0.12
      54

          0

 SIEStrainxy3
      =

    1.0e+15
       *

     6.37
      56

     0.10
      03

          0

 SIEStrainxy4
      =
```

```
   1.0e+15
      *

    4.78
     17

    0.07
     53

          0

SIEStrainxy5
     =

   1.0e+15
      *

    3.18
     78

    0.05
     02

          0

SIEStrainxy6
     =

   1.0e+15
      *

    1.59
     39

    0.02
     51

          0

SIEStrainxy7
     =

   1.0e+15
      *

     -
   1.593
     9

     -
   0.025
     1

          0

SIEStrainxy8
     =
```

```
   1.0e+15
      *

     -
   3.187
     8

     -
   0.050
     2

         0

SIEStrainxy9
      =

   1.0e+15
      *

     -
   4.781
     7

     -
   0.075
     3

         0

SIEStrainxy10
       =

   1.0e+15
      *

     -
   6.375
     6

     -
   0.100
     3

         0

SIEStrainxy11
       =

   1.0e+15
      *

     -
   7.969
     5

     -
   0.125
     4
```

```
SIEStrainxy12
      =

   1.0e+15
      *

     -
   9.563
     4

     -
   0.150
     5

         0
```

Total Stresses In Each Lamina

```
Stressxy1 = (Q0)*(SIEStrainxy1)          % Stress in 0 deg lamina
 1 (Pa)

Stressxy2 = (Qbar90)*(SIEStrainxy2)      % Stress in 90 deg lamina
 2 (Pa)

Stressxy3 = (Q0)*(SIEStrainxy3)          % Stress in 0 deg lamina
 3 (Pa)

Stressxy4 = (Qbar90)*(SIEStrainxy4)      % Stress in 90 deg lamina
 4 (Pa)

Stressxy5 = (Q0)*(SIEStrainxy5)          % Stress in 0 deg lamina
 5 (Pa)

Stressxy6 = (Qbar90)*(SIEStrainxy6)      % Stress in 90 deg lamina
 6 (Pa)

Stressxy7 = (Qbar90)*(SIEStrainxy7)      % Stress in 90 deg lamina
 7 (Pa)

Stressxy8 = (Q0)*(SIEStrainxy8)          % Stress in 0 deg lamina
 8 (Pa)

Stressxy9 = (Qbar90)*(SIEStrainxy9)      % Stress in 90 deg lamina
 9 (Pa)

Stressxy10 = (Q0)*(SIEStrainxy10)        % Stress in 0 deg lamina
 10 (Pa)

Stressxy11 = (Qbar90)*(SIEStrainxy11)    % Stress in 90 deg lamina
 11 (Pa)

Stressxy12 = (Q0)*(SIEStrainxy12)        % Stress in 0 deg lamina
 12 (Pa)
```

```
Stressxy1 =

   1.0e+27
      *

    1.41
     31

    0.00
     34

         0

Stressxy2 =

   1.0e+25
      *

    8.25
     32

    2.00
     92

         0

Stressxy3 =

   1.0e+26
      *

    9.42
     05

    0.02
     29

         0

Stressxy4 =

   1.0e+25
      *

    4.95
     19

    1.20
     55

Stressxy5 =

   1.0e+26 *

    4.71
     02

    0.01
     14

         0
```

```
Stressxy6 =

   1.0e+25 *

     1.65
      06

     0.40
      18

         0

Stressxy7 =

   1.0e+25 *

   -1.6506

   -0.4018

         0

Stressxy8 =

   1.0e+26 *

   -4.7102

   -0.0114

         0

Stressxy9 =

   1.0e+25 *

   -4.9519

   -1.2055

         0

Stressxy10
     =

   1.0e+26 *

   -9.4205

   -0.0229

         0

Stressxy11
     =

   1.0e+25 *

   -8.2532

   -2.0092

         0
```

```
Stressxy12
     =

   1.0e+27 *

   -1.4131

   -0.0034

         0
```

Max Forces In Each Lamina

```
F1 = Stressxy1*0.000145*156  % Forces in first
ply F2 = Stressxy2*0.000145*156  % Forces in
second ply F3 = Stressxy3*0.000145*156  % Forces
in third ply F4 = Stressxy4*0.000145*156  %
Forces in fourth ply F5 = Stressxy5*0.000145*156
% Forces in fifth ply F6 = Stressxy6*0.000145*156
% Forces in sixth ply

F7 = Stressxy7*0.000145*156  % Forces in seventh
ply F8 = Stressxy8*0.000145*156  % Forces in
eighth ply F9 = Stressxy9*0.000145*156  % Forces
in ninth ply

F10 = Stressxy10*0.000145*156  % Forces in tenth ply

F11 = Stressxy11*0.000145*156  % Forces in eleventh ply

F12 = Stressxy12*0.000145*156  % Forces in twelfth ply
```

```
F1 =

   1.0e+25
      *

    3.19
     64

    0.00
     78

         0

F2 =

   1.0e+24
      *

    1.86
     69

    0.45
     45
```

```
         0

F3 =

   1.0e+25
      *

    2.13
     09

    0.00
     52

         0

F4 =

   1.0e+24
      *

    1.12
     01

    0.27
     27

         0

F5 =

   1.0e+25
      *

    1.06
     55

    0.00
     26

         0

F6 =

   1.0e+23
      *

    3.73
     38

    0.90
     90

         0

F7 =

   1.0e+23 *

   -3.7338

   -0.9090
```

```
         0
F8 =
   1.0e+25 *
   -1.0655
   -0.0026
         0
F9 =
   1.0e+24 *
   -1.1201
   -0.2727
         0
F10 =
   1.0e+25 *
   -2.1309
   -0.0052
         0
F11 =
   1.0e+24 *
   -1.8669
   -0.4545
         0
F12 =
   1.0e+25 *
     -
   3.196
     4
     -
   0.007
     8
         0
```

Max Forces In Direction Normal To Seat Plate In Each Lamina

```
Fz = [F1(1,1); F2(1,1); F3(1,1); F4(1,1); F5(1,1); F6(1,1);
 F7(1,1); F8(1,1); F9(1,1); F10(1,1); F11(1,1); F12(1,1)]
```

```
Fz =

   1.0e+25 *

    3.19
     64

    0.18
     67

    2.13
     09

    0.11
     20

    1.06
     55

    0.03
     73

     -
   0.037
     3

     -
   1.065
     5

     -
   0.112
     0

     -
   2.130
     9

     -
   0.186
     7

     -
   3.196
     4
```

Max Force On Seat Plate

```
   Fzmax =
   Fz(1,1)
```

```
Fzmax =

   3.1964e+25
```

Factor of Safety

```
FS = Fzmax/(222.411)
```

```
FS =

   1.4371e+23
```

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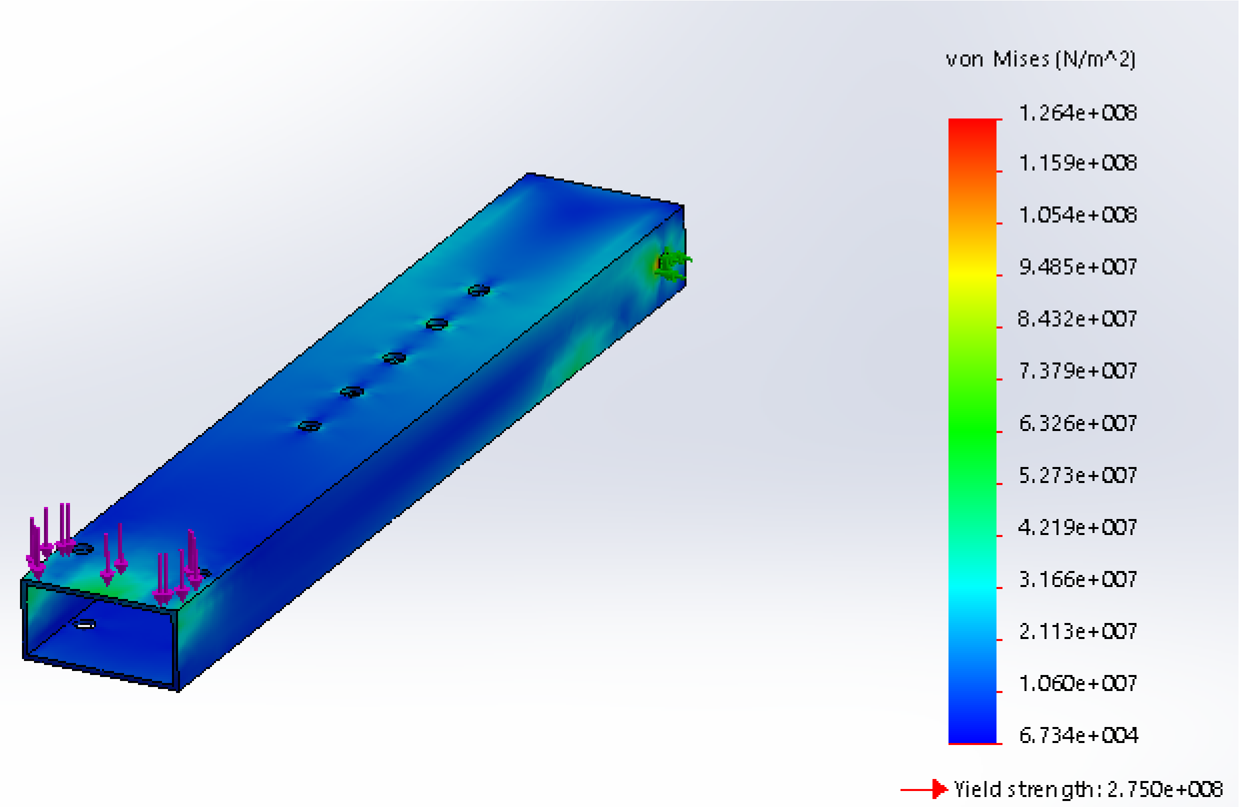
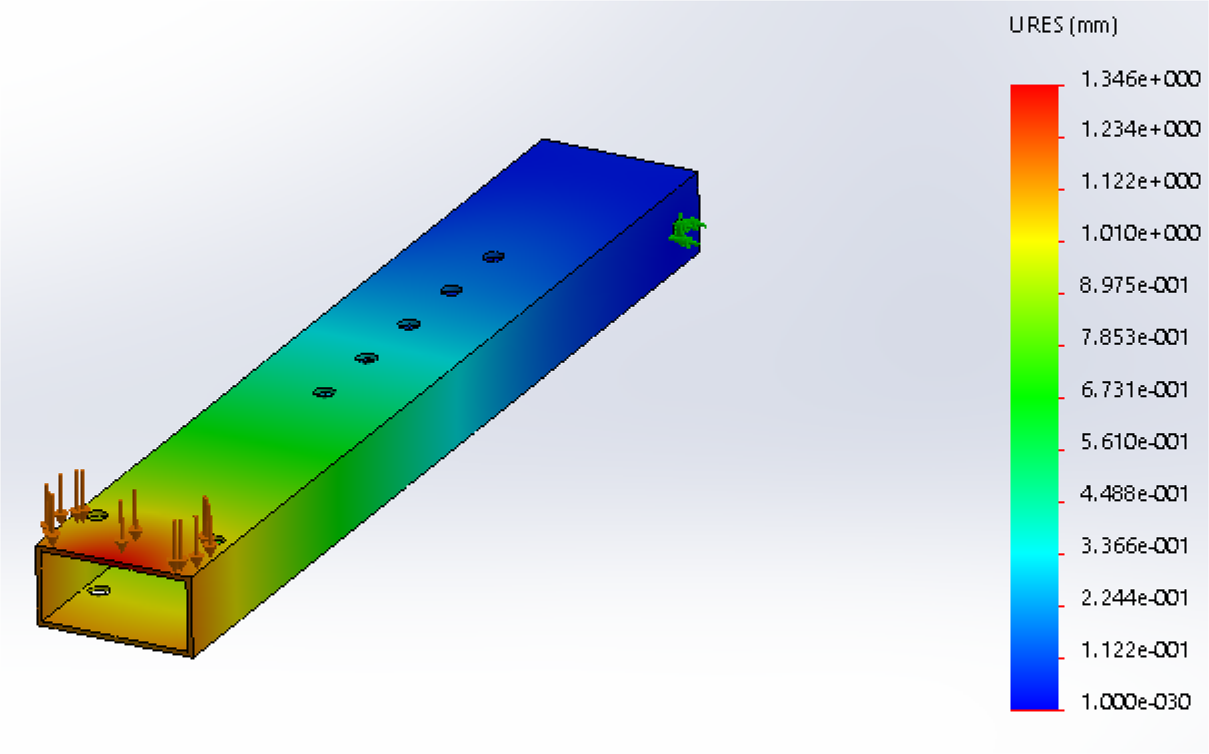
Appendix L - Final Analyses

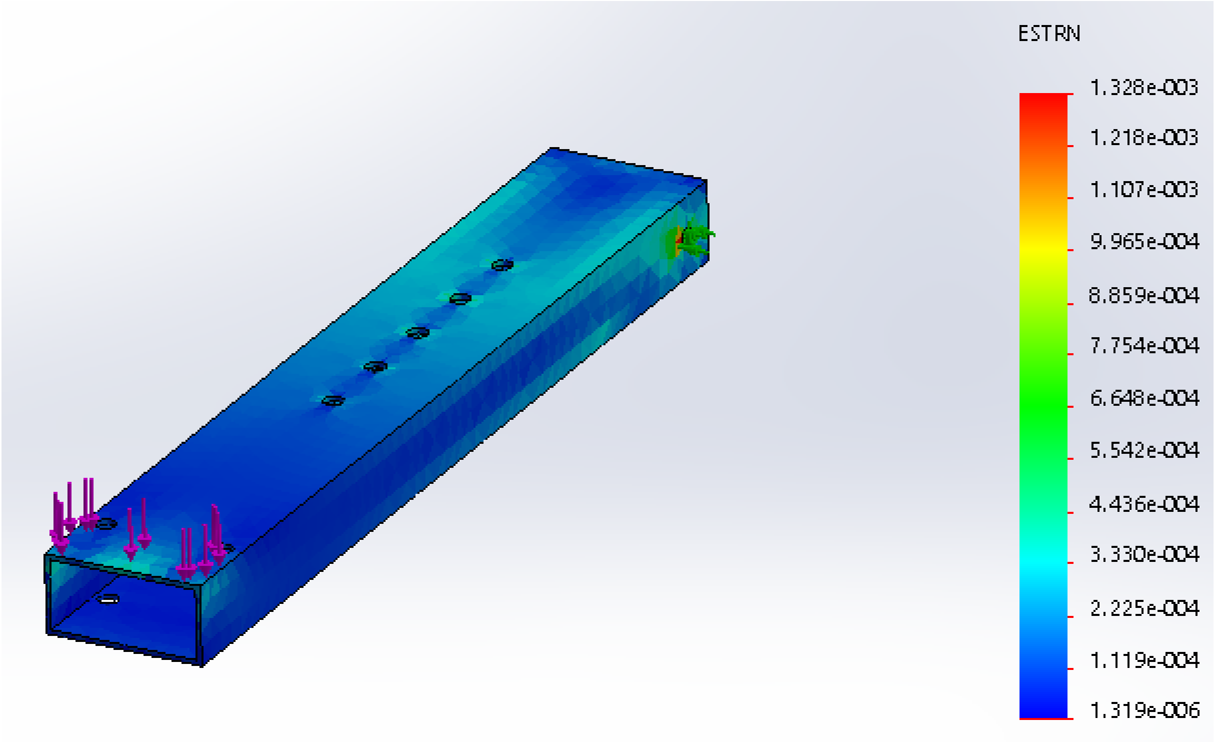
- 50lbs load at end of bar(max load case, not likely to ever actually happen)
- Fixed pin and fixed actuator attachment location
- 6061-T6 aluminum



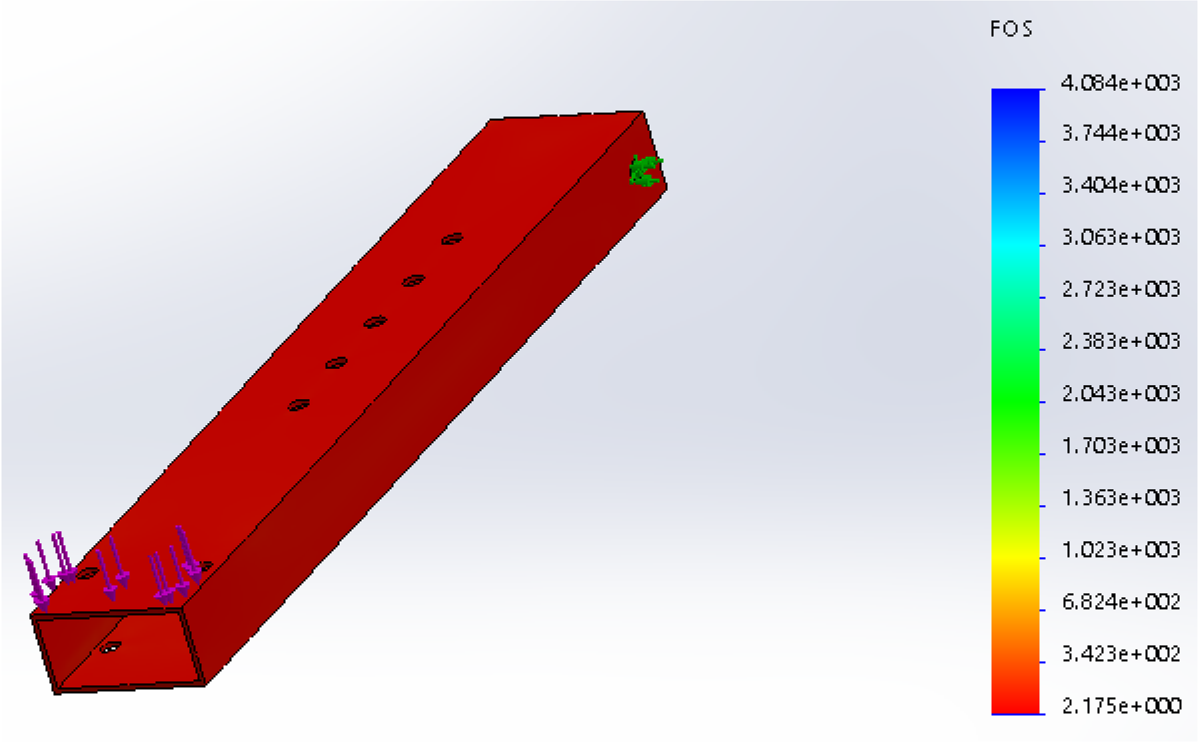
Stress



Displacement


ESTRN
1.328e-003
1.218e-003
1.107e-003
9.965e-004
8.859e-004
7.754e-004
6.648e-004
5.542e-004
4.436e-004
3.330e-004
2.225e-004
1.119e-004
1.319e-006

Strain



Factor of Safety

Appendix M – Budget Analysis

Total Funding Provided by CPConnect Grant			**$3,000**				
Account #	60182						
Name	**Cost**	**Date**	**Who Paid**	**Company**	**Description**	**Pro Card / Reimbursement**	**Reimbursted ?**
Pediatric Chair	$ 657.27		Moncerratt Peralta	Sunrise Medical	Purchase of the Quickie Z 500 Mobility Base	Reimbursement	Yes
Pediatric Chair Tune Up	$ 492.54		Sarah Harding	A1 Mobility	Purchase of cell batteries and 5 Amp Charger	Reimbursement	Yes
PVC Tubing Supplies	$ 50.57	11/5/2017	Moulay Salahdin	Home Depot	PVC supplies used to build prototype	Reimbursement	Yes
PVC Tubing Supplies	$ 14.48	11/5/2017	Moulay Salahdin	Home Depot	PVC supplies used to build prototype	Reimbursement	Yes
Supply Return	$ (28.94)	12/2/2017	Moulay Salahdin	Home Depot	1/2 inch PVC returned b/c not needed	N/A	N/A
Hinge	$ 9.60	1/19/2018	Moulay Salahdin	Home Depot	Hinge used for structural prototype	Reimbursement	Yes
3/4" and 1' Tubing	$ 88.10	2/15/2018	Pro Card	Online Metals	Structure of backrest and tilt-in-space	Pro Card	N/A
36" x 3/8' AL	$ 14.15	2/24/2018	Pro Card	McMaster-Carr	Alumumin 6061 - T6	Pro Card	N/A
Hatchbox ABS 3D Printer	$ 31.28	2/27/2018	Pro Card	Amazon	3D printer filament	Pro Card	N/A
Velcro and Nylon Straps	$ 17.97	2/27/2018	Pro Card	Amazon	Black Nylon Straps	Pro Card	N/A
Industrial Velcro	$ 7.97	2/27/2018	Pro Card	Amazon	Industrial Velcro with adhesive	Pro Card	N/A
8" X 8" Aluminum Plate	$ 10.20	3/2/2018	Pro Card	Online Metals	Aluminum Plate for Actuator attachment	Pro Card	N/A
1" X 1" X 12" Square Rods	$ 4.04	3/3/2018	Pro Card	Online Metals	Armrest raw aluminum	Pro Card	N/A
2 X 1" X 1" Aluminum Square	$ 6.20	3/4/2018	Pro Card	Online Metals	Footrest attachment raw aluminum	Pro Card	N/A
Shipping and Handling	$16.13	3/4/2018	Pro Card	Online Metals	Shipping associated with order (more than expected)	Pro Card	N/A
Actuators and Rocker Switches	$391.92	3/4/2018	Pro Card	Firgelli	Linear actuators with rocker switches	Pro Card	N/A
Actuator Brackets	$24.46	4/5/2018	Pro Card	Firgelli	Mounting for actuators	Pro Card	N/A
Wheelchair Armrest Pads	$24.09	4/5/2018	Pro Card	EnableYourLife	Padding for armrest	Pro Card	N/A
Gentry Welding	$75.00	4/3/2018	Pro Card	Gentry Welding	Welding from backrest and tilt-in-space frame	Pro Card	N/A
Foam Supplies	$49.56	4/11/2018	Steven	Quality Fabrics	Supplies for upholstery	Reimbursement	In Progress
Scotch Bright	$3.59	4/12/2018	Steven	Miners	Used to clean weld locations pre weld	Reimbursement	In Progress
Non-Adhesive Velcro	$25.00	4/13/2018	Steven	Beverlys	Velcro to attach	Reimbursement	In Progress
Buckles	$20.00	4/20/2018	Steven	Quality Fabrics	Buckles for Nylon straps	Reimbursement	In Progress
Meat Cutter	$7.50	4/14/2018	Steven	Goodwill	Used to cut the foam	Reimbursement	In Progress
Gentry Welding	$25.00	4/30/2018	Pro Card	Gentry Welding	Welding actuator mounts	Pro Card	In Progress
Electrical Parts	$46.42	5/10/2018	Matt	Fastenal	Electrical Components	Reimbursement	In Progress
Fabric	$51.09	5/10/2018	Steven	Quality Fabrics	Upholstery	Reimbursement	In Progress
Upholstery	$95.00	5/10/2018	Steven	Fine Touch Upholstery	Upholstery	Reimbursement	In Progress
Limit switch for actuators	$32.02	5/5/2018	Pro Card	Firgelli	Limit Switch	Pro Card	N/A
Mesh Cover	$77.99	5/5/2018	Pro Card	Sportaid	Seat Cover	Pro Card	N/A
Hatchbox ABS 3D Printer	$23.58	5/5/2018	Pro Card	Amazon	Plastic	Pro Card	N/A
Nuts and Bolts	$46.52	5/20/2018	Moulay	Home Depot / Miners	Nuts and bolts + miscellaneous	Reimbursement	In Progress
Powdercoating	$65.00	5/15/2018	Matt	Central Coast Powdercoating	Paint for the chair	Reimbursement	In Progress
Yueton Wiring Spades	$7.00	5/20/2018	N/A	Amazon	Connectors for the rocker switches	Pro Card	N/A
Cape, lights, stickers, ipad mount	76.22	5/28/2016	Matt	Amazon	Aesthetic Final touches	Reimbursement	In Progress
Headrest Cover	44.44	5/28/2018	Steven	Glidewear	Cover for seat cushion	Reimbursement	In Progress
Redel Cord	$150.00	5/31/2018	Steven	A1 Mobility	Joystick to controller cord	Reimbursement	In Progress
Total Budget Spent	$ 2,752.96						
Total Budget Remaining	$ 247.04						

Appendix N - BOM

BOM Level	0	1	2	3	4	5	6	7	Part #	Quantity	Unit of Measure	Cost	Vendor	Total Cost	Obtained?
0	Quickie 2- 500 Mobility Chair								0001	1	Each	657.27	Ebay	657.27	Yes
1		Base Platform Assembly							A0001	1	Each	Came with Chair	Ebay	N/A	N/A
1		Tilt-in-space Assembly							B0001						
2			Aluminum Tubing 6061-T6 X 3/4" x 6' x 0.065WT*						B0011	0.94445	Each	53.1	McMaster-Carr	50.150295	Yes
2			Carbon Fiber Unidirectional						B0021	2	lbs.	Cal Poly Donated	N/A	N/A	Yes
2			Cushion Assembly						B0031						
3				Meridian Varilite Cushion					B0032	1	Each	Came with Chair	N/A		
3				Mesh Cushion Cover					B0033	1	Each	77.99	SportAid		
4					3/16" x 1.5" Round Head Screws				B0201	8	Each	0.1	Fasteners	0.8	Yes
4					1/4" Locknut				B0202	10	Each	0.06	Fasteners	0.6	Yes
4					1.32 inch round cap				B0203	4	Each	0.15	3D Printed	0.6	Yes
4					Linear Actuator Bracket and Clevis Pin				B0204	1	Each	8.153333333	Firgelli	8.1533333	Yes
4					1/4" x 1.5" bolt				B0205	1	Each	0.35	Fasteners	0.35	Yes
4					Bearing Mount Bracket				B0206	1	Each	Came with Chair	N/A	N/A	Yes
4					Actuator Mount for Bracket				B0207	1	Each	0.15	3D Printed	0.15	Yes
4					Flat to Round Space				B0208	8	Each	0.15	3D Printed	1.2	Yes
1		Footrest Assembly							C0001						
2			Rectangular Aluminum Tubing 2" x 1" x 1" x 0.62 WT*						C0011	1	Each	3.1	Online Metal	3.1	Yes
2			Aluminum 12" x 6" x 0.25"						C0021	1	Each	Cal Poly Donated	N/A	N/A	Yes
2			Aluminum Rod 36" x 1/2"D						C0031	1	Each	6.39	McMaster-Carr	6.39	Yes
2			1/2" Bushing						C0041	2	Each	8.48	McMaster-Carr	16.96	Yes
2			Aluminum Plate 2" x 24" x 1/4"						C0051	0.2	Each	5.48	McMaster-Carr	1.096	Yes
2			Footrest Connector Assembly												
3				Insert Connector					C0101	2	Each	Came with Chair	N/A	N/A	Yes
3				Footplate Connector					C0102	2	Each	Came with Chair	N/A	N/A	Yes
4					1/4" Flat Head Bolt				C1001	4	Each	0.1	Fasteners	0.4	Yes
4					1/4" Locknut				C1002	5	Each	0.03	Fasteners	0.15	Yes
4					1/4" Washer				C1003	2	Each	0.01	Fasteners	0.02	Yes
4					1/4" x 4" Bolt				C1004	1	Each	0.3	Fasteners	0.3	Yes
3				Washer Footrest Connector					C0103	2	Each	Came with Chair	N/A	N/A	Yes
3				1/4" x 4" Bolt					C0104	1	Each	0.3	Fasteners	0.3	Yes
3				1/4" Washer					C0105	2	Each	0.01	Fasteners	0.02	Yes
3				1/4" Locknut					C0106	1	Each	0.03	Fasteners	0.03	Yes
3				Batman 3D Print					C0107	1	Each	1	3D Print	1	Yes
1		Armrest Assembly - Right							E0001						
2			Support Armrest						E0011	1	Each	Came with Chair	N/A	N/A	Yes
2			Support Connector						E0012	1	Each	Came with Chair	N/A	N/A	Yes
2			Joystick Support						E0013	1	Each	Came with Chair	N/A	N/A	Yes
2			Joystick Mounting Bracket						E0014	1	Each	Came with Chair	N/A	N/A	Yes
2			Joystick						E0015	1	Each	Came with Chair	N/A	N/A	Yes
2			Armrest Padding						E0016	1	Each	Came with Chair	N/A	N/A	Yes
3				Flat-Round Spacer					E0101	1	Each	Came with Chair	N/A	N/A	Yes
3				Washer					E0102	1	Each	Came with Chair	N/A	N/A	Yes
3				Adjustable Armrest Connector Inside					E0103	1	Each	Came with Chair	N/A	N/A	Yes
3				Adjustable Armrest Connector Outside					E0104	1	Each	Came with Chair	N/A	N/A	Yes
3				3/8" x 3/4" Hex Bolt					E0105	1	Each	Came with Chair	N/A	N/A	Yes
3				1/4" x 2.5" Bolt					E0106	1	Each	Came with Chair	N/A	N/A	Yes
3				1/4" Lock Nut					E0107	1	Each	Came with Chair	N/A	N/A	Yes
3				Joystick Spacer					E0108	2	Each	Came with Chair	N/A	N/A	Yes
3				1/4" x 1" Bolt					E0109	2	Each	Came with Chair	N/A	N/A	Yes
1		Armrest Assembly - Left							F0001						
2			Support Armrest						F0011	1	Each	Came with Chair	N/A	N/A	Yes
2			Armrest Padding						F0016	1	Each	Came with Chair	N/A	N/A	Yes
3				Flat-Round Spacer					F0101	1	Each	Came with Chair	N/A	N/A	Yes
3				Washer					F0102	1	Each	Came with Chair	N/A	N/A	Yes
3				Adjustable Armrest Connector Inside					F0103	1	Each	Came with Chair	N/A	N/A	Yes
3				Adjustable Armrest Connector Outside					F0104	1	Each	Came with Chair	N/A	N/A	Yes
3				3/8" x 3/4" Hex Bolt					F0105	1	Each	Came with Chair	N/A	N/A	Yes
3				1/4" x 2.5" Bolt					F0106	1	Each	Came with Chair	N/A	N/A	Yes
3				1/4" Lock Nut					F0107	1	Each	Came with Chair	N/A	N/A	Yes
3				Joystick Spacer					F0108	2	Each	Came with Chair	N/A	N/A	Yes
3				1/4" x 1" Bolt					F0109	2	Each	Came with Chair	N/A	N/A	Yes
1		Backrest Assembly							D0001						
2			Aluminum Tubing 6061-T6 X 3/4" x 6' x 0.065WT*						D0011	2	Each	53.1	McMaster-Carr	106.2	Yes
2			Aluminum Rod 5/8"						D0021	0.667	Each	7.3	McMaster-Carr	4.8691	Yes
2			Professional Aluminum Welding						D0031	1	Each	75	Gentry Welding	75	Yes
2			Aluminum Plate 2" x 24" x 1/4"						D0041	0.3	Each	3.1	McMaster-Carr	0.93	Yes
2			Aluminum Plate 3" x 6" x .125"						D0051	1	Each	Cal Poly Donated	N/A	N/A	Yes
2			Backrest Cushion						D0061						
3				Low Density Foam 24" x 48" x 1"					D0101	0.333	Each	48	Quality Fabrics and Foam Supplies	15.984	Yes
3				High Density Foam 48" x 96" x 2"					D0102	0.47	Each	18	Quality Fabrics and Foam Supplies	8.46	Yes
3				Black Vinyl					D0103	0.6	Each	45	Quality Fabrics and Foam Supplies	27	Yes
3				Professional Upholstery					D0104	1	Each	95	Fine Touch Upholstery	95	Yes
2			Rubber Grips						D0071	2	Each	4	Amazon	8	Yes
2			Bushing Enclosure Sleeve 5/8"						D0081	2	Each	7	McMaster-Carr	14	Yes
3				Flat-Round Spacer					D0105	4	Each	0.3	3D Print	1.2	Yes
1		Electrical Assembly							G0001	1	Each	N/A	N/A	N/A	N/A
2			Battery and Charger						G0011	1	Each	$ 492.54	A1 Mobility	$ 492.54	Yes
3				24V Linear Actuator					G0101	3	Each	$ 160.00	Firgelli	$ 480.00	Yes
4					Actuator Switches				G0101	3	Each	$ 15.00	Firgelli	$ 45.00	Yes
4					Aluminum Plate 2" X 24" X 1/8"				G0102	1	Each	$ 5.84	McMASTER-CARR	$ 5.84	Yes
4					Actuator Mounts				G0103	3	Each	$ 4.00	Firgelli	$ 12.00	Yes
4					Clevis Pin 3/16" X 1"				G0104	3	5 X	$ 5.63	McMASTER-CARR	$ 16.89	Yes
3				Hatchbox ABS 3D printer filament, 1kg					G0102	0.1	Each	$ 21.99	Amazon	$ 2.20	Yes
4					Rocker Switch for Linear Actuator				G0105	3	Each	$ 9.00	Firgelli	$ 27.00	Yes
5						Wiring Harnesses			G1001	3	Each	$ 8.00	Firgelli	$ 24.00	Yes
6							Limit Switches		G1011	3	3 X	$ 32.02	Firgelli	$ 32.02	Yes
6							Quick Connectors		G1012	20	Each	$ 0.07	Amazon	$ 1.40	Yes
6							Wire		G1013	15	per ft	$ 1.33	Amazon	$ 20.00	Yes
1		Headrest Assembly							H0001	1	Each	Came with Chair	N/A	N/A	N/A
2			Headrest Cover						H0011	1	Each	44.44	Slidewear	44.44	Yes
													Total Cost	2309.03	

Appendix O – FMEA

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
Back / Provide comfort in torso and stability and structure necessary to hold Nathan	Back is uncomfortable	Nathan is uncomfortable	5	1) Poor material choice 2) Dimensions are incorrect 3) Not enough padding	1) Make sure material chosen is right 2) Make sure all dimensions are correct 3) Communicate with Nathan first to see how much padding is comfortable for him	5	Nathan tests and leans back on backrest	1	25	Communicate with Nathan and have Nathan test out backrest to see how it feels for him	Team/Before end of Winter Quarter	Discussed backrest fit with Nathan; likes idea of having side torso guides	2	1	2
	Vertical Rails Break	1) Sharp edges at broken area 2) Back breaks 3) Nathan is injured	7	1) Rails too thin 2) Shear at junctions 3) Use over time 4) Fasteners not applied correctly	1) Measure thickness and other dimensions correctly and make sure through analysis rails are thick enough 2) Stress/force analysis 3) Deflection analysis	1	Apply force on vertical rails to see when they fail in tension, compression, and shear	1	7	Use material that minimizes chances of breaking, conduct extensive analysis with a high safety factor	Team/Before end of Winter Quarter	Using aluminum and minimizing pinch points	2	1	2
	Backrest has pressure points	1) Nathan is uncomfortable 2) Nathan's back develops worse posture	6	1) Backrest has bumps 2) Backrest not uniform in shape and texture 3) Seat cushion is too soft and squishy	1) Ensure backrest has no bumps 2) Do not lay or lean anything on padding before application	2	Nathan tests and leans back on backrest	1	12	Custom made back rest foam (Foam-in-place)	Team/Before end of Winter Quarter	Foam cut and sized to Nathan's liking	1	1	1
Seat / Provide bottom and lower back comfort and structure	Seat is uncomfortable	Nathan is uncomfortable	5	1) Non-uniform shape and texture of seat 2) Insufficient padding	1) Make sure texture of seat is flat and uniform 2) Make sure padding is sufficient 3) Buy various seat cushions to see which has best shape recovery	3	Nathan tests and tries out seat comfort	1	15	Buy seat cushion most comfortable for him	Matt/Before end of Winter Quarter	Used preexisting seat cushion which Nathan likes	1	1	1
	Seat does not keep Nathan in place	1) Nathan slides out of seat 2) Nathan falls 3) Nathan gets injured	5	1) Poorly made back support and wrong seat cushion 2) Not enough support in occipital head rest and seat isn't at correct angle 3) Seat is at a downward slope when viewed from the side	1) Make sure foam in backrest fits perfectly to Nathan 2) Ensure seat is perpendicular to backrest and flat on seat base plate when fastened together	1	Compare Nathan's posture with more than one manufactured foam backrests	2	10	Make several parts for the back seat foam and pick best manufactured part and recline seat to optimal position so sliding out of seat will not happen	Team/Before end of Winter Quarter	Using tacky strip on seat to keep Nathan in place and have seat structured so that he will not slip down out of seat	1	1	1
Foot Rest / Provide feet and leg comfort	Foot rest is not in comfortable enough position	Nathan's legs lock up in awkward position	4	1) Foot rest mounted incorrectly 2) Foot rest not far out enough 3) Foot rest flexes too much	1) Measure how far each foot rest needs to be from each side of device 2) Measure best distance from chair foot rest must be so his legs do not get stuck in an awkward position 3) Make sure foot rest is sturdy and strong before mounting 4) Force analysis	3	Nathan tests the angle at which his feet have to be to rest on the foot rests	1	12	Personally go to Nathan to test to see if angle is perfect for his liking	Team/Before end of Winter Quarter	Nathan is most comfortable with slight angle from vertical	1	1	1
	Foot rest breaks	Nathan cannot use foot rest to keep feet in natural position to prevent locking of legs	7	1) Fastened incorrectly 2) Not strong enough to handle load 3) Poor material choice 4) Foot rest made too flimsy	1) Make sure foot rest is mounted well so that there is not a lot of flexure or bending occurring while under loading 2) Make sure material chosen is correct	1	Apply more and more weight to one of the foot rests temporarily attached to a bar to see when the foot rest falls off	1	7	Make leg rest out of aluminum and test to see if Nathan's leg weight force would be supported	Team/Before end of Winter Quarter	Leg rest made out of aluminum with some 3-D printed parts for minimal weight	1	1	1
	Foot rest hinders movement and maneuverability of mobility device in tight spaces	1) Nathan has difficulty moving around 2) Nathan hurts feet bumping into things 3) Foot rest breaks	4	1) Foot rest extends too far out from mobility device 2) Foot rest does not have capability of retracting	1) Make sure measurements are correct so foot rests are in ideal locations 2) Provide capability to retract foot rests	3	Maneuver test between tables and chairs	1	12	Maneuver test between tables and chairs	Team/Before end of Winter Quarter	Program to maneuver with various speed settings	1	1	1
Head Rest / Provide head support	Head rest does not support head	1) Nathan is uncomfortable 2) Nathan cannot move head up to see what he is doing and where he is going	4	1) Head rest placed too far forward or back 2) Lack of side head supports	1) Make sure head rest is in line with the back rest and does not move forward and backward easily 2) Attach side supports on the head rest	2	Position head rest and test to see if Nathan's head leans more to one side than the other	1	8	Have Nathan test different positions and pick which one is most comfortable and most supportive	Lauren/Week 1 of Spring Quarter	Nathan enjoys occipital pad headrest and wants less material around his head	1	1	1
	Head rest breaks off	1) Nathan's head flops around 2) Nathan cannot see where he is going 3) Nathan hits something and gets hurt	7	1) Head rest made out of wrong material 2) Head rest does not have good structural support	1) Make sure team agrees on best material for the head rest 2) Stress/force analysis	1	Tie rope to head rest and tie other end to increasing weight until head rest comes off backrest	2	14	Place occipital headrest in middle of backrest with rod running down middle of back rest to evenly distribute load along length of the back rest to avoid failure as best as possible	Team/Week 1 of Spring Quarter	Occipital pad attached along center axis of backrest to ensure CG is in place to prevent tipping right or left	1	1	1
	Head rest does not feel comfortable/locks head in awkward position	Nathan's neck can get sore	5	1) Head rest too far forward or backward 2) Head rest is not stationary/can wiggle around too much 3) Head rest not mounted properly	1) Make sure head rest is in line with back rest 2) Make sure head rest does not move around when attached to back rest 3) Force analysis	2	Put Nathan in seat and have him rest his head between the head supports to see if it feels comfortable	1	10	Have Nathan test different positions and pick which one is most comfortable	Team/Week 1 of Spring Quarter	Only using occipital pad that will be curved around his head to provide sufficient support but not to the point of feeling like a helmet	1	1	1
Actuation / Power and control the motion of the backseat	Actuator breaks	1) The reclining chair does not have the necessary support 2) Chair can no longer recline	7	1) Actuator was bought broken or defective 2) Actuator located in exposed area 3) Actuator is subjected to too much loading/not strong enough	1) Create drawing and ensure dimensions for location of actuator is correct before mounting 2) Purchase actuator that can handle higher load than what it will be subjected to 3) Factor of Safety analysis	3	Try actuation motion out on something light before mounting	1	21	Conduct extensive testing on the linear actuator, positioning, and the circuit. Use a high safety factor. Then conduct extensive testing to verify the modeled calculations	Matt/Week 2 of Spring Quarter	Linear actuators researched and confirmed to be good for certain function. Positioned in place where pinch points are not a problem	2	1	2
	Actuator not strong enough to push back of chair	1) Nathan reclines back but very rapidly, scaring him 2) Force and speed of chair reclining breaks actuator	5	1) Wrong actuator purchased 2) Actuator overused	Make sure actuator purchased is correct	3	Connect actuator to power supply and test to see if actuator can push chair from reclined position to an upright position with a backpack laying on the backrest	1	15	Buy actuator that has enough force and power to supply to subsystem	Matt/Week 2 of Spring Quarter	Load analysis completed and confirmed bullet actuators will work	2	1	2

Actuation / Power and control the motion of the backseat	Actuator does not allow for smooth reclining	Nathan is scared of potentially falling back to quickly	3	1) Actuator is defective 2) Actuator is not strong enough	Make sure actuator purchased is correct	5	Connect actuator to power supply and test to see if actuator can push chair from reclined position to an upright position with a backpack laying on the backrest and vice versa	1	15	Buy a high quality linear actuator and conduct testing	Matt/Week 2 of Spring Quarter	Firgelli actuators work really well for the tasks they must complete	2	1	2
	Power source does not provide enough power	Actuator not able to power and stuck in one position	4	1) Incorrect power source bought 2) Circuitry is incorrect or has been messed with 3) Voltage too weak	1) Purchase correct voltage source 2) Avoid playing around with circuitry 3) Warn Nathan's family to stay clear of the circuitry and electrical components	3	Test out at A1 Mobility	2	24	Consult with multiple professors and A1 mobility to verify the safety and accuracy of the power source	Steven/Week 2 of Spring Quarter	A1 Mobility will confirm the wiring diagram and program to make sure electrical system is safe	2	1	2
	Power source provides too much power	Circuit can explode, wires melt, components get fried, Nathan gets electrocuted	5	1) Voltage too high 2) Circuitry messed with and incorrect 3) Wrong power source bought	1) Purchase correct voltage source 2) Consult team and professo before purchasing	1	Test out at A1 Mobility	2	10	Go to A1 Mobility to get tested	Team/Week 2 of Spring Quarter	Testing at A1 Mobility	2	1	2
	Circuit is inappropriately wired	Nathan gets electrocuted, explosion occurs, components get fried,	7	1) Previously messed wit 2) Heat melts wires together 3) Wires accidentally get loose	1) Ensure circuitry is not played with 2) Do not overheat device/take breaks once in a while	1	Test out at A1 Mobility	3	21	Go to A1 Mobility to get tested	Team/Week 2 of Spring Quarter	Testing at A1 Mobility	2	1	3
	Actuator does not work	The reclining chair gets stuck in a reclined or vertical position	7	1) Actuator damaged physically from environment 2) Purchased broken or defective actuator	1) Keep actuator safe from outside influence 2) Refrain from overusing reclining feature	1	Try actuation motion out on something light	3	21	Need to conduct multiple rounds of testing. In the case this does happen, put together a troubleshooting guide for Nathan and his family	Team/Week 2 of Spring Quarter	Create a operator's manual and troubleshooting guide	2	1	3
General / Hold parts together	Structural integrity does not support Nathan	1) Nathan falls 2) Nathan gets injured 3) A component falls on top of him	7	1) Fasteners are applied inadequately 2) Glue melts or comes apart	1) Purchase high performance glue that keeps things together well and for long periods of time 2) Measure and calculate optimum positions to apply fasteners	2	Nathan tests out mobility seat	1	14	Carefully put fasteners on without stripping bolts and practice applying glue and drying before actually doing it	Team/Week 3 of Spring Quarter	Fasteners will be tightened as much as possible using round-t flat adapter spacers	1	1	1
	Components fall off	1) Falls on Nathan 2) Disables the functionality of the chair	7	1) Glue melts or comes apart 2) Shear in glue 3) Fastener shear	Buy best glue possible in terms of how long it lasts and how strong it is	1	Check the fasteners to see if there is rust and if the glue completely surrounds what it needs to keep in place	1	7	Check the fasteners to see if there is rust and if the glue completely surrounds what it needs to keep in place	Team/Week 3 of Spring Quarter	Using 3-D printed round-to-fla adapters and aluminum (not oxidized) nuts and bolts	1	1	1
	Fasteners break or corrode easily	1) Components fall off 2) Protruding rust pokes Nathan in back	7	1) Fastener shear 2) Poor material choice selected for fastener 3) Not enough fasteners mounted to evenly distribute load 4) Weather/left out in rain	1) Purchase corrosion resistant fasteners 2) Apply just enough fasteners to keep components from falling apart	1	Test various materials to see which fastener corrodes first	3	21	Test various materials to see which fastener corrodes first	Team/Week 3 of Spring Quarter	Aluminum will be used for most of device; steel where strength is utmost importance	1	1	1
General / Provide necessary aesthetic appearance	Does not meet Nathan's aesthetic taste	1) Nathan is disappointed 2) Nathan cries or gets mad 3) Parents get upset and disappointed	3	1) Miscommunication 2) Wrong colors	Communicate with Nathan and parents to confirm what we are purchasing and will be putting on device	3	Show design to Nathan and ask for his reaction and opinion	1	9	Correctly take note of what Nathan wants	Team/Week 4 of Spring Quarter	Everything measured multiple times and met with Nathan to confirm everything	1	1	1
	Decals do not stay on for a long time	1) Nathan is disappointed 2) Device does not look as cool	1	1) Decals are faulty 2) Decals not sticky enough 3) Decals have air bubbles after application	1) Purchase more decals than needed 2) Use card to slide decals on to prevent bubbles	8	Test how long the decal will last on a surface before placing it on mobility device (splashing water on it, etc)	1	8	Unavoidable; buy typical decals	Team/Week 4 of Spring Quarter	Laser-cut Batman stickers	1	1	5
	Paint chips off easily	1) Appearance looks bad 2) Nathan is disappointed 3) Paint gets all over Nathan and irritates him	1	1) Not enough coats of paint applied 2) Wrong paint chosen 3) Device left out in rain while drying 4) Device left in environment with a lot of wind/rain/snow/etc.	1) Apply more coats than necessary to ensure coat stays on 2) Communicate with sponsors and professor about purchasing paint 3) Warn sponsors about potential effects weather can have on physical appearance of device	10	Paint an object not going to be used on the mobility device and let dry. Once dry, take a stick and run the edge across the length of the painted object looking to see if chipping or streaks appear.	1	10	Go to get sand blasted and coated nicely and completely	Team/Week 4 of Spring Quarter	Sand blast old paint and get new all black paint job	1	1	5

Appendix P – Operator's Manual

TEAM NATHAN'S OPERATOR'S MANUAL

Troubleshooting, Repair, Storage, and Maintenance (Technical Manual)

Written by:
Matt Brenholdt
Steven deCsesznak
Lansen Eto
Moulay Salahdin

Introduction

The purpose of this manual is to assist in maintaining the functionality of the device. Tasks outlined in this manual should not be carried out by minors or those not aware of the potential risks. This manual will outline proper maintenance and repair techniques to be carried out on the device and well as serve as a source for part names and sources.

Potential Safety Risks

- **Electrical Shock Warning**
- **Electrical Fire Warning**
- **Pinch Point Warning**
- **Heavy Object Warning**
- **Rotating Parts Warning**

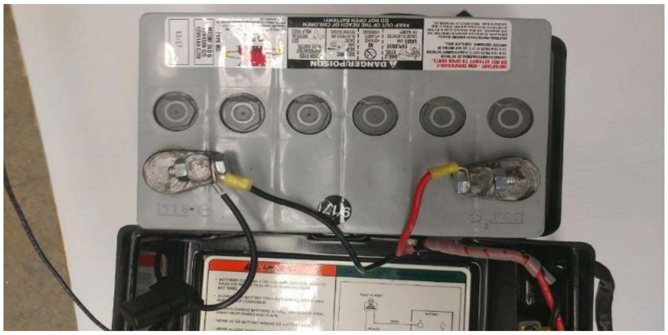
Troubleshooting

This purpose of this section is to highlight potential issues that may occur and the most likely cause of those problems. If experiencing any of the issues seen discussed in this manual, the list of causes is generally order from most to least likely issue.

Electrical System

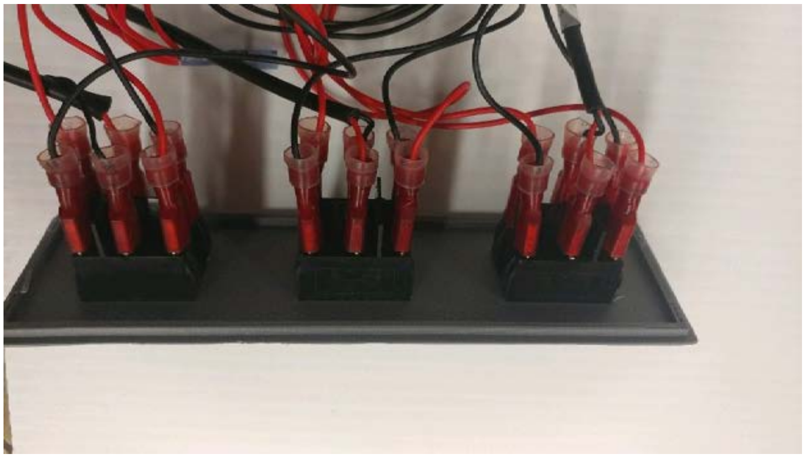
1) One or more linear actuators are not responding to user input

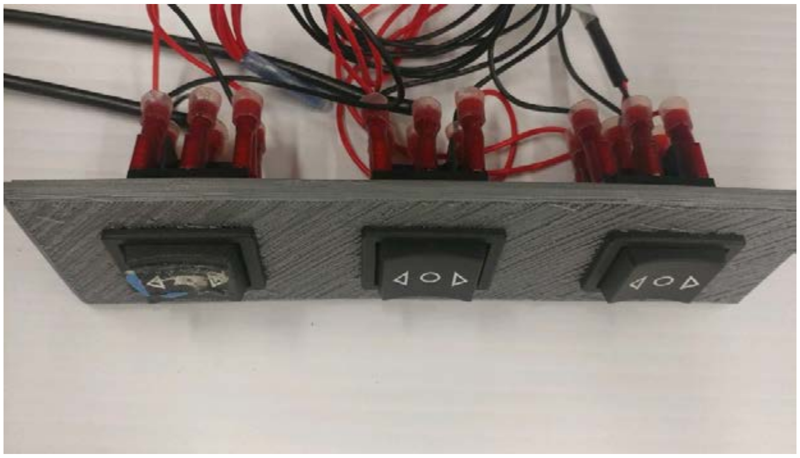
- Verify that the batteries are connected and the contacts are clean and free of foreign material
- Make sure the battery is fully charged
- Check the electrical system for any loose connections or damaged/frayed wires (**Disconnect battery before inspecting electrical system)**
- Check to see if fuses inside each battery box have blown (Fuses contained in black in-line sleeves)



- Check electrical system for signs of water damage
- If none of the above are the cause of the problem, these are strategies to check to see if the problem is in a component **(These tasks should only be carried out by professionals with proper tools and personal protective equipment)**
  - If one or more linear actuator systems still responds to user input, the rocker switch/s connected to the functional system can be connected to the dysfunctional

    system. If replacing the rocker switch fixes the problem, then the fault likely is with the disconnected rocker switch.
  - Apply a 24-Volt source to the linear actuators. If the actuator does not move, replug the positive and negative connections. If the actuator still does not move, it is likely that the problem is with the linear actuator. If the actuator moved when the voltage was applied, it is likely the rocker switch controlling the actuator is at fault.
- Check to make sure that there is no debris in the rocker switch crevices that prevent switches from “rocking” back and forth.





2) The linear actuators move slower than normal

- The designed load limit of the chair could be exceeded, so make sure no additional loads are applied to the system
- Verify that the battery is connected and well charged
- Check the telescoping arm of the linear actuator for debris. If the debris appears to be metal or plastic, it is possible the linear actuator is failing. If dirty, follow cleaning instructions outlined in the maintenance section.

Mechanical System

1. Free-wheel mode of wheelchair does not work

- Check the knobs at the bottom of the base behind the rear wheels to see if free wheel is enabled or disabled
- Check to see if there is debris blocking or tangled in the wheel

2) Head rest is not in optimal position or falling down

- Check to see if bolts are tightened into the back of the headrest
- Use a hex head wrench to tighten bolts if they are not already tightened

Maintenance

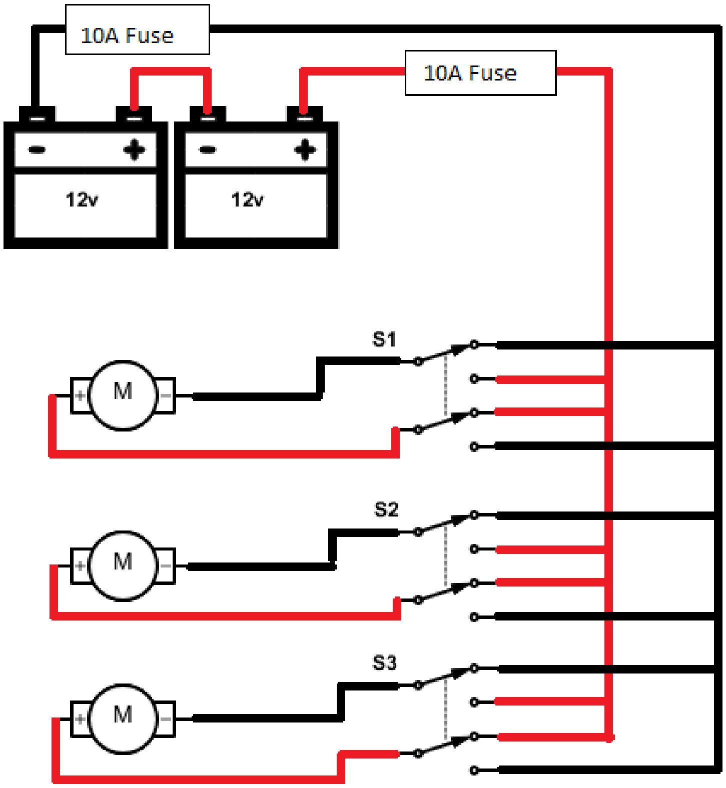
This section is meant to assist with maintaining the overall appearance and performance of the mobility device. This includes cleaning, damage prevention/reduction, etc.

Cleaning Instructions

- Before cleaning any components attached to the device, disconnect the battery
- Cushions should be removed from the device before they are to be cleaned
- In general, all cleaning can be performed with a damp cloth or disposable cleaning wipe
- Make sure to completely dry off damp areas after cleaning

- Mud and dirt can be removed from the wheels and undercarriage using small amounts of water and a scrub brush

Electrical System



Mechanical System

PPE (Personal Protective Equipment) Required:

- Safety Glasses/Goggles
  - Glasses are required for any self-maintenance that involves particles/debris that can fly into someone’s eyes
  - Goggles are recommended for maintenance for extra eye protection
- Rubber Gloves
  - Recommended when using cleaning solutions
- Workwear Gloves
  - Recommended for lifting to get better access to area that requires maintenance
  - Recommended to avoid getting hurt near pinch points
- Long Pants
  - Required when dealing with solutions or substances that can affect skin
  - Required to avoid getting cut from device
- Close-Toed Shoes with Rubber Soles
  - Required to avoid smashing feet severely in case device is dropped

Required Tools:

- Allen wrench kit
- Socket wrench kit
- Combination wrench kit

These tools are required for tightening and loosening the bolts and nuts that fasten their respective parts to the assembly.

Repair

This section discusses the necessary steps to take to fix any damaged or broken parts, subassemblies, and other systems. Remember that it is always a better option to contact a professional about repairing something that is unfamiliar rather than fixing it alone.

Mechanical System

1) Welds are breaking or deteriorating

- Bring to Gentry Welding and Fabrication for re-welding
- Do not try to fix alone without professional assistance

2) Frame damaged or dented

- Take pictures of damaged frame and seek help from A1 Mobility to get frame reverted back to original shape
- In the event that damage is beyond the abilities of A1 mobility, seek assistance from Gentry Welding and Fabrication

3) Damaged bearings and/or fasteners

- Take pictures of bearing or fastener and locate parts online from Quickie Z-500 user manual or in included parts list

4) Footrest wearing down or damaged

- Request CAD models from Cal Poly to reprint parts on 3D printer and sent as replacements for device. The information necessary to email Cal Poly can be found on the inside cover of the binder.

TEAM NATHAN'S OPERATOR'S MANUAL

Non-Technical User Manual

Written by:
Matt Brenholdt
Steven deCsesznak
Lansen Eto
Moulay Salahdin

Introduction

The purpose of this manual is to assist in maintaining the functionality of the device. Tasks outlined in this manual should not be carried out by minors or those not aware of the potential risks. This manual will outline proper maintenance and repair techniques to be carried out on the device and well as serve as a source for part names and sources.

Disclaimer: A more detailed technical manual is also included with the device

Charging the Batteries

In order to charge the batteries, the charger cable will need to be plugged into the joystick charging port as seen in the picture below.

When plugging in the cable, make sure the three prongs are appropriately positioned to the charging port.

Troubleshooting

Problem 1: Device will not move but batteries are charged

- Check to make sure the chair is on
- Verify that the lock lever is off as seen in the picture below

  - If the chair is on:

        - Are the batteries charged (if not then charge)
        - Are there any connectors that are not plugged in

Problem 2: Linear actuator does not work

- Are the batteries charged?
- Do the two other actuators work?
- Is there a foreign object/s in the way of the actuator’s movement?

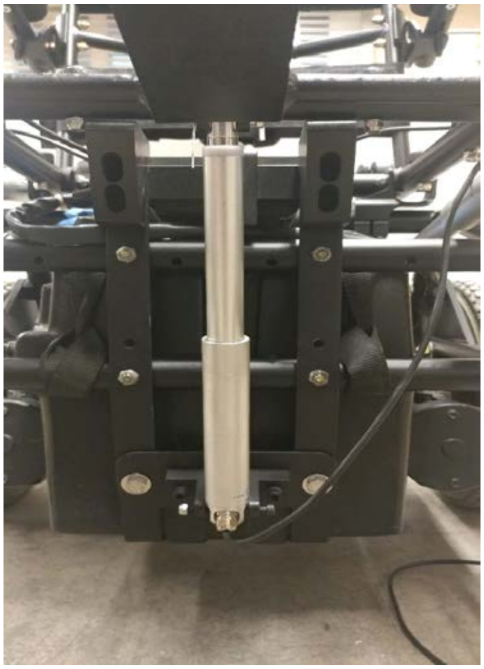
Problem 3: Device runs slow/performs poorly

- Check to make sure the right setting is being used
- It may be time to recharge or replace the battery
- Is there debris in/around the wheels?
- Is the device in free-wheel mode or driver mode?

Problem 4: Locked joystick

- Possible debris stuck in joystick; take to A1 Mobility to get checked out

Labeled Diagrams of Device



Tilt-in-space Actuation

Backrest Recline Actuation

Footrest Recline Actuation

Top view of tilt-in-space and electrical system

Backrest cushion (front side)

Backrest frame/straps along with headrest from front and back perspective

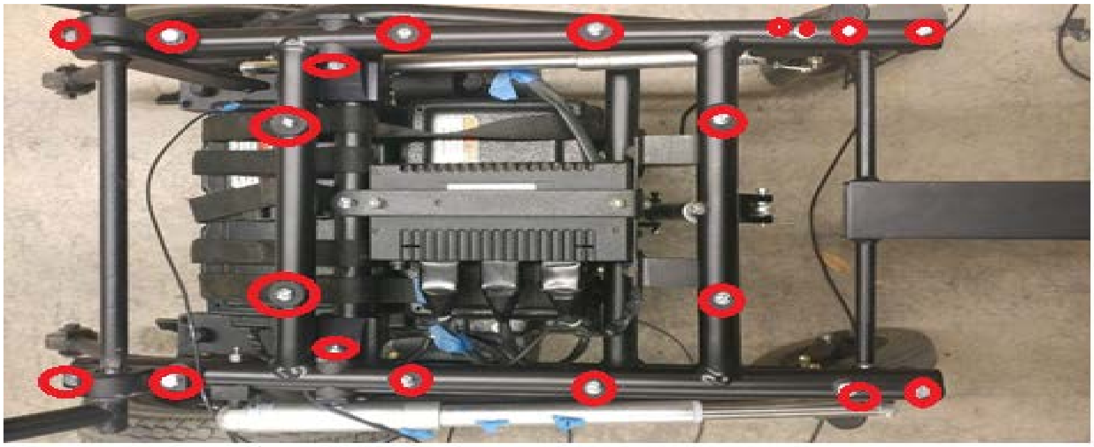
Battery box

Maintenance

Cushioning: (Minor maintenance: battery charging/removal, light cleaning, cushion removal/adjustment, etc)

1. Cushioning cannot be machine washed but should be cleaned regularly with a damp cloth with soap and water, and/or an alcoholic wipe to kill bacteria. The foam can be removed if necessary from the zipper located at the bottom.
2. Headrest cover (Glide Wear) can be removed and washed in the washer and dryer.
3. Velcro bands can be washed with soap and water by hand.
4. Metal frame can be cleaned using a rag with soap and water

5. Battery needs to be regularly check to ensure that it is still functional; if rust or a colored substance begins to form around the battery terminals, scrub with water and baking soda using a toothbrush
6. Ensure that the bolts and screws are properly and regularly tightened. The picture below illustrates the location of the bolts from a top perspective with the bolt callouts in red.



Locations of bolts and nuts fastening each major component

Storage

Storage (disconnect batteries, keep in dry place, don’t leave device alone while charging, etc)

1. Do not let the mobility device get wet or sit in a damp or humid environment
    a. Preferably standard room temperature
2. If the device is used on muddy/wet/sandy terrain, clean the debris off to prevent corrosion or damage to the body and functionality of the device
3. Avoid storing device near heavy objects or objects that can easily move around to prevent damage to the device
4. Do not leave device stored for long periods of time without regular cleaning/maintenance

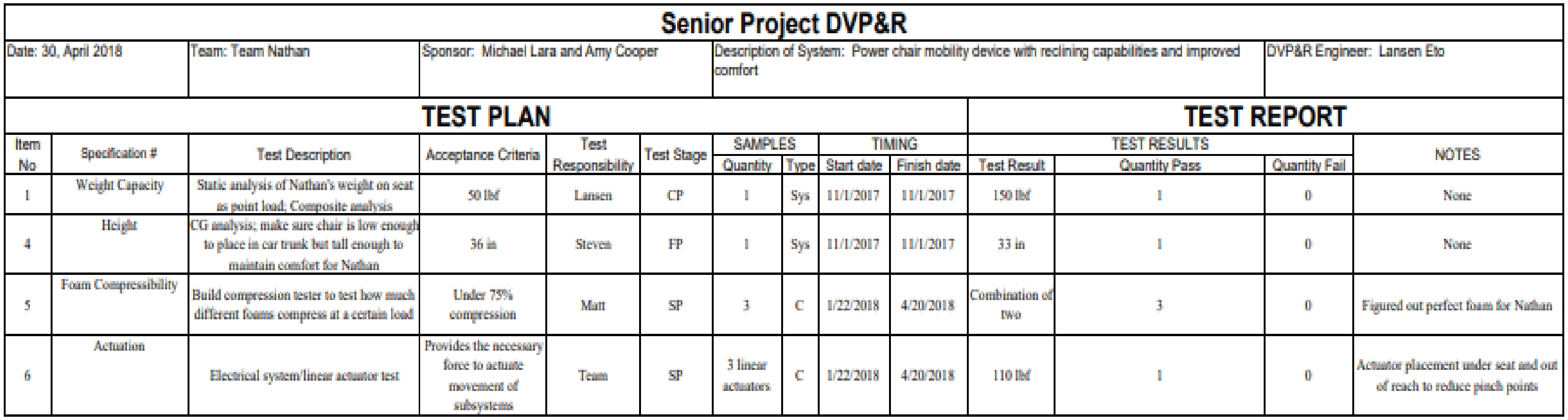
5. To remove battery boxes, verify that batteries are unplugged then disconnect buckles and velcro straps and carefully lift and pull on battery box handle. Be very careful as these batteries are VERY heavy and can cause serious injury.

Transportation

Transporting the mobility chair (being loaded into/out of car, being pushed, etc)

1. Do not grab the device by its rotating parts to avoid injury while transporting
2. Make sure wheels are in a locked position to prevent wheels from rotating an d hitting someone
3. Make sure battery is secured in place to avoid falling on someone’s toes/body parts

Appendix Q – Design Verification Plan



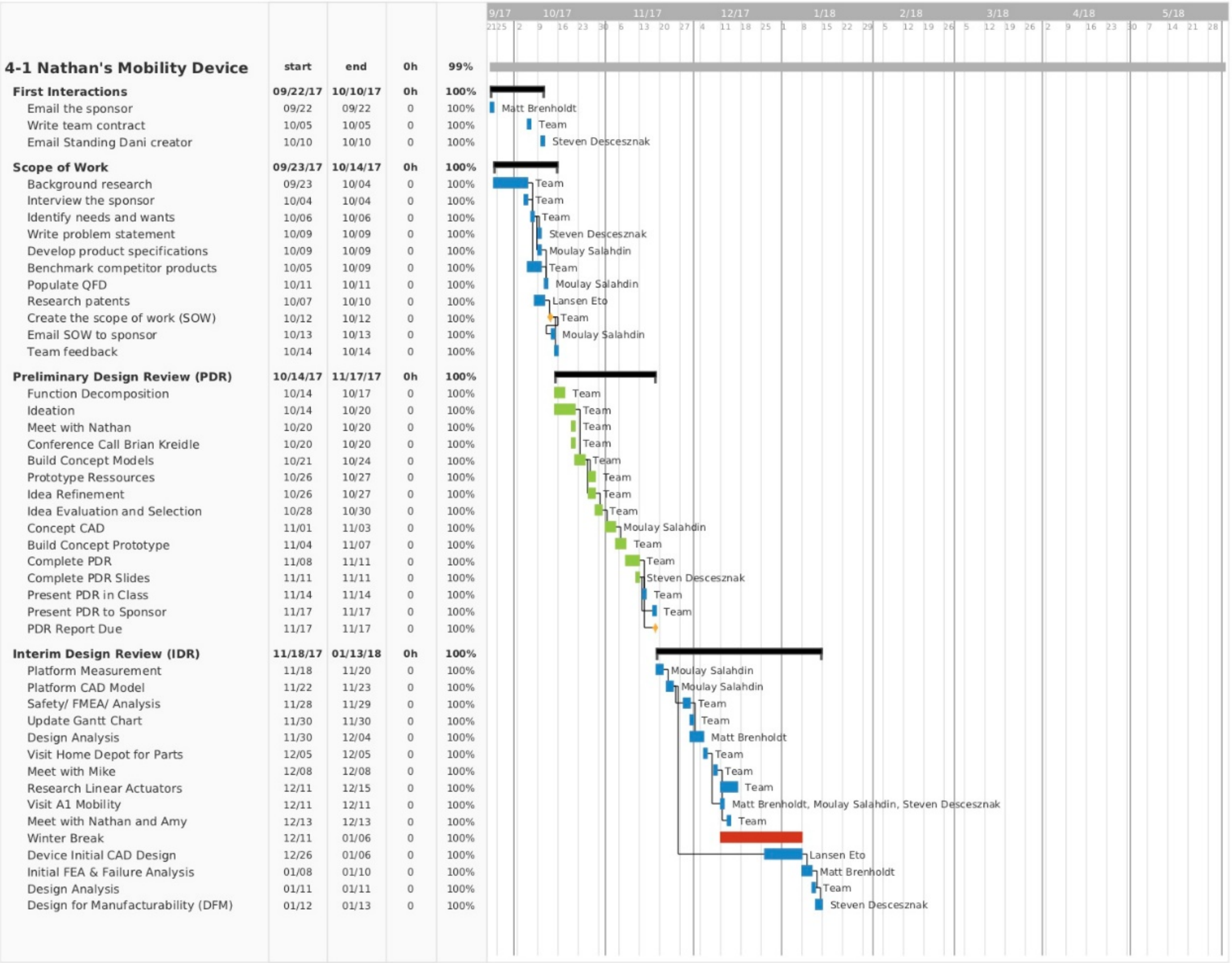
Senior Project DVP&R

Date: 30, April 2018
Team: Team Nathan
Sponsor: Michael Lara and Amy Cooper
Description of System: Power chair mobility device with reclining capabilities and improved comfort
DVP&R Engineer: Lansen Eto

TEST PLAN | **TEST REPORT**

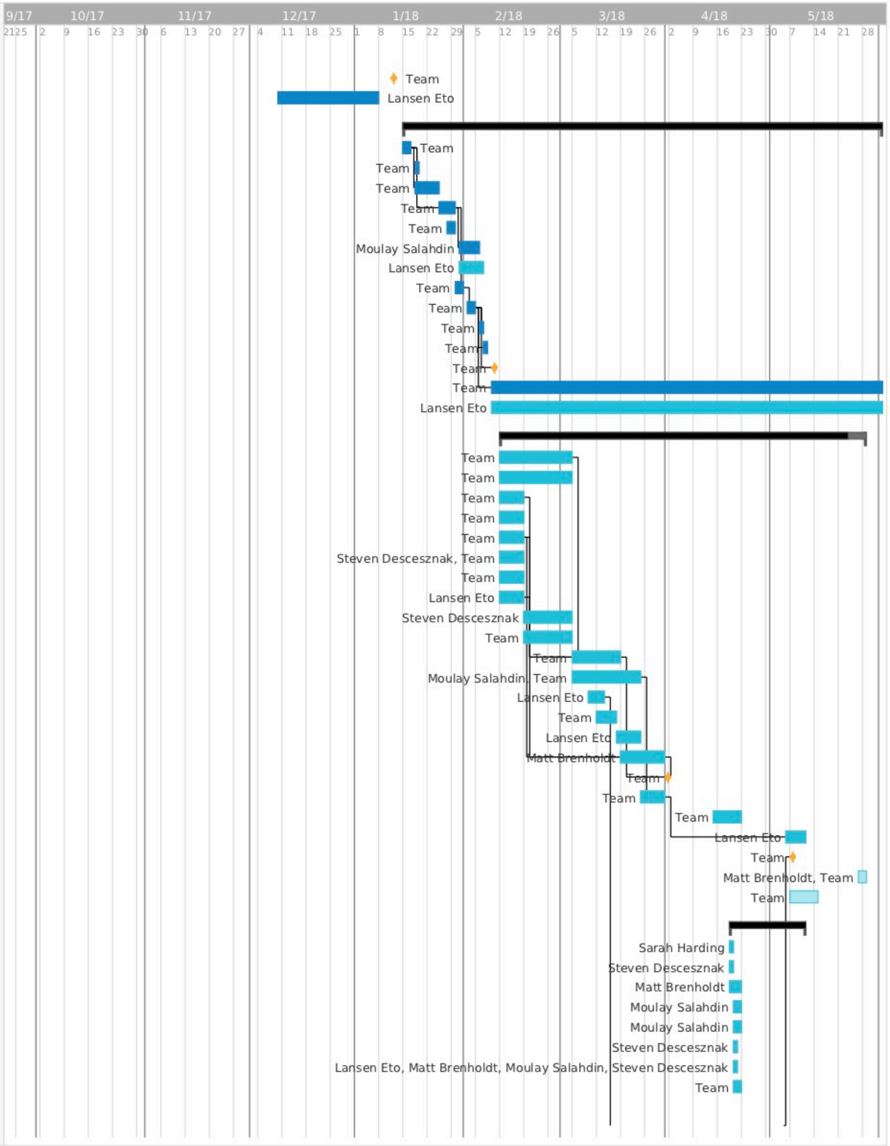
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Weight Capacity	Static analysis of Nathan's weight on seat as point load; Composite analysis	50 lbf	Lansen	CP	1	Sys	11/1/2017	11/1/2017	150 lbf	1	0	None
4	Height	CG analysis; make sure chair is low enough to place in car trunk but tall enough to maintain comfort for Nathan	36 in	Steven	FP	1	Sys	11/1/2017	11/1/2017	33 in	1	0	None
5	Foam Compressibility	Build compression tester to test how much different foams compress at a certain load	Under 75% compression	Matt	SP	3	C	1/22/2018	4/20/2018	Combination of two	3	0	Figured out perfect foam for Nathan
6	Actuation	Electrical system/linear actuator test	Provides the necessary force to actuate movement of subsystems	Team	SP	3 linear actuators	C	1/22/2018	4/20/2018	110 lbf	1	0	Actuator placement under seat and out of reach to reduce pinch points

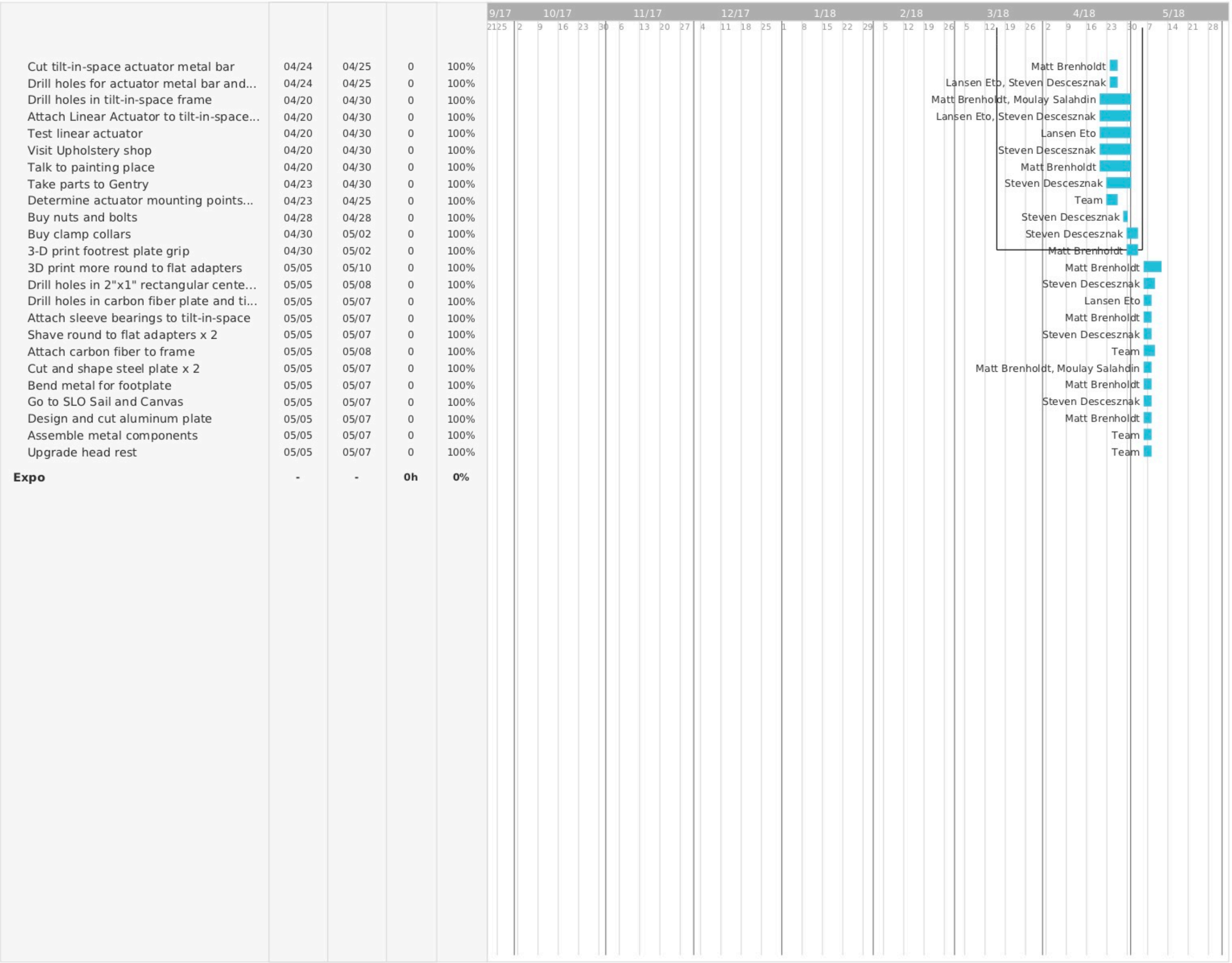
Appendix R – Gantt Chart



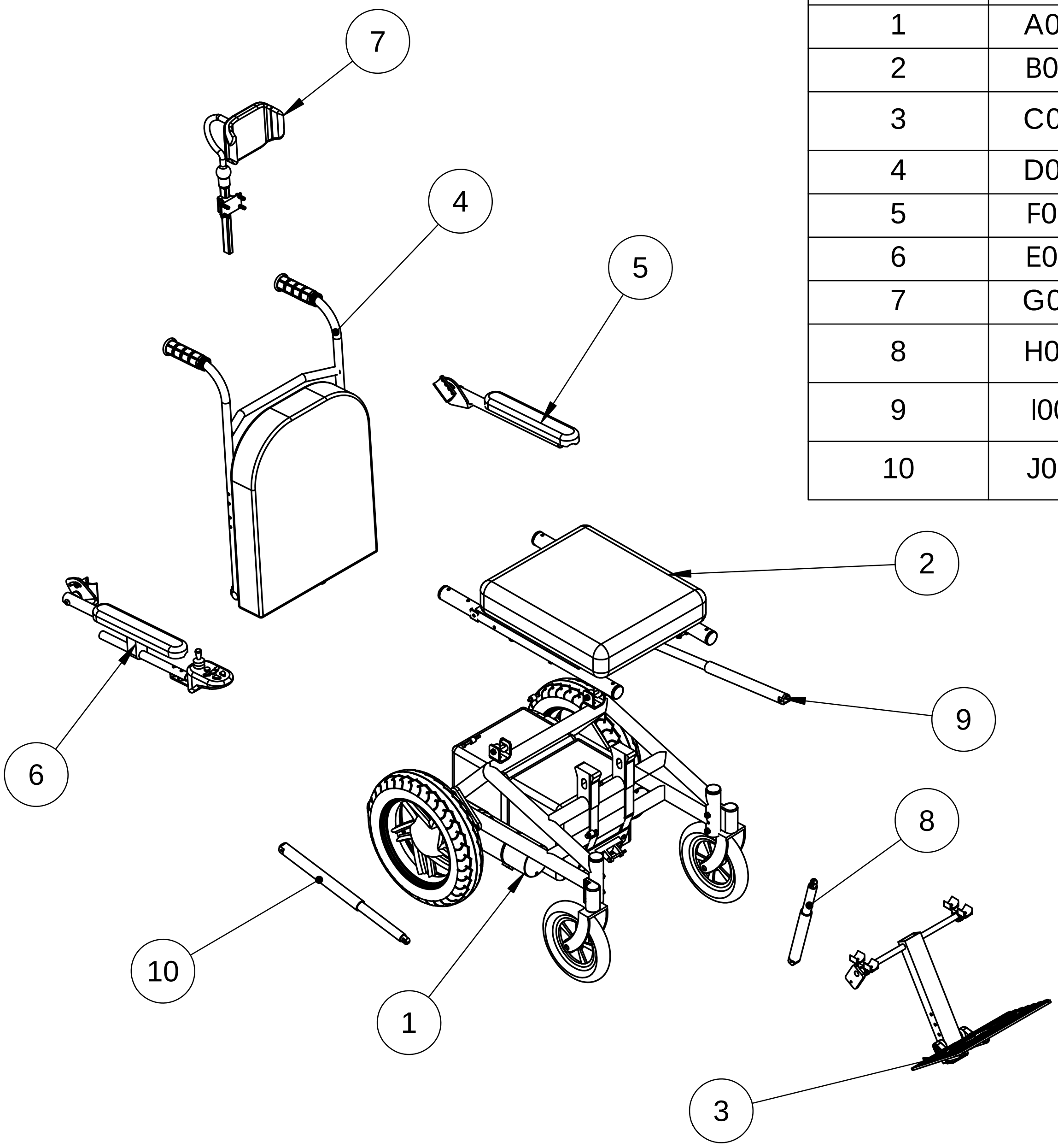
4-1 Nathan's Mobility Device	start	end	0h	99%
First Interactions	**09/22/17**	**10/10/17**	**0h**	**100%**
Email the sponsor	09/22	09/22	0	100%
Write team contract	10/05	10/05	0	100%
Email Standing Dani creator	10/10	10/10	0	100%
Scope of Work	**09/23/17**	**10/14/17**	**0h**	**100%**
Background research	09/23	10/04	0	100%
Interview the sponsor	10/04	10/04	0	100%
Identify needs and wants	10/06	10/06	0	100%
Write problem statement	10/09	10/09	0	100%
Develop product specifications	10/09	10/09	0	100%
Benchmark competitor products	10/05	10/09	0	100%
Populate QFD	10/11	10/11	0	100%
Research patents	10/07	10/10	0	100%
Create the scope of work (SOW)	10/12	10/12	0	100%
Email SOW to sponsor	10/13	10/13	0	100%
Team feedback	10/14	10/14	0	100%
Preliminary Design Review (PDR)	**10/14/17**	**11/17/17**	**0h**	**100%**
Function Decomposition	10/14	10/17	0	100%
Ideation	10/14	10/20	0	100%
Meet with Nathan	10/20	10/20	0	100%
Conference Call Brian Kreidle	10/20	10/20	0	100%
Build Concept Models	10/21	10/24	0	100%
Prototype Ressources	10/26	10/27	0	100%
Idea Refinement	10/26	10/27	0	100%
Idea Evaluation and Selection	10/28	10/30	0	100%
Concept CAD	11/01	11/03	0	100%
Build Concept Prototype	11/04	11/07	0	100%
Complete PDR	11/08	11/11	0	100%
Complete PDR Slides	11/11	11/11	0	100%
Present PDR in Class	11/14	11/14	0	100%
Present PDR to Sponsor	11/17	11/17	0	100%
PDR Report Due	11/17	11/17	0	100%
Interim Design Review (IDR)	**11/18/17**	**01/13/18**	**0h**	**100%**
Platform Measurement	11/18	11/20	0	100%
Platform CAD Model	11/22	11/23	0	100%
Safety/ FMEA/ Analysis	11/28	11/29	0	100%
Update Gantt Chart	11/30	11/30	0	100%
Design Analysis	11/30	12/04	0	100%
Visit Home Depot for Parts	12/05	12/05	0	100%
Meet with Mike	12/08	12/08	0	100%
Research Linear Actuators	12/11	12/15	0	100%
Visit A1 Mobility	12/11	12/11	0	100%
Meet with Nathan and Amy	12/13	12/13	0	100%
Winter Break	12/11	01/06	0	100%
Device Initial CAD Design	12/26	01/06	0	100%
Initial FEA & Failure Analysis	01/08	01/10	0	100%
Design Analysis	01/11	01/11	0	100%
Design for Manufacturability (DFM)	01/12	01/13	0	100%

Interim Design Review	01/11	01/11	0	100%
Update Gantt Chart	12/09	01/06	0	100%
Critical Design Review	**01/15/18**	**06/01/18**	**0h**	**100%**
Build Structural Prototype	01/15	01/16	0	100%
Prototype Initial Testing	01/18	01/18	0	100%
Final Part Selection	01/18	01/24	0	100%
Create a Detailed CAD	01/25	01/29	0	100%
Update Google Drive	01/27	01/29	0	100%
Seat FEA Analysis	01/31	02/05	0	100%
Composite Analysis	01/31	02/06	0	100%
Create a Manufacturing Plan	01/30	01/31	0	100%
Prepare CDR	02/02	02/03	0	100%
Present CDR in Class	02/06	02/06	0	100%
Present CDR to Sponsor	02/07	02/07	0	100%
CDR Report Due	02/09	02/09	0	100%
CDR Editing	02/09	06/01	0	100%
Edit Drawing Package	02/09	06/01	0	100%
Manufacturing and Test Review	**02/12/18**	**05/28/18**	**0h**	**95%**
Purchase Linear Actuators	02/12	03/03	0	100%
Order Rocker Switch for Linear Actua...	02/12	03/03	0	100%
Purchase Aluminum Tubing and Fast...	02/12	02/17	0	100%
Purchase Aluminum for Footrest	02/12	02/17	0	100%
Purchase metal for brackets	02/12	02/17	0	100%
Purchase seat cushion	02/12	02/17	0	100%
Purchase velcro, back straps,and bu...	02/12	02/17	0	100%
Get access to composites lab (Dr E.)	02/12	02/17	0	100%
Get welding vendor	02/19	03/03	0	100%
Find upholsterer	02/19	03/03	0	100%
Cut and shape all aluminum parts	03/05	03/17	0	100%
Build tilt-in-space frame	03/05	03/23	0	100%
Lay up carbon fiber seat plate	03/09	03/13	0	100%
Linear Actuator Extension Test	03/12	03/16	0	100%
Carbon Fiber Weight Capacity Test	03/17	03/23	0	100%
Bend aluminum backrest handlebars	03/19	03/30	0	100%
Assemble Backrest subsystem	03/31	03/31	0	100%
Weld tilt-in-space frame	03/24	03/30	0	100%
Linear Actuator Loading Test	04/14	04/21	0	100%
Assemble seat to frame	05/05	05/10	0	100%
Build and assemble footrest subsyst...	05/07	05/07	0	100%
CG Testing and other additional tests	05/26	05/28	0	0%
Vehicle Infill/Exfill Test	05/07	05/14	0	0%
Hardware and Safety Demo/FDR	**04/19/18**	**05/10/18**	**0h**	**100%**
Kick our butt into gear	04/19	04/19	0	100%
Email other team about straps	04/19	04/19	0	100%
Home Depot for buckles and battery...	04/19	04/21	0	100%
Cut Aluminum pins	04/20	04/21	0	100%
Cut backseat frame	04/20	04/21	0	100%
Buy the foam	04/20	04/20	0	100%
Meet w/ Amy to get measurements	04/20	04/20	0	100%
Clean existing wheels	04/20	04/21	0	100%



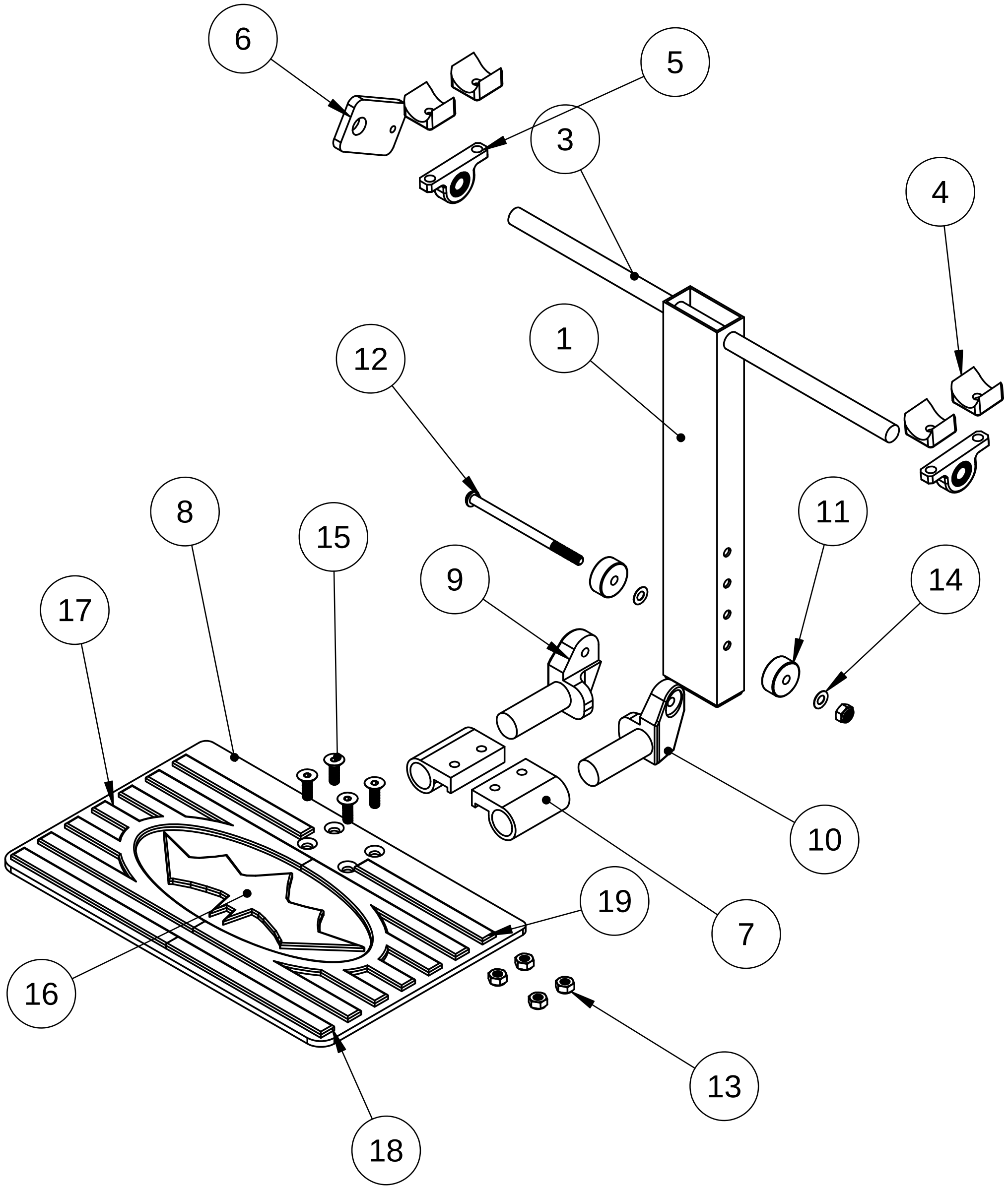


Cut tilt-in-space actuator metal bar	04/24	04/25	0	100%
Drill holes for actuator metal bar and...	04/24	04/25	0	100%
Drill holes in tilt-in-space frame	04/20	04/30	0	100%
Attach Linear Actuator to tilt-in-space...	04/20	04/30	0	100%
Test linear actuator	04/20	04/30	0	100%
Visit Upholstery shop	04/20	04/30	0	100%
Talk to painting place	04/20	04/30	0	100%
Take parts to Gentry	04/23	04/30	0	100%
Determine actuator mounting points...	04/23	04/25	0	100%
Buy nuts and bolts	04/28	04/28	0	100%
Buy clamp collars	04/30	05/02	0	100%
3-D print footrest plate grip	04/30	05/02	0	100%
3D print more round to flat adapters	05/05	05/10	0	100%
Drill holes in 2"x1" rectangular cente...	05/05	05/08	0	100%
Drill holes in carbon fiber plate and ti...	05/05	05/07	0	100%
Attach sleeve bearings to tilt-in-space	05/05	05/07	0	100%
Shave round to flat adapters x 2	05/05	05/07	0	100%
Attach carbon fiber to frame	05/05	05/08	0	100%
Cut and shape steel plate x 2	05/05	05/07	0	100%
Bend metal for footplate	05/05	05/07	0	100%
Go to SLO Sail and Canvas	05/05	05/07	0	100%
Design and cut aluminum plate	05/05	05/07	0	100%
Assemble metal components	05/05	05/07	0	100%
Upgrade head rest	05/05	05/07	0	100%
Expo	**-**	**-**	**0h**	**0%**



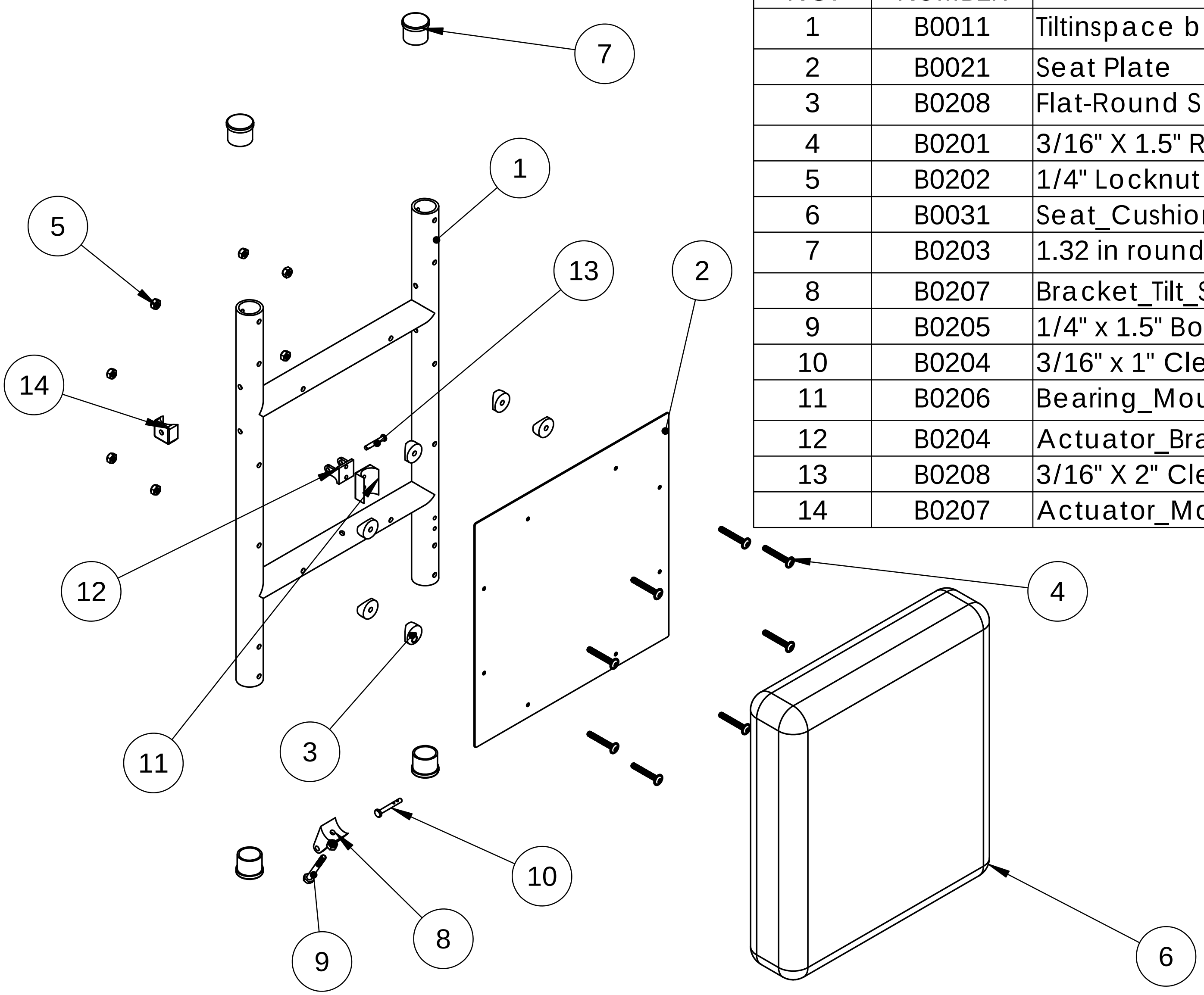
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A0001	Base Platform Assembly	1
2	B0001	TiltinSpace_Assy_Final	1
3	C0001	Footrest Assembly_Final	1
4	D0001	Backrest Assembly	1
5	F0001	Armrest_Assy_Left	1
6	E0001	Armrest_Assy_Right	1
7	G0001	Headrest_Assy	1
8	H0001	Actuator_Assembly_Tilt	1
9	I0001	Actuator_Assembly_Back	1
10	J0001	Actuator_Assembly_Foot	1

Cal Poly Mechanical Engineering	Material: N/A		Title: BATMOBILE SUB-ASSEMBLIES		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: 0001	Nxt Asb: N/A	Date: 5/30/18	Scale: 1:16	Chkd. By: STEVEN DECSESZNAK



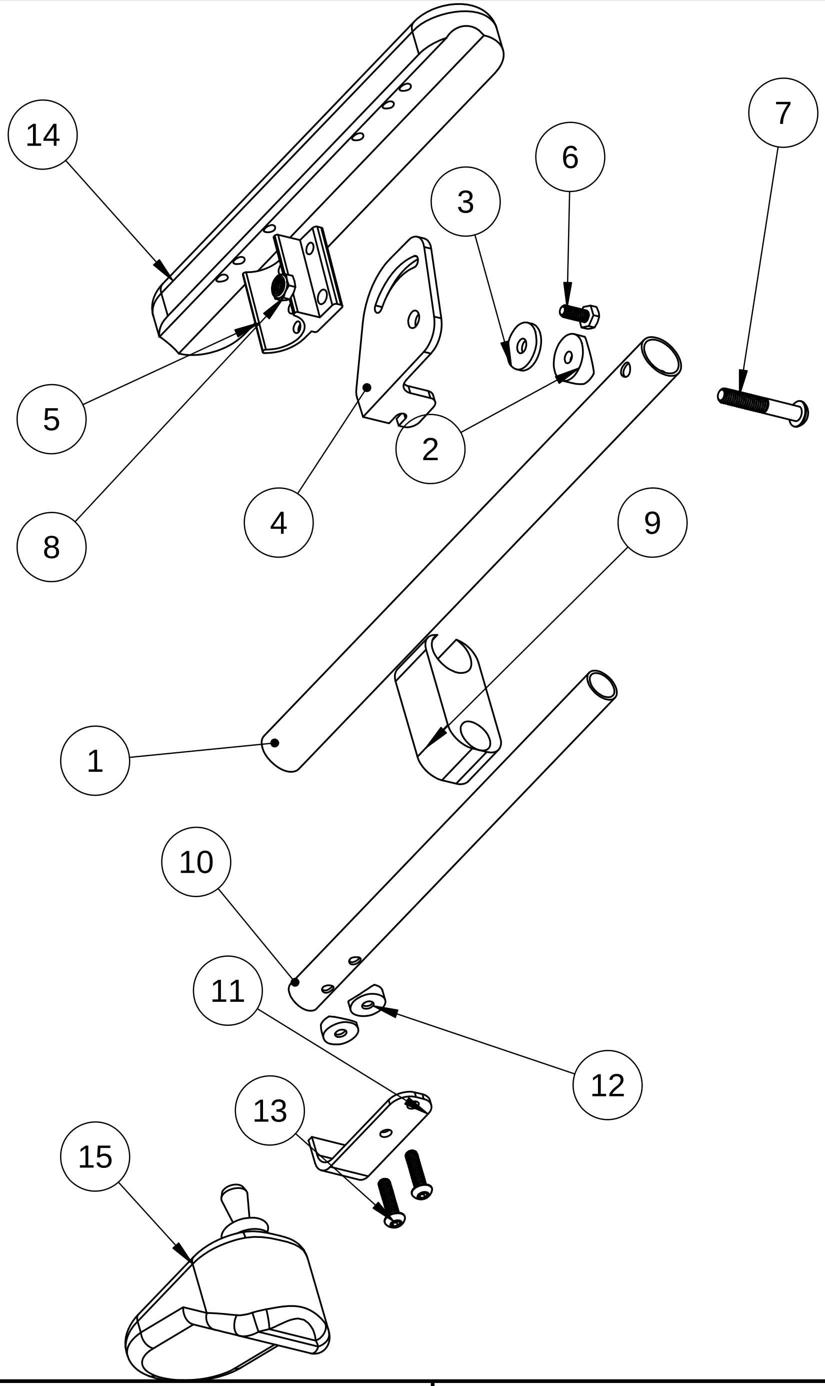
ITEM NO.	PART NUMBER	PART NUMBER	QTY.
1	C0011	Footrest Central Bar	1
3	C0031	Footrest_pin	1
4	C0042	Bearing_Mount_Bracket_Footrest	4
5	C0041	1/2" Enclosed Sleeve Bearing	2
6	C0051	Plate_Footrest_Actuator	1
7	C0102	Connector_Footplate	2
8	C0021	Footplate	1
9	C0101	Insert_Connector_Footplate	1
10	C0101	Insert_Connector_Footplate_Mirrored	1
11	C0103	Washer_Footrest_Connector	2
12	C1004	1/4" X 4" Bolt	1
13	C1002	1/4" Locknut	5
14	C1003	1/4" Waher	2
15	C1001	1/4" Flat Head Bolt	4
16	C0107	batman_texture	1
17	C0107	pattern_circle_left	2
18	C0107	pattern_front	2
19	C0107	pattern_rear_small	2

Cal Poly Mechanical Engineering	Material: N/A		Title: FOOTREST ASSY & BOM		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: C0001	Nxt Asb: 0001	Date: 5/30/18	Scale: 1:6	Chkd. By: STEVEN DECSESZNAK



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	B0011	Tiltinspace base	1
2	B0021	Seat Plate	1
3	B0208	Flat-Round Spacer	8
4	B0201	3/16" X 1.5" Round Head Screw	8
5	B0202	1/4" Locknut	10
6	B0031	Seat_Cushion1	1
7	B0203	1.32 in round cap_Tilt	4
8	B0207	Bracket_Tilt_Small	1
9	B0205	1/4" x 1.5" Bolt	1
10	B0204	3/16" x 1" Clevis Pin	1
11	B0206	Bearing_Mount_Bracket	1
12	B0204	Actuator_Bracket	1
13	B0208	3/16" X 2" Clevis Pin	1
14	B0207	Actuator_Mount_Bracket_Footrest	1

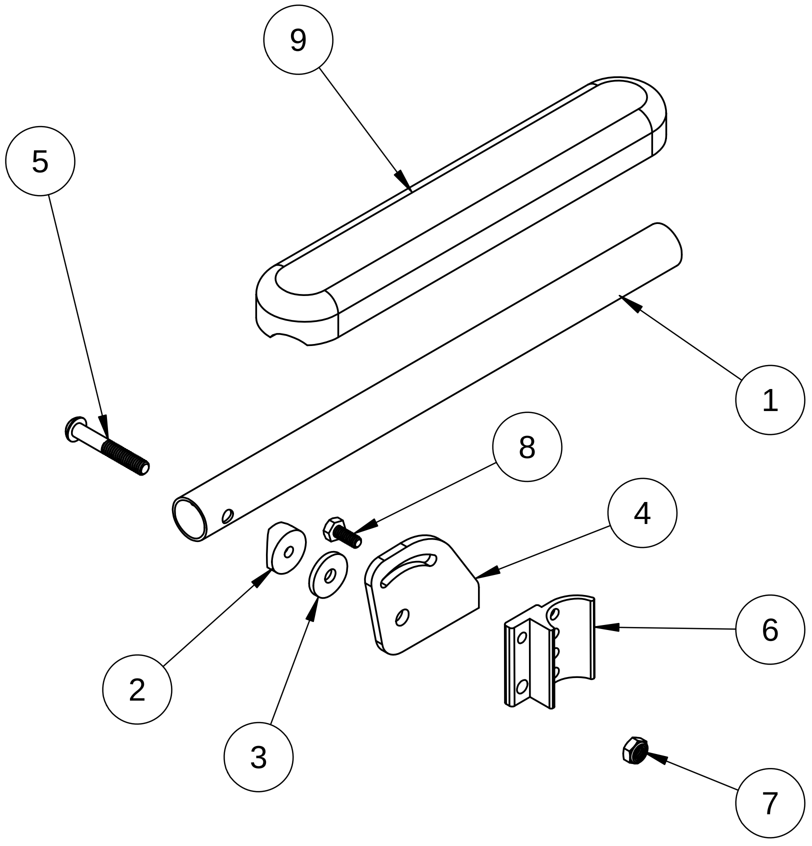
Cal Poly Mechanical Engineering	Material: N/A	Title: TILT-IN-SPACE ASSY & BOM	Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: B0001 Nxt Asb: 0001	Date: 5/30/18 Scale: 1:8	Chkd. By: STEVEN DECSESZNAK



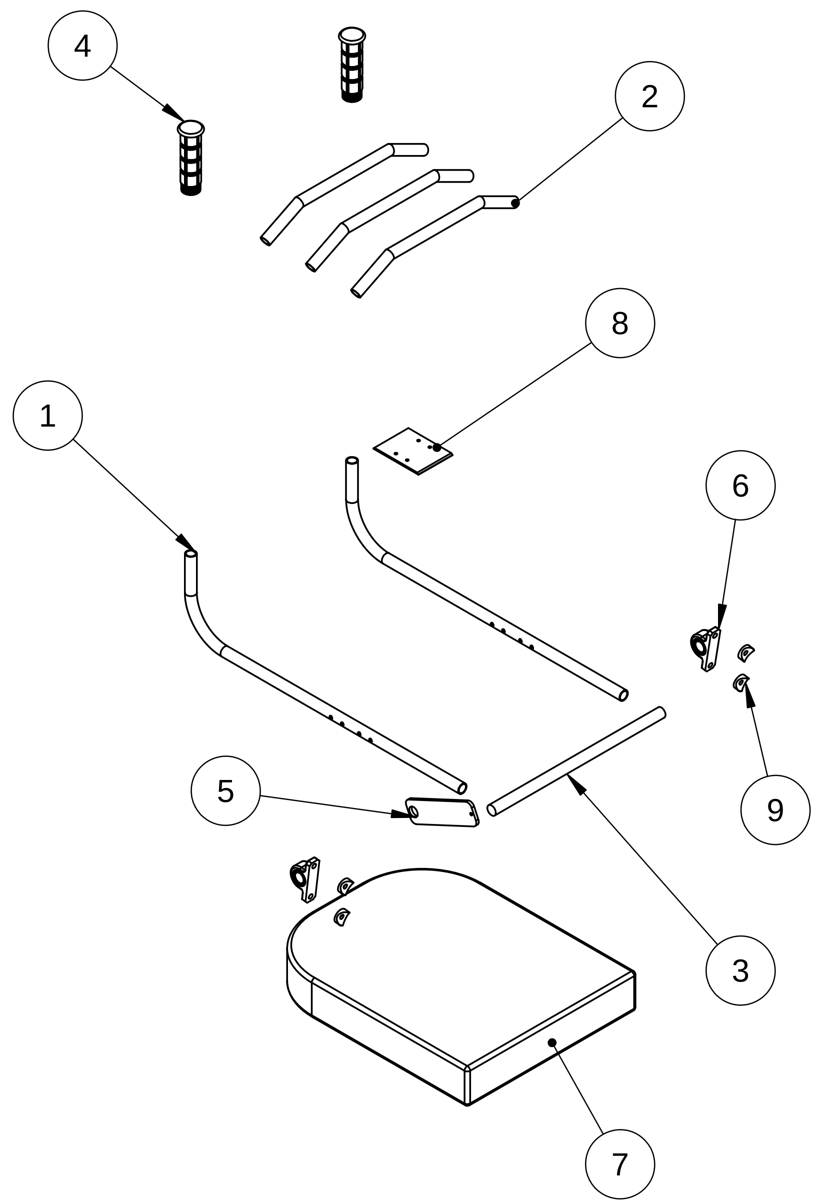
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	E0011	Support_Armrest	1
2	E0101	Flat-Round Spacer	1
3	E0102	Washer_Armrest	1
4	E0012	Connector_Armrest_Flat_Right	1
5	E0017	Connector_Armrest_Right	1
6	E0105	3/8" X 3/4" Hex Bolt	1
7	E0106	1/4" X 2.5" Bolt	1
8	E0107	1/4" Lock Nut	1
9	E0012	Support_Coonector_Right	1
10	E0013	Joystick_Support	1
11	E0013	Joystick_Mounting_Bracket	1
12	E0108	Joystick_Spacer	2
13	E0109	1/4" X 1" Screw	2
14	E0016	Pad_Armrest	1
15	E0015	Joystick	1

Cal Poly Mechanical Engineering	Material: N/A		Title: RIGHT ARMREST ASSY & BOM		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: E0001	Nxt Asb: 0001	Date:5/30/18	Scale: 1:4	Chkd. By: STEVEN DECSESZNAK

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	F0011	Support_Armrest	1
2	F0101	Flat-Round Spacer	1
3	F0102	Washer_Armrest	1
4	F0103	Connector_Armrest_Flat	1
5	F0106	1/4" X 2.5" Bolt	1
6	F0104	Connector_Armrest	1
7	F0107	1/4" Lock Nut	1
8	F0105	3/8" X 3/4" Hex Bolt	1
9	F0016	Pad_Armrest	1

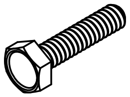


Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Material: N/A	Title: LEFT ARMREST ASSY & BOM	Drwn. By: MOULAY SALAHDIN
	Dwg. #: F0001 / Nxt Asb: 0001	Date: 5/30/18 / Scale: 1:4	Chkd. By: STEVEN DECSESZNAK

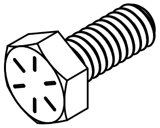


ITEM NO.	PART NUMBER	Description	QTY.
1	D0011	Back_rest_side_bar	2
2	D0011	Back_rest_horizontal_bar	3
3	D0021	Back_rest_pivoting _rod	1
4	D0071	Grip	2
5	D0041	Plate_Backrest_Actuator	1
6	D0081	5/8" Enclosed Sleeve Bearing	2
7	D0061	Backrest Cushion	1
8	D0051	Headrest Plate	1
9	D0105	Flat-Round Spacer	4

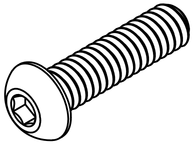
Cal Poly Mechanical Engineering	Material: N/A		Title: BACKREST ASSY & BOM		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: D0001	Nxt Asb: 0001	Date: 5/30/18	Scale: 1:12	Chkd. By: STEVEN DECSESZNAK



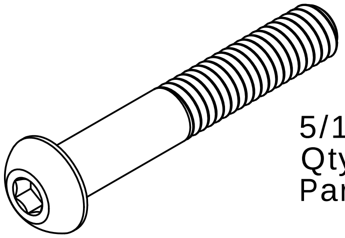
3/8"D X 5/8"L Hex Bolt
Qty: 2
Part #: E0105



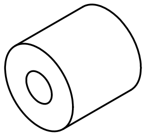
1/4"D X 5/8"L Hex Bolt
Qty: 2
Part #: E0110



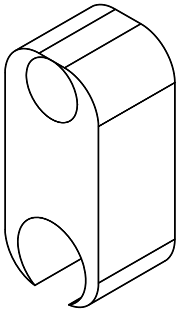
1/4"D X 1"L Hex Screw
Qty: 2
Part #: E0109



5/16"D X 2"L Hex Screw
Qty: 2
Part #: E0106

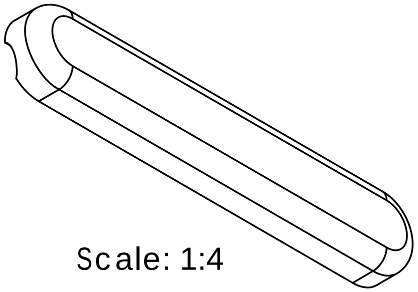


Vinyl Washer
ID 3/8" OD 1/2"
Qty: 3
Part #: E0102



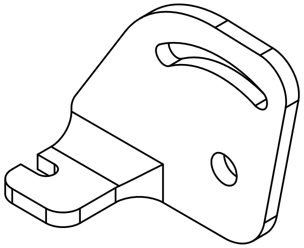
Joystick Support Carrier
Qty: 1
Part #: E0014

Scale: 1:2



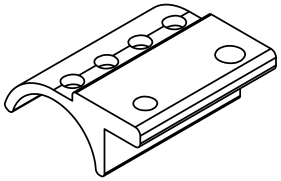
Wheelchair Armrest Pad
12"X2"X1"
Qty: 2
Part #: E0016

Scale: 1:4



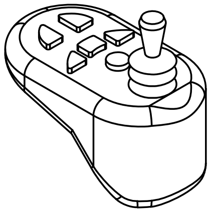
Armrest Support Connector
Qty : 2
Part #: E0103

Scale: 1:2



Armrest Support Flat-Round Connector
Qty: 2
Part #: E0104

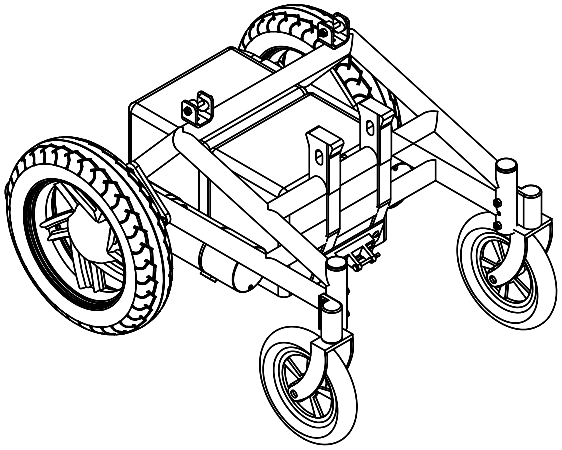
Scale: 1:2



Sunrise Medical Wheelchair Joystick
Qty: 1
Part #: E0015

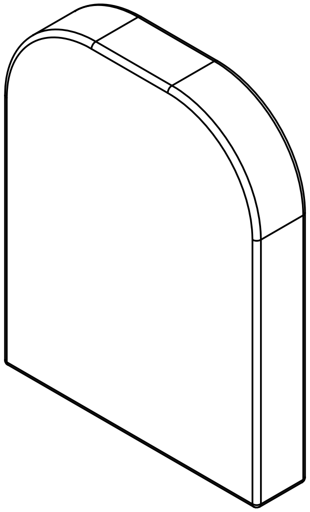
Scale: 1:4

Cal Poly Mechanical Engineering	Material: N/A		Title: ARMREST STANDARD PARTS		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: N/A	Nxt Asb: E0001	Date: 5/30/18	Scale: 1:1	Chkd. By: STEVEN DECSESZNAK



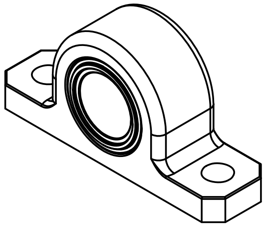
Wheelchair Base Platform
Qty: 1
Part #: A0001

Scale: 1:12



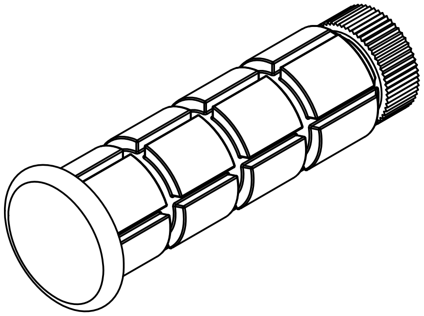
Backrest Cushion
Qty: 1
Part #: D0061

Scale: 1:8



Mc Master-carr Enclosed Sleeve Bearing
Bushing Diam: 3/4"
Qty: 2
Part #: D0081

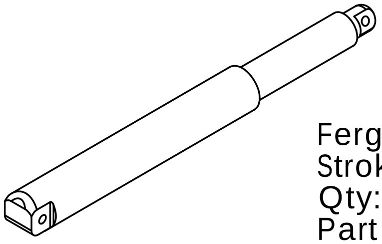
Scale: 1:2



Hand Grip
Qty: 2
Part #: D0071

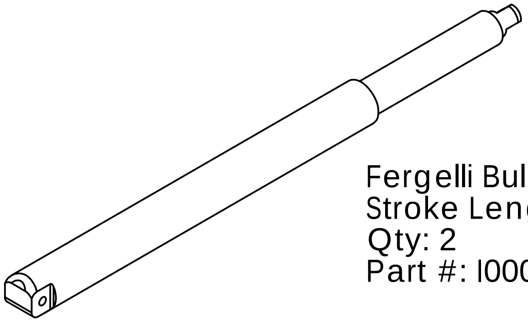
Scale: 1:2

Cal Poly Mechanical Engineering	Material: N/A		Title: BASE & BACKREST STD PARTS		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #:N/A	Nxt Asb: D0001	Date: 5/30/18	Scale: N/A	Chkd. By: STEVEN DECSESZNAK



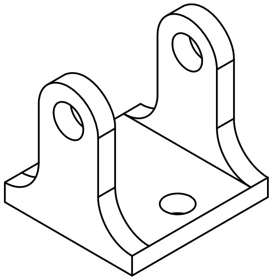
Fergelli Bullet Series Mini Actuator
Stroke Length: 4"
Qty: 1
Part #: H0001

Scale: 1:4

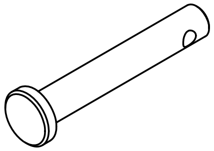


Fergelli Bullet Series Mini Actuator
Stroke Length: 6"
Qty: 2
Part #: I0001

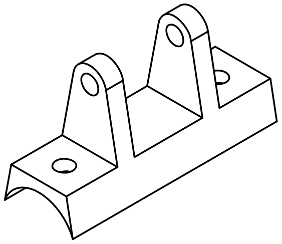
Scale: 1:4



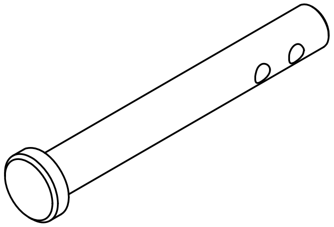
Fergelli Bullet Actuator Bracket
Qty: 1
Part #: I0101



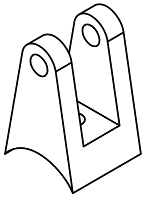
Clevis Pin
3/16"D X 1"L
Qty: 2
Part #: H0105



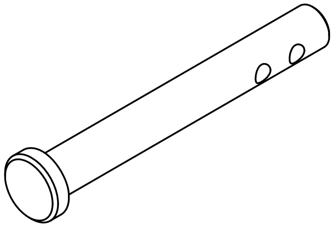
3" L Actuator Bracket with round Adaptor
Qty:
Part #: H0101



Clevis Pin
3/16"D X 2"L
Qty: 3
Part #: I0104

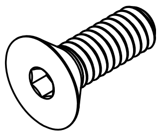


1"L Actuator Bracket with round Adaptor
Qty:
Part #: H0102

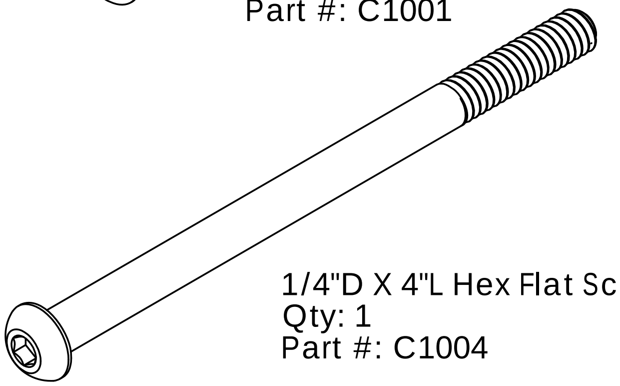


Clevis Pin
3/16"D X 3"L
Qty: 1
Part #: I0105

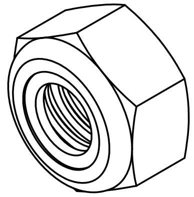
Cal Poly Mechanical Engineering	Material: N/A		Title: ACTUATOR STANDARD PARTS		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: N/A	Nxt Asb: H0001	Date: 5/30/18	Scale: 1:1	Chkd. By: STEVEN DECSESZNAK



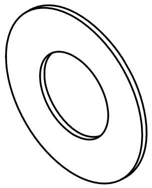
1/4"D X 3/4"L Hex Flat Screw
Qty: 4
Part #: C1001



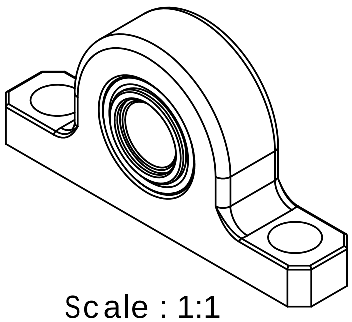
1/4"D X 4"L Hex Flat Screw
Qty: 1
Part #: C1004



1/4"D Locknut
Qty: 5
Part #: C0106

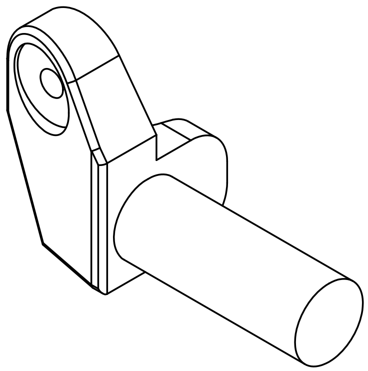


1/4" Washer
Qty: 2
Part #: C0103

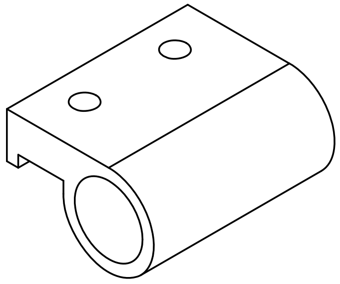


Scale : 1:1

Mc Master-carr Enclosed Sleeve Bearing
Bushing Diam: 1/2"
Qty: 2
Part #: C0041

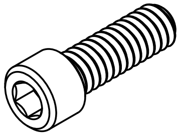


Footrest Plate Connector Insert
Qty: 2
Part #: C0101



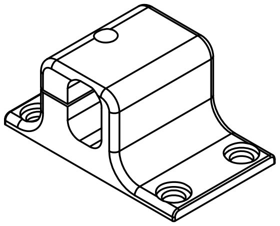
Footrest Plate Connector/Break
Qty: 2
Part #: C0102

Cal Poly Mechanical Engineering	Material: N/A		Title: FOOTREST STANDARD PARTS		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: N/A	Nxt Asb: C0001	Date: 5/30/18	Scale: 2:1	Chkd. By: STEVEN DECSESZNAK



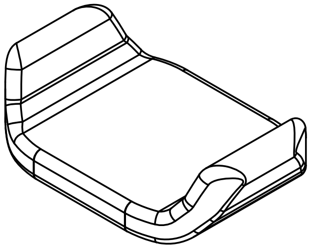
Socket Head Screw
1/4"D X 3/4"L
Qty: 4
Part #: G015

Scale: 1:1

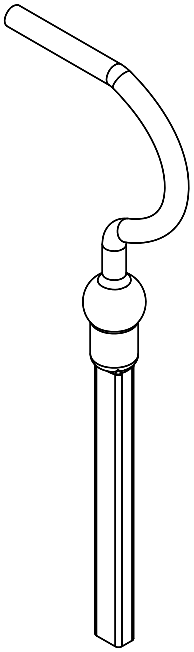


Headrest Connector
Qty: 1
Part #: G0102

Scale: 1:2



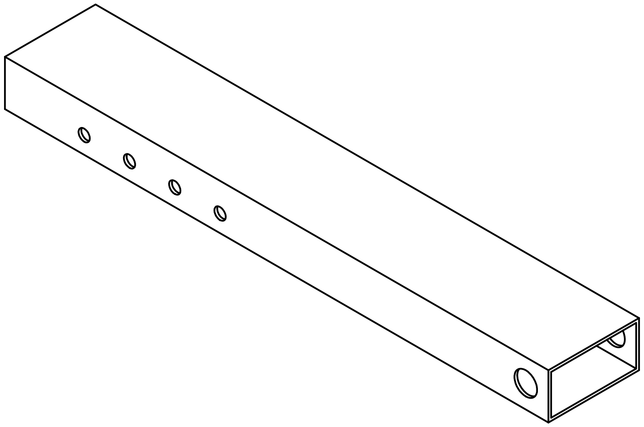
Occipital Pad
Qty: 1
Part #: G0103

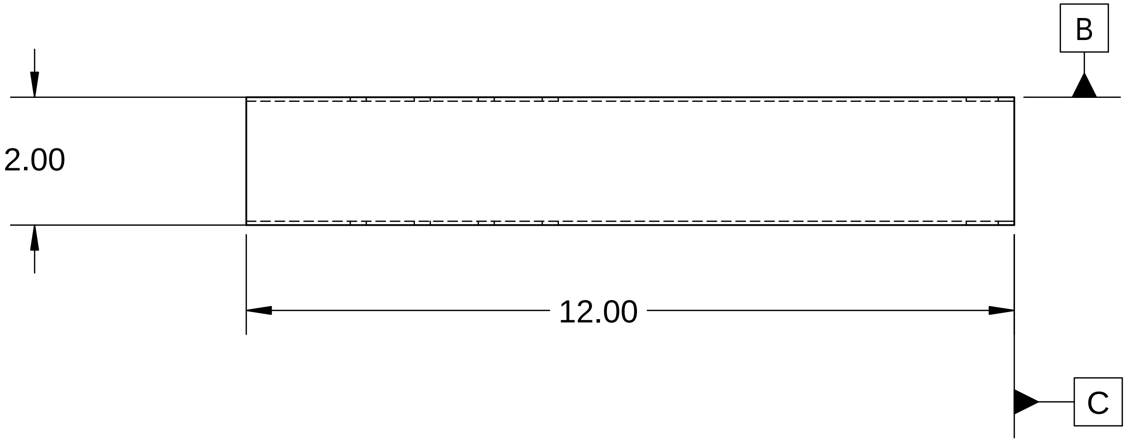


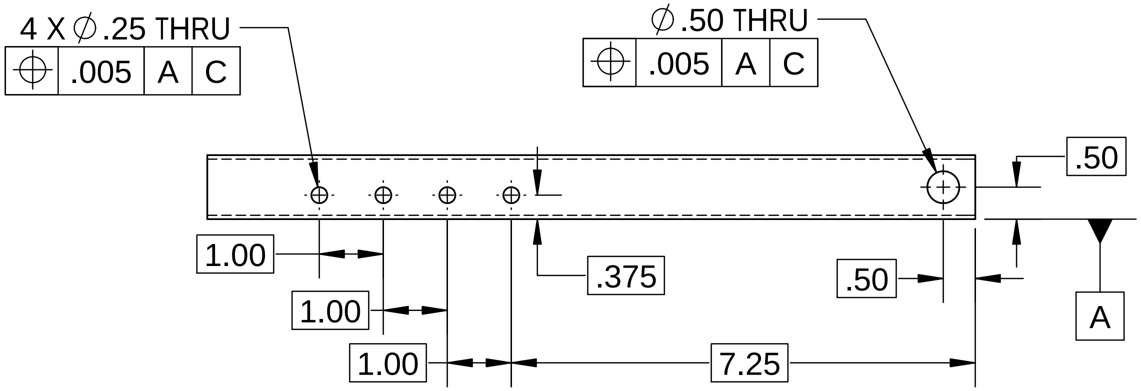
Headrest Holder
Qty: 1
Part #: G0012

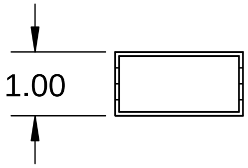
Cal Poly Mechanical Engineering	Material: N/A		Title: HEADREST STANDARD PARTS		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: N/A	Nxt Asb: G0001	Date: 5/30/18	Scale: 1:4	Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .062 INCHES
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001



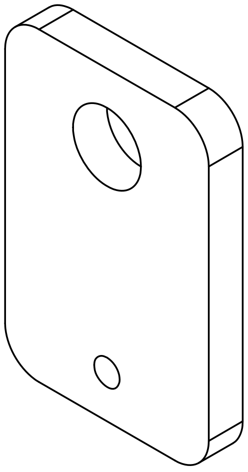


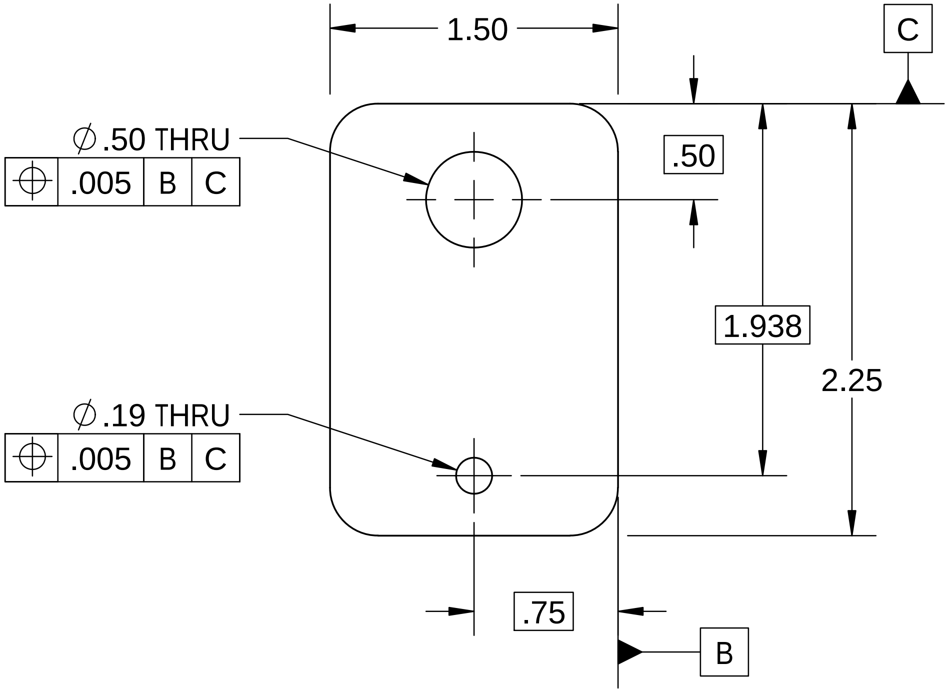


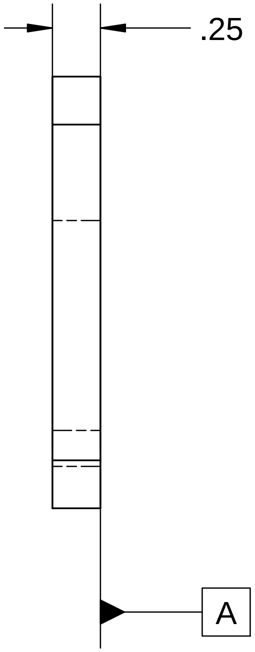


Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: FOOTREST SUPPORT	Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: C0011	Nxt Asb: C0001	Date: 5/29/18	Scale: 1:3	Chkd. By: STEVEN DECSESZNAK

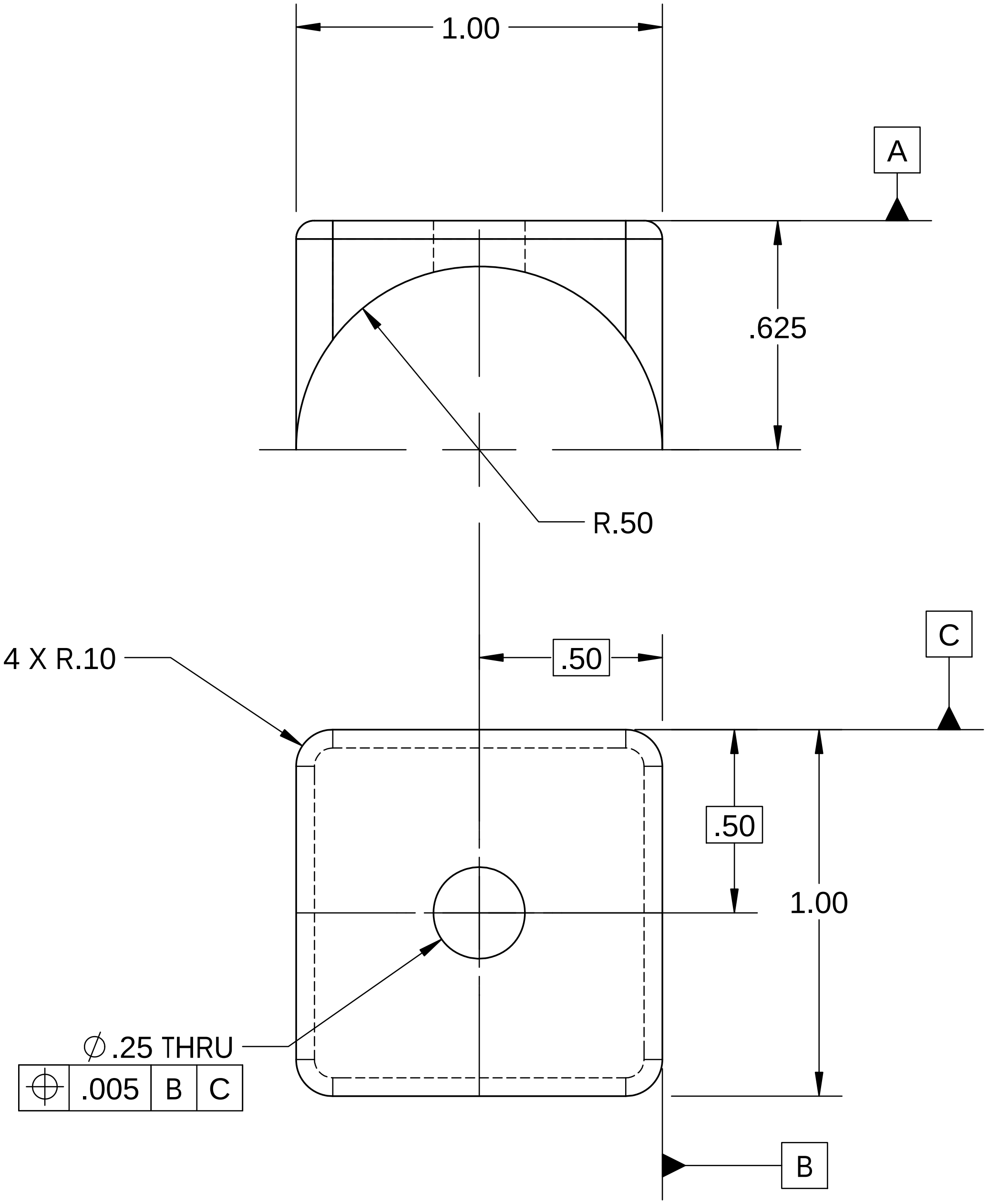
NOTES:
1. ALL DIMS IN INCHES
2. ALL FILETS RADIUS ARE .25 INCHES UNLESS OTHERWISE IS STATED
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001

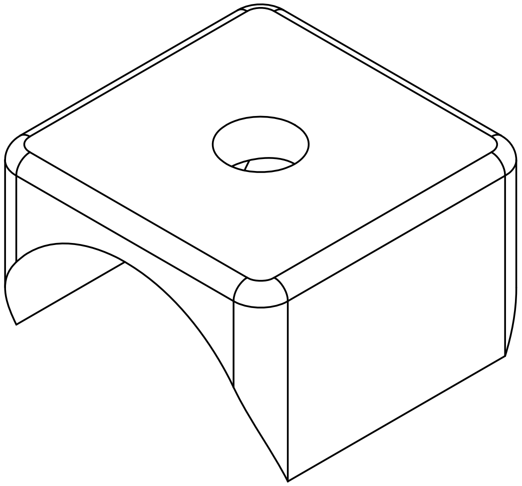






Cal Poly Mechanical Engineering
ME 430 - SPRING 2018
Material: ALUMINUM 6061-T6
Dwg. #: D0021
Nxt Asb: D0001
Title: FOOTREST ACT. MOUNT. PLATE
Date: 5/29/18
Scale: 1:1
Drwn. By: MOULY SALAHDIN
Chkd. By: STEVEN DECSESZNAK

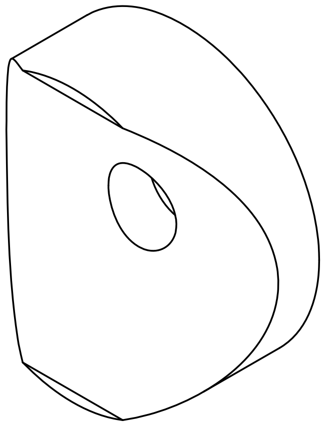


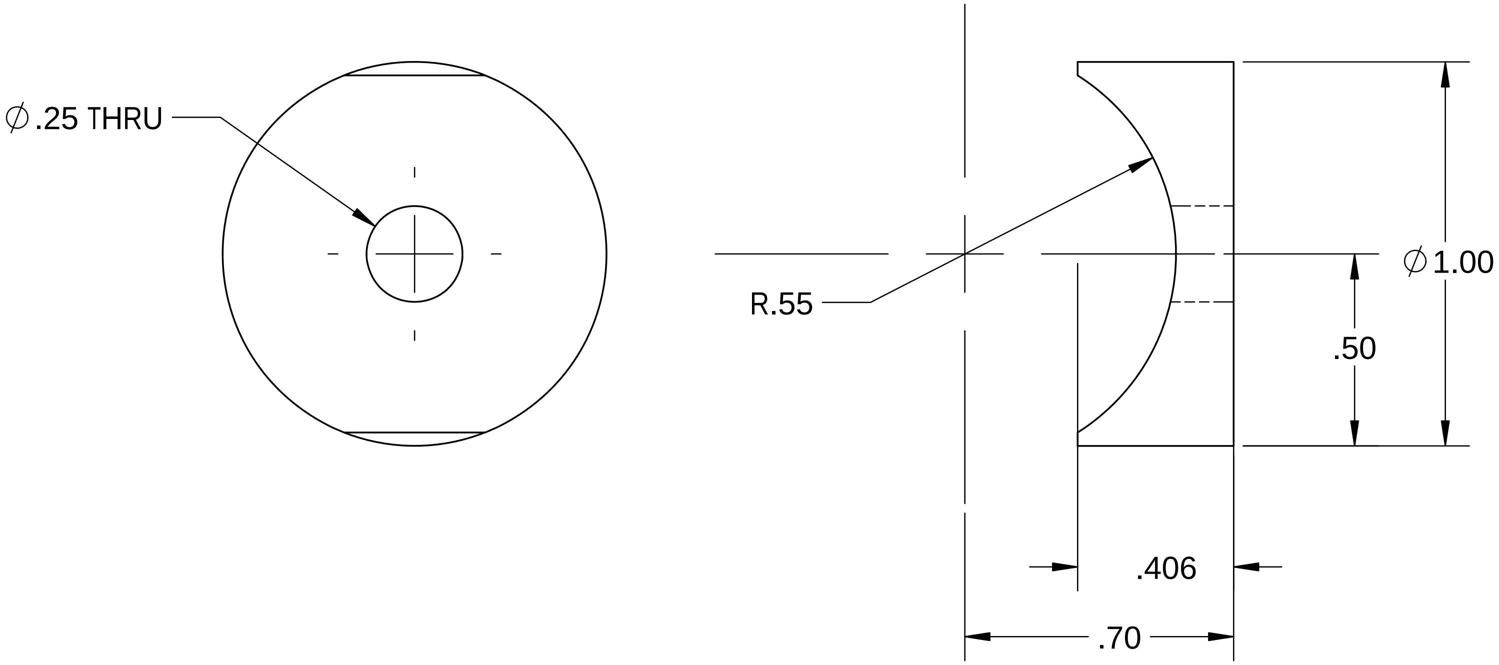


NOTES:
1. ALL DIMS IN INCHES
2. ALL FILETS RADIUS: .05 INCHES UNLESS OTHERWISE IS STATED
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001

Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: SQUARE FLAT-ROUND SPACER		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: B0206	Nxt Asb: B0001	Date: 5/29/18	Scale: 1:1	Chkd. By: STEVEN DECSESZNAK

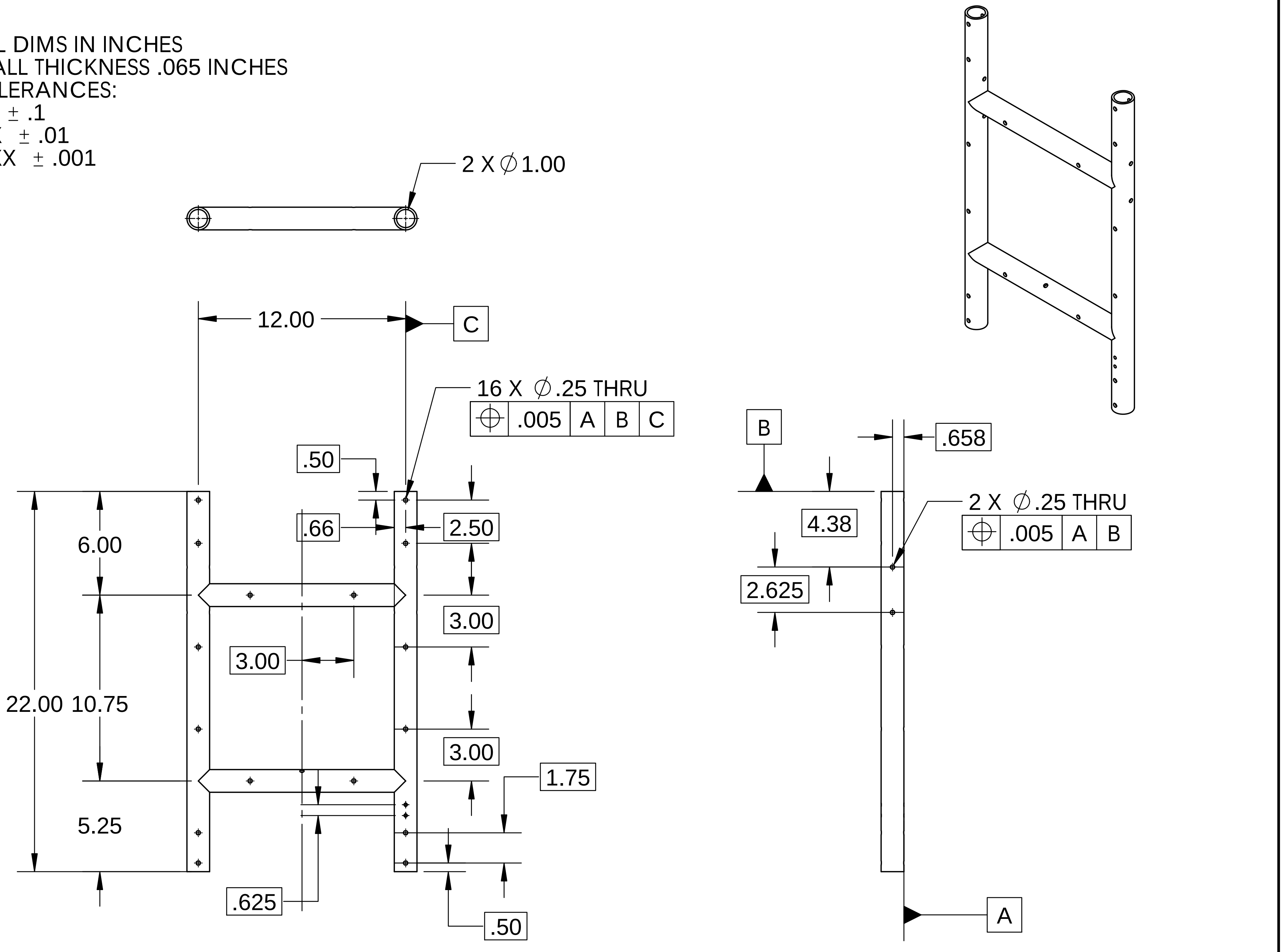
NOTES:
1. ALL DIMS IN INCHES
2. TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .001





Cal Poly Mechanical Engineering ME 430 - SPRING 2018	Material: PLASTIC	Title: CIRC. FLAT-ROUND SPACER	Drwn. By: MOULAY SALAHDIN
	Dwg. #: B0208 — Nxt Asb: B0001	Date: 5/29/18 — Scale: 1:1	Chkd. By: STEVEN DECSESZNAK

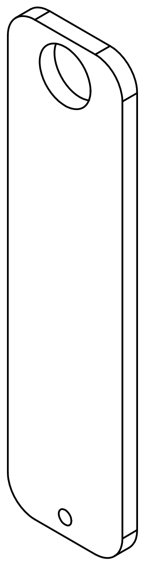
NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .065 INCHES
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001

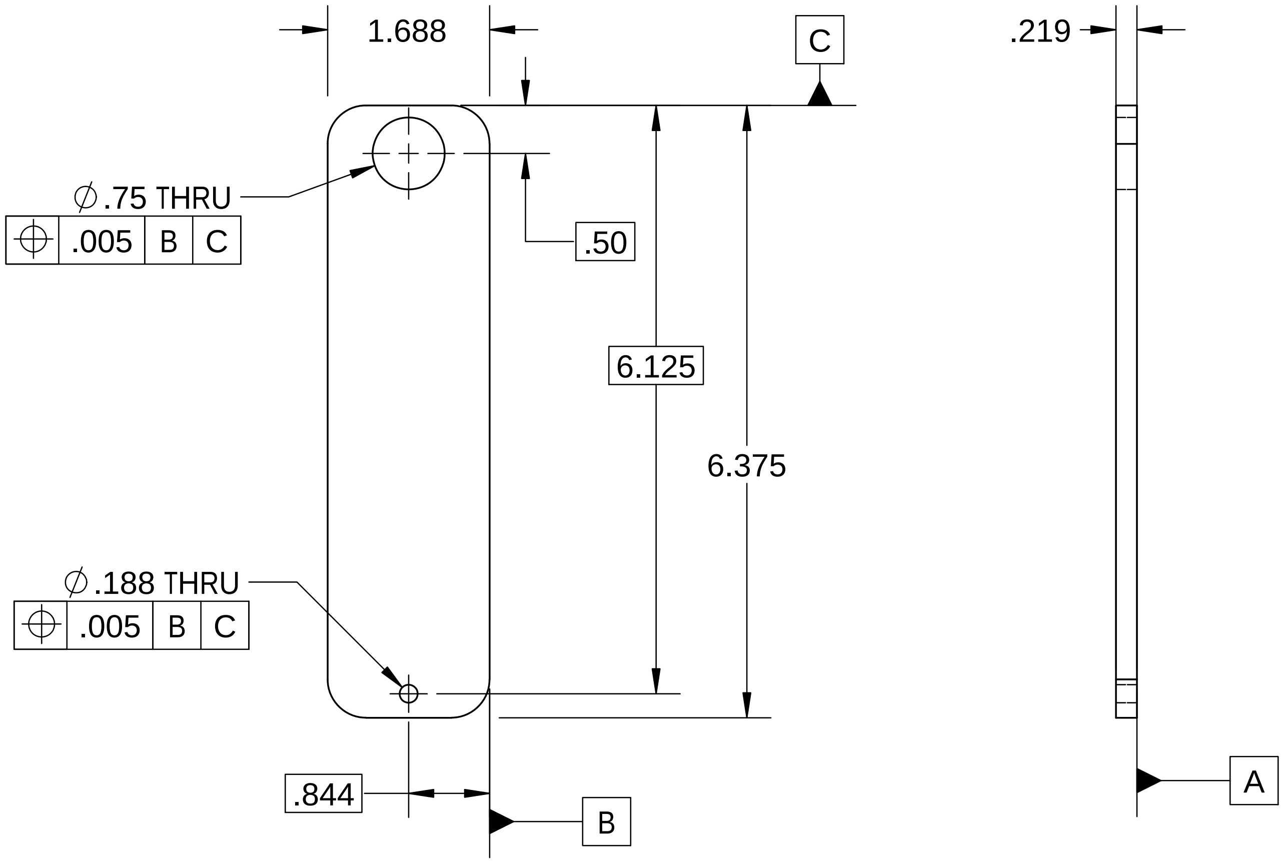


Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

Material: ALUMINUM 6061-T6
Dwg. #: B0011
Nxt Asb: B0001
Title: TILT-IN-SPACE BASE
Date: 5/29/18
Scale: 1:8
Drwn. By: MOULAY SALAHDIN
Chkd. By: STEVEN DECSESZNAK

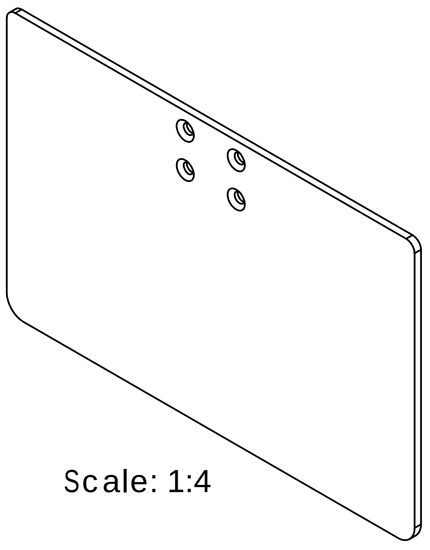
NOTES:
1. ALL DIMS IN INCHES
2. ALL FILETS RADIUS ARE .40 INCHES UNLESS OTHERWISE IS STATED
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001

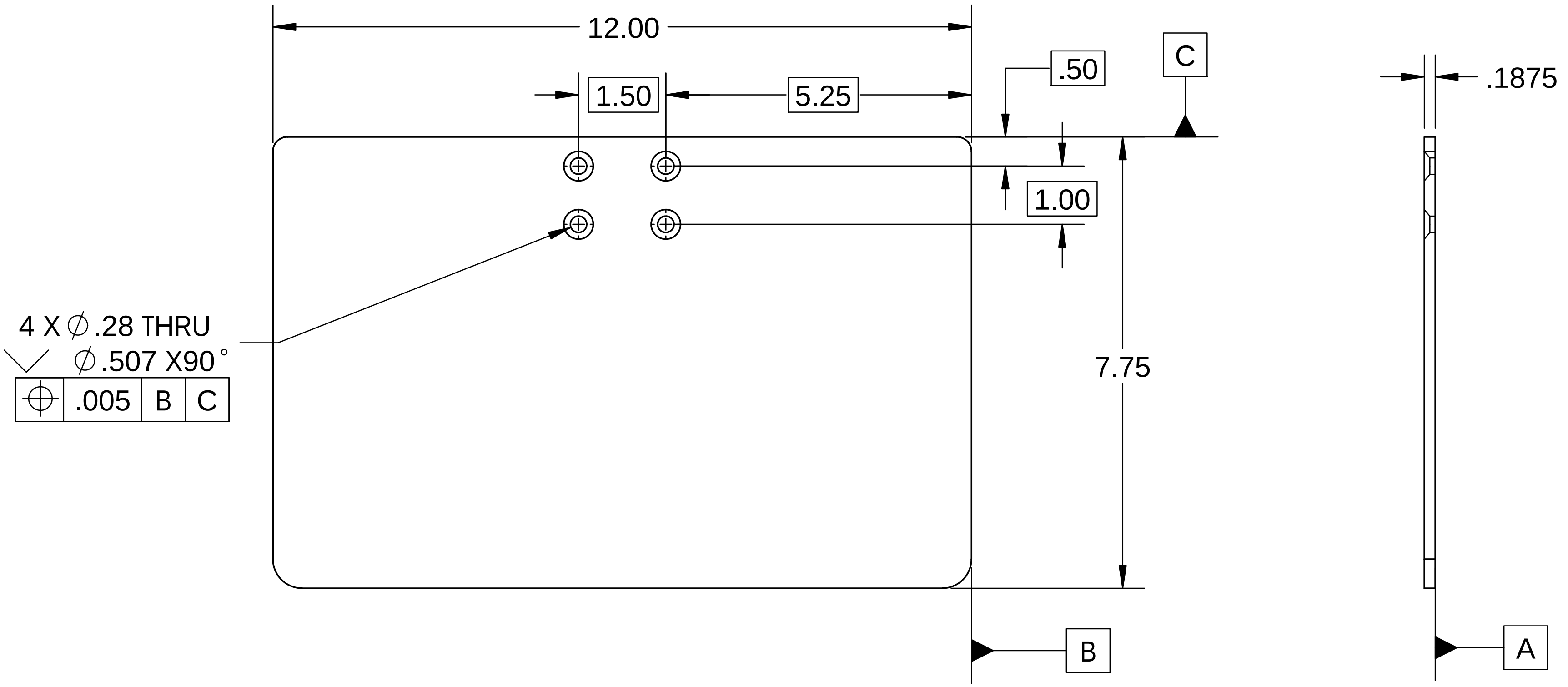




Cal Poly Mechanical Engineering
ME 430 - SPRING 2018
Material: ALUMINUM 6061-T6
Dwg. #: D0041
Nxt Asb: D0001
Title: BACKREST ACT. MOUNT. PLATE
Date: 5/30/18
Scale: 1:2
Drwn. By: MOULAY SALAHDIN
Chkd. By: STEVEN DECSESZNAK

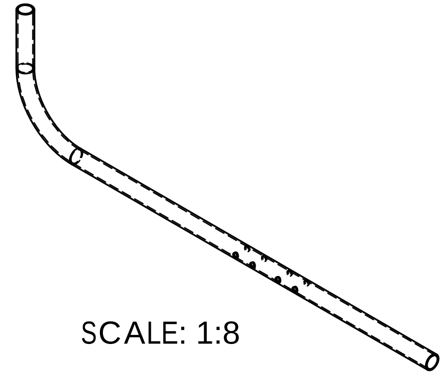
NOTES:
1. ALL DIMS IN INCHES
2. ALL FILETS RADIUS ARE .50 INCHES UNLESS OTHERWISE IS STATED
3. TOLERANCES:
    .X ± .1
    .XX ± .01
    .XXX ± .001

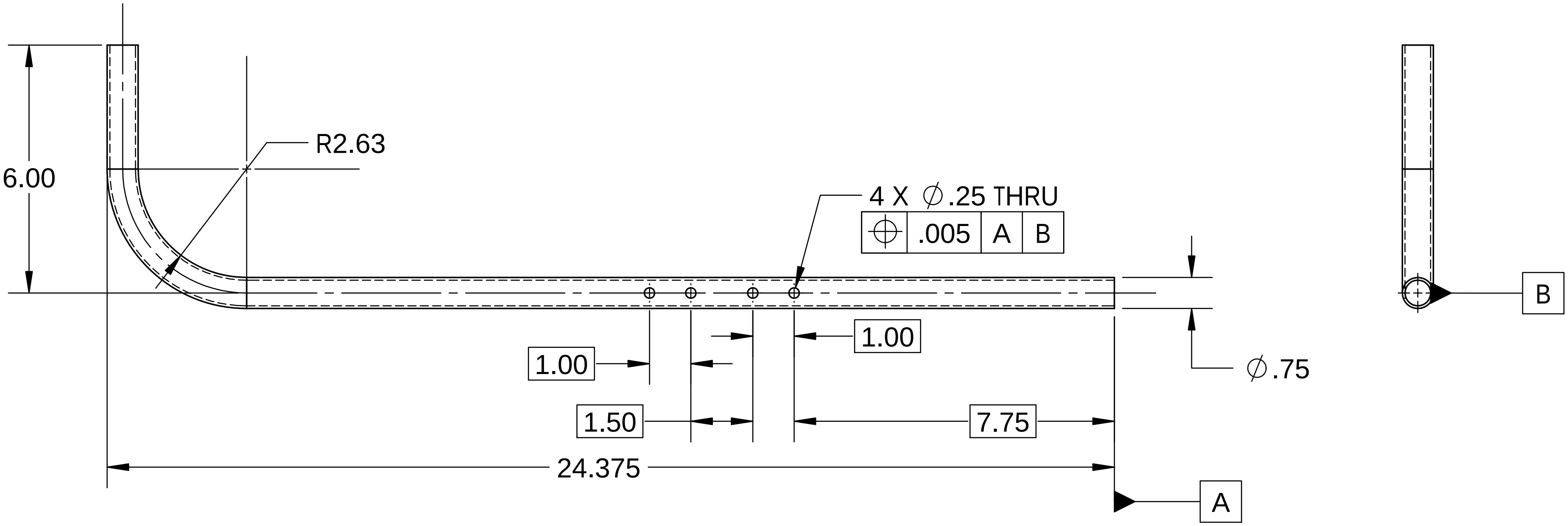

Scale: 1:4



Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: FOOTREST PLATE		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: C0021	Nxt Asb: C0001	Date: 5/30/18	Scale: 1:3	Chkd. By: STEVEN DESCSHESZNAK

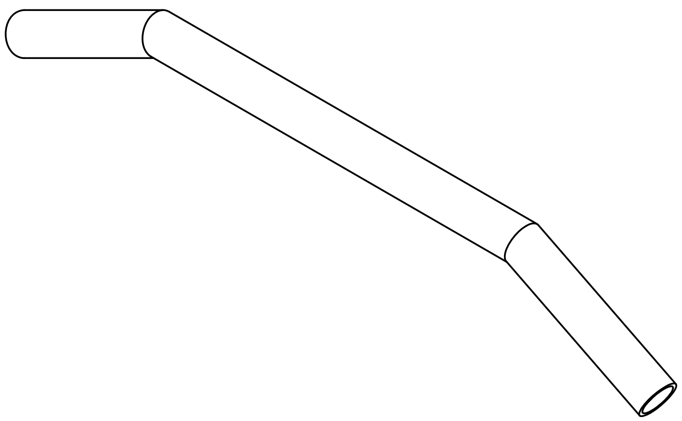
NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .065 INCHES
3. TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .001

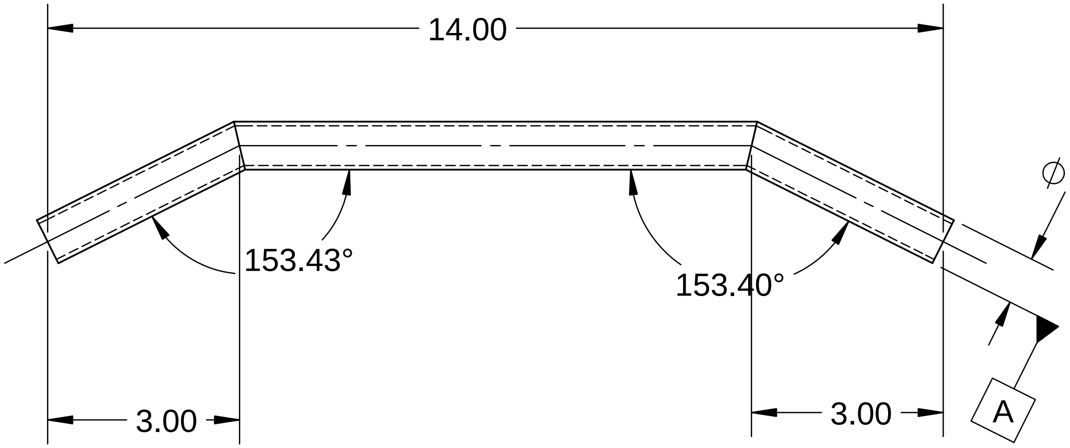


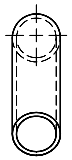


Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6	Title:BACKREST SIDE TUBE	Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: D0011 / Nxt Asb: D0001	Date: 5/31/18 / Scale: 1:4	Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .065 INCHES
3. TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .001

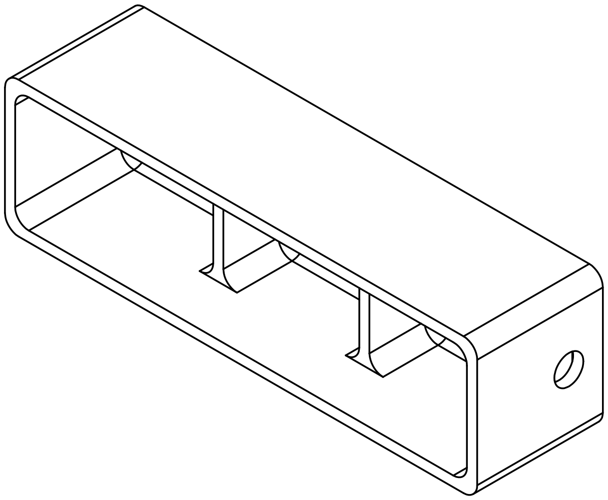


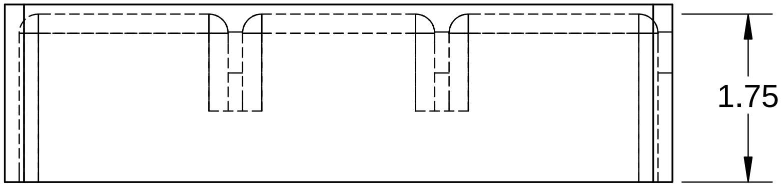


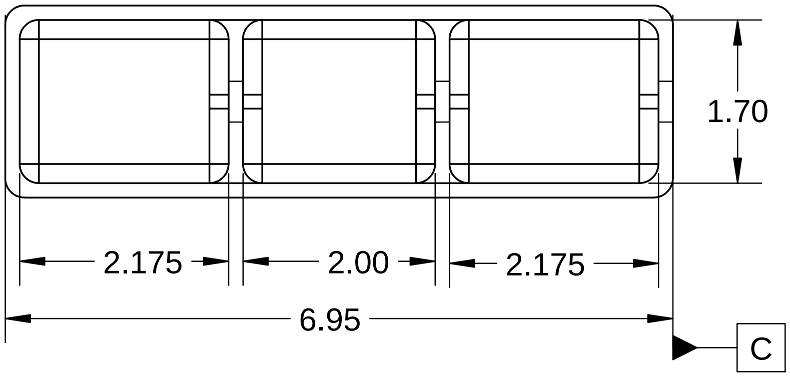


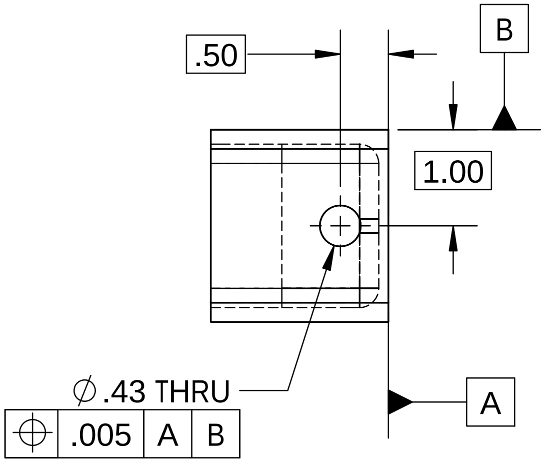
Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: BACKREST CENTER TUBE		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: D0011	Nxt Asb: D0001	Date: 5/31/18	Scale: 1:3	Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .15"
3. ALL FILETS RADIUS ARE .20 INCHES UNLESS OTHERWISE IS STATED
4. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001



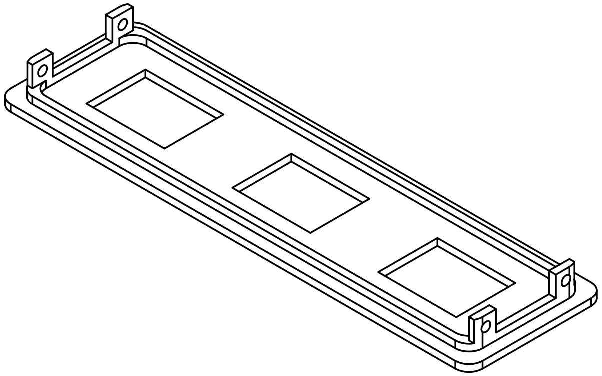


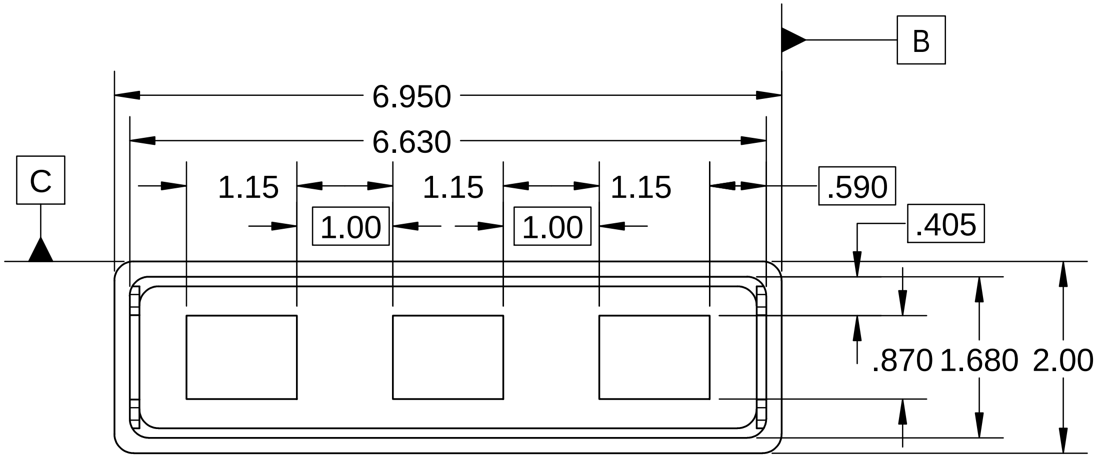


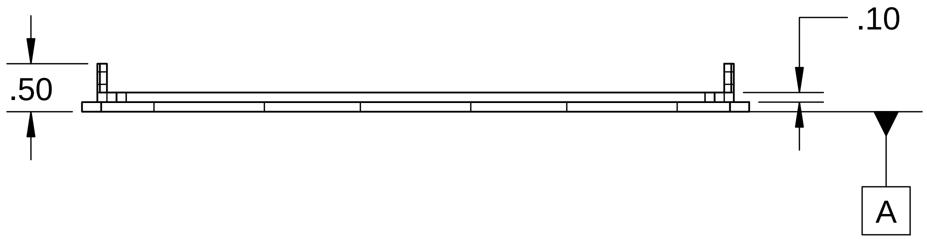


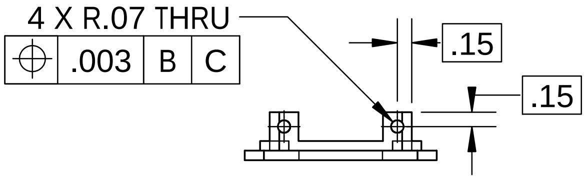
Cal Poly Mechanical Engineering	Material: PLASTIC		Title: BUTTON ELECTRICAL BOX		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: E0017	Nxt Asb: E0001	Date: 5/31/18	Scale: 1:2	Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. WALL THICKNESS .10"
3. ALL FILETS RADIUS ARE .20 INCHES UNLESS OTHERWISE IS STATED
4. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001



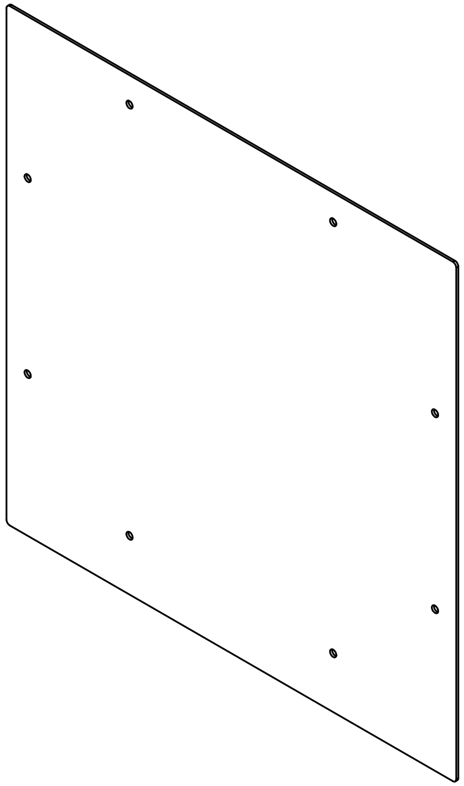


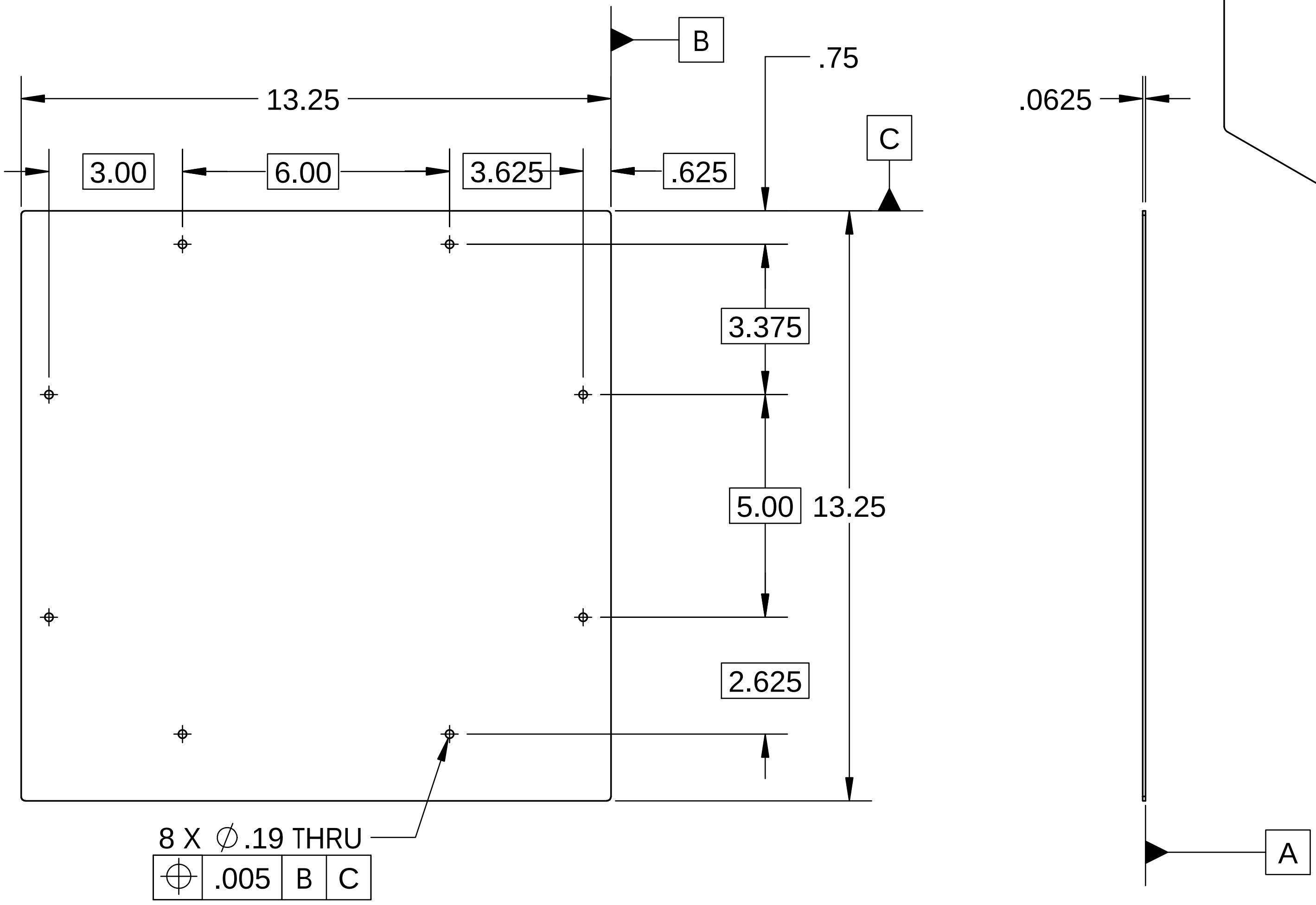




Cal Poly Mechanical Engineering	Material: PLASTIC		Title: ELECTRICAL BOX LID		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: E0018	Nxt Asb:E0001	Date: 5/31/18	Scale: 1:2	Chkd. By: STEVEN DECSESZNAK

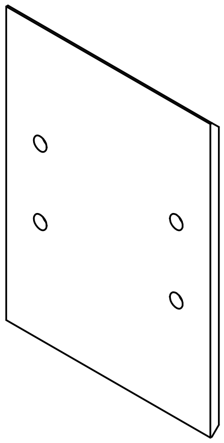
NOTES:
1. ALL DIMS IN INCHES
2. ALL FILETS RADIUS ARE .10 INCHES UNLESS OTHERWISE IS STATED
3. TOLERANCES:
   .X ± .1
   .XX ± .01
   .XXX ± .001



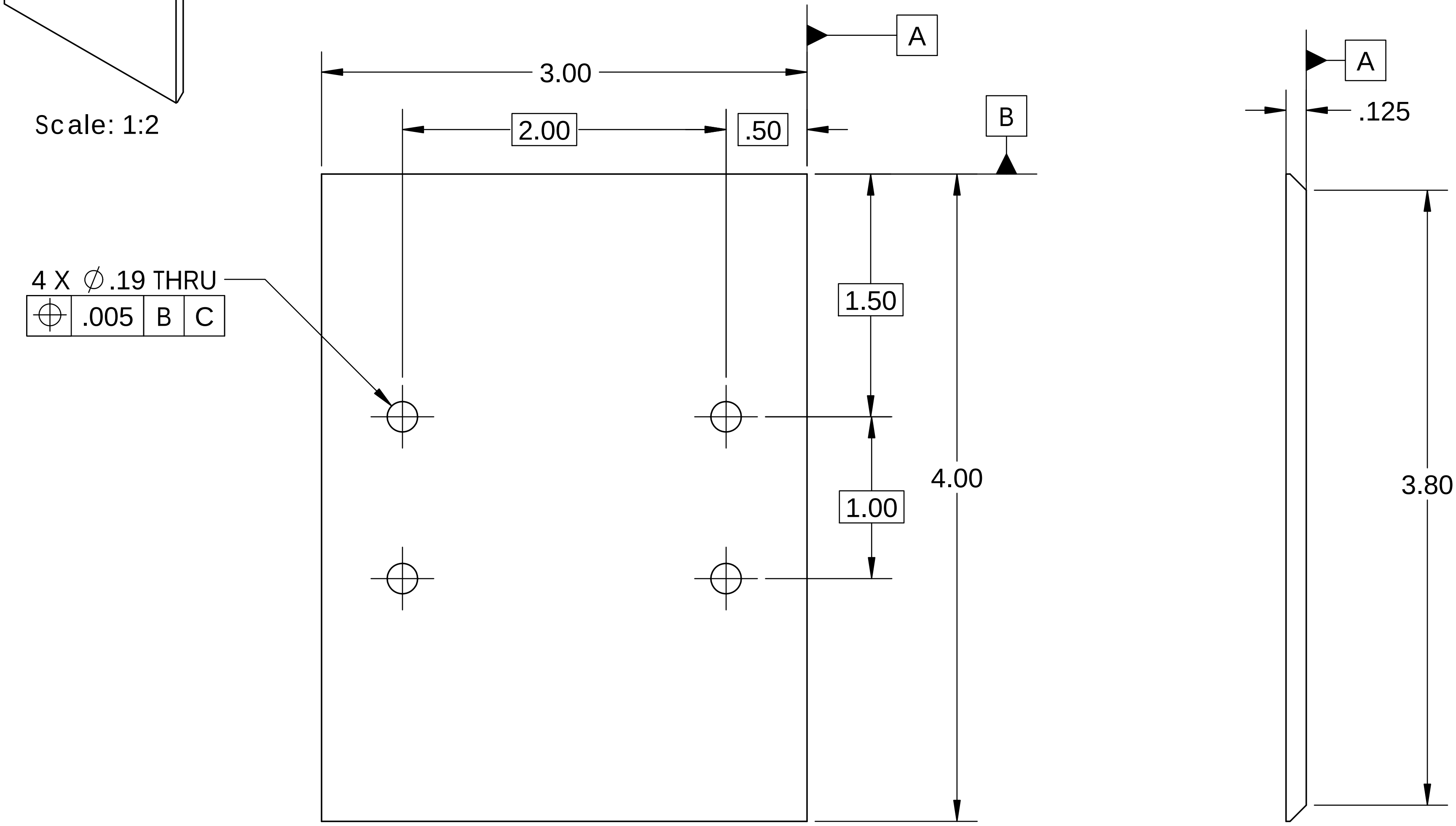


Cal Poly Mechanical Engineering	Lab Section: CARBON FIBER	Title: SEAT PLATE	Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: B0021 | Nxt Asb: B0001	Date: 5/31/18 | Scale: 1:4	Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .001



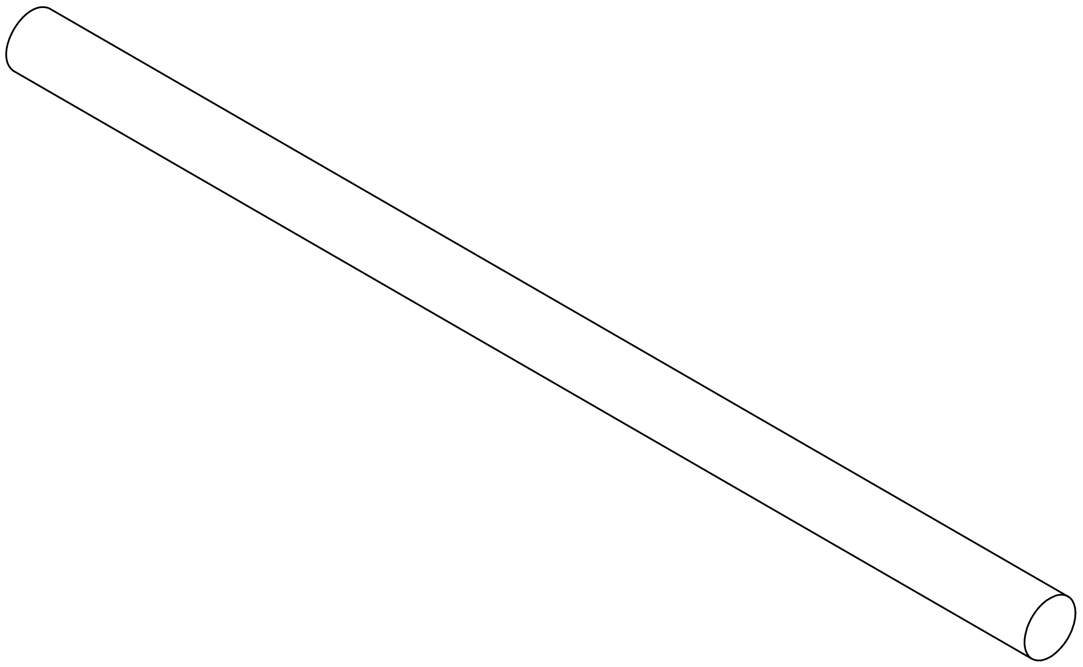
Scale: 1:2

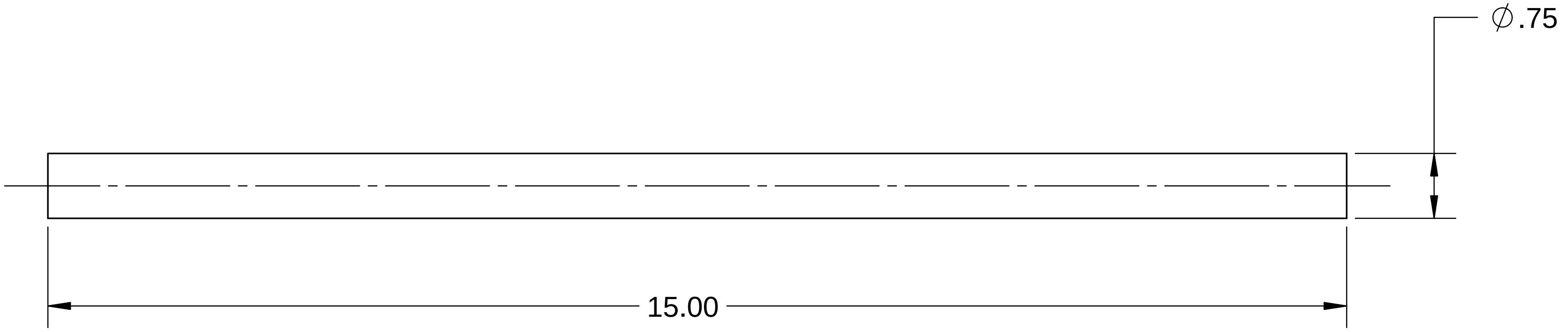


Cal Poly Mechanical Engineering
ME 430 - SPRING 2018

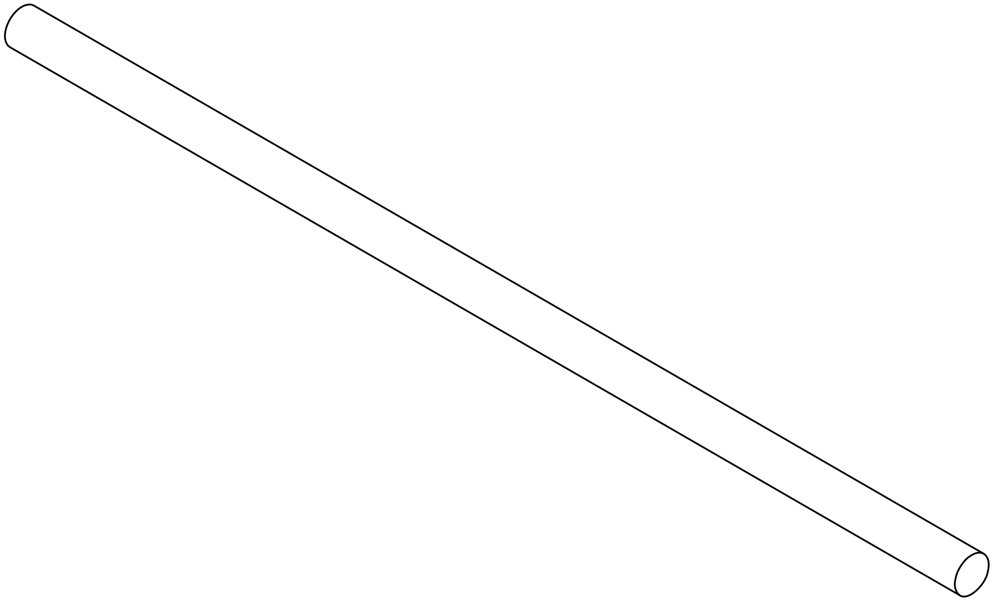
Material: ALUMINUM 6061-T6
Title: HEADREST MOUNT PLATE
Drwn. By: MOULAY SALAHDIN
Dwg. #: D0051
Nxt Asb: D0001
Date: 5/31/18
Scale: 1:1
Chkd. By: STEVEN DECSESZNAK

NOTES:
1. ALL DIMS IN INCHES
2. TOLERANCES:
.X ± .1
.XX ± .01
.XXX ± .001

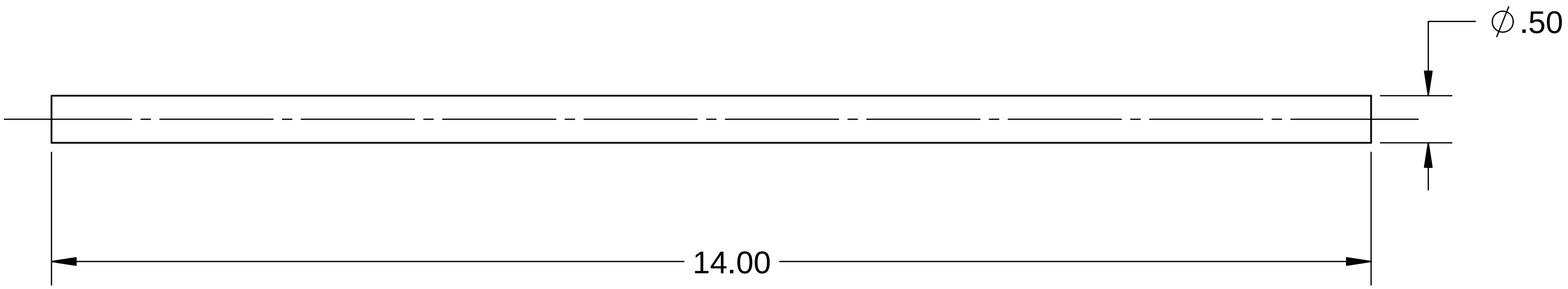




Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: BACKREST PIVOTING ROD		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: D0021	Nxt Asb: D0001	Date: 5/31/18	Scale: 1:2	Chkd. By: STEVEN DECSESZNAK



NOTES:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   - .X ± .1
   - .XX ± .01
   - .XXX ± .001



Cal Poly Mechanical Engineering	Material: ALUMINUM 6061-T6		Title: FOOTREST PIVOTING ROD		Drwn. By: MOULAY SALAHDIN
ME 430 - SPRING 2018	Dwg. #: C0031	Nxt Asb: C001	Date: 5/31/18	Scale: 1:2	Chkd. By: STEVEN DECSESZNAK