SoloStand

A Senior Project

presented to

the Faculty of the Biomedical Engineering Department

California Polytechnic State University – San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Biomedical Engineering

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Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

1 Executive Summary

The purpose of this scope of work is to highlight the progress and development of SoloStand sponsored by Derek Herrera, chief technical officer and founder of SpinalSingularity. SoloStand is an attachment to a wheelchair that will benefit paraplegics that use wheelchairs. A portable and customizable attachment to a wheelchair will allow the user to do everyday tasks without transferring into a separate standing wheelchair and travel more easily. This document outlines everything that has been done in fulfillment of our senior project requirements.

2 Introduction and Background

Our final goal for SoloStand is to have a lightweight device that will be reliable and easy to use for individuals with paraplegia. Our device is intended to attach to a Ti-Lite TR3 wheelchair and fit just above the seat of the wheelchair with a minimalist appearance.

We hope that the device we design will lead to future projects for SpinalSingularity that will enable your company to add a medical device to the market that will benefit not only the users, but also the company as a whole. The following sections will discuss the development of the device, design specifications, stage gate process, prototype development and manufacturing, design of experiments, and project plan.

2.1 Existing Designs

To understand what is already available on the market, we researched the existing designs and read customers' reviews to garner an understanding of their feelings towards current products. One user, Quad Xoch, said of the XO-505 by Karman Healthcare, "first the positive: the price; it's a third of what the high-end standing chairs cost," he goes on to explain the durability of the chair being above average before highlighting the negatives, "the only instructions that came with the chair are a photocopy of an instruction book, and the English is quite poor." Another user, Abrazoom, stated, "I like it, I need it, I can not afford it [6]." This indicates that although it is cheaper than most, this chair is still out of the price range for many in need. In **Table 2.1.1** below, there are summaries of existing models, designs, associated company, and an image of each product that was similar to our product or provided insight during our design process.

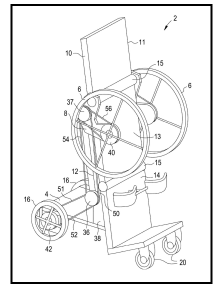
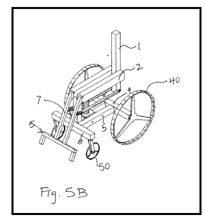
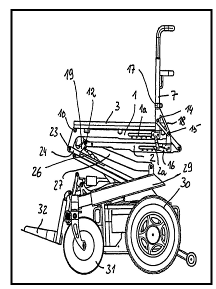
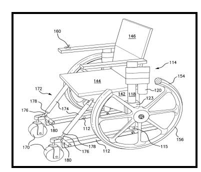
Table 2.1.1: Existing Designs

Number	Design Name	Premise of Design	Company	Image
	XO-505	Stand up wheelchair with brand new frame design, as well as LCD display that allows full control of all features	Karman Healthcare	
2	Zing MPS	Only multi-stander that pivots two directions. No need to transfer user in and out, flip pads, foot plates and trays. Provides more therapeutic options than other standing frames	EasyStand	
3	LEVO C3	Compact and agile mid-wheel drive power wheelchair allows for standing with a single electronic command. Available for children and adults.	Levo	
4	LEVO LCEV	Lightweight, manually propelled, power standing wheelchair.	Levo	
5	Lifestand LSR	Manual wheelchair with a motorized stand-up and relax functionality.	Cyclone Mobility	

2.2 Related Patents

In **Table 2.2.1**, there are existing patents and patent applications that were found to be relevant to our product. With this table we summarized the designs' names and what the patented designs are, as well as the inventor. We chose patents that were similar to standing wheelchairs because it's closely aligned to what our final product needs to be. The key aspect of this table is the premise of the design, as that is most applicable in the scope of this senior project.

Table 2.2.1: Patents

Number	Design Name	Premise of Design (with patent number)	Inventor	Images
1	Mobile Manual Standing Wheelchair	Improves the use of wheelchairs by offering the ability for the wheelchair to transition between seated and standing position. Also permits fixed gearing of multiple speeds that also accomodate forwards and backwards motion (US20130113178A1)	Gary Goldish Andrew Hansen	
2	Mechanically Assisted Standing Wheelchair	Provides a hydraulic powered wheelchair that can pivot from a sitting position to a standing position with minimal user effort. (US20010024025A1)	Mauricio Lizama-Troncoso David Serrano-Acevedo Dennis Martell-Solares Eduardo Carlo-Lopez Eduardo Bravo-Rios	
3	Stand-up wheelchair	Stand-up wheelchair comprising a frame to which two drive wheels and one steerable wheel are fixed. A stand-up unit provided with adjustable seat, back rest, and at least one foot rest, is arranged to pivot on wheelchair. (US7887133B2)	Heinrich Perk	
4	Sit-to-stand wheelchair	Comprises a low cost, high strength sit-to-stand wheelchair assembly. (US20190133856A1)	Maurice H. Dowding	
5	Be standing wheelchair	Wheelchair has a standing frame. The standing wheelchair is hingedly connected to the seat. (CN101835444B)	H·佩尔克	No image available

According to the first two citations, most individuals reported improvement in quality of life when using their standing wheelchair. Some improvements reported included less muscle spasms, improved bowel movements, and improved bone density. The reported time spent standing seemed to be correlated mostly with the age of an individual, as opposed to other factors. It was noted that the second citation's questionnaire answers received were from 319 individuals with different standing devices. So, the device itself could play a part on how often an individual wants to use it [1], [2].

Research done on behalf of the Heart and Stroke Foundation found that using a dynamic wheelchair after a spinal cord injury led to the reduction in supine blood pressure. This study showed that the inability to stand decreased supine blood pressure, but along with dynamic movement decreased the individual's blood pressure. Although these are positive observations, it should be noted that a risk of blood pressure falling too low should be considered in patients with certain spinal injuries [3].

In the fourth research study, a questionnaire was done with patients using a stand-up motorized prone cart. Some questions asked in the survey included overall comfort of the device and ease of use. In conclusion, the device was well perceived, although it was described as having an inconvenient turning radius [4].

In the final study, individuals with spinal cord injuries were placed in a standing wheelchair with pressure mats beneath them. Throughout the day, pressure on certain areas of the body was recorded. The results showed that individuals who had a standing wheelchair instead of a standard wheelchair recorded less overall load on the backrest and seat rest. The amount of load distribution was correlated to the angle the chair was placed in when standing. This was stated as potentially having clinical benefits and drawbacks for individuals [5].

2.3 Industry Codes

Our research included finding relevant industry codes and regulations that could impact our design and how we move forward with our device. In **Table 2.3.1** below, there is a list of the industry codes, as well as a brief explanation of each. After researching each regulation, we had better knowledge of what to consider most heavily when moving forward with our design.

Table 2.3.1: List of Industry Codes, Standards and Regulations

Industry Code/Standard/Regulations	Explanation
ISO 7176-10:2008	Determination of obstacle-climbing ability of electrically powered wheelchairs
ISO 7176-13:1989	Determination of coefficient of friction of test surfaces
ISO 7176-14:2008	Power and control systems for electrically powered wheelchairs and scooters — Requirements and test methods
ISO 7176-21:2009	Requirements and test methods for electromagnetic compatibility of electrically powered wheelchairs and scooters, and battery chargers
ISO 16840-4:2009	Seating systems for use in motor vehicles
ISO 7176-22:2014	Set-up procedures
ISO 7176-7:1998	Measurement of seating and wheel dimensions
ISO 7176-8:2014	Requirements and test methods for static, impact and fatigue strengths

3 Customer Requirements and Design Specifications

3.1 IFU

The purpose of the indications for use statement is to outline what SoloStand will do, what it will be used for, and who the intended users are. The indications for use statement is intended as a contract with the FDA and the information provided must be proven during testing before further consideration.

SoloStand is an attachment to a standard wheelchair that will allow individuals to stand. SoloStand is intended to be used by adult individuals aged 18 to 50 under 250 pounds that are between 5’4’’ to 6’2’’ in height to allow individuals to stand, not walk. It is intended for use both indoors and outdoors, but should only be stored inside.

3.2 Product Design Specifications

We understand that we want to address the issues that customers have faced using current products on the market. By using the information we gathered from our sponsor and market research, we determined the requirements that our product must meet for success.

As we have stated earlier, current products are costly and heavy. Therefore, our product must be cheap with a production cost of about $500. Our product must also be lightweight with a target weight of less than 50 pounds. Through research we concluded that the way our product attaches to the wheelchair, the weight, and the presence of a motor were the factors that would impact customer attraction the most. With this in mind, we decided to plan to create a product that is lightweight and could easily attach to a Ti-Lite wheelchair. These decisions were made in hand with the other customer requirements of the product being cheaper.

Other requirements that we focused on in our design included that the product must be collapsible, compatible with Ti-Lite wheelchairs, and able to withstand traveling and drops. Our design avoids the use of any software or electronics due to regulatory issues and is able to allow the user to maintain balance in an upright position. The features of our product include armrests, chest straps, a backrest, knee blocks, and an option to allow for various seat cushions. These features allow for the support and comfort needed by the user.

As part of our specification development, we created a house of quality (QFD). The purpose of our house of quality was to further our product development with the customer's desires at the forefront. With the house of quality we hoped to turn the requirements for SoloStand into measurable design targets with identifiable parameters. These measurable design targets were turned into our specifications matrix listed below with specific targets, tolerances, associated risk, and the compliance of each specification. The specification matrix has been modified to include more measurable targets as well as more detailed specifications.

Table 3.2.1: Product Design Specifications

Specification Number	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Weight	Less than 20lbs	Max.	H	ISO 16840-4:2009
2	Size	Accommodate up to 6'2''	Max.	M	ISO 7176-7:1998
3	Production cost	$1000	Max.	H	ISO 7176-22:2014
5	Stability when attached to wheelchair	Displacement < ½" when in use	Max.	H	ISO 7176-1:2014
6	Durability	Material must be able to withstand 250 lbs of force	Max.	H	ISO 7176-8:2014
7	Quick to use	Less than 5 seconds to reach upright position	Max.	M	ISO 7176-6:2018
8	Safety	Straps must withstand 250lbs	Max.	H	ISO 7176-1:2014

The parameters we are taking into account for our product are weight, size, production cost, max stress, stability, durability, quickness of use, and safety. To satisfy the requests of our sponsor we will be aiming to have our product fulfill the requirements listed earlier in the document, as well as having a maximum stress less than the ultimate tensile stress and a tolerance of less than 0.005 cm when attached to the wheelchair.

3.3 House of Quality

For this device, the House of Quality consists of customer and functional requirements, customer importance ratings and customer competitive assessment. The functional requirements and desired results compared to the previous designs were: weight, cost, how it attaches to the wheelchair, durability, appearance, compatibility with the Ti-Lite TR3 wheelchair, lack of electronics, ease of use and ability for the patient to remain stable while using the device.

Based on the relationship between the customer and functional requirements, we concluded that ability for the patient to remain stable while using a lightweight and low cost device were the three most important requirements.

Project:	SoloStand														
Date:	10/10/2019						+								
.						-	-	-							
				+	-	+	+	+							
			+	-	-	+	-	-	+						
		+	+	-	+	+	+	-	-	+					
Customer: Ages 13 to 75 y/o. Height: 5'4"-6'2". Up to 250lb		Functional Requirements													
	Direction of Improvement	▲	▲	▼	◻	▼	▼	◻	◻	▲	◻	Customer Competitive Assessmen			
Customer Importance	Customer Requirements	FEA	Mean time between failure	Overall Cost	Self-test	Accuracy	Stress Analysis	Kinematic Study	Metrology	Sponsor Satisfaction		Our Product	University of Minnesota/Veterans Affair	Otto Bock Healthcare GmbH	Rehabilitation Institute of Chicago
8	Lightweight	•	•	▽	•	○	•	•	○	•		5	4	1	3
9	Low Cost			•	•	•			▽	•		5	4	1	3
7	Attachable/Removable		▽		•	•		○	•	•		2	4	1	3
6	Easy to Travel with				•			▽	○			5	3	5	3
3	Durable/Strong	•	•		○		•	•				3	3	3	4
1	Minimalist Appearance			•	•					•		4	4	2	3
4	Compatible with Ti-Lite Wheelchai	•			•	•			•			5	4	3	4
5	No Electronics/Software			•	▽			▽	▽	•		5	5	1	5
2	Quick/Easy to Use			▽	○	○		•	•	•		4	4	5	4
10	Allow user to maintain balance				○	•	○	•	•	•		5	5	5	5
	Importance Sum	135	106	145	365	300	129	239	263	369					
	Target	7%	5%	7%	18%	15%	6%	12%	13%	18%					
	Benchmark # 1	4	3	5	3	4	4	5	4						
	Benchmark # 2	5	5	2	5	5	5	3	5						
	Benchmark # 3	5	4	3	4	4	4	5	4						
	Technical Competitive Assessment														

Correlations	
Positive	+
Negative	-
No Correlation	

Relationships		Weight
Strong	•	9
Medium	○	3
Weak	▽	1

Direction of Improvement	
Maximize	▲
Target	◻
Minimize	▼

Figure 3.3.1: House of Quality

4 Stage Gate Process

4.1 Concept Review

A morphology for three concepts was used to further our knowledge and creativity for the development of our final design. Morphology involves decomposing the function, developing concepts for each function, and then ultimately combining the concepts. With our morphology we intend to generate as many concepts as possible for each of the four functions crucial to our product. This resulted in three conceptual designs that were illustrated and then evaluated. **Figure 4.1.1** describes our morphology with the highlighted cells representing the concepts that were used to develop our designs.

Morphology						
Product: SoloStand	Organization Name: Cal Poly and Spinal Singularity					
Function	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Lift Gluteus maximus	Air piston	Spring	Hydraulics	Crank and Gears	Hand pedal	Pneumatic Cylinder
Move thoracic and abdominal cavity forward	Air piston	Spring	Hydraulics	Crank and Gears	Hand pedal	Pneumatic Cylinder
Locking mechanism	Pin	Lever and Pawl/Teeth	Brake Pads	Fit in lock mechanism	Hook and ratchet strap	
Transfer of momentum	Moment Arms/lever	Pulley	No force from arms needed			
Team member: Celina Dioso	Team member: Hau Doan	Prepared by				
Team member: Sydney Gray	Team member:	Checked by:	Approved by:			
The Mechanical Design Process Copyright 2008, McGraw Hill			Designed by Professor David G. Ullman Form # 15.0			

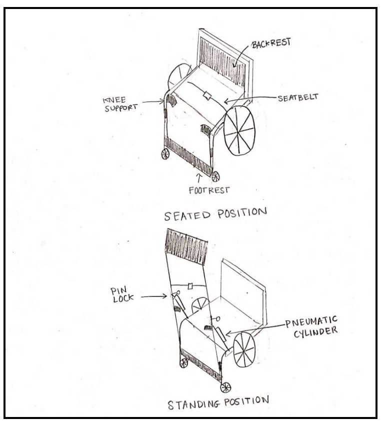
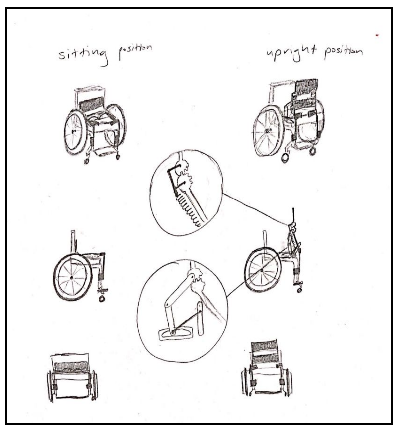
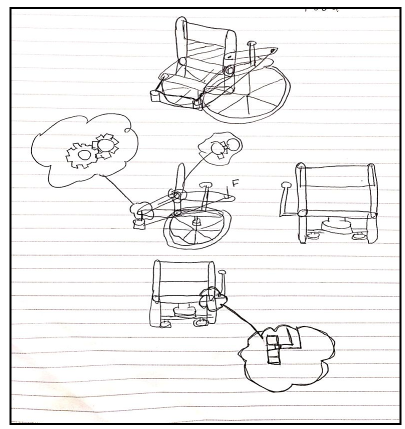
Figure 4.1.1 Morphology

The first concept design in **Table 4.1.1** features a pneumatic cylinder and a pin for the different functions of the design. The pneumatic cylinder would allow the device to move from a sitting to standing position, once the individual leans forward. Once the individual wants to sit, they lean back, and the cylinder retracts and moves them to their seat. The pin is used to lock the apparatus in the standing position to allow for more stability and remove the fear of the device moving to a seated position without the individual wanting that to happen. This design is supposed to allow the individual to sit and stand with minimal effort and to let the device do most of this work.

The second concept design in **Table 4.1.1** features a spring mechanism to help the seat rise to an upright position, a lever mechanism to transfer momentum from the user's arms to the device, and a self-locking mechanism where a part will fit into a slot when the device is fully extended in order to keep it in place. The spring mechanism was designed to hold potential energy when the user is seated in order to facilitate movement into an upright position. The gears were designed to stop turning when the seat is in its upright position to enhance stability. These gears would also be connected to a lever mechanism which would be moved by the user to push the seat into its standing position. The metal bars used in this mechanism would include a part that will slide into a slot when fully upright to hold the device in place when the user is standing.

The third and final concept design in **Table 4.1.1** was developed with the idea of an individual transferring some force with their arms and leaning forward so the air pistons could assist them to stand. This is so the pistons would not have to do all the lifting, making the weight range broader for users. Also, the locking mechanism was designed to be a simple bar, which is controlled by a lever and can be wedged between two holes when the bars are aligned. They will be aligned when the individual is fully standing. This apparatus makes it easily lockable when the person is standing.

Table 4.1.1 Overview of Design Concepts

Design Concept 1	Design Concept 2	Design Concept 3
		

The three above design concepts were evaluated and compared using Pugh charts. These charts can be found in **Appendix E**. Once these charts were all completed, we found that the design to continue with was a device with a gas spring system to raise and lower the individual from the sitting and standing position, fit-in-lock mechanism to keep the device in the standing position when needed, and one that relies on the individual leaning forward and back to trigger the motions.

4.2 Design Freeze

The final design that we decided on for the design freeze was design concept 1, shown in **4.1 Concept Review**. This design was the frontrunner because it seemed to fulfill the customer requirements of being easy to use and including no electronic component, as well as requiring minimal effort from the individual while achieving a minimalist appearance. The SolidWorks detailed drawings are shown in **Appendix C**.

Our final design in the seated and standing position is seen in **Figure 4.2.1** below. This design will directly attach to the wheelchair, with the user sitting directly on top of it. We have been provided a seat cover with velcro that would attach to the seat plate of our device and allow users to attach their own seat cushion. Not included in the model are the chest and waist straps that will be attached to the posterior side of the back plate and give the additional support that the user may need when going from a seated to standing position with this device. Additionally, the locking gas spring systems will have wire release systems attached that will allow the user to have control of the movement. The gas spring systems will be attached directly to the wheelchair via the mounting bracket to give the ideal angle for movement of the device from the seated to standing position. Clamps will be used towards the bottom of the leg frame to attach the frame to the wheelchair. The leg frame also has kickstands to adjust the center of gravity while achieving additional stability.

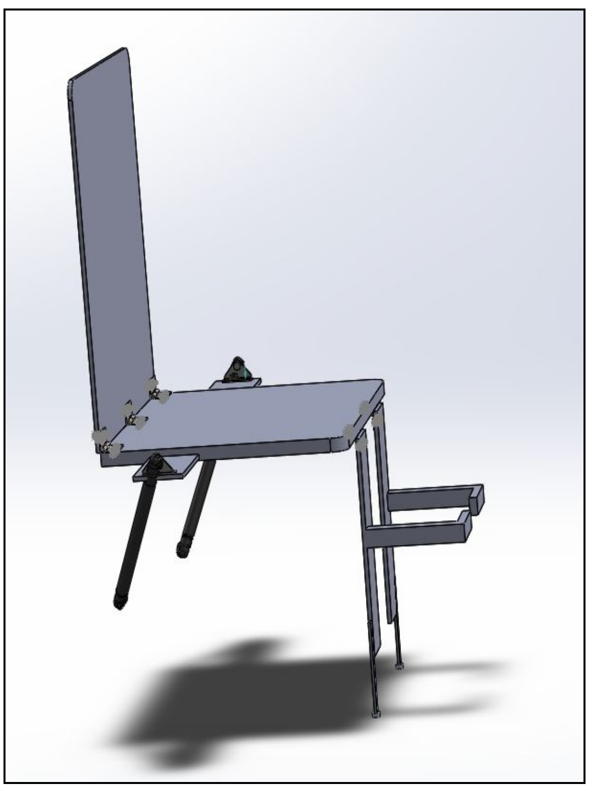
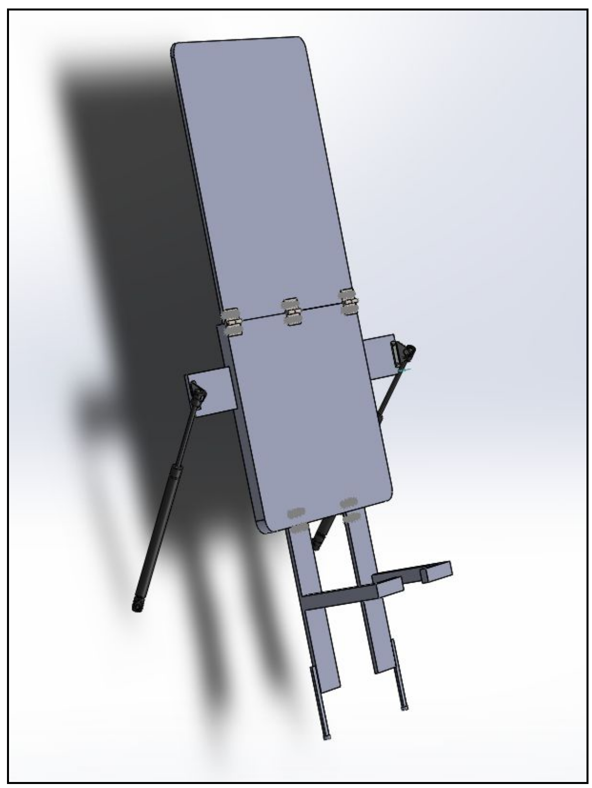
Device in Seated Position	Device in Standing Position
	

Figure 4.2.1: Detailed Design as of Design Freeze

4.3 Design Review

Our final design depicted in **Figure 4.3.1** had several diversions from our "finalized" concept for the design freeze. The dimensions of the newly added components of our design can be found in **Appendix J.** While manufacturing our device, we hit several roadblocks and challenges that were solved by modifying our overall design. The first modification we made was related to the gas spring systems. We found that there was a smaller gap between the seat and the wheels on the wheelchair than we had originally thought. We realized that we could not mount the gas spring systems between the wheels and seat anymore, so we added an additional gas spring support bar. This bar would connect the tip of the gas spring system to the seatplate after mounting the gas spring systems above the seat instead.

Another concern we had with our design was that the frame legs would create a pinch point underneath the user's legs. To address this issue, we placed our frame bars on the side of the user's legs rather than underneath. The frame would consist of two separate legs instead connected by a pinned connection around where the knees would be. The horizontal frame leg would be welded to our seat width adjuster while the vertical frame leg would be clamped to the frame of the wheelchair. The kickstand would then be connected to the bottom of the vertical frame leg. A small piece of metal would be welded in a perpendicular fashion to the bottom of the vertical frame legs and the kickstands would be screwed onto the small pieces of metal.

This change to our frame design led to us having to change our plan for the knee blocks as well. Our solution was to create a slot at the top of the vertical frame legs that would hold the removable knee blocks in place. The knee blocks would then have a curved shape in order to create enough space for the user's legs.

When creating the slot for the seat width adjusters we found that there were limitations to the equipment we had access to. If we were to make a slot, the equipment we had would not be able to make the slot nearly as deep as it should be. To address this issue, we altered our design to have the slot at the bottom of the seat plate. We would then cover the slot created with small bars of metal to prevent the seat width adjusters from slipping out of the slot when in use.

The final concern we had with our design at the design freeze was that it now needed a locking mechanism when it is in the standing position because of the additional gas spring support bar that we added to our design. The additional bars would have to be pushed downward to get the user into a fully upright position and we needed a mechanism to keep the device in that position so that the user would be able to have free use of their arms. To address this issue, we added the concept of a latching mechanism that would hold together the two frame bars that meet when the device is fully upright. When the user reaches the peak height, they would have to just flip down the latch to connect the bars to keep the device standing.

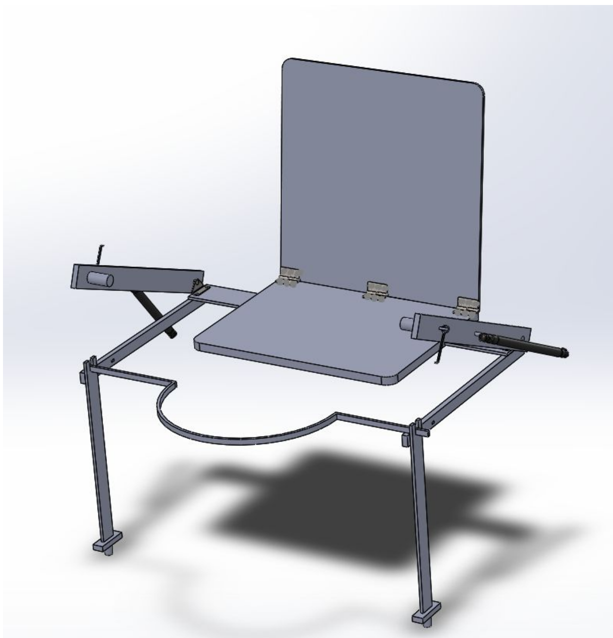
Final Device in Seated Position	Final Device in Standing Position
	

Figure 4.3.1: Final Detailed Design

5 Description of Final Prototype Design

5.1 Overview

After making many modifications to our final prototype throughout the manufacturing process, we can confidently say that our device meets each of the requirements outlined by our sponsor. After changing our design, we also used finite element analysis to confirm that our gas spring systems would still be able to support all potential forces. Also after analyzing the cost after all of the modification, our total cost of manufacturing for our prototype is still under our maximum cost of $500. Different hazards and risks would also be associated with the new components of our design. To address these risks, we set new planned corrective actions to make sure our device is still safe and easy to use.

5.2 Design Justification

The final proposed prototype was designed to meet the customer specifications given to us by our sponsor. The original design has been modified greatly. Instead of a frame that is only attached to the bottom of the seat plate via hinges, we welded the frame onto the seat width adjusters. The decision for this modification was made based on the requirement of the device as a whole being adjustable, and to remove the pinch point created behind the knee. This design aligns with the project goal of making an adjustable attachment to a wheelchair.

5.3 Analysis

To determine whether aspects of our proposed design would withstand the weight of an individual up to 250 lbs, a SolidWorks simulation was performed. This study was run on the gas spring system with a force of 556 N, which is the maximum weight that our device would need to withstand. The finest mesh was applied and finite element analysis was performed on both the inner and outer piston rods of the gas spring. **Figure 5.3.1** displays the Von Mises stress on the inner piston rod of the gas spring system.

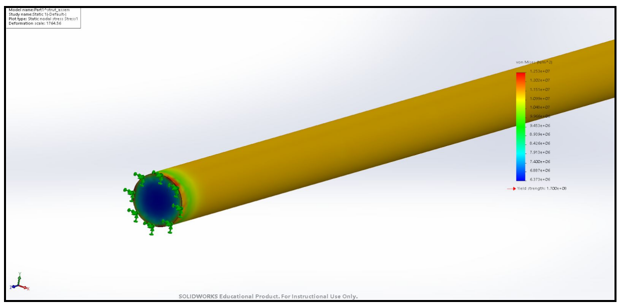


Figure 5.3.1: Mesh and Forces Applied to Inner Piston Rod

Figure 5.3.2 below displays the Von Mises stress on the outer piston rod of the gas spring system.

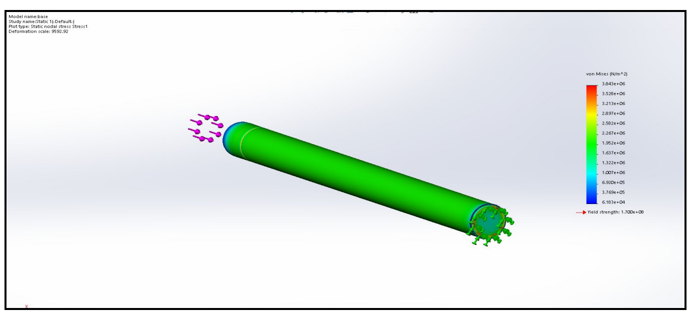


Figure 5.3.2: Mesh and Forces Applied to Outer Piston Rod

The FEA simulations on the piston rod indicated that it would most likely fail at the end that would be attached to the frame, or where the axial load is applied. Upon looking at the Von Mises stress, we saw that the piston rod was compressed to about 7/8ths of its original length; however, the highest stress value was 12.7 MPa which is significantly lower than the yield strength of 170 MPa. The FEA simulation on the base of the gas spring indicated that the Von Mises stress values of 3.84 MPa were also significantly under the yield strength of the base.

These values indicate that the gas spring system that we selected to run the simulation will not fail under the conditions we selected and are an appropriate model to use for our device.

5.4 Cost Breakdown

One requirement was that our device be under $500 to manufacture. **Figure 5.4.1** is the bill of materials, which details the cost to build one prototype of our device following the manufacturing plans and using the same material. The total cost of manufacturing our prototype was $470.71. If our device were to be streamlined, the cost would significantly drop and allow for long term profit.

Product:	SoloStand
Date:	2/29/2020
Part Count:	23
Total Cost:	$470.71

Part #	Product #	Part Name	Description	Material	Source	Quantity	Measurement	Unit Price	Total Price
1	1248	Back Plate	sheet	Al-6061	onlinemetals	1	12" X 12" X 0.25"	$37.16	$37.16
2	9704	Seat Plate	sheet	Al-6061	onlinemetals	1	12" X 12" X 0.75"	$129.51	$129.51
3		Back Plate Stopper	rectangular bar	Al-6061	mustang60	1	8" X 1" X 1"	$2.00	$2.00
4	7541	Frame	rectangular bar	Al-6061	onlinemetals	1.5	0.25" X 3" X 24"	$12.04	$18.06
5	311316	Knee Block	copper type m pipe	Copper	homedepot	1	0.5" X 24"	$4.30	$4.30
6	7541	Seat Width Adjuster	rectangular bar	Al-6061	onlinemetals	1	3" X 0.25" X 12"	$6.30	$6.30
7	7541	Gas Spring Support	rectangular bar	Al-6061	onlinemetals	0.5	0.25" X 3" X 10"	$12.04	$6.02
8	K0N0BK2-100-280	Locking Gas Spring	locking gas spring	steel	easylift	2	11.02"	$45.67	$91.34
9	20BZ0500TAAKP	EasyTouch Bowden Wire Release	wire release system	plastic/coil	easylift	2	20"	$33.63	$67.26
10	6DUN3	Gas Spring Bracket	bracket for gas spring	zinc-plate steel	grainger	2	8 mm	$8.03	$16.06
11	B07N8H2WTD	Gas Spring Bracket	bracket for gas spring	zinc-plated steel	amazon	2	10 mm	$4.83	$9.66
12		10/32" Screws	for attaching frame	steel	mustang60	15	10/32	$0.00	$0.00
13		Nuts and Bolts	for attaching frame and gas springs	steel	mustang60	2	7/32	$0.00	$0.00
14	816721	Eye Bolt	for handles	steel	homedepot	2	1" radius	$0.59	$1.18
15	551	Gas Spring Eye End	eye for attachment	steel	amazon	2	M8	$14.40	$28.80
16	60012	Gorilla Glue Duct Tape	for attaching material	tape	homedepot	1	1.88 X 12 yards	$4.97	$4.97
17	269	Gorilla Glue Adhesive	for attaching material	glue	homedepot	1	2 fl. oz.	$4.97	$4.97
18	97891	C-Clamp	attach frame to wheelchair	stainless steel	homedepot	2	1"	$2.97	$5.94
19	97892	C-Clamp	attach frame to wheelchair	stainless steel	homedepot	2	2"	$3.97	$7.94
20	14985	Hinge	attachment for seat	nickel	homedepot	2	3-1/2" X 1/4" Rad.	$3.28	$6.56
21	10030BULK2	Knee Block Padding	mutlipurpose padding	foam	homedepot	0.5	22" X 22" X 2"	$5.97	$2.99
22	B075ZTLKJC	Chest Strap	chest support	polyester	amazon	1	3/4" X 24"	$1.59	$1.59
23	B06XSXMRBK	KickStand	mini kickstand for frame	aluminum alloy	amazon	2	7.2" X 3.2" X 1"	$9.05	$18.10
								Total Cost	**$470.71**

Figure 5.4.1: Bill of Materials

5.5 Safety Considerations

When designing, building and assembling the prototype, the safety hazards in **Table 5.5.1** were taken into consideration while the proper mitigations were taken to limit disastrous effects.

Table 5.5.1 Hazard Mitigations

Description of Hazard	Planned Corrective Action
The assembly will be designed to be collapsible, creating multiple pinch points at each bending point.	The tolerance will be small enough to only allow the joints to move at a low speed.
The device will be moving a person upwards with a force great enough to get the user to an upright position	The gas spring system will have a dampening feature to control the amount of force released and the gas release system will allow the user to have control over the amount of force that is released
One of the components of the design is a gas spring system which will hold pressurized air in order to provide the force needed to move the user	The gas spring system will be connected to a gas release system that will control the amount of gas that is released
The user will be required to activate the gas release system in order to move the device and then will be moved entirely by the device into an upright standing position	The gas release system will be easily accessible by the user and we will design the device to mimic the natural movement of the human body as it reaches an upright position
The gas release system, if not operated correctly, may result in the device not being moved correctly which may result in harm of the user	The device will include instructions for use for the gas release system in order to ensure the user is aware of how it is operated.
The seat plate is made out of a large metal plate which has sharp edges and corners. This could be dangerous to the user if not handled correctly.	The edges and corners will be grinded out and rounded to make the plates safer to hold and handle.

6 Prototype Development

6.1 Model Analyses

The prototype is designed to move the user to a standing or seated position with as minimal effort as possible while maintaining stability throughout. It is made out of Aluminum 6061 sheet metal and bars, as well as Copper for the knee block. It consists of a gas spring with a wire release that will move the individual forward and back, as well as the Aluminum frame. The final detailed drawings can be found in **Appendix C**. The gas spring and knee blocks are required to be customizable, and will be discussed further on in the report. The company that we used manufactures gas springs that are easily customized to any weight needed. This means that the gas spring will need to be ordered for each specific patient's weight. The knee block is also customizable. For the most secure fit, each knee block must be made according to the patient's height.

6.2 Evolution of Prototypes

The design of our prototype has significantly changed throughout the process. Each iteration presented a unique set of issues that we were able to fix until we reached our final functioning prototype. The first iteration of our final prototype is seen in **Figure 6.2.1** . This iteration contains all components and modifications described in our Design Freeze and Design Review. This prototype was the unit used in all of our testing procedures. The results of our tests were used to make modifications and improve our overall final prototype.

Figure 6.2.1: First Iteration of Final Prototype

Figure 6.2.2 Prototype Handle

The first issue we observed when attempting to test our device was that the additional gas spring support bars were very uncomfortable to push down on in order to bring the device to a fully upright position. To make the device easier to use, we added handles to our device that were padded with foam which can be seen in **Figure 6.2.2**. These made it easier for us to grab hold of the bars to push them down without being in danger of getting cut by the metal.

Another issue we saw when observing our volunteers while they were testing our device was that it would be a little difficult for them to grab and push down on the short lever arms. It would appear awkward for them to use them and often they would not be able to push the arms all the way down. To solve this issue, we made the lever arms 5 inches longer which made them much more comfortable to use. In order to do this, we welded another 5-inch-long metal bar to the original lever arm since we did not have enough remaining aluminum to create entirely new lever arms. These parts can be seen in **Figure 6.2.3**.

Figure 6.2.3: Improved Lever Arms

Figure 6.2.4: Improved Locking Mechanism

The final iteration of our final prototype included all of the previous modification in addition to a new locking mechanism which is seen in **Figure 6.2.5**. When testing the device in all of our tests, we saw that the lever arms were rarely able to be pushed all the way down to meet the frame legs to engage the latch-like locking mechanism. We therefore decided that it would be best to modify the locking mechanism to make the device easier to use. Instead of a latch, the new locking mechanism is more of a swinging hook. The metal hook is about 5 inches long and would be attached to the lever arms. A 1/4-in hole was created in each of the horizontal frame legs. When in use, the hook would then be manipulated into swinging into the hole in the frame leg. The hook would successfully hold the device in place and the user would be able to have free use of their arms **(Figure 6.2.4)**.

Figure 6.2.5: Final Iteration of Final Prototype

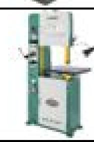
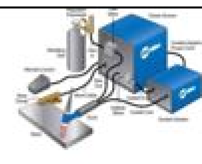
6.3 Manufacturing Process

Manufacturing instructions are written plans that incorporate requirements, design specifications, manufacturing specifications and other critical information. The manufacturing plans for our SoloStand were condensed in number formatting with pictures, to allow for ease of reading. **Table 6.3.1** and **Table 6.3.2** below compile all of the equipment and machines used for manufacturing our prototype.

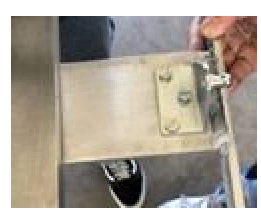
Table 6.3.1: Manufacturing Equipment with Images

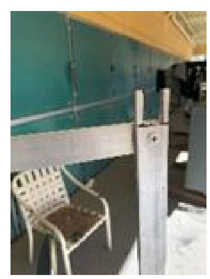
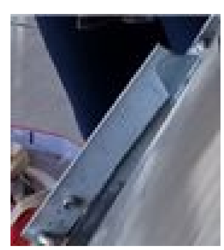
Number	Equipment	Image
1	Hinges	
2	Metal Screw	
3	Gas Spring Eye End	
4	Gas Spring Bracket	
5	Capped Gas Spring Bracket	
6	Nuts and Bolts	
7	Locking Gas Spring	
8	Wire Release	
9	Gorilla Glue Adhesive	
10	Knee Block Padding	
11	Kick Stand	
12	1" and 2" C-Clamps	
13	Chest Strap	

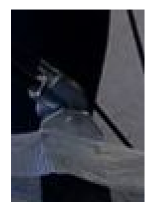
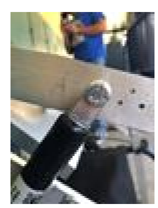
Table 6.3.2: Manufacturing Machines with Images

Number	Machine	Image
1	Granite Surface Plate	
2	Drill Press	
3	Vertical Band Saw	
4	Bench Grinder	
5	TIG Welder	
6	Bridgeport Mill	

The following table, **Table 6.3.3** is the detailed manufacturing instructions with each step, instructions, and images to aid in manufacturing. Please note that the first step includes dimensions of each Al 6061 piece that was cut to size with a bandsaw by us; however, the MPI is written as if the All 6061 pieces would be pre-cut to size.

Step	Instructions	Images
1	Verify measurements on the granite surface plate ● Back Plate: 12” X 12” X 0.25” ● Set Plate: 12” X 12” X 0.75” ● Frame: 2-18” X 1” X 0.25” & 2-0.25” X 15” X 1” ● Seat Track: 4-6” X 1.5” X 0.25” ● Gas Spring Support: 2-10” X 1.5” X 0.25” ● Seat Width Adjusters: 2-6” X 3” X 0.25” ● Back Plate Stopper: 8” X 1” X 1”	
2	Mill the seat plate ● Mill a 3” slot that is 0.25” deep into the seat plate 5” from the back	
3	Add seat track to the seat plate ● Attach via a drill press and tapping set, the seat track pieces on the seat plate over the slot	
4	Attach the back plate to the seat plate ● Position 2 hinges on the back and seat plates ● Using a drill press, drill holes into both the back and seat plate ● Tap each hole and then attach each screw	
5	Create and attach the back plate stopper ● Cut the aluminum square bar 1” on the edges using a vertical band saw ● Drill and tap a hole on each side into the 1” hole that you just created, drill and tap holes on the back plate as well ● Attach the back plate stopper to the back plate using metal screws	
6	Attach the gas spring bracket to each seat width adjuster ● Measure each seat width adjuster to allow the gas spring bracket to fit 0.85 +/- 0.10 on either side of the seat width adjuster ● Use the drill press and tap set to place the sheet metal screws into the gas spring brackets on the seat attachments with the ball stud towards the wheel	

Step	Instructions	Images
7	Weld the frame to the seat width adjusters ● Weld each 18" piece of the frame to the outside edge of each seat width adjuster so that the frame and seat attachment are perpendicular to each other	
8	Attach seat width adjusters to the seat plate ● Slide the seat width adjusters into both sides of the seat plate where the slot was made	
9	Create a slot on the 15" frame for the knee block ● Using the band saw, cut a 1" X 0.25" slot on the frame for the knee block leaving 0.375" on each side	
10	Weld the support to the bottom of the frame ● Weld the support to the bottom of the frame with the frame in the center	
11	Attach the frame together ● Create a countersink hole on one end of the 18" piece of the frame using a drill press ● Create another hole on one end of the 15" piece of the frame ● Secure pieces of the frame together by sliding a metal screw through each piece and attaching a nut on the back (this creates a pin for the frame to rotate) ● Repeat process for the other side of the frame	
12	Create the gas spring support for mounting of the gas spring ● Use the drill press and tap set to attach the gas spring bolt to the gas spring supports ● Use the drill press to create a hole on the gas spring supports for the gas spring bracket on the seat attachment 0.5" from the bottom ● Use the drill press and tap to create a threaded hole for the eye nut (armrest) ● Use the drill press and tap to create holes for the locking mechanism bracket 1" from the eye nut	

<table>
<tr><th>Step</th><th>Instructions</th><th>Images</th></tr>
<tr><td>13</td><td>Attach the locking mechanism to the frame
Use the drill press to create a hole for the locking mechanism to enter 2” from the pin on the leg frame</td><td></td></tr>
<tr><td>14</td><td>Add padding to the eye nut to create the armrest
Add foam padding around the eye bolt and secure with adhesive strips</td><td></td></tr>
<tr><td>15</td><td>Attach a wire release to each locking gas spring
Hand screw on the gas spring eye end with the wire release attachment
Attach the gas spring bracket to the metal frame of the wheelchair using the power drill and metal screws, making sure the ball stud is facing away from the wheelchair
Place the gas spring eye end into the ball stud</td><td></td></tr>
<tr><td>16</td><td>Attach gas spring bracket to wheelchair where side panels were attached 5” from the back
Using the predrilled holes and screws attach the gas spring bracket to the wheelchair</td><td></td></tr>
<tr><td>17</td><td>Attach locking gas spring to gas spring support and gas spring bracket on the wheelchair
Slide the hole of the gas spring support into the gas spring bracket on the seat attachment
Attach gas spring eye end of locking gas spring to the gas spring support ball mount to secure the gas spring
Attach eye of locking gas spring with the wire release to the gas spring bracket on the wheelchair</td><td></td></tr>
<tr><td>18</td><td>Make the knee block
Bend the copper bar using a conduit pipe bender
Using a vice, squeeze the sides of the copper bar allowing it to fit in the slot for the knee block
Attach foam padding to the knee block</td><td></td></tr>
</table>

Step	Instructions	Images
19	Clamp the wheelchair ● Use two c-clamps to attach the frame at the knee and towards the bottom near the frame of the wheelchair	
20	Attach the kickstand to the support ● Apply adhesive to the kickstand to attach the edge of the kickstand flush on the side and even with the width of the support	
21	Attach the chest straps ● Use adhesive to attach the chest strap 2" from the top edge on the posterior side of the back plate	

6.4 Divergence Between Final Design and Final Functional Prototype

7 IQ/OQ/PQ

7.1 DOE

The design of experiments for our project outlines the engineering metrics, specifications, testing method and location, and the sample sizes of each test. **Table 7.1.1** below displays the proposed design of experiments for testing our prototype. There was no additional training necessary for the testing methods. These specifications were designed to mitigate the risks identified earlier in the report.

Table 7.1.1: Design of Experiments

Engineering Metric	Specification	Criteria	Test Method	Test Location	Sample Size
Sizing	+/- 0.25 in. of detailed drawings		Tape Measure and Caliper	Mustang 60	3
Weight	< 20 lbs		Scale	Mustang 60	3
Secureness	No displacement		Straps	Mustang 60	3
Climatic	T ≤ 6 seconds		Stopwatch	Spark Yoga and Campus Dining	3
Speed	T ≤ 6 seconds		Stopwatch	192-329	20
Strength	75% or higher pass rate	Pass/Fail	Survey	192-329	20
Comfortability	Average Score ≤ 6	1-10	Survey	192-329	20
Stability	75% or higher pass rate	Pass/Fail	Survey	192-329	20

7.2 Verification and Validation

7.2.1 Testing Protocol

Our testing procedures were developed based on our product requirements. The goal of most of our testing plans was to confirm if our device satisfies each product requirement. The facilities and equipment that we will need in order to complete our testing procedures include a large cooler or room able to be cooled and a room able to be heated for the climatic tests, a stopwatch, tape measures, calipers, a scale, and straps large enough to hold down our Ti-Lite wheelchair. We may also use the machine shops in order to perform some tests and our red tag/yellow tag certifications will be needed to use these facilities.

We have determined eight different types of tests to evaluate the functionality of our product. They will include sizing tests, weight tests, secureness tests, climatic tests, speed tests, strength tests, comfortability tests, and stability tests. Each test will be conducted at least three times with a sample size of 20 individuals for the tests that require volunteers. Each volunteer will be within our range weights and heights meant to be accommodated by the device (<250 lbs in weight and 5’4” to 6’2” in height) including individuals as close to the end ranges as possible. The tests will be conducted as follows.

For the sizing tests, each dimension, including height, width, and depth, of the device as a whole will be measured carefully in the collapsed position, seated position, and standing position using a tape measure. Individual components, such as the seat and backrest will also be measured to confirm that our product fits the size requirements and will be compatible with the Ti-Lite wheelchair provided to us as seen in **Figures 7.2.1 and 7.2.2.** We expect that the final dimensions will be within 0.25’’ from our dimensions stated in our detailed design drawings. A dimension will be considered a failure if it is greater than 0.25’’ off of the expected dimension.

Figure 7.2.1: Sizing of Seat Plate.

Figure 7.2.2: Sizing of Vertical Frame Bar.

The weight tests will be conducted using a handheld scale. The weight of the wheelchair alone will be found first. Then the device will be attached to the wheelchair and weighed (**Figures 7.2.3 and 7.2.4**). The weight of the wheelchair alone will be subtracted from the total weight to find the weight of our device. This test will determine if the device satisfies the weight requirement which calls for the device to be less than 20 lbs. We expect that the final weight for the device will not exceed 20 lbs as planned by our design process and the test will be considered a failure if the weight exceeds the 20 lb limit.

Figure 7.2.3: Weight Test

Figure 7.2.4: Measurement of Total Weight

The secureness tests require the use of straps large enough to hold down the wheelchair. After securing the Ti-Lite wheelchair in place using the straps, we will attach our device to the wheelchair. We will then pull on the device with 50 lbs of force to determine if the clamps are strong enough to hold the device in place on the wheelchair. We measured 50 lbs of force by using the handheld scale and lifting up with the scale until it read 50 lbs. We expect our clamps to withstand the force of an average human being pulling on the device. The test will be considered a failure if the clamps fail and the device detaches from the wheelchair.

The climatic tests will require the use of a large cooler or room able to be cooled to a temperature of at least as low as 32 degrees Fahrenheit and a room able to be heated to a temperature of at least as high as 100 degrees Fahrenheit. The wheelchair will be placed in a cooler at a temperature of at most 32 degrees Fahrenheit and allowed to cool until the gas spring systems reach a temperature of 32 degrees (**Figures 7.2.5 and 7.2.6**). It will then be activated to move from a seated position to the standing position. Then it will be switched from a standing position to its original seated position. After removing it from the cooler, the wheelchair and device will be allowed to return to room temperature. The wheelchair and device will then be placed in a room heated to at least 100 degrees Fahrenheit and allowed to heat up until the gas spring systems reach a temperature of 100 degrees (**Figures 7.2.7 and 7.2.8**). It will then be activated to switch from its seated position to its standing position and then back to its original seated position. The purpose of these tests is to determine the functionality of the device in more extreme weather conditions. We expect our system to be able to ascend and descend in 5 seconds +/- 1 second. The test will be considered a failure if the device takes more than 6 seconds to change position.

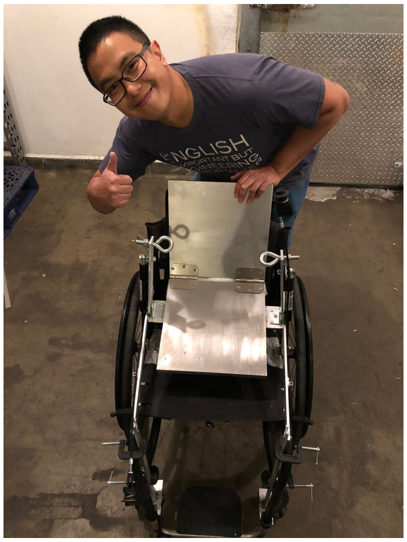


Figure 7.2.5: Climatic Test in Cooler

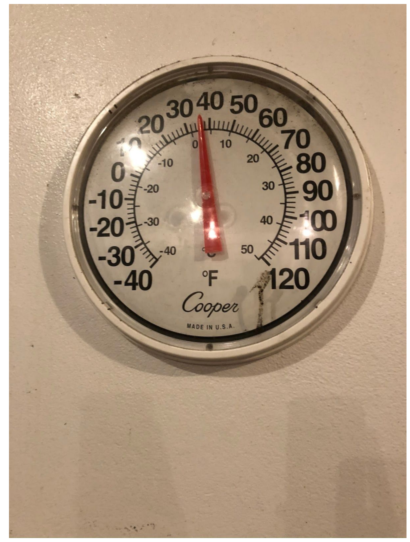


Figure 7.2.6: Temperature in Cooler

Figure 7.2.7: Climatic Test in Heated Studio

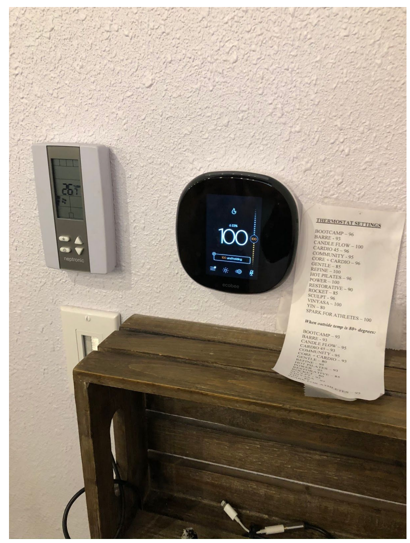


Figure 7.2.8: Temperature in Studio

The speed tests will require the sample of 20 individuals and the use of a stopwatch. Each individual will be asked to perform the test one at a time in an isolated area and without seeing another volunteer complete the test prior. Once the time starts, the volunteer will be asked to find the gas release system, use the system to activate the device to move into the fully-standing position, and then to move the device back into the original seated position. The time taken for the device to ascend and the time taken for the device to descend will both be recorded. The purpose of this test is to determine the convenience and ease of use of the device. This test also determines if the product satisfies the requirement of being able to switch position in under 5 seconds. We expect the gas spring system to be simple enough to allow for easy activation. We also expect the gas spring systems to be able to accommodate for a rise and descend time of no more than 5 seconds. The test will be considered a failure if the rise or descend time exceeds 5 seconds. In order to ensure the safety of the individuals, one of our team members will be holding onto the wheelchair while the other two team members will be spotting the individual on each side. The volunteers will also be wearing a helmet and there will be foam padding set in front of the wheelchair.

For the strength tests, the components to be tested for failure include the knee blocks and straps. This test will require the sample of 20 individuals as well. Each volunteer will be asked to push against the knee blocks with all of their weight while in the wheelchair. Then they will be asked to lean forward against the straps with all of their weight. These tests will evaluate the safety of the device and determine if the knee block attachments and strap attachments are durable enough to withstand the potential loads of each user. We expect each of these components to be able to withstand the force of the heaviest and tallest potential uses of the device due to our material choices and iterated designs. The test will be considered a failure if the chest straps break off at any point or if the knee blocks deform at all. To ensure the safety of the individuals, one of our team members will be holding onto the wheelchair while the other two team members will be spotting the individual on each side. The volunteers will also be wearing a helmet and there will be foam padding set in front of the wheelchair.

Comfortability testing will again require the 20 volunteers. Each individual will be asked to rank the level of comfort of 6 different components of the design. Each individual will be asked the questions without hearing the answers of any of the other volunteers. Individuals will be asked to rank their comfortability. This will be on a scale of 1 to 10 with 1 being very uncomfortable and 10 being very comfortable. The 6 components will include the seat comfort, strap comfort, leg comfort, comfort when sitting, comfort when standing, and comfort when using the gas release system. The purpose of this test is to determine if we must alter the design or gas release system in order to make it more comfortable and easier to use. We expect the initial prototype to not provide the maximum amount of comfort as it will be the first physical iteration, but the testing will guide us in finding the areas in which we can improve the comfort. The tests will be considered a failure if the average rating of the comfort for the area is less than 6.

The stability tests will require the sample of 20 individuals and each volunteer will be asked to lean back and forth when in the seated position and then when in the standing position. The users will be asked if they sense any form of discomfort and whether they feel stable or not when seated. This test will be given a pass or fail rating and the results will determine if any alterations must be made to the design to provide more stability. Again, to ensure the safety of the individuals, one of our team members will be holding onto the wheelchair while the other two team members will be spotting the individual on each side. The volunteers will also be wearing a helmet and there will be foam padding set in front of the wheelchair. Since wheel locks are included with the wheelchair and we included a kickstand in our design for the device, we expect the device to be quite stable in both the seated and standing positions. The test will be considered a failure if the stability when seated is given a fail rating.

7.2.2 Testing Results

The raw data for each of the completed tests, can be found in **Appendix F**. It should be noted that we were only able to acquire 20 samples in each test due to being restricted to only our class. The following table, **Table 7.2.1**, displays the results of the tests conducted without volunteers. The procedure for each test is described in section **7.2.1 Testing Protocol**. The sizing test resulted in a pass because the dimensions of each component of the wheelchair was within 0.25" of the detailed drawings. The weight test resulted in a failure because our device was 4.1 pounds overweight; however, our sponsor indicated structural integrity and functionality was more important than the weight. Due to time restrictions, we opted with making our device completely functional rather than cutting down on weight. The secureness test resulted in a failure because the c-clamps did not hold; therefore, we added additional c-clamps to the frame. Once these c-clamps were added, there were no problems with operation moving forward. The climatic test resulted in a pass in both the hot yoga studio and the warehouse cooler because the device continued to function in the more extreme temperatures and was able to ascend/descend in under 6 seconds.

Table 7.2.1 Results of Non-Volunteer Tests

Test	Metric	Result
Sizing	+/- 0.25 in. of detailed drawings	Pass
Weight	< 20 lbs	Fail
Secureness	No displacement	Fail
Climatic	≤ 6 seconds	Pass

Table 7.2.2 organizes the results of the speed and comfortability tests. The speed test was conducted with 20 individuals that were asked to go from the seated to standing position, and the standing to seated position while a timer was running. This was used to determine if our device meant the customer specifications of being used in less than 5 seconds. Our metric was that the time to go from seated to standing and vice versa would each be less than or equal to 6 seconds in order to pass. Our locking mechanism was not working at the time of testing, so it was unsafe to allow individuals to test from the locked standing position to seated position; therefore, only the results of the time it takes to get from a seated to standing position is summarized. The comfortability test was given in as a survey that asked how comfortable the following

components of our device were on a scale from one to ten: seat, strap, leg frame, and gas release comfort.

Table 7.2.2: Results of Volunteer Tests

Test	Metric	Mean	Standard Deviation	Result
Speed	T ≤ 6 seconds	4.56 s	2.27	Pass
Overall Comfortability	Average Score ≥ 6	7.66	0.99	Pass
Seat Comfortability		6.15	1.68	
Strap Comfortability		7.40	1.68	
Leg Comfortability		8.65	1.49	
Gas Release Comfortability		8.45	1.85	
Climatic (Hot)	T ≤ 6 seconds	5.89 s	0.27	Pass
Climatic (Cold)	T ≤ 6 seconds	5.88 s	0.94	Pass

The following table, **Table 7.2.3**, compiles the results of the strength tests for both the knee block and the chest strap, and the stability tests for both the standing and sitting positions. The knee block only worked for a small amount of individuals within a small height range; therefore, strength of the knee block earned a result of failure. After speaking with our advisors, we determined that the knee block should be customizable. Because the knee block is dependent on the patient's height, it will need to be customizable. This is achievable because a longer copper bar could be used for manufacturing of the knee block custom to the patient's height. The locking mechanism was not working at the time of testing; therefore, the stability while standing was not achieved and earned a result of failure.

Table 7.2.3: Results of Pass/Fail Tests

Test	Metric	Number of Pass	Number of Fail	Result
Strength - Knee Block	75% or higher pass rate	0	20	Fail
Strength - Chest Strap	75% or higher pass rate	20	0	Pass
Stability while Standing	75% or higher pass rate	0	20	Fail
Stability while Sitting	75% or higher pass rate	20	0	Pass

Following testing, we found a solution for our locking mechanism that allowed our device to reach full functionality. If there was additional time, we could have tested more subjects to ensure stability while standing and it would have passed our metric. The only reason that stability while standing did not achieve a successful pass was due to our locking mechanism not being functional at the time. Since functionality was achieved, we successfully met the customer requirements.

8 Conclusions and Recommendations

8.1 Recommendations

Our device meets the customer requirements given to us; however, there were limitations during testing that lead us to make recommendations. Earlier in the process, we decided that we would not submit our project to the Institutional Review Board to test on subjects outside of the class, rather we would keep our project testing within the scope of the class. This created limitations because we could only test those willing in the class, which was 20 individuals. A recommendation in the future would be to have a larger sample of volunteers for testing to further validate our results.

The gas springs ordered for our device were calibrated to a weight of 125 lbs each, or 250 lbs for our device in fulfillment of the customer requirements. The individuals that tested our device were no more than 210 pounds, and some air was released from the gas springs to ensure we could test our device. The gas springs were calibrated for a weight range of 110 to 160 lbs. Gas springs are essential to our device, and it is important to have a gas spring calibrated to the weight of the individual. The company that we ordered our gas springs from, have a customizable option allowing for the individual to enter the exact weight needed. Our recommendation is that each gas spring be ordered specifically for the weight of the individual that will be using it. This will ensure the functionality of the device and the safety of the individual. Another aspect of the design that will need to be customizable is the knee blocks. Each individual testing was a different height and when sitting, their knees were in different locations. The knee block adds stability to the device and keeps the individual in the position that allows for the most effective process of sitting and standing; therefore, the knee blocks should be customizable. This is easily achieved by ordering a longer copper tube while still bending at the appropriate angle of 80 degrees, and adding the right amount of padding so that the individual is stable yet comfortable.

Additional recommendations are to implement a locking mechanism that would be easier to use while still being durable. Our locking mechanism requires the user to push a pin through a small hole on the frame on our device, which requires more effort than we ideally want. Also, the way we attached our frame to the wheelchair could be improved upon. The c-clamps that hold our device to the frame of the wheelchair should be switched with something more durable; however, we were not able to manufacture such a clamp due to inexperience. Our device weighs 24 pounds, which is over the limit of 20 pounds or less. This weight can be decreased by cutting down the material on the back and seat plate. This was not achievable during the scope of the project due to time and the tools in the machine shop.

Improvements were made on our device following testing that achieved full functionality. Given more time, we would have tested the locking mechanism to ensure that it could hold the maximum weight that our device is built for, as well as conducting the tests again with it being fully functional. We believe that our device meets the customer requirements, yet recommend the above actions be considered in the future.

8.2 Conclusions

The final prototype is fully functional and meets all of the customer needs. The device is a minimalist design that is customizable, adjustable, accommodates different seat cushions, easy to travel with, durable, strong, collapsable, and has an integrated chest strap, armrest, and knee block. Our device has a locking mechanism that allows it to stay in the standing position while giving the user the ability to use their hands freely. We hope our device will pave the way for more accessible options than the current electronic standing wheelchairs, as our initial prototype was successful in functionality. The research and tests that went into our design ensures that our prototype is functional and can be modified in the future to exceed the customer requirements.

9 Acknowledgments

We would like to express our appreciation to our project sponsor, Mr. Derek Herrera, for his idea for this project and all the support he provided over the past six months. We would like to thank our advisors, Dr. Christopher Heylman and Dr. Michael Whitt for guiding us through this project with all the trials and tribulations along the way. We would like to thank Ms. Sabrina Jenkins for helping us with our travel forms and purchase request forms, the Cal Poly Machine Shop Technicians for all the help along the way, and Spark Yoga and Cal Poly Campus Dining for being very open to us testing. Our special thanks is extended to the Hannah Forbes Foundation and Cal Poly Biomedical Engineering Department for the additional funding. Finally, we would like to thank everyone in and outside of the senior project class that helped us in any way.

10 Appendices

10.1 Appendix A: References

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10.2 Appendix B: Project Plan (PERT Chart)

Task Name	Duration	Start	Finish
Preproject Planning	14 days	Thu 10/3/19	Tue 10/22/19
Indication For Use	6 days	Thu 10/3/19	Thu 10/10/19
Develop Budget	6 days	Thu 10/3/19	Thu 10/10/19
Conjoint Analysis Report	3 days	Tue 10/8/19	Thu 10/10/19
Quality Function Deployment	6 days	Thu 10/3/19	Thu 10/10/19
Pugh Chart	5 days	Wed 10/16/19	Tue 10/22/19
Project Requirments	3 days	Fri 10/11/19	Tue 10/15/19
Product Specifications	3 days	Tue 10/22/19	Thu 10/24/19
Overall Specifications	3 days	Tue 10/22/19	Thu 10/24/19
Hardware Specifications	3 days	Tue 10/22/19	Thu 10/24/19
Market Research	1 day	Tue 10/22/19	Tue 10/22/19
Conceptual Design	5 days	Thu 10/24/19	Wed 10/30/19
Conceptual Model	4 days	Thu 10/24/19	Tue 10/29/19
Status Update Memo	4 days	Thu 10/24/19	Tue 10/29/19
Hazard and Risk Assesment	1 day	Wed 10/30/19	Wed 10/30/19
Conceptual Design Review and Report	3 days	Thu 10/31/19	Mon 11/4/19
Critical Design	5 days	Mon 11/4/19	Fri 11/8/19
Status Update Memo	3 days	Wed 11/6/19	Fri 11/8/19
Supplier Specifications	3 days	Mon 11/4/19	Wed 11/6/19
SolidWorks	11 days	Sat 11/16/19	Fri 11/29/19
Individual Part Models	7 days	Sun 11/17/19	Sat 11/23/19
Status Update Memo	2 days	Sat 11/16/19	Mon 11/18/19
Assembly	7 days	Sun 11/17/19	Sat 11/23/19
Part Drawing	2 days	Sun 11/24/19	Mon 11/25/19
Assembly Drawings	2 days	Sun 11/24/19	Mon 11/25/19
Critical Design Review and Report with Detailed Drawings	6 days	Tue 11/26/19	Tue 12/3/19
Prototype Assembly	13 days	Tue 1/7/20	Thu 1/23/20
Prototype Testing	16 days	Fri 1/31/20	Fri 2/21/20
Testing	11 days	Fri 1/31/20	Fri 2/14/20
Iteration	6 days	Fri 2/14/20	Fri 2/21/20
Final Prototype	7 days	Mon 2/24/20	Tue 3/3/20
Senior Project Design Report and Presentation	6 days	Wed 3/4/20	Wed 3/11/20

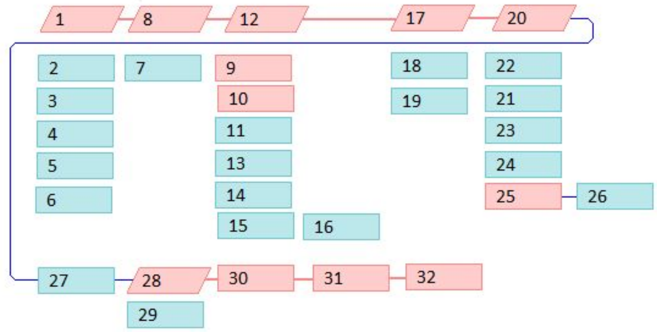


Figure 10.2.1: Network Diagram for Entirety of Project

Task Name	Duration	Start	Finish
Non-Volunteer Tasks	**4 days**	**Mon 2/10/20**	**Thu 2/13/20**
Sizing Test	1 day	Mon 2/10/20	Mon 2/10/20
Weight Test	1 day	Mon 2/10/20	Mon 2/10/20
Secureness Test	1 day	Mon 2/10/20	Mon 2/10/20
Heated Climatic Test	1 day	Thu 2/13/20	Thu 2/13/20
Cooled Climatic Test	1 day	Thu 2/13/20	Thu 2/13/20
Volunteer Tasks	**6 days**	**Tue 2/25/20**	**Tue 3/3/20**
Speed Test	3 days	Tue 2/25/20	Thu 2/27/20
Comfortability Test	3 days	Tue 2/25/20	Thu 2/27/20
Stability Test	3 days	Tue 2/25/20	Thu 2/27/20
Strength Test - Knee Block and Strap	3 days	Fri 2/28/20	Tue 3/3/20
Contingency Test	**1 day**	**Wed 3/4/20**	**Wed 3/4/20**
Strength Test - Locking Mechanism	1 day	Wed 3/4/20	Wed 3/4/20

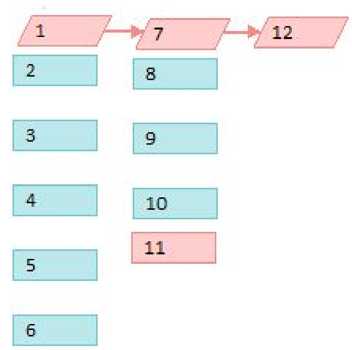


Figure 10.2.2: Testing Network Diagram

10.3 Appendix C: CAD Drawings

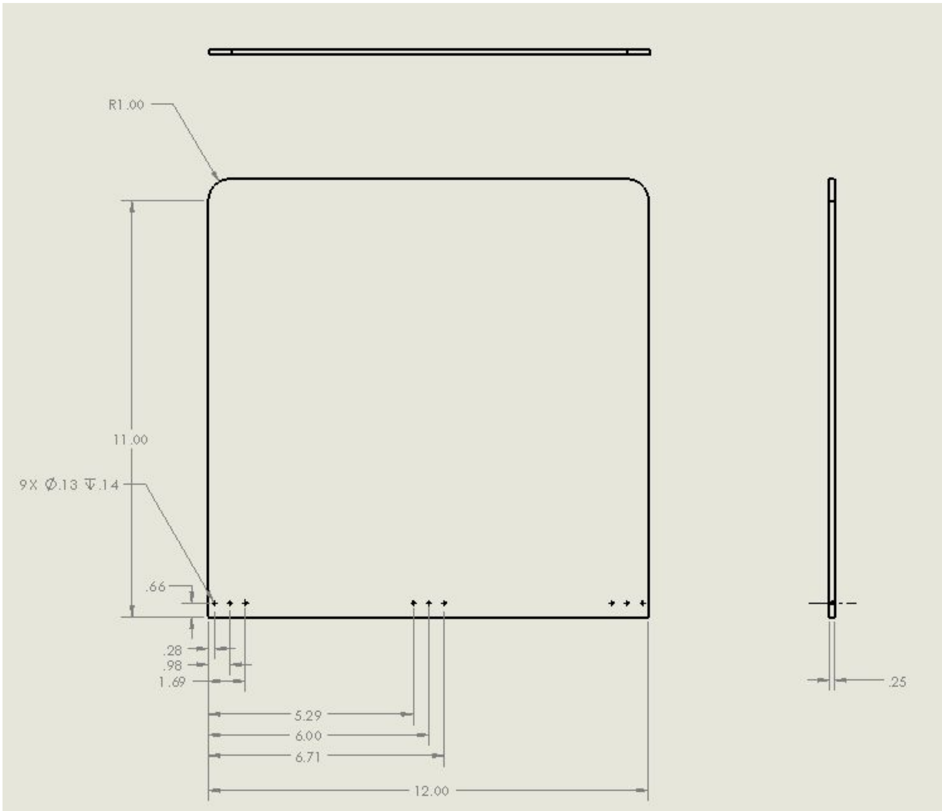


Figure 10.3.1: Detailed Design Drawings as of Design Freeze

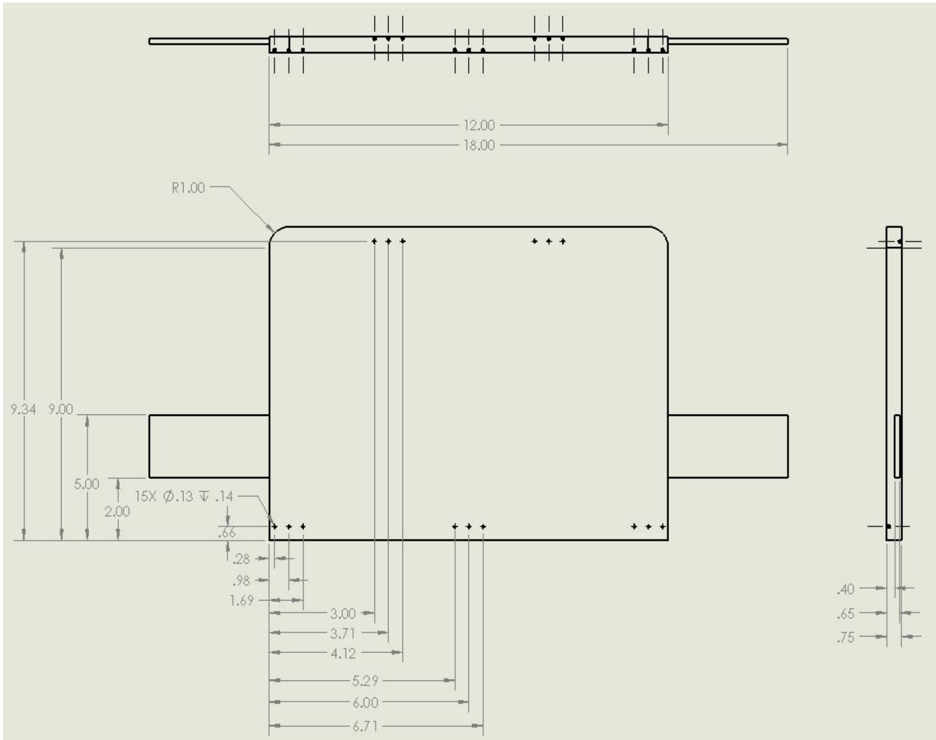


Figure 10.3.2: Detailed Design as of Design Freeze

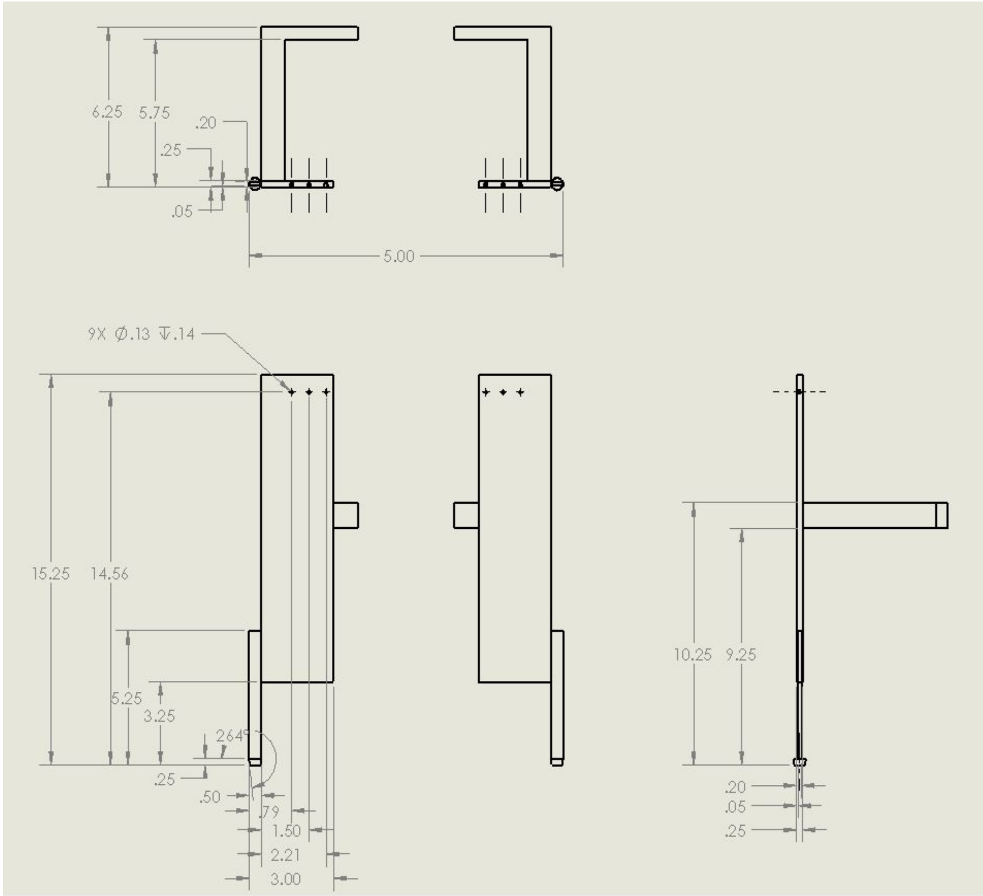
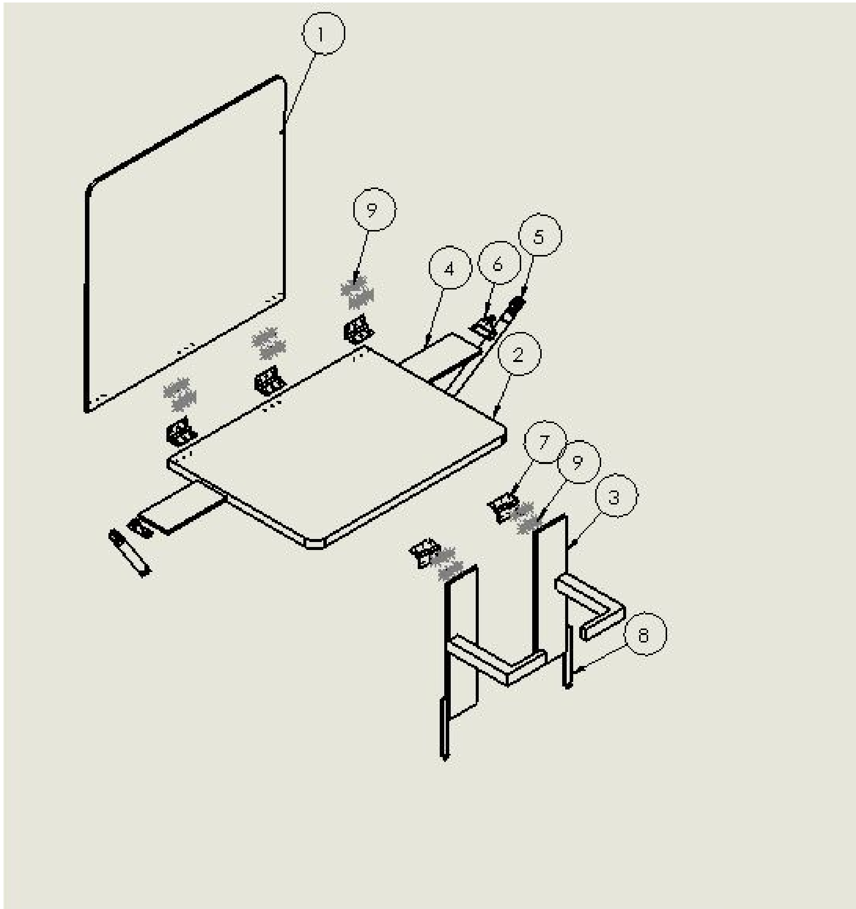


Figure 10.3.3: Detailed Design as of Design Freeze



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Back Plate	sheet	1
2	Seat Plate	sheet	1
3	Frame with Knee Block	rectangular bar	2
4	Seat Width Adjuster	rectangular bar	2
5	Locking Gas Spring	gas spring system	2
6	Gas Spring Bracket	mounting for gas spring system	2
7	Hinges	hinges to attach materials	5
5	Kickstand	for frame stability	2
9	Screws	holds sheets and hinges	30

Figure 10.3.4: Detailed Design as of Design Freeze

10.4 Appendix D: FMEA, Hazard & Risk Assessment

Table 10.4.1 Hazard and Risk Assessment

Description of Hazard	Planned Corrective Action	Planned Date	Actual
The assembly will be designed to be collapsible, creating multiple pinch points at each bending point in the design	The tolerance will be small enough to only allow the joints to move at a low speed.	11/30/2019	1/23/2020
The device will be moving a person upwards with a force great enough to get the user to an upright position	The gas spring system will have a dampening feature to control the amount of force released and the gas release system will allow the user to have control over the amount of force that is released	11/25/2019	11/25/2020
One of the components of the design is a gas spring system which will hold pressurized air in order to provide the force needed to move the user	The gas spring system will be connected to a gas release system that will control the amount of gas that is released	11/21/2019	1/24/2020
The user will be required to activate the gas release system in order to move the device and then will be moved entirely by the device into an upright standing position	The gas release system will be easily accessible by the user and we will design the device to mimic the natural movement of the human body as it reaches an upright position	11/30/2019	1/24/2020
The gas release system, if not operated correctly, may result in the device not being moved correctly which may result in harm of the user	The device will include instructions for use for the gas release system in order to ensure the user is aware of how it is operated.	1/24/2020	1/24/2020
The seat plate is made out of a large metal plate which has sharp edges and corners. This could be dangerous to the user if not handled correctly.	The edges and corners will be grinded out and rounded to make the plates safer to hold and handle.	2/10/2020	03/03/2020

10.5 Appendix E: Pugh Chart

Problem Area: lift gluteus maximus				
		Alternatives		
Design Criteria	Weight	Gas Spring System	Spring	Pneumatic Cylinder
Lightweight	20	-1	D	-1
Low Cost	25	0	A	0
Easy to travel with	10	0	T	0
Durable/Strong	25	1	U	1
Quick/Easy to Use	20	1	M	0
	Total	1		0
	Weighted Total	25		0

Figure E.1: Pugh Chart for Lifting of Center of Gravity

Problem Area: locking mechanism after standing				
		Alternatives		
Design Criteria	Weight	Pin	Lever and teeth	Fit in lock
Lightweight	20	D	-1	0
Low Cost	30	A	-1	0
Durable/Strong	30	T	1	0
Quick/Easy to Use	20	U	1	1
	Total	M	0	1
	Weighted Total		0	20

Figure E.2: Pugh Chart for the Locking Mechanism once Standing

Problem Area: transfer of momentum from arms to apparatus				
		Alternatives		
Design Criteria	Weight	Lever	Pulley	No force needed
Lightweight	20	D	-1	1
Low Cost	30	A	-1	1
Durable/Strong	30	T	0	-1
Quick/Easy to Use	20	U	-1	1
	Total	M	-3	2
	Weighted Total		-70	40

Figure E.3: Pugh Chart for the Transfer of Momentum from Arms to Apparatus

10.6 Appendix F: Vendor Information, Specifications, and Data Sheets

Table 10.6.1: Data from Speed Tests

Subject	Time to go up	Time to go down
1 (5’4, 130)	fail	4.75
2 (5’7, 155)	fail	fail
3 (5’1, 100)	9.44	7.62
4 (5’11, 155)	15.46	4.01
5 (5’10, 200)	fail	fail
6 (5’7, 170)	fail	5.21
7 (5’7, 135)	7.89	6.34
8 (6’0, 175)	fail	fail
9 (5’4, 170)	fail	3.56
10 (5’6, 140)	fail	4.65
11 (5’5, 140)	fail	5.67
12 (5’8, 150)	fail	6.37
13 (5’2, 135)	fail	4.38
14 (5’5, 145)	fail	6.32
15 (5’2, 107)	fail	7.02
16 (5’7, 150)	fail	4.57
17 (5’0, 130)	fail	5.23
18 (5’7, 160)	fail	5.67
19 (6’0, 210)	fail	3.34
20 (5’5, 115)	fail	6.56

Table 10.6.2: Data from Strength Test

Person	Knee block	Chest strap
1 (5’4, 130)	fail	pass
2 (5’7, 155)	fail	pass
3 (5’1, 100)	fail	pass
4 (5’11, 155)	fail	pass
5 (5’10, 200)	fail	pass
6 (5’7, 170)	fail	pass
7 (5’7, 135)	fail	pass
8 (6’0, 175)	fail	pass
9 (5’5, 170)	fail	pass
10 (5’6, 140)	fail	pass
11 (5’5, 140)	fail	pass
12 (5’8, 150)	fail	pass
13 (5’2, 135)	fail	pass
14 (5’5, 145)	fail	pass
15 (5’2, 107)	fail	pass
16 (5’7, 150)	fail	pass
17 (5,0, 130)	fail	pass
18 (5’7, 160)	fail	pass
19 (5’10, 210)	fail	pass
20 (5’5, 115)	fail	pass

Table 10.6.3: Data from Comfortability Test

Subject	Seat	Strap	Leg	Standing	Gas Release Buttons
1 (5’4, 130)	4	7	8	fail	8
2 (5’7, 155)	8	8	7	fail	10
3 (5’1, 100)	7	8	8	fail	10
4 (5’11, 155)	7	9	9	fail	10
5 (5’10, 200)	8	10	10	fail	10
6 (5’7, 170)	3	10	10	fail	10
7 (5’7, 135)	4	6	8	fail	10
8 (6’0, 175)	6	5	8	fail	8
9 (5’5, 170)	8	10	10	fail	10
10 (5’6, 140)	8	5	10	fail	7
11 (5’5, 140)	4	7	10	fail	8
12 (5’8, 150)	4	9	7	fail	8
13 (5’2, 135)	8	9	4	fail	9
14 (5’5, 145)	5	7	10	fail	9
15 (5’2, 107)	5	7	10	fail	4
16 (5’7, 150)	8	6	9	fail	7
17 (5’0, 130)	7	5	8	fail	10
18 (5’7, 160)	7	8	9	fail	10
19 (6’0, 210)	7	5	8	fail	7
20 (5’5, 115)	6	3	10	fail	8

Table 10.6.4: Data from Stability Tests

Subject	Sitting	Standing
1 (5’4, 130)	pass	fail
2 (5’7, 155)	pass	fail
3 (5’1, 100)	pass	fail
4 (5’11, 155)	pass	fail
5 (5’10, 200)	pass	fail
6 (5’7, 170)	pass	fail
7 (5’7, 135)	pass	fail
8 (6’0, 175)	pass	fail
9 (5’5, 170)	pass	fail
10 (5’6, 140)	pass	fail
11 (5’5, 140)	pass	fail
12 (5’8, 150)	pass	fail
13 (5’2, 135)	pass	fail
14 (5’5, 145)	pass	fail
15 (5’2, 107)	pass	fail
16 (5’7, 150)	pass	fail
17 (5’0, 130)	pass	fail
18 (5’7, 160)	pass	fail
19 (6’0, 210)	pass	fail
20 (5’5, 115)	pass	fail

10.7 Appendix G: Budget

Part #	Part Name	Description	Source	Fund	Quantity	Unit Price	Total Price (Before Tax)	Total Price After Tax
1	B-Locking Gas Spring	locking gas spring	EasyLift	BMED Dept.	3	$45.67	$137.01	$149.00
2	Gas Spring Mounting Brackets	bracket for gas spring attachment	Amazon	BMED Dept.	1	$28.99	$28.99	$31.53
3	Emson Car Cane	handle	Amazon	BMED Dept.	2	$9.98	$19.96	$21.71
4	Aluminum Square Bar	hollow bar for back plate	Mustang60	Sponsor	1	$2.00	$2.00	$2.18
5	Gorilla Glue	adhesive	Walmart	Sponsor	1	$5.26	$5.26	$5.72
6	Latch	gate latch for locking mechanism	Home Depot	Sponsor	2	$3.78	$7.56	$8.22
7	Gorilla Glue Duct Tape	duct tape	Home Depot	Sponsor	1	$4.97	$4.97	$5.40
8	2" C Clamp	clamp for wheelchair frame	Home Depot	Sponsor	2	$3.18	$6.36	$6.92
9	1" C Clamp	clamp for wheelchair frame	Home Depot	Sponsor	2	$1.97	$3.94	$4.28
10	Sheet Metal Screws	screws	Home Depot	Sponsor	1	$5.25	$5.25	$5.71
11	6 in Paint Tray	for epoxy application	Home Depot	Sponsor	1	$1.68	$1.68	$1.83
12	Respirator Mask	for epoxy application	Home Depot	Sponsor	1	$5.47	$5.47	$5.95
13	Latex Gloves	for epoxy application	Home Depot	Sponsor	1	$1.98	$1.98	$2.15
14	Flat Head Screws	screws	Home Depot	Sponsor	1	$1.18	$1.18	$1.28
15	Kwikweld	epoxy	Home Depot	Sponsor	1	$6.98	$6.98	$7.59
16	1 Qt Paint Stick	for epoxy application	Home Depot	Sponsor	1	$0.98	$0.98	$1.07
17	Luggage scale	scale for testing	Amazon	Sponsor	1	$10.29	$10.29	$11.19
18	Release Buckles and Strap	for chest strap	Amazon	Sponsor	1	$7.99	$7.99	$8.69
19	Steel Duct Clamps	for attaching frame	Amazon	Sponsor	1	$7.99	$7.99	$8.69
20	10mm Ball Studs	gas spring attachment	Amazon	Sponsor	1	$8.50	$8.50	$9.24
21	M8 eye fitting	gas spring eye end	Amazon	Sponsor	1	$5.13	$5.13	$5.58
22	M8 release screw	for releasing pressure in spring	EasyLift	Sponsor	1	$59.99	$59.99	$65.24
23	20" Wire release system	wire release for gas spring	EasyLift	Sponsor	3	$33.63	$100.89	$109.72
24	Steel Bracket	bracket for gas spring attachment	Grainger	Sponsor	4	$10.98	$43.92	$47.76
25	Flash Furniture Chair Cushion	seat comfort	Home Depot	Sponsor	1	$7.20	$7.20	$7.83
26	Door hinge	hinges for plates	Home Depot	Sponsor	1	$26.98	$26.98	$29.34
27	2" Foam	for padding	Home Depot	Sponsor	2	$5.97	$11.94	$12.98
28	Eye nut	for handle	Home Depot	Sponsor	2	$1.18	$2.36	$2.57
29	0.25" Aluminum plate	back plate	Online Metals	Hannah Forbes	2	$37.13	$74.26	$80.76
30	0.75" Aluminum plate	seat plate	Online Metals	Hannah Forbes	2	$129.51	$259.02	$281.68
31	0.25" X 3" Aluminum bar	frame	Online Metals	Hannah Forbes	2	$6.30	$12.60	$13.70
32	0.25" X 3" Aluminum bar	frame	Online Metals	Hannah Forbes	2	$12.04	$24.08	$26.19
33	M10 eye endfitting	for gas spring	Amazon	Hannah Forbes	2	$14.44	$28.88	$31.41
34	Mini Parking Stand	kickstand	Amazon	Hannah Forbes	2	$9.05	$18.10	$19.68
35	Flat Head Screws	screws	McMaster	Hannah Forbes	1	$5.67	$5.67	$6.17
							TOTAL	$1,138.95

10.8 Appendix H: DHF

10.8.1 TAM and Competitive Advantage

Total available market (TAM) is the total market demand for a product. We took into account the price per device of $1500 and the number of customers being 100, 700. This number was determined by a previous survey finding that 38% of the 265,000 would be willing to pay for a similar product. Multiplying the price per device and the amount of customers, we found that the total available market is 1.51 million dollars. The competitive advantage matrix below highlights the factors considered, as well as how our product measures up to the two biggest competitors, LifeStand and LEVO. It is important to note that our product is made from different materials, yet is still lightweight, removable, and more cost effective.

Table 10.8.1: Competitive Advantage Matrix

Factor	SoloStand	Competitor #1 (LifeStand LSE)	Competitor #2 (LEVO LCEV)
Cost	$1500	$9,995	$13,250
Weight	20lbs	63lbs	57lbs
Material	Al 6061	Aircraft Aluminum and Titanium	Aircraft Aluminum
Color	Metallic	Black and Blue	Black and Blue
Motor	No	Options with and without	Yes, battery powered
Height	5'4'-6'2'	5'4'-6'2'	5'4'-6'2'
Attachment to Wheelchair	Removable	Built-in	Built-in
Max Load	250lbs	265lbs	265lbs

10.8.2 Conjoint Analysis

Analysis and testing were conducted to ensure our device met requirements and is safe for everyday use. As part of the scope of this project we were required to conduct a conjoint analysis; however, the results were inconsistent and have been removed for clarity.

10.8.3 Analysis of Gas Spring System

Following Finite Element Analysis, we conducted hand calculations using the equations listed below. It should be noted that the hand calculations were lower than FEA. This may be due to the cylinders having rivets and fillets in them. This will cause stress concentration in the area. An attempt was made to get these stress concentrations, but charts used may not be completely accurate for geometry of base. Because of this a larger max in FEA may occur.

To verify our FEA results, we first calculated the maximum stress on the inner extending rod of the gas spring system. Using the stress equation for an axial load acting on a slender rod with one fixed end, and values for the force and cross sectional area, we determined that stress was equivalent to 11.34 MPa. This can be seen in **Equation 1**.

$$\sigma_{yx} = \left|\frac{P_{max}}{A}\right| = 11.34\ MPa \tag{1}$$

Using Von Mises' stress equation for maximum stress, we confirmed our value of 11.34 MPa in **Equation 2.**

$$\sigma = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 - 2\sigma_{yz}^2 = 11.34\ MPa \tag{2}$$

Before moving on to the hand calculations for the outer rod, we used the Distortion Energy Theory to find the principal stresses needed to calculate the factor of safety using the equation below.

$$\sigma' = \left(\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}\right)^{\frac{1}{2}} = 11.34\ MPa \tag{3}$$

The factor of safety was calculated using the principal stress and the known ultimate strength of material. Our value was 14.99, which is acceptable for our device. This can be seen in **Equation 4.**

$$n = \frac{S_y}{\sigma'} = 14.99 \tag{4}$$

After calculating the maximum stress and the factor of safety for the inner extending rod of the gas spring system, we used the same equations with different parameters to solve for the outer rod of the gas spring system. The stress was determined to be 2.029 MPa through **Equation 5**.

$$\sigma_{xx} = \left|\frac{P_{max}}{A}\right| = 2.029\ MPa \tag{5}$$

Once again, Von Mises' equation was used to determine the principal stresses for the outer rod, in order to move forward in our stress analysis. This can be seen in **Equation 6.**

$$\sigma = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 - 2\sigma_{yt}^2 = 2.029\ MPa \quad (6)$$

The equation for maximum stress takes into account that the outer rod is a cylinder, with the final value being more accurate at 2.84 MPa, using the equation below.

$$\sigma_{max} = \sigma(k_t) = 2.84\ MPa \quad (7)$$

The Distortion Energy theory was used to determine the principal stress, which was the same value as the maximum stress. This can be seen in **Equation 8**.

$$\sigma' = \left(\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}\right)^{\frac{1}{2}} = 2.84\ MPa \quad (8)$$

The factor of safety was calculated using the principal stress and the known ultimate strength of material. Our factor of safety was calculated to be 83.79, which can be seen in Equation 9. This is more than acceptable for our device.

$$n = \frac{S_y}{\sigma'} = 83.79 \quad (9)$$

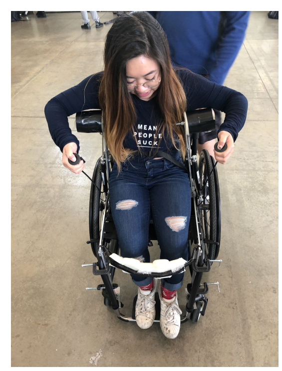
The FEA simulation on the piston rod indicated that it would most likely fail at the end that would be attached to the frame, or where the axial load is applied. Upon looking at the Von Mises stress, we saw that the piston rod was compressed to about 7/8ths of its original length; however, the highest stress value was 12.7 MPa which is significantly lower than the yield strength of 170 MPa. The FEA simulation on the base of the gas spring indicated that the Von Mises stress values of 3.84 MPa were also significantly under the yield strength of the base. These values indicate that the gas spring system that we selected to run the simulation will not fail under the conditions we selected and are an appropriate model to use for our device.

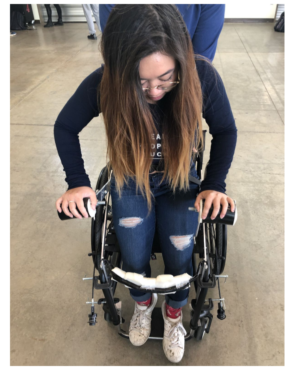
After considering the results of our Finite Element Analyses, we proceeded to design our product with a system similar to this gas spring as it will not fail even under our maximum weighted load.

10.9 Appendix I: Operation Manual

Safety Precautions: our current prototype should only be used by adults weighing 100 to 165 pounds who are in good health, as it has only been tested under those requirements. All directions in the operation manual should be followed to ensure safety of the individual. Additional supervision is recommended at time of operation for our current prototype. Individuals must ensure that gas springs are fully extended before using the device to ensure the integrity of the gas spring.

Step	Directions	Images
1	Place and unfold SoloStand on Ti-Lite Wheelchair	
2	Activate brakes on wheelchair	
3	Press and hold both wire release buttons as you sit down on the seat	

Step	Directions	Images
4	Move the kickstand into the downward position to allow for stability	
5	Place the knee block into the slot on the frame	
6	Buckle the chest strap	
7	When you want to stand lean forward press both buttons on the wire release systems	
8	Once the gas spring is fully extended stop pressing the wire release buttons	

Step	Directions	Images
9	Hold onto the handles and push downward to move yourself into the vertical position	
10	When you want to return to the sitting position, lean backwards, and press both buttons on the wire release systems	
11	Move the kickstand into the upward position	
12	Unbuckle the chest strap	

Step	Directions	Images
13	Remove SoloStand and fold it for easy transportation and storage	

10.10 Appendix J: CAD Drawings Revised for Final Prototype

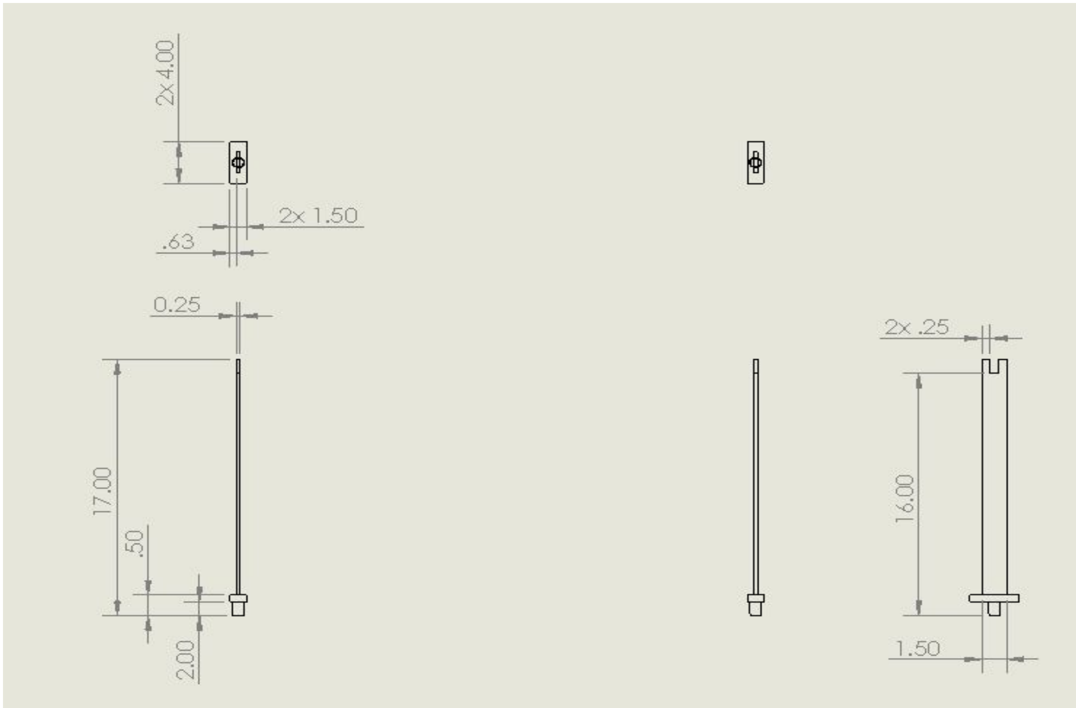


Figure 10.10.1: Revised Leg and Kickstand

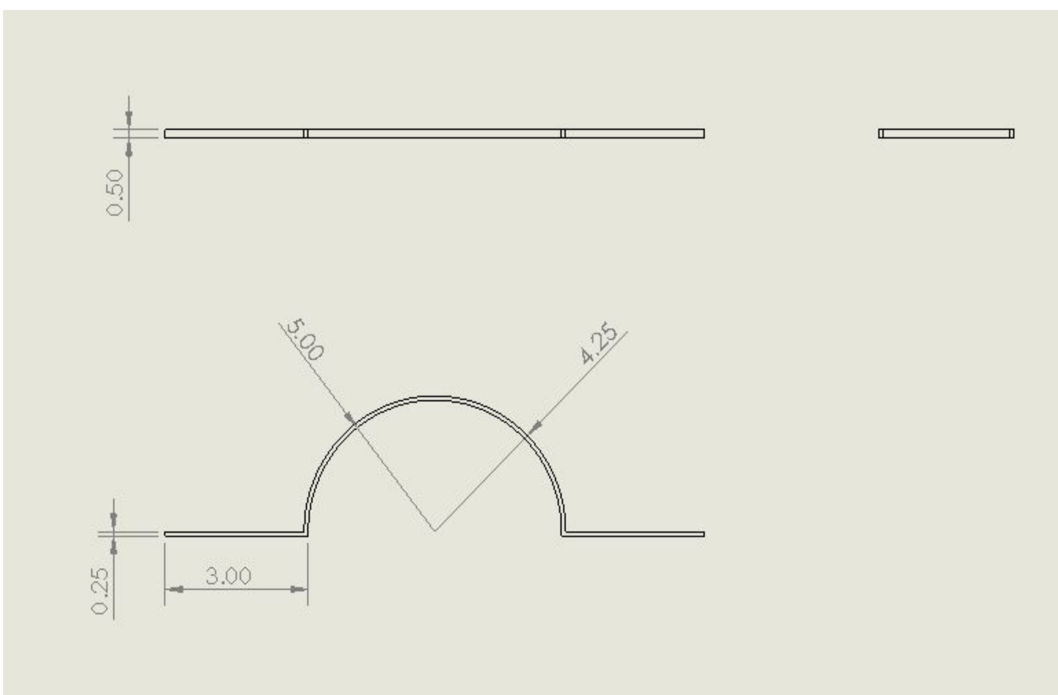


Figure 10.10.2: Knee Block

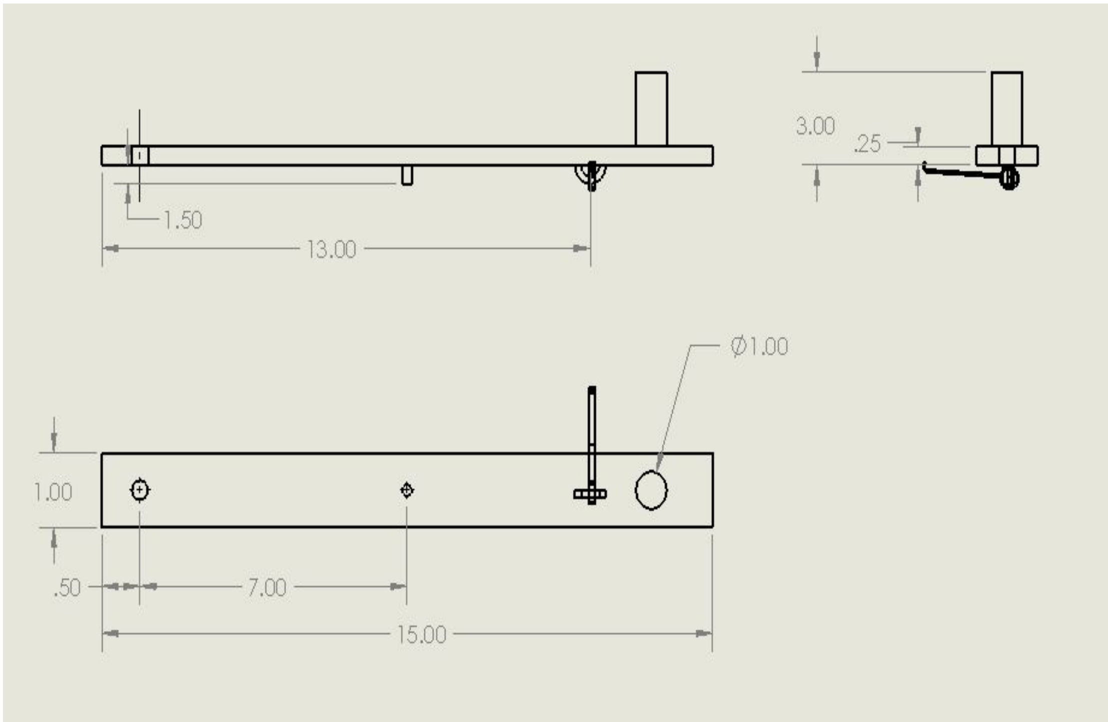


Figure 10.10.3: Arm Lever

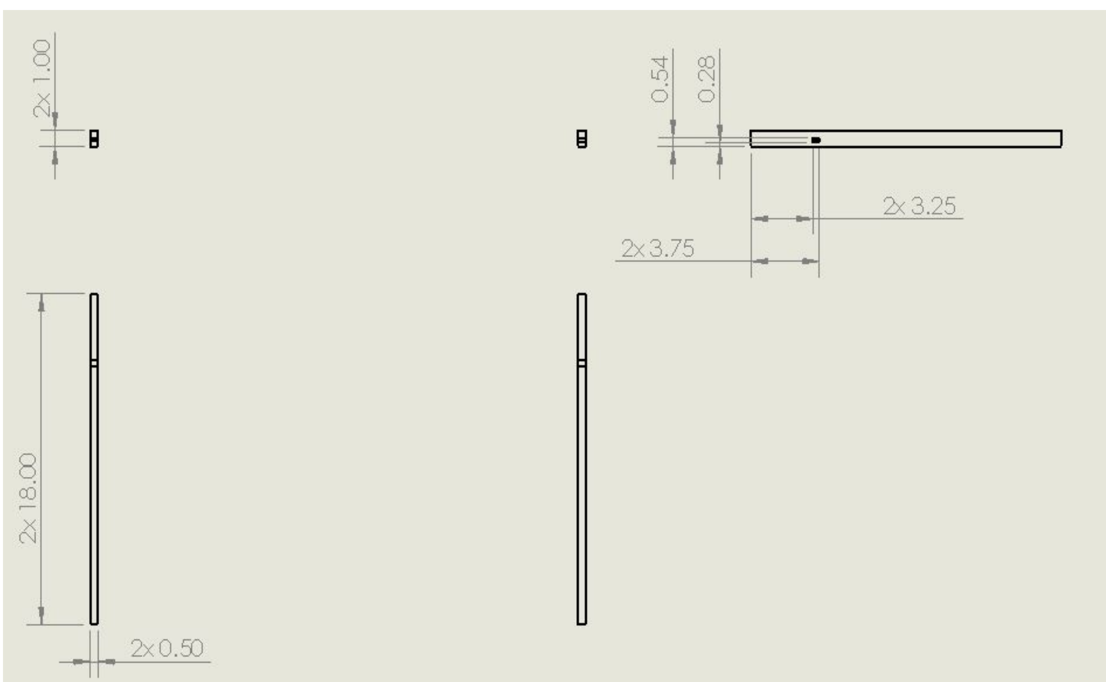
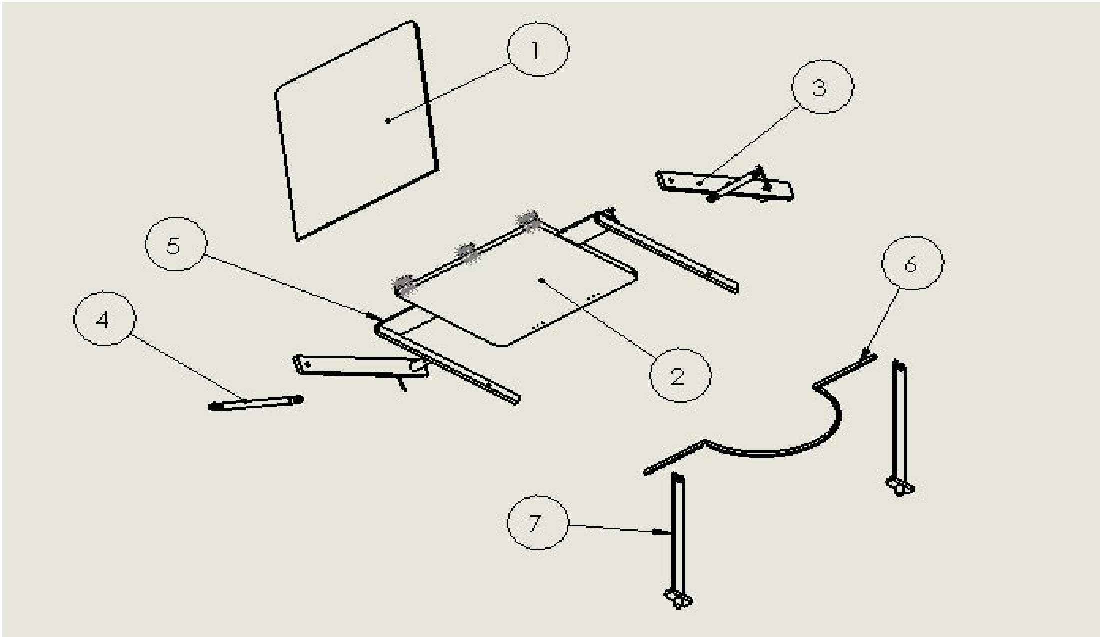


Figure 10.10.4: Leg Attachment to Adjuster



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Back Rest	Al Sheet	1
2	Seat	Al Sheet	1
3	Arm Lever	Screw handles and Al rect. Bar	2
4	Air Piston	Steel Gas Spring	2
5	Seat Adjuster	Al rectangular bar	2
6	Knee Block	Flatten Cu Bar	1
7	Leg and Kickstand	Al rectangular bar	2

Figure 10.10.5: Exploded View and Part List for Final Prototype