ME450 Senior Design Project: Elevating Wheelchair
Professor Koren, Fall 2007,October 19, 2007
Final Report, Team 3: Section 2

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ABSTRACT

Wheelchair users who work in plant environments are constantly struggling to establish their independence and increase their capabilities. To provide them with further support, a manual-elevating wheelchair, currently unavailable, will be explored through research, design, and prototype modeling. The goal of this project is to provide an economical and lightweight alternative to existing wheelchairs that provide the user, in this case an assembly line worker, the same reach capabilities as a standing person as well as the same mobility from a lightweight manual wheelchair.

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1. INTRODUCTION

In many factory or plant environments, people confined to wheelchairs have difficulty completing the tasks that are required of them, specifically reaching high and low places. The National Science Foundation Center for Reconfigurable Manufacturing Systems is sponsoring our project. We are working with Dr. Yoram Koren and April Bryan to develop a workable and economical alternative to existing elevating or standing wheelchairs, whose main drawbacks are cost, mobility, and elevating speed. This project will involve detailed market research, conceptual and engineering design, and prototype modeling. The design and prototype must be manual powered, lightweight, stable, safe, and low cost. In addition, the design and prototype must allow a user to reach heights equal to that of an average standing man. The purpose of this report is to detail the steps taken, decisions made, and current progress of the manual elevating wheelchair project.

2. INFORMATION SEARCH

In order to further understand the problem and any possible similar solutions, an information search was conducted. This research comprised of a US patent search, visiting local businesses and hospitals, and an internet search for similar existing technology.

From this research, we discovered that four main types of wheelchairs exist which allow the user to change his or her orientation: power elevating chairs, power standing chairs, manual standing chairs, and power tilting chairs. Although these options do provide some aspects which are needed for our scenario, no single chair meets all the specifications required for a successful design. In addition, no available chairs are within our $750 budget for the project.

In order to further comprehend some of the elevation mechanisms and elevation assists found in morphological chart, an information search was implemented. This internet based information search was primarily focused on their applications and specifications of engineering characteristics. As a result of our investigations on pneumatic cylinders, scissor lifts and gas springs, a wide variety of applications and corresponding specification ranges were found. Specially, pneumatic cylinders and gas springs were noted to be practical in our design concepts for ease of assembly and cost effectiveness.

2.1 Power Elevating Wheelchairs

Power elevating chairs are the most common category and range in price from $8,000 to $25,000. The main factors in price are the amount of available features, battery life, and weight of the chair. The chairs are propelled either by the user or a motor; however, all use some type of power source to achieve elevation. Power elevating chairs provide vertical motion for the user controlled by a joystick or switch using a variety of mechanisms. Lift mechanisms currently used in power elevating wheelchairs include a scissor lift, screw mechanism, and a hydraulically powered lever arm. The models available have a range of vertical motion as great as 57.2 cm with varying elevation times from 25 to 90 seconds. The main design flaw with power elevating chairs for our purpose is the time taken to complete the elevation change. Figure 2.1 (p.2) is an example of a power elevating wheelchair [1, 2].

Figure 2.1: Typical Power Elevating Chair [2]

2.2 Power Standing Wheelchairs

Another prominent technology on the market is power standing chairs which have a price range of $4,000 to $30,000. With these chairs the user is extended from a sitting position to a full standing position. The user's legs are locked and support the weight of the body at full extension. A hydraulic lift is used to complete the motion with elevation times ranging from 3 to 60 seconds. The main problem with this design for our project is the fact that the users must have legs meeting a minimum bone density to undergo this motion. Our design must allow for all types of users with or without legs. Figure 2.2 (below) is an example of a power standing wheelchair [1].

Figure 2.2: Typical Power Standing Chair [3]

2.3 Manual Standing Wheelchairs

Similar to the power standing wheelchairs are the manual standing wheelchairs. A typical manual standing wheelchair is shown in Figure 2.3 (p.3) highlighting the key components. These chairs operate by the user pushing on the armrests similar to pushing oneself out of a desk chair to stand up. The gas cylinders provide an assist for this motion and the legs are locked in place at full extension with padded knee supports. Due to the lack of an elevating mechanism, these wheelchairs cost less but still range from $2,000 to $20,000. Since the elevation is achieved by the user, the lift time is dependent on the user's physical capabilities with typical times ranging from 3 to 10 seconds. The problem with this design again is the need for legs with a minimum bone density to support the user's weight in the standing position [1].

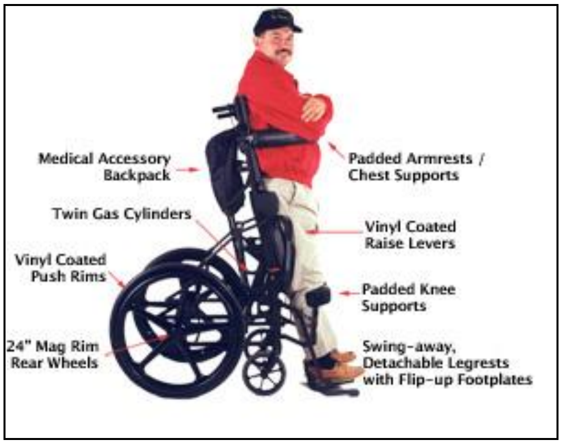


Figure 2.3: Typical Manual Standing Wheelchair [4]

2.4 Power Tilting Wheelchairs

The last category of wheelchairs currently on the market is power tilting chairs with a price range from $3,000 to $35,000. These chairs allow the user to orient their body in a variety of positions. The tilt feature may be used to extend the users side to side reach, forward reach, or allow them to tilt and reduce strain on different parts of their body. The main problem with this design is that although the reach of the user may increase to the sides or front, the vertical reach provided is not sufficient for our scenario. Figure 2.4 (below) shows an example of a power tilting wheelchair [1].

Figure 2.4: Typical Power Tilting Wheelchair [5]

2.5 Manual Elevating Wheelchairs

One area of the market in which there is a void is manual elevating wheelchairs. This option is an alternative for users with no legs or whose legs do not have the minimum bone density that is needed for standing wheelchairs. The elimination of electronic components will lower the price of the wheelchair and the elimination of a need for a battery will reduce the chair's weight. Since this area of the market does not currently exist, a manual elevating chair will allow us to produce an innovative design.

2.6 Pneumatic Cylinders

Pneumatic cylinders convert pressurized fluid (mostly, air or Nitrogen) into linear motion. There are several types of pneumatic cylinders that are very useful in many different engineering applications where smooth motion and an average stroke of 10 ~ 30 cm (40% - 60% of initial length) is needed. Some of the most important selection criteria are; stroke (how far the piston extends when activated), bore size (surface area of the piston face), pressure rating, and mounting method.

Sequentially, it was found that the stainless steel gas cylinders shown in Figure 2.5 are one of the appropriate choices in our designs and have following specification ranges and characteristics shown in Table 2.1.

Figure 2.5: Stainless steel pneumatic cylinders [1]

Table 2.1: Characteristic specifications of pneumatic cylinders [6]

Specification	Specification Values	Units
Working medium	Air	N/A
Operating pressure range	1 - 9.0	kgf/cm°C
Ensured pressure resistance	9.0 - 13.5	kgf/cm°C
Operating temperature	0 to 70	°C
Operating speed range	50 - 800	mm/s
Buffer type	Adjustable buffer	N/A
Stroke	100 – 300	mm
Length	100 - 700	mm
Diameter	13 - 50	mm

The price of the above stainless steel pneumatic cylinder ranges from $30 - $70, which also suits our budget. Considering overall specifications, pneumatic devices were determined to be appropriate enough to fit into our designs.

2.7 Scissor Lifts

The two main kinds of scissor lifts found from our search are hydraulically powered scissor lifts and screw driven scissor lifts. Hydraulically powered scissor lifts vary from portable elevating tables to industrially used heavy duty scissor lifts (Figure 2.6) that are mostly used in construction.

Figure 2.6: Portable elevating table and an industrial hydraulically powered scissor lift [7, 8]

Our internet based search shows that their specification ranges of characteristics vary significantly. This information is summarized in Table 2.2 below.

Table 2.2: Specifications of hydraulically powered scissor lifts [7, 8]

Specification	Specification Values	Units
Maximum lift capacity	150 – 2000	kg
Weight	45 – 1200	kg
Maximum Height	0.80 – 5.0	M
Cost	150 – 6,000	$

Screw driven scissor lifts have slow operation, do not require a lot of input force, and are capable of lifting heavy weights. As an example, Figure 2.7 shows a few examples of a screw driven scissor lift.

Figure 2.7: Manual (left) and electrical (right) screw driven scissor lifts [9, 10]

Table 2.3: General specifications of pneumatic cylinders [10]

Specification	Specification Values	Units
Maximum Lift Capacity	2200	kg
Dimensions	160 X 70 X 30	mm
Weight	310	g
Minimum Height	90	mm
Maximum Height	365	mm
Cost (electric car jack)	60-80	$
Cost (Manual)	15-25	$
Maximum lift capacity	2200	kg
Dimensions	160 X 70 X 30	mm

If we implement this system into a design concept, it is important to note that manual operation takes much longer time than a motor driven screw scissor lift. As such, without further investigation, it was decided that screw driven scissor lifts are not suitable for our final design due to its slow operation for manual input.

2.8 Gas Springs

Gas springs are also another essential component in mechanical engineering; they are used as motion assisting device. One of the most common applications of gas springs, as shown in Figure 2.8, is to assist the lifting of car hoods.

Figure 2.8: Gas springs used to assist lifting of a car hood [11]

The selection criteria of a gas spring do not differ much from that of a pneumatic cylinder; therefore, stroke (how far the piston extends when activated), capacity and mounting method are important when selecting a gas spring. As an example, the following gas spring (Figure 2.9) from Magnus Caster-Pro Limited was chosen to describe its characteristics, which are shown in Table 2.4.

Figure 2.9: Gas spring model "LIFT-O-MAT®" from Magnus Caster-Pro Limited [12]

Table 2.4: Gas Spring Specifications from Magnus Caster-Pro Limited [12]

Specification	Specification Values	Units
Price	10.35 ea	$
Type	Fixed Force Gas Springs	N/A
Capacity	440	N
Extended Length	304.8	mm
Stroke	88.9	mm
Rod Diameter	6.1	mm
Tube Diameter	15.0	mm

In addition, there are many options of the above model for a range of force capacity from 90 – 1100 N and strokes from 60 – 250 mm. According to above specifications, it can be concluded that integration of gas springs in our designs would be very cost effective and makes the assembly easier comparing to pneumatic cylinders and scissor lifts.

2.9 Summary of Pneumatic Cylinders, Scissor Lifts, and Gas Springs

Table 2.5 (p.7) summarizes the information obtained through the information search on pneumatics, gas springs, and scissor lifts.

Table 2.5: Specification comparison of pneumatic cylinders, scissor lifts and gas springs

Elevation Mechanism Assist / Characteristic Specifications	Pneumatic Cylinders	Scissor Lifts	Gas Springs
			
Working Medium	Air	Air, Oil (if hydralically powered)	Air
Operating Pressure	1 to 9.0kgf/cm°C	N/A	N/A
Operating Temperature	0 to 70°C	N/A	N/A
Operating Speed	50 to 800mm/s	N/A	N/A
Stroke	100 - 300mm	N/A	0.09 m
Initial Length/Height	N/A	0.09 ~ 1.0 m	0.02 m
Tube Diameter	N/A	N/A	0.015 m
Rod Diameter	N/A	N/A	0.006 m
Lift Capacity	N/A	150 ~ 2200 kg	440 N
Weight	N/A	45 ~ 1200 kg	N/A
Maximum Height	N/A	0.365 ~ 5.0 m	0.031 m
Dimensions	N/A	0.16 X 0.07 X 0.03 m^3 (Scissor Car Jack)	N/A
Type	N/A	N/A	Fixed Output Force
Extended Length	N/A	N/A	0.031 m
Cost	$30 ~ $70	$150 ~ $6000	$11 ~ $50

2.10 Patent Search

An additional consideration for our design is the existence of patents for similar technology. A US patent search revealed apparatus similar to the technology previously mentioned, but no patents were found depicting a fully manual elevating wheelchair. A device able to lift any wheelchair was found, shown in Figure 2.10 below, but is not manually powered and requires a non-handicapped user to transport and setup the drive-on lift mechanism. This design is not portable or practical for our needs but illustrates another solution to the problem of providing elevation to those in wheelchairs.

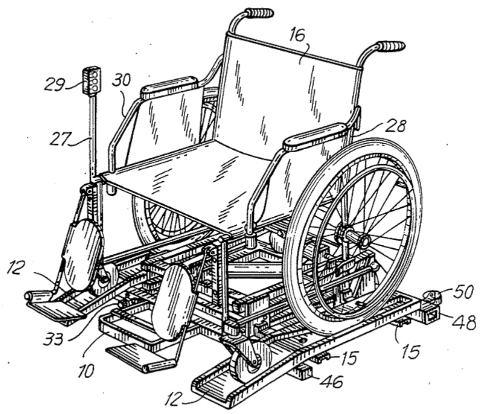


Figure 2.10: US Patent No.: 5,421,692, Apparatus for Elevating a Wheelchair, Issued June 6, 1995 [13]

The other patents found depict technology similar to that previously mentioned such as the manually operable standing wheelchair (Figure 2.11), and elevating manual wheelchair (Figure 2.12, pg.9). The elevating manual wheelchair is only manual in translational motion and requires batteries to power the vertical lifting mechanism. Although this reference is from a published patent application and the exact patent number is not known, this technology was found to currently exist on the market and does not provide significant new information.

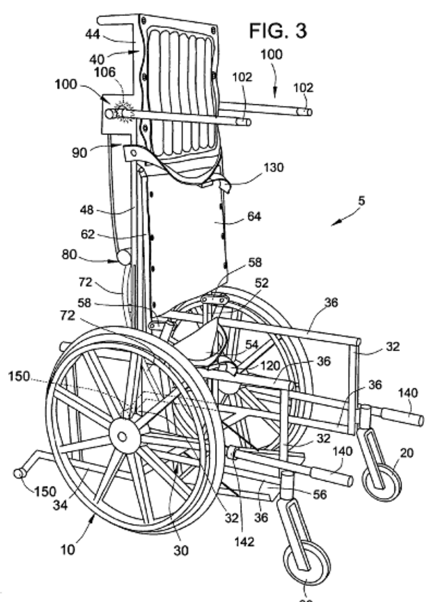


Figure 2.11: US Patent No.: 7,165,778 B2, Manually Operable Standing Wheelchair, January 23, 2007 [13]

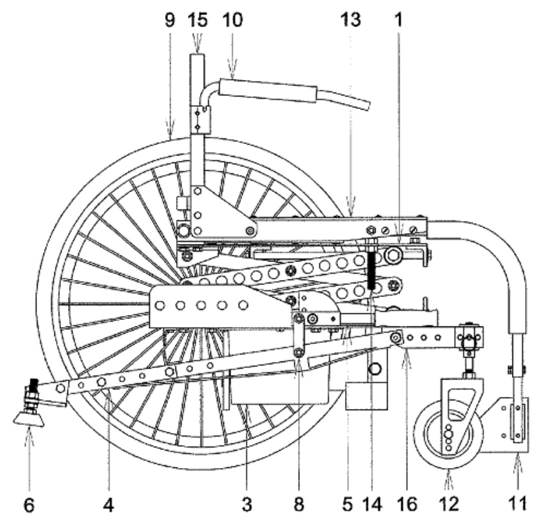


Figure 2.12: US Patent Application. No.: 09/835,966, Elevating Manual Wheelchair, Filed: April 17, 2001 [13]

The last category of patents found involved accessories for wheelchairs such as baskets or folding desks. Since we wish to provide some sort of tool carrying mechanism on our wheelchair, we must consider current US patents covering these types of mechanisms. Figure 2.13 below depicts a patent for systems and methods for a wheelchair tray. This patent covers a variety of ways to secure the tray such as a magnetic locking mechanism. As we finalize our design we will investigate this patent in more detail to ensure we are not infringing on the owner's intellectual property.

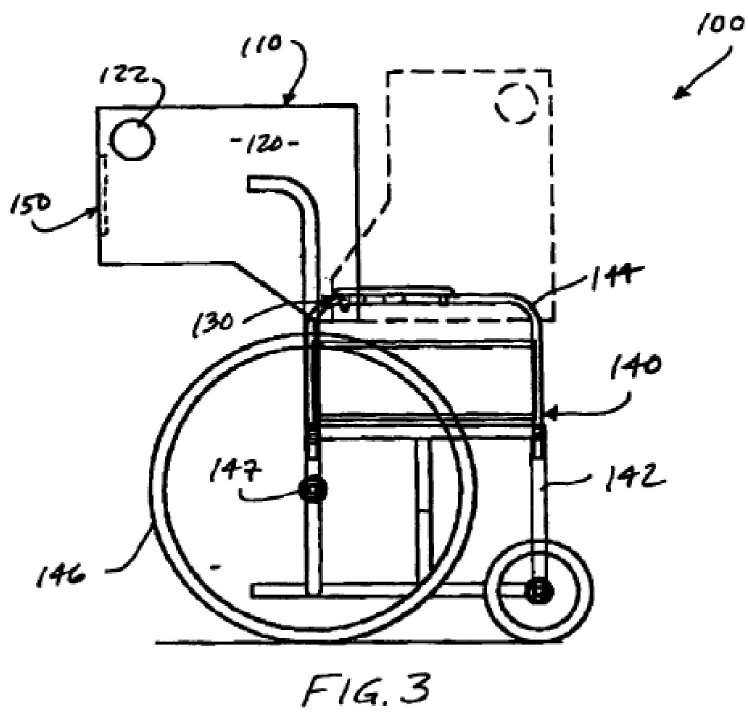


Figure 2.13: US Patent No.: 7,216,929 B2, Systems and Methods for a Wheelchair Tray, May 15, 2007 [13]

Overall, our information search has provided a variety of solutions currently on the market to change the orientation of a wheelchair user, but none of the current solutions meet all of our needs. The patent search revealed similar technology as is on the market and no patents specifically involving fully-manual elevating chairs were discovered. We must consider the designs available and any applicable patents to ensure our design is a unique solution and is not infringing on the intellectual property of others.

2.10 Contacts

In order to provide a practical working solution, additional information will be needed throughout the design process. We have developed a network of contacts that will provide insight and guidance as we continue to refine our design. Our contacts include members of the medical rehabilitation field, medical suppliers, as well as ergonomic and human motion experts. A complete list of contacts can be found in the contacts section of the appendix. In addition we have discovered two ergonomic analysis tools to help establish our design in the future. 3D SSPP(3D Static Strength Prediction Program) and EEPP (Energy Expenditure Program) will be used to help set limits on the forces applied by the user while operating the elevating wheelchair.

3. CUSTOMER REQUIREMENTS

In order to determine the most important customer requirements of the elevating wheelchair, the end user was defined to be a physically challenged automotive plant worker who is unable to perform any leg functions but will be required to perform tasks at the heights of an average person.

Once the customer requirements were collected and examined in detail, they were prioritized and classified into five categories: Safety, Mechanism Functionality, Wheelchair Functionality, Geometry and Budget. The customer requirements classified as above are shown in Table 3.1 below.

Table 3.1: Elevator wheelchair customer requirements

Categories	Customer requirements
Safety	1. No harm to user
	2. Stable
Mechanism Functionality	3. Manual powered
	4. Multiple height adjustments
	5. Quick height change
	6. Durable
Wheelchair Functionality	7. Same personal mobility as standard wheelchair
	8. Able to transport tools
	9. Easy to move around
Geometry	10. Fit in factory aisle
	11. Achieve average person's height
	12. Comfortable
Budget	13. Low cost (< $750)

3.1 Safety

It is required that no harm should be caused to the user during to any normal operation of the wheelchair. Further, the elevating wheelchair should be stable within normal user reach and loading at all possible elevations.

3.2 Mechanism Functionality

The wheelchair needs to be manual powered (wheelchair motion and mechanism motion powered completely by the user), and the wheelchair user should be able to reach multiple heights. The wheelchair should also be equipped with multiple height adjustments within its elevation range. Additionally, in order to improve the user's work efficiency, the height adjustments need to be completed relatively quickly and preferably in less than 20 seconds. Furthermore, the durability of the wheelchair is also very important, and the mechanism should be able to withstand all possible factory conditions while maintaining performance and prolonging lifetime.

3.3 Wheelchair Functionality

Even though the elevating wheelchair is primarily designed to be used in a working environment, it must possess the same mobility as a standard wheelchair to enable the users to utilize existing facilities accessible for regular wheelchairs. The users of the elevating wheelchair should be able to move around easily, and it should allow the user to carry tools or parts.

3.4 Geometry

It is essential that the wheelchair user has good mobility inside the factory environment; therefore, it should be no wider than the factory aisles or taller than the average man. Moreover, the comfort of this elevating chair is also very important as the worker would remain seated in this chair for 8+ hours a day.

3.5 Budget

It is required for the wheelchair to be low cost; thus, materials, manufacturing methods and mechanism assembly must not be too complex.

4. ENGINEERING SPECIFICATIONS

A total of 20 engineering characteristics were developed to meet the customer requirements listed in Table 1. These engineering characteristics and their specifications are shown in Table 4.1 (pg 12).

Table 4.1: Elevator wheelchair engineering specifications

Engineering Characteristics (EC)	Specifications	Units
1. Allowable weight at maximum height at arm's length	220	N
2. Maximum force applied to user mechanism	Ave. force < 21% max. force	N
3. Brake force	> 500	N
4. Number of exposed dangerous moving parts	0	#
5. Number of height settings available	> 3	#
6. Lifetime of elevating mechanism	> 600,000	cycles
7. Elevating velocity range	0.01 – 0.15	m/s
8. Time to reach maximum possible height	< 20	sec.
9. Number of electrical components	0	#
10. Storage capacity (volume)	0.0045	m^3
11. Maximum storage weight	3.5	kg
12. Range of frontal ground level reach	180	degree
13. Seat dimensions - (L x W)	L = 0.43 W = 0.40	m
14. Wheelchair dimensions - (L x W x H)	< L – 1.10 W = 0.65 H = 1.60	m
15. Mass of wheelchair	< 25	Kg
16. Un-elevated reach (vertical and oblique)	Vertical = 1.8 Oblique = 1.6	m
17. Minimum vertical travel range and reach	ΔH = 0.4 Oblique = 2.0	m
18. Number of armrest position adjustments	> 2	#
19. Number of leg rest position adjustments	> 2	#
20. Maximum weight to be elevated	100	kg

Sequentially, the following justifications are presented to show the translations of customer requirements into the above engineering specifications.

4.1 No harm to user

In order to make the elevator wheelchair less hazardous it was decided that the amount of force applied to the mechanism should be within a safe range for the user (EC2). Additionally, all the dangerous moving parts of the mechanism should not be exposed in a way that could cause injuries (EC4).

4.2 Stable

Some of the main engineering characteristics that affect the stability of wheel chair are: allowable weight at maximum height at arm's length (EC1), wheel chair dimensions (EC14), and brake force (EC3). When the user holds a weight at maximum height it creates a torque, thus it is necessary to define a safe moment arm and a weight. Moreover, the size (L x W) of the wheel chair base should be large and strong enough to support all the varying moments and loads.

4.3 Manual powered

The force required to operate the mechanism should be within the average person's capability as defined (EC2). This specification is a standard in ergonomics for characterizing fatigue limits.

4.4 Multiple height adjustments
Depending on the tasks of the end user, it may be required to reach different height levels. To facilitate this requirement, three or more height settings must be incorporated into the design (EC5).

4.5 Quick height change
The maximum vertical distance (EC17) and the time it takes to reach maximum elevation (EC8) correspond with the quick height change customer requirement.

4.6 Durable
As a measurement of durability, the life time of the elevating mechanism is defined in number of cycles it can withstand before failure (EC6).

4.7 Same personal mobility as standard wheelchair
This customer requirement is achieved by defining an area of reach at zero elevation (EC12), and by ensuring that the geometry of the wheelchair is no larger than an average manual wheelchair (EC14)

4.8 Able to transport tools
In order to satisfy this customer requirement, it was decided that the wheelchair should be equipped with an optional retractable storage bin (EC10&11).

4.9 Easy to move around
Maintaining the normal wheelchair dimensions (EC14) and minimum mass (EC15) will allow the user to easily move in the wheelchair.

4.10 Fit in factory aisle
Dimensions of the elevating wheelchair should not exceed the width of a factory aisle (EC14).

4.11 Achieve average person's height
Minimum vertical travel range is defined to be 0.40 meters (EC17), which allows the user reach the same heights as a standing person.

4.12 Comfortable
Seat dimensions (EC13) and number of armrest/leg-rest settings (EC18&19) are considered to be important factors to improve the comfort of the wheelchair.

4.13 Low cost
The cost of the elevating wheelchair is affected by mass (EC15) and not having electrical devices (EC9).

5. QUALITY FUNCTION DEPLOYMENT (QFD)

The QFD was completed using the customer requirements from Table 1 and the design characteristics from Table 2. The customer requirements were rated on a scale from 1-10, with 10 being most important, as shown in the QFD (Appendix A). Relationships among the customer requirements and the design characteristics were then rated 1, 3, or 9 for low, medium, or high correlation. These correlations along with the rated customer requirements were used to rank the importance of each design characteristic. The top 10 design characteristics are listed in Table 5.1 (pg.14) below.

Table 5.1: Top 10 Design Characteristics

Rank	Engineering Characteristics (EC)	Specifications	Units
1	Wheelchair dimensions - (L x W x H)	< L – 1.10 W = 0.65 H = 1.60	m
2	Maximum vertical travel distance and reach	ΔH = 0.4 Oblique = 2.0	m
3	Maximum force applied to user mechanism	Ave. force < 21% max. force	N
4	Maximum weight to be elevated	100	kg
5	Number of height settings available	> 3	#
6	Brake force	> 500	N
7	Seat dimensions - (L x W)	L = 0.43 W = 0.40	m
8	Mass of wheelchair	< 25	Kg
9	Time to reach maximum possible height	< 20	sec.
10	Number of exposed dangerous moving parts	0	#

We will use the design characteristic rankings found in the QFD throughout the design process to ensure that our design encompasses the most important aspects expected from the customer. Additionally, the QFD rates a similar elevating wheelchair that we will use for a benchmarking. The QFD also allowed us to set quantitative goals for our engineering characteristics that we will use as targets for our engineering specifications.

6. CONCEPT GENERATION

To proceed with the concept generation phase of the design process we first classified each of the functions and their subsequent sub-functions into relevant categories using the aid of the FAST diagram. The next step was to generate high-level designs utilizing the Morphological chart. We split each of the designs into the main elevating mechanisms as well as the additional mechanisms that will be needed to achieve our goal of safely elevating the occupant.

6.1 Fast Diagram

In order to further understand the functions of a wheelchair and to facilitate concept generation, we constructed a FAST diagram. This diagram (Appendix C) consists of a tree of functives that describe relationships between functions performed by the wheelchair. The main function of the chair, to transport the user, was divided into five primary sub-functions: lift user, ensure dependability, translate user, transport tools, and prevent injury. These functions were then further divided until the description was detailed enough to describe a specific mechanism. The primary sub-function of prevent injury for example was further decomposed into stabilize structure which led to the final function lock wheels. Since there are many specific mechanisms which can be used to lock the wheels, enough detail is provided and further decomposition is not required. The functions from the last branch of the diagram were then incorporated into a morphological chart used to brainstorm possible corresponding mechanisms.

6.2 Morphological Chart

The morphological chart (Appendix D) is organized according to the results of the FAST diagram and was used to generate complete concepts. After determining the required functions, we brainstormed methods that could be used to perform each. The function to elevate the user, which primarily describes the structural components of the chair, resulted in numerous solutions. A scissor lift for example, similar to existing industrial scissor lifts, could be used to elevate the user over the necessary range of motion (40 cm). Additional solutions include a screw mechanism, pulley system, linkage, and rack and pinion. To generate a complete design, one concept from each sub-function category was selected.

6.3 Mechanisms

The main goal of this design is to elevate the user so the most important mechanism is that which performs this task. The secondary mechanisms were developed to keep the users safe which include the addition of stabilizer bars, extending the wheelbase, and automatic braking. Each of these mechanisms were developed and refined with the use of the FAST diagram and Morphological chart.

6.3.1 Lifting Mechanisms

The following design concepts fulfill the main objective "Lift User", one of the second level requirements of the FAST diagram. The corresponding portion of the FAST diagram with associated sub functions is shown below in Figure 6.0.

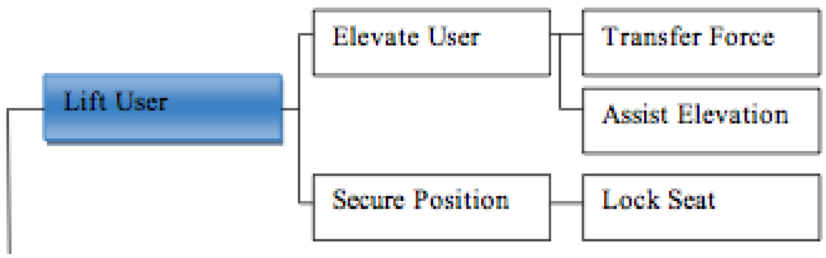


Figure 6.0: "Lift User" requirement and its sublevels from FAST diagram

Upon brainstorming and analyzing over a dozen lift mechanisms, four possible designs were selected and are outlined below. The concepts were generated to meet the customer requirements and followed engineering specifications as previously outlined.

6.3.1.1 Pneumatic Linkage Lifting Mechanism

The pneumatic linkage mechanism, shown in figure 6.1 below, consists of a four-bar linkage arrangement controlled by a pneumatic cylinder (similar in characteristics as an office chair, used to lock the motion) and assisted with a gas spring. Below is an isometric view of the proposed mechanism.

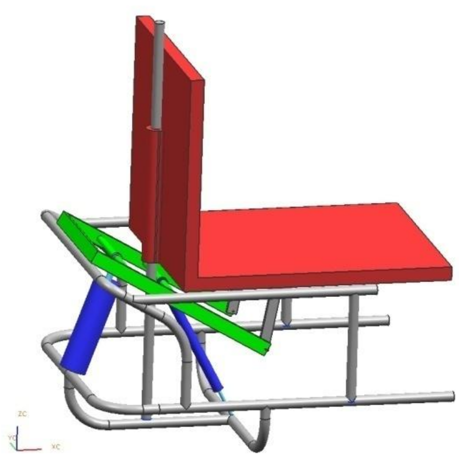


Figure 6.1: Isometric View of Pneumatic Linkage Lifting Mechanism

The mechanism is simple, consisting of only a frame, two links, a seat, and a horizontal stabilizing bar. The frame is made of steel tubing and the majority of pieces would only need to be bent on one plane easing manufacture. The four-bar linkage has four components; the frame, two links, and the seat. The two links would be constructed of either metal tubing or bars. The seat would be purchased and would likely be one solid plastic piece. The purpose of the horizontal stabilization bar is to constrain the motion of the seat to the vertical direction, and to provide further support against instability of the users' seat. The frame is shown below in figure 6.2. As illustrated, the frame consists of tubing with simple 45 or 90 degree bends. The pieces would be united by welding. Due to its construction the fame will be strong and lightweight.

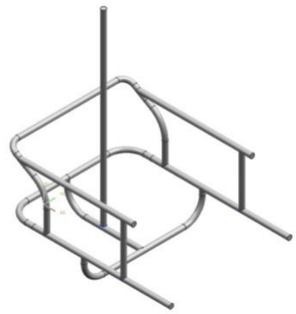


Figure 6.2: Frame for Pneumatic Linkage Lifting Mechanism

The four-bar linkage which is essential to this design is shown below in figure 6.3. The linkage would be grounded (attached to the frame) at the rear, and attached to the underside of the seat. The linkage would be forced up by the gas spring, thus elevating the seat.

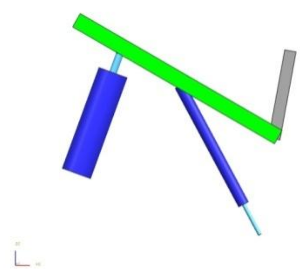


Figure 6.3: Four-Bar Linkage for Pneumatic Linkage Lifting Device

The seat is shown below in figure 6.4 and is composed of one solid part. The motion is constrained in the vertical direction by the stabilizing bar on the frame which travels through the track in the rear of the seat.

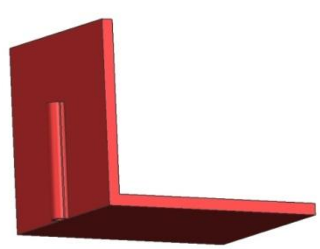


Figure 6.4: Proposed Seat Design for Pneumatic Linkage Lifting Device

The mechanism would be activated by a device very similar to a bicycle brake handle mounted on adjustable height armrests. A user would squeeze the handle to activate the pneumatic cylinder, lift weight off the seat by pushing down on the adjustable height armrests, and the seat would rise when weight was taken off the seat. Then the user would then adjust the height of the armrests for comfort, or use them to elevate further. To return to the original position, the user would once again squeeze the handle to activate the pneumatic cylinder, pull down on the armrests and descend.

6.3.1.2 Pneumatic Scissor Lifting Mechanism

The pneumatic scissor mechanism consists of a four linkage scissor mechanism to constrain motion of the seat to the vertical direction, a pneumatic cylinder for locking the mechanism at the desired elevation, and a gas spring to assist the motion. Below is an isometric view of the proposed pneumatic scissor mechanism. Note that the mechanism is show in the elevated position for clarity.

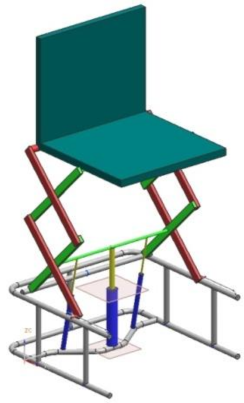


Figure 6.5: Proposed Pneumatic Scissor Lifting Mechanism

This mechanism is more complicated than the pneumatic linkage mechanism; however, this design is still simple. It consists of a four linkage scissor mechanism which would be made of steel bars to lift the user in the vertical direction. The scissor mechanism is grounded at the rear of the seat and at the rear of the frame. The front of the mechanism is free to slide in the x-direction. The frame is a simple tubular design with all bends being in the same plane. The frame would be united by welding. The pneumatic cylinder activates the motion of the seat, and the gas springs are implemented to assist the user in elevation.

The mechanism is shown below in Figure 6.6. The scissor mechanism is grounded at the bottom left joint, and pinned to the seat at the top left joint. The top and bottom right link ends are slider joints in which the linkage would be allowed to move in the x-direction (front to back direction).

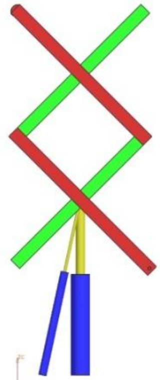


Figure 6.6: Proposed Mechanism for Pneumatic Scissor Lifting Mechanism

The frame is shown below in Figure 6.7 similar to the pneumatic linkage design. It consists of metal tubing welded together. The frame is composed entirely of pieces that can be bent in plane for easier manufacturing. The frame was also designed to be rigid yet lightweight.

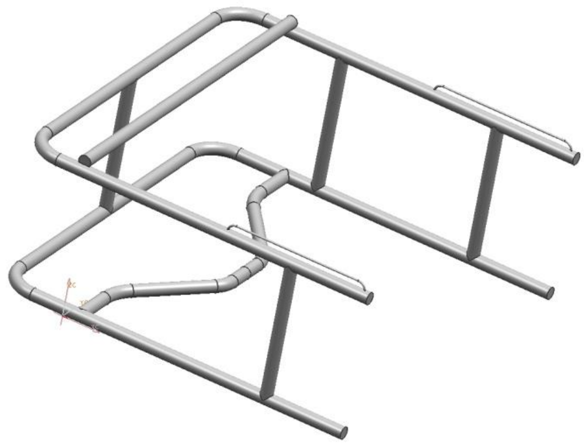


Figure 6.7: Proposed Frame for Pneumatic Scissor Lifting Mechanism

The seat for this design is shown below in Figure 6.8. It would consist of a solid seat made out of plastic, wood, or metal. The seat would incorporate a slot for the scissor mechanism to slide in. The mechanism would be activated in the same way as the pneumatic linkage design with adjustable armrests.

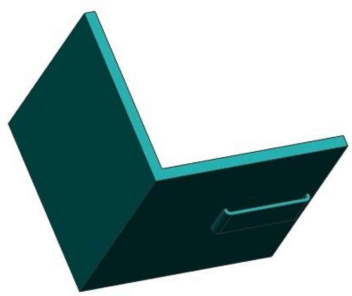


Figure 6.8: Proposed Seat for Pneumatic Scissor Lifting Mechanism

6.3.1.3 Screw-Scissor Lifting Mechanism

This design incorporates a scissor lift which is screw driven, similar to a car jack. The user would activate the mechanism by turning the crank on the right side. The crank would drive a threaded rod which runs through the top links in the scissor lift. As the rod turns, the links move in and out allowing the user to travel up and down to the desired height. Figure 6.9 (pg.19) depicts a simple CAD model of this design.

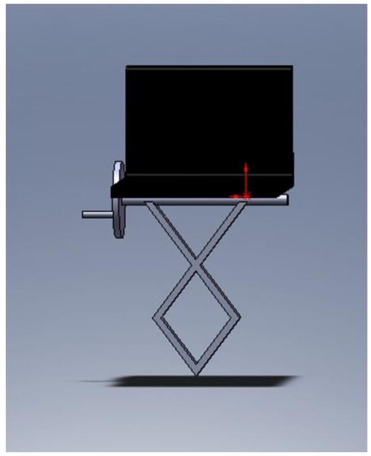


Figure 6.9: Proposed Screw Scissor Lifting Mechanism

The links are stationary at the base in the middle where they come together, however at the top of the scissor mechanism the links would need to slide. In order for the crank to remain at a fixed distance from the user, a slider joint would be needed to connect the scissor to the seat. Because this slider would allow unwanted motion from side to side, we would include a second scissor mechanism including fixed links at the base of the seat.

This mechanism would allow for travel greater than the 40 cm required but as the user elevates higher and the links become closer, stability will be reduced. The mechanism as sketched is only 35 cm wide and would easily fit within the 50 cm frame. The details of the frame are not integral to this concept and would be similar to those of the previous designs. The materials required for this design include steel tubing and steel bars. We would need to purchase a threaded rod to ensure it is precisely machined and also a gas spring to provide assist for lift.

6.3.1.4 Torsional Lever Lifting Mechanism

Our last concept was generated by combining a variety of mechanisms and components found in the morphological chart. Gas springs, torsional springs, a two-bar linkage system, a disk locking device and a lever were selected from the chart and incorporated into this design.

In order to describe how all the mechanisms and components were combined, the sketch shown in Figure 6.10 (pg.20) below will be used.

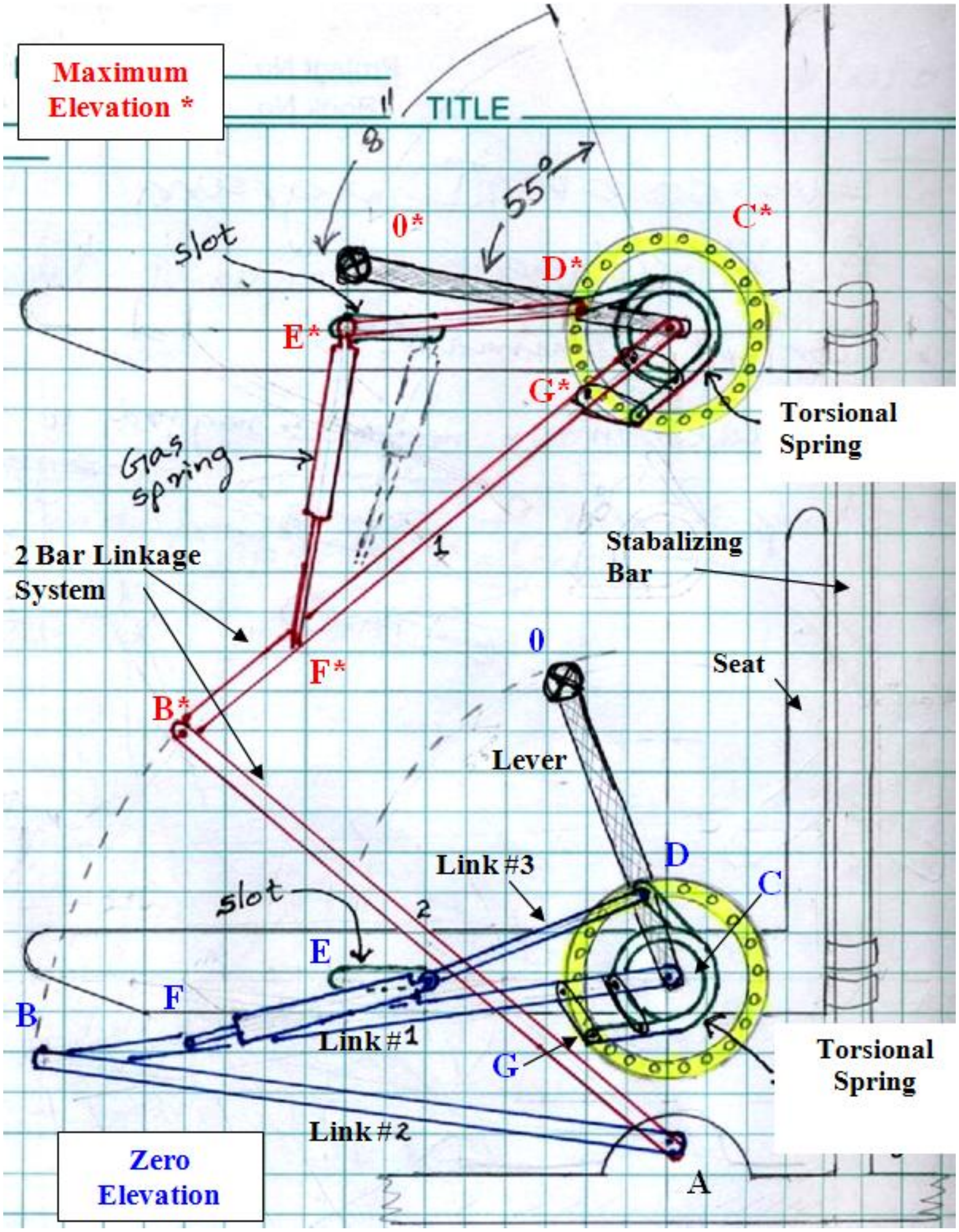


Figure 6.10: Torsional springs and gas springs integrated elevating linkage system.

As seen in Figure 6.10, Link 1 and 2 are colored in blue and red indicating r zero elevation and maximum elevation positions respectively. At point A, link 2 is pined to the wheelchair frame, while link 1 is connected to Link 2 at point B. A torsional spring and height adjustment disk locking device are connected to the seat frame at point C. At the upper end of the torsional spring, link 3 and a lever are connected to the disk locking device at point D. The lower end of the torsional spring is connected only to Link 1 at point G. Link 3 is then connected to the gas spring at point E (Note: point E can travel horizontally with in the slot) and the other end of the gas spring is connected to link 1 at point F.

When the levers (on each side of the seat) are pushed to the left, two things happen simultaneously: the torsional springs get compressed and point E moves forward in the slot. As a result, the gas springs output force increases the perpendicular force-component on link 1, while the torsional springs attempts to increase the angle between link 3 and link 1, allowing the supporting 2 bar linkage system to vertically expand. For further comprehension, CAD models were developed and two views are shown in Figure 6.11. (Note: Figure 6.11 shows only one side of the wheelchair, but in the actual concept the lifting mechanism would be installed on both sides of the wheelchair.)

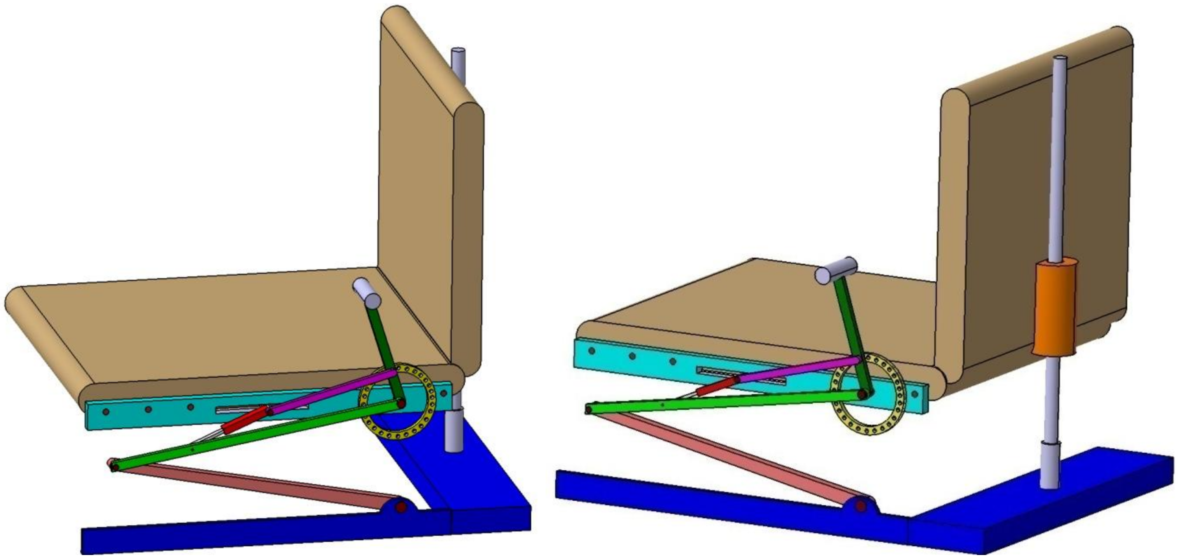


Figure 6.11: Isometric vies of CAD models (lifting mechanism is shown only on one side)

This design will allow for the needed 40 cm travel distance due to the lengths of links one and two estimated at 39 and 15 cm respectively. The width (48 cm) and length (63 cm) will fit well within our geometric constraints. The pneumatic cylinder will travel 10 cm and the gas spring will travel around 10.2 cm depending on the final design.

The proposed material selection for the above design concept will include many parts. Cost and ease of manufacture weighed heavily with material choices. The seat would be made from an existing office chair while additional parts such as two gas springs and two torsional springs would also be purchased. The links would be made of steel or aluminum bar of rectangular cross section.

6.3.2 Sub-Function Mechanisms

Besides the main elevating mechanism, many mechanisms are required for a complete design that satisfies the various sub-functions for our elevating wheelchair. Although these components are not the main focus for our design we have developed three main mechanisms that we will further refine as the design process develops.

6.3.2.1 Front Wheel Motion Mechanism

To increase the stability of the elevating wheelchair, we propose a design that will automatically widen the footprint of the wheelchair when elevated by moving the front wheels (castors) outward. This motion will be accomplished by a rotating caster assembly that will be allowed to open when the seat is elevated, and will be closed when the seat returns from elevation. Energy will be stored in a gas spring in the closed position. An Isometric view of this design is shown below in Figure 6.12 (pg.22).

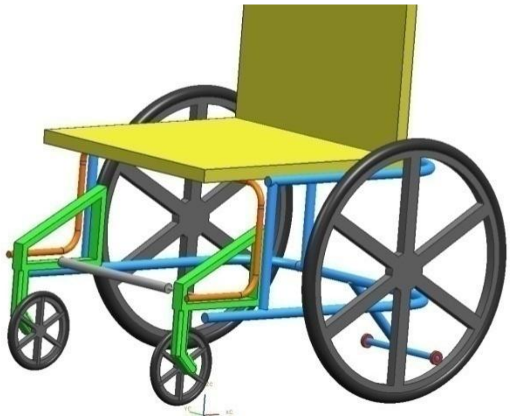


Figure 6.12: Isometric View of Automatic Caster Mechanism

When the seat elevates, the gas spring will no longer be constrained by the vertical bars connected to the seat, and it will expand causing the casters to move outward. A top view of the extended castors is shown below in Figure 6.13. This motion will add approximately 12 inches the total width of the wheelchair, while reducing its wheelbase by approximately 3 inches. This is an acceptable compromise since stability in the y-direction is of greater need.

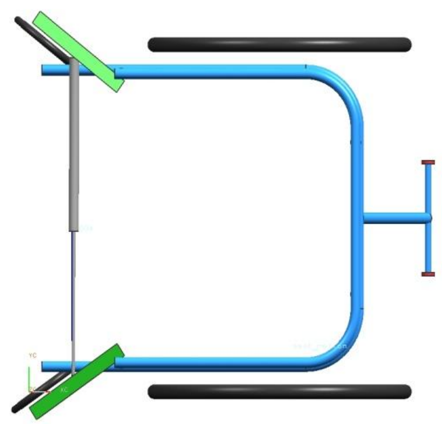


Figure 6.13: Top View of Automatic Caster Mechanism

Finally, an isometric view of the extended mechanism is show below in Figure 6.14. This design will allow the user to reach side to side without risk of tipping the wheelchair.

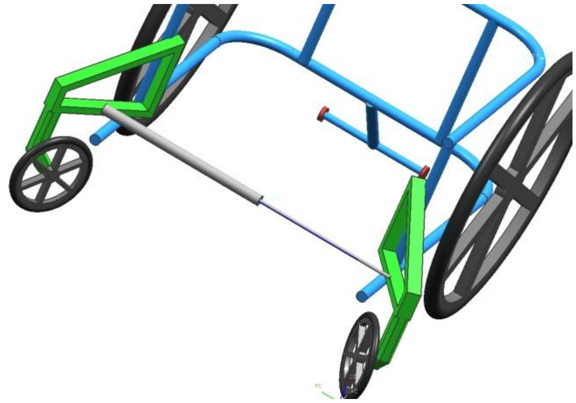


Figure 6.14: Isometric View of Extended Automatic Caster Mechanism

6.3.2.2 Automatic Brake Activation Mechanism

In order to satisfy our customer requirement of a safe design we realize it is necessary to lock the wheels of the chair during elevation. We have thus developed two solutions which automatically engage brakes when the user begins to elevate.

Figure 6.15: Cable Activated Automatic Brake Mechanism

The first solution, shown in Figure 6.15, is a cable brake system similar to bicycle brakes. When the seat elevates, the casters will be extended due to the automatic system. As the bar connecting the casters rotates it will pull a cable which is connected. The cable will then activate the brakes to apply pressure to the wheels. This design will require an additional brake system which may be adapted from existing bicycle brakes. The cables will be enclosed within the tubing of the wheelchair so they are not exposed.

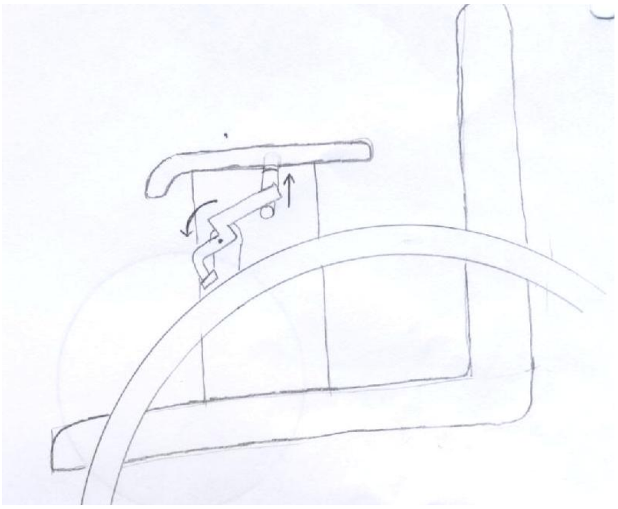


Figure 6.16: Lever Activated Automatic Brake Mechanism

The second solution, shown in figure 6.16, utilizes the existing brakes on the wheelchair but incorporates an automatic activation feature. A protruding hook on the armrest will pull on the brake lever when the seat elevates, rotating the brake and applying pressure to the wheel. When the brakes are fully activated, the hook will be able to pass freely as the chair continues to elevate. This mechanism is purely a backup for user neglect. If the user does activate the brakes before elevating, the hook will freely pass. When the user returns to the original vertical position, the hook will again pass by the brake lever and the brakes will remain locked. The brakes can only be unlocked by the user.

6.3.2.3 Stabilizer Bar Mechanism

In relation to FAST diagram, this design concept is to prevent the toppling and improve wheelchair safety. Therefore, the main purpose of this design is to increase the foot print of the chair and thus its stability. As shown in Figure 6.17, the design consists of three main components listed in the morphological chart.

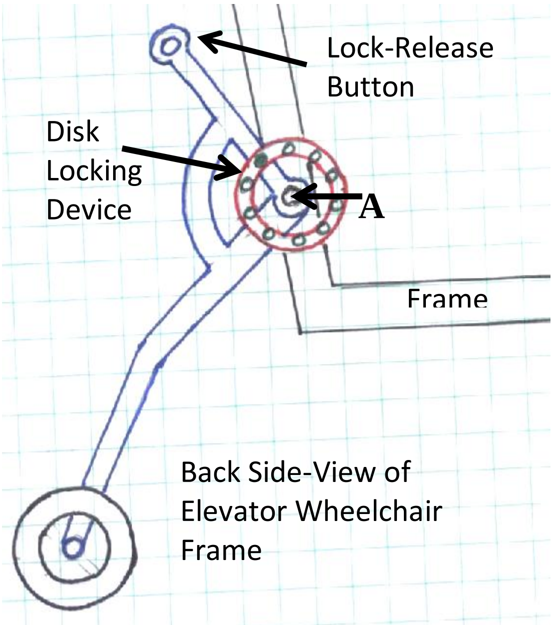


Figure 6.17: Disk locking device integrated wheelie bar system.

A lock and release button, disk locking device, and pair of wheelie bars are used in the design concept. The lever, wheelie bars and disk locking device are connected to the wheelchair frame at point A. Once the user pushes the lever button the lever is free to rotate and the wheelie bars can be lowered to the ground. Once lowered, the bars lock in position until later released. It is imperative that the bars are able to be raised and lowered since ramps are commonly used and require raised wheelie bars.

7. CONCEPT EVALUATION

In order to evaluate each of our four concepts and propose our two main concepts, we critiqued each design for how they met the customer requirements as well as some of our own requirements. These additional requirements include cost, ease of manufacturing, its innovativeness and feasibility. Additionally each design concept was evaluated using a Pugh chart to compare its functionality with specific customer requirements.

7.1 Pugh Chart Evaluation

The Pugh Chart shown in Appendix E was used to evaluate each of the four concepts and rate how they met each of the customer requirements. Each design was critiqued against the pneumatic linkage mechanism with simple plusses and minuses given if it was better or worse than the baseline. Furthermore, to obtain the same customer requirement weighting scheme as utilized in the QFD a simple normalization of the values was used as shown.

7.2 Pneumatic Linkage Lifting Mechanism

This design offers an easier manufacturing and assembly process, as well as its less structure or failure points and less harm to the user than any of the other designs. It is also an innovative design due to the lever linkage. This design has drawbacks of only three support points and requires a stabilizing track to prevent forward motion. As this concept was chosen to be the baseline for evaluation it had a 100% rating from the Pugh chart and zero positives or negatives from customer requirements. Upon proposing to the class and due to its positive attributes, this concept was chosen by the class during the second design review presentation.

7.3 Pneumatic Scissor Lifting Mechanism

This concept was one of the two proposed to the class and sponsors for further evaluation and comparison. It obtained plusses for not needing a stabilizing track and, its durability, and for having more contact points with the seat which increases stability. This device had negative aspects including its harm to users from pinch points from the scissor mechanism and its costly manufacturing and assembly time (both in time and money). From the Pugh chart it came in slightly better than the baseline (104%) due to its positive attributes.

7.4 Screw-Scissor Lifting Mechanism

The screw-scissor concept was stable, could lock in any position, did not require any guides for additional support and by only needing one hand to operate allows the user to have more function. However, this device had the following negative attributes: the crank can interfere with the functionality of the chair, elevation time is limited, the one arm motion can cause fatigue, and the scissor mechanism can be harmful to the user if not properly enclosed. From the Pugh chart, this device received a score of 89% compared with the baseline. It received positives for being more durable and stable, but negatives for being harmful, having a more timely height change and for limiting the wheelchair’s functionality.

7.5 Torsional Lever Lifting Mechanism

This torsional lever concept had fewer parts that needed to be manufactured compared to the other designs which saves time and cost. Less structure and fewer joints allows further durability due to having less failure points, and the design would be less harmful to the user. It received negatives for its stability in that it only had three support points as well as requiring an additional stabilizing track to prevent forward motion, and its user input motion is unnatural. Due to these factors, this design received a 92% from the Pugh chart.

7.6 Sub-Function Evaluation and Selection

During the design process thus far we have focused on the main function of the wheelchair, to elevate the user, and evaluated the corresponding mechanisms. We have not performed a detailed analysis of the secondary mechanisms of the wheelie bars and locking brakes, as they are not the primary concern of this design review. We have however ensured that the secondary mechanism designs proposed will work with the proposed primary mechanisms. As we further refine our design we will have a better understanding of which secondary mechanisms we will use.

A preliminary evaluation delivers the drawbacks and advantages of each mechanism. The wheelie bars we have proposed require the user to activate the safety mechanism. Ideally the wheelie bars would be automatic to prevent injury even with user neglect. We will continue to refine this design to resolve a better solution. The brake mechanisms we have proposed are both automatically activated when the seat elevates. The cable brakes would require adding a second brake system to the standard parking brake on a wheelchair but would not require modification to the existing brakes. The lever activated braking system would prevent the need for an additional braking mechanism but would require some modification to the existing brakes. Further consideration and cost analysis is needed to determine which system we will include in our design.

8. SELECTED CONCEPT

Our selected concept is the pneumatic linkage mechanism, with automatic braking and caster motion, and adjustable wheelie bars. This section will detail each main and sub function, the reasoning behind each design, and further details of the design characteristics (dimensions, motions, etc.).

8.1 Pneumatic Linkage Lifting Mechanism

The pneumatic linkage mechanism is our chosen design concept lifting mechanism. Once again, the pneumatic linkage mechanism lifts the user through a four-bar linkage arrangement that is controlled by a pneumatic cylinder and assisted with gas springs. Below is a side view of our selected lifting mechanism.

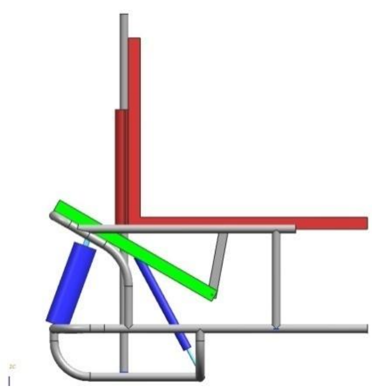


Figure 8.1: Side View of Proposed Lifting Mechanism

This mechanism was designed for simplicity, involving as few components as possible while still remaining a rigid and stable design. The pneumatic cylinder was chosen as a locking mechanism for the motion of the seat. The idea was inspired by an office chair, where motion can be controlled by a pneumatic cylinder with a spring assist. We wanted to use the same principle; however, we were unable to find a cylinder that had the required travel. To reduce the travel necessary, we developed a four-bar linkage around the cylinder.

To reduce the load on the user, we needed something to provide and store force. We thought of torsion springs and helical springs but we ended up choosing a gas spring because of it near horizontal force vs. extension plot. Once again, travel was a problem with our gas spring, and to accommodate for this, we strategically placed the gas spring in a position that would reduce it travel, while still using its stored force in constructive way.

8.2 Design Characteristics

Table 8.1 describes the design characteristics and lengths of travel for this design concept. All numbers are estimates which may be changed throughout our detailed engineering design.

Table 8.1: Design Characteristics Detailing Lengths of Travel

Design Characteristic	Expected Results
Length of Seat Travel	40 cm
Width of Frame	48 cm
Length of Frame	63 cm
Height of Frame	30 cm
Link 1 Length	39 cm
Link 2 Length	15 cm
Pneumatic Cylinder Travel	10 cm
Gas Spring Travel	17 cm
Length of Horizontal Stabilizer Bar	76 cm
Caster Motion Y-Direction	15 cm
Caster Motion X-Direction	-7 cm

As table 8.1 illustrates, this design meets our main design requirements of 400 mm of seat travel, as well as wheelchair width, length, and height (seat only 380 mm off ground). These dimensions were taken from our Unigraphics V.4 part file and are representative of our expected final design.

8.3 Material Choices

Table 8.2 (pg.28) details components and expected material choices of our selected concept. These are preliminary selections and may change throughout our detailed engineering evaluation.

Table 8.2: Material Selection of Each Component

Part	Material Selection
Seat	Existing Wheelchair Seat
Link 1	Steel or Aluminum Bar with Tube Cross Connections
Link 2	Steel or Aluminum Bar with Tube Cross Connections
Frame	Welded Steel or Aluminum Tubing
Frame – Link 1 Connection	Fabricated Pin System
Link 1 – Link 2 Connection	Locking Pin System
Link 2 – Seat Connection	Fabricated Pin System
Pneumatic Cylinder	Purchased (Steel)
Gas Spring	Purchased (Steel)
Wheelie Bars	Steel or Aluminum Tubing with Purchased Mechanism
Brake Mechanism	Purchased Brake Components
Caster Pivots	Welded Steel Tubing
Seat – Castor Bar	Steel Tubing
Frame – Castor Connection	Fabricated Hinge

8.4 Purchased Components

We plan on purchasing some components for our project. These components are too complex to feasibly fabricate ourselves, and are relatively inexpensive. We will need a pneumatic cylinder, two gas springs, a seat, steel or aluminum tubing and bars as well as fasteners and pins.

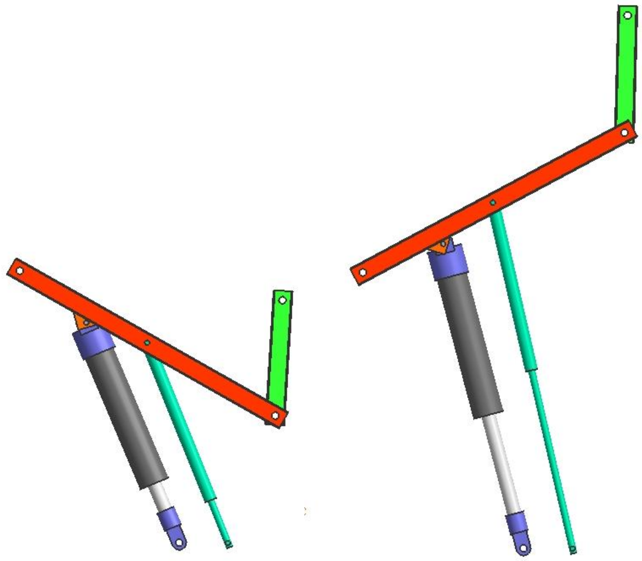
9. ENGINEERING ANALYSIS

In order to ensure a viable design, we completed a comprehensive engineering evaluation involving geometric, qualitative, and quantative analysis. Each type of engineering evaluation and its relevance is discussed in the following subsections.

9.1 Geometric Engineering Analysis of Four-Bar Pneumatic Linkage

Geometric analysis was important to ensure that our components could be integrated to create a working prototype and that parts would fit together as planned. We used data for our chosen gas springs and pneumatic cylinder along with our proposed vertical elevation of the seat relative to the frame to complete a geometric analysis of the four bar linkage. This analysis allowed us to calculate proper pivot points for the gas springs, pneumatic cylinder, and both elevating links. Additionally, the geometric analysis allowed us to design components that would not interfere with others. Figure 9.1 Shows the two positions used to calculate the seat travel, pneumatic cylinder stroke, and gas spring stroke lengths.

Figure 9.1: Two Position Geometric Analysis and Results



Object	Compressed Length	Extended Length
Pneumatic Cylinder	8.5"	12.5"
Gas Spring	11.25"	19.25"
Rear Linkage Travel	30° S of Horizontal	30° N of Horizontal

9.2 Qualitative Engineering Analysis

In order to ensure an overall quality design, we completed qualitative engineering analysis of our elevating wheelchair. We considered Design for Manufacturing and Assembly (DFMA), Failure Mode and Effects Analysis (FMEA), as well as Design for Environment (DFE) and followed the established guidelines for improving product design.

9.2.1 Design for Manufacturing and Assembly (DFMA)

Throughout the process of finalizing our design we actively considered and implemented design characteristics to ease manufacture and assembly. We followed the guideline of design for assembly system (DFAS) through a variety of ways. We minimized part counts by using bent tubing at corners instead of joining two pieces. We permitted assembly in open spaces by making the armrest out of two pieces to allow easy assembly of the complicated pin activating mechanism. We also standardized to reduce part variety by using the same size tubing on all parts of the frame and the same sized bars for the linkage.

We also implemented the guideline of design for part handling (DFPH). We maximized part symmetry by using symmetric tubing for the frame (cylindrical). We also added features to facilitate orientation such as having the front of the armrest extend downward making it different than the back.
In addition we considered design for part insertion (DFPI). We added alignment features such as a circular button on the pin mechanism which automatically centers the rod.

We designed for joining (DFJ) in a variety of ways. By bending tubes at the corners we eliminated fasteners which would be needed for a corner joint. We allowed access for tools by making the armrest out of two pieces where the pin activating mechanism is located.

Lastly, we considered design for machining (DFMC). The guidelines require the use of standard materials shapes and ranges of sizes. We are using standard tubing sizes for the frame and links as well as a standard threaded rod and nuts for the pin activating mechanism. We are also using standard dimensions by having all parts in 1/8 inch increments.

9.2.2 Design for Environment (DFE)

During the design process we have considered the environmental impact of our product throughout its lifecycle through multiple designs for environment (DFE) guidelines. We considered the guidelines concerning physical optimization. We integrated product functions by combining a wheelchair with a lift mechanism which may otherwise exist as two separate components. We also eased maintenance and repair by allowing easy access to all components of the mechanism such as the gas springs and pneumatic cylinder.

We also optimized material use in our design. We chose cleaner materials such as eliminating batteries from our design which must be replaced over time and produce hazardous waste such as lead or exotic materials. We also used an assist mechanism of gas springs which use air as the working fluid as opposed to other materials which must be controlled. We also reduced material usage in our design by using the rear vertical seat tubing as the rear stabilizer rack which could have existed as two separate components.

In addition we reduced impact during use by using cleaner energy sources. By eliminating electrical components from our design we rely solely on human energy input. We have provided mechanical assist mechanisms with the gas springs to allow for lifting.

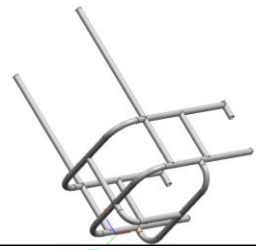
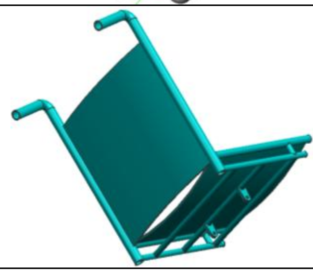
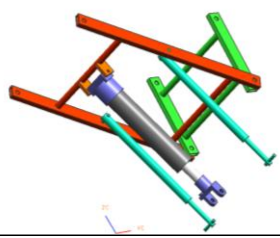
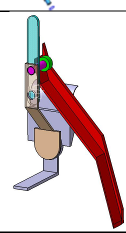
We optimized end-of-life systems by using standard wheelchair parts which can be easily reused in other wheelchairs. In addition, the wheels will be connected by only a bolt to provide easy removal during recycling.

For mass production we will consider optimizing production techniques and distribution. By using less packaging and eco-friendly transportation to distribute our product we can further reduce the environmental impact of our design.

9.2.3 FMEA Analysis

Failure Mode and Effect Analysis (FMEA) is a method used to identify potential failures, the effects of those failures, and ways in which those failures can be presented. They type of FMEA that was used for our project was a design FMEA which focused mostly on the components and sub-systems. Our design was broken into the subsystems shown below in table 9.1. Each subsystem was then evaluated on its design and likelihood of failure. This brought about design changes that improved our FMEA results.

Table 9.1: FMEA Components for Analysis

Sub-Function	Picture of Sub-Function	Description and Components Involved
Wheelchair Frame		All tubing and brackets associated with fixed frame, and wheel attachments, stabilizer bar attachments, and linkage attachments
Seat Frame		All tubing and brackets associated with moving seat frame
Pneumatic Linkage		All tubing, pins, and cylinders associate with the four bar pneumatic linkage
Adjustable Armrests		All tubing and mechanism components associated with adjustable armrests
Automatic Braking Mechanism		All components including sliding track associated with automatic braking system

After breaking our system into sub-functions, we were able to evaluate each sub-function according to the criterion shown in table 9.2. Each criterion was then ranked according to how likely or un-likely an event was to occur under each type of evaluation. A description of ranking is also shown in table 9.2.

Table 9.2: FMEA Evaluation Criterion

Evaluation Criteria	Description of Criteria and Ranking
Likelihood of Occurrence (O)	This evaluates how likely a failure mode is to occur, with one being least likely and ten being most likely.
Potential Severity (S)	This evaluates how severe a failure would be, with one being no effect and ten being great effect of product function.
Likelihood of Detection (D)	This evaluates how easily a failure can be detected, with one being most detectable and ten being least detectable.
Risk Priority Number (RPN)	This is the product of O, S, and D evaluation and provides a general assessment of risk of failure. A lower RPN is better.

9.2.3.1 Sub-Function FMEA Evaluation

This section will detail the FMEA evaluation of each of the five sub-functions listed in Table 9.1 above. The evaluation also details the types of failure likely to be seen, the severity of those failures, and some proposed changes in design that were implemented to reduce the RPN of each sub-function. Because of the many areas where failure could occur in each subsystem, each failure mode could either result in a minor product failure or a major product failure. See table 9.3 below for an overview of these types of failures.

Table 9.3: Minor and Major Product Failure Descriptions

Evaluation Criteria	Description of Criteria and Ranking
Minor Product Failure	This type of failure affects the performance of the subsystem, but it does not cause the entire subsystem to fail. These types of failure would include cracks forming in the frame, small weld failures, or yielding of materials
Major Product Failure	This type of failure affects the performance of the subsystem causes failure of the subsystem. These types of failures would include complete weld failure, large amounts of plastic deformation, or dislocation of parts.

Wheelchair Frame FMEA Evaluation

The wheelchair frame FMEA evaluation uncovered areas of concern, mostly with the frame material choice and orientation, which were important in the design. These concerns caused changes to be made in tube orientation and gauge in order to provide a strong load path where necessary and to avoid bending stresses where possible. We were able to reduce the RPN of the wheelchair frame from 100 to 64 through the FMEA evaluation. The results are shown below in table 9.4

Table 9.4: Wheelchair FMEA Evaluation

Sub-Function	Part & Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls / Tests	Detection (D)	Recomended Actions	RPN	New (S)	New (0)	New (D)	New RPN
Wheelchair Frame	Frame Tubing	Yield (From Bending of Sheer) Severity Dependent of Location of Fialure	Minor Product Failure	5	Over Loading, Improperly Loading, Allignment	3	Load Wheelchair with Expected Maximum Load to Ensure No Yield / Failure Seen	2	Increasing Gauge of Tubing will Lower Occurance, but is not Feasible.	30	4	2	2	16
			Major Product Failure	8		1		2		16	7	1	2	14
		Weld Failure (Severity Dependent on Location of Failure)	Minor Product Failure	5	Over Loading, Improperly Loading, Allignment	1	Load Wheelchair with Expected Maximum Load to Ensure No Yield / Failure Seen	2	Increse Thickness of Welds, Ensure No Voids, Eliminate Stresses by Good Fixturing when Welding.	10	4	1	2	8
			Major Product Failure	8		1		2		16	7	1	2	14
	Mechanism Mounting Brackets	Yield (from Sheer or Bending)	Major Product Failure	7	Over Loading, Improperly Loading, Allignment	2	Load Wheelchair with Expected Maximum Load to Ensure No Yield / Failure Seen	1	Increase Product Gauge to Reduce Yield/Bending Failures, Increase Welding Area/Thickness to Reduce Risk of Weld Failure.	14	6	1	1	6
		Weld Failure	Major Product Failure	7		2		1		14	6	1	1	6

Seat Frame FMEA Evaluation

The seat frame FMEA evaluation uncovered areas of concern that were important in the design. We changed tube orientation and gauge in order to provide a strong load path where necessary and to avoid bending stresses where possible. We were able to reduce the RPN of the original seat frame from 70 to 30 through the FMEA evaluation. The results are shown below in table 9.5 (pg 33).

Table 9.5: Seat Frame FMEA Evaluation

Sub-Function	Part & Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls / Tests	Detection (D)	Recomended Actions	RPN	New (S)	New (0)	New (D)	New RPN
Seat Frame	Frame Tubing	Yield (From Bending of Sheer) Severity Dependent of Location of Fialure	Minor Product Failure	4	Over Loading, Improperly Loading, Allignment, Impacts	2	Load Wheelchair with Expected Maximum Load to Ensure No Yield / Failure Seen	2	Increase Tube Gauges, Design for Load Path Efficiency.	16	4	1	2	8
			Major Product Failure	8		1		1		8	7	1	1	7
		Weld Failure (Severity Dependent on Location of Failure)	Minor Product Failure	5	Over Loading, Improperly Loading, Allignment	3	Load Wheelchair with Expected Maximum Load to Ensure No Yield / Failure Seen	2	Increase Weld Thickness, Aviod Voids in Welds, Reduce Stress by Prope Fixturing when Welding	30	4	1	2	8
			Major Product Failure	8		2		1		16	7	1	1	7

Pneumatic Linkage FMEA Evaluation

The pneumatic linkage FMEA evaluation uncovered areas of concern that were important in the design. We changed link orientation and gauge and pin diameter because of the FMEA results in order to provide a strong load path where necessary and to minimize bending stresses where possible. We were able to reduce the RPN of the pneumatic linkage from 88 to 55 through the FMEA evaluation. The results are shown below in table 9.6.

Table 9.6: Pneumatic Linkage FMEA Evaluation

Sub-Function	Part & Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls / Tests	Detection (D)	Recomended Actions	RPN	New (S)	New (0)	New (D)	New RPN
Lifting Mechanism	Frame Tubing	Yield (From Bending of Sheer) Severity Dependent of Location of Fialure	Minor Product Failure	7	Over Loading, Improperly Loading, Allignment	3	Load Wheelchair to Maximum Expected Load, and Test Linkage Mechanism in Many Positions of Travel	2	Increse Tubing Gauge, Increase Hold Diameter to Reduce Fatigue Risk	42	6	2	2	24
			Major Product Failure	9		2		1		18	8	1	1	8
		Weld Failure (Severity Dependent on Location of Failure)	Minor Product Failure	5	Over Loading, Improperly Loading, Allignment	2	Load Wheelchair to Maximum Expected Load, and Test Linkage Mechanism in Many Positions of Travel	2	Increase Weld Thickness, Aviod Voids in Welds, Reduce Stress by Proper Fixturing when Welding	20	4	2	2	16
			Major Product Failure	8		1		1		8	7	1	1	7

Adjustable Armrests FMEA Evaluation

The adjustable armrests FMEA evaluation uncovered areas of concern that were important in the design. We chose tube orientation and alignment in order to provide smooth operation and to minimize bending stresses where possible. We were able to reduce the RPN of the adjustable armrests from 63 to 42 through the FMEA evaluation. The results are shown below in table 9.7.

Table 9.7: Adjustable Armrests FMEA Evaluation

Sub-Function	Part & Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls / Tests	Detection (D)	Recomended Actions	RPN	New (S)	New (0)	New (D)	New RPN
Adjustable Armrests	Tubing	Yield from loading	Major Product Failure	7	Over Loading, Improper Loading, Allignment	3	Load Armrests with maximum expected load (users weight)	2	Ensure proper allignment, increase tube diameter if necessary, reduce distance between tubes	42	7	2	2	28
	Mechanism	Fatigue from cyclic loading	Major Product Failure	7	Too many cylces	3	Cycle Armrests for testing to ensure long lasting working life	1	Provide accurate manufacturing, strong components with long expected working life	21	7	2	1	14

Automatic Braking FMEA Evaluation

The automatic braking FMEA evaluation uncovered areas of concern that were important in the design. We were able to realize how important orientation and strength of the automatic braking track was to ensuring the proper operation of the automatic braking system. We were able to reduce the RPN of the automatic braking system from 18 to 6 through the FMEA evaluation. The results are shown below in table 9.8 (p.34).

Table 9.8: Automatic Braking FMEA Evaluation

Sub-Function	Part & Function	Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes of Failure	Occurance (O)	Current Design Controls / Tests	Detection (D)	Recomended Actions	RPN	New (S)	New (0)	New (D)	New RPN
Automatic Braking Mechanism	Guide Channel	Yield (From Bending, Sheer, or Impact)	Prodcut Featuer Failure	3	Overloading, Improper Allignment	3	Repeated Elevation of Seat to Ensure Smooth Operation	2	Modify Channel to Ensure Smooth Transition from Elevated to Lowerd Positions	18	3	1	2	6

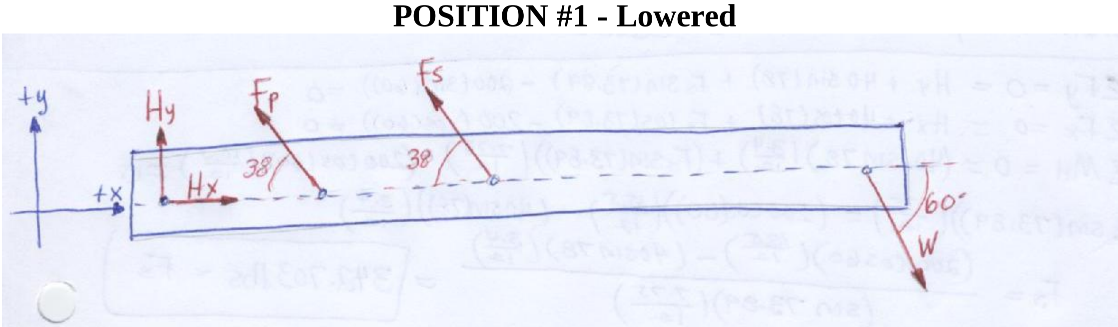
9.3 Quantitative Engineering Analysis

Quantitative engineering analysis consisted of five multi-position static analysis of the design concept. The static analysis provides us with confirmation of material choice as well as a prediction of wheelchair stability. The results showed us that our initial material choices were incorrect in some positions and provided us the information necessary to ensure safe and reliable operation. The complete static analysis is attached in Appendix K.

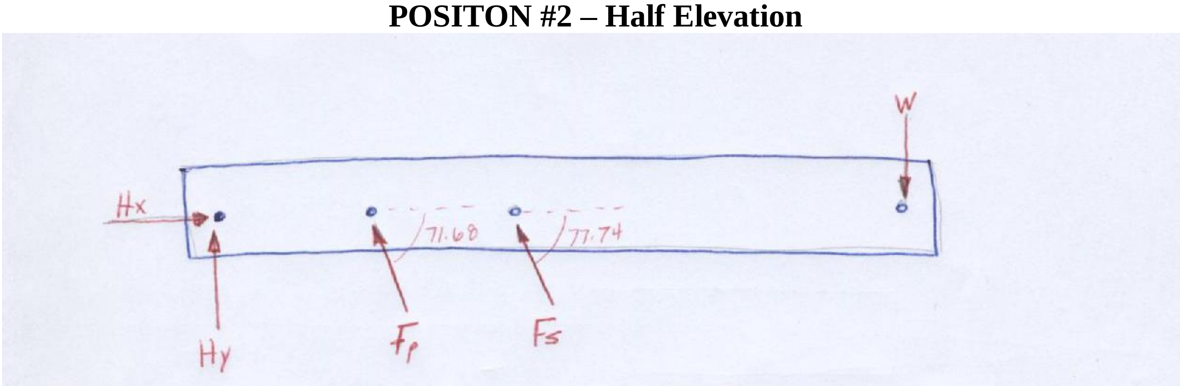
9.3.1 Gas Spring Force Calculation

To determine the necessary force from the gas springs, we completed a three position static analysis. The three positions that were used were lowered, center elevation, and fully elevated; three were used in order to fully understand the force required of the gas springs, even though only fully elevated and fully lowered were necessary. The free body diagrams for each position are shown below in Figure 9.3. A generalization was made according to the vertical force exerted on the linkage by the seat. It was assumed that the force would be 200 lbs (890 N) in the vertical direction. Horizontal forces were neglected, as they would contribute very little to stresses seen in the linkage, as axial stresses are much less than bending stresses. The nomenclature of the free body diagrams is show in Table 9.9 below the free body diagrams.

POSITION #1 - Lowered



POSITON #2 – Half Elevation



POSITION #3 – Full Elevation

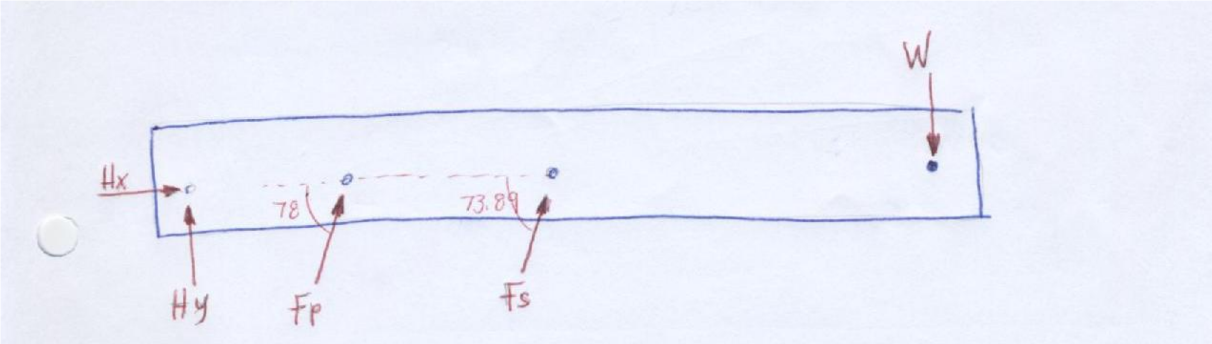


Figure 9.3: Three Position Gas Spring Static Analysis Free Body Diagrams

Table 9.9: Nomenclature of Free Body Diagrams

Name	Description
Hx	Hinge Force in the Horizontal Direction
Hy	Hinge Force in the Vertical Direction
Fp	Pneumatic Spring Force
Fs	Gas Spring Force
W	Weight from User

We used a summation of forces in both the vertical and horizontal directions as well as moment balance in order to determine the force on the gas springs. It was assumed that the pneumatic cylinder produced a constant force of 40 lbs (180 N) when engaged (compressed force is approximately 20% larger than extended force). The static analysis is shown below.

3 Position Static Analysis Position # 1 Lowered

$$\sum \begin{aligned} F_y &= 0 = FY1 + FPS\sin(38) + FGS\sin(38) - FW\sin(60) \\ F_x &= 0 = FX1 - FPS\cos(38) - FGS\cos(38) + 200\cos(60) \\ M_h &= 0 = FPS\sin(38)(3.4) + FGS\sin(38)(7.75) - 200\sin(60)(15.5) \end{aligned}$$

$$FGS = \frac{200\sin(60)(15.5) - FPS\sin(38)(3.4)}{\sin(38)(7.75)} = 272\frac{Lbf}{spring}$$

3 Position Static Analysis Position # 2 Horizontal

$$\sum \begin{aligned} F_y &= 0 = FY1 + FPS\sin(72) + FGS\sin(77) - FW\sin(0) \\ F_x &= 0 = FX1 - FPS\cos(72) - FGS\cos(77) + 200\cos(0) \\ M_h &= 0 = FPS\sin(72)(3.4) + FGS\sin(38)(77) - 200\sin(0)(15.5) \end{aligned}$$

$$FGS = \frac{200\sin(0)(15.5) - FPS\sin(72)(3.4)}{\sin(77)(7.75)} = 196\frac{Lbf}{spring}$$

3 Position Static Analysis Position # 3 Raised

$$\sum \begin{aligned} F_y &= 0 = FY1 + FPS\sin(78) + FGS\sin(73) - FW\sin(60) \\ F_x &= 0 = FX1 - FPS\cos(78) - FGS\cos(73) + 200\cos(60) \\ M_h &= 0 = FPS\sin(78)(3.4) + FGS\sin(73)(77) - 200\sin(60)(15.5) \end{aligned}$$

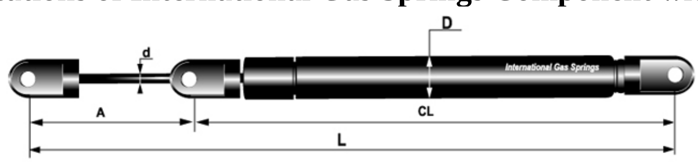
$$FGS = \frac{200\sin(60)(15.5) - FPS\sin(78)(3.4)}{\sin(73)(7.75)} = 171\frac{Lbf}{spring}$$

To find the force on the gas springs we assumed static equilibrium and solved for the spring force from Figure 9.3 above. The calculated spring force is shown below in table 9.10. We determined that two gas springs with 200 lbs (890 N) of force would be ideal. The specifications of the chosen gas springs are shown in Figure 9.4.

Table 9.10: Calculated Spring Force from Three Position Static Analysis

Position	Spring Force Total
Lowered	550 lbs (2450 N)
Half Travel	390 lbs (1730 N)
Raised	350 lbs (1550 N)

Figure 9.4: Specifications of International Gas Springs Component with 200 lb Charge



Intl. Gas Springs	Rod Dia. (d)	Cyl. Dia (D)	Stroke (A)	Ext. Length (L)	Comp. Length (CL)	Eye Dia.	Force
1CU203468MM0890	0.393 in.	0.866 in.	8 in.	19.24 in.	11.24 in.	8 mm	100 to 250 lbs.

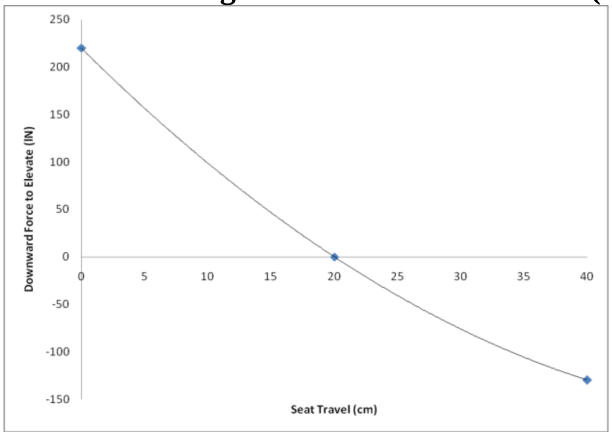
From these results, we chose two gas spring with combined force of 400 lbs (1780 N) or 200 lbs (890 N) each. We then used this gas spring force to determine the upward force on the seat. The upward force at each elevation is shown below in table 9.9.

Table 9.9: Upward Force on Seat Increases with Increased Elevation

Position	Upward Force
Lowered	150 lbs (670 N)_
Half Travel	200 lbs (890 N)
Raised	230 lbs (1020 N)

These results show that a 200 lb user would need to apply 50 lbs (220 N) downward to elevate the wheelchair, and 30 lbs (130 N) upward to lower the wheelchair from maximal elevation, and an intermediate force at other positions. The estimated necessary user force needed to change elevation is shown below in Figure 9.5, which a trend line is drawn on the three data points from table 9.9.

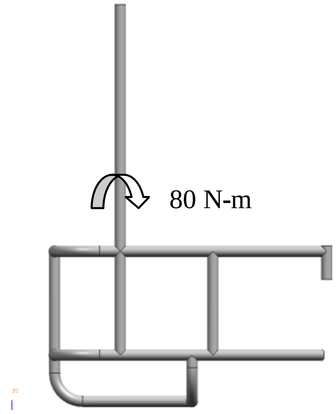
Figure 9.5: User Input Force to Change Elevations vs. Elevation (Downward = + Force)



9.3.2 Wheelchair Frame Static Analysis

Next, we completed a static analysis on the wheelchair frame. This analysis was similar in format and depth as the gas spring and pneumatic linkage evaluation of the previous section. Through static analysis, it was determined that the maximum stress on any part of the wheelchair frame would be due to the moment caused by the seat frame. This was found by approximation of forces at various points on the wheelchair frame. The maximum moment on the seat frame was determined to be 80 N-m. The free body diagram of this static analysis is shown below in Figure 9.6.

Figure 9.6: Maximum Wheelchair Frame Stress caused by 80 N-m Moment

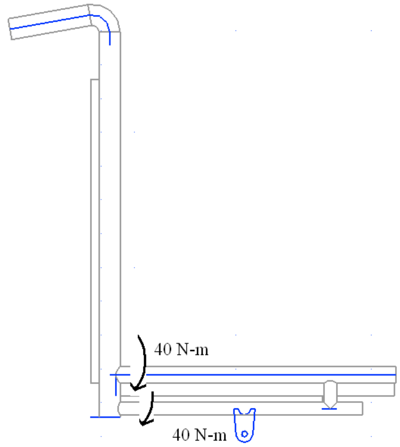


After completing a summation of forces and moments for the above free body diagram, we determined that the maximum stress that would occur in the wheelchair frame would be 110 Mpa. This stress is acceptable and provides a safety factor of at least 2.0 (using yield as failure criteria). We thus confirmed that our material selection was adequate for our application. The complete analysis can be seen in Appendix K.

9.3.3 Seat Frame Static Analysis

We next completed a static analysis on the seat frame. Through static analysis, it was determined that the maximum stress on any part of the seat frame would be due to the moment caused by the users weight on the seat back, this is similar to the calculations as shown in 9.3.1. This was found by approximating the forces at various points of the seat frame. The maximum moment was determined to be 40N-m. The free body diagram of this static analysis is shown below in Figure 9.7.

Figure 9.7: Maximum Seat Stress Caused by 40 N-m Moment

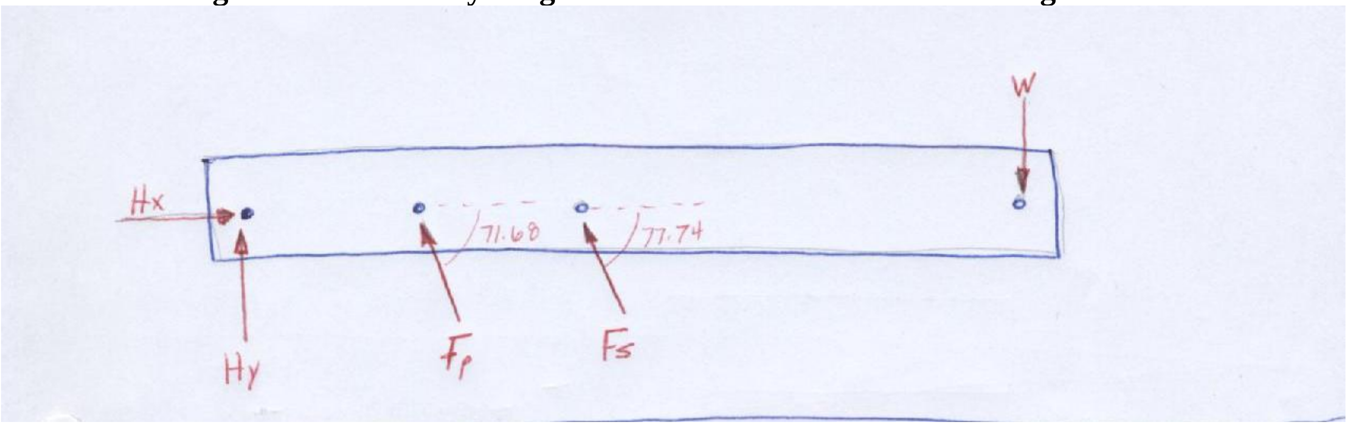


Completing a summation of forces and moments allowed us to calculate the maximum seat frame stress to be 110 Mpa. This stress is acceptable and provides us a safety factor of at least 2.0 (using yield as failure criteria). We thus confirmed that our material selection was adequate for our application. The complete static analysis can be seen in Appendix K.

9.3.4 Pneumatic Linkage Static Analysis

A static analysis of the pneumatic linkage was completed to determine the maximum stress that would occur to our linkage and to confirm that our material choice was adequate. The free body diagram of this static analysis is shown below in Figure 9.8. The maximum stress occurs when the seat is half elevated and the force due to the seat is perpendicular to the link as shown in the free body diagram (Figure 9.8).

Figure 9.8: Free Body Diagram of Maximum Pneumatic Linkage Stress

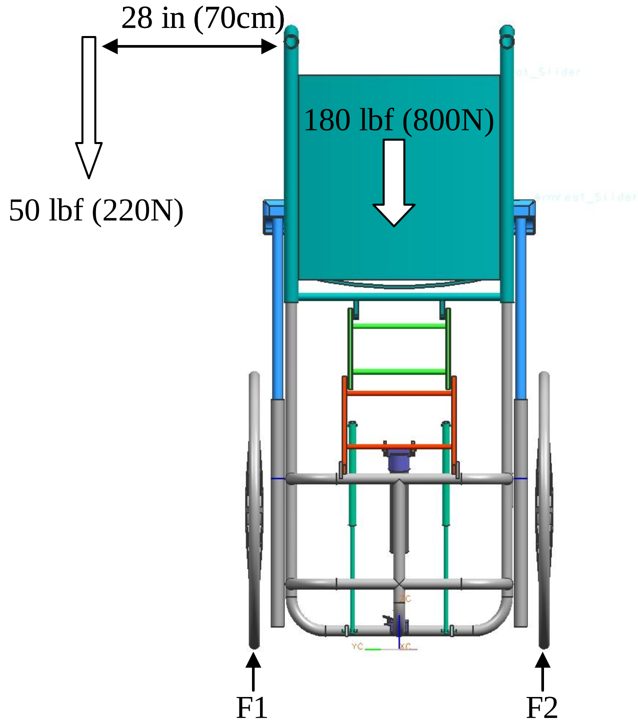


Completing a summation of forces and moments showed that the maximum linkage stress occurs at the point where the gas springs meet the pneumatic linkage. We found this stress by using the relationship of stress to bending moment and geometric moment of area. Using this, we found the maximum stress is 80 Mpa, providing us with a safety factor against yield of 3, and additionally proving that our material choice was adequate for this application.

9.3.5 Toppling Static Analysis

A static analysis of the elevated wheelchair was completed to ensure that the chair was stable at the highest elevation. To complete this, we assumed that the user would hold a 50 lb weight at arms length at maximum elevation. We wanted to ensure that the user would not topple under this condition. The free body diagram of this scenario is shown below in Figure 9.9 (pg.37).

Figure 9.9: Toppling Static Analysis Free Body Diagram



We completed a summation of moments about the left wheel of figure 9.9 above. We assumed the user would weight 180 lbf and would hold a 50 lbf weight at arm's length. We also determined the minimum user weight (140 lbf) to ensure the wheelchair would not topple.

$$\sum M_1 = 0 = (50lbf)(28in) - (180lbf)(10in) + (F2)(20in) = 0$$

F2 = 20 lbf (confirming wheelchair will not topple)

If F2 = 0 lbf, the wheelchair will topple if occupant exerts less force than 140 lbf.

10. FINAL DESIGN

Our final design based on the above engineering calculations is shown in Figure 10.1 (pg 40). The front caster wheels and anti-tip bars are not included as they will be taken directly from an existing wheelchair.

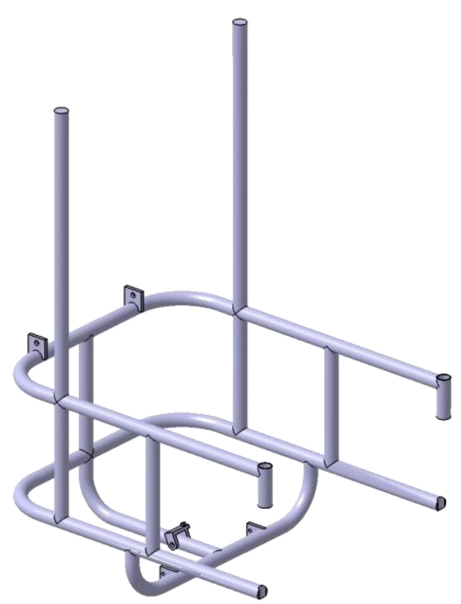
Figure 10.1: CAD Model of Elevating Wheelchair Final Design

In order to explain our design in more detail, we have divided it into five main components: frame, seat, linkage system, brakes, and armrests. We have analyzed each of these components and created a bill of materials (BOM), 3D CAD models, engineering drawings, and prototype plans as will be further outlined.

10.1 Wheelchair Frame

The structural support for the elevating wheelchair is provided by the frame. In addition to structural support, the frame could also be considered as the interface of other components of wheelchair. As such, the frame is mainly used to install the elevating mechanism, the seat, wheels, brake system and armrests. Therefore, it is designed to withstand all possible loading conditions while maintaining a low overall weight. A 3D CAD model of the finalized elevating wheelchair frame is shown below in Figure 10.2.

Figure 10.2: Finalized elevating wheelchair frame.



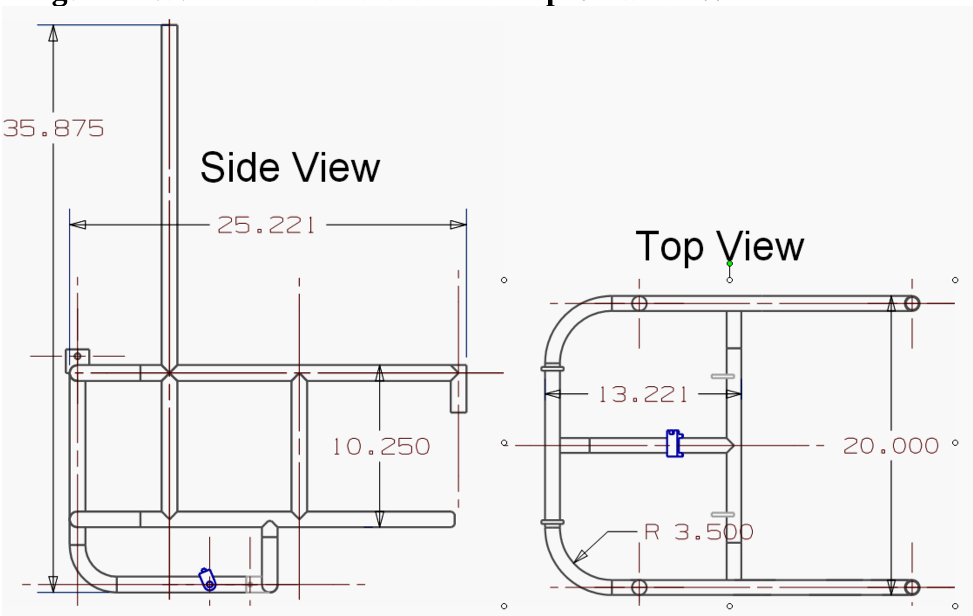
This wheelchair frame is consists of 1-inch diameter by 1/16-inch wall steel tubes, and steel plates were used for the brackets that connect the gas springs and pneumatic cylinder to the frame. A detailed bill of materials (BOM) is shown below in Table 10.1.

Table 10.1: BOM for elevating wheelchair frame

Qty.	Part Name	Part Description	Purchased From	Part#	Cost
1	Gas Spring Runner Bar	35" of 3/8"X1" steel tube	UM	1	$0.00
1	Pneumatic Runner Bar	25" of 3/8"X1" steel tube	UM	2	$0.00
1	Bottom U-Frame	75"of 3/8"X1" steel tube	UM	3	$0.00
1	Rear Top U-Frame	35" of 3/8"X1" steel tube	UM	4	$0.00
2	Front Top Frame	22" of 3/8"X1" steel tube	UM	5	$0.00
2	Seat Runner Bar	40" of 3/8"X1" steel tube	UM	6	$0.00
3	TopBottom U-Frame Connector	11" of 3/8"X1" steel tube	UM	7	$0.00
1	Gas Spring Mounting Brkt	2"X0.25"X5" steel bar	UM	1a	$0.00
1	Pneumatic Cylinder Mounting Brket	2"X0.25"X5" steel bar and 2" of 3/8"X1" steel tube	UM	2a	$0.00
1	Lifting Linkage Mounting Brackets	2"X0.25"X5" steel bar	UM	4a	$0.00
				Total	**$0.00**

According to engineering characteristics, it was decided to maintain the overall frame size as in a normal wheelchair. Therefore, overall dimensions were 36 inches, 20 inches and 26 inches for height, width and length respectively. Figure 10.3 below shows top and side views of the frame with finalized dimensions.

Figure 10.3: Dimensioned Side and Top Views of Wheelchair Frame



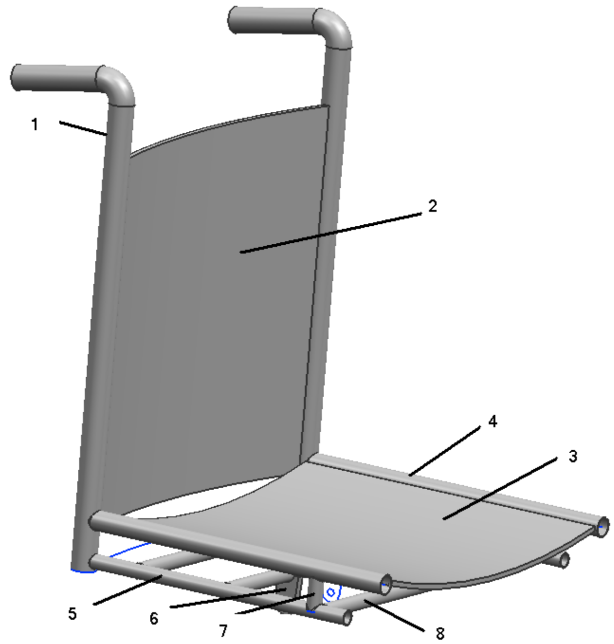
10.2 Seat Frame

The final design for the seat frame is shown below with regards to engineering drawings and the bill of materials for the total seat assembly. Each part's drawings and manufacturing plans are further detailed in the appendices. The total seat assembly and the subsequent manufacturing file for assembly is shown section 11.3.2.

10.2.1 Fully Assembled Seat

Shown below in Figure 10.4 (pg.40), is the assembled seat with their respective parts identified. The table that follows it shows the nomenclature used to identify each part.

Figure 10.4: Detailed fully assembled seat with key parts identified



No.	Name
1	Upper bar (2X)
2	Cushion back rest
3	Cushion seat rest
4	Horizontal upper runner (2X)
5	Horizontal lower runner (2X)
6	Linkage bracket (2X)
7	Connector brace(2X)
8	Cross brace (3X)

10.2.2 Upper Bar

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix H. The seat's upper bar will be made of (2) 1" thick steel tubes that are 30" in length. It will rest outside of the frame's extending bar and will be made precisely to accommodate for travel with the permanent bar that is attached. It will function to ensure purely vertical travel and provide stability to the user. It also will have a near 90 degree bend at the end to provide for someone to push the user.

10.2.3 Cushion Backrest

This part is not made nor purchased, we will be using the existing donated wheelchairs backrest and mounting device to provide the user optimal comfort.

10.2.4 Cushion Seat

This is another part that is neither made nor purchased, we will be using the existing donated wheelchairs seat rest and mounting device to provide the user optimal comfort.

10.2.5 Horizontal Upper Runner

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix H. This bar will be made of (2) 3/4" thick steel tubes that are 17" in length. It will mount to the upper bar in the back and the connector bar in the front. Its function will be to provide load transfer from the seat to the frame. It will have holes drilled into it for connecting it with the cushion. Care will be needed to ensure proper welding and location of these bars to provide optimal comfort and functionality of the mechanism.

10.2.6 Horizontal Lower Runner

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix H. This bar will be made of (2) 3/4” thick steel tubes that are 15” in length. It will be welded to the upper bar in the rear and to the connector bar in the front. Additionally, the cross braces will be welded to this bar that will ultimately lift the user. It will function to ensure purely vertical travel and provide stability to the user.

10.2.7 Linkage Bracket

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix H. It will be made of (2) 3/8” thick by 1.25” wide steel plates. It will be welded to the cross braces to connect the linkage to the seat. It will need to be machined precisely to provide smooth movement.

10.2.8 Cross Brace

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix H. The seat’s upper bar will be made of (3) 3/4” thick steel tubes that are 19” in length. It will be welded to the lower runners and the brackets will be connected to it, so precise holes will need to be drilled in these bars.

10.2.9 Seat Bill of Materials

The seat will be made with all off the shelf materials obtained from our manufacturing shop. It will include all of the raw materials outlined below in Table 10.2.

Table 10.2: Seat Bill of Materials

Qty	Part Description	Purchased From	Part #	Cost
7	Ft. of 1” steel tube (1/8” thick)	UM	n/a	$0.00
5	Ft. of ¾” steel tube (1/8” thick)	UM	n/a	$0.00
1	Ft. of 3/8” x 1.25” steel plate	UM	n/a	$0.00

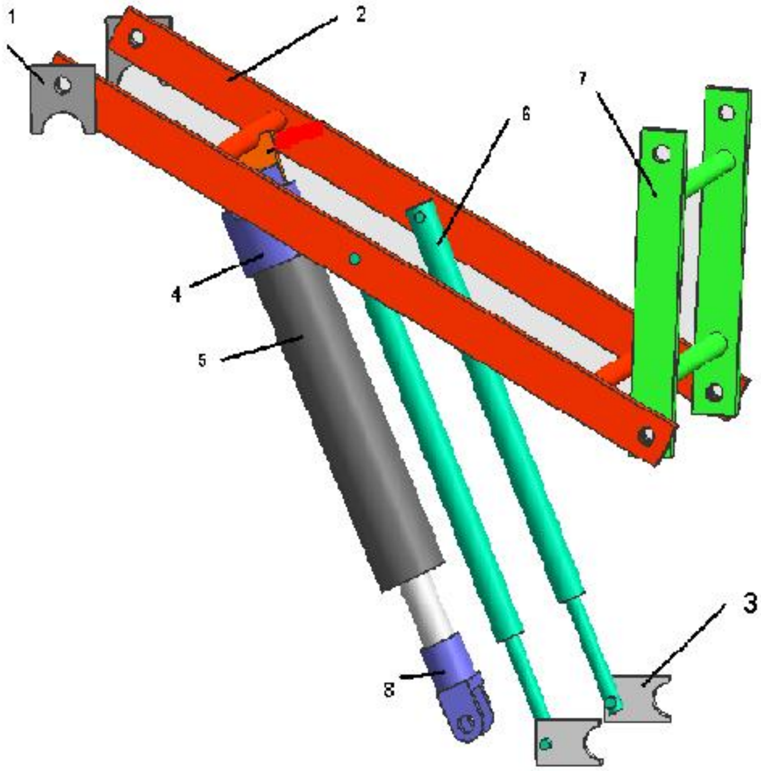
10.3 Pneumatic Linkage

The final design for the linkage is shown below with regards to engineering drawings and the bill of materials for the total assembly. Each individual part drawings and manufacturing plans are further detailed in the appendices. The total linkage assembly and the subsequent manufacturing file for assembly is shown 11.3.3.

10.3.1 Fully Assembled Linkage

Shown below in Figure 10.5 (p.42) is the assembled linkage with their respective parts identified. The table that follows it shows the nomenclature used to identify each part.

Figure 10.5: Detailed fully assembled linkage with key parts identified



No.	Name
1	Rear Linkage bracket (2X)
2	Lower linkage complete
3	Gas spring bracket (2X)
4	Upper Pneumatic bracket
5	Pneumatic cylinder
6	Gas spring (2X)
7	Upper Linkage complete(2X)
8	Lower pneumatic bracket

10.3.2 Rear Linkage Bracket

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix G. It will be made of (2) 1/4” thick by 1” wide steel plates. It will be welded to the frame in the rear and to the lower complete linkage. It will need to be machined precisely to provide smooth movement and for the locations of holes.

10.3.3 Lower Linkage Complete

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix G. It will be made of (2) 3/8"X1" square tubes and (2) 1/2" thick tubes. The cross-link tubes will be welded to the outer square tubes to provide structure and a place for the pneumatic cylinder to connect. The outer tubes will be connected to the upper complete linkage in the front and the rear linkage brackets in the rear using the purchased clevis pins.

10.3.4 Gas Spring Bracket

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix G. It will be made of (2) 3/8” thick by 1.25” wide steel plates. It will be welded to the cross braces to connect the linkage to the seat. It will need to be machined precisely to provide smooth movement. It will be welded to the frame in the rear and connected to the gas springs in the front using the provided pins from the gas springs.

10.3.5 Upper Pneumatic Bracket

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix G. It will be made of (2) 3/8” thick by 1.25” wide steel plates. It will be welded to the cross braces to connect the linkage to the seat. It will need to be machined precisely to provide smooth movement.

10.3.6 Pneumatic Cylinder

The pneumatic cylinder is a device that we removed from a computer chair. It will be the main elevating mechanism. It has a relief valve that is operated by the user squeezing the bike brake mechanism, to provide numerous elevating positions. It is attached to the linkage using the upper bracket and to the frame using the lower brackets.

10.3.7 Gas Spring

The gas springs will be purchased from International Gas Springs and will assist the user in elevating themselves. The total price for both was $73.88 and this is outlined in the total bill of materials.

10.3.8 Upper Linkage Complete

The dimensioned drawing for this part as well as the manufacturing plan is shown in Appendix G. It will be made of (2) 3/8" x 1" square tubes and (2) 1/2" thick tubes. The cross-link tubes will be welded to the outer square tubes to provide structure for the mechanism. The outer tubes will be connected to the lower complete linkage in the bottom and the seat on top using the purchased clevis pins.

10.3.9 Lower Pneumatic Bracket

The pneumatic bracket consists of three machined parts that were made according to the plans outlined in Appendix G. Its primary functions are to connect the cylinder to the frame as well as to operate the cylinder. Precision was required in machining these small parts to ensure functionality.

10.3.10 Linkage Bill of Materials

The linkage will be built with all of the shelf materials obtained from the machine shop with the exception of the clevis pins which will be purchased from McMaster-Carr that will be used to assemble the parts. Listed below in Table 10.3 is the bill of materials for the linkage.

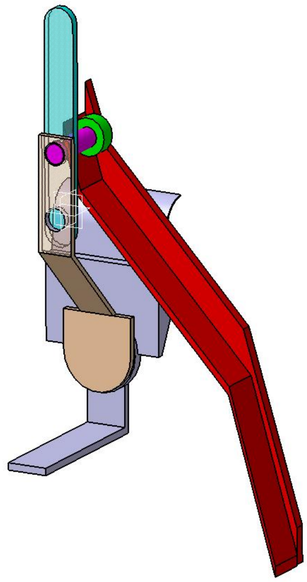
Table 10.3: Linkage bill of materials

Qty	Part Description	Purchased From	Part#	Cost
5	ft. of 3/8"X1" steel tube	UM		$0.00
4	ft. of 1/2" tube	UM		$0.00
1	ft. of 1/4"X1" steel	UM		$0.00
0.5	ft. of 3/4"X1" steel	UM		$0.00
0.5	ft. of 2" solid steel tube	UM		$0.00
0.5	ft. of 1" solid steel tube	UM		$0.00
0.5	ft. of 1/4"X1/8" steel	UM		$0.00
2	Gas Springs	IGS	1CU203468MM0890	$73.88
10	5/16" dia. clevis Pins	McMaster-Carr	97245A658	$5.13
10	3/8" dia clevis pins	McMaster-Carr	97245A679	$7.40
5	3/8" dia clevis pins	McMaster-Carr	97245A697	$4.92
			Total	**$91.33**

10.4 Automatic Braking System

To reduce the cost of production and make the manufacturing process efficient, one of the existing brake systems was used. This brake system was improved to make it an automatic engaging brake system which activates with the seat elevation. While this brake system can be operated just like a regular wheelchair brake system, it also reduces the force needed to activate the mechanism. A 3D CAD model of elevating wheelchair automatic brake system is shown below in Figure 10.6 (pg.46).

Figure 10.6: Finalized automatic brake system.



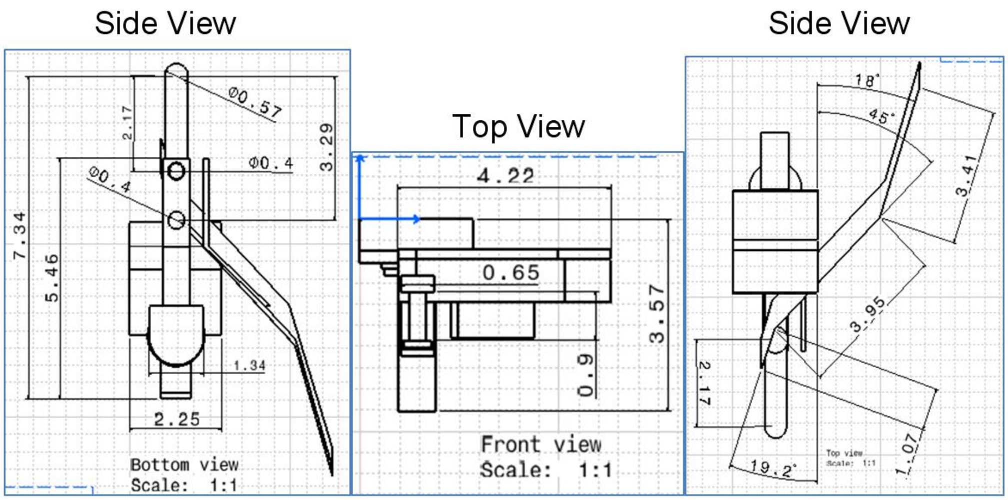
Additional sub components of this brake system are manufactured from “L” cross-section Aluminum bars and circular cross section Aluminum rods to maintain the weight. A detailed bill of material (BOM) for this brake system is shown below in table 10.4.

Table 10.4: BOM for elevating wheelchair brake system

Qty.	Part Name	Part Description	Purchased From	Part#	Cost
1	Wheel Track ("L" cross section)	12" of 1.5"X1.5" Alminum	UM		$0.00
1	Wheel Shaft	4" of 0.5"dia solid Aluminum bar	UM		$0.00
1	Wheel	Plastic wheel	UM		$0.00
				Total	**$0.00**

As per engineering specifications, the overall size of the brake system is kept minimal even with the additional components added. It was assumed that the force exerted by this brake mechanism against seat elevation is very small thus can be neglected. Figure 10.7 (pg.47) below shows top, bottom and side views of the wheelchair brake system with finalized dimensions. The complete manufacturing worksheets for all parts required of the automatic braking assembly can be found in Appendix I.

Figure 10.7: Top and side views of automatic brake system with dimensions.

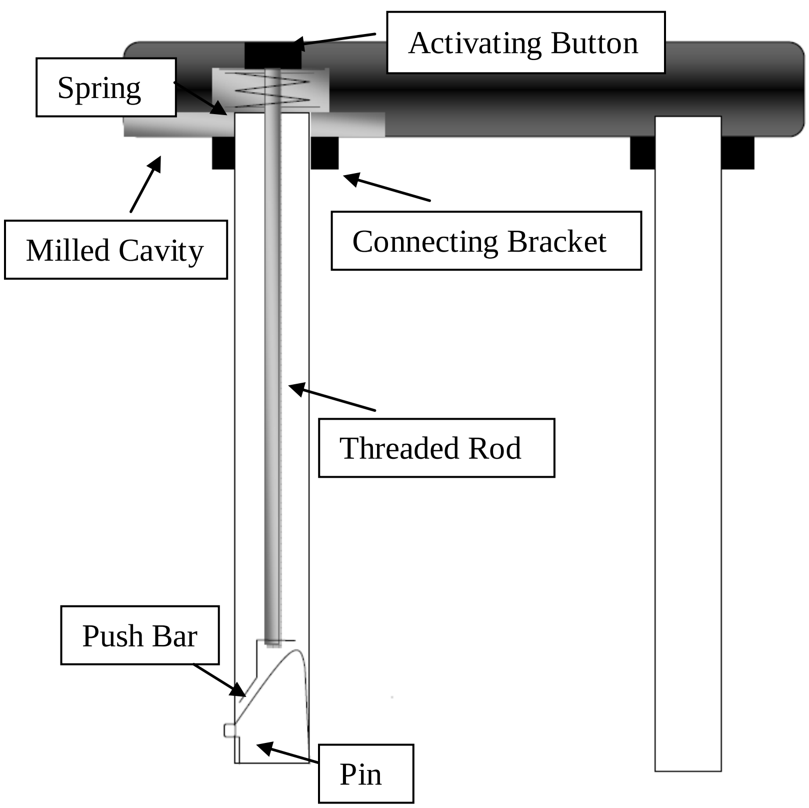


The complete manufacturing worksheets for all parts required of the automatic braking assembly can be found in Appendix H

10.5 Adjustable Armrests

The final main component of our design is the telescoping armrests. The design of the armrests is similar to both a suitcase telescoping handle and an umbrella pin system. Figure 10.9 schematically illustrates the key features of this design.

Figure 10.9: Schematic of Telescoping Armrests



To adjust the armrests, the user must press the activating button on the armrest. A threaded rod inside the tubing will then be depressed, allowing the push bar to move the pin. In this position, the inner tube is free to travel in the outer housing. When the user stops pressing the button, it will return to its position flush with the armrest due to the internal spring which is contained by two washers. A connecting bracket will be used to mount the tubing to the armrests with screws. The milled cavity allows easy access for assembly of the pin mechanism but requires the armrest to be made of two pieces.

Detailed CAD drawings, manufacturing plans and assembly plans are included in Appendix I. The main body of the armrests will be made from 2in. x 2in. PVC bar which can be easily milled as needed. Due to the small tolerances (±0.005 in.) with the telescoping tubing we will be required to purchase aluminum tubing from Alro Metals Plus. The tubing will be aluminum 1in. OD x 0.058 wall and 7/8 in. OD x 0.049 wall. In addition we will need to purchase one bicycle hand brake and 60 in. of bicycle brake wire from Campus Student Bike Shop. These materials are included in the bill of materials for the armrests which will cost $92.97 as shown below in table 10.5. The remaining materials will be acquired from the machine shop at the University of Michigan.

Table 10.5: Bill of Materials for Telescoping Armrests

Part	**Telescoping Armrests**		
Qty.	**Part Description**	**Purchased From**	**Price (each)**
1	8 ft. 1 in. OD x 0.058 Aluminum Tubing	Alro Metals Plus	$42.32
1	8 ft. 7/8 in. OD x 0.049 Aluminum Tubing	Alro Metals Plus	$36.72
1	Bicycle Brake Hand Lever	Student Bike Shop	$8.95
1	60 in. Bicycle Brake Cable	Student Bike Shop	$4.98
1	2 ft. length of 2in. X 2in. PVC Bar	University of Michigan	$0.00
1	42.5 in. of 1/4-20 threaded rod	University of Michigan	$0.00
1	1 in. of 1 in. diameter PVC rod	University of Michigan	$0.00
			$92.97

10.6 Complete Design Bill of Materials

Table 10.6 below shows our total estimated costs to manufacture our prototype design. The total cost of our design is estimated to be approximately $385.00.

Table 10.6 Complete Design BOM

Subsystem	**Cost**
Wheelchair Frame	$ 00.00
Seat Frame	$ 00.00
Pneumatic Linkage	$ 91.33
Automatic Braking System	$ 00.00
Adjustable Armrests	$ 92.97
Paint and Miscellaneous	$200.00
TOTAL	$384.30

11. MANUFACTURING

11.1 Material Procurement

All necessary materials will be purchased and shipped as soon as possible to ensure sufficient manufacturing time. The tubing will be purchased from Alro Metals Plus and the bicycle hand brake and brake wire will be purchased from Campus Student Bike Shop. Both will be purchased and acquired in person. The gas springs will be purchased online from International Gas Springs. Additional components such as fasteners will be purchased as needed.

11.2 General Manufacturing and Assembly Plan

The first step we will take in the manufacturing processes is to complete the wheelchair frame assembly. It is important to note that the two seat runners must be parallel and vertical in relation to the wheelchair frame. To complete this we will tack weld the two tracks together with two equal length tubes at both ends of the tracks This will ensure that they are parallel and vertical. We will then assemble the frame off of the two seat tracks to complete the wheelchair frame assembly.

The next step in the manufacturing processes will be to complete the seat frame. Since we have already completed the frame, we will use the vertical and parallel seat tracks when assembling the seat frame to also ensure that the seat frame will slide easily along the wheelchair frame. We will assembly the seat frame off of the two seat tracks to complete the seat frame assembly.

Then, we will complete fabrication and assemblies of the four bar linkage. We will fabricate brackets as well as the links, and the use the already assembled seat and wheelchair frame to ensure that our pneumatic linkage is assembled correctly. This will also allow us to make changes to the design if we run into problems.

Next, we will complete fabrication of brackets and mounting hardware for the pneumatic cylinder and gas springs, and then attaches them to the already assembled seat frame, wheelchair frame, and four bar linkage. Once again, completing the assembly in this order will allow us to make changes as we move along if our design is not quite as it was designed to be.

Finally, we will complete fabrication and assembly of all hardware in relation to the wheels and rear stabilizer bars. We will mount both front and back wheels to the wheelchair along with the stabilizer bars. This will allow us then to complete manufacturing of the automatic braking system. Once again, this process will allow us to make changes if necessary without having to change the entire design.

Overall, we think this process will ensure that we very few setbacks along the manufacturing and assembly processes, and if they do arise, that we have ample opportunity to correct them.

11.3 Sub-Function Manufacturing and Assembly Plans

We broke each sub function into manufacturing and assembly plans. These plans were incorporated to the complete manufacturing plan discussed in the previous section. The following sections further detail the manufacturing and assembly process.

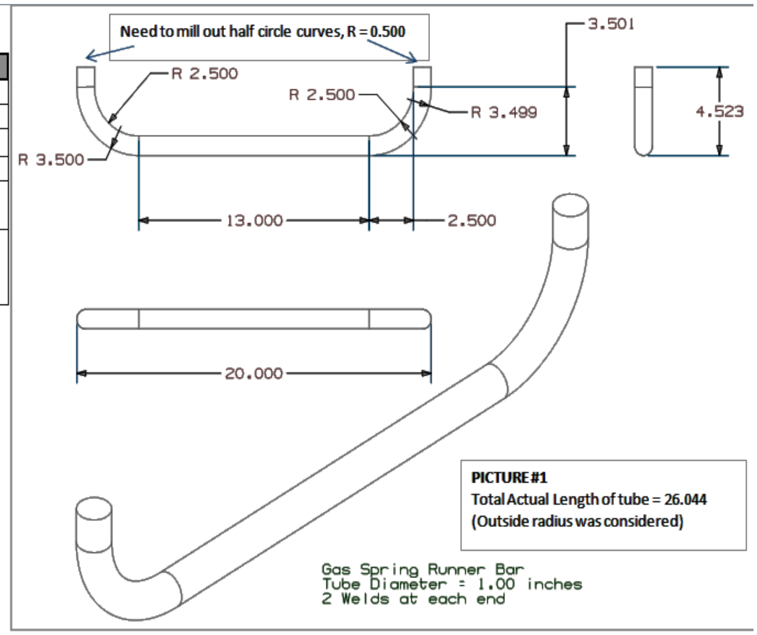
11.3.1 Wheelchair Frame Manufacturing and Assembly Plan

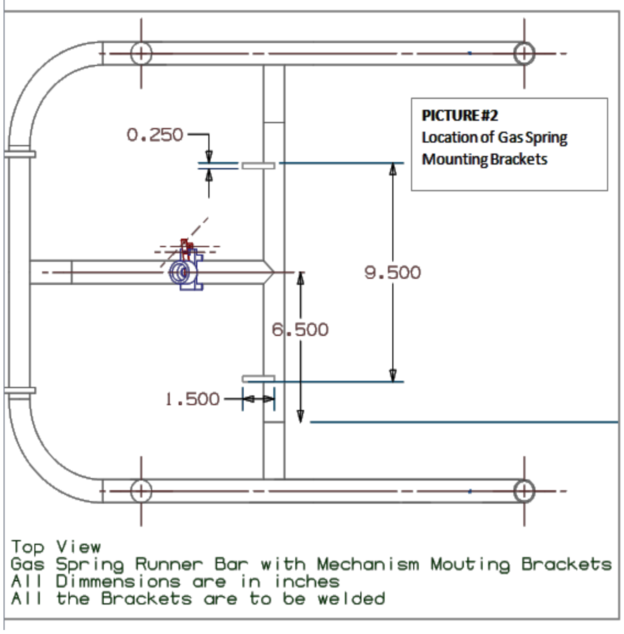
We have made some assumptions in manufacturing this frame such as using bent tubes will not cause any changes in material properties and also all the welds are strong enough for all the loading conditions.

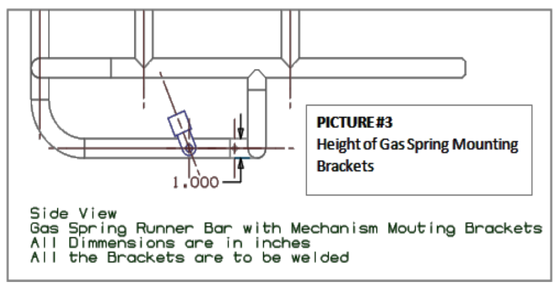
In order to build this frame systematically, manufacturing standard worksheets with required tool information were created for each sub component of the frame and they are attached in the Appendix F. The manufacturing worksheet for gas spring runner bar is shown below in Figure 11.1 as an example.

Figure 11.1: Manufacturing worksheet for gas spring runner bar

Part Name:		Gas Spring Runner Bar			
Raw Material:		1/4" thick, 1" Diameter steel Tube			
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 30~35" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Bend Tube as shown in Picture #1			Bending Fixure	Clamp
4	Cut steel tube at each end	Band saw	90 fpm		vise
5	Mill out half circle shap at each end for fitting	Manual Mill	200rpm		vise
6	Weld gas spring mounting brackets as shown in Picture 2 and 3	Welding machine	200rpm		Clamp/Vise







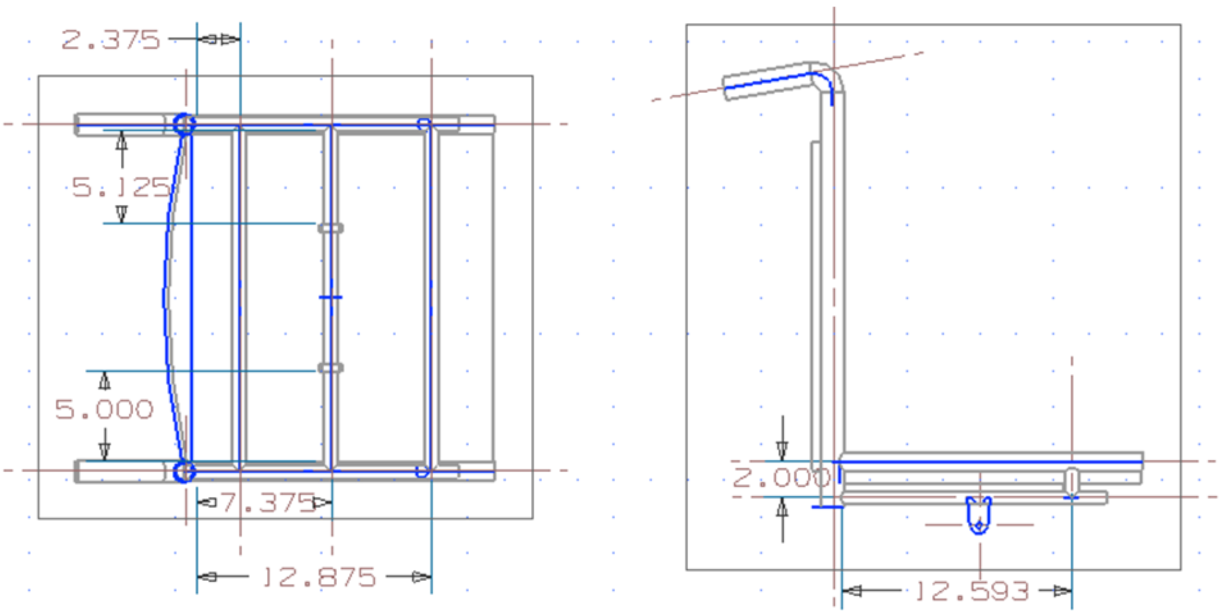
Once, all sub components of the frame are created, the frame is assembled to if everything coincides with each other according to engineering drawings. If necessary corrections are made at this stage and the entire frame is then welded at each joint. After attaching all the brackets on to the frame and completing further inspection, the frame then will be cleaned and prepare for panting.

11.3.2 Seat Frame Manufacturing and Assembly Plan

The seat will be assembled according to the assembly plan listed below in figure 11.2. It will use all of the machined parts that were outlined in 10.3.2 and in the Appendix G. Additionally, the existing wheelchairs seat back and seat will be mounted to the finished assembled frame, which will require drilling and using the given screws.

Figure 11.2: Manufacturing Worksheet for Seat Frame

Raw Material:					
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Layout and weld (2) brackets to center cross-brace	TIG welder			clamp
2	Layout and weld (3) cross-braces to lower runner	TIG welder			clamp
3	Layout and weld (2) 2" conn. to upper & lower guides	TIG welder			clamp
4	Layout and weld seat platform to back guide	TIG welder			clamp



11.3.3 Pneumatic Linkage Manufacturing and Assembly Plan

The linkage will be assembled according to the assembly plan listed below in Table 11.1 (p.52). It will use all of the machined parts that were outlined in 10.3.3 and in Appendix H. Special attention should be given to the positioning of the brackets to ensure proper and safe elevation.

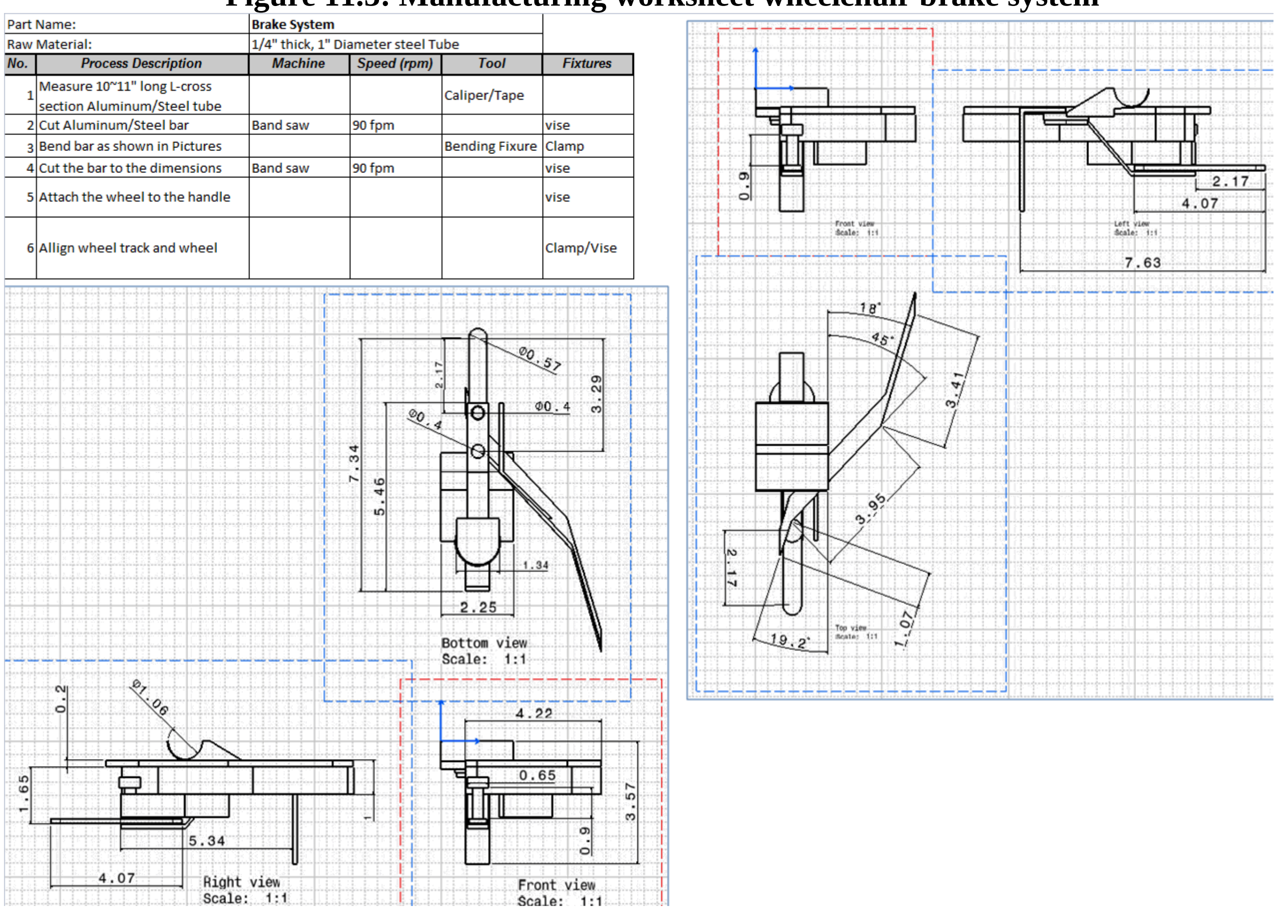
Table 11.1: Pneumatic Linkage Manufacturing Plan

Part Name:		Linkage Total Assembly		
Raw Material:				
No.	**Process Description**	**Machine**	**Tool**	**Fixtures**
1	Layout & weld (2) rear linkage brackets to frame	TIG welder		clamp
2	Layout & weld (2) pneumatic brackets to frame	TIG welder		clamp
3	Layout & weld (2) gas spring brackets to frame	TIG welder		clamp
4	Assemble & weld lower pneumatic bracket	TIG welder		clamp
5	Layout & weld (2) upper pneum. brkt. lower frame	TIG welder		clamp
6	Connect upper frame to bracket using 2 (3/8") pins			
7	Connect lower frame to bracket using 2 (3/8") pins			
8	Connect lower frame to upper frame using 2 (3/8") pins			
9	Connect (2) gas springs to brkts (4) (5/16") pins			
10	Connect pneumatic cylinders to brkts (2) (3/8") pins			

11.3.4 Automatic Brake Manufacturing and Assembly Plan

As mentioned above, a manufacturing standard worksheet was created for the brake system as well and it is shown in Figure 11.3 (p.51) below.

Figure 11.3: Manufacturing worksheet wheelchair brake system



Part Name:	Brake System				
Raw Material:	1/4" thick, 1" Diameter steel Tube				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 10~11" long L-cross section Aluminum/Steel tube			Caliper/Tape	
2	Cut Aluminum/Steel bar	Band saw	90 fpm		vise
3	Bend bar as shown in Pictures			Bending Fixure	Clamp
4	Cut the bar to the dimensions	Band saw	90 fpm		vise
5	Attach the wheel to the handle				vise
6	Allign wheel track and wheel				Clamp/Vise

Once wheel shaft and the wheel are attached to the existing brake mechanism, the entire sub assembly is mounted on the wheelchair frame as shown below in Figure 11.4.

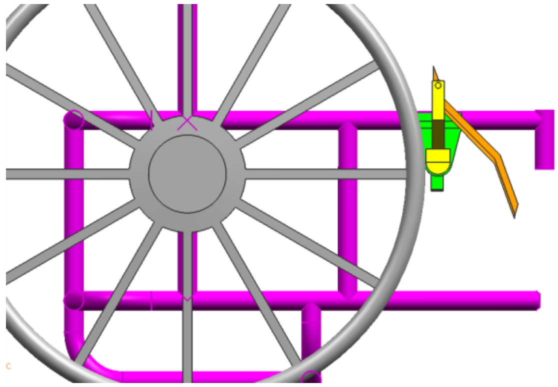


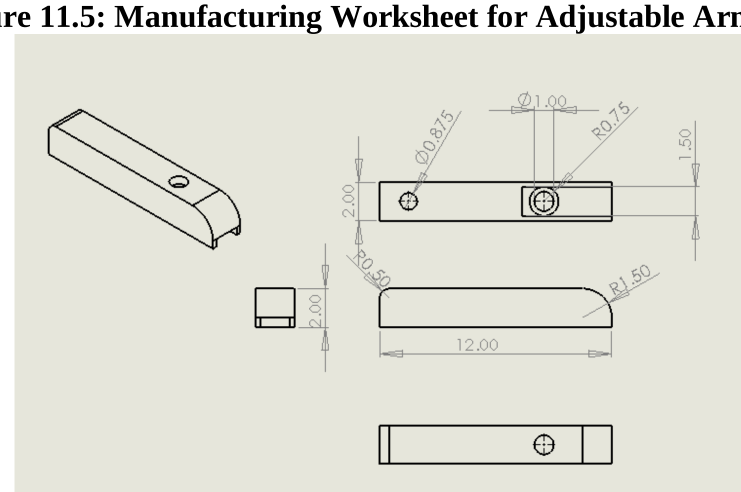
Figure 11.4: Brake system mounting location

Then, wheel track is attached to the seat frame. When the seat elevates, the wheel track moves vertically upward while, pushing the brake lever forward to engage brake. Since angle of wheel track is very critical to the force applied on the wheel, it was decided to test several different angles to minimize the delay in brake engagement.

11.3.5 Adjustable Armrest Manufacturing and Assembly Plan

The main component of the adjustable armrests is the armrest housing itself. This piece will consist of 2in x 2in PVC bar which will be milled and drilled according to the process plan and engineering drawing shown below in Figure 11.5. The telescoping tubing will require cutting to length and drilling holes for the pin mechanism in 2 in. increments. Details of the telescoping tubing are located in appendix I.

Figure 11.5: Manufacturing Worksheet for Adjustable Armrests



Part Name:		Armrest part 1			
Raw Material:		2 in. x 2 in. PVC bar			
No.	***Process Description***	***Machine***	***Speed***	***Tool***	***Fixture***
1	Measure 12 in. long bar			ruler, marker	
2	Cut bar to length	Band saw	120 fpm		vise
3	locate front hole center	Mill			vise
4	Drill 1 in. Thru Hole	Mill	200 rpm	1 in. drill bit	vise
5	drill 1.5 in. hole 1.5 in. depth	Mill	200 rpm	1.5 in. end mill	vise
6	Mill 1.5 in wide cavity 4.625 in. from end with 0.5 in. depth	Mill	200 rpm	3/8 in. end mill	vise
7	Locate rear hole center	Mill			vise
8	drill 7/8 in. hole 0.5 in. depth	Mill	200 rpm	7/8 in. end mill	
9	Create 1.5 in radius fillet at front	Mill	200 rpm	3/8 in end mill	vise
10	Create 0.5 in radius fillet at rear	Mill	200 rpm	3/8 in end mill	vise

During the manufacturing process we will refine this design as any problems arise. Specifically we will need to finalize the location and method of mounting the bicycle hand brake and cables to activate the pneumatic cylinder. In general this will involve bolting the hand brake into a channel in the bottom of the right armrest. Slight modifications such as drilling holes and cutting away unneeded material will need to be made to the bicycle hand lever.

11.4 Prototype Manufacturing

First, we established a manufacturing sequence plan in order to understand the priorities and to identify key points where accessibility can become an issue in assembly process. According to the sequence established, we would first make the frame, followed by seat frame, linkage system, brake, leg rests, arm rests and stabilizer bars. Each sub component was manufactured according to standardized work sheets and all the joints to be MIG (Metal Inert Gas) welded are first tack welded before the final weld.

11.4.1 Wheelchair Frame

As stated in manufacturing standardized worksheet, the wheelchair frame was created out of one inch diameter steel tubes. First, the straight tube parts were cut according to dimensions and then shaped to fit with other parts (putting a U-shape on each end). Other tube parts: gas spring runner bar, pneumatic runner bar, bottom U-frame and rear top U-frame were bent using a manual pipe bender and then cut according to the dimensions. Bending steel tubes using a pipe bender was challenging since we had to figure out exactly where we want bending to start and where to stop, at what angle, and what is the radius of curvature.

Then, the gas spring runner, pneumatic runner bar and bottom U-frame were tack welded together and dimensions were measured. Before seat runner bars are attached to the bottom U-frame, they were tack welded to two same length spacers to keep them parallel. Once both seat runners were tack welded to the bottom U-frame, top-bottom U-frame connector bars also are connected to the bottom U-frame. Next, the rear top U-frame and both front-top frames were tack welded to the partially completed wheelchair frame. Front wheel attaching bars, stabilizer mounting bars and wheel attaching brackets were then welded to the frame. Finally, gas spring brackets, pneumatic cylinder bracket and linkage brackets were welded to the frame.

11.4.2 Seat Frame

As shown in Figure 10.4 and Table 10.2, the seat frame is made out of three different diameters steel tubes: 1.25, 1 and ¾ inches. First, all straight tubes were cut according to pre-determined dimensions and two upper bars were bent and cut. Upper and lower horizontal runner bars were connected using two connector braces and three cross braces. Just like the seat runner bar welds in the wheelchair frame, the two upper bars of seat were welded to an external bar to keep them parallel before connecting them to the rest of the seat frame. Next, two linkage brackets were welded to the middle of the cross brace and two leg rest brackets were attached to the horizontal upper runner bars. Finally, the automatic brake system's "L" cross section steel bar tracks were welded to each side of the seat.

11.4.3 Linkage System

The linkage system was manufactured using materials shown in Table 10.3. After all the steel bars were cut according to dimensions, the upper linkage complete and the lower linkage complete were welded as shown in Figure 10.5. Using 3/8" diameter pins, the upper and lower linkages were united.

11.4.4 Brake System

The pair of existing wheelchair brakes were modified by attaching a small solid Aluminum bar to the inside surface of each of the brake levers (Figure 10.6). In order to attach wheelchair brakes to the frame, two small brackets were made out of 0.5 X 0.125" cross section steel bar. These two brackets were welded to each side of wheelchair frame at the desired location. To create the automatic brake activation, we bent 1/2" L section channels to the desired shape. Slight modifications to the curvature were made during manufacture to fine tune the motion.

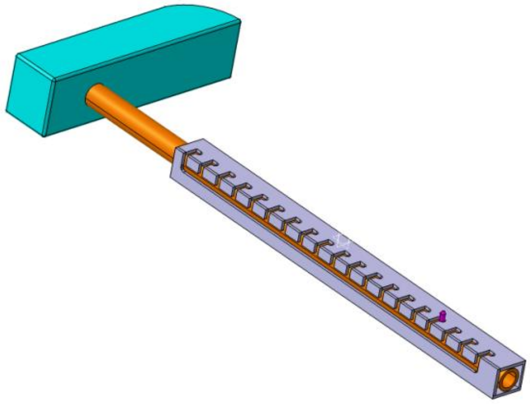
11.4.5 Leg Rests

The leg rests came from an existing wheelchair and were modified by cutting off unnecessary parts and then in the assembly process, they were attached to the front of seat frame using bolts and nuts.

11.4.6 Armrests

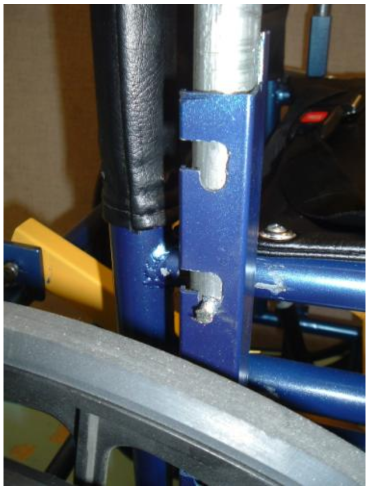
According to the armrest design (Figure 10.9), one armrest was manufactured using PVC and Aluminum bars. As shown in Figure 11.5, 2" square solid PVC bar were cut according to the dimensions and then milled out the cavities on a manual milling machine. The outer front curved surfaces were also milled out and smoothed using a manual file. Then the purchased bicycle brake activation lever was attached to the right armrest using a 1/4"-20 bolt. Next two 1 inch diameter hollow Aluminum tubes were cut to dimension and a series of holes (.25 inches of diameter) were drilled for the push-pin system. The inner telescoping tubes to be connected to armrest were made out of two ¾" diameter hollow steel tubes. They were cut according to dimensions and pin systems were attached to the each end. At this point, we tested the entire mechanism for its rigidity and durability. We found that even though it was rigid enough for the application, it was not durable for continuous smooth operation. Due to this we had to change the height adjustment mechanism and a sketch of a final design is shown below in Figure 11.7.

Figure 11.7: CAD Model of Revised Armrests



This mechanism would allow the user to adjust armrest height by rotating the armrest 90 degrees to the outside, set the armrests to the desired height and by rotating armrest back 90 degrees to the inside. As shown above, two 1" x 0.058" wall square cross section steel tubes were machined using a manual mill. The inner tubes from the original design were used by adding a 1/4-20 bolt protruding through the hole for the pin mechanism. The brake cable was routed through the aluminum tube. Then, both square cross section hollow steel bars were offset by 1" diameter steel tube brackets and a 1/4" spacer and welded to both sides of wheelchair frame. The offset allowed sufficient room for the armrests to pass by the seat edges. A picture of manufactured armrest is shown below in Figure 11.8.

Figure 11.8: Modified Armrest on Prototype



11.4.7 Stabilizer Bars

Using 1" square cross section hollow steel tubes, the stabilizer mounting bars were cut according to dimensions and holes drilled for screw attachment of salvaged stabilizer bars from an existing wheelchair. These two stabilizer mounting bars were welded to the bottom side of rear bottom U-frame.

11.5 Prototype Assembly

Once all the components were manufactured, we assembled a dry fit to ensure accurate assembly. Since everything functioned as expected, we then disassembled them and completed the final welds where necessary. Then we removed weld spatter and smoothed rough surfaces and edges using a pneumatic grinder. All the parts to be painted were cleaned and transported to the paint booth.

First a primer coating was applied to the seat frame, linkage system and to the wheelchair frame. The seat frame and wheelchair frame were then painted in dark metallic blue, while the linkage system was painted in yellow to highlight the elevating mechanism. The seat cushion obtained from an existing wheelchair was painted black to match the parts.

Once all the painted surfaces were dry and ready to be assembled, the large wheels and front caster wheels obtained from an existing wheelchair were attached to the frame. Next, the seat frame was inserted over the seat runner bars. The linkage system along with two gas springs and a pneumatic cylinder was assembled while the seat frame was at its maximum elevated position. Then the modified armrests were mounted on the brackets of each side of the wheelchair frame and leg-rests were also mounted to the front of the seat frame. Before installing the seat cushion, we lowered the seat by pushing it down with brakes engaged and locked in place by the pneumatic cylinder. The bottom seat cushion was attached to the seat frame using screws while the back seat cushion was slid over the upper bars of the seat frame. Then the end of the brake cable was connected to the pneumatic cylinder activation lever. Finally, we completed the assembly process by attaching the stabilizer bars to the stabilizer mounting bars located under rear u-frame. A picture of elevating wheelchair final assembly is show below in Figure 11.9.

Figure 11.9: The Final Assembly of Elevating Wheelchair

Upon initial testing, it was clear that the gas springs were too powerful for this design. The initial calculations estimated a required force of 400 lbs (1780 N), but provided too much force to easily lower the user from the elevated position. Slight changes in the orientation of the gas springs due to the mounting brackets caused the vertical component of the force to change. After additional calculations it was determined that the springs should provide 250 lbs (1110 N), so two springs charged at 125 lb (555 N) each were purchased and installed.

12. TESTING AND VALIDATION OF PROTOTYPE

12.1 Testing

In order to ensure all of our design requirements are met, we conducted a variety of tests to analyze our prototype as outlined in Table 12.1 below. Each test was designed to analyze a specific characteristic of our design. The results of the testing are outlined below.

Table 12.1: Testing Plan and Description

Test Description	Test Purpose
Operate Wheelchair with 100 Kg Mass	Confirms specifications of speed and height as well as maximum elevated mass
Push on Wheelchair with 500 N Force (lowered/elevated)	Confirms brake effectiveness
Weigh Wheelchair	Confirms mass under 25 kg
Hold 10 Kg Mass At Arms Length Elevated	Confirms stability of wheelchair
Use Wheelchair in Public Areas	Confirms smoother operation and ease of use

Test #1: Operate wheelchair with 100 Kg mass (including user)
This test confirms specifications of elevation (speed and height) and allowable elevated mass. This test showed that our design could withstand the load required of 100 kg. The pneumatic cylinder was able to lock the position at maximum elevation. An extension of over 40 cm is possible with this design however with heavier users, some sag occurs upon locking so the final elevation may be reduced. In addition the time to elevate was under 20 seconds as required but will depend on the physical abilities of the user.

Test #2: Push on wheelchair with 500 N force with brakes engaged
This test confirms stability of wheelchair and effectiveness of brakes. The chair remained stationary despite the exertion of the force. During additional testing we discovered that the wheels will slip relative to the floor before they will rotate.

Test #3: Weigh wheelchair
The goal of this test was to confirm a mass under 25 kg. (55 lbs). The wheelchair weighed 33 kg (74 lbs). Although this was above our target weight this is not extremely heavy and is lighter than other comparable models. The New Heights Manual Elevating Wheelchair which is electrically elevated but manually propelled weighs 36 kg. (80 lbs). Although we did not meet our goal the chair is not difficult to propel. Additionally, material changes could be used to reduce the overall weight and are discussed in the improvements section.

Test #4: Hold 10 Kg mass at arm's length
This test confirms stability of the wheelchair. The chair has a large wheelbase which provides significant stability. This condition was previously analyzed to be stable through free body analysis but was confirmed through our prototype tests.

Test #5: Analyze wheelchair through trials
The goal of this testing was to confirm smooth operation and ease of use. By allowing multiple individuals to use the wheelchair we were able to confirm it is indeed easy and straight foreword to use. After a few trials, the user is easily acquainted with the operation. The user also easily remembers which height setting on the armrests to use to allow full elevation. The force exerted by the users was not

significant and no users complained of discomfort. The motion is regulated by the pneumatic cylinder and is thus smooth and continuous.

12.2 Validation of Customer Requirements

In order to achieve a successful design, we needed to evaluate our prototype against the customer requirements. Table 12.2 shown below is repeated to show each of the customer requirements.

Table 12.2: Elevating Wheelchair Customer Requirements

Category	Customer Requirement
Safety	14. No harm to user
	15. Stable
Mechanism Functionality	16. Manual powered
	17. Multiple height adjustments
	18. Quick height change
	19. Durable
Wheelchair Functionality	20. Same personal mobility as standard wheelchair
	21. Able to transport tools
	22. Easy to move around
Geometry	23. Fit in factory aisle
	24. Achieve average person's height
	25. Comfortable
Budget	26. Low cost (< $750)

Safety

This design meets the customer requirement of safety. As proved through our evaluations and confirmed through testing in the elevated position, the prototype is not unstable. Additionally, the design itself was chosen in part due to its ability to prevent user harm. This design uses no crossing linkages which could lead to user injury. Large gaps were made where parts move relative to each other to prevent pinch points. Lastly, care was taken in the manufacturing process to ensure there were no sharp edges or protrusions that could be dangerous.

Mechanism Functionality

Our design is fully manual powered which fulfills one of these customer requirements. Also the pneumatic cylinder allows for infinite height settings and a quick height change. It takes approximately 10 seconds to go from the lowered to fully elevated positions. The design is also very durable as everything is made of steel and has a large safety factor.

Wheelchair Functionality

The functionality requirement was not completely met. The user loses some range of reach around the sides of the chair due to its additional size. This was needed to ensure both stability in the elevated position as well as room for the armrests and linkage. The final design did include a hook that attached to the rear of the seat for carrying tools fulfilling the transportation of tools requirement. The chair is very easy to move. Although it cannot be quantified, it had a very similar rolling motion as a standard chair.

Geometry

The geometrical requirements were completely met. It will indeed fit in a standard factory aisle which we quantified as being 1.5 meters. In the fully elevated position, we were able to give the user the same reach as an average standing person (an oblique reach of 2 meters). By utilizing the existing wheelchair's back rest and cushion we met the requirement of being comfortable.

Budget
We were under the budget requirement of $750 as our total prototype cost was $517.74. If we wanted to sacrifice cost we could have used a lighter weight material which in turn would have helped us meet the engineering specification of weighing less than 25kg.

13. PROTOTYPE BUDGET REPORT

Table 12.3 below summarized the allocation of funds to complete the manufacture and assembly of our prototype.

Table 12.3: Allocation of Funds for Prototype Production

Part	Cost
Gas Springs	$187.34
Hand Lever	$14.77
Metal	$246.45
Paint	$32.68
Fasteners	$36.50
Total	**$517.74**

Due to a variety of factors, the prototype cost more than it could have. Since we had to reorder two additional gas springs, the cost for that part was double what it could have been. Additionally, the metal supplier had minimum quantities for the orders so additional scrap metal was left behind. We did however make up for some of this cost through the use of salvaged parts from donated wheelchairs such as all four wheels, the stabilizer bars, the leg rests, and the seat cushions. These parts if purchased separately would cost hundreds of dollars. Overall, we were efficient in our spending and easily maintained a cost within our budget.

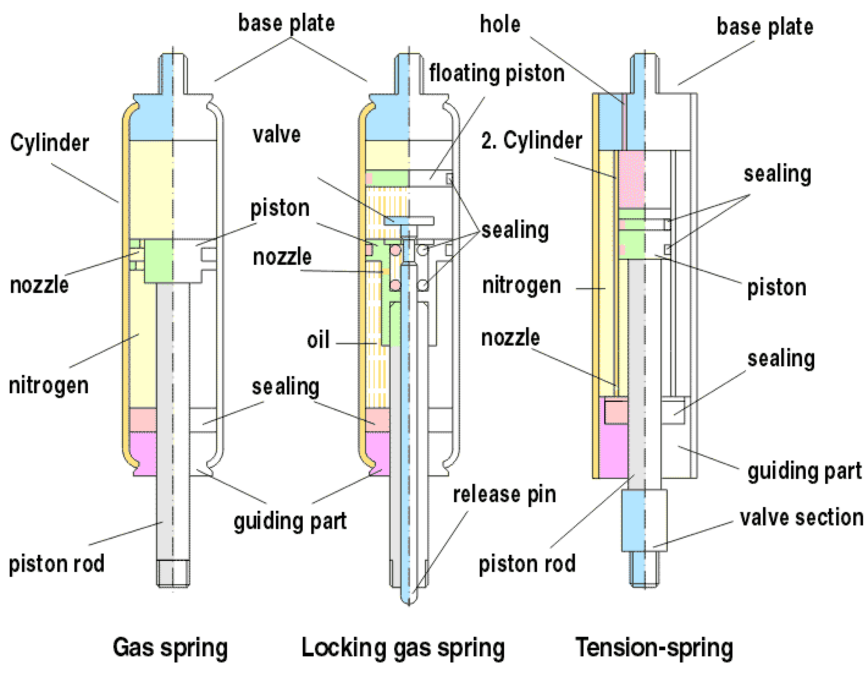
14. FUTURE IMPROVEMENTS

There are a variety of ways in which this design may be improved that were not implemented in the prototype. Some of the improvements will not be feasible except on a mass production scale.
One main area to improve is comfort. Most wheelchairs are customized for the individual with personalized seat dimensions and leg rest sizes. This could easily be incorporated into our current wheelchair design. An ergonomic analysis should be conducted to improve the shapes of parts the user interacts with such as the armrests and the lever. Additionally a more comfortable material could be used for the seat and armrests such as foam padding.

A second improvement could be to create a more compact design. The width of the chair could be reduced by making slight modifications to the frame although the reduced wheelbase would affect lateral stability slightly. The seat height at lowest elevation could be reduced to accommodate smaller users. In addition, material changes would reduce the weight of the chair. Aluminum would be a good alternative to steel due to its similar material strength with one third the density. This change would increase the cost of the chair however and must be considered in the design.

Lastly a refined design could reduce the number of parts. One larger central gas spring with double the charge of the existing springs could be used to reduce parts and cost. The pneumatic cylinder, primarily used as a locking mechanism, could be removed if locking gas springs were used. The locking gas spring would be activated in the same manner as the pneumatic cylinder; a plunger would be depressed to allow fluid motion within the cylinder. As Figure 14.1 below shows, the locking gas spring is more complicated with additional internal parts, but entirely replaces the pneumatic cylinder.

Figure 14.1: Schematic of Locking Gas Spring



15. CONCLUSION

To meet the demand of a low-cost, safe, manually powered elevating wheelchair we researched the market, spoke with our sponsors and met with key individuals in the field in order to fully define the scope of our task. From this research, customer requirements were defined which were turned into engineering specifications and correlated using the aid of a QFD diagram. From the QFD the most important design characteristics are the wheelchair dimensions, maximum vertical travel distance and maximum user force applied to mechanism. To move forward with the design a project plan was developed that outlined key deadlines including dates for the design reviews as well as dates for the completion of CAD drawings, manufacturing plans, material selection, fabrication and assembly and lastly testing and prototype refinement.

The second design review included concept generation and selection. To meet these requirements, we organized our thoughts using high-level FAST diagrams and morphological charts. This led us to developing the ideas for the main function, to elevate the user, and the secondary functions which included keeping the user safe. Each of the design concepts was critiqued using a Pugh chart which compared the designs against the customer requirements as well as our own requirements which included feasibility and ease of manufacturing and assembly. We chose the pneumatic linkage lifting mechanism to elevate the user and discussed design characteristics and material choices to achieve this design. The updated project plan outlined the steps to design review three in which we presented our engineering drawings and specifications.

The third design review involved engineering analysis (quantitative, qualitative, and geometric) to confirm that our design was viable and would achieve the necessary goals of this project. It also included the manufacturing processes, materials, and assembly processes that would be used to create the prototype. These, coupled with our detailed and dimensioned CAD drawings, allowed us to build the prototype with confidence that it will operate as expected. Additionally, considerations were also made to assure that materials were ordered on time and that tools needed would be available.

Finally, our prototype was manufactured exposing a few weaknesses in our design. We were able to fix many problems that arose during manufacturing and in the end; the prototype was more successful than we had originally thought.

Overall, our design is successful, providing an innovative and low cost solution to our design problem. While there are other models available which provide elevation of the user, our design is unique. It is the only design which combines the mobility of an ordinary wheelchair, the reach of an average standing person, quick elevation, and a low cost design. For these reasons, our elevating wheelchair is the only chair suitable for an assembly plant environment.

15. ACKNOWLEDGEMENTS

We would like to thank the following people for their help and support throughout the semester. Your guidance and wisdom proved valuable and is greatly appreciated.

Prof. Yoram Koren, Center for Reconfigurable Manufacturing Systems Director, University of Michigan
April Bryan, Mechanical Engineering Graduate Assistant, University of Michigan
Steve Erskine, Technical Services Supervisor, ERC
Bob Coury, Engineering Technician, University of Michigan
Robert Bechtel, Certified Rehabilitation Technology Supplier, Wheelchair Seating Services
Donn Hilliker, Rehibilation Engineering Program, University of Michigan Health Systems
Rock Lewis, Director of Purchasing, Mitchell Home Medical
Dr. Greg Lindemann, MedEquip Home Care
Rock Lewis, Mitchell Home Medical
Dr. Matthew Reed, Associate Research Scientist, Biosciences Division, UMTRI
Donn Hilker, Supervisor and Senior Rehabilitation Engineer, Rehabilitation Engineering Program
Prof. Thomas J. Armstrong, Department of Ergonomics, University of Michigan

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[6] Reid Supply Company, <https://reidecom.reidtool.com/xephr/edit/ITEM_GROUP_DETAIL?query=*ITEM_NO=SMC-5027&query=*GROUP_ID=134469>

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[13] United States Patent Office, <www.uspto.gov>

17. CONTACTS

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Dr. Matthew Reed, Associate Research Scientisy. Biosciences Division. University of Michigan Transportation Research Institute. (734) 936-1111

Donn Hilker, Supervisor and Senior Rehabilitation Engineer. Rehabilitation Engineering Program Physical Medicine and Rehabilitation. (734) 936-7172

Steve Erskine, Technical Services Supervisor. Mechanical Engineering/ERC. (734) 763-4039

18. TEAM BIOGRAPHIES

Josh Diaz

Joshua Diaz is originally from Memphis Michigan a rural town about an hour north of Detroit. His high school math teacher first sparked his interest in becoming an engineer, as she herself is a Mechanical Engineering graduate from our university. His previous work includes time spent with Faurecia Automotive as a manufacturing and project engineering intern and a laboratory assistant with the ERC here at the university. His projected graduation date is April, 2008 where he will then pursue a career in product development.

Calvin Helfenstine

Calvin Helfenstine is from Hudson, Ohio, a suburb of Cleveland. He has been strong in math and science throughout school but developed his interest in engineering in high school. He has been interested in design and extreme projects that push the limits of what is deemed possible. Magazines such as Popular Mechanics and shows like Extreme Engineering sparked his interest in the Mechanical Engineering field. He has previously worked as an intern at Swagelok Company in Solon, Ohio and Shell Oil Company in Houston, Texas. He plans to work in industry for a few years, obtain his MBA and start his own business in an interesting international location.

Scott Hyder

Scott Hyder is from Oxford Michigan, located approximately 1 hour north of Ann Arbor. He knew that he would become an engineer well before high school, where he always had a fascination with how things worked. Scott plans to work in either product development or manufacturing. His past work experience includes: Mechanical Intern for Shell Chemicals, Design Engineering Intern for Faurecia Automotive, Apprentice Electrician for the City of Auburn Hills, and Precision Machinist for Welty Precision Fabrication

Milinda Kannangara

Milinda Kannangara came to United States in 2002 from his home country of Sri Lanka, the county known as Holiday Island, just south of India. Since playing with *LEGOs* when he was younger, Milinda had an interest in automotive engineering. He started his college degree in computer information systems but later changed to mechanical engineering. Milinda has completed a 6 month co-op at Toyota Motor Engineering and Manufacturing (TEMA). His future plan is to practice automotive engineering with an emphasis on lean manufacturing.

Appendix A

Quality Function Deployment for Elevating Wheelchair

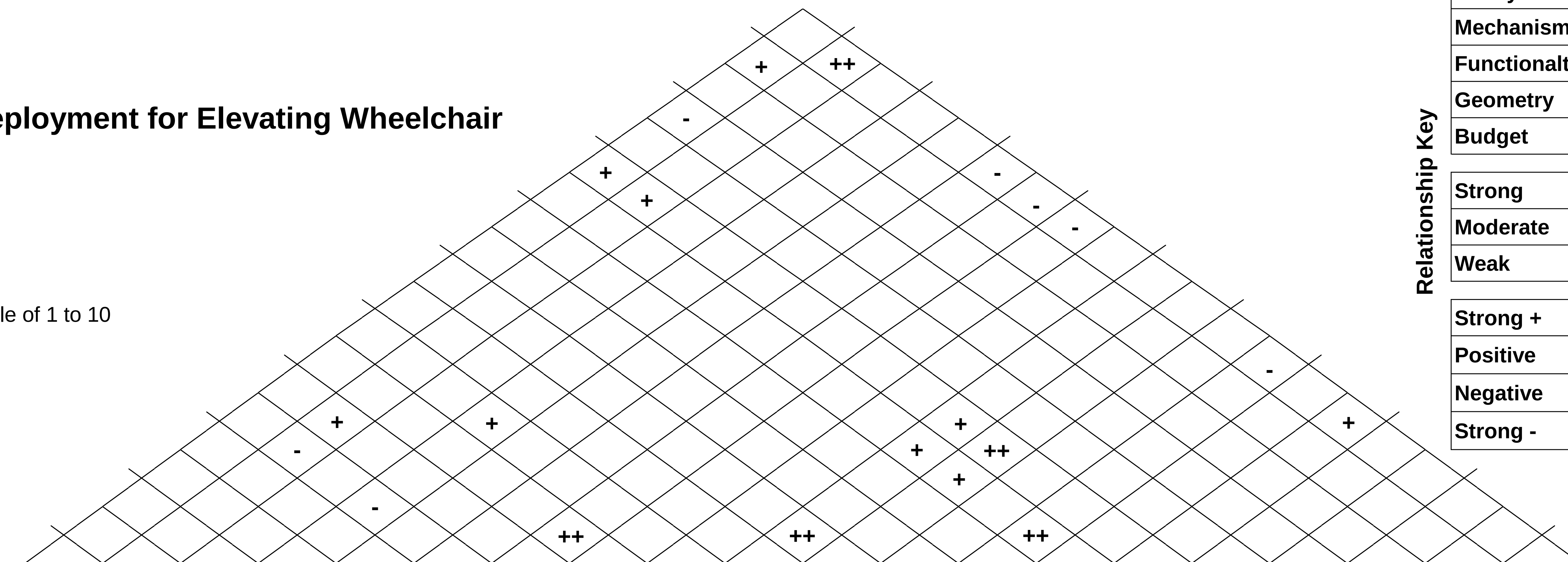
Relationship Key

Safety	(green)
Mechanism	(yellow)
Functionalty	(blue)
Geometry	(pink)
Budget	(orange)

Strong	9
Moderate	3
Weak	1

Strong +	++
Positive	+
Negative	-
Strong -	--

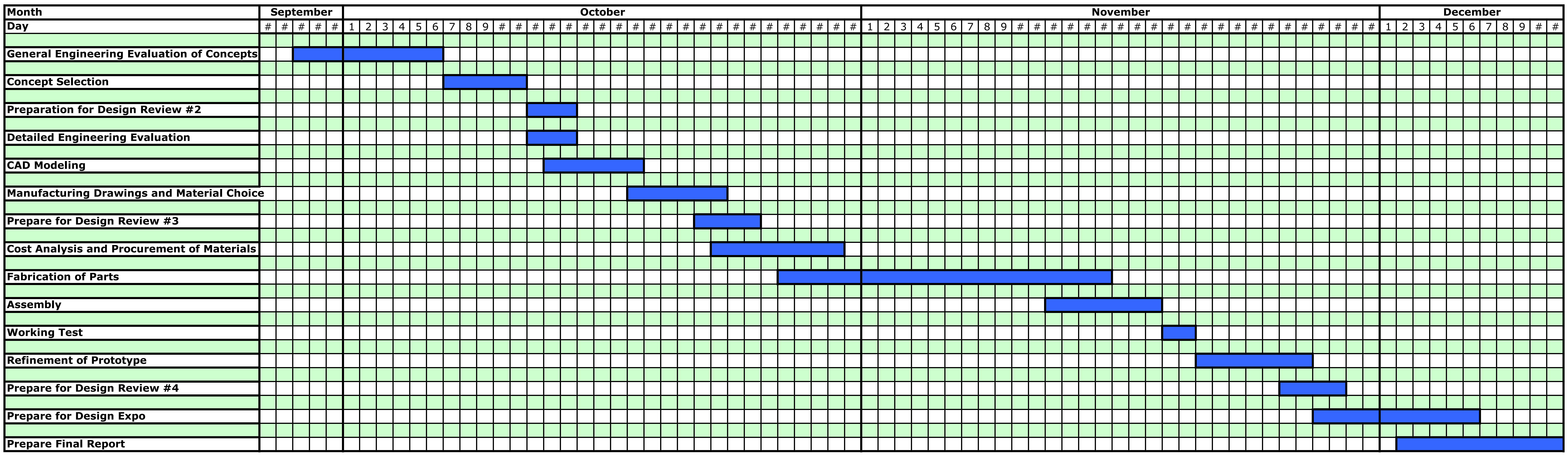
***Weights** are figured on a scale of 1 to 10
(10 bering the most important)



Engineering Characteristics
(+) more is desired
(-) less is desired

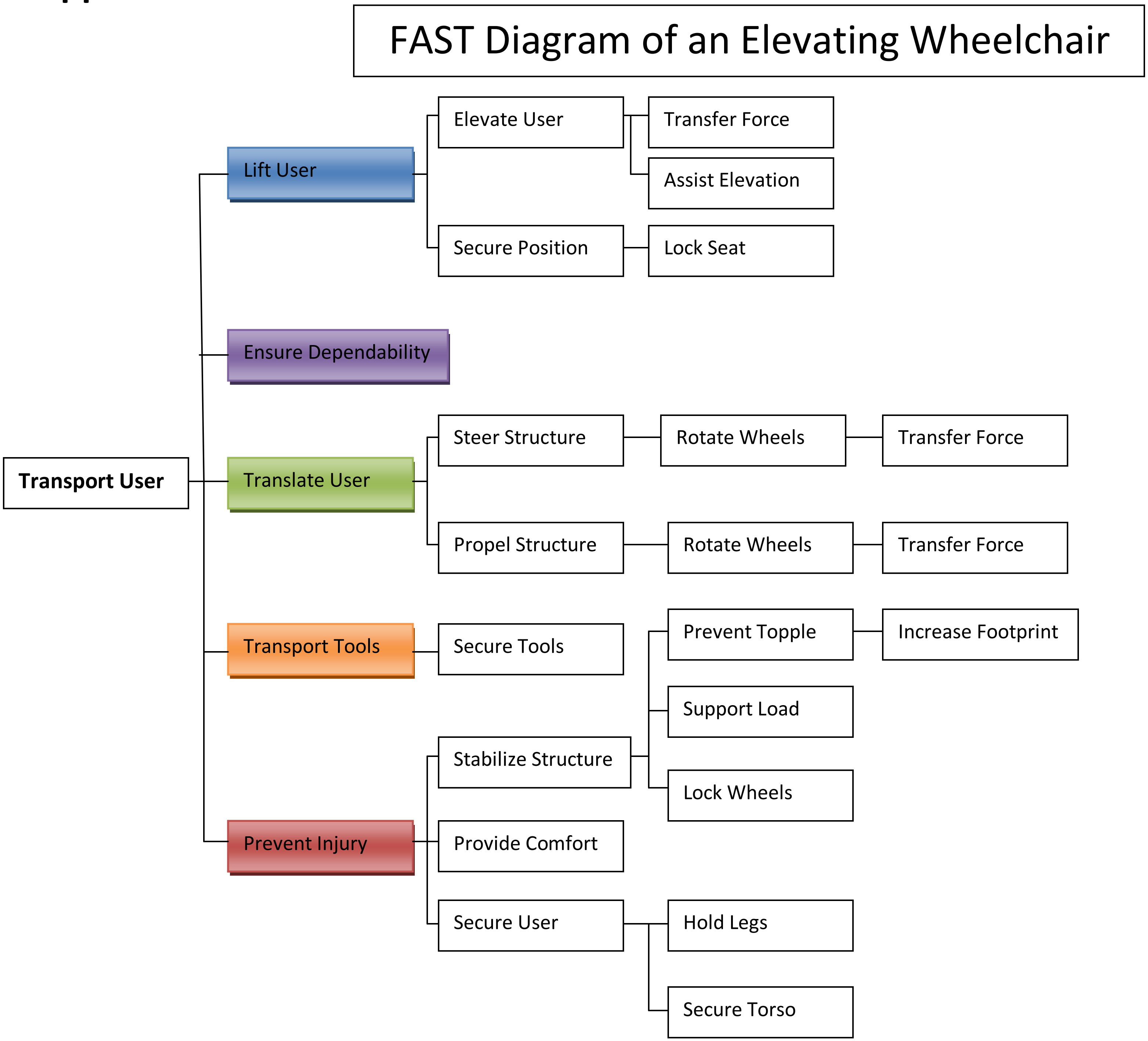
	Customer Requirements	Weight*	1 Allowable weight at max. height at arm's length (+)	2 Maximum force applied to user mechanism (-)	3 Brake force (+)	4 Number of exposed dangerous moving parts	5 Number of height settings available	6 Lifetime of elevating mechanism	7 Elevating velocity range	8 Time to reach max. possible height	9 Number of electrical components	10 Storage capacity (+)	11 Max. storage weight(+)	12 Range of frontal ground level reach (+)	13 Seat dimensions - (L x W)	14 Wheelchair dimensions - (L x W x H)	15 Mass of wheelchair	16 Unelevated reach	17 Max. vertical travel distance and reach	18 Number of armrest position adjustments (+)	19 Number of legrest position adjustments (+)	20 Maximum weight to be elevated (+)	New Heights Manual Chair
Safety	No harm to user	10	3	9	3	9			3	3					1		3					3	4
	Stable	9	9		9		1	1	3	3			3	1		9	3	1	9			9	5
Mechanism	Manual powered	9		9		1	3	1	3	3							3						3
	Multiple height adjustments	7					9	1	1								3		9			1	5
	Quick height change	7		9			9		9	9							1		3			9	3
	Durable	5	3	1		9		9			3						1						3
Functionality	Same personal mobility as standard wheelchair	8			9						3	3	3	9	3	3	3	9		3	3		5
	Able to transport tools	7										9	9										1
	Easy to move around	3			1						3				3	9	3						3
Geometry	Fit in factory aisle	10													3	9							5
	Achieve average person's height	9					3												9			3	5
	Comfortable	9												1	9	3		1		9	9		3
Budget	Low Cost	8				3	3	3		3	3	3			3	3	3					3	1
	Unit		N	N	N	#	#	cycles	m/s	sec.	#	m^3	Kg	degree	m	m	Kg	m	m	#	#	Kg	
	Target Value		220	Ave. force < 21% max.	> 500	0	3	600000	0.01 - 0.15	20	0	0.0045	3.5	180	L=0.43, W=0.40	< L=1.10, W=0.65, H=1.60	< 25	Vertical =1.8, Oblique= 1.6	0.4, Oblique = 2.0	3	2	100	
	New Heights Manual Chair		Not Available	5	> 500	2	Infinite	Not Available	0.01	67	1	0	0	270	L=0.46, W=0.46	L=0.54, W=0.58, H=0.70	36	Vertical = 1.87, Oblique = 1.67	0.53, Oblique = 2.24	N/A	0	115	
	Total		126	239	186	168	213	94	154	171	72	111	114	90	175	264	174	90	255	105	105	235	3141
	Normalized		4.0%	7.6%	5.9%	5.3%	6.8%	3.0%	4.9%	5.4%	2.3%	3.5%	3.6%	2.9%	5.6%	8.4%	5.5%	2.9%	8.1%	3.3%	3.3%	7.5%	100%

Appendix B



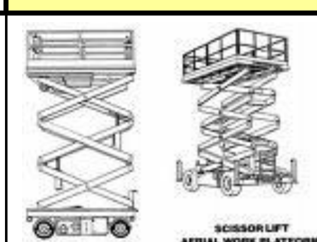
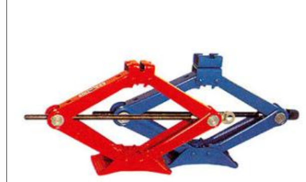
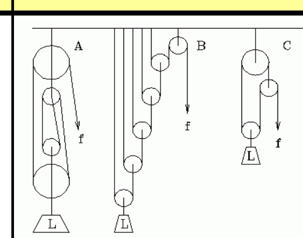
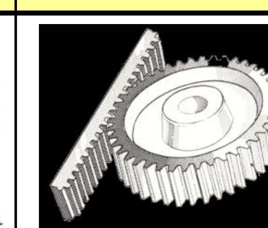
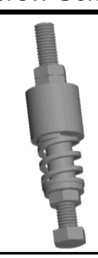
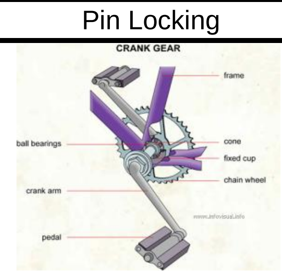
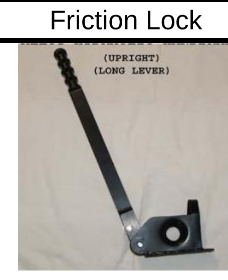
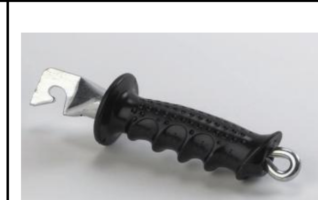
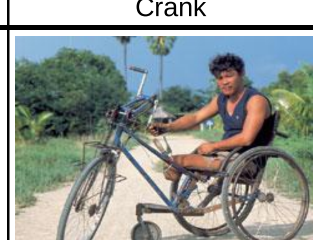
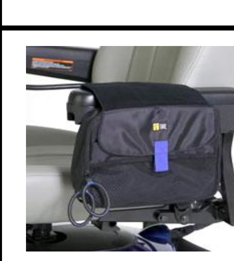
Month
Day
September
October
November
December
General Engineering Evaluation of Concepts
Concept Selection
Preparation for Design Review #2
Detailed Engineering Evaluation
CAD Modeling
Manufacturing Drawings and Material Choice
Prepare for Design Review #3
Cost Analysis and Procurement of Materials
Fabrication of Parts
Assembly
Working Test
Refinement of Prototype
Prepare for Design Review #4
Prepare for Design Expo
Prepare Final Report

Appendix C


FAST Diagram of an Elevating Wheelchair
Transport User
Lift User
Elevate User
Transfer Force
Assist Elevation
Secure Position
Lock Seat
Ensure Dependability
Translate User
Steer Structure
Rotate Wheels
Transfer Force
Propel Structure
Rotate Wheels
Transfer Force
Transport Tools
Secure Tools
Prevent Topple
Increase Footprint
Support Load
Stabilize Structure
Lock Wheels
Prevent Injury
Provide Comfort
Secure User
Hold Legs
Secure Torso

Appendix D

Morphological Chart for Elevating Wheelchair

Elevating Wheelchair Sub Functions		#	Function	A	B	C	D	E	F	G	H
				Methods							
				A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	Lift User	**1**	**Elevate User**	 Hydraulic Scissor Lift	 Screw Scissor Lift	 Vertical Screw	 Pulley System	 Linkage	 Pneumatic Cylinder	 Hydraulic Lift	 Rack and Pinion
		2	**Assist Elevation**	 Gas Springs	 Helical Spring	 Pulley (counterweight)	 Torsional Spring				
		3	**Lock Height Setting**	 Pin Locking	 Friction Lock	 Pneumatic Cylinder					
		4	**Receive User Input**	 Crank	 Lever	 Handle	 Joysticks				
	Translate User	**5**	**Propel User**	 Hand Crank	 Push on Wheels	 Electric Motor					
	Prevent Injury	**6**	**Apply Brakes**	 Lever	 Bicycle Brakes	 Disk Brake					
		7	**Rest Arms**	 Fixed Armrest	 Armrest with Tool-bin	 Height Adjustable					
		8	**Secure Legs**	 Single Footrest	 Double Footrest	 Adjustable Footrest	 Horizontal Footrest				
		9	**Prevent Topple**	 Wheelie Bars	 Adjustable Bars	 Extend Casters					
	Transport Tools	**10**	**Secure Tools**	 Tray	 Holster	 Rear Pouch	 Side Pouch	 Armrest Tool-bin			

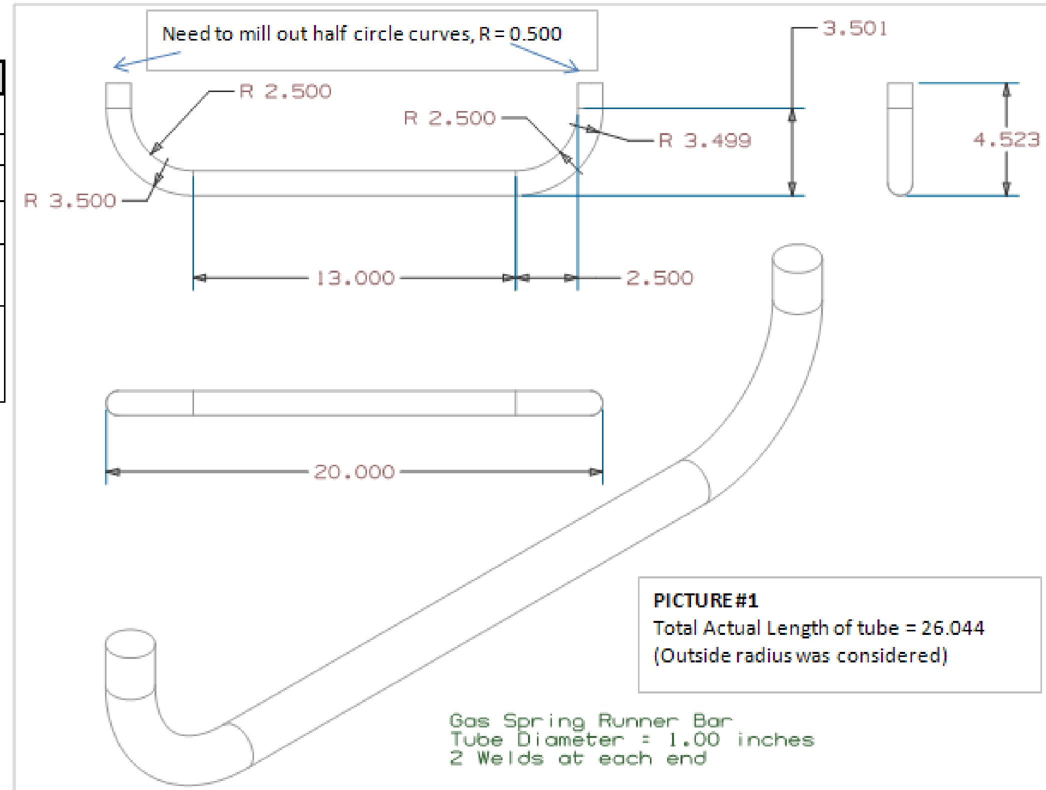
Appendix E

Concept Evaluation Matrix for Elevating Wheelchair

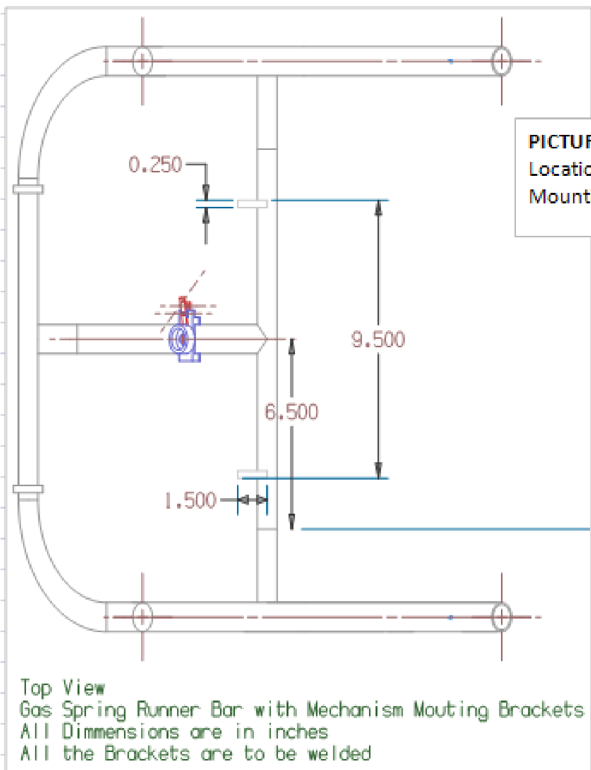
	From QFD					
	Customer Requirement	Weight	Pneumatic Linked (base)	Pneumatic Scissor	Screw Scissor	Torsional Spring
Safety	No harm to user	10	0	-	-	0
	Stable	9	0	+	+	0
Mechanism	Manual powered	9	0	0	0	0
	Multiple height adjustments	7	0	0	0	0
	Quick height change	7	0	0	-	0
	Durable	5	0	+	+	0
Functionality	Same personal mobility as standard wheelchair	8	0	0	-	-
	Able to transport tools	7	0	0	0	0
	Easy to move around	3	0	0	0	0
Geometry	Fit in factory aisle	10	0	0	0	0
	Achieve average person's height	9	0	0	0	0
	Comfortable	9	0	0	0	0
Budget	Low Cost	8	0	0	0	0
		Total (+)	0	2	2	0
		Total (-)	0	1	3	1
		Total	0	1	-1	-1
		Weighted Total	100%	104%	89%	92%

Appendix F

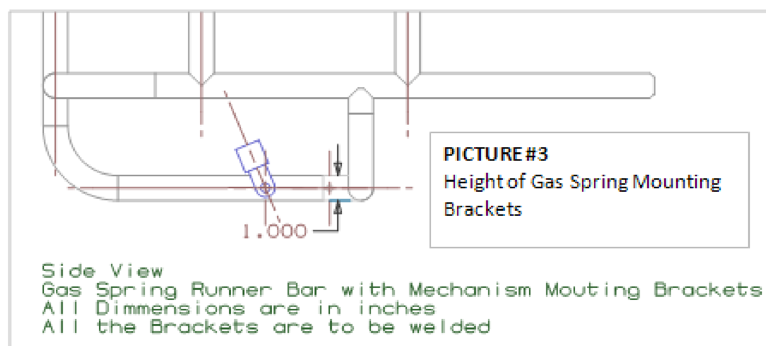
Part Name:	Gas Spring Runner Bar				
Raw Material:	1/4" thick, 1" Diameter steel Tube				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 30~35" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Bend Tube as shown in Picture			Bending Fixure	Clamp
4	Cut steel tube at each end	Band saw	90 fpm		vise
5	Mill out half circle shap at each end for fitting	Manual Mill	200rpm		vise
6	Weld gas spring mounting brackets as shown in Picture 2 and 3	Welding machine	200rpm		Clamp/Vise



PICTURE #1
Total Actual Length of tube = 26.044
(Outside radius was considered)



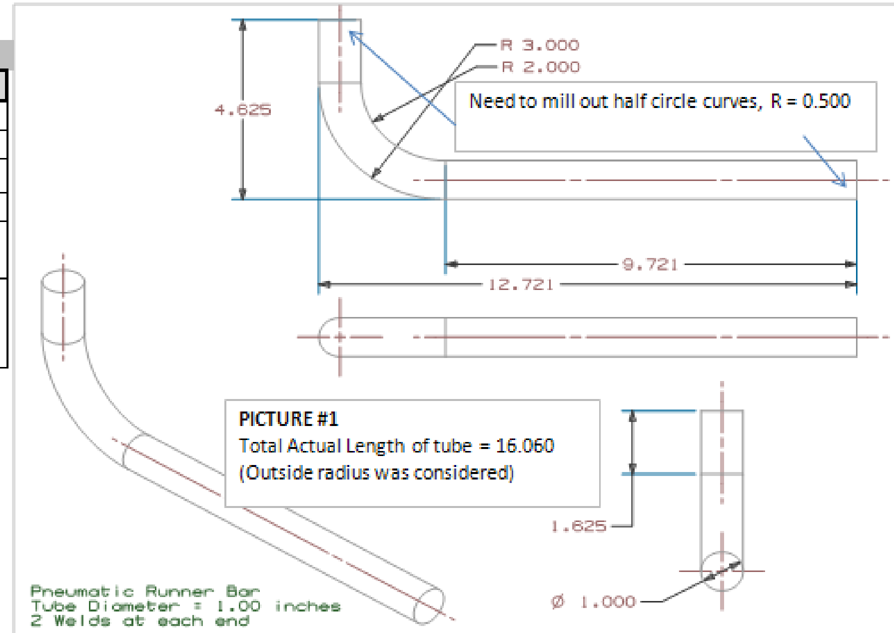
PICTURE #2
Location of Gas Spring Mounting Brackets

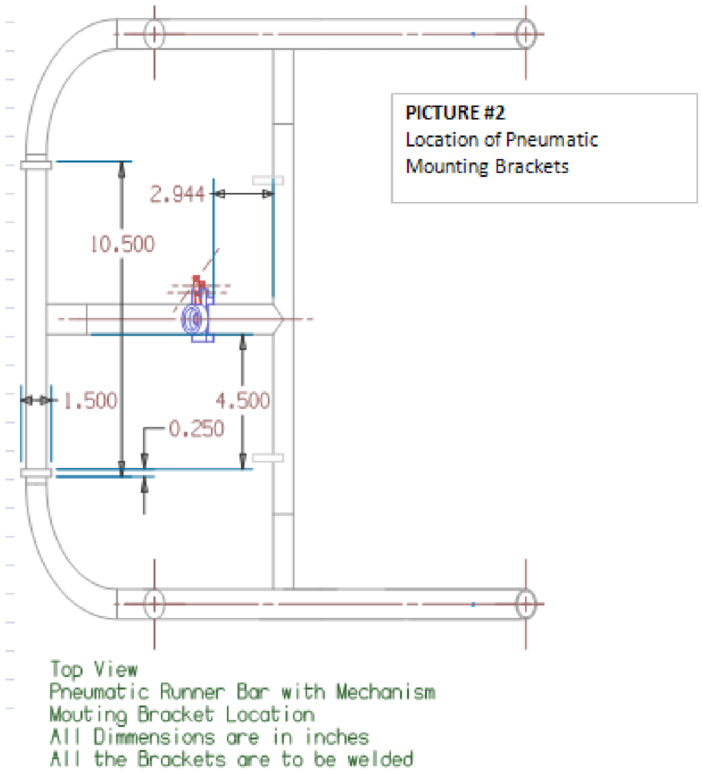


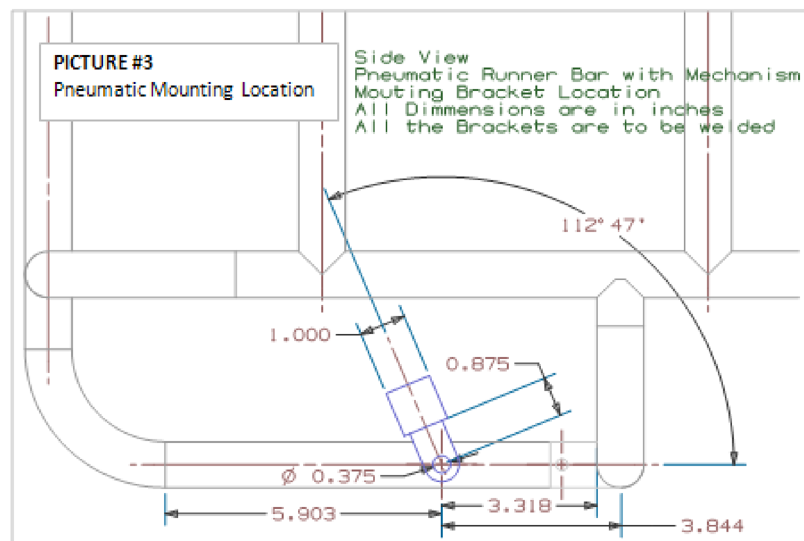
PICTURE #3
Height of Gas Spring Mounting Brackets

Appendix F

No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
Part Name:		Pneumatic Runner Bar			
Raw Material:		1/4" thick, 1" Diameter steel Tube			
1	Measure 20~25" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Bend Tube as shown			Bending Fixure	Clamp
4	Cut steel tube at each	Band saw	90 fpm		vise
5	Mill out half circle shap at each end for	Manual Mill			vise
6	Weld Pneumatic Mounting Brkt as shown in Picture 2	Welding machine			Clamp/Vise

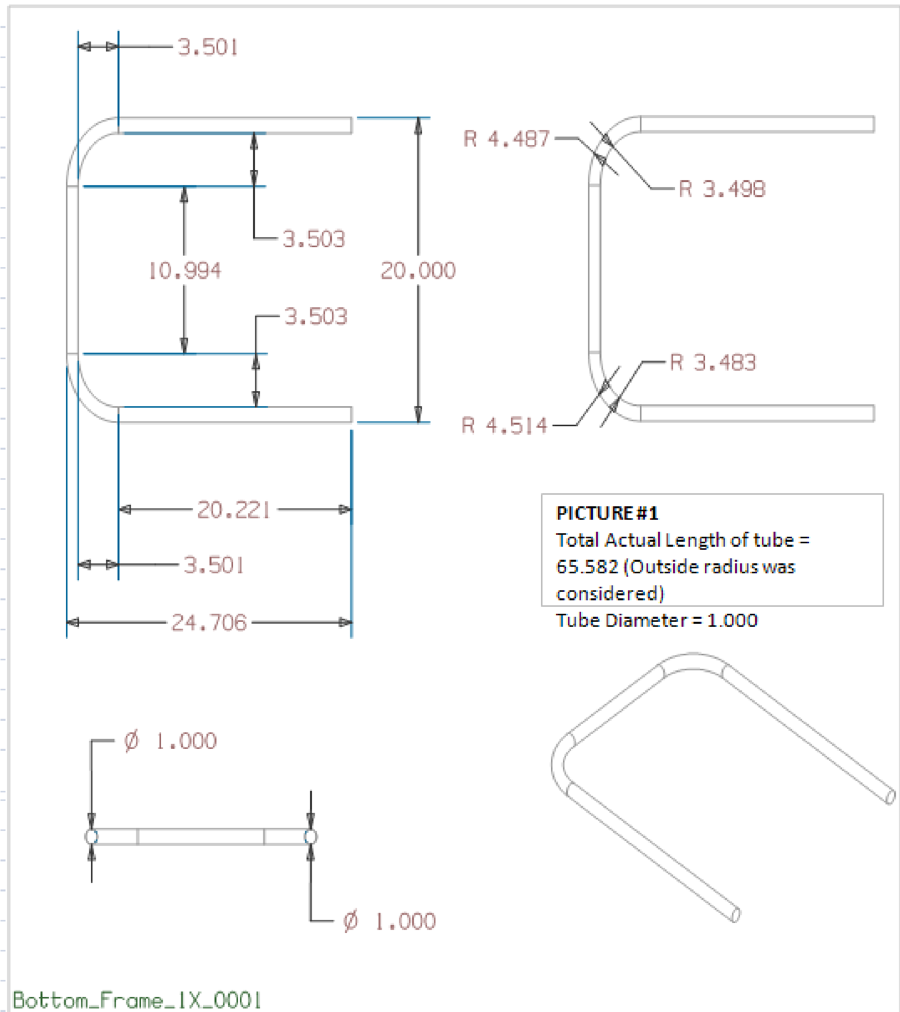






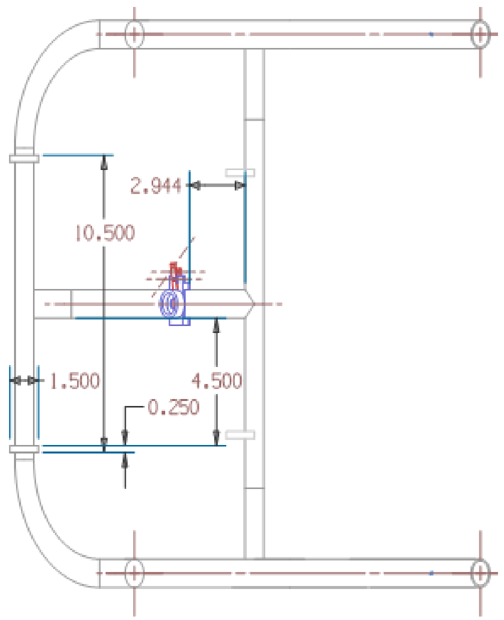
Appendix F

Part Name:		Bottom U-Frame			
Raw Material:		1/4" thick, 1" Diameter steel Tube			
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 70~75" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Bend Tube as shown in Picture #1			Bending Fixure	Clamp
4	Cut steel tube at each end	Band saw	90 fpm		vise

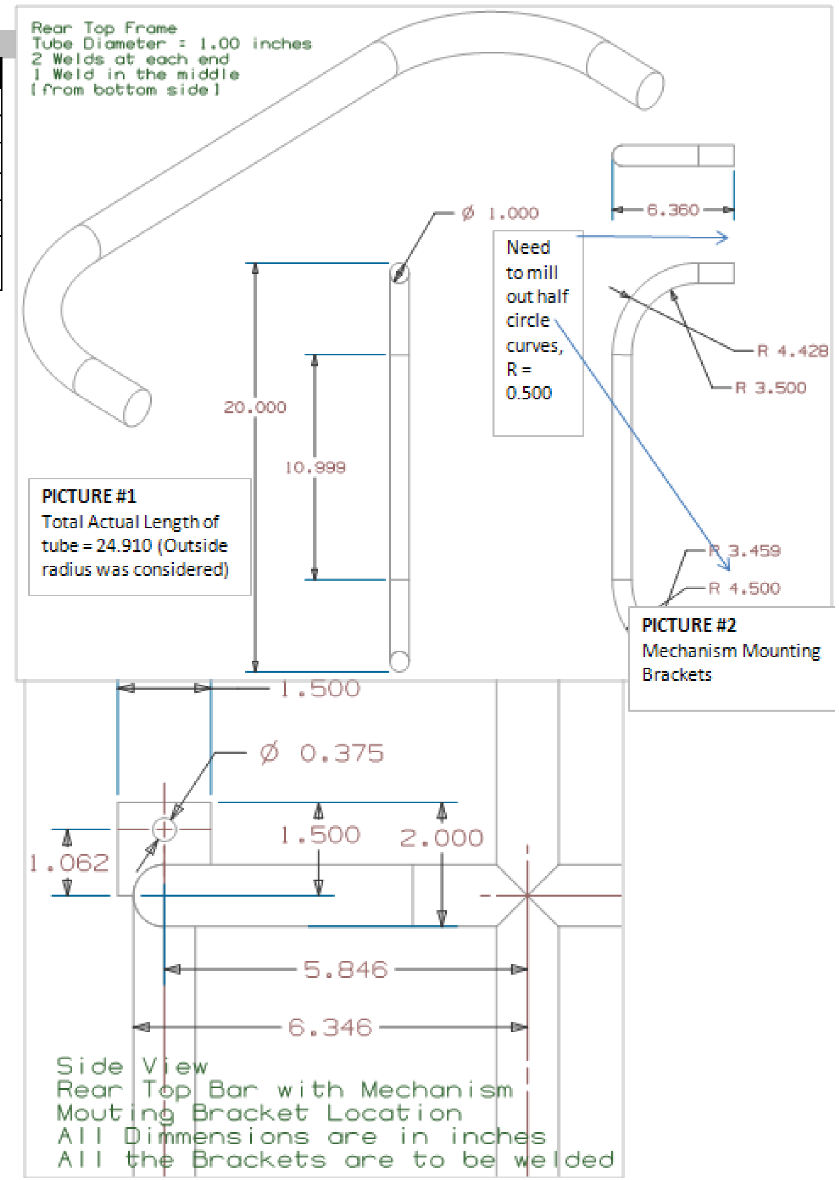


Appendix F

Part Name:		Rear Top U-Frame				
Raw Material:		1/4" thick, 1" Diameter steel Tube				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**	
1	Measure 30~35" long steel tube			Caliper/Tape		
2	Cut steel tube	Band saw	90 fpm		vise	
3	Bend Tube as shown in Picture #1			Bending Fixure	Clamp	
4	Cut steel tube at each end	Band saw	90 fpm		vise	
5	Mill out half circle shap at each end for fitting	Manual Mill			vise	
6	Weld mechanism mounting brackets as shown in Picture 2 and 3	Welding machine			Clamp/Vise	



PICTURE #3
Mechanism Mounting Brackets

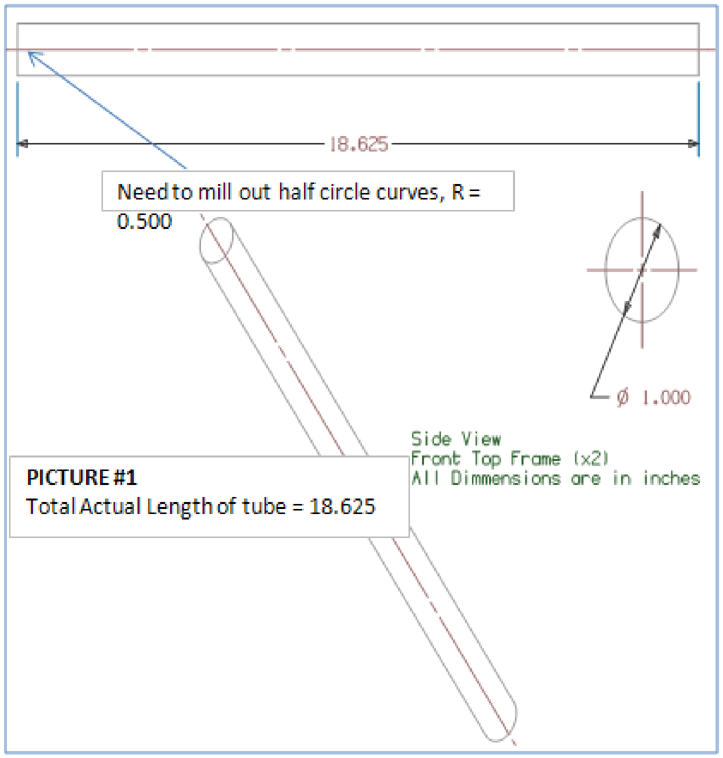


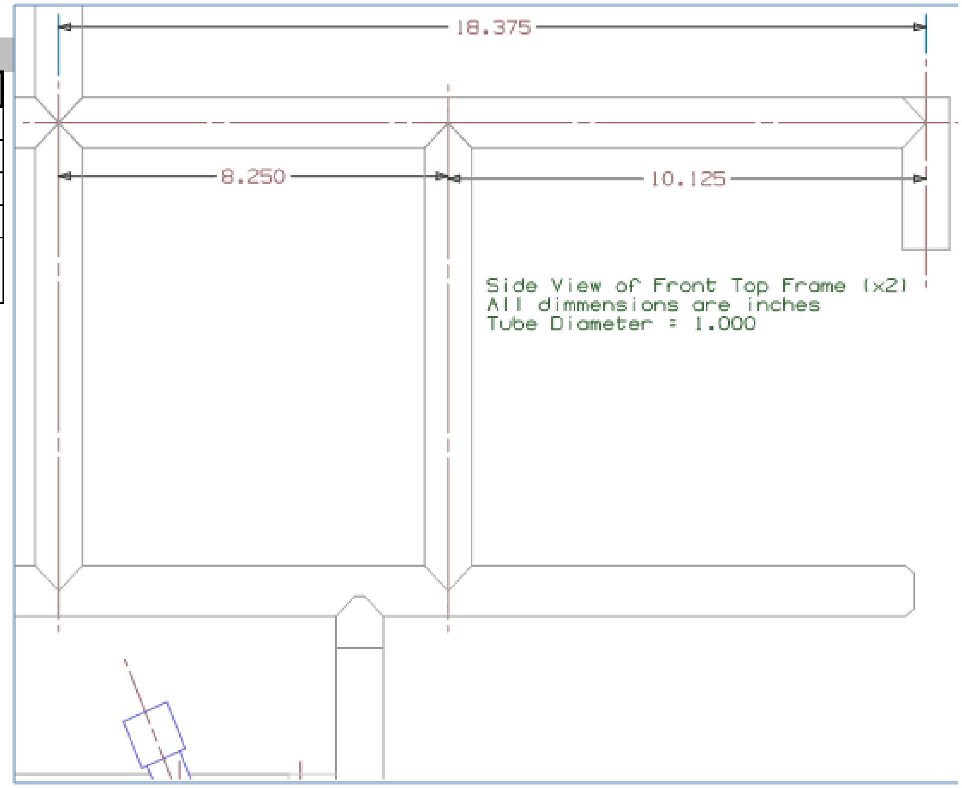
PICTURE #1
Total Actual Length of tube = 24.910 (Outside radius was considered)

PICTURE #2
Mechanism Mounting Brackets

Appendix F

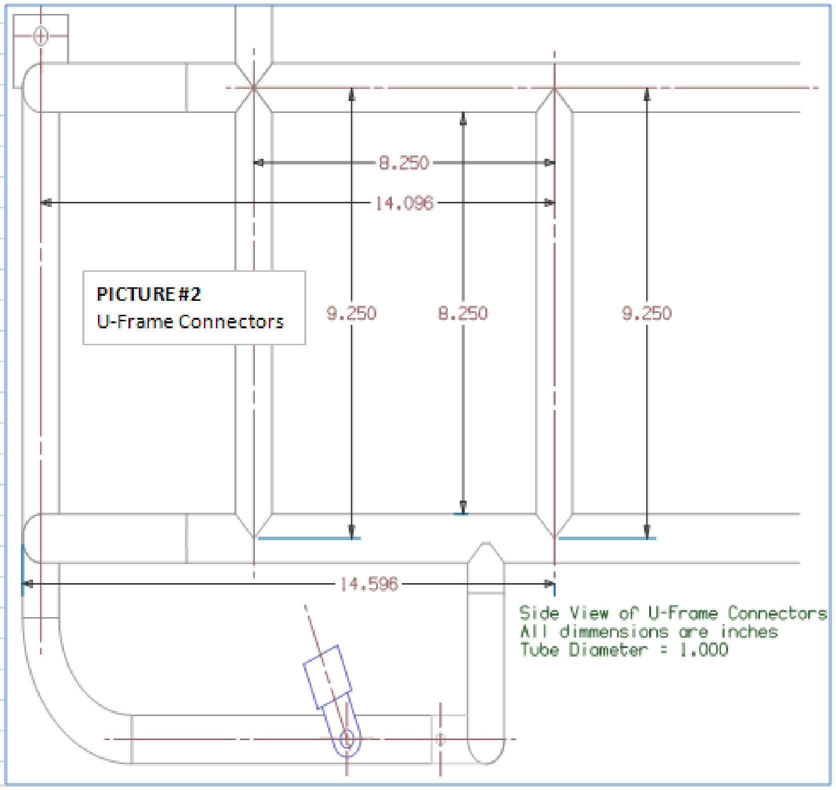
Part Name:	Front Top Frame (x2)				
Raw Material:	1/4" thick, 1" Diameter steel Tube				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 20~22" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Drill a slot for to attach brake	Drill/Mill			vise/clamp
4	Cut steel tube at each end	Band saw	90 fpm		vise
5	Mill out half circle shap at ONE end for fitting	Manual Mill			vise

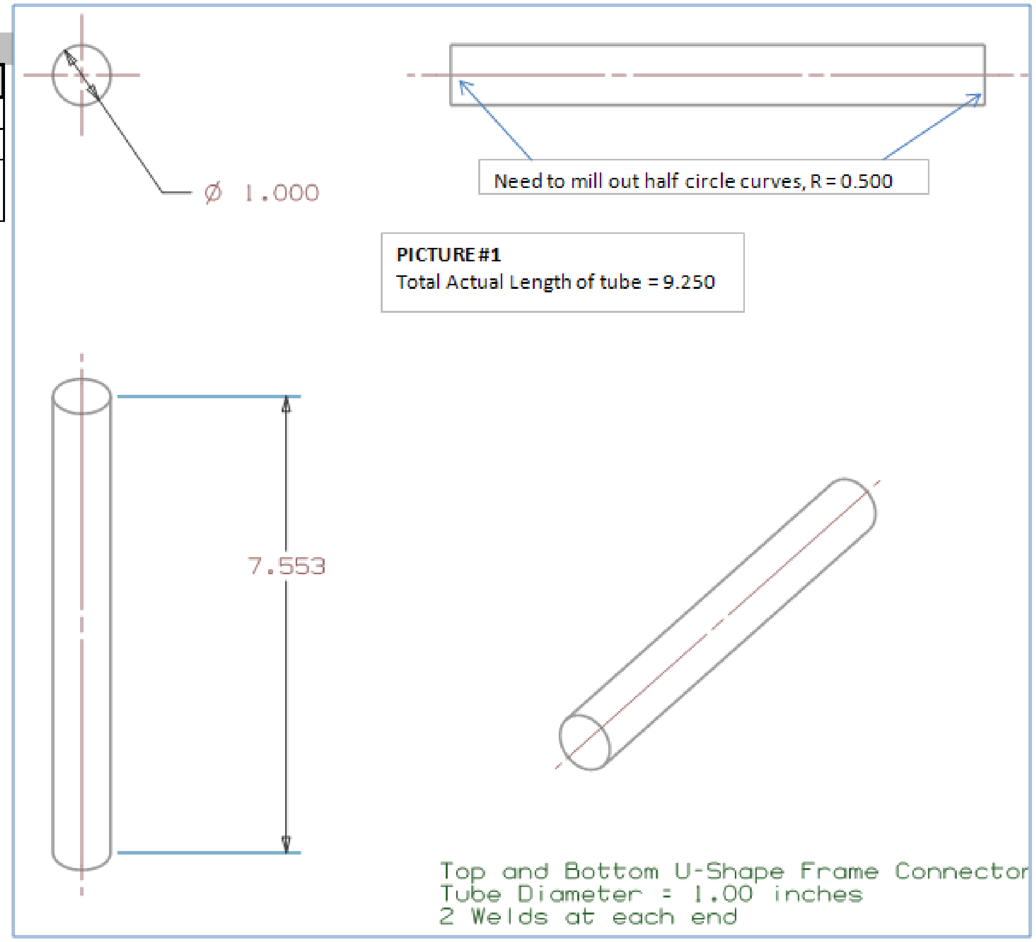




Appendix F

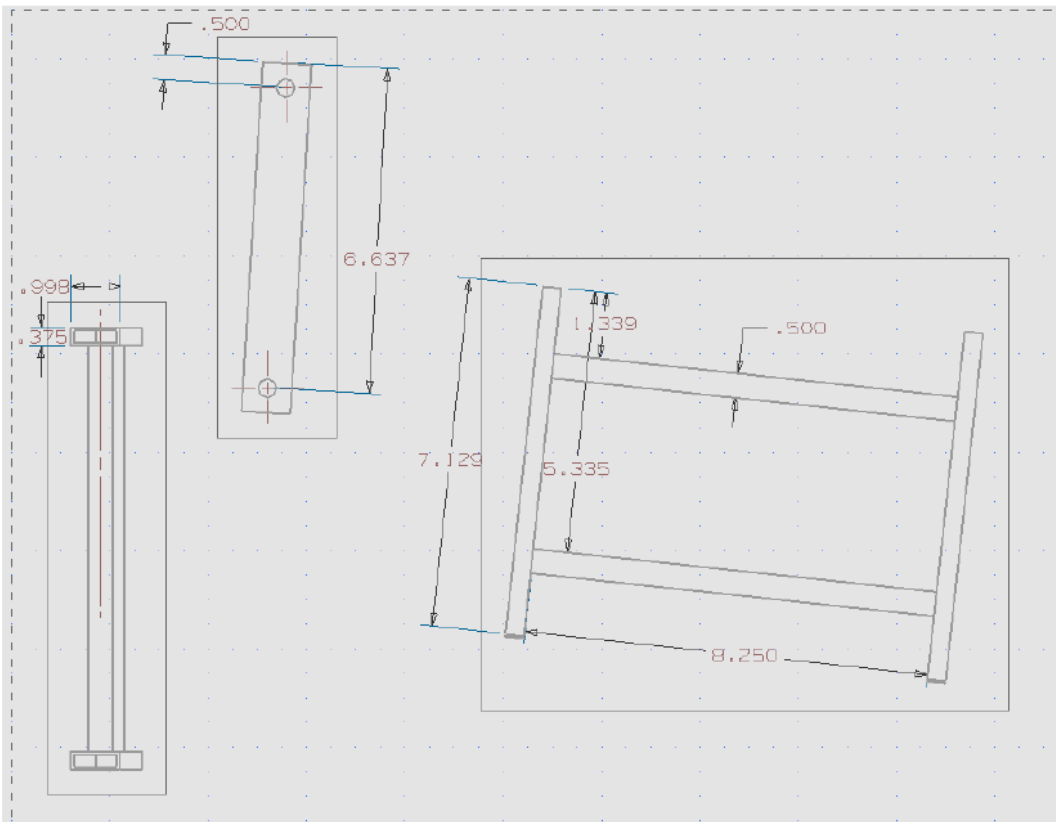
Part Name:	Top and Bottom U-Frame Connector (x3)				
Raw Material:	1/4" thick, 1" Diameter steel Tube				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 10~11" long steel tube			Caliper/Tape	
2	Cut steel tube	Band saw	90 fpm		vise
3	Mill out half circle shap at each end for fitting	Manual Mill			vise





Appendix G

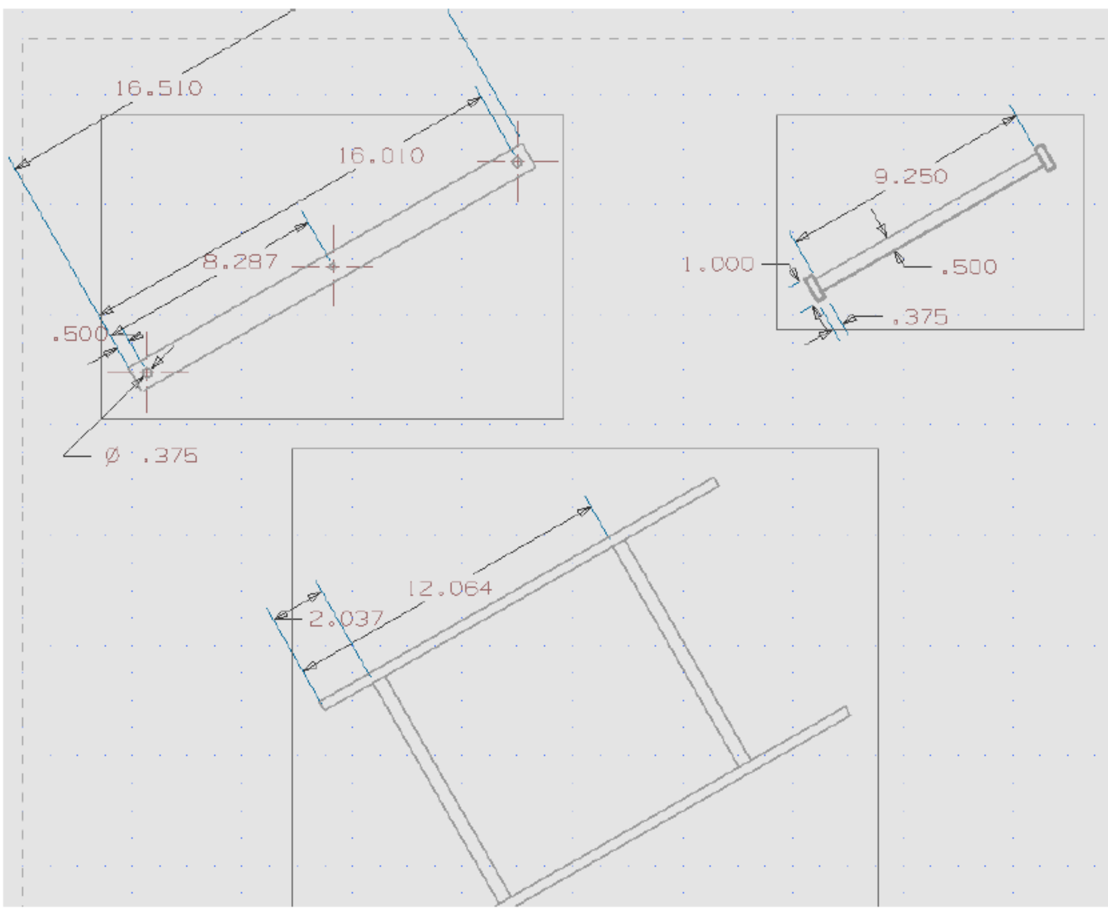
Part Name:		Linkage Upper Complete			
Raw Material:		(2) 3/8"X1" square tube, (2) 1/2" dia tubes			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure (2)7.2" square steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Drill (2) 3/8" hole in each	drill press	200 rpm	3/8 drill	vise
4	Measure (2)8.25" steel tube			Caliper	
5	Cut steel	Band saw	90 fpm		vise
6	Measure & Strike weld spots			Tape	
7	Weld tube to square			TIG welder	



Appendix G

Part Name:	Linkage Rear Complete
Raw Material:	(2) 3/8"X1" square tube, (2) 1/2" dia tubes

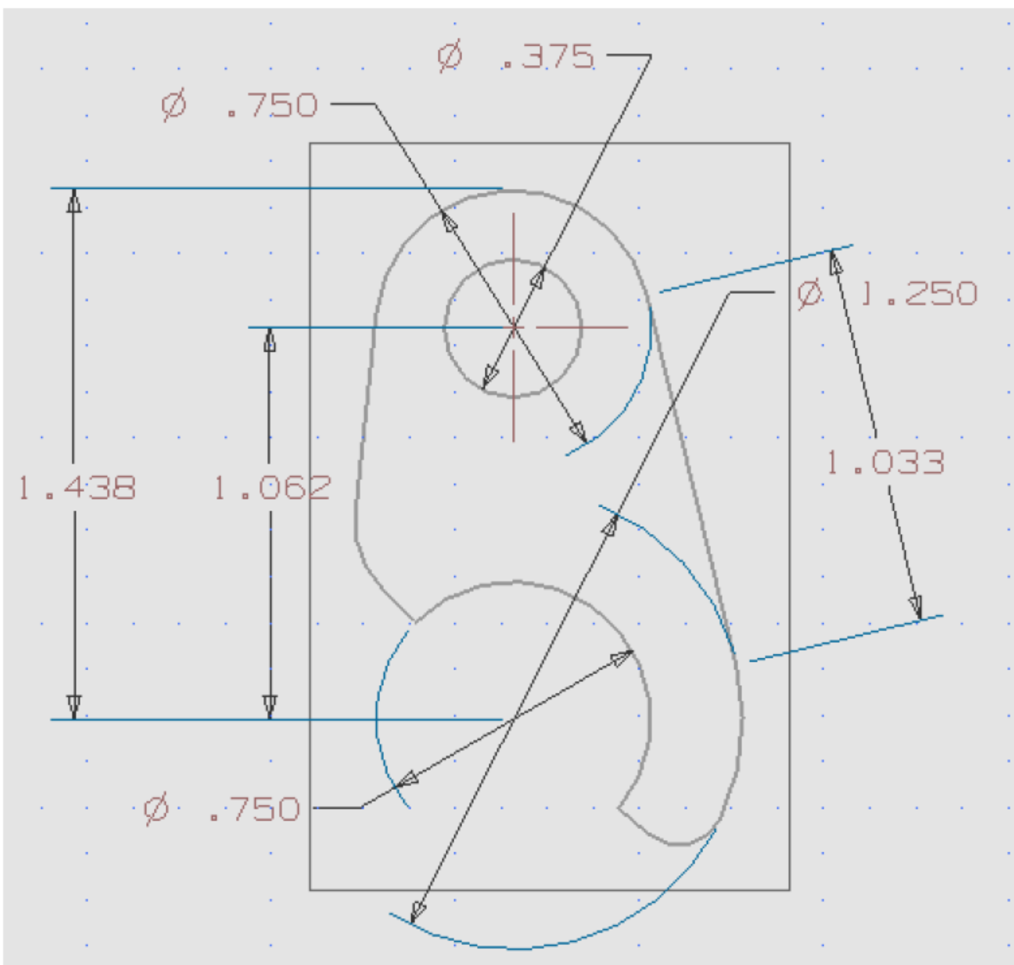
No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
1	Measure (2)16.5" square steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Drill (3) 3/8" hole in each	drill press	200 rpm	3/8" drill	vise
4	Measure (2)9.25" steel tube			Caliper	
5	Cut steel	Band saw	90 fpm		vise
6	Measure & Strike weld spots			Tape	
7	Weld tube to square			TIG welder	



Appendix G

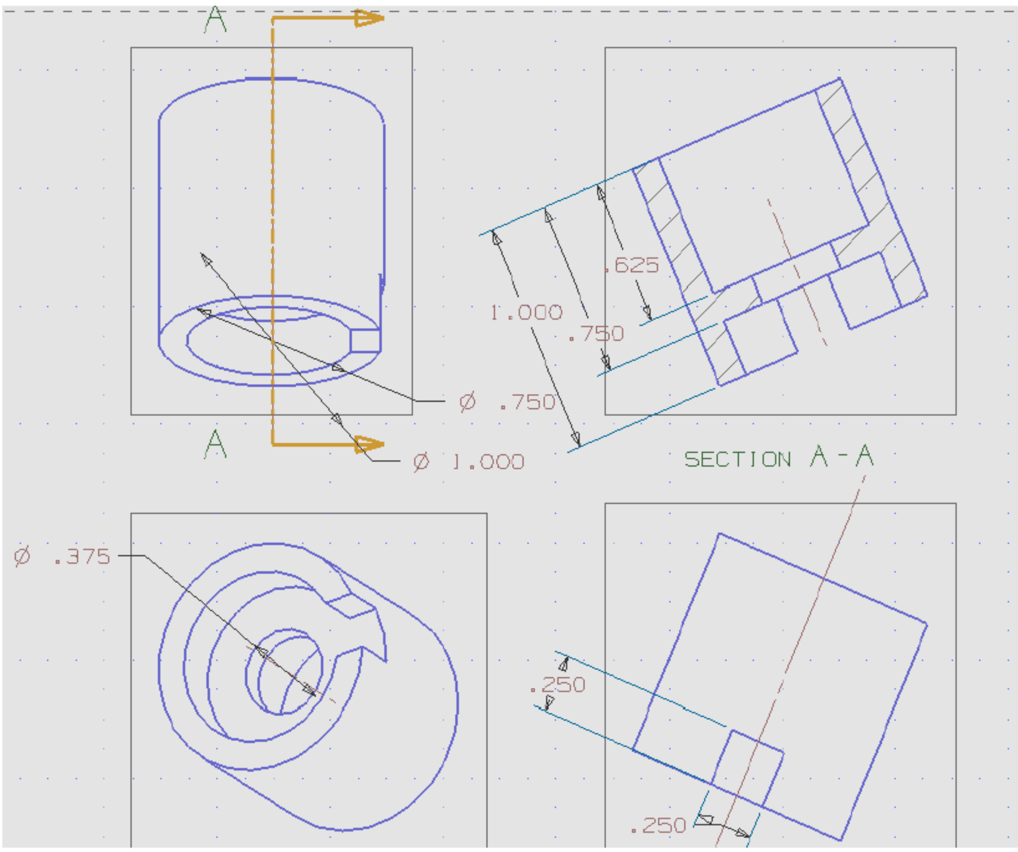
Part Name:	Linkage Rear Link Bracket
Raw Material:	1/4"X1" steel

No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
1	Measure 2" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Sketch patern on steel			Caliper	
4	Mill outer 3/4" arc	mill	200 rpm	3/8"end mill	vise
5	Mill inner 3/4" arc	mill	200 rpm	3/8"end mill	vise
6	Mill sides	mill	200 rpm	3/8"end mill	vise
7	Drill 3/8" hole	mill	200 rpm	3/8" drill	vise



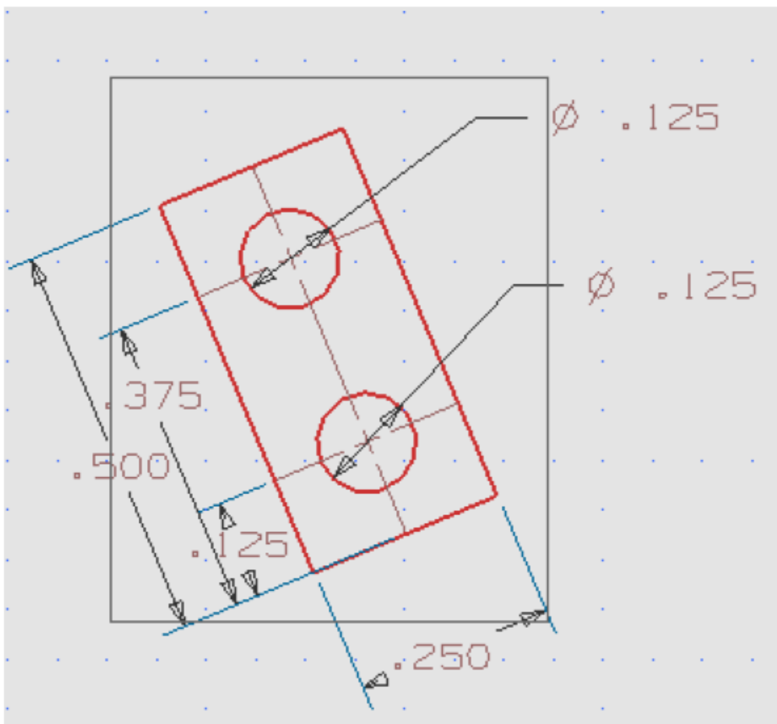
Appendix G

Part Name:		Linkage Pneumatic Bracket 3			
Raw Material:		1" solid steel tube			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 1" long tube			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Turn inner tube .75" (.625")	Lathe	200 rpm	Drill	vise
4	Turn inner tube .75" (.25")	Lathe	200 rpm	Drill	vise
5	Drill center hole .375"	Lathe	200 rpm	drill	vise
6	Mill tube hole 1/4"	mill	200 rpm	1/4"drill	vise



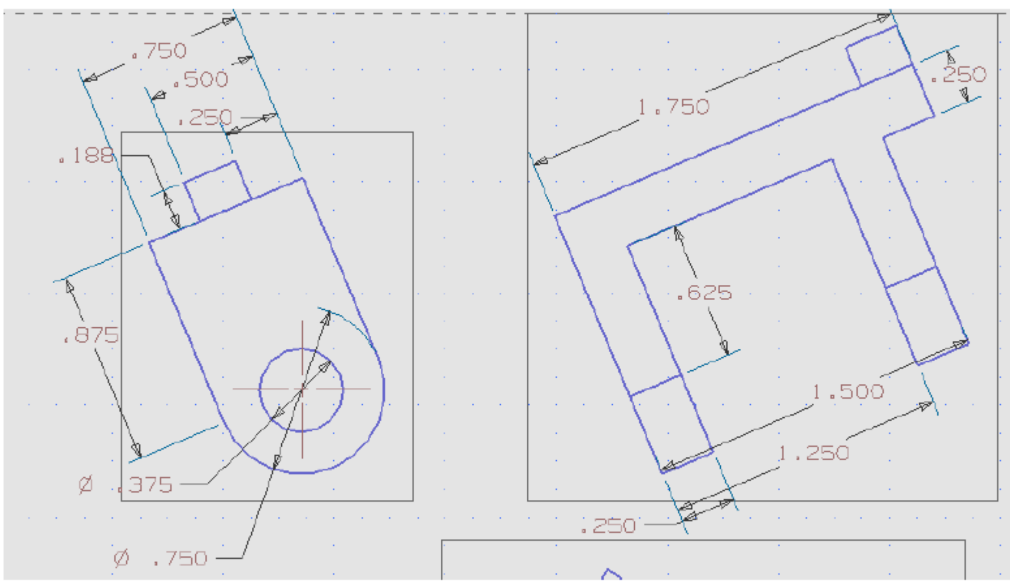
Appendix G

Part Name:	Linkage Pneumatic Mechanism 2				
Raw Material:	1/4" wide 1/8" thick steel				
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 1/2" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Measure 2 1/8" holes			Caliper	
9	Drill hole 2X1/8"	Drill press	200 rpm	1/8" drill	vise



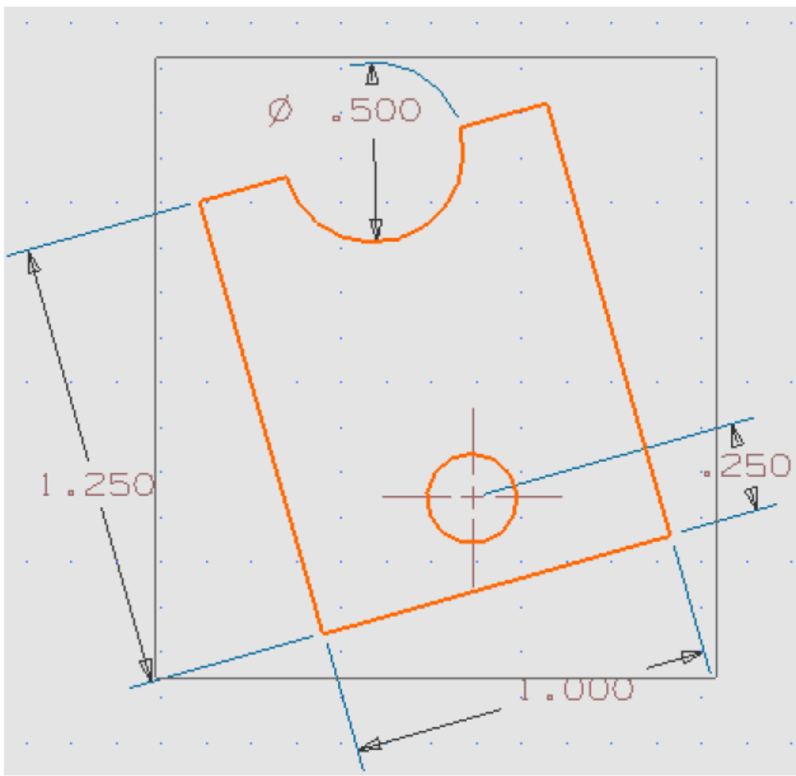
Appendix G

Part Name:		Linkage Pneumatic Mechanism 1			
Raw Material:		1/2" thick 3/4" wide steel			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 1.75" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Mill Top (1/4")	Mill	200 rpm	3/8 end mill	vise
4	Measure Sides 2X.675"				
7	Cut steel	Band saw	90 fpm		vise
8	Mill Outer dia. 2X.75"	mill	200 rpm	3/8" end mill	vise
9	Drill hole 2X3/8"	Drill press	200 rpm	3/8" drill	vise
10	Weld two side pieces to top			TIG weld	



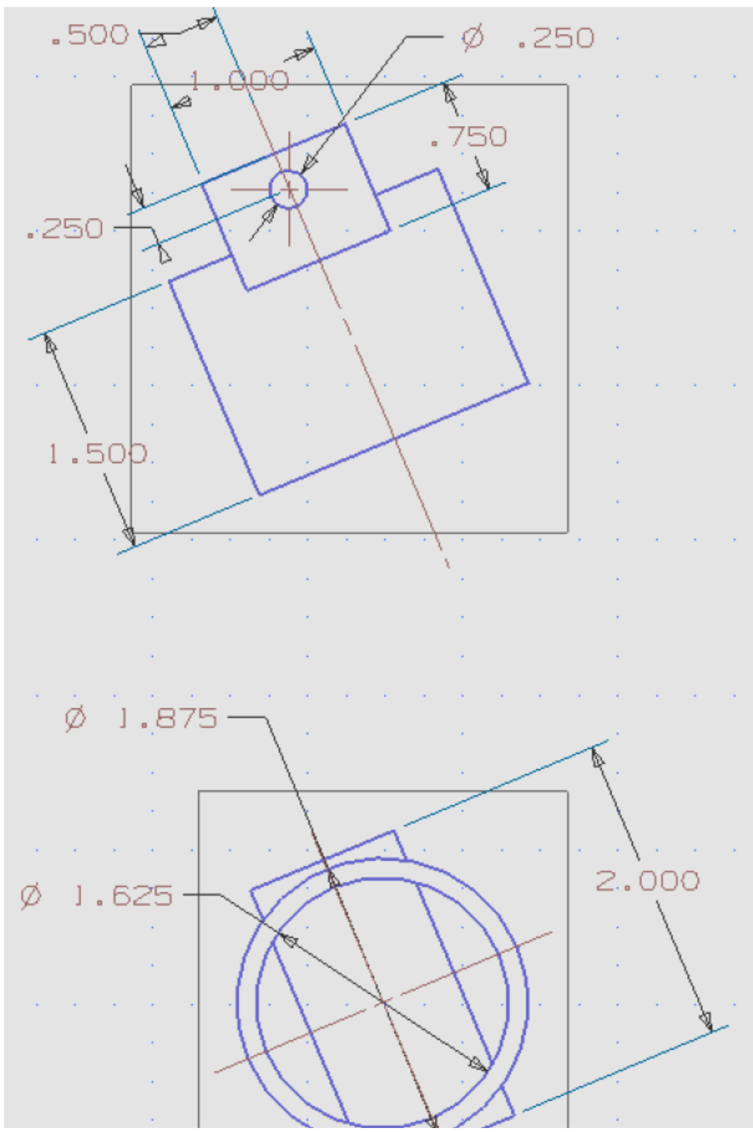
Appendix G

Part Name:		Linkage Pneumatic Bracket 2			
Raw Material:		1/4" thick 1" wide steel			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 1.25" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Measure & strike 1/2" dia.			protractor	
4	Mill outer edge (1/2" dia.)	Mill	200 rpm	3/8" end mill	vise
6	Mill outer edge (length)	Mill	200 rpm	3/8" end mill	vise
7	Measure 1/4" hole			Caliper	
8	Drill 1/4" hole	Drill press	200 rpm	1/4" drill	vise



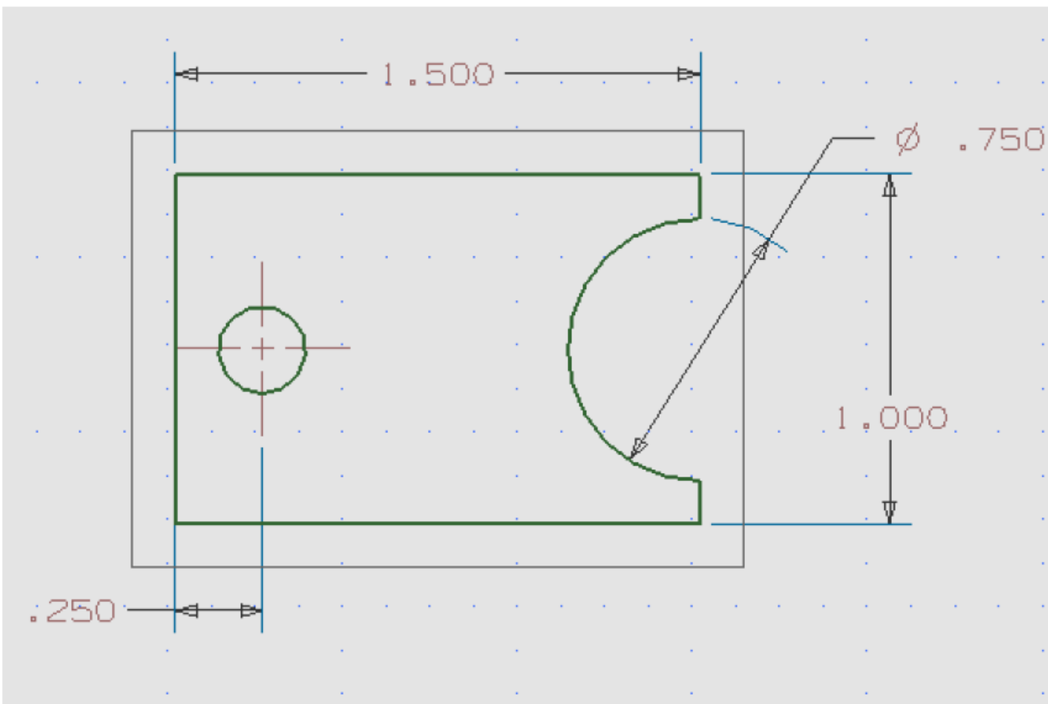
Appendix G

Part Name:	Linkage Pneumatic Bracket 1				
Raw Material:	2" solid steel tube, 1"X3/4" steel				
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 2" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Measure 1/4" hole			Caliper	
4	Drill 1/4" hole	Drill press	200 rpm	1/4" drill	vise
5	Measure 1.5" length of tube			Caliper	
6	Cut steel tube	Band saw	90 fpm		vise
7	Lathe Center of tube (1.625)	Lathe	200 rpm	Drill	Vise
8	Weld Square to Tube			TIG weld	



Appendix G

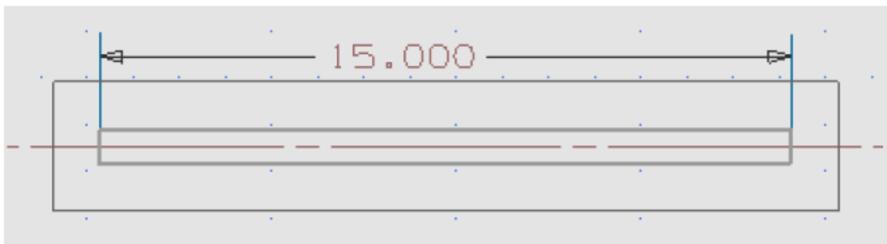
Part Name:		Linkage Gas Spring Bracket 2			
Raw Material:		1/4" thick 1" wide steel			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 1.5" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Measure & strike 1/2" dia.			protractor	
4	Drill outer edge (1/2" dia.)	Mill	200 rpm	1/2" Drill	vise
7	Measure 1/4" hole			Caliper	
8	Drill 1/4" hole	Drill press	200 rpm	1/4" drill	vise



Appendix H

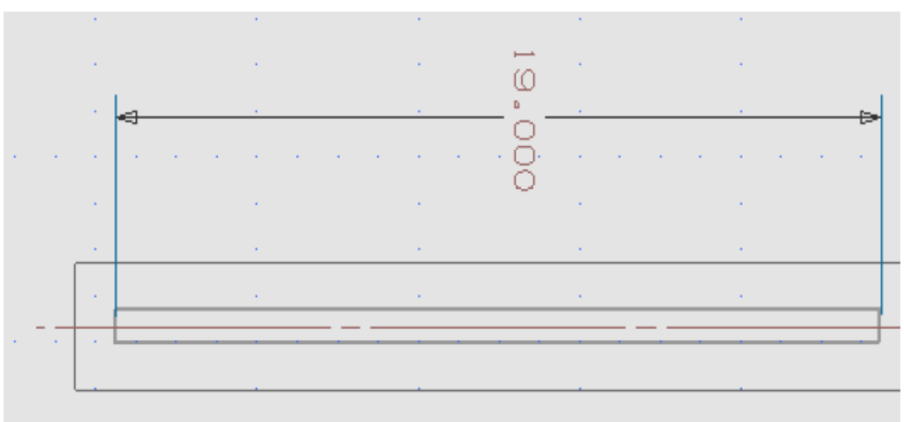
Part Name:	Seat Horizontal Lower Runner (2X)
Raw Material:	3/4" Steel 1/8" thick by 15" long

No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 15" tubing			Tape	
2	Hold in vise				vise
3	Cut part	Band Saw	90 fpm		vise



Part Name:	Seat Cross Brace (3X)
Raw Material:	3/4" Steel 1/8" thick by 19" long

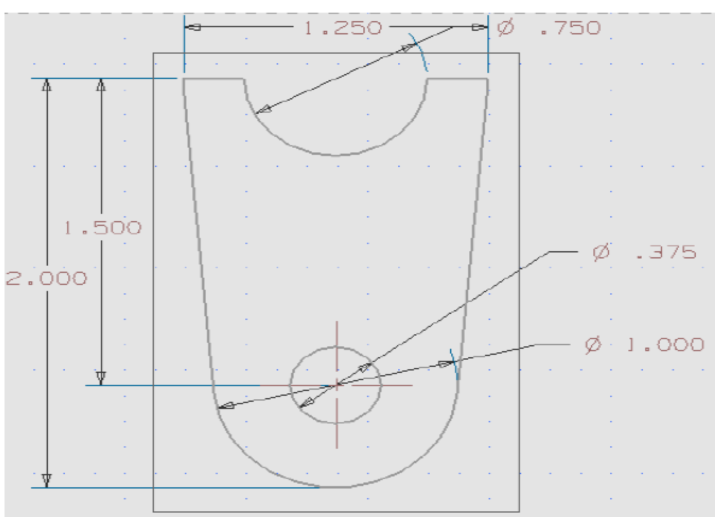
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 19" tubing			Tape	
2	Hold in vise				vise
3	Cut part	Band Saw	90 fpm		vise



Part Name:	Seat Horizontal Upper Runner (2X)
Raw Material:	3/4" Steel 1/8" thick by 17" long

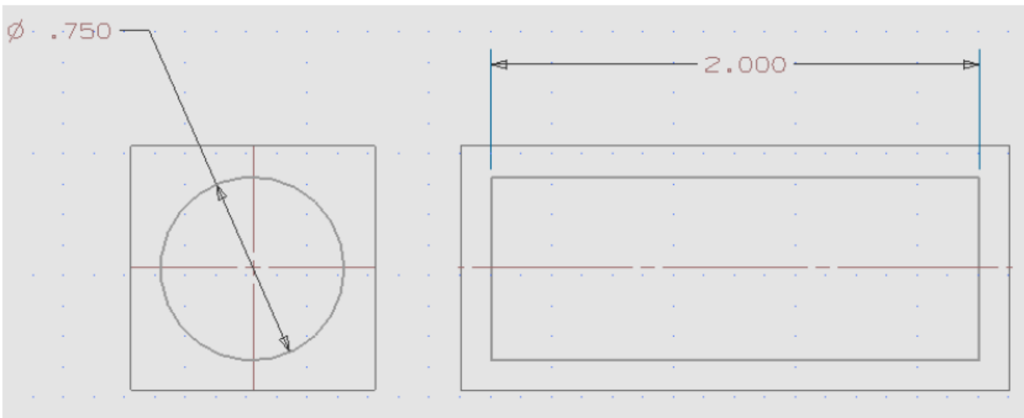
No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
1	Measure 17" tubing			Tape	
2	Hold in vise				vise
3	Cut part	Band Saw	90 fpm		vise

Part Name:		Seat Linkage Bracket (2X)			
Raw Material:		3/8" thick 1.25" wide steel			
No.	**Process Description**	**Machine**	**Speed (rpm)**	**Tool**	**Fixtures**
1	Measure 2" long steel			Caliper	
2	Cut steel	Band saw	90 fpm		vise
3	Measure & strike 1" dia.			protractor	
4	Mill outer edge (1" dia.)	Mill	200 rpm	3/8" end mill	vise
5	Measure & strike outer edge			Ruler	
6	Mill outer edge (length)	Mill	200 rpm	3/8" end mill	vise
7	Measure & strike .75" dia.			protractor	
8	Mill outer edge (3/4" dia.)	Mill	200 rpm	3/8" end mill	vise
9	Measure 3/8" hole			Caliper	
10	Drill 3/8" hole	Drill press	200 rpm	3/8" drill	vise



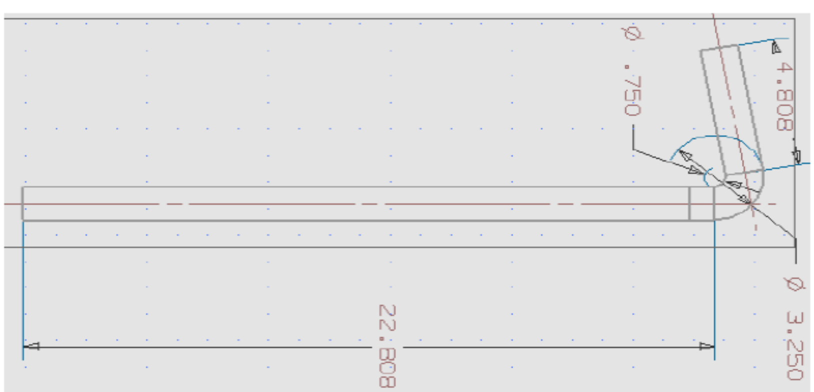
Part Name:	Seat Connector Brace (2X)
Raw Material:	3/4" Steel 1/8" thick by 2" long

No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
1	Measure 2" tubing			Tape	
2	Hold in vise				vise
3	Cut part	Band Saw	90 fpm		vise



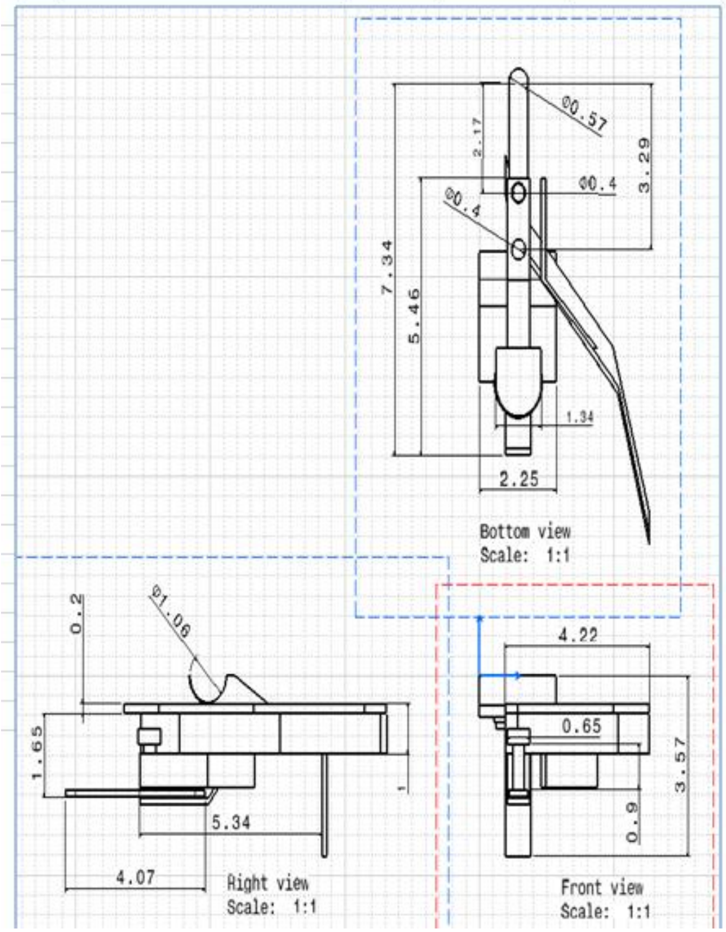
Part Name:	Seat Upper Bar (2X)
Raw Material:	1" Steel tube by 30" long

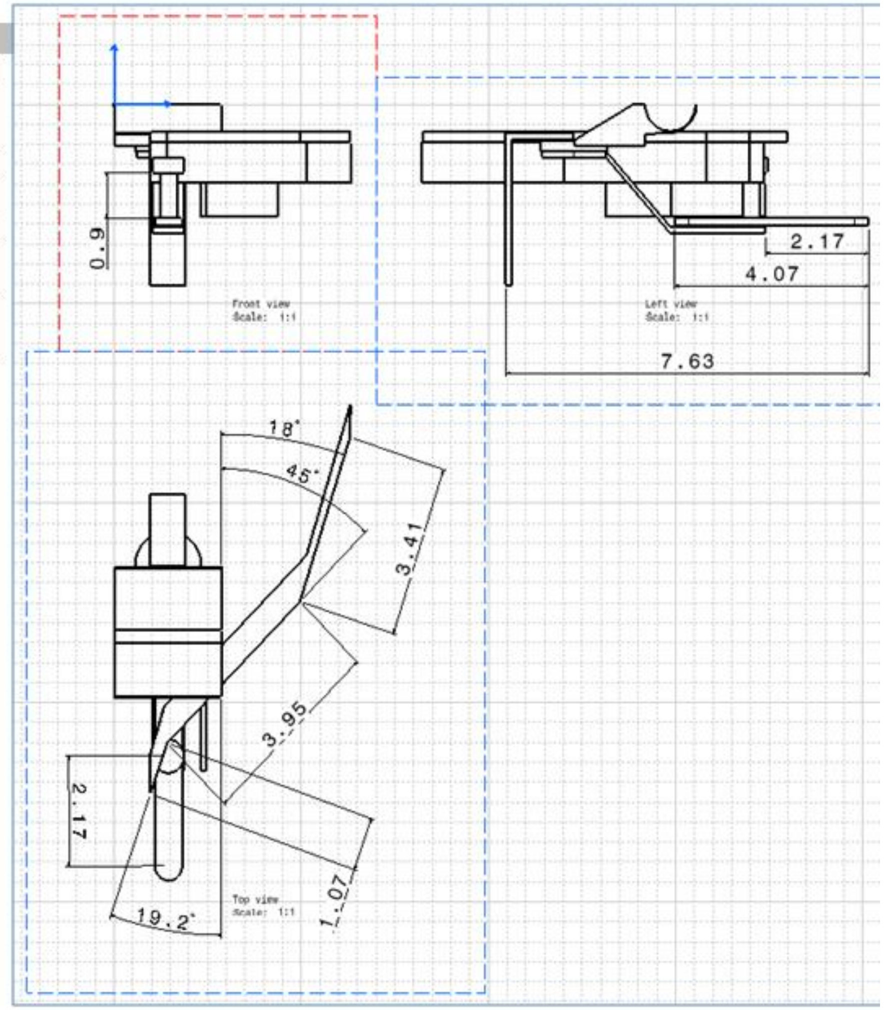
No.	Process Description	Machine	Speed (rpm)	Tool	Fixtures
1	Measure 30" tubing			Tape	
2	Hold in vise				vise
3	Cut part	Band Saw	90 fpm		vise
4	Measure 26" from one end			Tape	
5	Strike a line				
6	Place in pipe bender				
7	Bend a 80 degree angle			Pipe Bender	



Appendix I

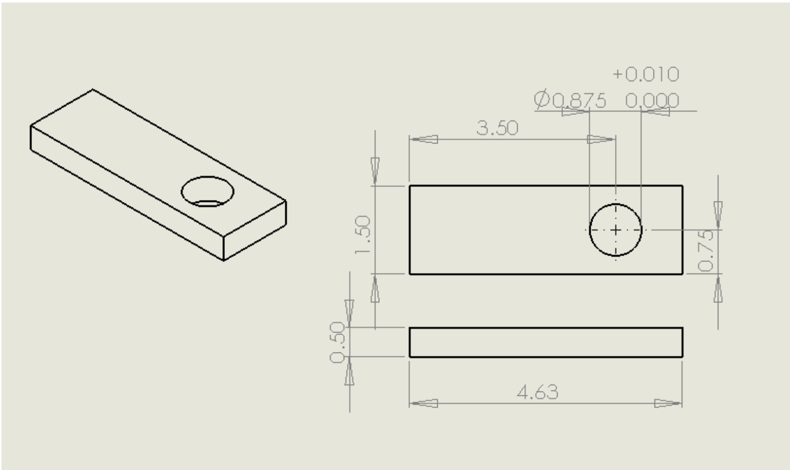
Part Name:		**Brake System**			
Raw Material:		1/4" thick, 1" Diameter steel Tube			
No.	***Process Description***	***Machine***	***Speed (rpm)***	***Tool***	***Fixtures***
1	Measure 10~11" long L-cross section Aluminum/Steel tube			Caliper/Tape	
2	Cut Aluminum/Steel bar	Band saw	90 fpm		vise
3	Bend bar as shown in Pictures			Bending Fixure	Clamp
4	Cut the bar to the dimensions	Band saw	90 fpm		vise
5	Attach the wheel to the handle				vise
6	Allign wheel track and wheel				Clamp/Vise



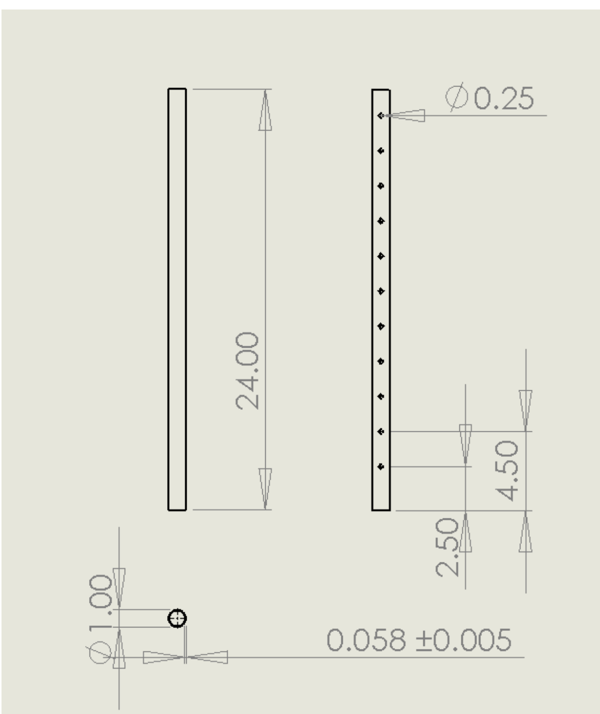


Appendix J: Manufacturing Plans/Drawings for Adjustable Armrests

All tolerances are ±0.05 in. unless otherwise noted.

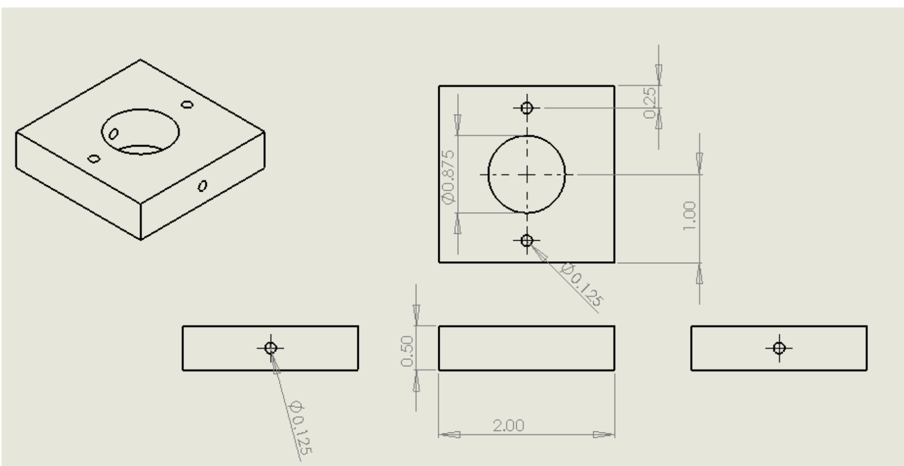


Part Name:	armrest part 2				
Raw Material:	1/2 in PVC plate				
No.	***Process Description***	***Machine***	***Speed***	***Tool***	***Fixtures***
1	Measure 1.5 in. x 4.625 in plate			ruler, marker	
2	Cut plate to size	Band saw	120 fpm		vise
3	locate hole center	Mill			vise
4	Drill 7/8 in. hole 0.5 in depth	Mill	200 rpm	7/8 in. end mill	vise

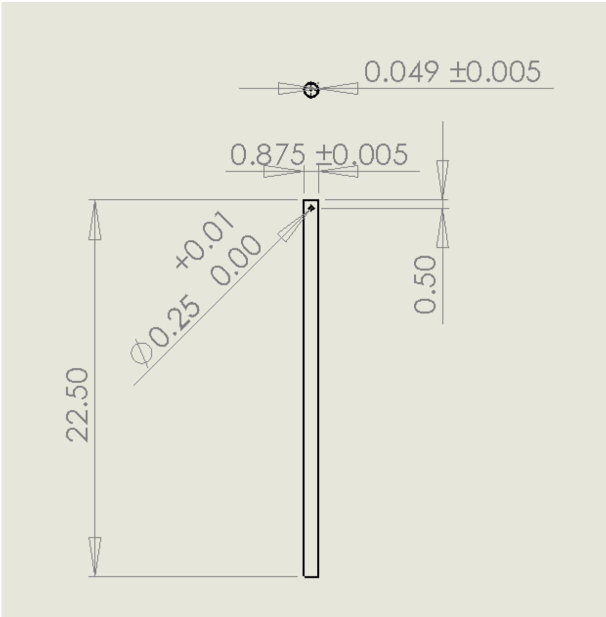


Part Name:			outer armrest pole (with holes)		
Raw Material:			1 in. OD x 0.058 in. aluminum tubing		
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	measure 24 in. length			ruler, marker	
2	Cut tubing to length	Band saw	120 fpm		vise
3	Drill 1/4 in. hole 2.5 in. from end	Mill	200 rpm	1/4 in. drill bit	vise
4	Drill 1/4 in. holes entire length of tube in 3/4 in. increments				
5	Deburr all ends			hand deburring tool	vise
6	Chamfer ends	Grinder	200 rpm		

Part Name:			outer armrest pole (without holes)		
Raw Material:			1 in. OD x 0.058 in. aluminum tubing		
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	measure 24 in. length			ruler, marker	
2	Cut tubing to length	Band saw	120 fpm		vise
3	Deburr all ends			hand deburring tool	vise
4	Chamfer ends	Grinder	200 rpm		



Part Name:			Armrest Connecting Bracket		
Raw Material:			2in. X 2in. PVC bar		
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	0.5 in. length			ruler, marker	
2	Cut to length	Band Saw	120 fpm		
3	Measure Hole centers			ruler, marker	
4	Drill 7/8 in. hole	Drill Press	400 rpm	7/8 in. Drill bit	Vise
5	Drill 1/8 in. holes	Drill Press	400 rpm	1/8 in. Drill bit	Vise



Part Name:	inner armrest pole (with hole)				
Raw Material:	7/8 in. OD x 0.049 in. aluminum tubing				
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	measure 22.5 in. length			ruler, marker	
2	Cut tubing to length	Band saw	120 fpm		vise
3	Drill 1/4 in. hole 1/2 in from end	Mill	200 rpm	1/4 in. drill bit	vise
4	Deburr all ends			hand deburring tool	vise
5	Chamfer ends	Grinder	200 rpm		

Part Name:	inner armrest pole				
Raw Material:	7/8 in. OD x 0.049 in. aluminum tubing				
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	measure 22.5 in. length			ruler, marker	
2	Cut tubing to length	Band saw	120 fpm		vise
3	Deburr all ends			hand debur tool	vise
4	Chamfer ends	Grinder	200 rpm		

Part Name:	pin activating mechanism rod				
Raw Material:	14 in.- 20 threaded rod				
No.	**Process Description**	**Machine**	**Speed**	**Tool**	**Fixtures**
1	measure 21.25 in. length of rod			ruler, marker	
2	Cut rod to length	Band saw	120 fpm		vise
3	chamfer ends	Grinder	200 rpm		

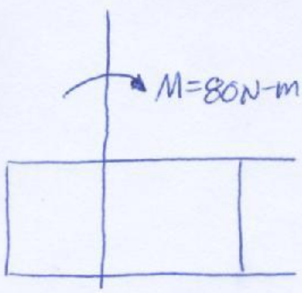
Part Name:		pin activating mechanism button			
Raw Material:		1in. diameter PVC rod			
No.	***Process Description***	***Machine***	***Speed***	***Tool***	***Fixtures***
1	Measure 1/2 in.			ruler, marker	
2	Cut rod to length	Band saw	120 fpm		vise
3	Drill 1/4 in. hole 1/4 in. depth	Drill press	400 rpm	1/4 in. drill bit	vise
4	Tap hole			1/4-20 tap	vise

Part Name:		pin activating mechanism pusher			
Raw Material:		1/8 in. sheet metal			
No.	***Process Description***	***Machine***	***Speed***	***Tool***	***Fixtures***
1	measure 1/2 in. x 2 in. strip			ruler, marker	
2	Cut material to length	Band saw	120 fpm		vise
3	chamfer ends	Grinder	200 rpm		
4	drill 1/8 in. hole	Drill Press	2500 rpm	1/8 in. drill bit	vise
5	Bend strip to shape			hammer	vise

Appendix K

Max Frame Stress Calculation

Max Stress occurs because of moment of seat on frame equal to 80 N-m.



- check stress to assure material choice is correct.

$$\sigma = \frac{MC}{I}$$

M = moment
C = point of action
I = moment of area

$M = 80\text{ N-m} \qquad C = 0.03175/2 = 0.015875\text{ m}$

$$I = \frac{\pi}{64}(D_o^4 - D_i^4) = \frac{\pi}{64}\left(0.03175^4 - \left(0.03175 - \frac{0.03175}{16}\right)^4\right)$$

$I = 1.13494 \times 10^{-8}$

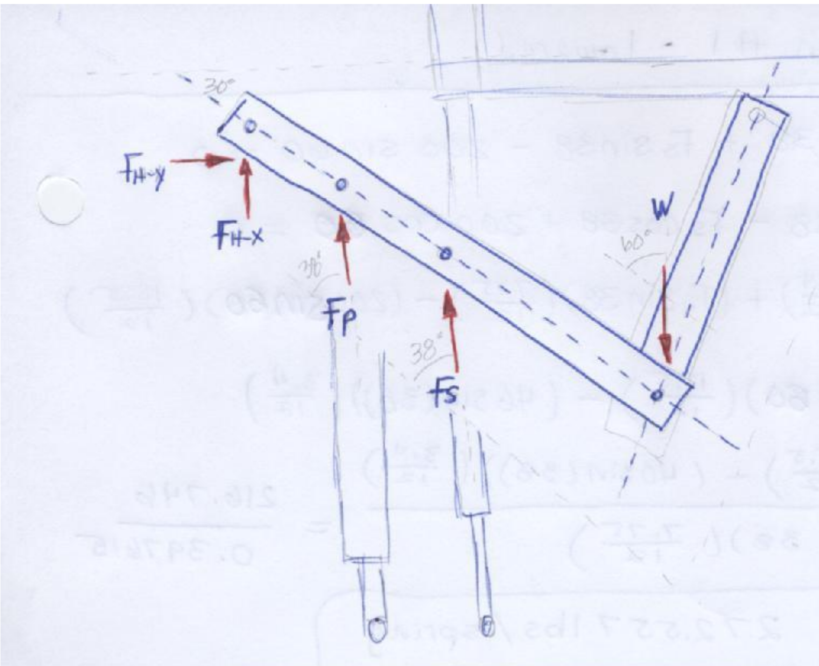
$$\sigma = \frac{(80\text{ N-m})(0.015875)}{1.13494 \times 10^{-8}} = 111.9\text{ Mpa}$$

$\sigma_{y,steel} \simeq 200 - 500$ Mpa,

This design includes a safety factor of 2x

Design will work.

Appendix K



W = Force due to seat

F_s = Spring Force

F_p = Pneumatic Cylinder Force

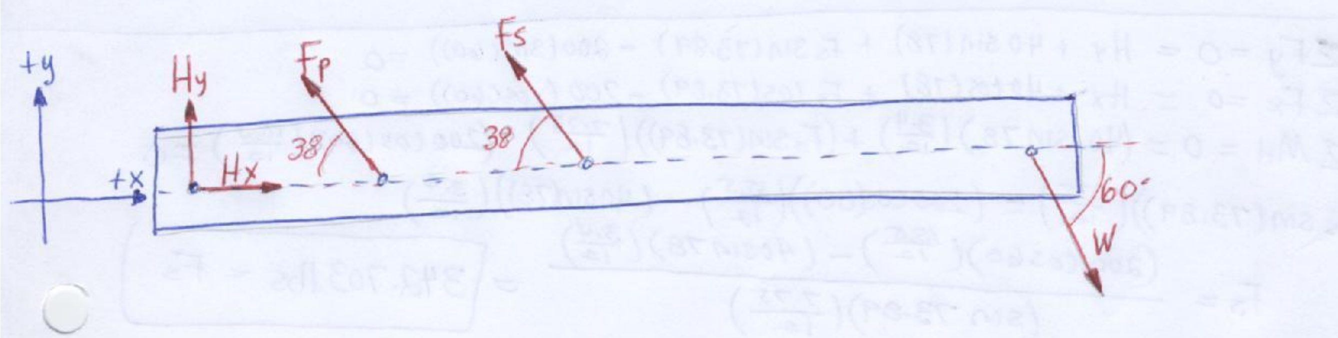
F_H = Hinge Reaction Force

Assumptions

W = 200 lbs – 180 lb occupant + 20 lb seat + frame

F_s = Unknown – We want to purchase springs with ideal force to reduce impact on user.

F_p = 40 lbs – Constant pneumatic cylinder force



Appendix K

Static Analysis - Position #1 - Lowered

$$\Sigma F_y = 0 = H_y + 40\sin 38 + F_s \sin 38 - 200 \sin 60 = 0$$

$$\Sigma F_x = 0 = H_x + 40\cos 38 - F_s \cos 38 + 200 \cos 60 = 0$$

$$\Sigma M_H = 0 = (40\sin 38)\left(\frac{3.4}{12}\right) + (F_s \sin 38)\left(\frac{7.75}{12}\right) - (200 \sin 60)\left(\frac{15.5}{12}\right)$$

$$(F_s \sin 38)\left(\frac{7.75}{12}\right) = (200 \sin 60)\left(\frac{15.5}{12}\right) - (40\sin(38))\left(\frac{3.4}{12}\right)$$

$$F_s = \frac{(200\sin 60)\left(\frac{15.5}{12}\right) - (40\sin(38))\left(\frac{3.4}{12}\right)}{(\sin 38)\left(\frac{7.75}{12}\right)} = \frac{216.746}{0.397615}$$

$$F_s = 545.115 \text{ lbs} \Rightarrow 272.557 \text{ lbs/spring}$$

Static Analysis Position #2 - Horizontal

$$\Sigma F_y = 0 = H_y + 40\sin(71.68) - F_s \sin(77.74) - 200 = 0$$

$$\Sigma F_x = 0 = H_x + 40\cos(71.68) - F_s \sin(77.74) - 0 = 0$$

$$\Sigma M_H = 0 = (40\sin(71.68))\left(\frac{3.4}{12}\right) + (F_s \sin(77.74))\left(\frac{7.75}{12}\right) - 200(15.5)$$

$$(F_s \sin(77.74))\left(\frac{7.75}{12}\right) = +200(15.5) + (40\sin(71.68))\left(\frac{3.4}{12}\right)$$

$$F_s = \frac{200\left(\frac{15.5}{12}\right) - (40\sin(71.68))\left(\frac{3.4}{12}\right)}{(\sin(77.74))\left(\frac{7.75}{12}\right)} = 392.287 \text{ lb} = F_s$$

Static Analysis Position #3 - Elevated

$$\Sigma F_y = 0 = H_y + 40\sin(78) + F_s \sin(73.89) - 200(\sin(60)) = 0$$

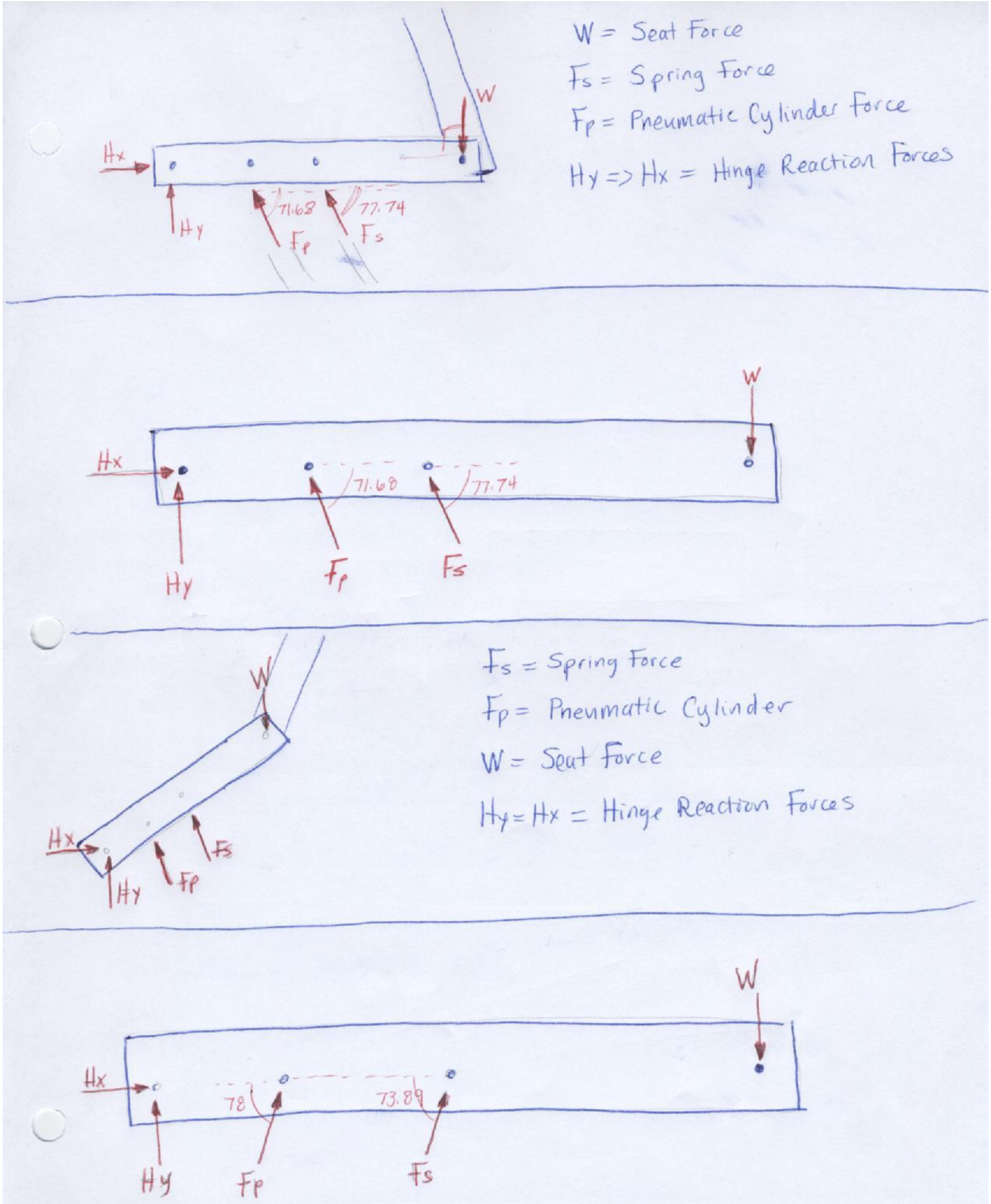
$$\Sigma F_x = 0 = H_x + 40\cos(78) + F_s \cos(73.89) - 200(\cos(60)) = 0$$

$$\Sigma M_H = 0 = (40\sin 78)\left(\frac{3.4}{12}\right) + (F_s \sin(73.89))\left(\frac{7.75}{12}\right) - (200\cos(60))\left(\frac{15.5}{12}\right) = 0$$

$$(F_s \sin(73.89))\left(\frac{7.75}{12}\right) = (200\cos(60))\left(\frac{15.5}{12}\right) - (40\sin(78))\left(\frac{3.4}{12}\right)$$

$$F_s = \frac{(200\cos 60)\left(\frac{15.5}{12}\right) - (40\sin 78)\left(\frac{3.4}{12}\right)}{(\sin 73.89)\left(\frac{7.75}{12}\right)} = 342.703 \text{ lbs} = F_s$$

Appendix K


W = Seat Force
Fs = Spring Force
Fp = Pneumatic Cylinder Force
Hy => Hx = Hinge Reaction Forces
W
Hx
Hy
Fp
Fs
71.68
77.74
W
Hx
Hy
Fp
Fs
71.68
77.74
Fs = Spring Force
Fp = Pneumatic Cylinder
W = Seat Force
Hy = Hx = Hinge Reaction Forces
W
Hx
Hy
Fp
Fs
W
Hx
Hy
Fp
Fs
78
73.89

Appendix K

Max Linkage Stress Calculation

Max moment seen = 100N-m occuring at attachment of gas springs

Check Stress $\sigma = \frac{MC}{I}$.

M = moment
C = point of action
I = moment of area

$M = 100 N\text{-}m$ $C = 0.01905$

$$I = \frac{0.01905\left(0.0381^3 - (0.0381 - 0.0042164)^3\right)}{12}$$

$$I = 2.604 \times 10^{-8}$$

$$\sigma = \frac{(100)(0.01905)}{2.604 \times 10^{-8}} = 73.1567 \text{ Mpa}$$

$\sigma_{y,\text{steel}} \cong 200 - 400$ Mpa

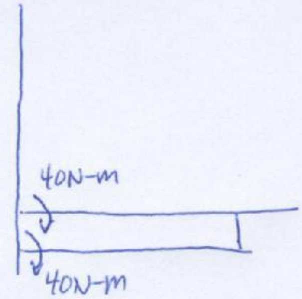
Safety factor over 2x employed

Design will work.

Appendix K

Seat Frame Maximum Stress Calculation

Max stress occurs where seat back meets seat bottom and has magnitude of 40 N-m



check stress to ensure no yielding

$$\sigma = \frac{MC}{I}$$

M = moment
C = point of application
I - moment of area

$M = 40$ N-m $C = 0.0127$ m

$$I = \frac{\pi}{64}\left(0.0254^4 - \left(0.0254 - \frac{0.0254}{16}\right)^4\right) = ~~1.91347 \times 10^{-8}~~ \; 4.6487 \times 10^{-9} \, m^4$$

$$\sigma = \frac{(40 \text{ N-m})(0.0127)}{4.6487 \times 10^{-9}} = 109.27 \text{ Mpa}$$

$\sigma_{y,\,steel} \approx 200 - 500$ Mpa

This design includes a safety factor of 2X

Design will work

Appendix K

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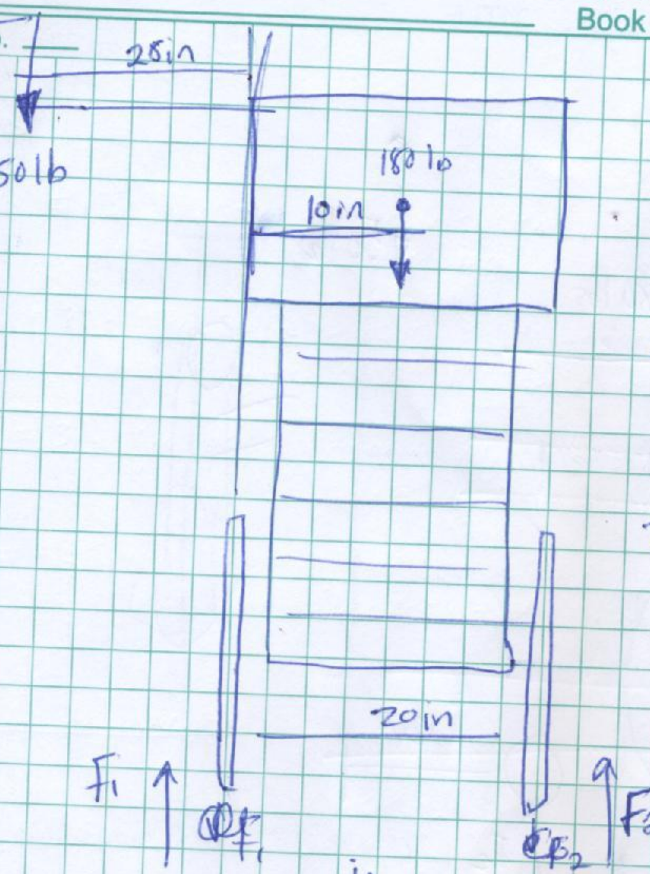

Σ

Tip when $F_2 = 0$

$50 \cdot 28 = 1400$ in-lb

$180 \cdot 10 = 1800$ in lb

no need for Stabelizer

$\Sigma M_1 = 50 \cdot 28 - 180 \cdot 10 + F_2 \cdot 20$

$F_2 = 20$ lbs

Would not tip unless occupant was 140 lbs

good over 140 lbs with 20" width.

ed & Understood by me, | Date | Invented by: | Date

Recorded by:

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