ME450 Design and Manufacturing III
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Innovative Bathtub Shower Chair for Geriatric
Final report

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ABSTRACT

Showering in a bathtub is a key barrier for the rapidly growing geriatric generation. Based on previous ME 450 projects of designing a shower chair our team will improve the chair to prepare it for commercial use. This project is sponsored by Albert Shih, Naomi Gilbert, and Susan Murphy. The new shower chair should allow independence for an elderly person to get into and out of the bath safely. It will also be able to fold up in the shower to allow others to use the shower as well. The device will help geriatric patients safely bathe while maintaining privacy and stability.

EXECUTIVE SUMMARY

Showering in a bathtub is a key barrier for the rapidly growing geriatric generation. In addition, it becomes a dangerous and inconvenient place when water spills out onto the floor. It is a difficult task for geriatric patients to get into and out of the bathtub. So there is a need to design a better assistive transfer device for the common bathtub.

Information Sources

We went to local medical shops to investigate the available products and searched US Patents. We also researched the existing products on the online markets similar to ours to find some of their flaws. We were able to find three main types of shower chairs, a simple chair, a wall-mounted chair, and a sliding transfer bench. Each had their own positives and negatives.

Sponsor Requirements

Our sponsors have given us some requirements that our design must meet. Some of the main requirements of our design are safety/stablity, easy to use, affordablity, and allowing the shower curtain to close.

Engineering Specifications

We developed 15 engineering specifications that correspond to customer requirements. We ranked them based on the survey results and the sponsor requirements. The top five engineering specifications are the cost, the number of safety locks to hold the chair, weight capacity, the number of hand rails, and the number of steps to get into the bathtub.

Concept Generation and Selection Process

We concluded six main functional groups that we need to improve in our design. We developed several concepts for each of these groups. A review of all the concepts was completed and we selected the most feasible design for each group. Lastly we constructed a Pugh Chart, using the advantages and disadvantages table, to determine an Alpha Design to proceed with.

Alpha Design

From the concept selection, an Alpha Design was created. Our Alpha Design has the same overall feel that the previous ME 450 team’s had. While there are many similarities, we have made some changes to improve the design, including the supporting legs, the handrail and the springs to hold the collapsed seat.

Engineering Design Parameter Analysis

In order to find the most suitable material for all the parts of our shower chair design, the forces and the shear stresses of each component need to be calculated. These values are used to determine what type of material properties are needed for each part of our design. Some of the calculations will be used to decide the suitable part we need to purchase.

Material Selection

We used CES EduPack 2009 to determine the material for our prototype and SimaPro 7 to evaluate the environmental impact of our prototype. Aluminum alloy, stainless steel, and plastic were the mainly material for the prototype. These choices were determined based on the criteria of strength, resistance to fresh water corrosion, density, and cost.

Final Design Description

Our final design can be divided into four main categories: swivel seat, sliding beam, supporting legs and folding mechanism. The swivel seat enables user to turn in 90° increments both clockwise and counterclockwise. This extending mechanism of the sliding beam enables the user to extend the seat out to the edge of the tub where they can easily sit down and retract to the middle of the tub when using the shower. This device allows clearance between the inside edge of the bathtub and the mechanism so that the curtain can be closed. The chair legs are able to fold flat for easy storage. We used a pair of torsion springs to help users to fold the seat up and down easily and safely.

Manufacturing Plans

We purchased a few of our parts that we were not able to manufacture ourselves. We bought the seat and swivel mechanism together, the main sliding beam, crossed legs and two torsional springs. What we need to manufacture include the seat plate, leg plate, handrail, and the wall mounts. The U-Channel and Box Beam are made from pieces of rectangular and square extruded aluminum. Holes were drilled in all of these to allow for assembly with fasteners.

Validation Results

Stability and safety is the most important requirement we need to meet in our design. We performed four tests when the seat is in use position and one test when the seat is folded up against the wall. During the tests the shower chair remains stable and no permanent damage occurs, so the mechanism passes all the tests.

Special Challenges Unique to the Project

One problem may be the weight is higher than expected. This weight could be optimized by ordering specialized component if we have more time. In addition, leg height adjustability and magnetic catch ability will be other problems sources. It is also a challenge for us to show our prototype and operate it at the Design Expo. We needed to construct a wall to mount the shower chair to.

INTRODUCTION

The Bathroom is an inconvenient place for elderly people. It can get even more dangerous when water is involved. Getting into and out of the bathtub is a particularly difficult task for these people. There are several shower chairs available, but none of them allow the user to sit down on the chair outside of the bathtub and allow transfer to the inside with the curtain resting inside the bathtub. This is necessary because it keeps the water from running down the shower curtain and collecting on the floor. Water makes the floor slippery and the bathroom becomes an even greater hazard for the elderly and disabled.

Our sponsors are Susan Murphy, an Assistant Professor of Physical Medicine and Rehabilitation with the Medical School, Naomi Gilbert, an Occupational Therapist, Department of Physical Medicine and Rehabilitation, and Albert Shih, a University of Michigan Mechanical Engineering Professor. They have determined that there is a need for a product like this to be available for use in private homes.

INFORMATION SOURCES

We conducted research on the geriatric and disabled population along with the shower chair market. Some of the articles on Geriatric/Disable Population and shower chair market:

"Older American: Key Indicators of Well-Being" [1]
Findings: This article gave us many important facts about the elderly population including: size, age, physical limitations, living situations and poverty level.

"Common Geriatric Conditions Overlooked" [2]
Findings: This article gave us information about how prevalent certain geriatric conditions are and how often they are overlooked. The article gave the impression that there is not much of an effort to assist the elderly with these conditions.

Several shower chairs have been design for elderly/disable people but with an expensive price due to the complex structure ($100-400) [3] or without a Leg-lifting help device [4].

We also looked at existing patents and benchmarks which can be seen in Appendix D.

SPONSOR REQUIREMENTS

We developed ten customer requirements based on meetings with our sponsors Susan Murphy and Naomi Gilbert. In addition, we made a survey (Appendix E) about the previous shower chair design (Appendix F) and received 31 responses from University of Michigan Clinicians. The customer requirements are listed in Table 1, on Page 9.

Based on the survey results of 31 experienced therapists, the target customers for our device are most likely walker and wheelchair users. According to our survey, cost is one of the common problems for similar products in the market. Since the device is not covered by insurance, some families cannot afford them. Among 31 therapists who had taken the survey, 13 of them agreed a reasonable cost to be $100-200 and another 9 people agreed the cost to be $200-300. The most important customer requirements focus on safety and stability, ease of use, cost, and is able to allow the shower curtain to be closed. We ranked the importance of the customer requirements as shown in Table 1, below, based on the survey responses. The previous team also put emphasis on the safety and making sure that the curtain can be closed in their customer requirements. (Appendix F) Our goal is to improve their design. Our design will focus on the stability and safety of the chair when in use. According to the responses of our survey, most individuals who need to use a cane or walker can step into the shower independently. However, the slippery surfaces can cause falls. The seat extending outside the tub will increase ease of transfers for the users. A collapsible handrail was strongly recommended for the user to hold on and keep balance while sliding the seat towards the center of the tub. In addition, only one handrail instead of two is suggested to avoid limiting the sitting space so that users with various body types are able to use the device. We decided to add a safety belt for stability issue as well. The therapists also suggested strengthening the chair legs because the current design seems like they may slip.

Table 1: Customer Requirements

Customer Requirements	Importance Rating
Maintaining stability when in use / Safe	10
Easy to use	9
Low cost	8
Allows shower curtain to close	7
Extend to outer edge of bathtub	6
Non-invasive for other shower users	5
Handrails	4
The comfort of the seat	2
Easy to install	2
No sharp edges	1

ENGINEERING SPECIFICATIONS

We developed 15 engineering specifications correspond to customer requirements which are shown in Table 2, on Page 10. These engineering specifications and target values are based on the results of a survey taken by University of Michigan Clinicians, the specifications of similar products in the market, measurements of common bathtubs, the specifications from the previous team (Appendix F) and established general engineering practices.

We determined the cost of our design to be less than $250, which is close to the price of competitive products in the market, but our design can be superior in functionality. One top customer requirements is safety and stability. In our engineering specification, in order to keep chair balance, we determined to use double safety locks to hold the chair when the loading position and in-use position. The weight capability of our design is 300 lbs. Based on our discussions with our sponsors and the feedbacks from therapists, the handrail/armrest that assists the patient to stand up and secure the patient when the chair is moving is very important. We specified four steps to get in and out of bathtub corresponding to the customer requirement that it be easy to use. We determined the dimension between the seat and the edge of bathtub to be 2” so that the shower curtain can be closed. We determine the seat depth to be 15” to make the seat comfortable. We also specify that the seat is extended to outer edge of bathtub during loading and the user can sit on the chair from the outside of the tub which makes geriatric transfer easier and safer. We decided to strengthen the chair legs so the device is stable with a weight restriction of 300 lbs. In addition, we determined the thickness of collapsed mechanism to be less than 5” to allow other people in the home use the same shower. Moreover, the therapist also recommended involving in our design a seat belt, a supportive backrest and a wall bar that assists the patient to stand when exiting the seat.

The Quality Function Deployment (QFD) is established to clearly show our design goals and how we are going to achieve them by specifying both the customer and engineering requirements together. The engineering specifications are ranked based on the importance ratings of the customer requirements and the correlation of the engineering specifications with the customer requirements. The QFD is shown in Appendix G.

Table 2: Engineering Specifications and Target Values

Rank	Engineering Specification	Target
1	Cost ($)	<250
2	Number of safety locks to lock the chair when in use and loading position	2
3	Weight capacity (lbs)	300
3	Number of handrails on the chair	1
5	Number of steps to get in and out of bathtub	4
6	Dimension from inside edge of bathtub when in use (inch)	2
7	Seat Depth (inch)	15
8	Dimension from outside edge of bathtub when loading (inch)	1
9	Adjustable range of chair height (inch)	19-23
10	Seat Width (inch)	20
11	Back height (inch)	13
12	Weight of mechanism (lbs)	<20
13	Thickness of collapsed mechanism (inch)	<5
14	Number of attachment locations	<4
15	Safety factor	2

CONCEPT GENERATION

Based on the sponsor requirements and engineering specifications, we concluded six main functional categories that we need to improve or include in our design: the folding mechanism, method of seat attachment, stability of legs, the swivel mechanism of seat, height adjustability, as well as a non-attached shower chair design. The first five categories intend to improve the previous work and make it ready for commercial use. Since our sponsor also wants to find a way to avoid mounting the shower chair on the wall, the last category is going to develop a totally different idea where there is no need for installation.

We also developed several designs for a leg-lifting mechanism. Since the leg-lifting design is not a sponsor requirement, it also increases the cost and cannot be folded up when not in use; we put these concepts in Appendix E and treated this mechanism as an extra design.

We developed several concepts for each functional category. After generating rough drawings of each concept, we noted the advantages and disadvantages of the various designs. A review of all the concepts was completed and we selected the most feasible design for each group to meet all the sponsor requirements and engineering specifications. The rough drawings of the seven finalized designs are shown in Figures 1- 6, on Pages 11 – 14, and the explanation of each mechanism is included next to the figure. A table demonstrating the advantages and disadvantages of each design is shown in Table 3 on Page 13. All the other concepts and their advantages and disadvantages are listed in Appendix H to L.

Folding Mechanism

This folding mechanism, Figure 1 below, allows geriatric patients to fold the seat up and down easily and safely. This spring will reduce the force needed to move the seat. To prevent injury, we considered adding a damper to this folding mechanism. This damper is used to slow down the folding speed of the seat and make sure geriatric patients don't get their hands caught on the seat. The advantage of this design is that geriatric patients need less force to fold up the seat. However, it is difficult to find the right spring and the spring is easy to be rusted in the wet environment. We decided that a casing would be needed for the spring to avoid rust and a pinching hazard.

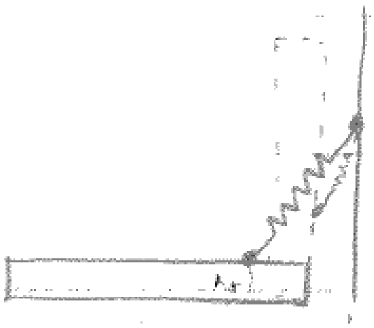


Figure 1: folding mechanism using a spring

Method of Seat Attachment

The shower chair is designed to be able to fold up to make sure that another person can also use the bathtub. To make the folded device thinner, we considered removing the seat and the swivel part when folding the chair. The seat is attached by a pin that connects the sliding beam and the swivel part as shown in Figure 2, on Page 12. The first advantage of this attachment mechanism is stability. It is also simple to use and easy to manufacture. The disadvantage is that the pin needs to sustain a large force.

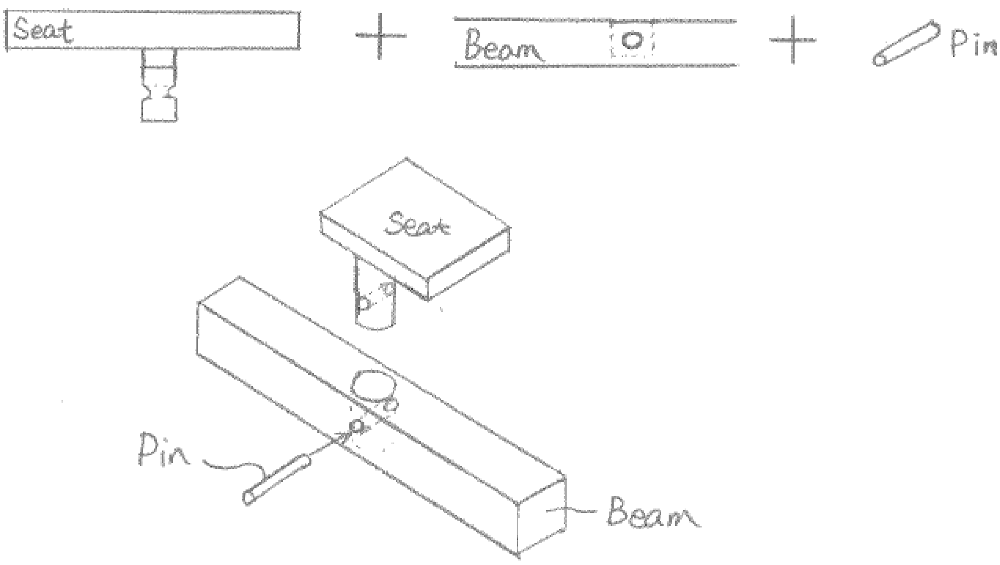


Figure 2: Seat attachment mechanism with a pin

Stability of Legs

This design comprises a pair of leg frames each of which comprises of U-Shaped legs that are pivotally connected together in the middle, as shown in Figure 3, below. There are two stoppers positioned for limiting the inclination of each leg. Each crossed leg comprises an upper slide rod and a support leg. The slide rods can slide within a respective support leg to adjust the height. The advantages of this concept are stability and less material is needed to produce it. It also can be folded easily for storage. But it is difficult to manufacture.

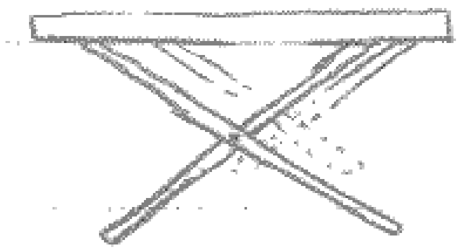


Figure 3: Foldable supporting legs with two opposing pairs of leg frames crossed

Swivel Mechanism of Seat

The seat should be locked when geriatric patients are sitting down, standing up, and taking a shower, otherwise it will cause injuries. The seat swivel mechanism comprises an upper plate attached to the bottom of the seat and a lower plate connected to the sliding beam as shown in Figure 4, on Page 13. The upper plate swivels relative to the lower plate and stops by the circular obstruction. The swivel seat enables user to turn 90° both clockwise and counterclockwise. The advantage of this swivel mechanism is that it can lock the seat in each 90 degrees. This lock mechanism can make sure that geriatric patients will move the seat safely. The disadvantage of this concept is the unknown amount of force that must be applied to this obstruction.

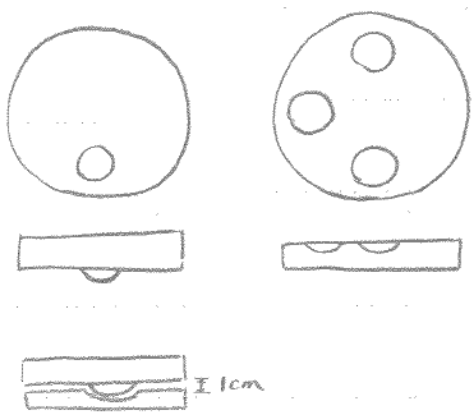


Figure 4: Swivel mechanism with circular obstruction

Height Adjustability

The shower chair is attached on the wall by connecting the end of the beam to a pivot rod which is connected to wall mounts. There are four rods on the wall, two on each side. Figure 5, below, shows just one side. The steel plate with several holes is placed on the rods mounted on the wall. There are multiple holes to allow for adjustment of the seat height. The height can be adjusted in 1” intervals. To adjust the height of the shower chair, the wall mount is simply placed at the desired height and fixed to the rods with two nuts. The primary advantage of this concept is adjustability. It is also easy to manufacture. Its disadvantage is that a caregiver needs to adjust the height. The geriatric patients probably cannot do this by themselves.

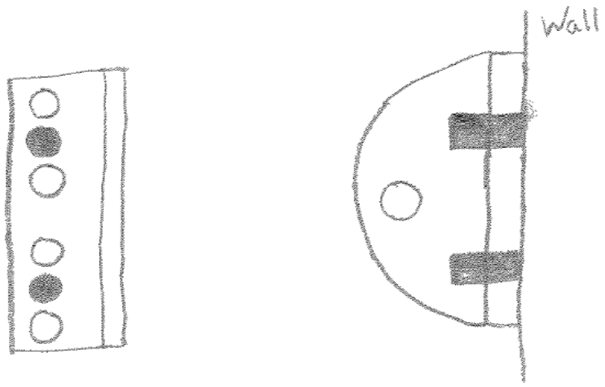
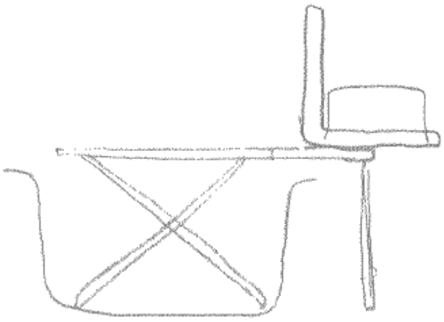


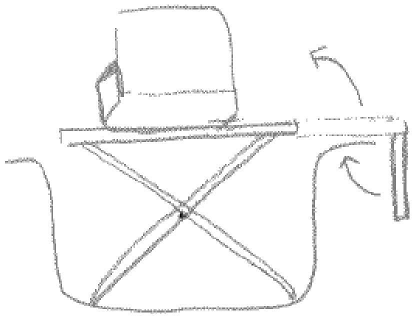
Figure 5: Height adjustable wall mounts

Non-attached Shower Chair Design

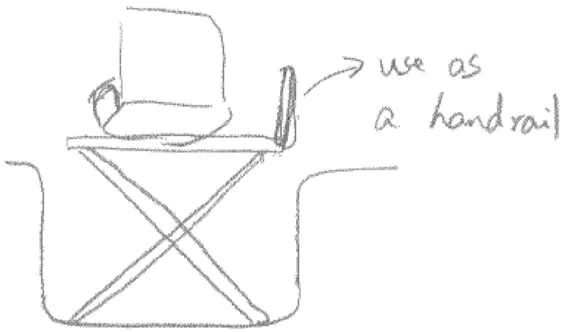
Since some users may not want to make a change to their house, for example, drilling a hole on the wall to install this shower chair, this design solves this problem. This shower chair does not need to be mounted on the wall and it can be folded up when not in use. There are six legs in this design, four are inside the bathtub and two are outside the bathtub. When the seat slides in, the two legs and the sliding beam outside the bathtub can be folded up and locked as shown in Figure 6 (c), on Page 14. The folded part can be used as a handrail. The whole chair can be folded up and stored in the closet. The primary advantage of this design is that it does not need to drill holes on the wall to install this shower chair. Geriatric patients can carry this chair when they travel. The disadvantage is that it may not be stable when the seat slides outside.



(a)



(b)



(c)

Figure 6: Nonattached shower chair design

Table 3: A Summary of Main Design Advantages and Disadvantages

Design	Advantages	Disadvantages
Folding mechanism with spring	-Need less force to fold in and out the seat -Safe with damper	-Hard to find the right spring -Easy to rust
Seat attachment mechanism	-Stable -Simple to use -Easy to manufacture	-Pin needs to sustain a large force
Folding cross legs	-Stable -Need less material -Can be folded up easily	-Difficult for manufacturing
Swivel mechanism of seat	-Can lock in each 90 degrees -Slide the seat safely	-Unsure amount of force that can be applied by this mechanism
Height adjustability mechanism	-Stable -Easy to manufacture	-Need a caregiver to adjust the height
Nonattached shower chair design	-Do not need to mount to the wall -Easy to carry	-Unstable when the seat is extended out of bathtub

CONCEPT SELECTION PROCESS

Functional decomposition and Pugh Charts

We defined and decomposed the show chair into four main functions: folding, swivel, transfer and chair leg support. The functional decomposition diagram is shown in Figure 7, on Page 15. It shows the overall function that needs to be accomplished and the sub-functions each part contained.

Furthermore, it presents a person's motion of operating the chair by his/her hand force and leg force. The decomposition helps us understand how and when different functions will have an effect on a person's motion, such as folding up the chair and taking shower.

We used the Pugh Charts methods to help us select the concepts. We determined the concept with the highest scores to be the best concepts. The Pugh Charts are shown in Appendix M.

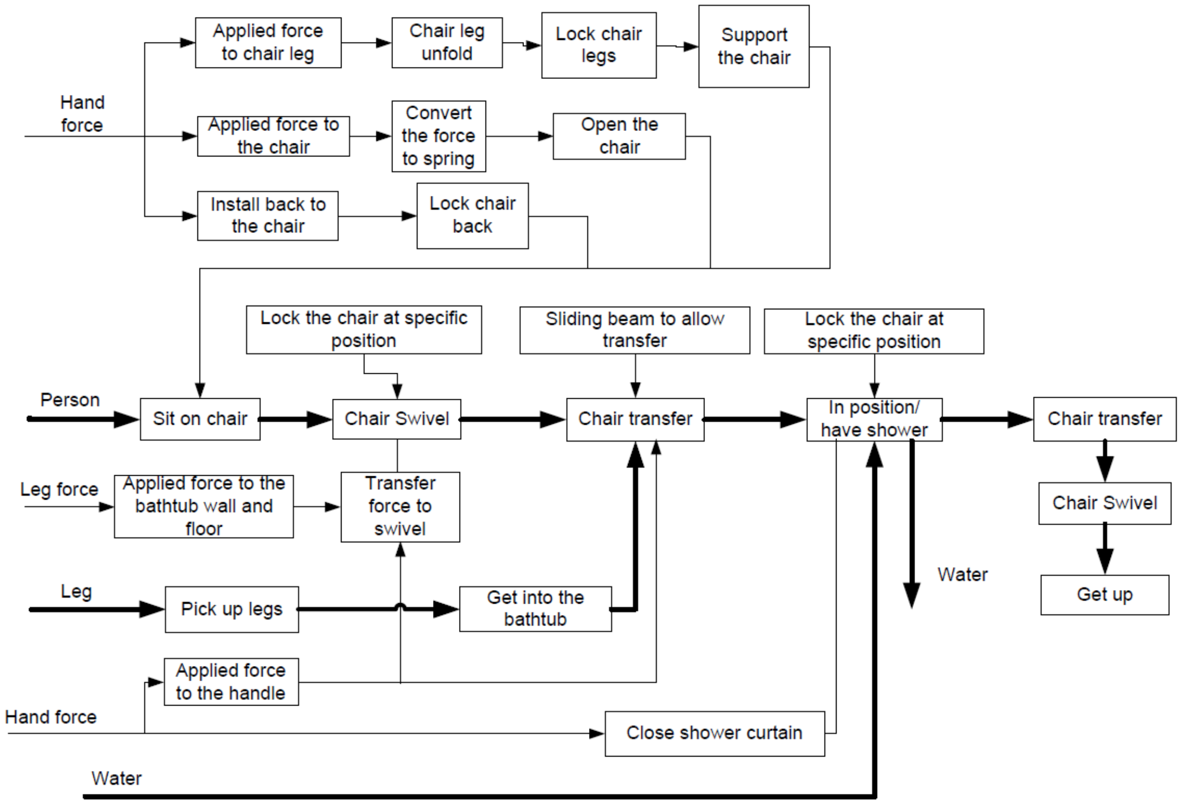


Figure 7: Functional Decomposition

ALPHA DESIGN

Our Alpha Design has the same overall feel that the previous ME 450 team's had. As you can see in Figures 8 and 9, on Page 16, it is bolted to the wall with legs that pivot to support it in the folded out position. The sliding beam is the same idea as well. While there are many similarities, we have made some changes to improve the design. The leg support has been changed to a cross instead of just a bar. Also, on the bottom of the legs suction cups were added. We have added a handrail to the seat. The wall mounts have been made adjustable as well as rounded to eliminate the dangerous sharp edges. Instead of using a latch to hold the collapsed seat we are using a spring/damper system. To fold the seat up against the wall the seat will have to be removed.

Our additions to the previous design will push this product closer to the commercial market, which is the goal of our sponsor Albert Shih. The handrail will add more stability for the user when sitting down and standing up. It will also give the user something to grasp when showering. The leg support with will have more stability with the use of the cross plate. On the bottom of the legs suction cups will be attached to keep the legs from unwanted motion when the seat is deployed. The wall mounts can now be moved up or down to adjust the overall height of the seat. The latch the last design used to hold the seat when it was folded up was targeted by our survey as a dangerous part. The spring will do away with that dangerous edge. It will also help with the closing of the seat. The seat will only have to be lifted approximately 60° and then the spring force will be greater than the moment caused by the weight of the seat and will close itself. The Alpha Design, when folded up, will only stand 5" off of the wall. To achieve the small protrusion the seat must be detached. Detaching the seat will be a minor inconvenience, but the seat will completely collapse, including the handrail and back, to make it easy to store underneath the sink or in a closet. This will allow another person to use the shower without the seat impeding their motion. These additions will greatly enhance the value of this product. Comparison pictures between the Previous Model and out Alpha Design can be seen in Appendix N.

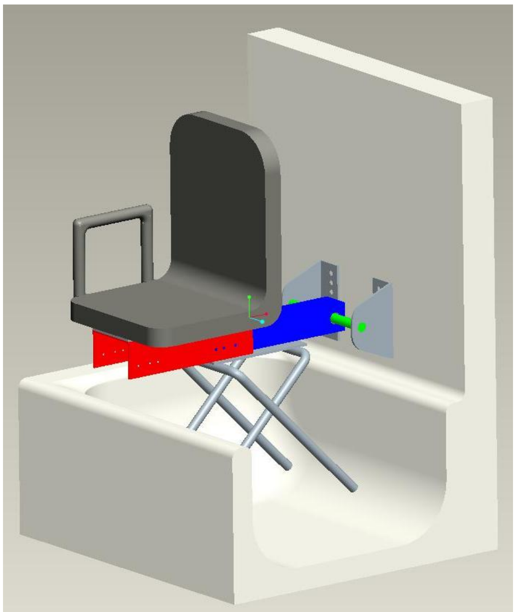


Figure 8: Alpha Design loading position

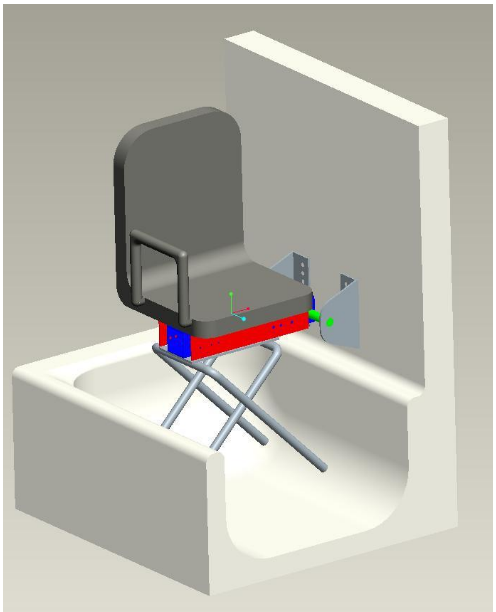


Figure 9: Alpha Design wash position

ENGINEERING DESIGN PARAMETER ANALYSIS

This section includes all the calculations of the major forces acting on each part of our shower chair. These values will be used to determine what type of material properties are needed for each part of our design. Some of the calculations will be used to decide the suitable part we need to purchase.

Major Forces

In order to do these calculations, we first establish the dimension of the bathtub and the dimension of our design, as shown in Figure 10, on Page 17.

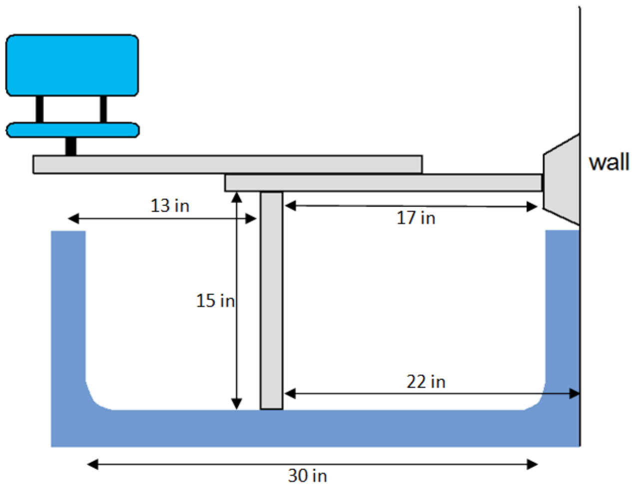


Figure 10: Dimensions of bathtub and our shower chair design

Before all calculations, we assumed that the sliding mechanism would act as a rigid body. The weight capacity of our shower chair is designed to be 300 lb. The free body diagram of the whole mechanism is shown in Figure 11, below. Based on the equilibrium of forces and moments, we obtained the forces acting on the legs and the wall mounting mechanism.

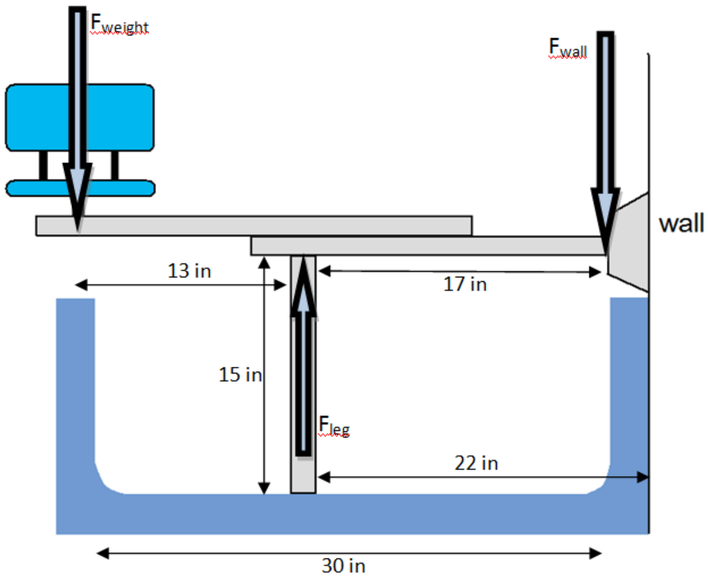


Figure 11: Free body diagram of the whole mechanism

F_{weight} = 300 lbs
M_{leg} = (300 lbs) (13 in) – (F_{pivot}) (17 in) = 0
F_{leg} - F_{weight} - F_{pivot} = 0

Thus
F_{pivot} = 229.4 lbs
F_{leg} = 529.4 lbs

Shear Stress of Bolt on the Top of the Legs

The force acting on the legs is the largest when the sliding mechanism is in the extended position. So we just need to check if the bolts on the top of the legs can withstand this force without shearing at this point. If they can, the bolts will also be able to withstand the forces at other positions. There are two legs and one bolt on each leg. The forces acting on the bolt is shown in Figure 12, below. We chose a bolt which has a diameter of 3/16". So the cross-sectional area of this bolt is 0.0276 in^2. By using a safety factor of 2, we calculated the shear stress in the bolt. The material we choose must satisfy this shear stress requirement.

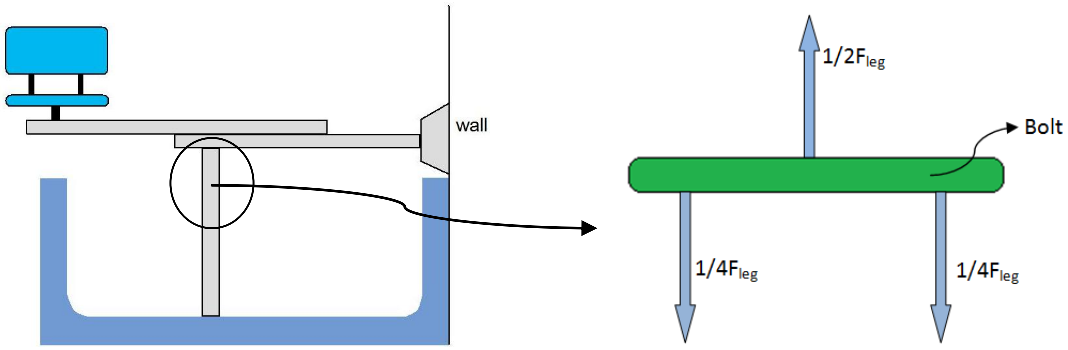


Figure 12: Free body diagram of bolt on the top of the legs

F_{leg} = 529.4 lbs

A = cross-sectional area of the bolt = 0.0276 in^2

$$\text{Shear stress on each bolt} = \tau = \frac{2 \times (\frac{F_{leg}}{4})}{A} = 9590.6 \text{ psi}$$

$$Yield\ strength\ needed = \frac{9590.6psi}{0.55} = 17437psi$$

Tear Out of the Leg Material

We again looked at the largest force when the sliding mechanism is in the extended position and analyzed whether the area can survive. The area is shown in Figure 13, below. The calculation was performed by using a safety factor of 2.

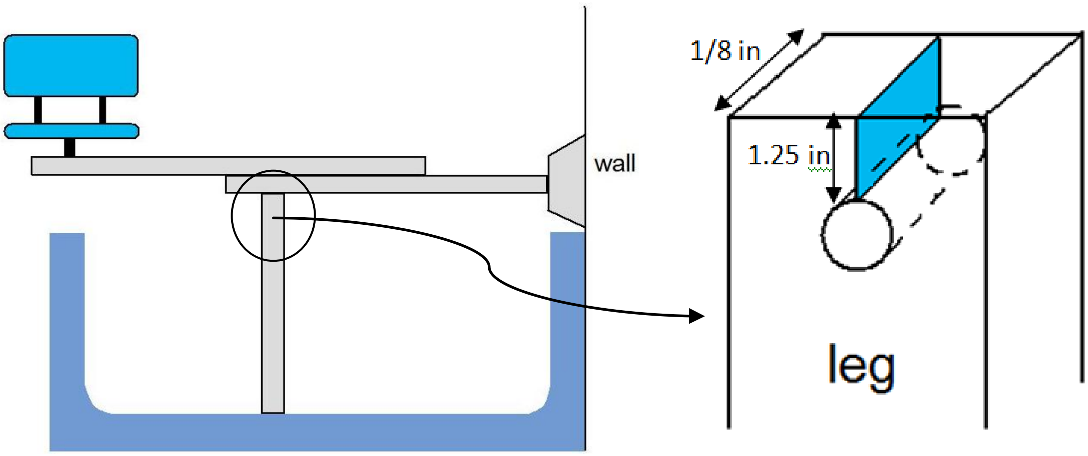


Figure 13: Area that need to withstand the force of leg

F_{leg} = 529.4 lbs
d = distance of the bolt to the edge of the U-channel = 1.25 in
t = thickness of the leg material = 1/8 in
A = td = 0.15625 in^2

$$\text{Shear stress on each area} = \tau = \frac{2 \times (\frac{F_{leg}}{4})}{A} = 1694.1 \text{ psi}$$

$$Yield\ strength\ needed = \frac{1694.1psi}{0.55} = 3080psi$$

Force of Pivot Rod on the End of the Sliding Beam

The shower chair is attached on the wall by connecting the end of the beam to a pivot rod which is connected to wall mounts. In order to check whether the rods would fail due to the force acting on it, we calculated the force by the equilibrium of force and moment. The free body diagram of the sliding beam is in Figure 14, below.

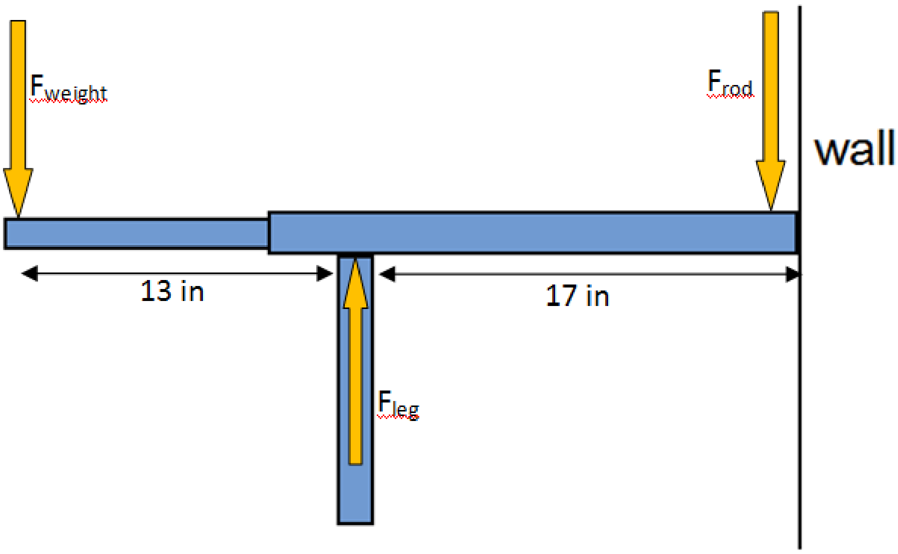


Figure 14: Free body diagram of the sliding beam

F_{weight} = 300 lbs
M_{leg} = (300 lbs) (13 in) – (F_{rod}) (17 in) = 0
F_{rod} = 229.4 lbs

Shear Stress of Pivot Rod on the End of the Sliding Beam

There are four rods mounted on the wall, two on each side. The shear stress of the rod was calculated by using the similar method with the calculation of the bolt on the top of the legs as shown in Figure 15, on Page 20. We chose the diameter of the rod to be ½” so that the cross-sectional area of the rod is 0.196 in^2.

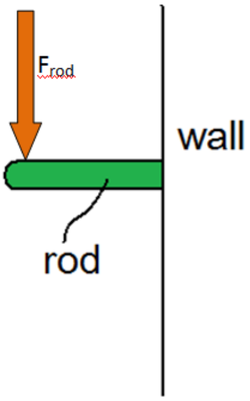


Figure 15: Force acting on the pivot rod

F_{rod} = 229.4 lbs
A = cross-sectional area of the bolt = 0.196 in^2

$$\text{Shear stress on each bolt} = \tau = \frac{2 \times (\frac{F_{leg}}{4})}{A} = 585.2 \text{ psi}$$

$$Yield\ strength\ needed = \frac{585.2psi}{0.55} = 1064psi$$

Torsional Spring Force

The torsional spring is used to provide a force to help the user to fold the device up. To select a suitable spring that can provide enough torque, we need to calculate the torques at different positions. The total weight we need to consider includes the weight of the sliding beam, legs, the top aluminum plate which supports the seat, and the bottom aluminum plate which connects the legs. The weight of each plate is 3.53 lbs, which is calculated from the density of aluminum and the volume of the plates. The total torque according to the total weight is 222 lb-in. When the beam is 45^o from the horizontal line, the torque of the torsional spring is 157 lb-in, while the torque is 111 lb-in when that angle is 60^o. Figure 16, below, and Figure 17, on Page 21, show the torques on the torsional spring.

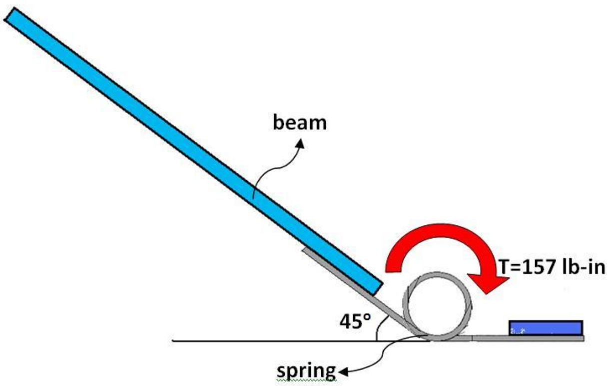


Figure 16: Torque when the beam is 45 degrees from the horizontal line

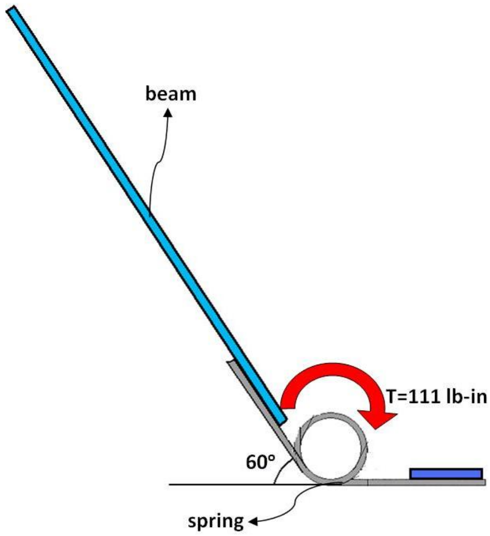


Figure 17: Torque when the beam is 60 degrees from the horizontal line

$T_{total\ weight}$ = 222 lb-in
When 45°,
T_{45} = 222 lb-in/$\sqrt{2}$ = 157 lb-in
When 60°,
T_{60} = 222lb-in/2 = 111lb-in

FINAL DESIGN DESCRIPTION

Our final design can be divided into four main categories: swivel seat, the sliding beam, supporting legs and folding mechanism. We have determined the material properties needed for each part of the design based on the engineering analysis. We also used CES software to select the material used for each part of the design.

After taking into consideration of the feasibility of manufacturing, we made some modifications on the final design. One change is the way to lock the chair when in use and loading position. Before, we specified two safety locks would be used. For the final design, we decided to use 12 pairs of magnetic catches each provide 8 lb pushing power to lock the outer U-channel and inner box-channel. Second, since we decided to buy the pre-fabricated swivel seat, the dimensions of the seat have changed to 17.5”×13.5” with a back height 12.5”. The total weight of the mechanism has also changed to about 18 lb when the seat is not attached to it. Finally, the method of seat attachment has changed. Instead of using a pin to connect the sliding beam and the swivel part we determined use four bolts to attach the seat on the top of an Aluminum plate which is wielded to the beam.

The modified views of the CAD model can be seen in Figure 18, on Page 22, and Figures 19 and 20, on Page 23. The CAD models show the device when the seat is not attached to it in order to see the parts beneath the seat, since we considered removing the seat and the swivel part when folding the chair to make the collapsed device thinner and easier for another person to use the bathtub. Figure 18, below, shows the device in use position. The two aluminum plates are joined to the top and bottom of the beam with fasteners. The seat can be attached to the top plate by using bolts and the foldable legs will be attached to the bottom plate using bolts as well. Figure 19, on Page 23, shows the device in the extended position. The main beam can be extended to the outer edge of the tub to allow the user to sit down and then retract back to the in-use position. The main beam is composed of three parts: the U-channel, the box-channel and a pair of sliding rails. One side of the sliding rails will be attached to the inner box-channel and the other side to the outer U-channel. The U-channel with the seat attached to it can extend out and retract back with the help of the sliding rails. Figure 20, on Page 23, shows the device folded up. We will remove the seat when the beam is folded up. We will install two torsion springs on both sides of the pivot rod. One leg of the spring will be attached to the wall mount and the other leg to the bottom of the box-channel. The torsion springs will help the user to fold up the seat and hold the collapsed mechanism against to the wall.

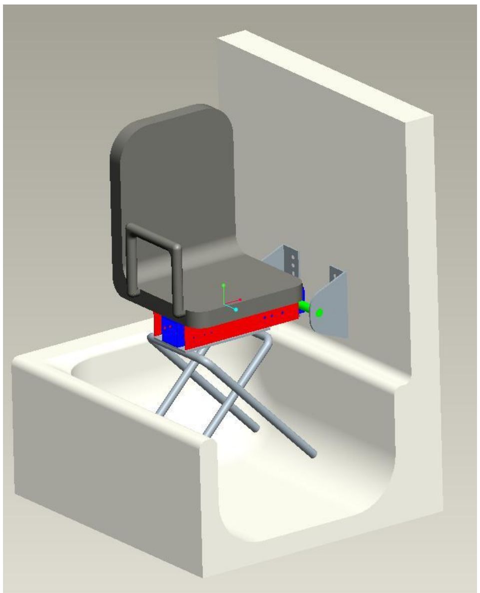


Figure 18: Finalized CAD design in-use position

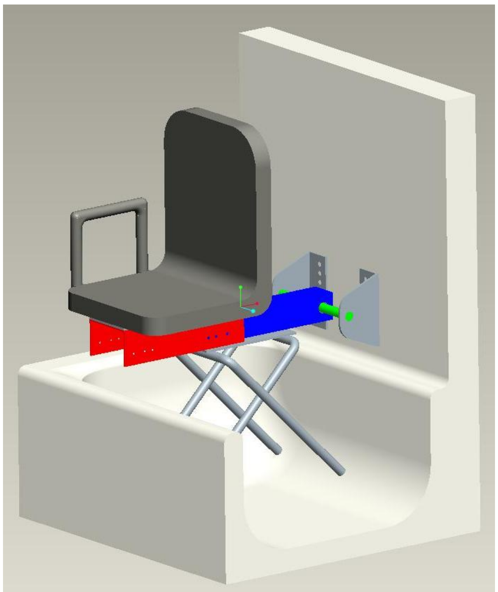


Figure 19: Extended Design

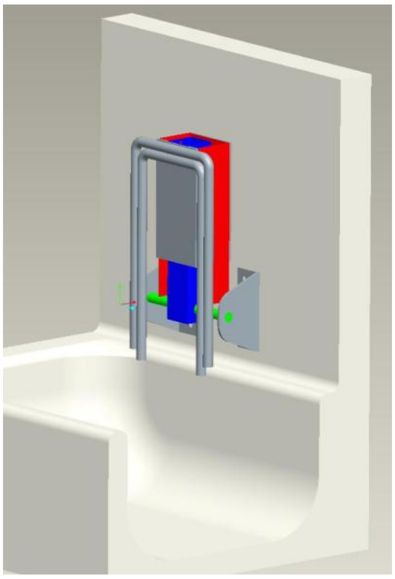


Figure 20: Collapsed Design

Seat

The swivel seat was bought from Eagle Health Care Co., shown in Figure 21, on Page 24. The chair is plastic molded with a dimension of 17.5”×13.5”. The back height to top of the seat is 12.5”. The seat and backrest have non-slip texture finish. The backrest can be installed in either side of the seat. A safety belt is also included to provide additional stability. The swivel seat enables user to turn in 90° intervals both clockwise and counterclockwise. In addition, the secured locking mechanism ensures the stability for both patient transfers as well as when showering. The chair costs approximately $170 including shipping fee.

Figure 21: Seat with Swivel Mechanism

Sliding Beam

This extending mechanism enables the user to extend the seat out to the edge of the tub where they can easily sit down on it and to retract to the middle of the tub when using the shower. This device allows clearance between the inside edge of the bathtub and the mechanism so that the curtain can be closed. The sliding beam will compose of five main components: sliding rails, outer U channel, inner box channel, top seat attachment plate, and bottom leg attachment plate.

Sliding Rails

We will use a pair of 16" 7500 Series 400 LB Super Duty Slides produced by Bold Hardware Co., shown in Figure 22, below. The device has a load capacity of 400 lbs in the fully extended position. The slides are made of stainless steel. The slider extends from 16" to approximately 28" fully extended. This sliding device costs approximately $60 including shipping fee. The data sheet for the sliding rails can be found in Appendix O.

Figure 22: Super Duty Slide

Outer U-Channel and Inner Box Channel: We ordered two 6063 Aluminum rectangular tubes from Discount Steel. The U channel will be manufactured from Aluminum tube with dimension of 6"× 4" × 1/8" and box channel from Aluminum tube with dimension of 3" × 3" × 1/8. We will drill holes on both U and box channel using the drill pass for mounting the sliding rail to the track. The sliding rails have both 3/16" and 3/8" holes. We will use ½" long 3/16" as well as ½" long 3/8 stainless steel pan heat bolts with locking washers to attach the sliding rail to the inner box channel and the outer U-channel. The outer U-channel will be locked with inner box channel using 12 pairs of Ultra Thin magnetic catches produced by McMaster, Model #1745A15, shown in Figure 23, on Page 25. Each pair of magnets will provide 8 lbs of pull power. They each cost $ 5.33.

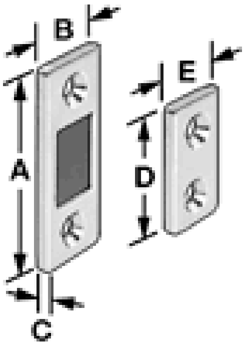


Figure 23: Ultra Thin Magnetic Catches

Top Seat Attachment Plate and Bottom Leg Attachment Plate: The seat attachment plate is a 6061 aluminum plate measure 12” ×12” ×1/4” ordered from Discount Steel, shown in Figure 24 below. This aluminum plate will be welded on the top of the U channel and the swivel seat will be attached to the plate using bolts. The leg attachment plate is the exact same as the seat plate. This plate will be welded on the bottom of the box channel. Then the supporting legs will be attached to the plate using bolts.

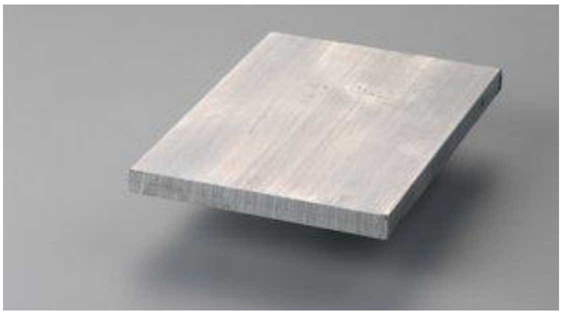


Figure 24: 6061 Aluminum Plate

Supporting Legs

We will order pre-fabricated folding shower chair legs produced by Drive Medical Design & Manufacturing, shown in Figure 25, below. The chair legs are made of a durable and corrosion proof aluminum frame and are able to fold flat for easy storage. The chair legs are adjustable from 16” to 18” (1” increments). The angled legs provide additional stability and overall have a weight capacity of 300 lbs. The supporting legs will be attached to the bottom of leg attachment plate using bolts.

Figure 25: Folding Chair legs

Folding Mechanism

Torsion springs: We will use a pair of torsion spring, shown in Figure 26, below, to help users fold the seat up and down easily and safely. The spring will reduce the pushing force for folding the mechanism and slow down the rate when releasing the device. We chose the torsion spring with deflection angle 360° and each providing a torque of 42.86 in•lbs. One of the springs is wound clockwise and the other is counterclockwise wound. The springs were provided by McMaster-Carr.

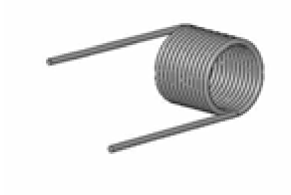


Figure 26: Torsion Spring

Wall attachments: Two wall attachment brackets will be used for wall mounting. We will fix the wall brackets with a pivot rod with diameter 1” by using a press fit. Then, the main beam will be attached to the pivot rod using ball bearing and be able to rotate freely. We will create the wall attachment brackets from an aluminum box channel with dimension 2”×8”×4”. The aluminum box channel will be provided by Home Depot. We will purchase a threaded steel rod with diameter ½” as the pivot rod from Home Depot as well.

Materials and Parts List

Table 4, below is the bill of materials and part list. All the parts are listed along with the manufacturer, part number, quality, and cost. The matching Engineering Drawings can be found in Appendix P.

Table 4: Bill of Materials

Item	Quantity	Source	Catalog Num.	Cost ea.	Contact
Seat Assembly	1	Eagle Health Care	37662	$170	http://www.allegromedical.com
400LB Super Duty Slide	1	Bold Hardware Co.	16" 7500 series	$49	http://www.drawerslides.com
16” 6063 Aluminum Rectangular Tube	1	Discount Steel	6” × 4” × 1/8”	$37	http://www.onlinemetalstore.com
18” 6063 Aluminum Square Tube	1	Discount Steel	3” ×3” ×1/8”	$11	http://www.onlinemetalstore.com
Ultra Thin Magnetic Catches	12	McMaster-Carr	1745a15	$5	http://www.mcmaster.com
Aluminum Plate	2	Discount Steel	12”× 12” × ¼”	$22	http://www.discountsteel.com
Folding Legs	1	ActiveForever	A13331	$40	http://www.activeforever.com
Torsion Springs left hand	1	McMaster-Carr	9271k136	$6	http://www.mcmaster.com
Torsion Springs right hand	1	McMaster-Carr	9271k135	$6	http://www.mcmaster.com
Bearing	2	McMaster-Carr	5905k28	$6.60	http://www.mcmaster.com

Pivot Rod	1	Alro Metals Plus	AAA02500	$5.50	(734) 213-2727
Wall Mounts	1	Alro Metals Plus	26323100	$1.36	(734) 213-2727

Prototype Description

Since the aim of our team is to improve the shower chair design of the previous ME 450 team and prepare the device for commercial use. We will manufacture the prototype exactly like the final design. At this stage, we have to order all the material and pre-fabricated parts we need.

FABRICATION PLANS

Purchased Parts

We will be purchasing a few of our parts that we are not able to manufacture ourselves. We will buy the seat and swivel mechanism together. The seat will require some minimal machining to enlarge existing holes for the handrail. We would be unable to create a plastic seat in a timely fashion. The main sliding beam will be purchased as well. A spring and damper system will need to be purchased for our seat. Our Eningeering Drawings can be found in Appendix P.

Machined from Scratch Parts

The U-Channel

The U-Channel is made from a piece of 6” x 3” rectangular extruded aluminum. One of the long sides of the rectangle will have to be cut off to creat the “U” shape. There will also have to be holes machined to allow the slide rails to be attatched.

The Box Beam

The Box Beam will have holes machined for the pivot bar and the attatchment of the slide rails.

Seat Plate

The seat plate will be machined from a square piece of 1/4” thick aluminum. It will have four holes drilled in it for screws to attach the bottome of the swivel part of the seat to it.

Leg Plate

The leg plate is designed to allow the legs to fold up and fold out. It will be machined out of aluminum with dimensions of 12” x 12” x 1/4”. There will need to be eight holes machined for leg attatchments to be connected to the plate.

Wall Mounts

We are planning on using an extruded aluminum rectangle cut in half diagonally for the wall mounts. We will machine six to eight holes for the adjustable heights and another hole for the pivot bar. This will allow for the adjustable holes to line up perpendicular to the wall and the pivot bar hole to be parallel to the wall.

Seat Handrail

The seat handrail will be made of hollow aluminum tubing. It will be cut and then bent into the final shape.

Minor Adjustment Parts

The Seat

We will have to enlarge four of the holes on the seat for the handrail to be added. Two holes on each side of the seat will allow for the user to decide which side they want the handrail on.

Operations, Feeds and Speeds

Our team had to manufacture some parts for our prototype. Some of our parts were purchased because we were unable to create them in the machine shop. In Table 5 below, is a list of the fabricated parts our team created. Everything we machined was aluminum.

Table 5: Operations along with Feeds and Speeds

Item	Material	Operation(s)	Feeds and Speeds
U-Channel	Aluminum	Drill and Cut	1200 RPM / 300 ft/min
Box Channel	Aluminum	Drill and Bore	1200 RPM / 200 RPM
Seat Plate	Aluminum	Drill, Cut, and Tap	1200 RPM / 300 ft/min
Let Plate	Aluminum	Drill, Cut, and Tap	1200 RPM / 300 ft/min
Wall Mounts	Aluminum	Drill and Cut	1200 RPM / 300 ft/min
Pivot Rod	Aluminum	Drill and Tap	1200 RPM

VALIDATION RESULTS

Our shower chair will be used mainly by geriatric patients. So stability and safety is the most important requirement we need to meet in our design. In order to make sure that our design is safe to use, we performed four tests when the seat is in use position and one test when the seat is folded up against the wall. Additionally, the shower chair was tested numerous times with many different people at the Design Expo.

Loading Position Weight Test

The seat needs to extend to the edge of the bathtub before loading. When the seat is in the loading position, a 360 lbs force will be loaded on the seat. This test weight is determined from the weight capacity of our design with a safety factor of 1.2. This test simulates that the user is sitting down at the seat in the loading position. Since the force and shear stress in each component is the largest when the sliding mechanism is in the extended position, we develop this test to make sure that the shower chair can withstand enough force. The test will be repeated ten times. When loaded we will take note of any fractures, permanent bending, or catastrophic failure. If the seat remains stable with the weight added and no fracture or damage occurs the seat passes the loading weight test. Figure 27, on Page 29, shows the test process.

When it was tested, the whole mechanism was stable and showed no deflection. After all of the tests the seat remained stable and did not show any signs of fatigue.

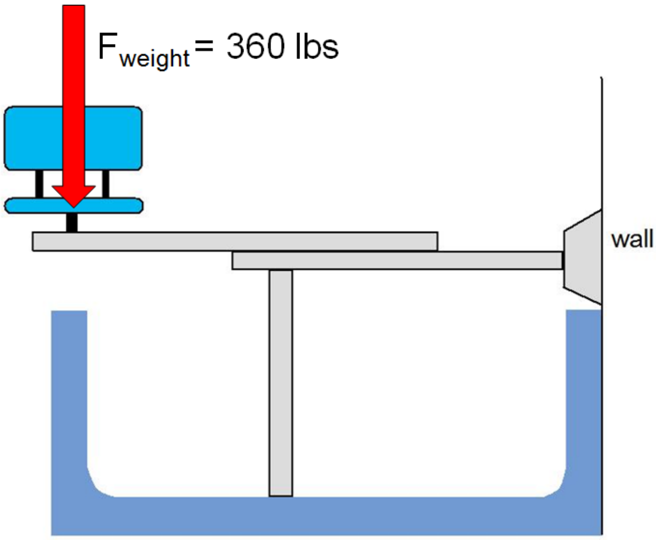


Figure 27: Loading position weight test

In Use Position Weight Test

When people use the shower chair to take a shower, the seat is in the in-use position and the seat will be located just above the legs. A weight of 360 lbs will be loaded onto the seat. This test simulates that the user is taking shower sitting in the seat. We develop this test to check if the whole shower chair can be stably used. This test will be repeated ten times. When loaded we take note of any fractures, permanent bending, or catastrophic failure. If the seat remains stable with the weight added and no permanent damage occurs the seat passes this test. Figure 28 below, shows the test process.

When tested the seat was stable. After all of the tests the seat remained stable and did not show any fracture or permanent bending.

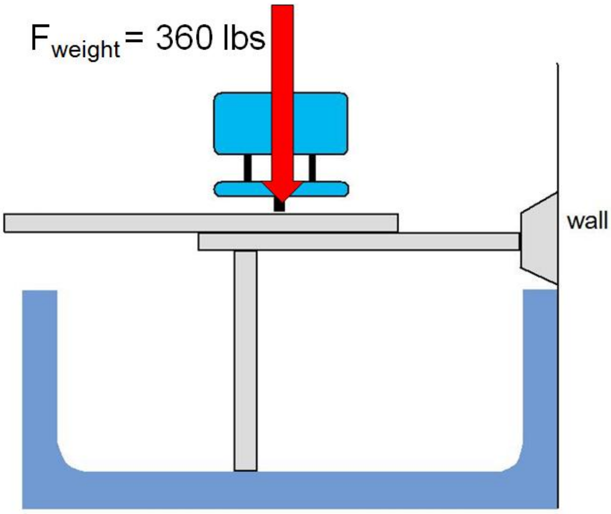


Figure 28: In use position weight test

Seat Stability Test

This test will be preformed twice, once in the loading position and once in the in-use position. Using hand strength a tester will grab the seat and push and pull with reasonable force, roughly 25 lbs, simulating a user leaning back and rocking forward in the seat. This weight is estimated by the pushing strength of a geriatric doing a back extension. Perform ten cycles of pushes and pulls; note any fractures, permanent bending, or catastrophic failure. If the seat remains stable and no permanent damage occurs the seat passes this test. Figure 29 below, shows the test process.

The chair remained stable and showed no signs of fracture in the seat stability test. After all of the tests the seat remained stable.

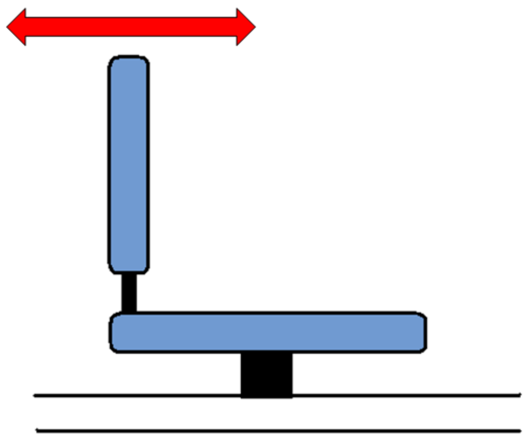


Figure 29: Seat stability test

Leg Stability Test

This test intends to check the stability of the legs. A force will be applied by kicking the legs in different directions. It will simulate the worst case of a user accidently kicking the leg. If the chair passes this test, the legs are proved to be stable and safe. The kick will be standardized by bending tester's leg roughly 45° and releasing it and taking note of any fractures, permanent bending, or catastrophic failure. If the legs and the whole chair remain stable and no permanent damage occurs the seat passes the leg stability test. Figure 30 below, shows the test process.

During the "kick" test, there no sign of permanent damage or fracture in the mechanism. After the tests the seat remained stable and did not show any signs of fatigue.

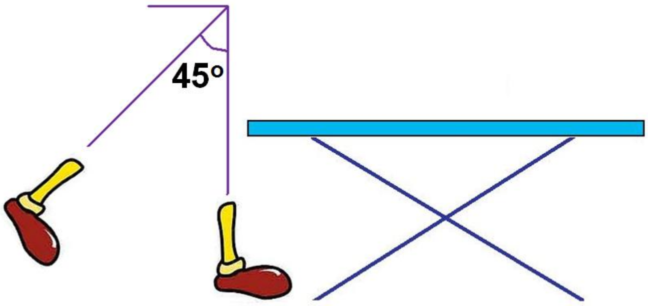


Figure 30: Leg stability test

Pull Test

When the shower chair is in the stored position, the top of the collapsed mechanism will be pulled down about 10° with hand strength. This simulates other users of the bathtub pulling on the seat accidentally. This test will check if it is safe to use springs to keep the whole mechanism folded up. To pass the test the chair should not be able to be pulled down. The torsional springs should pull the whole mechanism back against the wall. This test will be performed ten times. Figure 31 below, shows the process of this test. During the test, the collapsed mechanism can be pulled back to the wall by the two torsional springs.

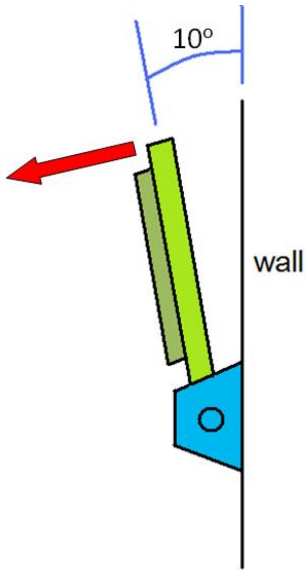


Figure 31: Pull test

SPECIAL CHALLENGES UNIQUE TO YOUR PROJECT

For the rest of the project, a problem may occur with the assembly or when fabricating our prototype. Failure or unexpected results may occur when assembling the legs and beam, beam and seat, beam and shaft, shaft and bracket, shaft and torsional spring together. Furthermore, we are not highly trained at welding, which will increase the probability of causing assembly problems. If these problems happen, we will ask Bob Coury and Marv Cressey for help.

Another problem that may occur, the weight of the chair may be higher than expected. We want to keep the weight of the chair as low as possible, however, due to material selection constraints, the limit of available products in market, and time constraint to select the chair components, the overall weight of the chair may be larger than we designed. This weight could be optimized by ordering a more specialized component if we have extra time and the chance of exploring, such as a light beam which can also support 360 lbs.

In addition, leg height adjustability and the magnetic catches will be other problems sources. We are not sure whether the leg height can be adjusted suitably and weather the magnets can supply enough force to lock the beam. Changing the height of wall bracket and using more magnets can help us solve the problems.

It is also a challenge for us to display our prototype and operate it at the design expo. It is difficult to bring a real bathtub to the design expo and have a wall to mount our chair safely. Finding appropriate alternatives will be the only solution.

DISCUSSION AND RECOMMENDATIONS

We have evaluated the design features and continually redesigned it for improvement over the past three months and built our prototype just like the final design to validate that our design works. While the prototype successfully passed all the validation tests there is always room for improvement. The following section focuses the strengths and weaknesses of the current prototype, and recommendations for further improvement.

Strengths

Seat

The pre-fabricated seat was purchased from Eagle Health Care including a swivel mechanism that can turn and lock at ever 90 degrees both clockwise and counterclockwise. A safety belt was also included to provide additional stability. Moreover, the seat with swivel mechanism beneath was removable from the mean beam since it was attached to the seat plate using four bolts. This design feature dramatically reduced the thickness of collapsed mechanisms.

Sliding Mechanism

We bought a pair of super duty sliding rails from Bold Hardware Co., which has a load capacity of 400 lbs in the fully extended position. The rails were stainless steel and very smooth sliding in and out.

Foldable Supporting Legs

The pre-fabricated chair legs were purchased from Drive Medical Design & Manufacturing and were made of a durable, corrosion proof aluminum frame. One benefit is they are able to fold flat for easy storage. The triangle shaped supporting legs were more stable compared with the vertical legs of the previous team. In addition, it weighs less helping us reduce the weight of the mechanism.

Adjustable Height

Four rods were mounted to the wall (two on each side) and the steel plates with several holes that allowed adjusting the seat height were placed on the rods. To adjust the height of the shower chair, the wall mount was simply placed at the desired height and fixed to the rods with two nuts.

Torsion Springs

We redesigned the previous team’s idea for the wall-locking device. Instead of using a hook to hold the collapsed mechanisms, we used a pair of torsion springs. Each spring provided a torque of 42.86 in•lb to reduce the force needed to fold the seat up and to hold the seat against the wall in collapsed position. We determined after testing that a damper was not required to slow down the seat when folding it up.

Recommendations of Improvements

Magnetic Catches

We doubled the amount of magnetic catches, from four to eight, in the loading position compared with the previous design. However, it still did a poor job for providing enough force to hold the chair in the loading position so it was easy to drag the seat too far past the edge of the tub. The magnetic catches did keep the seat from sliding back when people were sitting in the chair. We concluded that the amount of force provided by the catches were different in the cases of a loaded chair and an unloaded chair. To prevent the seat from extending forward too far, we decided that milling a track on the top surface of the box channel and attaching a bolt on the top U-channel that would slide in the track would accomplish this. Doing this would allow the U-channel to slide along the box channel and stop exactly at the edge of the tub.

Sliding Channel

The current U-channel was about 1 inch larger than it needed to be. There was a significant gap between the sliding rails and the U-channel. This weakened the overall strength of the beam because the bolts used between the U-channel and the sliding moved more than we had intended each time the sliding rails were used. We suggested changing the width of the U-channel. We found another problem with the sliding beam during the validation test which was it seemed to be hard for the user to slide back while sitting on the seat. However, there was not any problem moving the seat without a user sitting in it. We thought this happened due to the fact that the U-channel contacted the surface of the box channel when loaded and the friction force between became so large that it was hard for the user to move. We suggested leaving enough space between the U-channel and box channel to solve this problem and again we thought using an U-channel with smaller width so that it attached to the sliding rails without a gap. This would help keep the U-channel from contacting the top of the box channel.

Torsion Springs

We suggested to use torsion springs made of stainless material since the current ones were made of steel and are not resistant to corrosion. If stainless steel is not an option, then designing a casing that can protect the springs from water would be another possibility.

Cover All the Sharp Edges

The current prototype had a lot of rectangle shape feature such as the U-channel, box channel, seat attachment plat, etc. Even though we smoothed all the sharp edges with a file, we would have liked cover all the sharp features with rubber or plastic tubing if we had enough time.

Handrail

The current handrail is made of wood, which was not a good idea to use in a wet environment. We suggested making a plastic molded handrail if capable. Making sure the handrail can switch sides of the chair is imperative because some patients can only use one hand and it could be either their left or right.

CONCLUSIONS

Background

Showering in a bathtub is a key barrier for the rapidly growing geriatric generation. Based on a previous ME 450 project our team improved the chair to prepare it for commercial use. The new shower chair keeps elderly people safe and independent when bathing. It is also able to fold up in the shower to allow others to use the shower. The device will help geriatric patients safely bathe while maintaining privacy and stability.

Requirement and Specification

Our sponsors are Susan Murphy, an Assistant Professor of Physical Medicine and Rehabilitation with the University of Michigan Medical School, Naomi Gilbert, an Occupational Therapist, Department of Physical Medicine and Rehabilitation, and Albert Shih, a University of Michigan Mechanical Engineering Professor. They have given us requirements that our design must meet. The feedback from the survey also gave us good professional insight. Some of the main requirements of our design are safety/stability, easy to use, affordability, and allowing the shower curtain to close. We developed 15 engineering specifications that correspond to customer requirements. We ranked them based on the survey results and the sponsor requirements. The top five engineering specifications are the cost (affordability), the number of safety locks to hold the chair in place when in the loading position and in-use position (safety / stability), Weight capacity (safety / stability), the number of hand rails (safety / stability), the number of steps to get into the bathtub (ease of use).

Concept Generation, Selection and Description

Based on the sponsor requirements and engineering specifications, we concluded six main functional groups that we need to address in our design: the folding mechanism, method of seat attachment, stability of legs, the swivel mechanism of the seat, height adjustability, and a non-attached shower chair design. We developed several concepts for each of these groups. After generating rough drawings of each concept, we noted the advantages and disadvantages of the various designs. A review of all the concepts was completed and we selected the most feasible design for each group. Lastly we constructed a Pugh Chart, using the advantages and disadvantages table, to determine an Alpha Design to proceed with.

Parameter Analysis

In our design, several scientific fields are included: solid mechanics, dynamics, material science, and manufacturing. By calculating the stress applied on the beam and the mounting mechanism, we can select the correct material for our prototype by using CES EduPack 2009 software. We also used SimaPro 7 software to help us evaluate the environmental impact of our prototype. The dimension and weight of our design can be easily measured using the engineering model. Our design is going to have unique challenges. It has to be affordable for private users. In addition, stability of the leg supports is absolutely crucial since the shower chair will be used by geriatric patients. Our design will be constructed of rust proof aluminum except the seat will be made of plastic to guarantee user safety in wet environment. We checked the requirements of the bolt on the top of the legs, the beam, the legs, the wall bracket, and the seat. Aluminum alloy, stainless steel, and plastic were the mainly material we would use for the prototype. These choices were determined based on the criteria of strength, resistance to fresh water corrosion, density, and cost. For the environmental impact, we evaluated the raw material, the air emission, water used, and waste caused. We realized that the production of shower chairs would not have a significant on the environment.

Final Design and Prototype

From the Concept Selection an Alpha Model was created, this design performed best in our selection matrix. The alpha design was refined into the final design after discussion following DR #2. Our final design incorporated a swivel seat which slid along channels using high strength rails. X-shaped legs were used for support. The seat and sliding mechanism are attached to the wall using an aluminum rod and aluminum wall bracket along with two torsional springs. The sliding mechanism hinged about the rod allowing the seat, sliding mechanism and legs to fold up against the wall.

Prototype

There are six engineering differences that demonstrate the changes that were made between our final design and the actual prototype. These changes were made due to availability of product, strength of material, and to add additional support to the prototype. Some of the changes include the closing the gap between the U-channel and the sliding rail, reducing the contact between the U-channel and the box beam, and making the handle out of plastic, which were discussed earlier in the report.

Validation Testing

To test the structural stability of our prototype five different tests were performed: the loading weight test, the in-use weight test, the kick test, the seat stability test and fold-up limit angle test. All the tests have been passed.

Recommendations

We recommended several changes to help improve the shower chair. The magnetic catches, sliding channel, torsion springs, covering all the sharp edges and making a plastic handrail are areas to focus on in future design revisions according to our tests and the suggestions from visitors during Design Expo.

ACKNOWLEDGEMENTS

We would like to thank Professor Alan Wineman for all his help and time with our project. Professor Wineman has set up regular meetings every week with us to check our progress and discussed details about our project and gave us suggestions. In addition, Professor Wineman helped us to conduct the validation test himself as a potential user. We really appreciated his effort throughout the project. We also would like to thank our sponsors Naomi Gilbert and Susan Murphy for their valuable inputs and support throughout our project. Based on their suggestion on our first meeting, we narrowed down our focus users to geriatric people who may be taken care of a caregiver and family members or who want to live independently. They also helped us obtain 31 experienced therapists responses to our online survey about the previous team design. Most of our design features and customer requirements were determined based on the survey results. We would like to thank Professor Albert Shih for his support throughout our project. He inspired us to improve the previous team design so that it would be ready for commercial use. He promised us a design budget of $600 due to the pre-fabricated chair

alone would cost $170. We were very grateful that he came with a group of people to support us at the Design Expo. We also would like to thank both Bob Coury and Marv Cressey for all their great help throughout the machining process. Bob helped us welding the wall mounts and gave us all kinds of great idea for ways to attach our parts. At last, we would like to thank our GSI Phil Bonkoski who responding to all our questions and help us in using the software we needed.

BIOS

Yangbing Lou is a senior taking dual degree in Mechanical Engineering and Electrical Engineering. Yangbing is from China and he transferred to University of Michigan two years ago. Last summer, he did an independent research on Automated Quantitative Sensory Testing System for Human Subjects, which involves both engineering and medical science. Yangbing enjoys traveling around the world and playing soccer. Recently Yangbing has applied to the Master Program of Mechanical Engineering at the University of Michigan.

Mitchell Polavin is a senior Mechanical Engineer at the University of Michigan and will be graduating with a B.S.E. in December of 2010 with a Manufacturing Systems Concentration and a Music Minor. Mitchell has had internships at both Steelcase Inc. and Henry Dreyfuss Associates working as a product engineering intern and human factors intern. He grew up in West Michigan in Grandville and has lived there his entire life. He has played the French Horn in the Michigan Marching Band and Athletic Bands for four years. He enjoys playing and watching all sports and has been a Wolverine fan his entire life.

Linxiang Wang is a senior in Mechanical Engineering. She transferred from Shanghai Jiao Tong University to the University of Michigan in 2008. She will be graduating this coming summer with two bachelor's degrees from both Shanghai Jiao Tong University and University of Michigan. This study abroad opportunity let her become more independent and have the chance to integrate sides from both cultures. She has applied for Masters Program in Mechanical Engineering and would like to continue studying in University of Michigan.

Wu Xiao is a senior in Mechanical Engineering and will be graduating in April 2010 with a bachelor's degree. Wu is an international student from Liaoning, China. She has applied for Master Program in Industrial and Operations Engineering. Wu took two months to study abroad at TU Berlin, in Germany, doing one project about the improved capability of fuel economy due to an auxiliary power unit. She enjoys traveling and exploring different cultures around the world.

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APPENDIX A: Bill of Materials

Table A.1: Bill of Materials

Item	Quantity	Source	Catalog Num.	Cost ea.	Contact
Seat Assembly	1	Eagle Health Care	37662	$170	http://www.allegromedical.com
400LB Super Duty Slide	1	Bold Hardware Co.	16" 7500 series	$49	http://www.drawerslides.com
16” 6063 Aluminum Rectangular Tube	1	Discount Steel	6” × 4” × 1/8”	$37	http://www.onlinemetalstore.com
18” 6063 Aluminum Square Tube	1	Discount Steel	3” ×3” ×1/8”	$11	http://www.onlinemetalstore.com
Ultra Thin Magnetic Catches	12	McMaster-Carr	1745a15	$5	http://www.mcmaster.com
Aluminum Plate	2	Discount Steel	12”× 12” × ¼”	$22	http://www.discountsteel.com
Folding Legs	1	ActiveForever	A13331	$40	http://www.activeforever.com
Torsion Springs left hand	1	McMaster-Carr	9271k136	$6	http://www.mcmaster.com
Torsion Springs right hand	1	McMaster-Carr	9271k135	$6	http://www.mcmaster.com
Bearing	2	McMaster-Carr	5905k28	$6.60	http://www.mcmaster.com
Pivot Rod	1	Alro Metals Plus	AAA02500	$5.50	(734) 213-2727
Wall Mounts	1	Alro Metals Plus	26323100	$2.72	(734) 213-2727

The Engineering Drawing for each part can be found in Appendix P.

APPENDIX B: Description of Engineering Changes since Design Review #3

Our Alpha Prototype was pretty well developed by Design Review 3. The only thing that was changed is the handle in our prototype made of wood instead of plastic. This was because there was no solid plastic stock available in the machine shop. Our handle needed to be solid because there needed to be material for the screw to tighten the handle to the seat. The dimensions of the handle didn't change, just the material.

APPENDIX C: Design Analysis Assignment from Lecture

Functional Assingment

Material Selection for Performance

We used CES EduPack 2009 (CES) software to help us select the material used for each part of chair. The CES software allows us to set-up a number of criteria that the materials must pass. We looked at four categories to help determine the appropriate material selection: cost, resistance to corrosion from fresh water, yield strength, and weight. Yield strength was a concern since it represents the deformation of the material. For all of our material selections, plastic, aluminum alloy, and stainless steel were the main materials we considered. Furthermore, the price of the material we are shooting for is to be below 5US$/lb. These criteria, as well as a weight limit, were set to ensure that the materials we selected were able to perform well in a wet shower environment and to keep both the price and weight low. The material selection of different parts by using CES for the bolt on the top of the legs, the beam and legs, the wall bracket, and the seat are described below.

Bolt on the Top of the Legs

For the selection of the material of the Bolt on the top of the legs, we used the graph of yield strength vs. price; see Figure C.1, below. The yield strength used to set the region for appropriate materials was found during the technical analysis of the bolts on the top of the leg. The necessary yield strength was found to be 17437 psi.

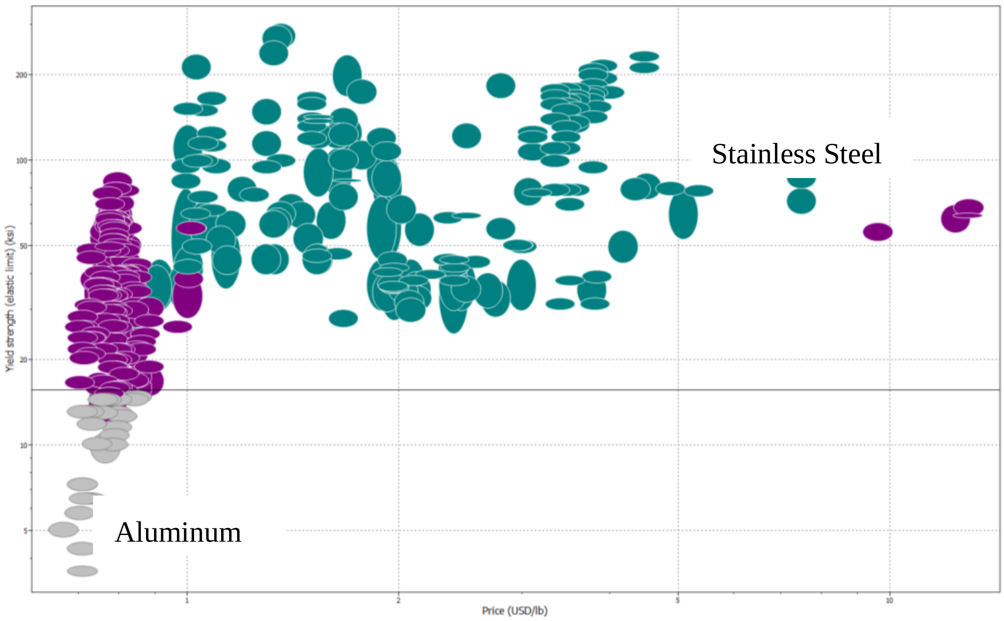


Figure C.1: Stainless steel is the most appropriate material for the bolts on the top of the legs

We chose stainless steel since the strength of the bolts is so important to our design that a yield strength as high as possible is required. Stainless steel was the material that was almost entirely among the appropriate region and had the highest yield strength. Density of the material was not concerned too much since the bolt would not require lots of material that had a significant effect on our overall weight.

The Beam and the Legs

For the selection of the material of the beam and the legs we still used Figure 18, above, in addition to Figure C.2, below, to help us determine the material. The required yield strengths found in the technical analysis for the beam and the legs were found to be no less than 4000psi.

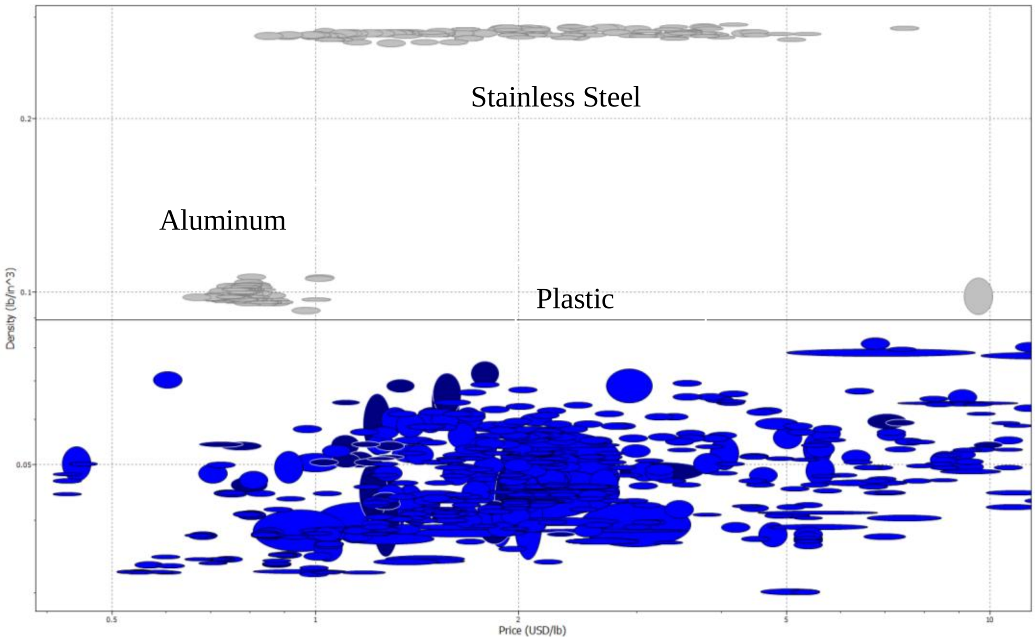


Figure C.2: Aluminum is the most appropriate material for legs and beam.

We chose aluminum alloy since we need to consider both strength and density. Aluminum alloy was the material that was almost among the appropriate region in both figures which has lower density and high strength.

The Wall Bracket

For the selection of the material of the wall bracket, we used Figure 20, below, to aid in our selection. The necessary yield strength was found to be only 1064 psi.

We chose aluminum alloys from Figure C.3, on the next page, because aluminum is relatively cheap and readily available. We did not look at density of the wall bracket because the wall bracket does not add to the overall weight of our mechanism when it is in use.

Figure C.3: Aluminum alloys are most appropriate material selection for the wall bracket

The Seat

For the selection of the material of the seat we used Figure C.2, above, and Figure C.3 to help us determine the material. The resistance to fresh water and density were the two criteria we considered.

We chose plastic since we need to consider both resistance and density. Plastic was the material that was almost among the appropriate region in both figures which has excellent fresh water resistance to corrosion and low density.

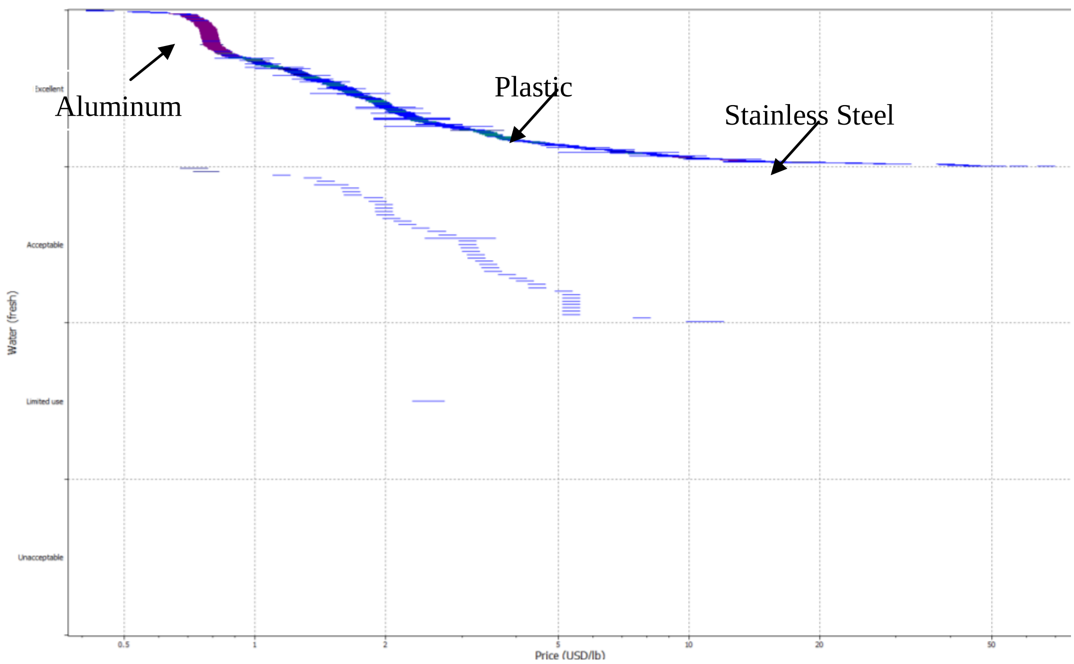


Figure C.4: Plastic is the most appropriate material for seat

Environmental Assignment

Using the SimaPro software, our group was able to determine the environmental impact of our material selection. Our design is comprised of 4 kg 5182 stainless steel, 5 kg of 304 aluminum, and 3 kg of PVC. Inputting these materials and quantities using the EcoIndicator 99 method we were able to calculate the environmental impact.

According to the software, the environmental impact of our material selection on raw materials is totaling about 2 tons of raw materials. The second largest environmental impact was to the air, releasing 53 kg of material during manufacturing. There should be some misunderstanding of our use of the software. This may be because manufacturing a single chair and a large quantity of chairs has different manufacturing processes, which results in a different material and energy requirements for each chair. While designing our prototype, we did not take any environmental impact into consideration. Figure C.5, below, demonstrates our estimation for a single chair impact on different areas of the environment. The environmental impact graphs, including the characterization, normalization, and single score SimaPro plots are shown on the next two pages.

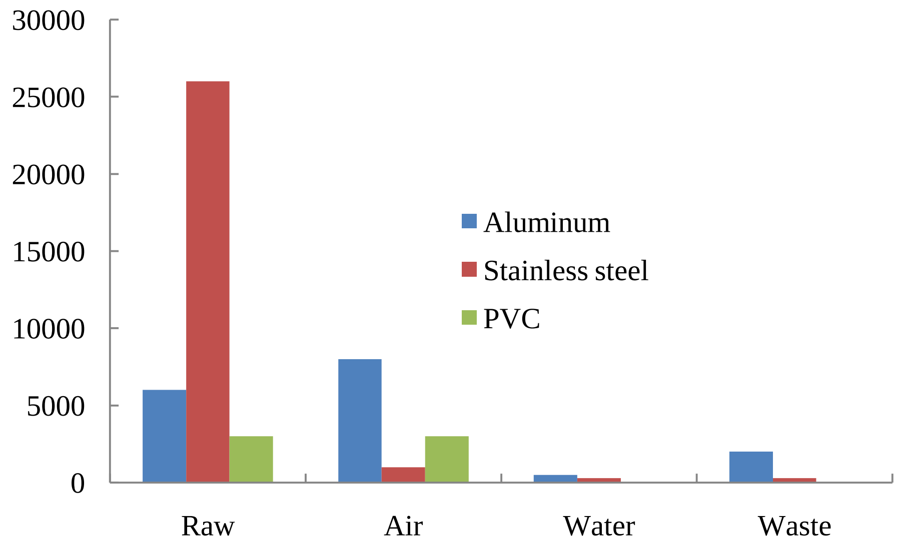
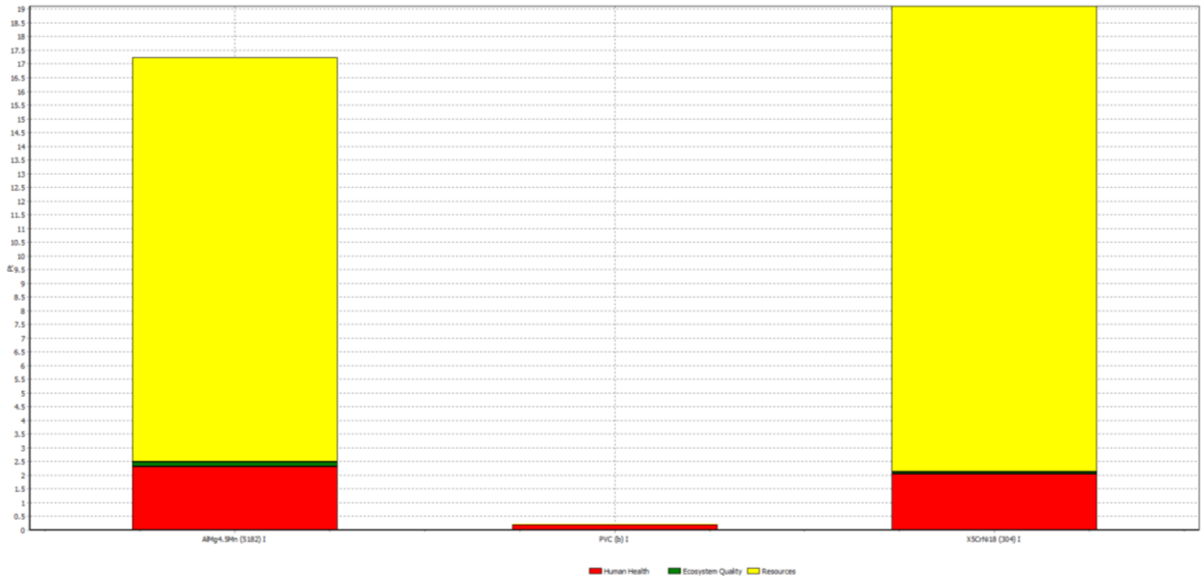
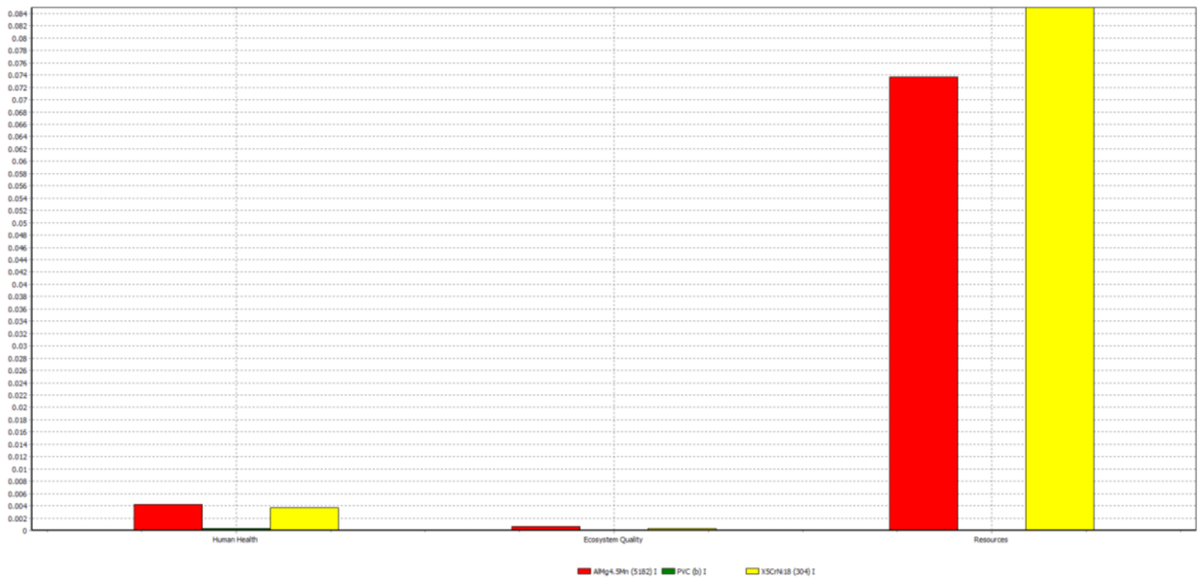


Figure C.5: Estimate environmental impact from single chair in a large quantity production

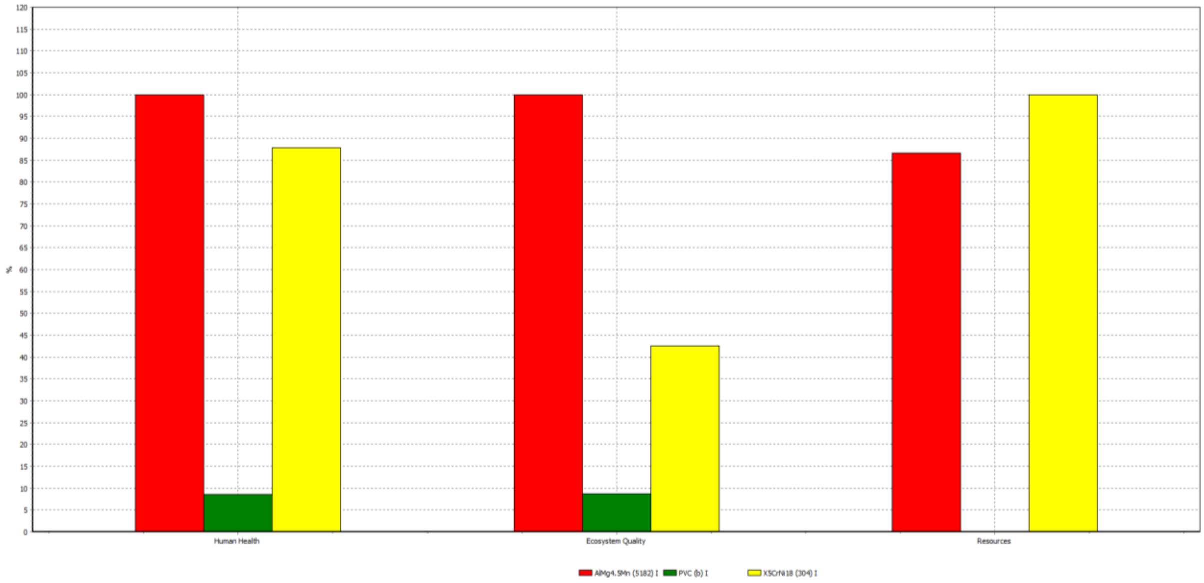
SimaPro single score



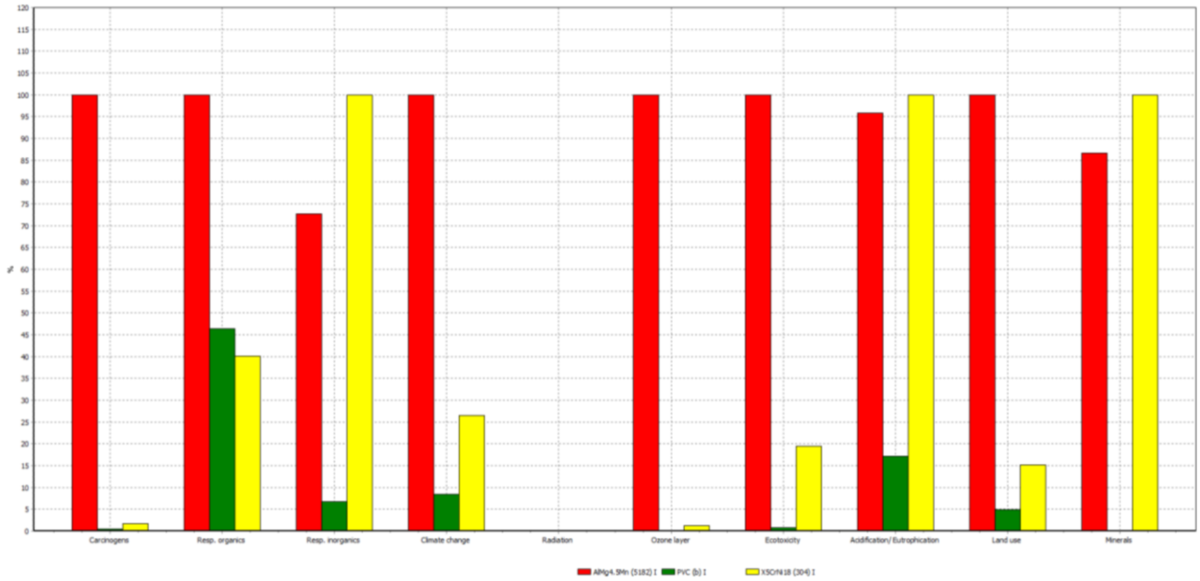
Normalization



Damage



Characterization



Manufacturing Process Selection

Possible production volume

According to a showering/bathing limitations report in a 2005 study [15], 7% of people from age 65 to 74, 14% of people from age 75-84, and 35% of people above age 85 have showering/bathing limitation. Furthermore, in 2008, 12.3% of United States population was above age 65, which is about 36.8 million [16]. Since there are some alternatives to our product that exist in the market, we assume 1-5% of people aging above 65 will buy the shower chair or their children and caregivers will buy the shower chair for them. Hence, the possible production volume is between 0.368 million and 1.84 million. Considering the whole world's demand, the possible production volume is between 1.84 million and 9.2 million, which is 5 times the United States' production volume, based on our assumptions.

Process Selection

By applying CES EduPack 2009 software, we select aluminum and stainless steel as required for making most parts of our shower chair (See Figures C.1 to C.4).

Our sliding rails are made by stainless steel. According to the production volume we determined, we suggest use die casting to make the sliding rail. The cost of using die casting is relative low while the process can maintain high precision as well as small tolerance. The economic batch size for die casting is from 10^3 to 10^5 units, which means the production volume for our sliding rails is quite competitive in the market [17].

The plastic chair we used can be easily manufactured by injection modeling. This method is commonly use in factories and has low-cost, high production rate advantage in making our shower chair [18].

The rest parts of our prototype such as U-channel, Box Channel, and wall mount, are made by aluminum. These parts can also produced by Extrusion.

APPENDIX D: Existing Patents and Benchmarks

Existing patents

A shower chair invention for elderly or disable people involves the technology of mechanical engineering and medical science. In the market, there are hundreds of shower chairs, which are designed for normal/healthy people. Several patents are listed below with representative quotes from their abstracts or descriptions.

US Patent #6182304 [5]**:** A bathing transfer apparatus for transferring a person into and out of a bathing device. The bathing transfer apparatus includes a pair of supports. Each of the supports is generally U-shaped and has a two legs and base portion. A pair of rails is each elongate. Each of the rails is fixedly coupled to one of the base portions. The pair of rails defines a track. A chair device includes a seat portion having a top side, a bottom side, a front edge and a back edge and a back support portion, which is fixedly coupled to the back edge of the seat portion. A plurality of wheel assemblies for rolling on the rails is fixedly coupled to the bottom side of the seat portion. The wheel assemblies are positioned such that the wheel assemblies are in communication with the rails.

US Patent #6195814 [6]**:** A shower bath apparatus which enables hot water bathing in a relaxed condition and provides a warm feeling over the whole body, equivalent to bathing in a bath tub. The shower bath apparatus comprises a shower bath apparatus body, a seat, on which a bathing person is seated, a spray nozzle for jetting hot water to the bathing person, and an arm provided with at least one spray nozzle. Sprayed hot water envelops the whole body of a user in a seated position to give the user a warm feeling.

US Patent #6226810 [7]**:** A lightweight portable seating unit for a bathtub which unit includes a platform adapted to be supported by and clamped to the sidewalls of the bathtub and on which a seat is sliding-allowed carried and pivotally adjustable to facilitate positioning of an individual seated on the unit. In some embodiments the seat may include an adjustable backrest and head support and/or a bidet attachment.

US Patent #6279178 [8]**:** A bathing chair gives a user maximum comfort and versatility while using the device. The bathing chair has a rotatable seat with a reclining back member and a reclining leg member attached thereto. A roller assembly attachable to a hand rail prevents the bathing chair from tipping over. Conduits disposed within the seat member and the back member allows warm water to be channeled there through in order to provide heating for the user. A waste pan and a cart are removable, attachable to the bathing chair.

US Patent #6681415 [9]**:** A transfer seat apparatus structured for simultaneous dependent sliding-allowed translation during manual rotation, through preferably about 90 degrees of rotation, of a seat section of the apparatus with a person seated atop the seat section. The apparatus is particularly useful for transferring a physically impaired or weakened person into a bathtub or over a collecting basin when adapted and used as a commode. Thus, as the seat section is rotated with the person seated thereon, lateral linear translation is simultaneously effected which is dependently responsive to manual seat section rotation.

US Patent #6842919 [10]**:** This invention relates to a chair device for assisting handicapped or non-ambulatory persons to bath or shower in a conventional setting. The chair device of the present invention has side flap portions provided with water dispensing holes wherein the side flap portions are pivotally attached to a seat portion to aid in reaching hard to reach areas of the body when bathing.

Benchmarked Designs

Simple chair (Figure D.1) [11]: This is a completely removable chair. The design is built out of plastic. This design incorporates suction cup feet and removable back and handle. This design can be used in either left or right hand tubs.

Wall Mounted Shower Chair (Figure D.2) [12]: This wall mounted design incorporates a seat that folds from the vertical to horizontal position for use. This motion causes the support legs to fall automatically to the floor. The leg length is completely adjustable by positioning screws. When the seat is down it has a height of 20". This design can accommodate weights up to 285 lbs.

Figure D.1: Simple Chair

Figure D.2: Wall Mounted Shower Chair

Sliding Transfer Bench (Figure D.3) [13]: This transfer bench incorporates a sliding motion along two rails. The base is built out of aluminum that uses suction cup feet. The seat is a contoured shape with a non-skid finish. The sliding motion may be restricted to 0.5 inch increments by the use of a locking mechanism.

Figure D.3: Sliding Transfer Bench

Previous Team Design
A previous ME 450 team [14] has designed a sliding shower chair. They focused on making the product safe, intuitive, simple to use, and compact. Previous design is shown in Appendix B.

Their design incorporated a swivel seat which slid along channels using rails. Two aluminum extendable legs were used for support. The seat and sliding mechanism was attached to the wall using a steel rod and wall bracket. The sliding mechanism hinged about the rod allowing the seat, sliding mechanism and legs to fold up against the wall. When in the stowed position, a simple gate latch is used to lock the seat to the wall.

They recommended developing a more refined prototype with better supported legs to allow more adjustability. Additionally, for the project to be commercialized the design should be optimized to eliminate unnecessary weight and could be made more ascetically pleasing by adding plastic covers to hide the channels for instance.

Lacking Information
The lacking Information is as follows: the weight of the showering chair; the dimensions (width, length and depth) of different bathtubs; the abilities of the elderly/disable person such as grip strength, movements and leg lifting; customers' concerns about their safety and privacy.

Where to Find Lacking Information
We will be able to find this lacking information through our sponsors Susan Murphy (Assistant Professor, Physical Medicine and Rehabilitation, Medical School) and Naomi Gilbert (Occupational Therapist, Department of Physical Medicine and Rehabilitation). We plan on arranging a meeting with them at least once a month. They will be able to give us the information about elderly people based on their extensive work in their respective fields and the survey delivered. The dimensions of the typical tub can be found by some online research.

APPENDIX E: Survey responses about Previous ME 450 Team’s Design

1. What group of people do you think are the target customers for this device? Create Chart Download

	Response Percent	Response Count
Cane Users	3.2%	1
Walker Users	**35.5%**	**11**
Wheelchair Users	**35.5%**	**11**
Lower-Body Surgery Patients	6.5%	2
Show replies Other (please specify)	19.4%	6
	answered question	**31**
	skipped question	**0**

2. What do you think is a reasonable cost for this shower chair? Create Chart Download

	Response Percent	Response Count
Below $100	20.0%	6
$100-200	**43.3%**	**13**
$200-300	30.0%	9
$300-400	3.3%	1
Above $400	3.3%	1
	answered question	**30**

3. How important to the chair design is: Create Chart Download

	Not Important									Very Important	Rating Average	Response Count
The comfort of the seat?	0.0% (0)	0.0% (0)	0.0% (0)	6.5% (2)	6.5% (2)	12.9% (4)	6.5% (2)	**32.3% (10)**	12.9% (4)	22.6% (7)	7.81	31
A handrail on the side of the seat?	0.0% (0)	3.2% (1)	0.0% (0)	0.0% (0)	0.0% (0)	3.2% (1)	16.1% (5)	16.1% (5)	16.1% (5)	**45.2% (14)**	8.65	31
The ability to fold the chair and affix it to the wall?	0.0% (0)	3.2% (1)	3.2% (1)	0.0% (0)	6.5% (2)	12.9% (4)	16.1% (5)	16.1% (5)	**22.6% (7)**	19.4% (6)	7.65	31
An additional design feature that would assist people in moving their legs into the bath?	0.0% (0)	6.5% (2)	9.7% (3)	3.2% (1)	**19.4% (6)**	3.2% (1)	9.7% (3)	**19.4% (6)**	12.9% (4)	16.1% (5)	6.71	31
The ability to allow the shower curtain to close inside the tub?	0.0% (0)	3.2% (1)	0.0% (0)	0.0% (0)	6.5% (2)	0.0% (0)	19.4% (6)	**32.3% (10)**	19.4% (6)	19.4% (6)	8.00	31
											answered question	**31**
											skipped question	**0**

4. Please rate the following problems from 1 to 4: Create Chart Download

	Least Important			Most Important	Rating Average	Response Count
Stability	0.0% (0)	3.7% (1)	22.2% (6)	**74.1% (20)**	3.70	27
Rate of sliding	**53.6% (15)**	35.7% (10)	10.7% (3)	0.0% (0)	1.57	28
Easy to use	0.0% (0)	10.3% (3)	**55.2% (16)**	34.5% (10)	3.24	29
Easy to install	36.7% (11)	**46.7% (14)**	16.7% (5)	0.0% (0)	1.80	30
					Show replies Other (please specify)	2
					answered question	**30**
					skipped question	**1**

Q5. Do you find any features of this device that could have the potential to cause any safety issues?

1. It is not clear if the seat swivels to face the shower. I assume it does. Safety wise - it must be stable.
2. catching skin, clothes in slide
3. If someone can not lift their legs up then their legs might get caught up under them.
4. Drop arms secondary to many pts have core stability issues, changes in spinal alignment
5. There should be a collapsible handrail for the consumer to hold onto, they may have poor trunk balance and if there is nothing to hold onto they may fall while sliding the seat towards the center of the tub. Fingers may get pinched in sliding mechanism
6. What will prevent the chair from sliding into position while the patient is lifting their legs into the tub? What is the weight capacity of the chair and the dimensions of the seat?
7. The device as presented in the diagram appears to present safety risk getting feet/legs into tub.
8. lack of seat belt
9. Most, who would use this, need assist. Ability to close the curtain is good, but may not be practical if people need to assist with the showering.
10. Needs handrails and non-skid surface on the seat
11. Wall brackets may not anchor into the wall well enough for safety.
    Legs of chair look like they might slip
12. Rust? Weight restrictions. A wall bar may be interpreted by a patient as reason to stand. Maybe it could be an accessory, such as a seat belt. Most tub seats are now plastics to minimize injury from falls and control price.
13. Can a seat belt or safety harness be added?
14. I am not sure how stable to chair is with just the two legs next to each other. It does not look stable and consumers may look at this same feature
15. Durability is very important- but since I haven't seen your design, I can't give feedback on anything specific.
16. Does the seat lock when patient is sitting down/standing up - likely fall risk at this point? Would definitely recommend at least one handrail as someone who would use this would likely have difficulty standing up from lower surface.
17. At first glance, it appears to have many sharp edges. Lack of side support with limit that can use it.
18. You m may want to consider some type of trunk support belt as well as a way to lock the chair in place so it doesn't slide inadvertently while in use.
19. Patients would have to have high level of sitting balance/trunk control as the chair has no rails and moves
20. Might want to add a belt to "hold" the patient in place. Maybe a "guard" over the wall mounting device to protect the patient's arm in case they "hit" it.......have decreased sensation, UE paralysis etc.
21. Biggest safety issue is usually if people can sit on the chair from the outside of the tub or if they need to step into the tub to sit down safely.

Q6. What are the common problems for the similar products in the market?

1. Unknown
2. water on the floor
3. durability with increased exposure to water

4. Areas, where two differently angled surfaces come together (vertical/ horizontal) have just enough wiggle they cause skin to be pinched.
   A one size fits all design, you should have several sizes, I have found if a patient is too small for the design they slip around and feel very unstable, and larger patients then to overhang the seat in some areas and come in contact with rails and locking mech. and also get pinched.
   As the seat ages, and you lower it into place it doesn't lock all the way and when someone sits on it they get a "micro fall" and they stop trusting the chair. Even if it is stable bathing becomes a more fearful. also could result in fall.
   Poor sealant where the chair is bolted to the wall, when it is folded up, the water runs off the wet chair and collects in the folding mechanism, and sometimes in the wall, that has caused several of the wall mounted benches here to break and pull away from the wall.
   The chair is not locked to the rail correctly so when the patient sits down the end up on the rails and the chair slide away.
   You might also want to think long term plan for your seat, and offer a warranty included in the price, "frugal" patients will replace your seats with something out of their boat to save a few bucks when on a fixed income. I saw a very hi end hat this weekend which was "insured against loss and they would replace it if it wore out, all included in the price, perhaps you should pass this along to marketing.
5. Too bulky, too expensive, requires professional to install which adds expense, not adaptable for individual situations (space issues, etc)
6. Most individuals who ambulate with a cane or walker independently can step into the shower, however slippery surfaces can cause falls.
   A seat extending outside the tub surface will increase ease of transfers for wheelchair users or ambulates.
7. The device is hard enough to use that it goes un-used.
8. fit for the various size tubs-weight restrictions
9. not fixed to the floor.
10. Cost
11. Cost. Shallow seat depth. Instability. Height adjustment limitations. Appearance within the home.
12. not aware of any
13. Ease of use and installation, stability, as well as ability to fit inside the tub and allow other people in the home use the same shower.
14. They aren't covered by insurance, so families can't afford them. The other issue is that for people who are very dependent- severe brain injury with tone, higher level spinal cord injury, where total body support is needed, they are often difficult to individualize to the user's/caregiver's needs.
15. cost and ease of installing - cost of equipment is typically main reason someone either delays and purchases less quality product
16. Don't know of any other products
17. Cost, cost, cost mostly! Also, the space it occupies in some bathrooms makes it a cumbersome peeve of equipment.
18. price, weight limit, amount of support/stability, inability to wash groin/buttocks if there is not a cut-out in the chair
19. Cost, instability, not easy to use.
20. durability after repeated showering/moisture

Q7. Please specify any suggestion for improvements:

1. This is in the case of an attendant assisting a person on your chair. If you could figure out how to create a variable size seat opening to wash peril area the nursing homes would love it. A less flexible design of the same could be used with great success in the home. If you really want the Holy Grail, try to maintain sitting balance, and allow the care worker to wash the gluts as well as the peril area, without having the care worker off load the patient from side to side.
2. Add an optional seatbelt for improved safety
3. The seat should be made of a padded vinyl surface if individuals who have limited sensation on skin issues are using it. However, these surfaces tend to be difficult to slide on so it depends on your target group.

   If individuals who are non-ambulatory are transferring onto the chair then they will use the backrest to hold onto during their transfer. Make sure it is secure and reinforced with proper support.

   Also, I don't see how the mechanism of sliding the seat works. Make sure if you have a lever that needs to be released in some way that it is an easy push/pull type instead of a knob. Patient may also have limited hand function.

   GOOD LUCK!
4. "Elbow Rests" on side of seat to optimize safety and stability.
5. more supportive back rest
6. Chair arm rests for safely.
7. Needs to be light weight but durable and above all else safe to use.
8. See above comments. This product may be very marketable in institutions such as nursing homes and rehab facilities due to its cost/appearance.
9. Good job, no suggestions. Good luck
10. Instead of a hand rail on the chair may consider using a cut in the chair for consumer stability. Make sure seat surface is not slippery when wet. Imagine yourself an older adult living independently with arthritis in hands and maybe low vision. Is everything easy to use and see?
11. Let us see the design. We would be happy to give feedback.
12. I would put arm rests on the sides of chair.
13. an arm rest or grab bar the patient could stabilize self with, wider seat, cutout center so pt. could wash between legs

APPENDIX F: Previous ME 450 Team's Design

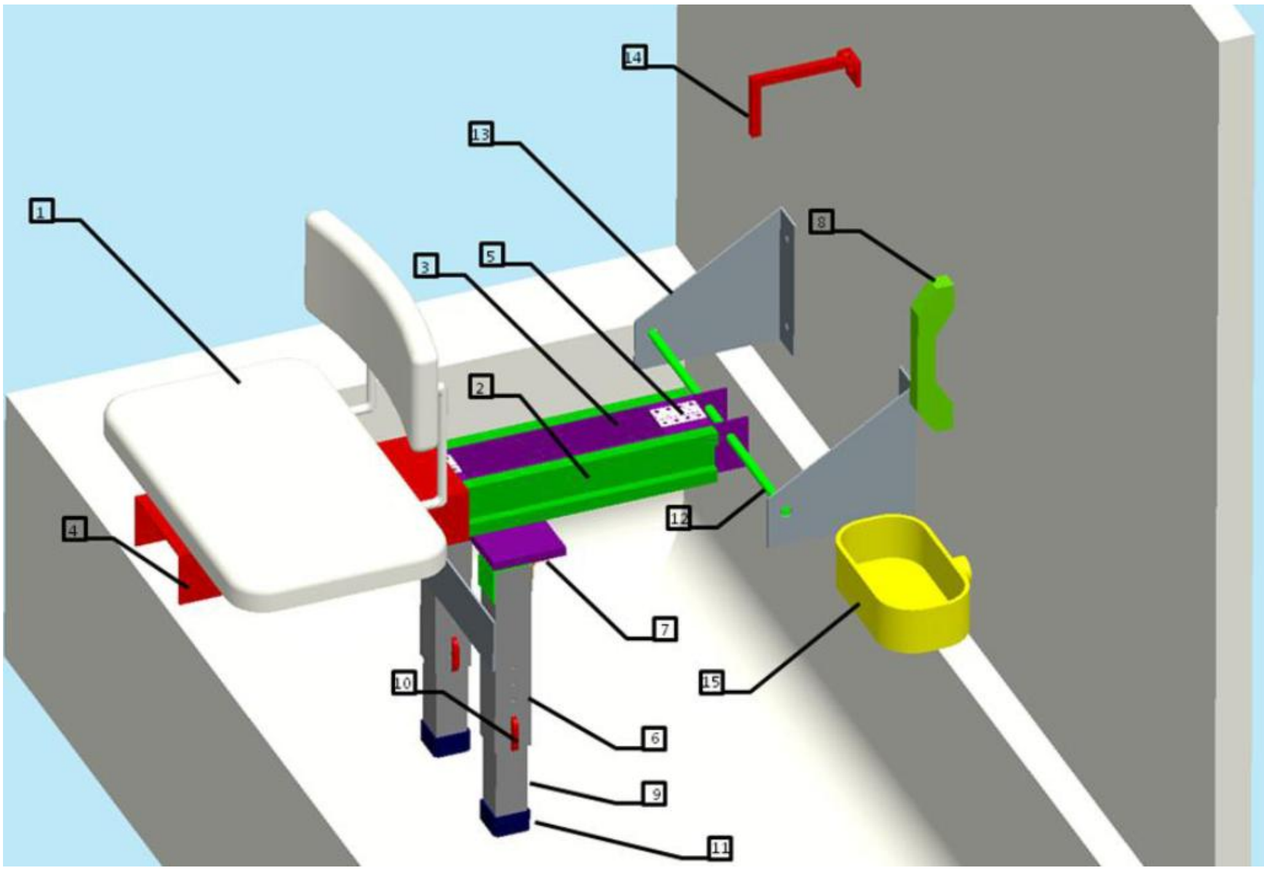


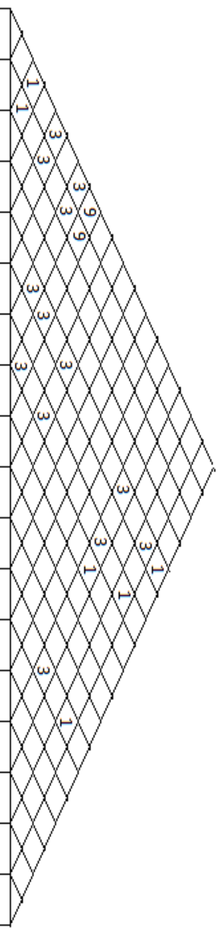
Figure F.1: CAD model of previous design in the extended position used for loading

In the figure above the numbers refer the following parts:

1. Seat
2. Sliding Rails
3. Inner Channel
4. Outer Channel
5. Magnetic Catches
6. Outer Leg
7. Leg Hinge
8. Wall Handle
9. Inner Leg
10. Leg Locking Pins
11. Plastic Feet Covers
12. Steel Rod
13. Wall Brackets
14. Wall Locking Device
15. Shampoo Holder

APPENDIX G: QFD Chart

	Low cost	Maintaining stability when in use/Robust/Safe	Allows shower curtain to close	Non-invastive for other shower users	Extend to outer edge of bathtub	Easy to use	Easy to install	Handrails	No sharp edge	The comfort of the seat	Total	Rank	Target
	8	10	7	5	6	9	2	4	1	2			
%	0.15	0.19	0.13	0.09	0.11	0.17	0.04	0.07	0.02	0.04	1		
Seat Width (inch)	3		1							9	0.91	10	20
Seat Depth (inch)	3				1					9	0.56	7	15
Dimension from inside edge of bathtub (inch)			9								1.17	6	2
Dimension from outsid edge of bathtub (inch)					9						1.00	8	1
Cost($)	9	1				1	1	1		1	1.83	1	<250
Weight Capacity (lbs)		9									1.67	3	300
Weight of mechanism(lbs)		1				3	3	1			0.87	12	<20
Back Height (inch)		3								9	0.89	11	13
Safty factor		3									0.56	15	2
Number of attachment locations	3						9				0.78	14	<4
Number of steps to get in and out of bathtub						9					1.50	5	4
Thickness of collapsed mechanism (inch)				9							0.83	13	<5
Number of handrails on the chair	3	3						9			1.67	3	1
Adjustable range of chair height (inch)	3					3					0.94	9	19-23
Number of safety locks to lock the chair when in use and loading position	1	9									1.81	2	2
Adjustable Transfer Bench	3	4	1	3	3	1	4	4	4	2			
Heavy Duty Sliding Transfer Bench	3	3	1	3	4	3	3	2	2	2			
Wall Mounted Shower Seat	3	4	4	3	1	4	1	4	3	3			



APPENDIX H: Leg-lifting Mechanism

1. Lazy-boy leg-lifting mechanism

Advantages: familiar lazy-boy concept

Disadvantages: need a lot of apace; complex mechanism; cannot be folded up

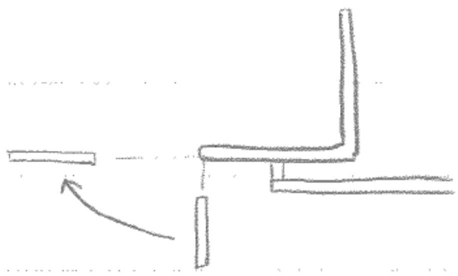


Figure H.1: Lazy-boy leg-lifting mechanism

2. Sliding leg-lifting mechanism

Advantages: save space

Disadvantages: not comfortable

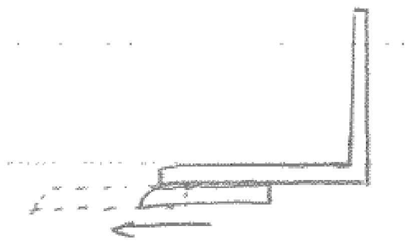


Figure H.2: Sliding leg-lifting mechanism

3. Separate leg-lifting mechanism

Advantages: save space; comfortable

Disadvantages: cannot be folded up

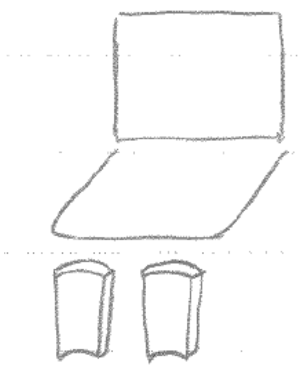


Figure H.3: Separate leg-lifting mechanism

APPENDIX I: Folding Mechanism

1. Hook lock mechanism
Advantages: simple concept
Disadvantages: apply large force; sharp edge may cause injury

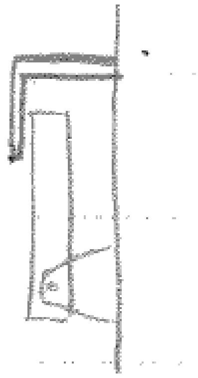


Figure I.1: Folding mechanism with a hook to lock the folded device

APPENDIX J: Method of Seat Attachment

1. Seat attachment with “O-Ring” on the bottom of the seat
Advantages: simple concept
Disadvantages: not fixed well; need to sustain large force

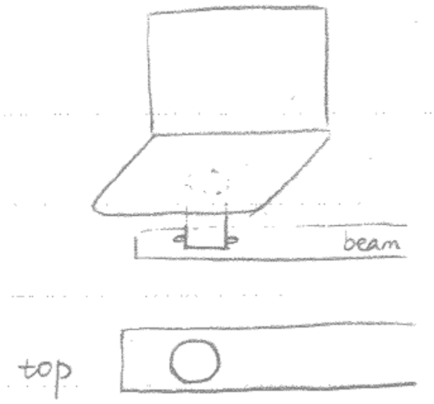


Figure J.1: Seat attachment locked by “O-Ring” on the bottom of the seat

2. Attachment with holes on bottom of the seat and blocks on beam
Advantages: resist tipping
Disadvantages: not stable; difficult to manufacture

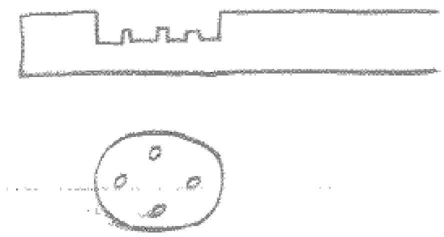


Figure J.2: Attachment with holes on bottom of the seat and blocks on beam

3. Screw seat attachment
Advantages: stable; small force to attach
Disadvantages: cannot lock in each 90 degrees

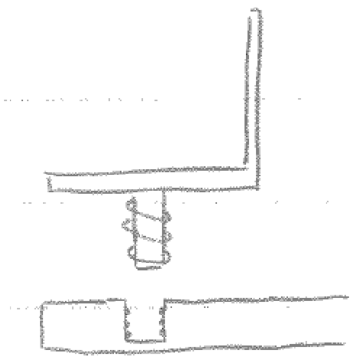


Figure J.3: Screw seat attachment

APPENDIX K: Stability of Legs

1. X-bar legs

Advantages: easy for manufacturing; sturdier

Disadvantages: need a lot of material

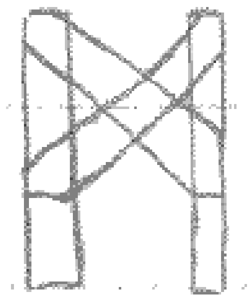


Figure K.1: X-bar legs

2. Tripod legs

Advantages: stable; simple concept

Disadvantages: non-connected legs; hard to lock legs; hard to adjust height

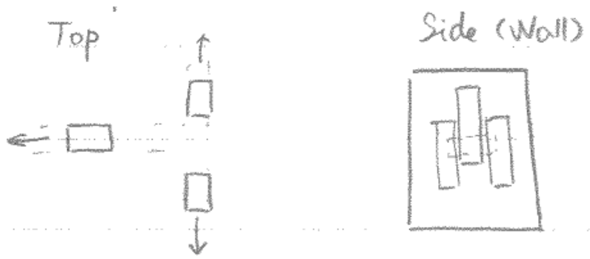


Figure K.2: Tripod legs

APPENDIX L: Height Adjustability

1. Office chair design to adjust height of the shower chair

Advantages: do not need caregiver to adjust the height

Disadvantages: still need user to stand up to adjust the height

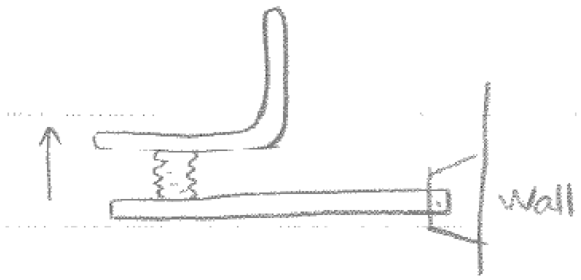


Figure L.1: Office chair design to adjust height of the shower chair

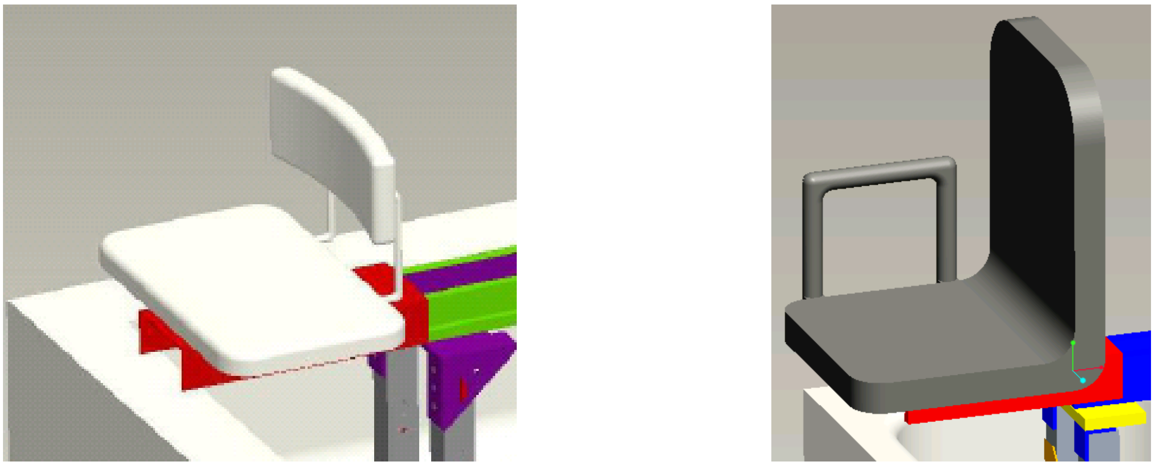
APPENDIX M: Pugh Charts

Selection Criteria	Weight	Concept for leg support							
		Two legs		Three legs		For legs, X shape		Two legs, connected	
		Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Low cost	0.15	5	0.75	4	0.6	3	0.45	4	0.6
Ease of Use	0.2	5	1	4	0.8	4	0.8	5	1
Stability	0.25	2	0.5	4	1	5	1.25	4	1
Dose Metering Accuracy	0.1	3	0.3	3	0.3	4	0.4	4	0.4
Durability	0.15	4	0.6	4	0.6	3	0.45	4	0.6
Ease of Manufacture	0.05	5	0.25	4	0.2	3	0.15	4	0.2
Small weight	0.1	4	0.4	3	0.3	5	0.5	4	0.4
Total Score		3.8		3.8		4.3		4.2	
Rank		3		3		2		1	
Continue								Develop	

Selection Criteria	Weight	Concept for leg height adjust			
		pins and holes		Office chair	
		Rating	Weighted	Rating	Weighted
Low cost	0.15	5	0.75	4	0.6
Ease of Use	0.2	3	0.6	4	0.8
Stability	0.25	4	1	4	1
Dose Metering Accuracy	0.1	4	0.4	4	0.4
Durability	0.15	5	0.75	4	0.6
Ease of Manufacture	0.05	5	0.25	3	0.15
Small weight	0.1	5	0.5	3	0.3
Total Score		4.25		3.85	
Rank		1		2	
Continue		Develop			

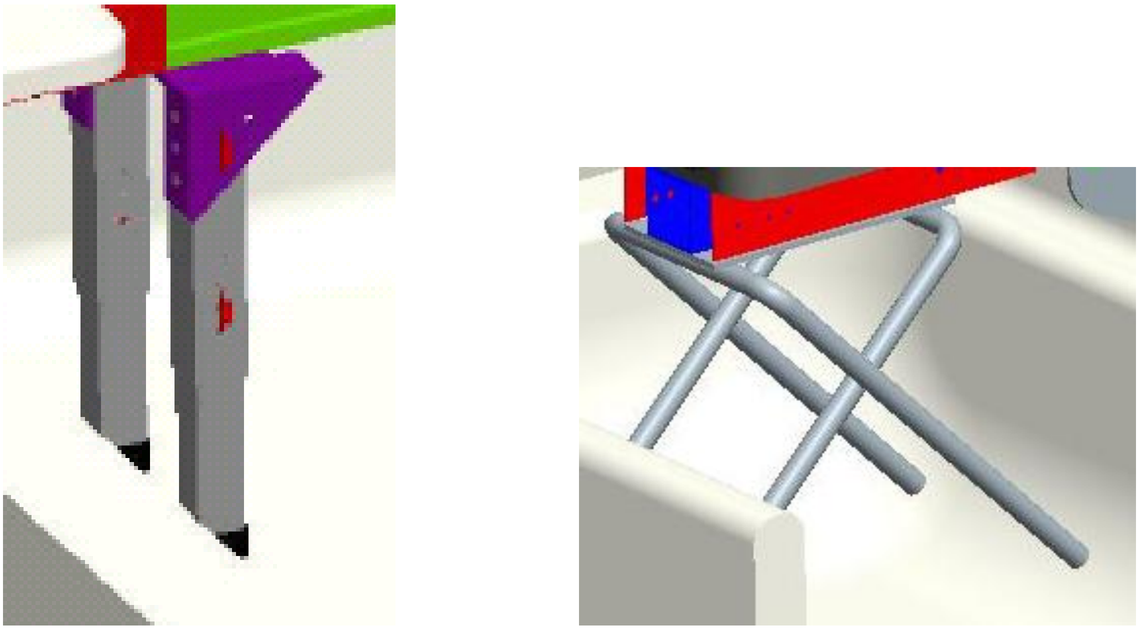
Selection Criteria	Weight	Concept for folding							
		Hook		Spring		Pin		Lean angle	
		Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Low cost	0.15	5	0.75	5	0.75	4	0.6	5	0.75
Ease of Use	0.2	4	0.8	5	1	3	0.6	5	1
Stability	0.25	4	1	4	1	5	1.25	3	0.75
Dose Metering Accuracy	0.1	5	0.5	4	0.4	4	0.4	3	0.3
Durability	0.15	5	0.75	4	0.6	5	0.75	5	0.75
Ease of Manufacture	0.05	5	0.25	4	0.2	4	0.2	5	0.25
Safety	0.1	3	0.3	5	0.5	4	0.4	3	0.3
Total Score		4.35		4.45		4.2		4.1	
Rank		2		1		3		4	
Continue				Develop					

APPENDIX N: Comparison between Previous Version and Alpha Design



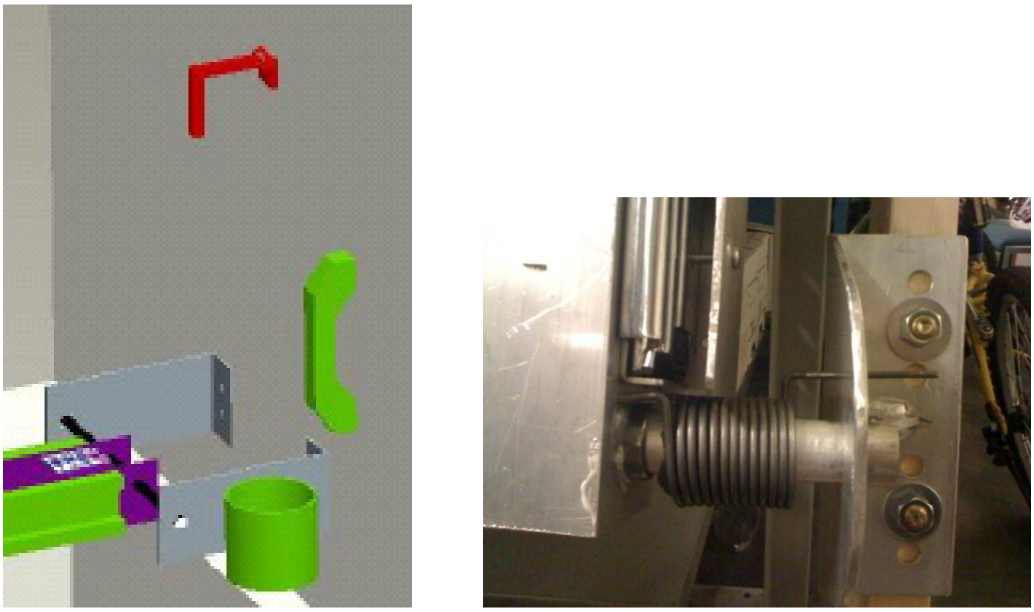
(a) (b)

Figure N.1: Handrail Comparison (a) Previous Version (b) Alpha Design



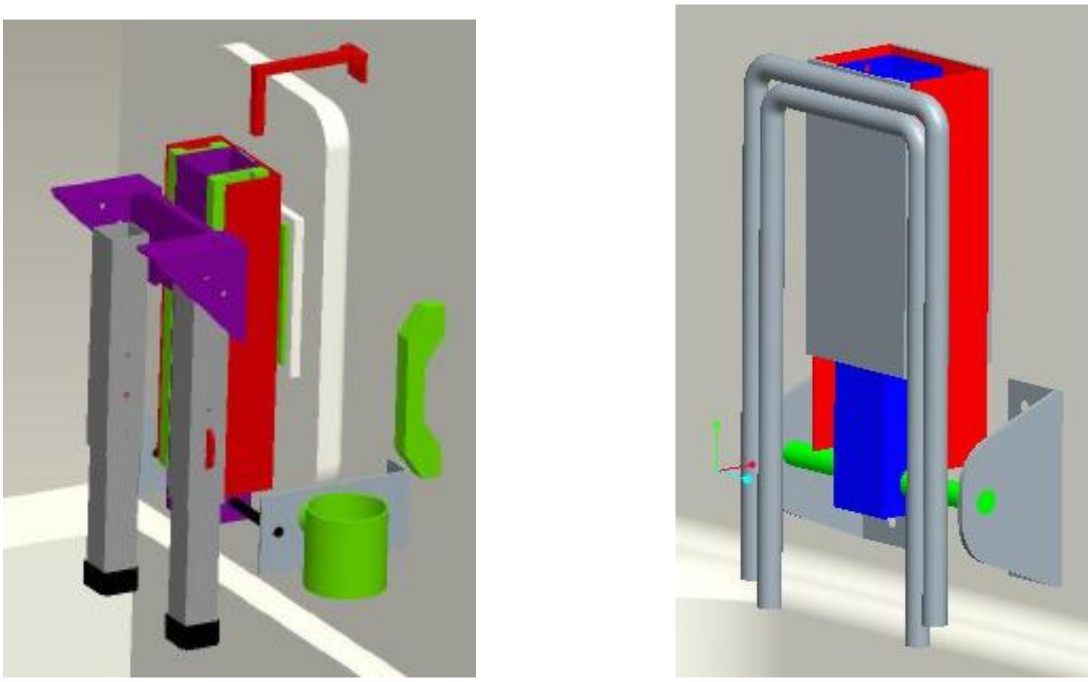
(a) (b)

Figure N.2: Leg Support Comparison (a) Previous Version (b) Alpha Design



(a) **(b)**

Figure N.3: Folding Mechanism Comparison (a) Previous Version (b) Alpha Design



(a) **(b)**

Figure N.4: Folded Up Comparison (a) Previous Version (b) Alpha Design

APPENDIX O: Data Sheet for Sliding Rails

FINESLIDE©

7500 SERIES DRAWER SLIDE

SPECIFICATION SHEET

SPECIFICATIONS

Model: 7500

Sizes: 16"-28"(400mm-700mm)

Load Capacity: 400 lbs(181kg)/pair

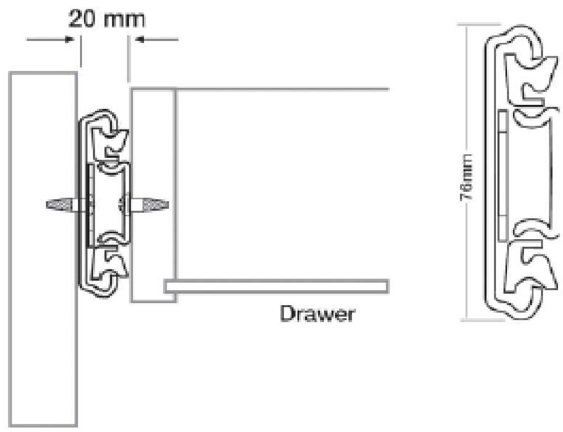
Packaging: 2 pair/box

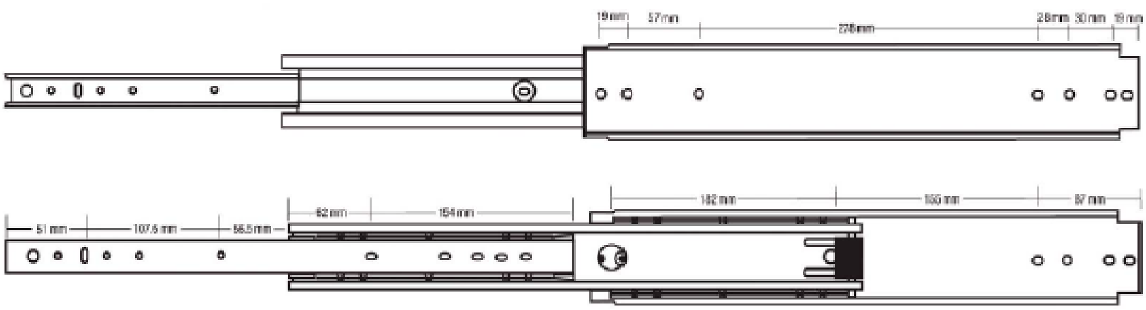
Material: Work hardened cold rolled steel/stainless steel

Finish: Zinc

FEATURES

* Super duty construction for truck body, tool chests and metal fabricator applications
* Side mounted
* Chassis allows for welded installations
* High performance precision chassis design
* Non releasable slide members
* No detent or locking mechanism
* Non handed design
* Limited lifetime warranty





The HardwareHouse Manufacturing Co.
www.thehardwarehouse.com
3525 N. Huetter Road * Coeur D'Alene, ID 83814
phone: 925-961-9911 * fax: 925-605-0353

APPENDIX P: Engineering Drawings

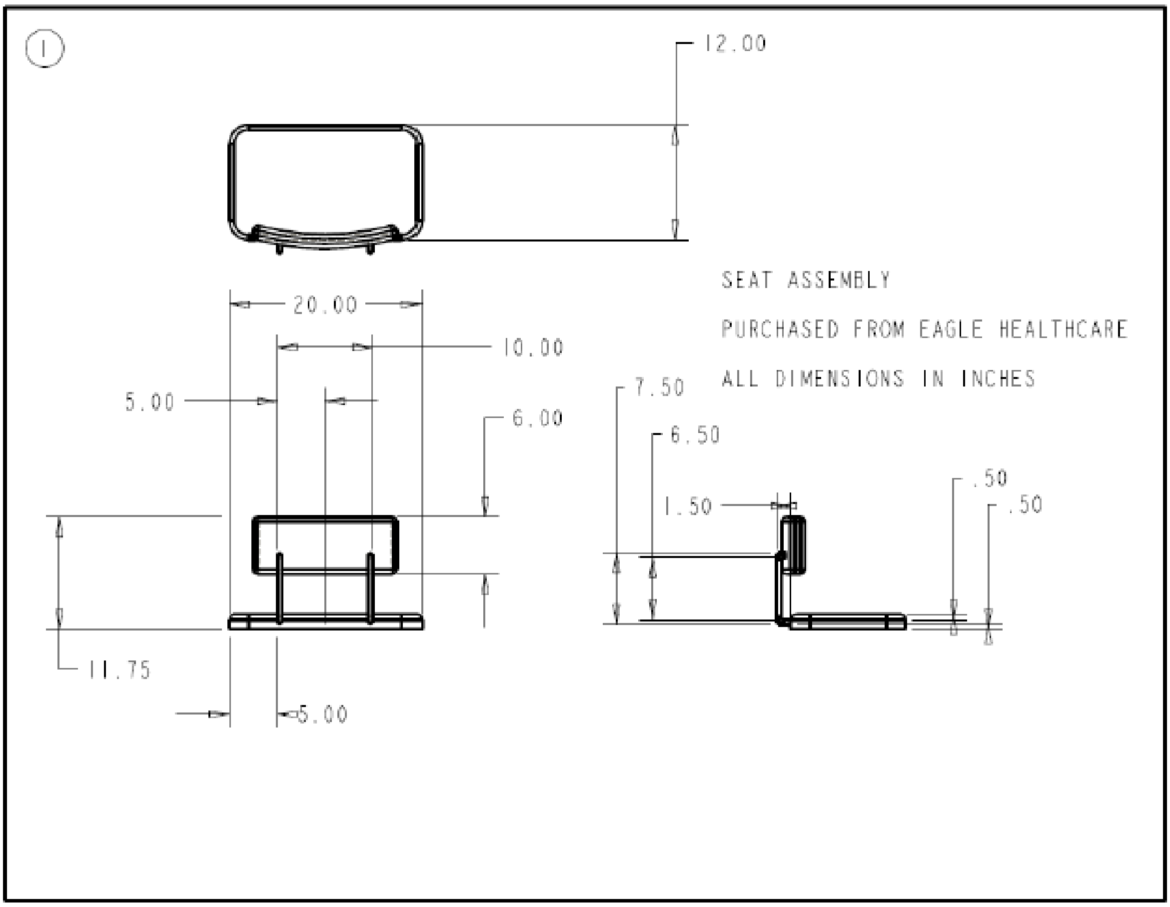


Figure P.1: SEAT [14]

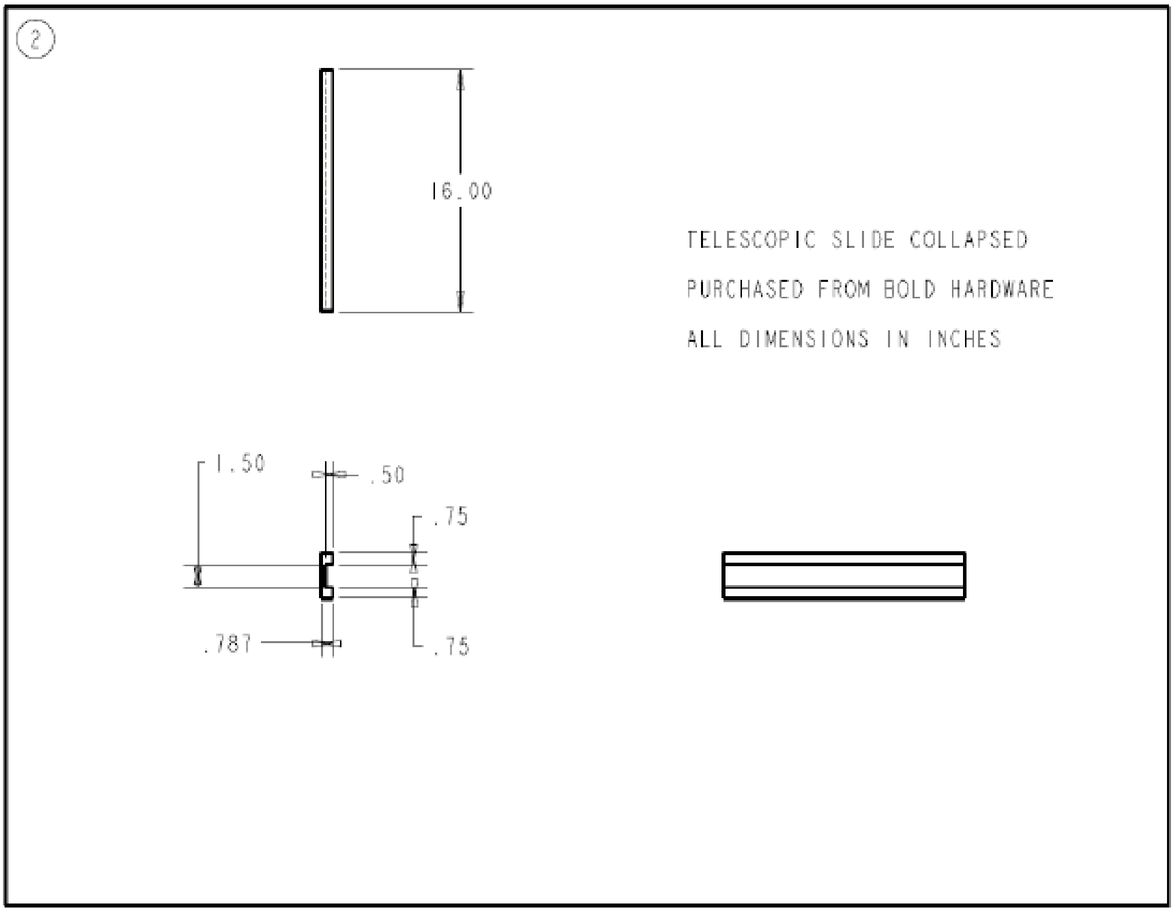


Figure P.2: SLIDING ARM [14]

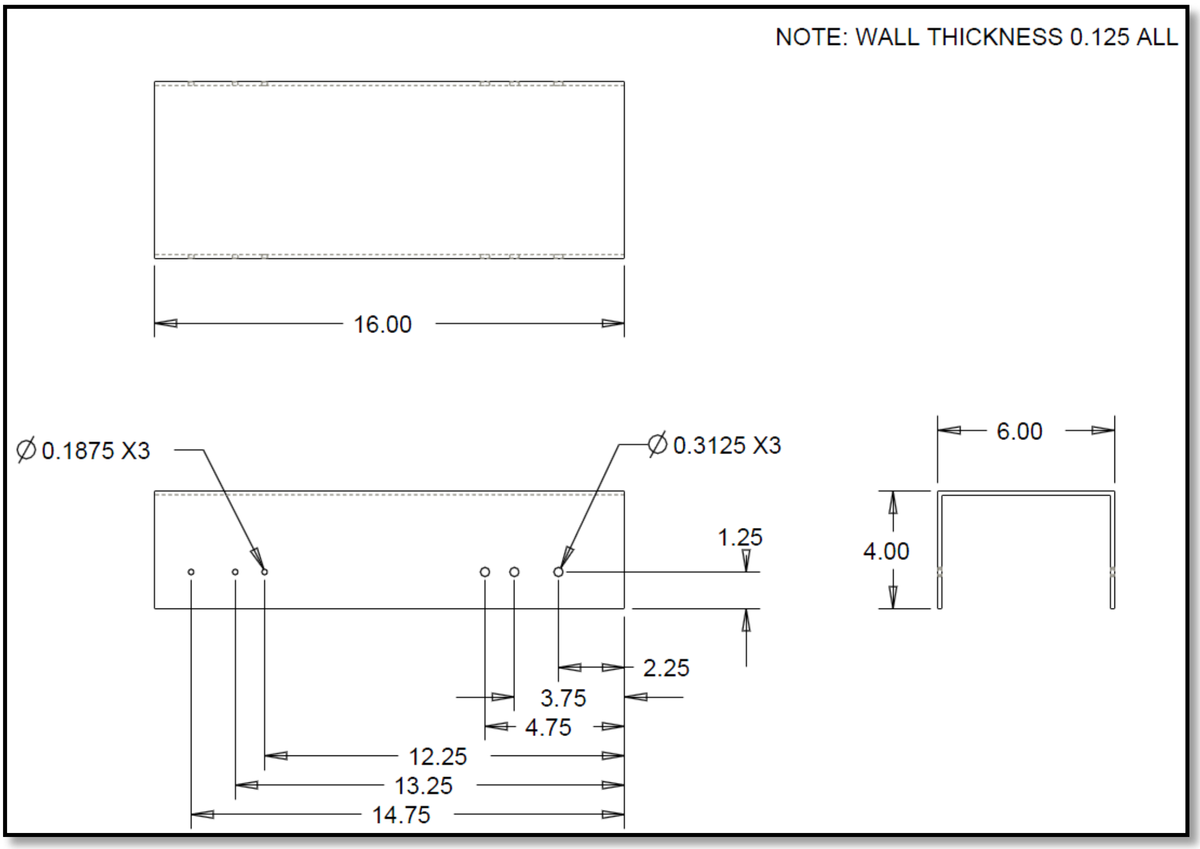


Figure P.3: U-CHANNEL

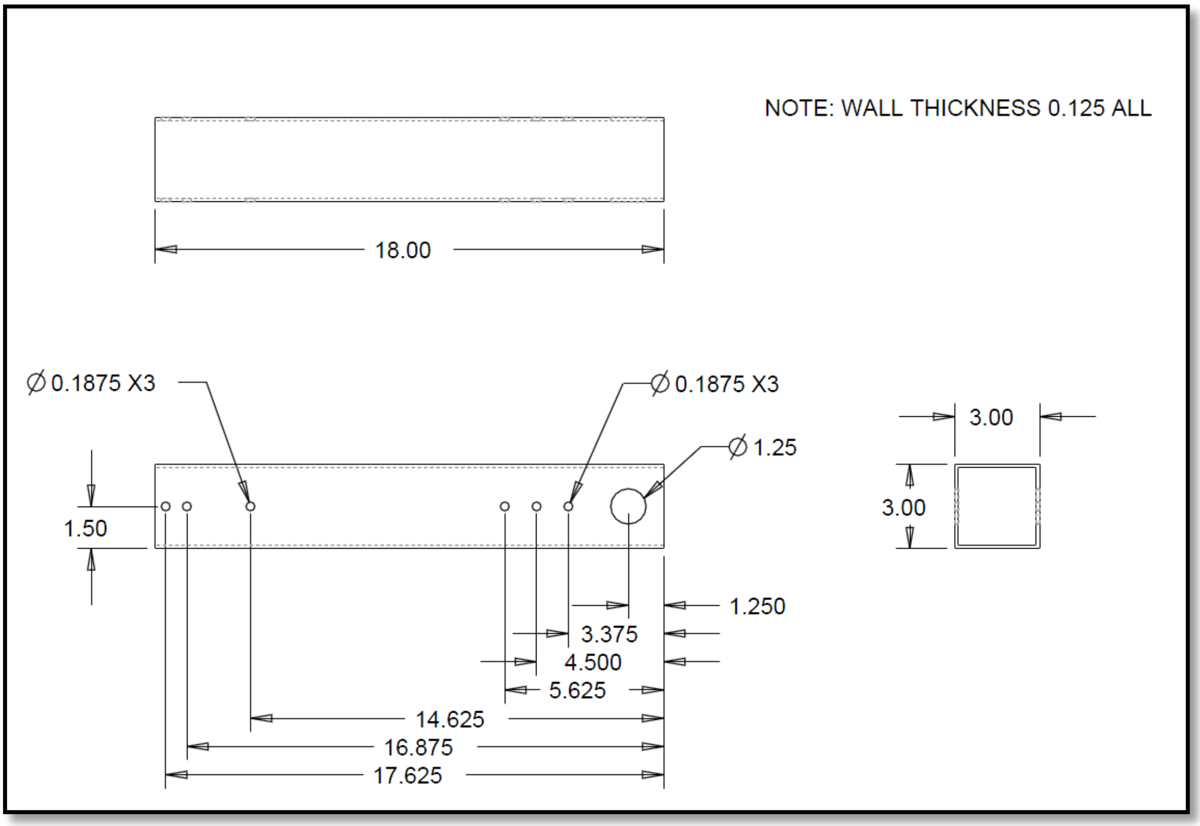


Figure P.4: BOX BEAM

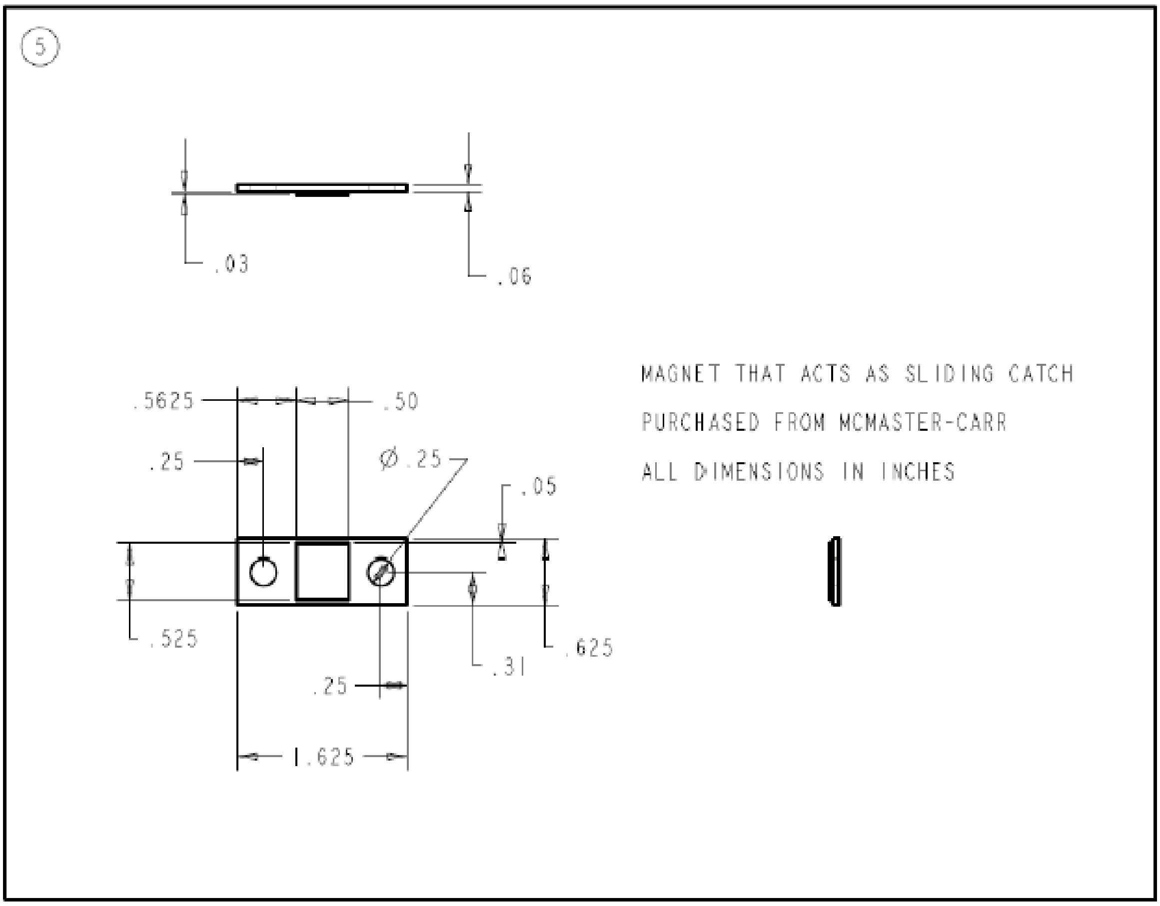


Figure P.5: MAGNETIC CATCHES [14]

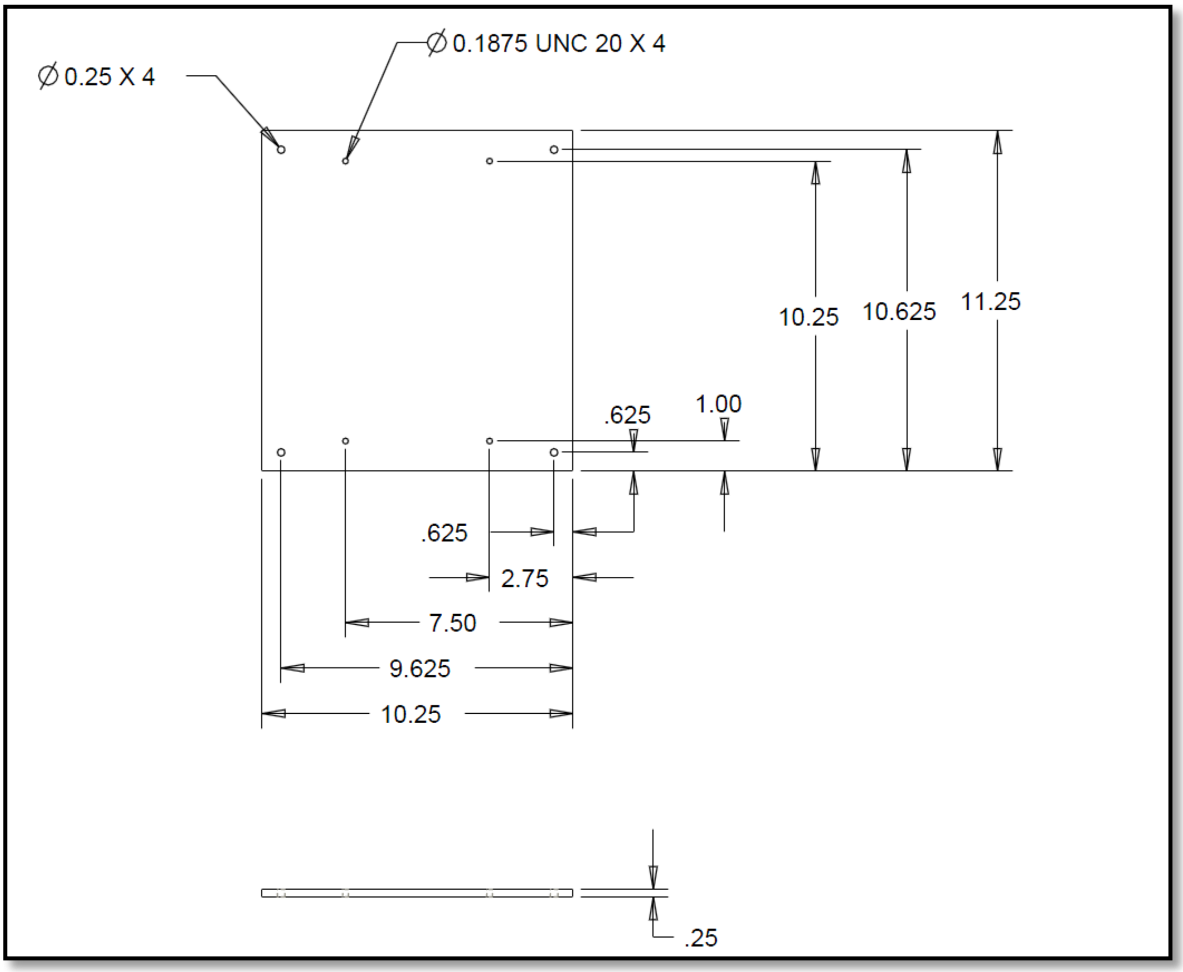


Figure P.6: SEAT PLATE

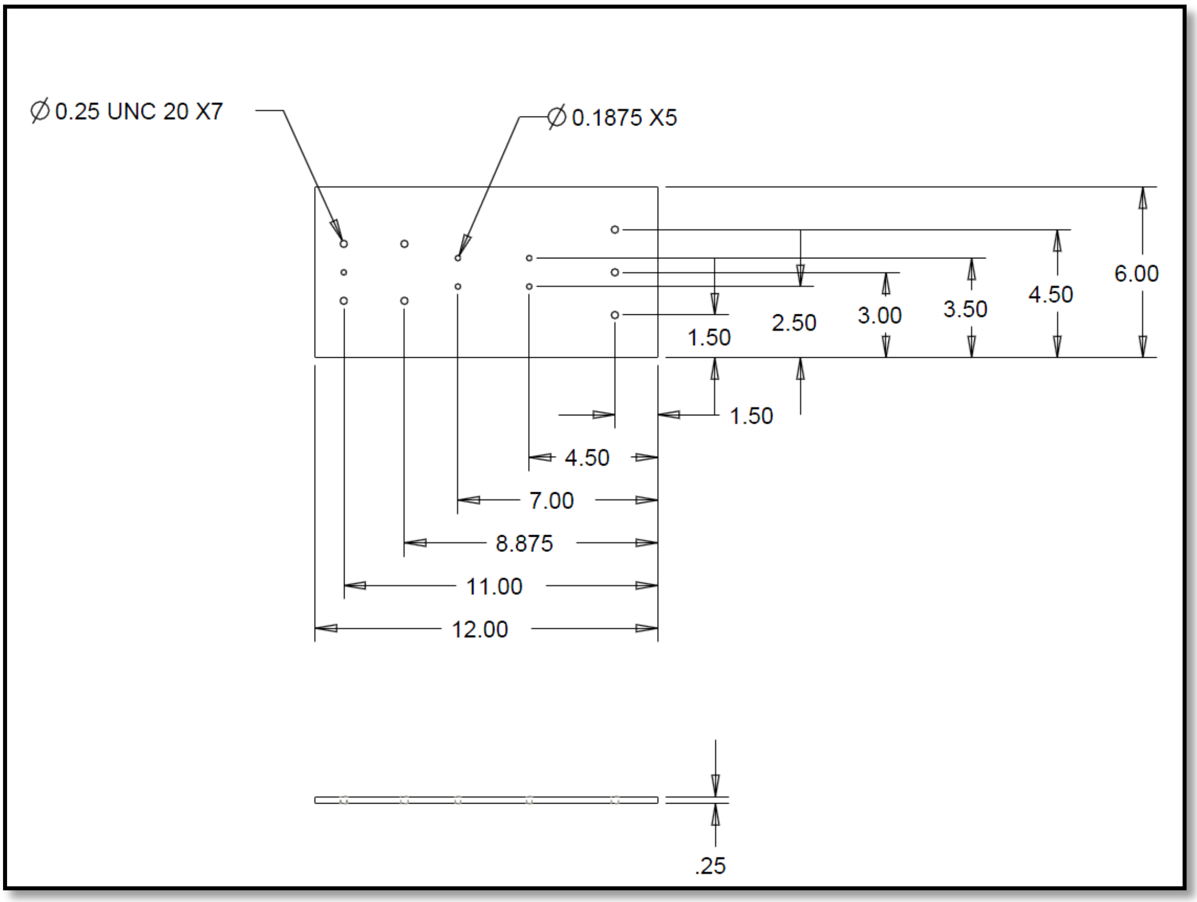


Figure P.7: LEG PLATE

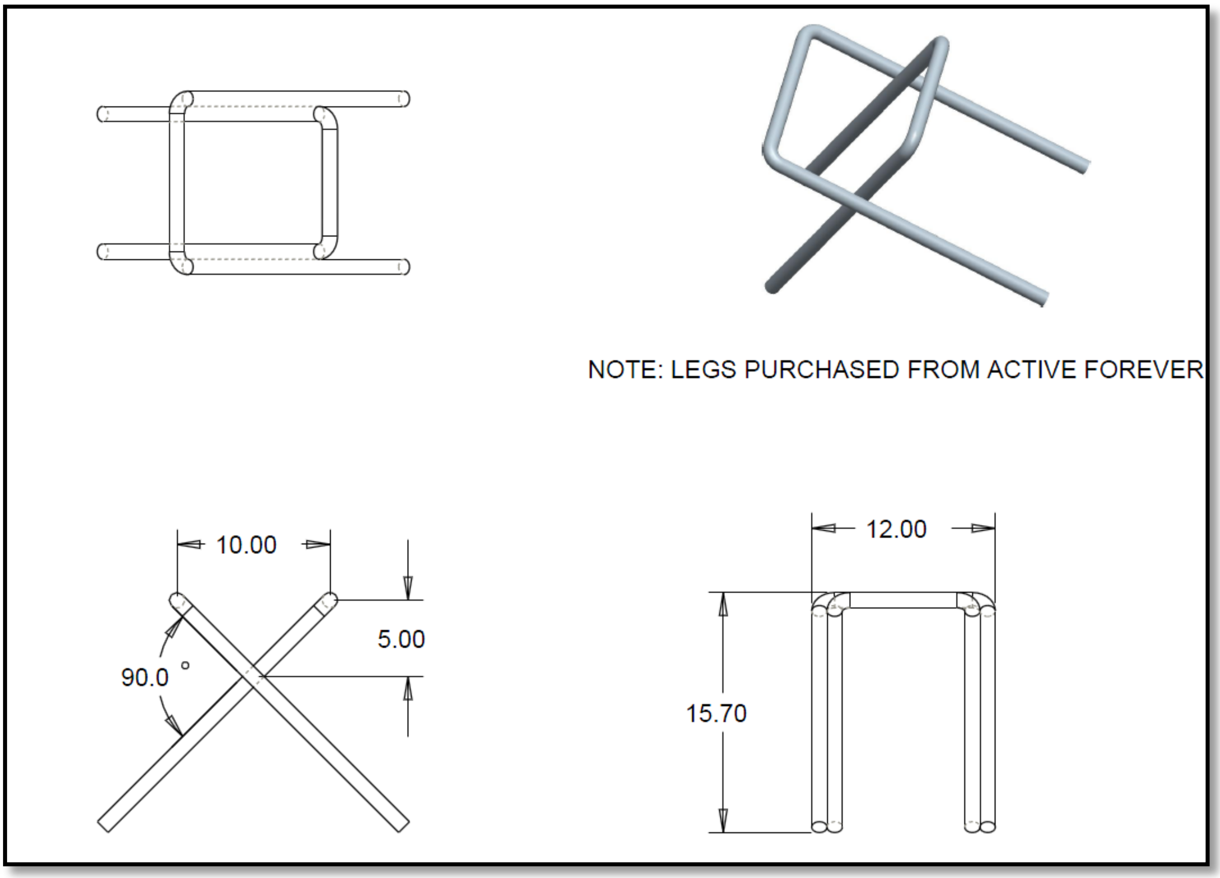


Figure P.8: FOLDING LEGS

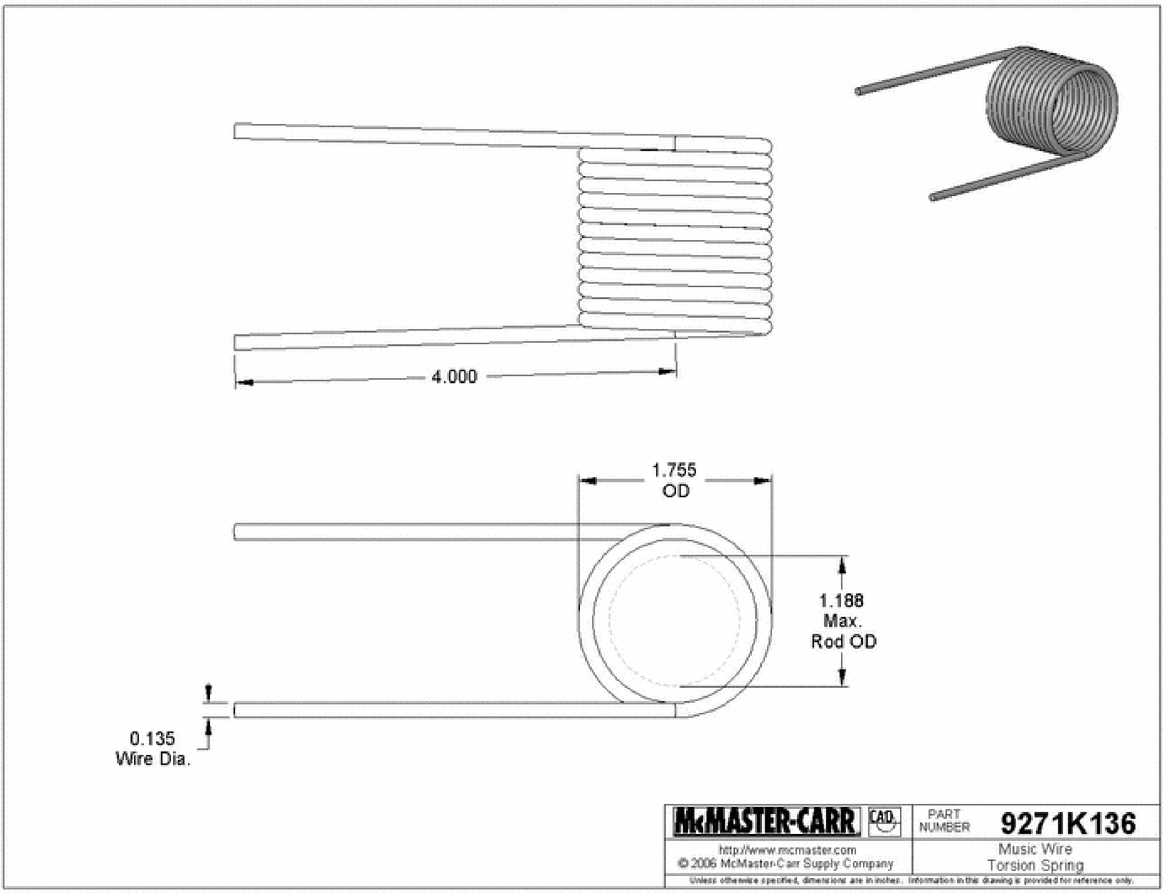


Figure P.9: CLOCKWISE WOUND SPRING

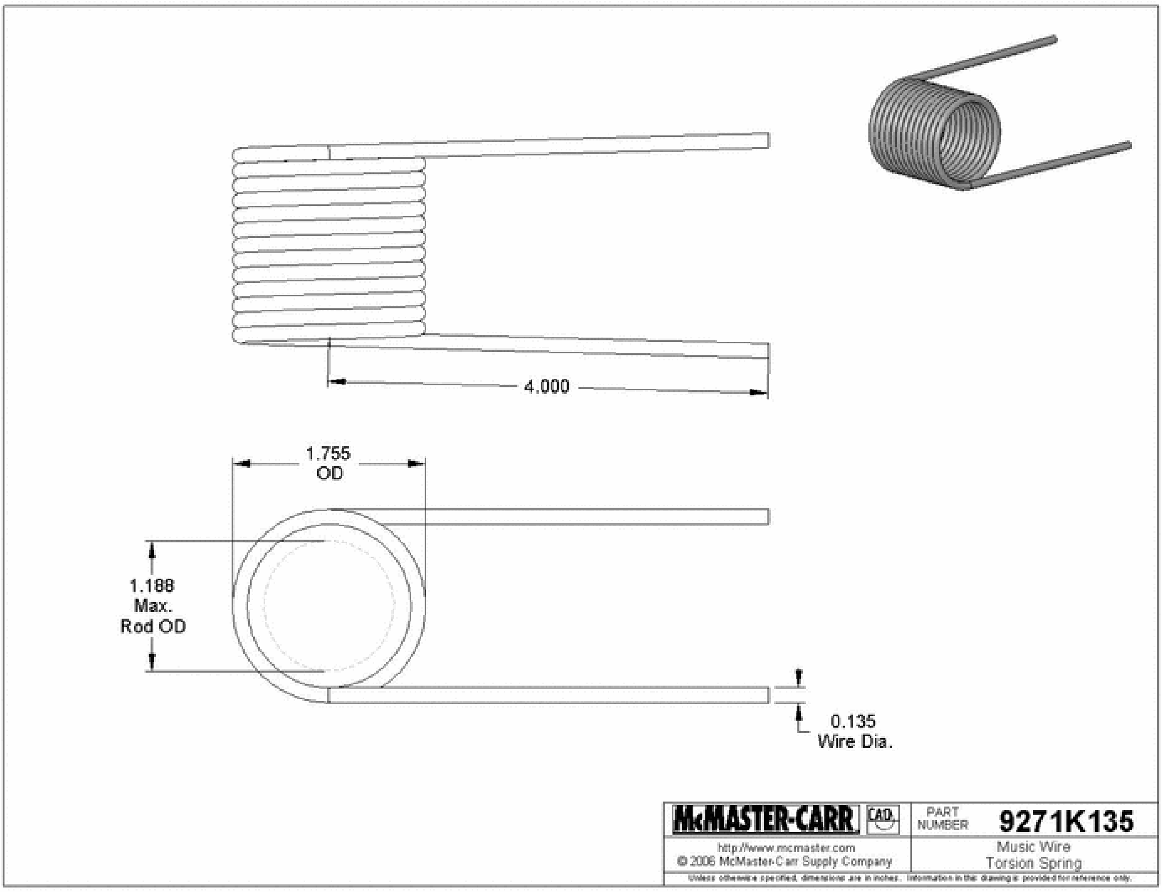


Figure P.10: COUNTER CLOCKWISE WOUND SPRING

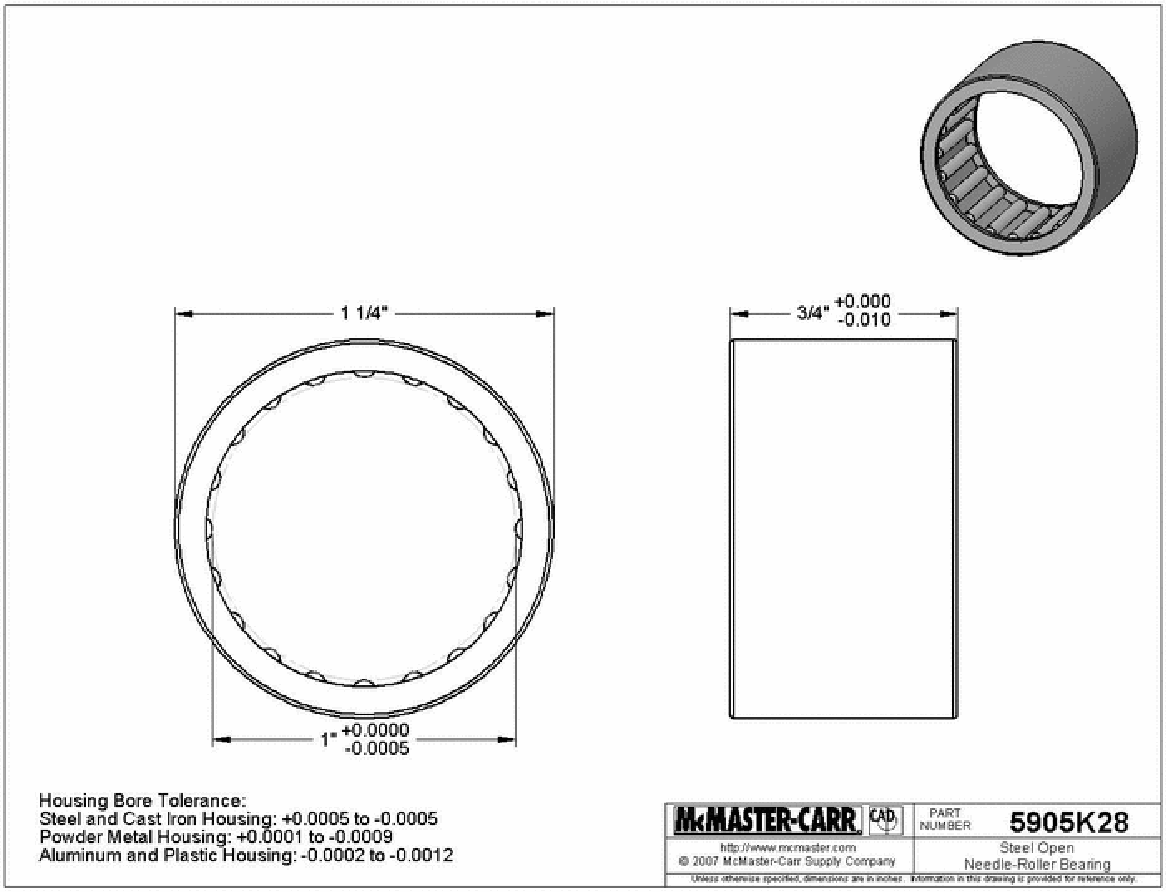


Figure P.11: BEARING

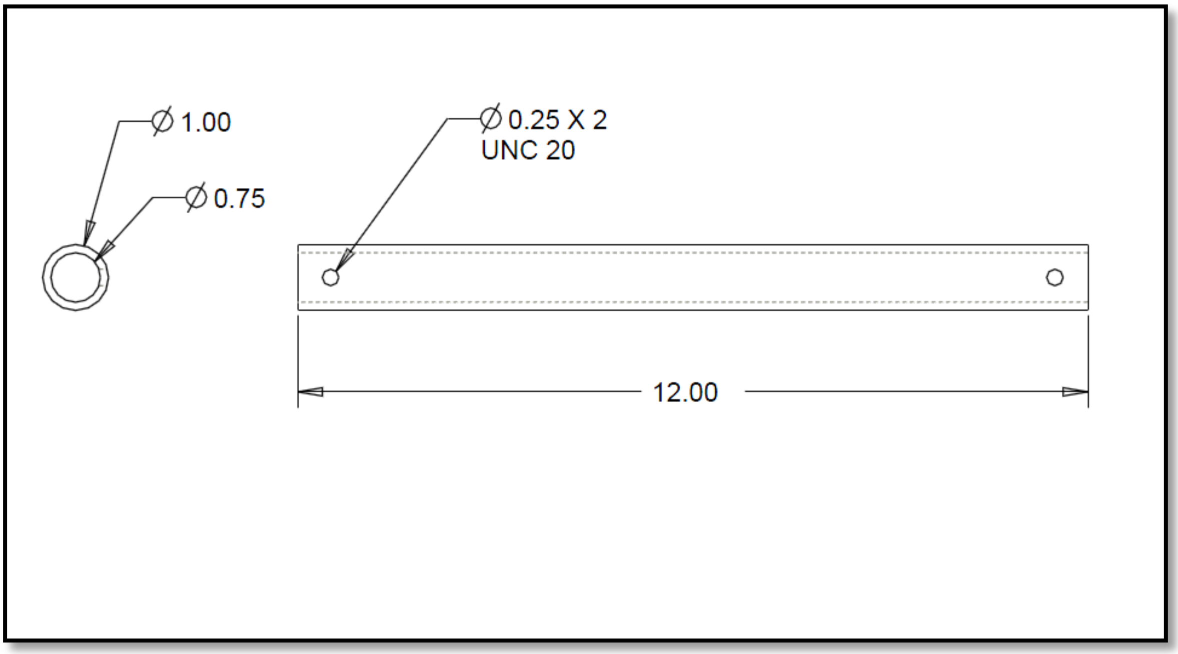


Figure P.12 PIVOT ROD

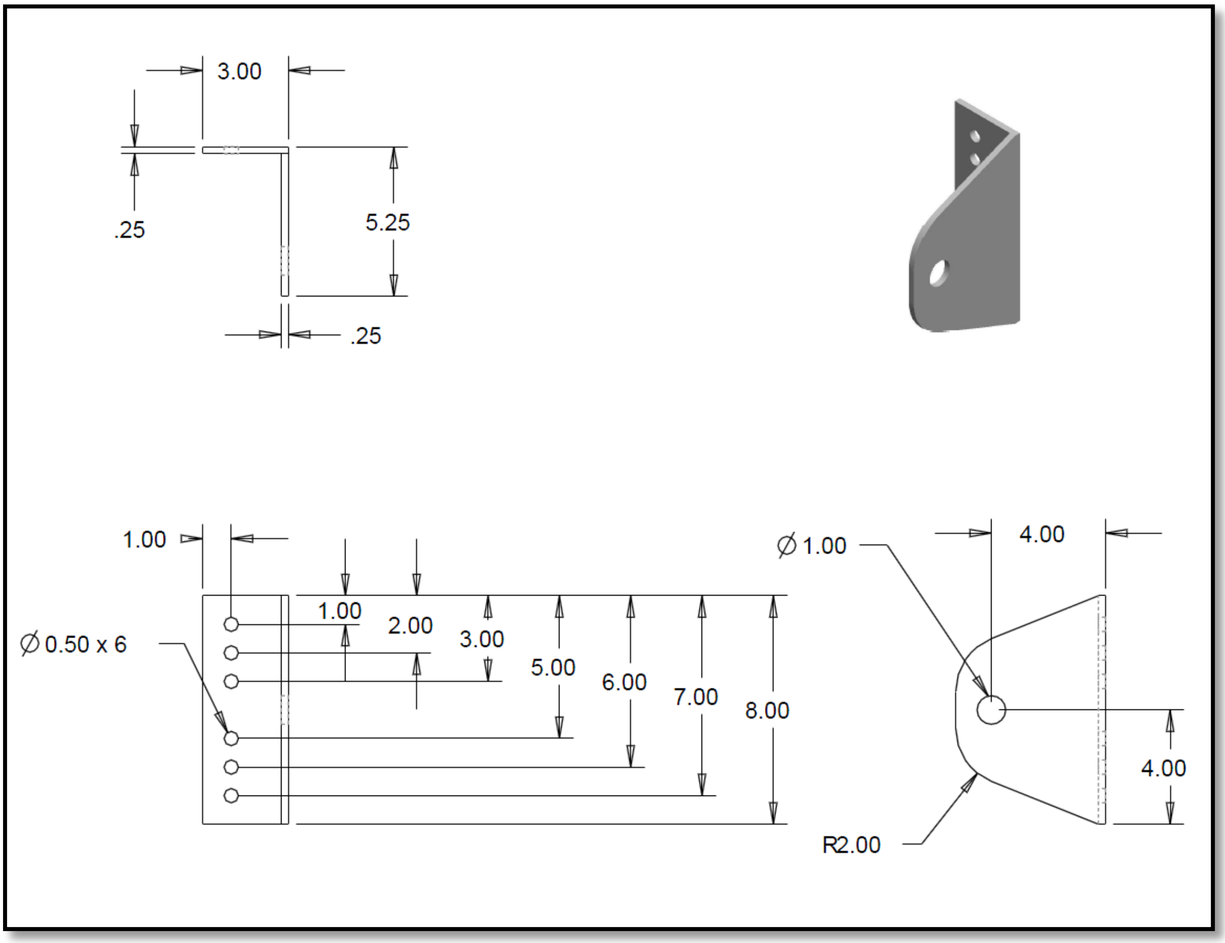


Figure P.13 WALL MOUNT

APPENDIX P: Gantt Chart