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BATH TUB LIFT FOR DISABLED INDIVIDUALS

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ABSTRACT

This project focuses on improving the design of a previously developed bathtub lift. A bathtub lift is a device that provides assistance to individuals with physical limitations. The client is a wheel chair user who relies on this type of device daily. However, the model she is currently using does not meet her needs. The goal of this project is develop a powered bathtub lift that is, among other requirements, sturdy, comfortable, easy to use and clean, makes minimal noise, and takes into account any physical limitations the user may have. The expected end result is an installed bath lift for daily use that allows the user to maintain autonomy and privacy. The methods selected throughout the process should consider the specific needs of autonomy and provide safe and efficient solutions. This paper outlines the design of the bath tub lift with test and calculations.

NOMENCLATURE

$E = modulus\ of\ Elasticity$
$F_x = Force$
$I = moment\ of\ inertia\ (in^4)$
$L = length\ (in)$
$M_{xx} = Moment\ at\ \text{"x"}\ at\ the\ \text{"x"}\ direction$
$P = Allowable\ load\ (lbs)$
$R_{xx} =$ Reaction at “x” at the “x” direction
$b = base$
$h = height$
$n = factor\ with\ respect\ to\ end\ conditions$

INTRODUCTION

A bathtub lift is a device that provides assistance for taking a bath or shower to an individual with physical disabilities, including limited balance, coordination, or mobility. The device can greatly reduce movement difficulties by raising and/or lowering an individual into the tub by utilizing a seat paired with a simple control module. Additionally, the lift can be used to facilitate tub entry and exit. As a result of accelerating population growth, the number of aged individuals will greatly increase over the coming decades. Among other needs, the demand for powered assist devices will grow due to the device's compatibility with most existing structures, ease of use, and overall reliability.

The primary stakeholder and user of this product needed a new and improved bathtub lift. The bath tub lift that the client owned was a water powered unit. The device was not stable, limiting the safety of the client. The seat had arm rests on both sides, but the arm rest on the left side was broken due to clashing with the tub side shelf. Furthermore, the current model was no longer in production – when attempting to contact the vendor it was found that the company was no longer in business. Parts have been replaced and fixed due to wear over the years. The parts that do still work do not operate properly. Finally the user had difficulty accessing the chair. The current model has the capability to rotate out where she uses her arms to support herself to stand up and get on to the seat. With one of the arms in a broken state and the instability of the seat when it is raised, she has trouble keeping balance when trying to sit on the device. Eventually, the current device was disposed of and she has no bath tub lift to use. Many medical stores do not provide bath tub lifts that are powered and meet the specifications the client needs. Figure 1 below shows the condition of the existing product. As of the month of October 2014 the bath tub lift went obsolete and the client has no bath tub lift to use.

Figure 1: Current condition of the "Tubmate" bath tub lift.

Bathtub lifts are effective for many worst case scenarios for the disabled and elderly people. Due to an individual's mobility disabilities, he or she may often have a hard time being able to sit properly on the seat of the lift. Issues such as slipping or periods of instability may occur due to the undivided need to get in the actual tub before lowering the lift. Individuals' confidence is decreased due to the potentially dangerous method of accessing the bathtub.

DESIGN PROCESS

The deliverables for the bathtub lift were to effectively assist the user for bathing purposes. In addition, it needs to be easy to access from starting position. Operation time needs to be minimized and the device needs to provide a comfortable and supportive seating area. The seat on the bathtub lift needs to be accessible to 10^{th}-70^{th} percentile for both genders, regardless of age. In addition, the lift needs to be reasonably lightweight and portable, able to be transported (this deliverable changes overtime due to the needs of the primary customer). The device was originally intended to be assembled for the client but the scope of the project was enlarged for other stakeholders other than the client. More customer requirements were added to define the project.

The device must fit a bathtub within a 24 by 32 by 15-inch space (in the center of the tub). Originally the secondary stakeholders for this device were considered for the design of the device. These stakeholders were individuals that were disabled/handicapped, or in hospitals and nursing homes. Requirements such as a lightweight design and the ability to fold down to fit in a car were required. These requirements were later removed as they were not needed by our primary customer. For example, she would not be transporting the device as she travels.

A functional decomposition along with a morphological analysis, which can be seen in Figure 2 and Figure 3 for concept generation, was created to generate different ideas of the bathtub lift. The final design chosen was a base battery powered bathtub lift. Other options were to have the device water powered, fully battered powered, or implement a crane design. A base battery powered bathtub lift is powered to go up and down with a battery as the energy source with some components that are operated manually. For a fully battery powered lift, all moving components of the device are operated by the battery. Components that are not powered by a battery in the base battery device are the sliding and rotating of the seat. The conceptual design of the device can be seen in Figure 4.

The budget for the project was initially $1500. However, the budget had to be expanded in order to meet customer and engineering requirements, as the prototype will be used by Theresa in her home. The product was comprised of purchased and manufactured parts, which were obtained through vendors that met project specifications.

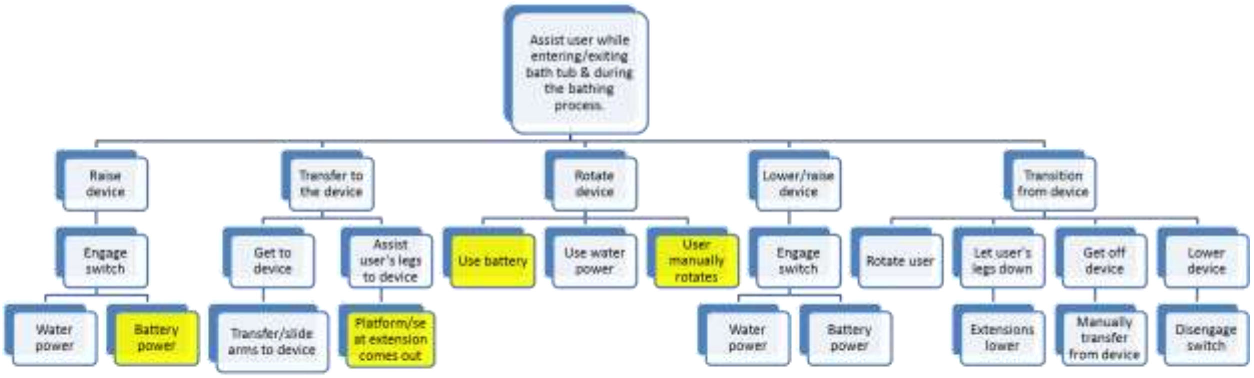

Figure 2: Functional decomposition of the bath tub lift

	Criteria	 Base (Existing) Design	 Base Battery Design	 Fully Battery Powered Design	 Crane Design
1	***Raise Device***	DATUM	+	+	+
2	***Transfer Device***		S	+	+
3	***Assist Legs***		S	+	+
4	***Rotate/Slide Device***		-	+	+
5	***Lower Device***		+	+	+
6	***Turn on Water to Fill Tub***		S	S	+
7	***Affordable***		-	-	-
8	***Fits Time Constraints***		+	-	-
9	***Safety***		-	+	-
10	***Light Weight***		-	-	-
11	***Portable***		-	-	-

Figure 3: Morphological Chart used to generate concepts and assist in with the decision making process

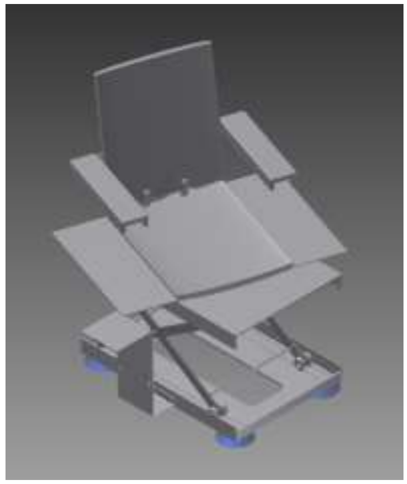

Figure 4: Conceptual CAD model of the battery powered bathtub lift

Components that the base battery powered bathtub lift is composed of is a seat that is able to rotate 360 degrees and slide forward and backward. In addition, the scissor legs that are attached to a rail and carriage system that will be used to help moved the legs to raise the seat. The bathtub lift energy source will be coming from a battery and actuator provided by Linak. Dr. DeBartolo, from the Mechanical Engineering Department at Rochester Institute of Technology, suggested this solution. The company has actuators that are used in numerous medical devices, as well as in many water-prone applications.

SEAT & TRAC-LOCK

The seat and the slide/rotate the device were ordered from Springfield Marine Company. The seat, known as the Commodore Seat Shell, is a one piece white molded shell made from LLDPE plastic with UV Inhibitors [3]. It has armrests that the customer can use to help transitions to and from the device. Testing was conducted on the seat by having a team member sit in the chair. This component met the ergonomic requirements for Theresa in terms of size. The seat dimensions are 20” X 16” x 19”. In addition, there is a hole that will drain water out from the base of the seat.

A Trac-Lock Slide was purchased with the capabilities of sliding and rotating the seat. This component has the ability to rotate 360 degrees clockwise and counterclockwise, and can additionally lock in 12 different positions (every 30 degrees) [2]. Material for this component is stainless steel. While testing the component, the sliding part was fairly easy to use but rotating feature required a high amount of force to operate. Waterproof lubricant with PTFE from the Lube Tube product was added to the bearings, which decreased the force needed to rotate the component.

ACTUATOR

The actuator was provided by Linak. It can push up to 6,000N (1350 lbs) and pull 4,000N (900 lbs) [5]. It possesses an emergency lowering/retraction for in the case the battery is low or dies. It is powered by a 24V DC magnet motor and has a 2.25m cable. Furthermore, the actuator has an IPX6 rating, which indicates that it is protected against high-pressure water streams from any angle. However, it cannot be submerged due to the fact that water may ingress through moving parts due to hydrostatic pressure. The actuator was tested using a wood prototype which replicates the design from Figure 4. The actuator will be attached to a stainless steel rod, which will in turn pull or push the scissor legs to raise or lower the seat. While testing the actuator with the wood prototype, a metal rod was bent due to the stress from the weight of the chair. This indicated that a stronger metal would be needed for the final design. This will be discussed more in the “Base & Legs” section of this paper.

Since the actuator cannot be submerged in water, a rubber bellow was purchased from McMaster Carr. The bellow, which is made out of polyurethane, was placed on the actuator rod - with clamps and wires tying off both ends in order to seal out water [4]. In addition, a rubber seal spray was applied to the actuator and bellow to further prevent the possibility of water ingress.

SUCTION CUPS

Four 4.5” suction cups were purchased from SeaSucker. These are vacuum cups that are rated to pull up to 120 lbs. A threaded center hole made from stainless steel attached the cups to the base plate by stainless steel screws. The suction cups were tested and can be submerged under water only if applied vacuum pump is used before being submerged. Prior to purchasing the suction cups, calculations were conducted (seen below) to determine if they provided enough suction force to keep the system upright and stable. Based on the results of the calculations it is evident that four suction cups would be able handle the forces and moments that occur during use.

$$Assuming \sum F_X = 0 \ for\ A, B, C, \&D$$

$$\sum F_Y = 0$$
$$R_{AY} = R_{BY}$$
$$R_{DY} = R_{CY}$$
$$-R_{AY} - R_{BY} + R_{CY} + R_{DY} - 350 = 0$$
$$2R_{CY} - 2R_{AY} = 350$$

$$\sum M_{AB} = 0$$
$$2R_{DY}(15) - 350(14.5) = 0$$
$$R_{DY} = 169.18\ lb$$
$$R_{DY} = 169.18\ lb$$
$$-2R_{AY} + 2(169.18) = 350$$
$$-2R_{AY} = 11.68$$
$$R_{AY} = 5.34\ lb$$

MOTION SYSTEM

The rails and carriages were purchased from McMaster Carr. Originally, stainless steel rails were purchased from PBC Linear but no carriages were included. The price of ordering the carriages separately was not feasibly within the team budget, so a different, complete assembly was purchased from McMaster Carr. The rail material is chromated zinc while the carriages consist of anodized aluminum. The clevises for the device were purchased from Cylinder Repair Components, though problematically they were made from cast iron. Due to the constant moist environment, the clevises would corrode relatively quickly. Cast iron is extremely strong and durable when used appropriately and protected from adverse exposure, but this component will be submerged underwater. Therefore, it will be highly susceptible to corrosion when exposed to moisture and humidity. New clevises were made using scrap stainless steel that was cut from the base and top plate. These components were drilled on top of the carriages and slide forward and backward to raise and lower the scissor legs.

BASE & LEGS

During the design phase of the base and the legs, stress analyses were conducted. Figure 5 shows the displacement analysis of the top base and scissor region with A36 steel and a weight of 350 lbs on top.

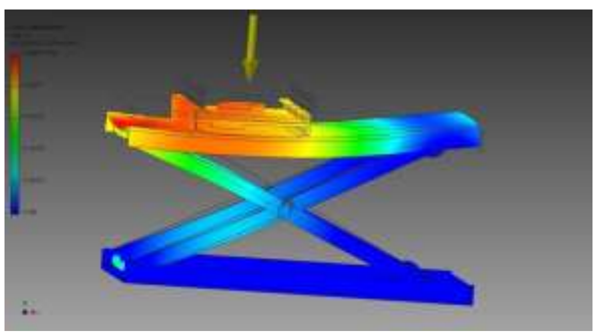

Figure 5: Displacement analysis showing maximum displacement if 0.03537" while scissor region obtained 0.007-0.023".

In addition, a stress analysis was performed on the device with the slide and the seat at its maximum extended position, which can be seen in Figure 6. From the test, maximum stress occurred in the upper pin region. After observing this and the displacement analysis from Figure 5, it is evident that a high grade of steel must be used for the pins. Stress values in the scissor region were between 3-22 ksi. The maximum displacement at the edge of the extending pillar was 0.1456".

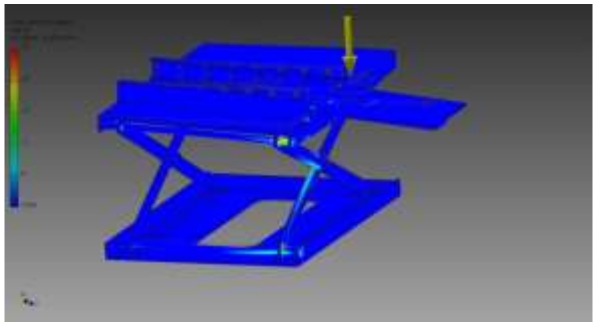

Figure 6: Stress Analysis at maximum extended position.

The factor of safety (FOS) range in the scissor region was around 1.5 to 6. By increasing the thickness of the scissor frame by 1/8" will increase the lower FOS values to the desired range. The FOS values for the pins dropped below 1 due to lower grade of steel (A36) used for this analysis; this further confirms that a high grade of steel must be used for the pin region. The final material chosen was 304 stainless steel as it met the engineering requirements and will not rust or corrode even while submerged underwater.

Concerns for the leg buckling were addressed by performing mathematical analysis. The assumptions made were the following:

$$n = 1 \; where \; pivots \; occur \; on \; both \; ends$$

$$E = 29{,}000 \; \times 10^3$$

$$I = \frac{1}{12} bh^3$$

For the moment of inertia the worst case scenario was calculated.

$$I = \frac{1}{12}(1)(0.4)^3 = 0.00533 in^4$$

$$P = \frac{n\pi EI}{L^2}$$

$$P_{allowable} = \frac{(1)(\pi)(29{,}000 \; \times 10^3(0.00533)}{400}$$

$$P_{allowable} = 1{,}213.98 \; lb$$

$$F.O.S. = \frac{P_{allowable}}{P_{actual}} = \frac{1{,}213.98}{500} = 2.427$$

The top and bottom plates of the device were purchased from Klein Steel. A water jet was used to machine both the top and bottom plates. The middle portion of the base plate and top plate were cut out to reduce the weight and to help drain water that may sit on the device. In addition, four corner sections were cut out to accommodate recessed suction cups. This would reduce the sitting height of the seat when it is at its lowest point.

RESULTS AND DISCUSSION

Figure 7: Final design of the bathtub lift.

The final design, which can be seen in Figure 7, required parts from vendors in addition to machined parts from the team. The device was then assembled and tested. Additional drilling and welding was required in order to meet the engineering specifications set. The device can rotate 180-360 degrees both and clockwise and counterclockwise. In addition, the seat meets the need of being accessible to the 10^{th} -70^{th} percentile women based on their height. The base of the seat is 16” x 20” with the back rest at 19”. It includes arm rests which are ergonomically wide enough for the 10^{th} percentile women [1]. Since the user does not rely on using the armrests while bathing, their height was not critically important. Furthermore, the device can drain water since there is a cut out on the seat, top plate and base plate.

The bathtub lift can raise and lower in approximately 45 seconds. In addition, it can raise the user 12.5 inches from its initial position. The device is rated to handles weights of up to 350 lb. The battery powering the actuator can last for a month, if used once per day. It takes approximately 4 hours for the device to fully charge. The functional structure of the device can be seen in Figure 8 below. This diagram explains how the actuator integrates with the device to power and operate it.

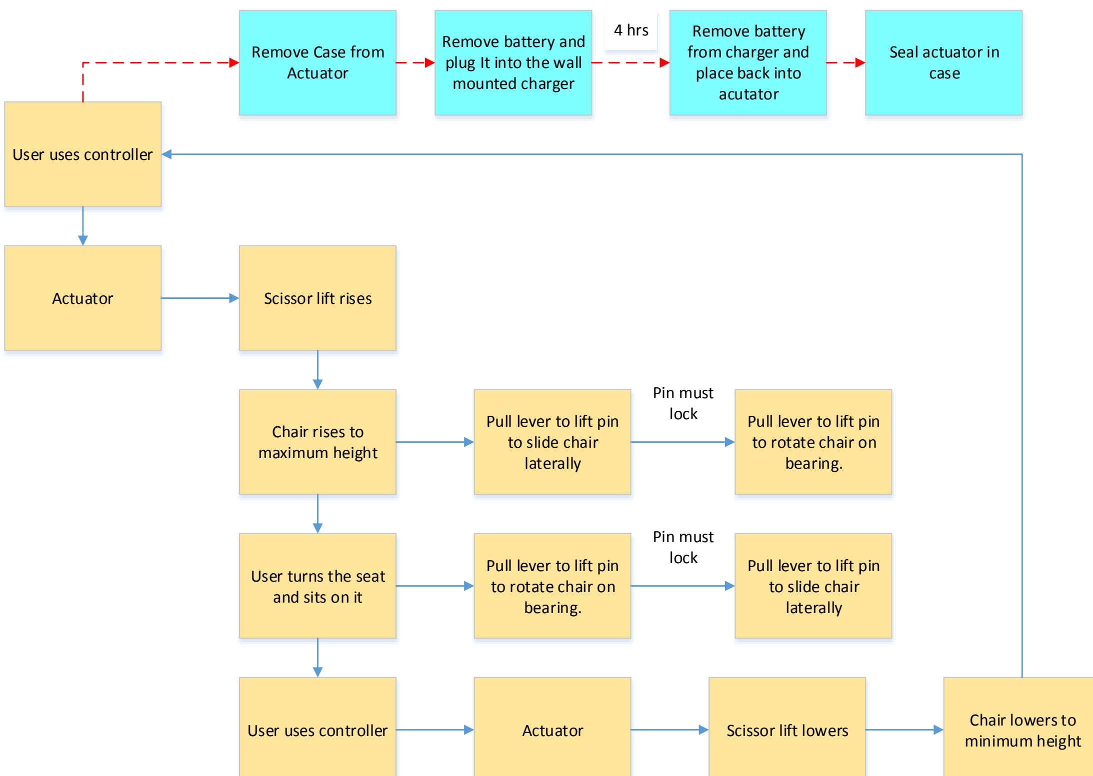

Figure 8: Mechanical architecture of the bath tub lift.

CONCLUSIONS AND RECOMMENDATIONS

This project was intended to create a lift for disabled users to take a bath within the privacy of their home. The device was completed but not on schedule as there were many challenges that were dealt with. PBC Linear, which was the original company that the rails and carriages were ordered from, delayed delivery by one week. Additionally, the company only delivered the rails for the system, requiring another purchase for the necessary carriages. This company is not recommended for ordering rails or carriages due to their poor customer service and cooperation.

In addition, there were many alterations to the overall device since some of the components could only be purchased in standardized sizes. Some parts that were manufactured needed alteration to reduce weight, sitting height of the device, and have symmetry between the bottom and top plate. Since the client will use the final product for many years once it is delivered, the decision making process was intensive and time consuming. This was largely due to the fact that all components were held to the highest standards of quality and safety, so as to prevent any chance of injury. In addition, it would have been helpful to have a more detailed bill of materials during the design phase to have a better outline to work with when ordering and looking for parts.

All customer requirements were satisfied in full with the exception of CN17, CN18, CN19, CN20, and CN22, which can be seen in Table 1 in the appendix. This was largely due to the fact that the requirements were updated to meet only Theresa's needs, in contrast to the broad public scope that was initially planned. If produced for commercial use, the device weight should be reduced. In addition, the device should have the ability to recline and the capability to measure water temperature. Furthermore, the sitting height should be reduced as much as possible so the user is close to the bottom of the tub.

REFERENCES

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[3]"Commodore Seat." *Springfield Group RSS*. Web. 2 Oct. 2014. <http://www.springfieldgrp.com/products/chairs/molded-seats/commodore-seat>.

[4]"McMaster-Carr." *McMaster-Carr*. Web. 2 Dec. 2014. <http://www.mcmaster.com/#protective-bellows/=uuj0rx>.

[5]"LA31 Careline Linear Actuator." Linak. Web. 23 Apr. 2014. <http://www.linak-us.com/products/linear-actuators.aspx?product=LA31 CARELINE>.

ACKNOWLEDGEMENTS

We would like to thank Linak for providing a customized electric linear actuator at a discounted price. In addition, we would like to thank the academic staff that supported this project with the stress analysis on the scissor legs and providing information about Linak to use as a supplier. Furthermore, we would like to thank the Brinkman Lab in the Kate Gleason College of Engineering for the manufacturing of this product. Finally, all expenses were covered by Rochester Institute of Technology.

APPENDIX

Customer Need	Importance	Description
CN01	1	Chair turns 180-360 degrees
CN02	1	Chair has handles/armrests
CN03	1	Requires minimal setup
CN04	1	Comfortable and safe to use
CN05	1	Sturdy attachment to tub; cannot move
CN06	1	Non-corrosive
CN07	1	Easy to use
CN08	1	Easy to clean
CN09	1	No use of Nickel - allergic
CN10	1	Able to lift at least 150 lbs
CN11	1	Accessible to 10th percentile women (height)
CN12	1	Controls/handles must be easy to use
CN13	1	Compatible with existing tub/system
CN14	2	Easy to maintain/fix
CN15	1	Takes 0-5 minutes to rise
CN16	2	Minimal noise
CN17	2	Flexible temperature control
CN18	1	Can recline to lay user flat in tub
CN19	2	Can fold down to fit in car
CN20	2	Lightweight
CN21	1	Partially/fully powered by battery
CN22	1	Way to measure temperature

Table 1: Customer needs for the bathtub lift.

Number	Source	Function	Specification (metric)	Unit of Measure	Marginal Value	Ideal Value	Comments/Status
S1	CN01/CN10/CN16	System	Rotation of chair	degrees	180	>= 180	
S2	CN02/CN04/CN07/CN11/CN13	System	Width of armrests	in	17-19	17 1/2	
S3	CN03/CN08/CN14	System	Time to get device in/out of tub	minutes	0-2	1	
S4	CN04/CN11/CN13	System	Correctly dimensioned seating area	in^2	< 17 x 15	17 x 15	Must fit within tub
S5	CN02/CN06/CN07/CN08/CN13	System	Chair secured to tub using suction cups	psi	secure equivalent of 150 lbs	secure equivalent of 150-350 lbs	
S6	CN02/CN06	System	Long lasting material	year	100-120	120-260	
S7	CN04/CN14/CN07	System	Time to engage hydro lift	seconds	5-Jan	3-Jan	
S8	CN04/CN06/CN08/CN09/CN14	System	Material use, fixture design	minutes	5-Feb	3	
S9	CN02/CN04/CN09	System	Concentration of nickel	%	0	0	Client allergy
S10	CN10	System	Lifting capabilities	lbs	150	>= 150	
S11	CN11/CN04	System	Height of user	in	58 - 62	60	women's 10th percentile
S12	CN12/CN04	System	Diameter of lever	in	1.5 - 2.5	2	
S13	CN13	System	Dimensions of device/fixture	in	18 - 19	19	
S14	CN17	System	Rising time	minutes	5	<= 5	
S15	CN16	System	Noise	dB	30	<= 30	
S16	CN17	System	Operates on wide range of temperatures	Fahrenheit	70-110	60-130	
S17	CN18/CN04/CN07/CN10/CN11/CN13/CN14/CN15/CN16	System	Chair reclining ability	degrees	40-90	90	
S18	CN19/CN03	System	Compact transport design	ft^3 (LxWxH)	20-27(L) x 16-19(W) x 20-30(H)	25(L) x 17.5(W) x 30(H)	Dimensions restricted to tub size
S19	CN20/CN08	System	Lightweight system design	lbs	20-30	25	
S20	CN21/CN01/CN04/CN07/CN12/CN18	System	Device powered by battery	V	12-24	12-30	Alternative to hydraulic
S21	CN22/CN07	System	Thermometer to gauge water temperature	F	90-106	104	

Table 2: Engineering requirement for the bathtub lift based on customer requirements.

			Engineering Requirement	Rotation of chair	Width of armrests	Time to get device in/out of tub	Correctly dimensioned seating area	Chair secured to tub using suction cups	Long lasting material	Time to engage hydro lift	Material use, fixture design	Concentration of nickel	Lifting capabilities	Height of user	Diameter of lever	Dimensions of device/fixture	Rising time	Noise	Operates on wide range of temperatures	Reclining ablity	Compact transport design	Lightweight system design	Device Powered by Battery	Thermometer to gauge water temperature
			#	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21
Customer Need	Priority	#																						
Device turns at least +/- 90 degrees	1	CN01		x																			x	
Device has handles/armrests	1	CN02			x				x			x												
Requires minimal setup	1	CN03				x															x			
Comfortable and safe to use	1	CN04			x		x			x	x	x		x	x					x			x	
Sturdy attachment to tub; cannot move	1	CN05						x																
Non-corrosive	1	CN06						x	x		x													
Easy to use	1	CN07			x			x		x										x			x	x
Easy to clean	1	CN08				x		x			x											x		
No use of nickel - allergic	1	CN09									x	x												
Able to lift at least 150 lbs	1	CN10		x									x							x				
Accessible to 10th percentile women (height)	1	CN11			x		x							x						x				
Controls/handles must be easy to use	1	CN12			x										x								x	
Compatible with existing tub/system	1	CN13		x	x		x	x								x				x				
Easy to maintain/fix	2	CN14				x				x	x									x				
Takes 0-5 minutes to rise	1	CN15															x			x				
Minimal noise	2	CN16																x		x				
Flexiblle temperature control	2	CN17																	x					
Can recline to lay user flat in tub	1	CN18																		x			x	
Can fold down to fit in car	2	CN19																			x			
Lightweight	2	CN20																				x		
Fully/Partially Battery Powered	1	CN21																					x	
Way to measure water temperature	1	CN22																						x
		Unit		Deg	in	min	in^2	psi	year	sec	min	%	lbs	in	in	in	min	dB	F	deg	ft^3	lbs	V	F

Table 3: Matrix containing customer and engineering requirements.