Final Report

ME 493

Portland State University
Inclusive Recreation Department

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Executive Summary

The purpose of a pool lift is to enable a paraplegic person to enter a pool when there is otherwise no means for them to safely enter. The purpose of this project was to build a lift to allow access to the spa located inside the Student Recreation Center (SRC) at Portland State University. The SRC's spa has a 18 inch outside height and 16 inch depth curb which makes most pool lifts unusable because they are not designed to lift a person over the described curb. The lifts that can accommodate the raised curb are usually manually operated by an assistant and are fixed to the floor.

The objective of the PSU ME Adaptive Rec Capstone Team was to design and build a fully mobile and automated spa lift to deliver a paraplegic person into the aforementioned spa. The lift and supporting documentation are to be delivered to the PSU Inclusive Rec Department by June of 2013.

The objective of the Adaptive Rec Capstone Team was to identify and fulfill customer and internal product design specifications (PDS) through interviews and team brainstorming. These PDS requirements were to be fulfilled by the completion of internal and external searches of existing products, the development and evaluation of various concepts, the creation of a final design, and manufacturing of the design. SolidWorks® was used in the modeling and finite element analysis of a final. Manufacturing and product procurement was done through known market vendors to insure compatibility with the SRC's current pool lift.

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Background

Last year marked the beginning of a great humanitarian relationship between the Mechanical Engineering (ME) Department, and the Inclusive Recreation (IR) Department. The 2012 ME capstone team brought the IR department a hand cranked bike, and a cross country sit-ski. This year, the Adaptive Rec Capstone Team was asked to design and build a lift to transport paraplegics into and out of the hot tub in the Student Recreation Center (SRC).

Introduction

From the Inclusive Rec's web page, "We are proud to provide equipment and programming that creates an inclusive environment and makes every effort to be accessible to all abilities". PSU's SRC has provided an assisted lift chair for the swimming pool, but the situation is not the same for hot tub or spa area due to geometry. The spa area has a raised curb with dimensions of a outside height of 18 inches, depth of 16 inches, and inside height of 26" down to the seat. The spa is covered in tiles which must remain undisturbed. This is seen in Figure 1.

Figure 1: The spa showing the curb and tiles

There are assisted lift products on the market, but they cannot account for all the problems the spa dimensions create. The current mobile system can only lower a person into the pool; thus it cannot be employed due to lack of a ramp to upper part of the spa. Other products on the market cannot lift a person up and over the wide lip or if they can, the system is not mobile.

Mission Statement

Team Adaptive Rec will design, fabricate, and deliver a spa lift that will allow a paraplegic person unassisted access to the spa in the SRC. This spa lift will comply with ADA standards as well as provide simple four button controls for the user. The lift will address any aesthetic and ergonomic issues requested by the IC and their intended customers.

Product Design Specifications

These PDS requirements were created through interviews with the SRC and IR departments. The requirements can be split up into 2 areas: customer major in red and minor requirements in orange. The customer major requirement of spa lift mobility was created to insure that the tiles of the spa area are not damaged. Maintenance plan documentation was created to insure the proper maintenance of the lift and provide a list of vendors for part acquisition due to any unexpected breakdowns. The minor requirement of unassisted operation was to insure that the person keeps their independence. This does not mean that the person cannot be assisted. Visual aesthetics was included to insure that the lift will match its surroundings due to the lift's semi-permanent location. The only request of the customer is that the lift cannot be pink.

Requirement	*Maintenance Plan Documentation*	
Customer	*SRC and IR*	
Matrix	**Target**	**Basis**
Document Availibility	*Document Present*	*Ongoing SRC Maintenance*
Verification	*Inspection*	
Priority	*High*	

Requirement	*Spa Lift Mobility*	
Customer	*SRC and IC*	
Matrix	**Target**	**Basis**
Cart: Yes or No	*Mount to Cart*	*Lift must be moved during Non-Use*
Verification	*Design and Inspection*	
Priority	*High*	

Requirement	*Unassisted Operation*	
Customer	*IR and End User*	
Matrix	**Target**	**Basis**
Degrees of Freedom	*2 Degrees of Freedom*	*In and Out of Spa*
Verification	*Controls Design*	
Priority	*Medium*	

Requirement	*Must Fit Current Visual Aesthetics*	
Customer	*PSU and SRC*	
Matrix	**Target**	**Basis**
Visually Fits Environment	*PSU Compliance*	*Customer Requested*
Verification	*Inspection*	
Priority	*Medium*	

The adaptive rec capstone team also came up with team PDS requirements: ease of engineering design, budget/cost, and power. Ease of engineering design was to insure only one project. Other separate mini-projects can be controls from scratch, slew drive design, seat design, automatic stops programing, and graphic designing for aesthetics.

A budget of $4000 dollars was issued for parts and manufacturing procurement. The closest spa lift with the correct motion is the AquaCreek Pro Spa 40 Lift which retails at $6,620. However, this lift does not extend over the 16 inch deep cub and is not mobile.

Power was an initial concern. AC deals with safety issues that the team did not want to deal with. The current pool lift is a DC model. Selection for the linear actuator and gear motor can consist of AC, DC, and pneumatic power.

Alternative Conceptual Designs

Three different types of spa lift designs were developed as alternative conceptual solutions. They are shown in figures 2, 3, and 4.

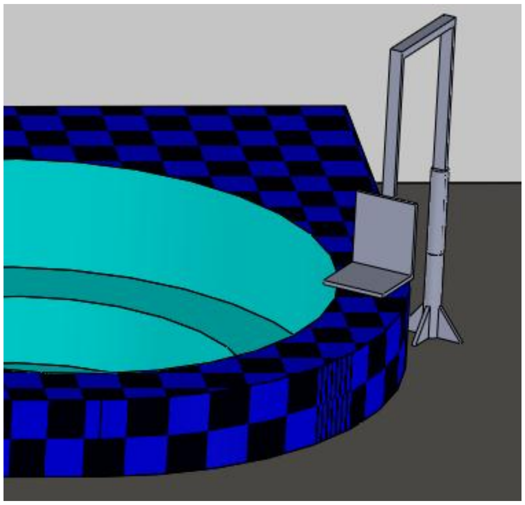


Figure 2: The Z-Rotator lift in the spa environment.

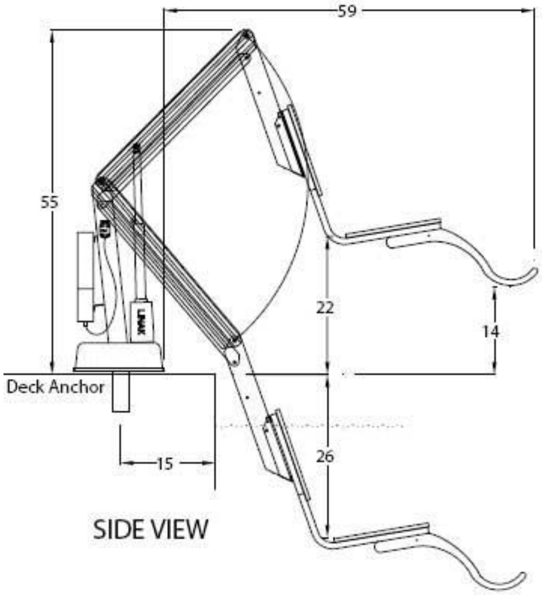


Figure 3: A profile view of the Excavator-style lift.

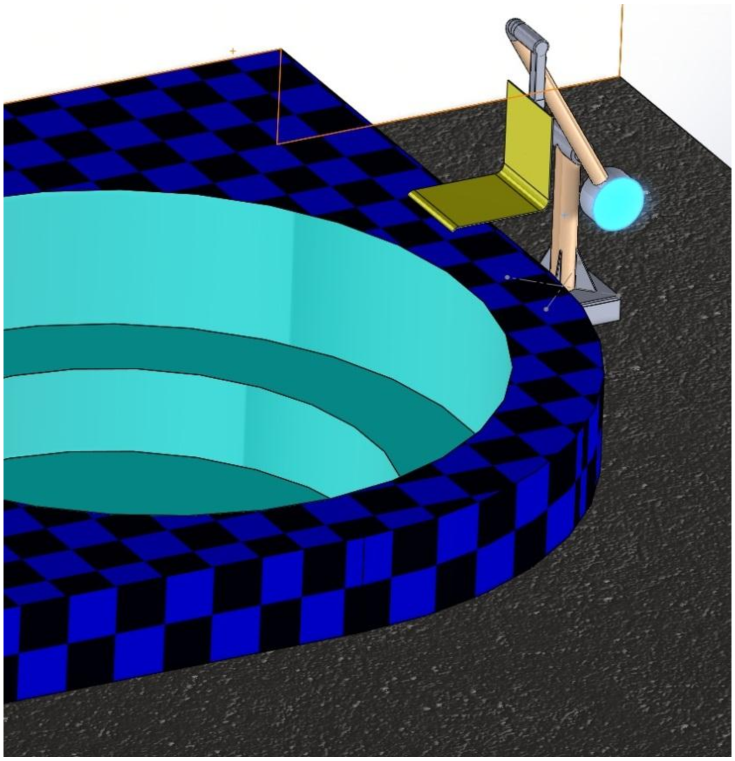


Figure 4: Man on a Clock lift in the spa environment

The team selected six criteria and scored these for each lift design shown in table 1. The Z-Rotator had the highest score and got selected as a solution of our capstone project. The simplicity of engineering design determined the selection of the Z-Rotator.

Table 1 - Results of the design selection

Selection Criteria	**Man on a Clock**	**Excavator**	**Z-Rotator**
Safety	5	10	9
Maintenance	12	6	9
Mobility	8	5	9
Budget	8	5	8
Engineering Simplicity	7	6	10
Totals	40	32	45

Final Design

The previous Z-Rotator model (fig 2) fulfilled most of the PDS requirements except for mobility. The concept of cart is adopted to maximize the mobility of the spa lift, and the final design is shown in figure 5. The spa lift mechanism has two degree of freedom; rotational and linear vertical movement. Both movements are integrated in a powered controller which enables the end user to operate the spa lift without any assistance.

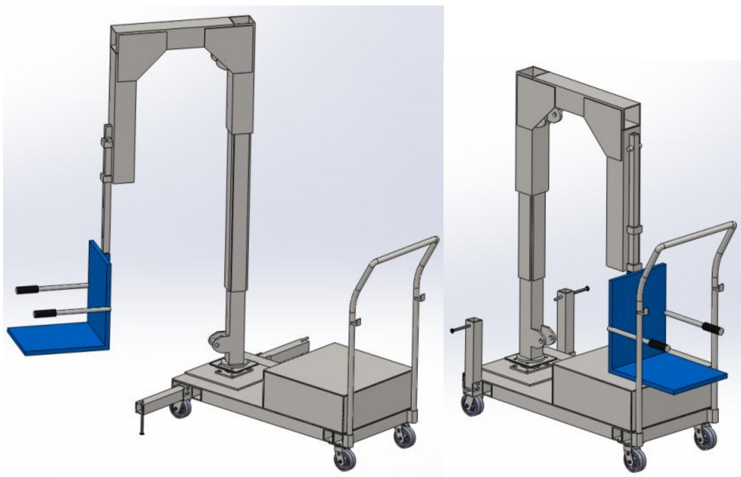


Figure 5: Final Design of Z-Rotator in motion (left) and in storage positions (right).

The final design fulfills the PDS requirements:

Maintenance Documentation is being written and will be given with the delivery of the lift to the SRC and IC departments.

Spa Lift Mobility has been accomplished with the cart.

Unassisted Operation has been accomplished with off-the-counter controls from AquaCreek, a lift system manufacturer. This is the same company as the other pool lift.

Visual aesthetics have been accomplished by painting the lift flat black. This color was chose as a baseline color. Glossy was determined to be a possible hazard due to the amount of light and windows in the spa area.

Figure 6 shows the lift in the spa environment, spanning the 16 inch curb. Figure 7 show the lift rising above the 18 inch curb. Figure 8 show the lift dropping down the 26 inch spa seat depth. Figure 9 show the lift in the stored position.

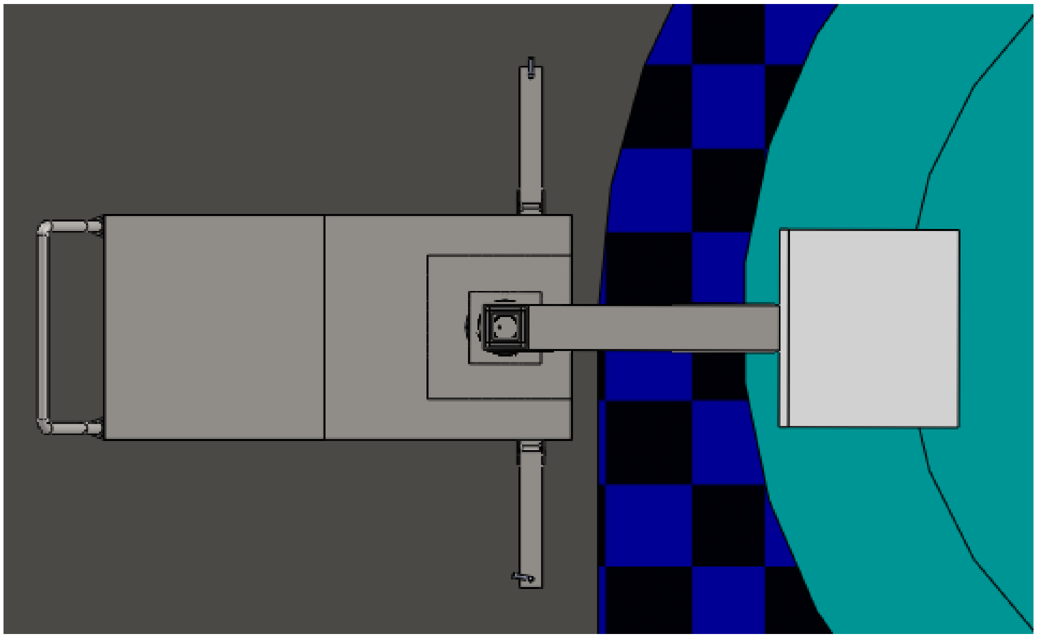


Figure 6: The lift spaning the 16 inch curb.

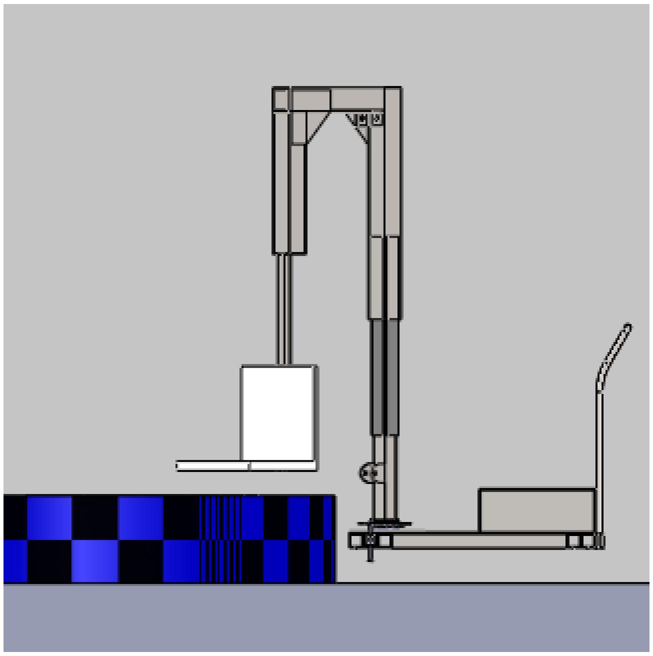


Figure 7: The lift rising above the 18 inch curb.

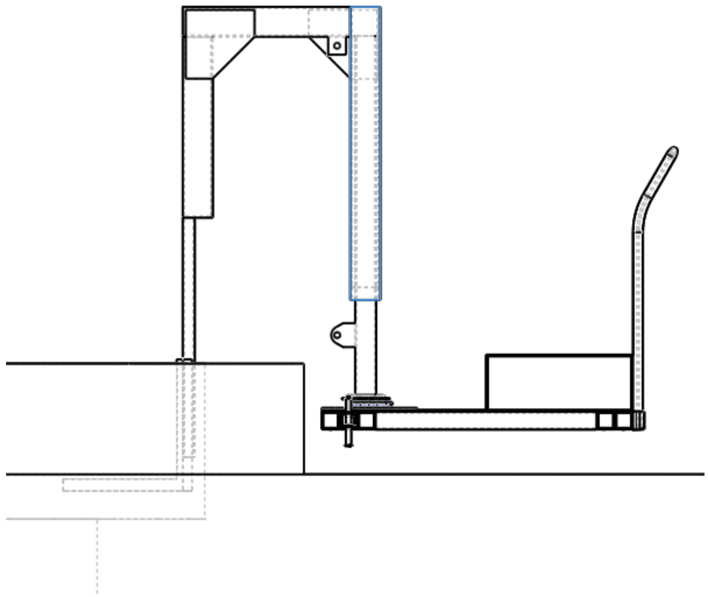


Figure 8: The lift dropping into the spa

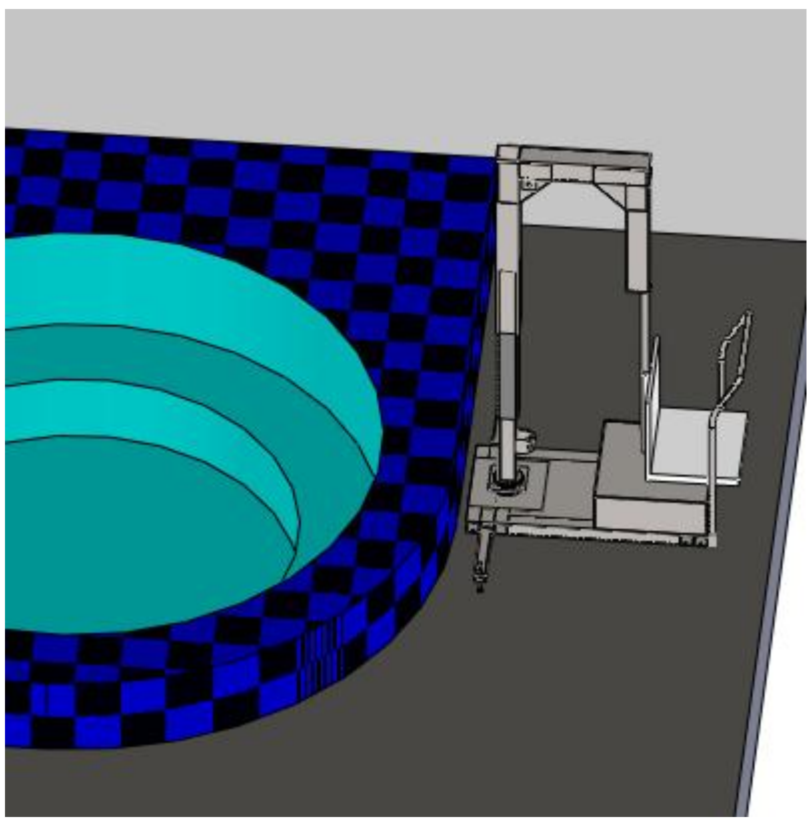


Figure 9: The lift in the storage position.

Final design analysis was performed to determine whether the design would perform as specified. A finite element analysis of the lift was performed and the results are shown in figure 10 and 11. The analysis for counter can be found in the Appendix C. The lift was determined to be able to hold the required weight of 450lbs.

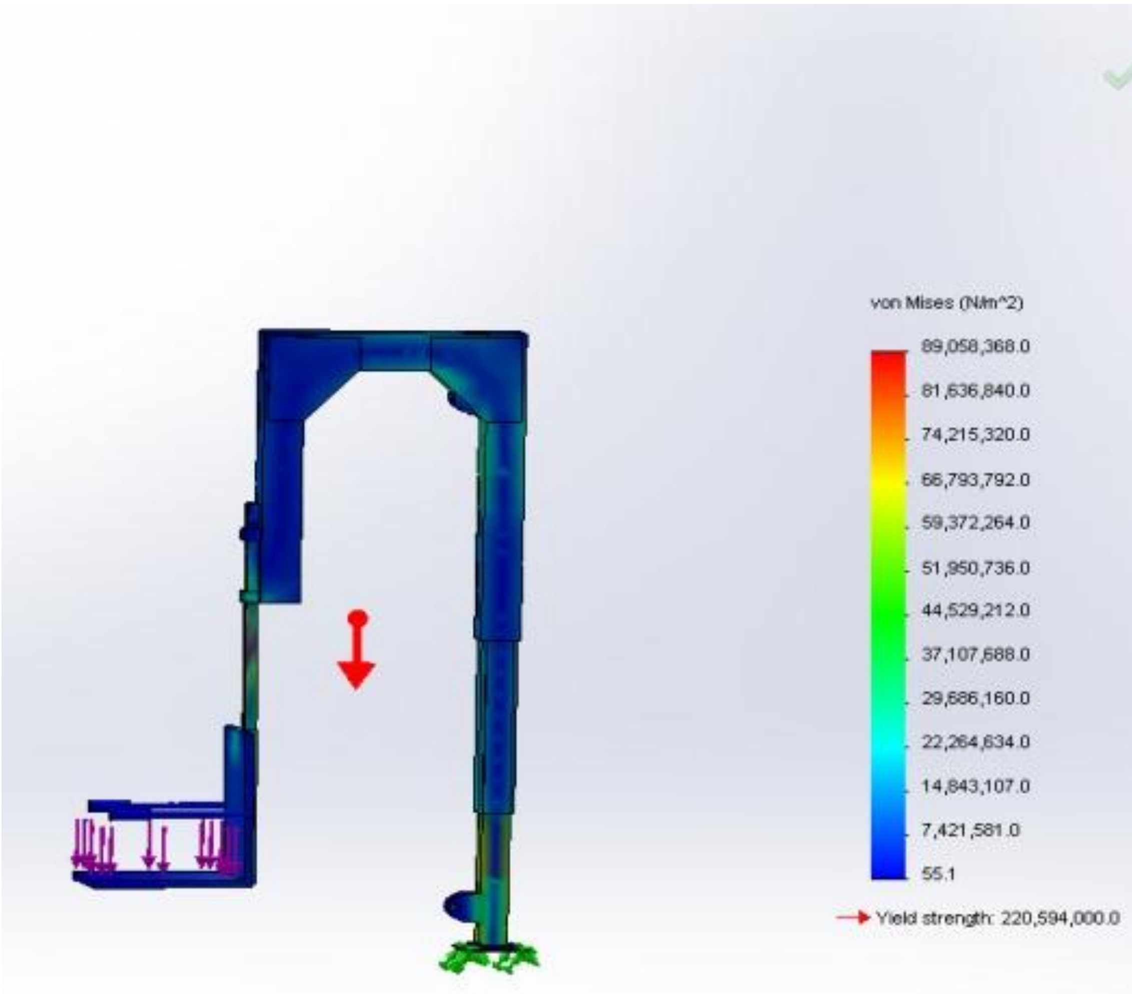


Figure 10: an example of the FEA performed on the lift

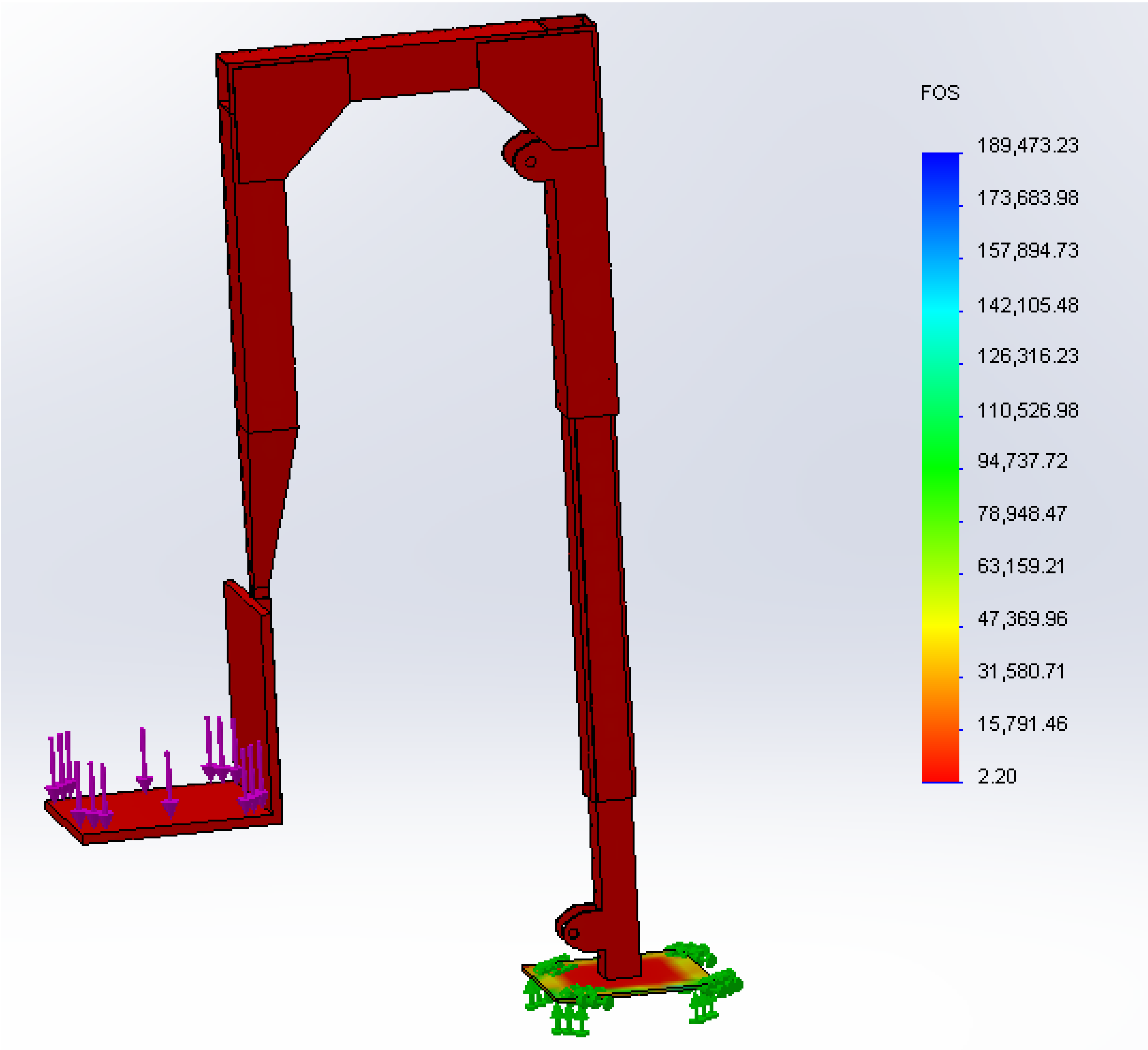


Figure 11: The FEA analysis showing factor of safety of 2.2.

Conclusions and Recommendations

The spa lift met all the PDS requirements. After reflecting on the final prototype, there are a few improvements that could be made on a future design. The PDS should have a defined weight limit for the lift. The current lift is heavy with a theoretical weight of 900 lbs. However, given its size, the lift is manageable. If a different material or lighter frame design could be incorporated into the current design, the user would be able to move the lift around easier. One suggestion to lighten the spa weight would be to reduce the mass of the arm. The current arm has more load capacity than required and could be reduced to lighten the weight.

Visual inspection of the arm after the paint was applied produced another future improvement. Due to metal on metal contact, the retracting seat post should have been made out of stainless steel. This would help with aesthetics because, even if it gets scratched during motion, there would be no paint to be rubbed or scraped off.

The following items will be given as recommendations to the SRC and IR departments to improve the current design:

1. The use of a plastic shell for aesthetics. This will also give additional surface area for any logos and graphical designs.
2. A more resilient coating instead of paint. Powder coating would be more resilient to continued use than paint. However, once powder coating is scratched off, it is hard to match the texturing on touch-ups.
3. Replace the plastic wheels with rubber wheels. This would be easier on the floor in the spa environment. However, it would increase the rolling resistance when the lift is being moved to the storage location.
4. Design and build a leg rest. Due to length constraints on custom linear actuators, the original equipment manufactured (OEM) seat could not be incorporated.

Appendix A

Detailed description of the design

The spa lift design can be distinguished in two part; mechanical and control design.

Mechanical design

The mechanical part consists of lift and cart assemblies (figure 12 and 18).

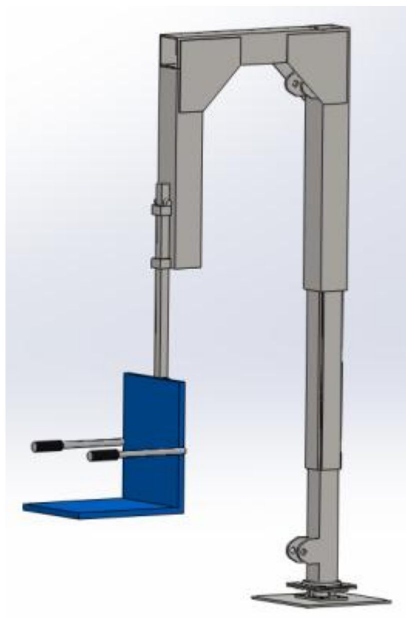


Figure 12 shows the Lift assembly

The lift assembly consists of the chair with arm rests (figure 13), the seat post (figure 14), the U-shaped arm (figure 15), the mast (figure 16), and various other parts. The chair is an OEM part and is the same as the current pool lift in the SRC. The seat post is square tubing with a cylindrical stop at the top. This is stops the seat post from detaching from the U-shaped arm. The U-shaped arm was designed to accept the telescoping seat post. The telescoping seat post was incorporated to decrease the overall height of the lift, enabling the lift to fit through a standard door frame. The U-Shaped consists of steel square tubing. The thickness was for visual awareness of strength. The front protrusions encapsulate the seat post allowing for a telescoping motion. The gussets were to increase rigidity in the junction points. Under the gussets, near the center post are the connection points for the linear actuator. The U-shaped arm pieces were welded together.

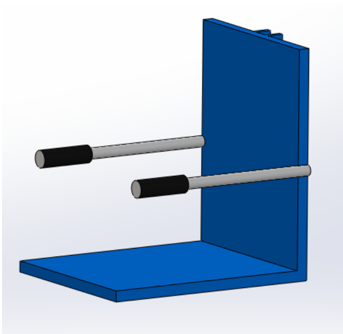


Figure 13: The OEM seat with armrests and holes for optional seat belts.

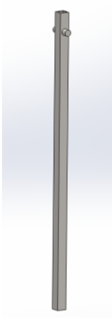


Figure 14: The seat post shows the cylindrical stop at the top.

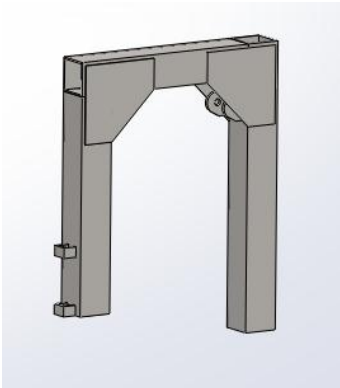


Figure 15: The U-shaped Arm was built for strength

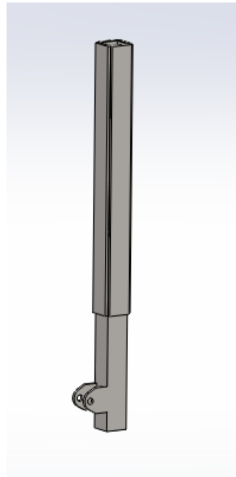


Figure 16: The mast assembly with connection points for the linear actuator

The mast and various parts conclude the lift assembly. The mast is steel square tubing surrounded by ABS plastic. The ABS plastic helps with friction during the lifting action. The connection points on the bottom are for the linear actuator. These points coincide with the connection points on the U-shaped arm. The various parts include the gear spacer, turntable adapter, and turntable seen in figure 16.

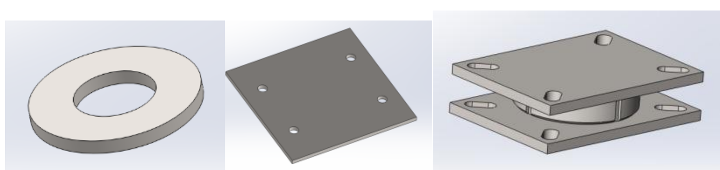


Figure 17: The gear spacer, turntable adapter, and turntable round out the lift assembly

The Cart Assembly

Figure 18: The full cart assembly

The cart in figure 18 is supported by four heavy duty wheels that can hold up to 2000 lb. More than 400lb of concrete was poured into the rectangular box on the cart to balance the spa lift. Two side arms in figure 19 also prevent the spa lift from tipping over when it is operated in rotational movement. Two side arms is connected to the cart frame by bolts and pins.

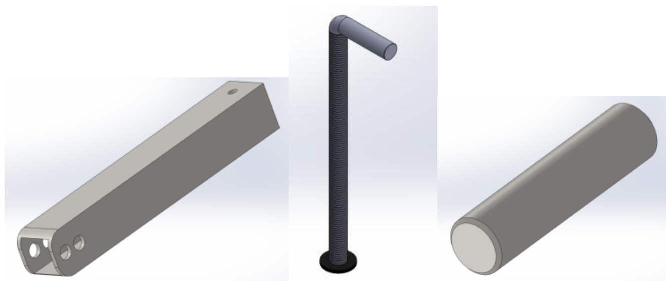


Figure 19: The side arms consist of arms, adjustment screw, and pins.

Control Design

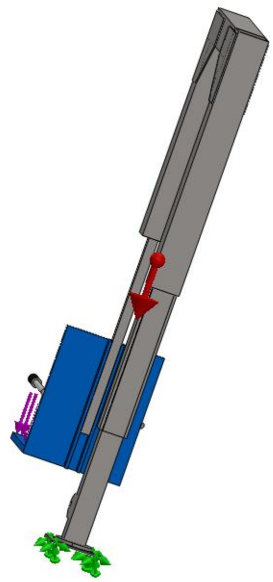
The control system consists of a linear actuator, rotary motor, control box, 24v rechargeable battery, and hand controller. All but the linear actuator are OEM parts from AquaCreek.

Linear actuator, from Progressive Motion, is inserted between the vertical arm and the mast. It lift the structure up and down. It is connected to control box and powered by 24v rechargeable battery. The rotary motor is installed right behind the mast on the cart. Through a belt system, it is connected to the turntable on which the whole lift assembly is constructed. The motor is also powered by the same battery and connected to the control box. The hand controller is a device that the end user order the movement to the spa lift. Our system has two degree of freedom so the end user can order up, down, left, and right.

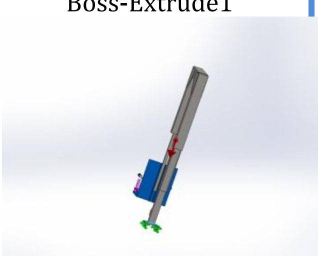
Control box is where all the input and output signals come in and out. A specific two degree of freedom program is installed in it. When it gets signals such as up, down, left or right from the end user, it will output a signal to a corresponding device so that the spa lift operates correct.

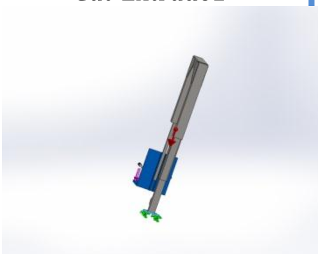
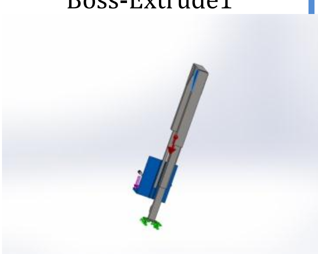
Appendix B

Model Information



Model name: Lift assembly
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:1.39067 kg Volume:0.000178291 m^3 Density:7800 kg/m^3 Weight:13.6285 N	C:\Users\Admin\Downloads\Dale's\Dale's\Gear spacer.SLDPRT May 14 13:41:54 2013

Cut-Extrude1 	Solid Body	Mass:1.80523 kg Volume:0.00023 144 m^3 Density:7800 kg/m^3 Weight:17.6913 N	C:\Users\Admin\Downloads\Dale's\Dale's\Gear .SLDPRT May 14 13:41:56 2013
Boss-Extrude1 	Solid Body	Mass:2.58235 kg Volume:0.00033 107 m^3 Density:7800 kg/m^3 Weight:25.307 N	C:\Users\Admin\Downloads\Dale's\Dale's\Guss et.SLDPRT Jun 09 16:11:59 2013
Boss-Extrude1 	Solid Body	Mass:2.58235 kg Volume:0.00033 107 m^3 Density:7800 kg/m^3 Weight:25.307 N	C:\Users\Admin\Downloads\Dale's\Dale's\Guss et.SLDPRT Jun 09 16:11:59 2013
Boss-Extrude1 	Solid Body	Mass:2.58235 kg Volume:0.00033 107 m^3 Density:7800 kg/m^3 Weight:25.307 N	C:\Users\Admin\Downloads\Dale's\Dale's\Guss et.SLDPRT Jun 09 16:11:59 2013
Boss-Extrude1 	Solid Body	Mass:2.58235 kg Volume:0.00033 107 m^3 Density:7800 kg/m^3 Weight:25.307 N	C:\Users\Admin\Downloads\Dale's\Dale's\Guss et.SLDPRT Jun 09 16:11:59 2013

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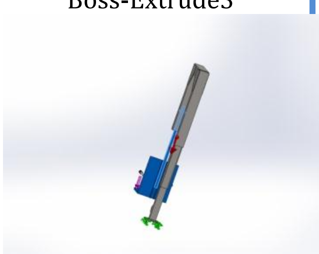
Boss-Extrude3 	Solid Body	Mass:5.98859 kg Volume:0.000767767 m^3 Density:7800 kg/m^3 Weight:58.6881 N	C:\Users\Admin\Downloads\Dale's\Dale's\Seat support2.SLDPRT Jun 08 01:00:18 2013
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Boss-Extrude1	Solid Body	Mass:9.3947 kg Volume:0.00120 445 m^3 Density:7800 kg/m^3 Weight:92.0681 N	C:\Users\Admin\Downloads\Dale's\Dale's\ABS plates.SLDPRT May 17 23:34:41 2013
Boss-Extrude1	Solid Body	Mass:9.3947 kg Volume:0.00120 445 m^3 Density:7800 kg/m^3 Weight:92.0681 N	C:\Users\Admin\Downloads\Dale's\Dale's\ABS plates.SLDPRT May 17 23:34:41 2013

Cut-Extrude2	Solid Body	Mass:26.5506 kg Volume:0.00340393 m^3 Density:7800 kg/m^3 Weight:260.196 N	C:\Users\Admin\Downloads\Dale's\Dale's\Vertical male shaft.SLDPRT May 14 13:41:52 2013

Study Properties

Study name	Study 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	Direct sparse solver
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	On
Compute free body forces	Off
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (C:\Users\Admin\Downloads\Dale's\Dale's)

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	Name: **Plain Carbon Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **2.20594e+008 N/m^2** Tensile strength: **3.99826e+008 N/m^2** Elastic modulus: **2.1e+011 N/m^2** Poisson's ratio: **0.28** Mass density: **7800 kg/m^3** Shear modulus: **7.9e+010 N/m^2** Thermal expansion coefficient: **1.3e-005 /Kelvin**	**SolidBody 1(Boss-Extrude1)(Gear spacer-2), SolidBody 1(Cut-Extrude1)(Gear-1), SolidBody 1(Boss-Extrude1)(Gusset-1), SolidBody 1(Boss-Extrude1)(Gusset-2), SolidBody 1(Boss-Extrude1)(Gusset-3), SolidBody 1(Boss-Extrude1)(Gusset-4), SolidBody 1(Boss-Extrude1)(Horizontal Arm-1), SolidBody 1(Cut-Extrude1)(Mast-1), SolidBody 1(Cut-Extrude1)(Seat Support-2), SolidBody 1(Boss-Extrude3)(Seat support2-1), SolidBody 1(Boss-Extrude3)(Seat-1), SolidBody 1(Cut-Extrude1)(armrest-1), SolidBody 1(Cut-Extrude1)(armrest-2), SolidBody 1(Boss-Extrude1)(interior shaft with abs-1/ABS plates-1), SolidBody 1(Boss-Extrude1)(interior shaft with abs-1/ABS plates-2), SolidBody 1(Boss-Extrude1)(interior shaft with abs-1/ABS plates-3), SolidBody 1(Boss-Extrude1)(interior shaft with abs-1/ABS plates-4), SolidBody 1(Cut-Extrude2)(interior shaft with abs-1/Vertical male shaft-1)**
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Loads and Fixtures

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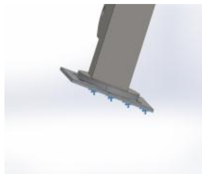
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
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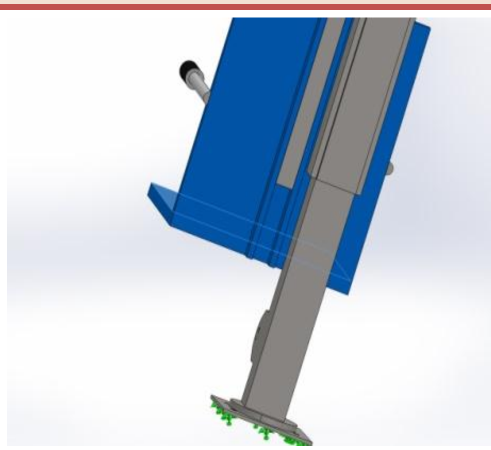
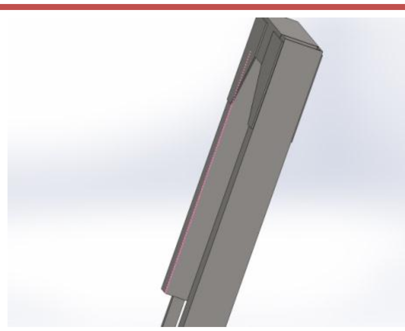
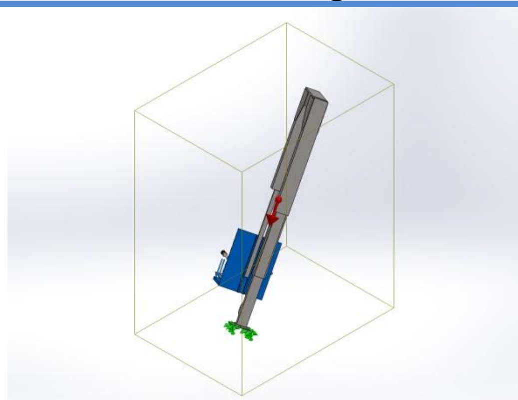
Reaction Moment(N-m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 450 lbf
Gravity-1		**Reference:** Edge< 1 > **Values:** 0 0 9.81 **Units:** SI

Contact Information

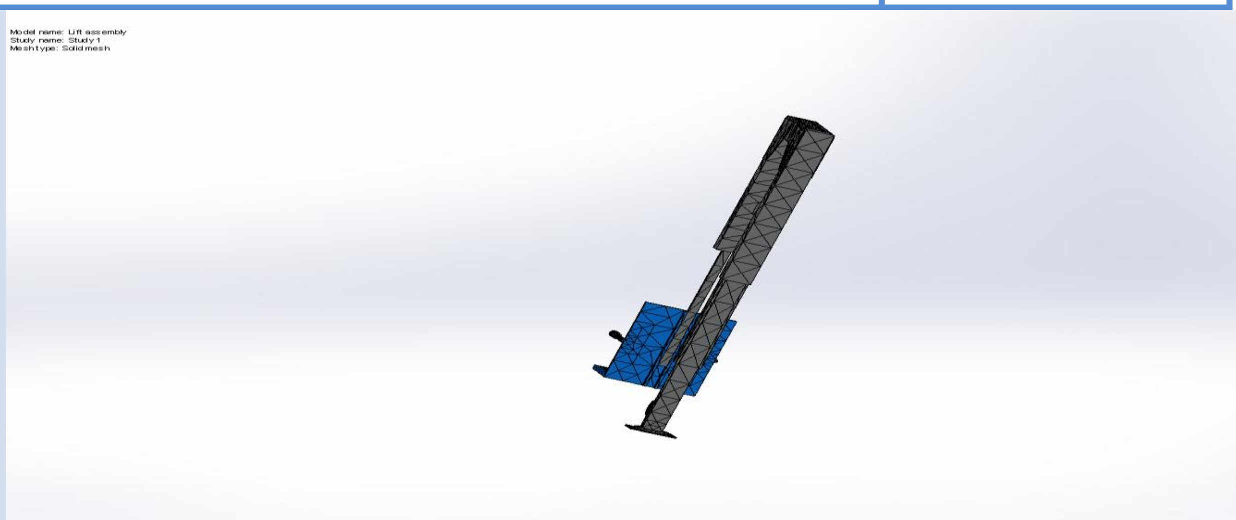
Contact	Contact Image	Contact Properties
Global Contact		**Type:** Bonded **Components:** 1 component(s) **Options:** Compatible mesh

Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	4.21634 in
Minimum element size	0.843268 in
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off

Mesh Information - Details

Total Nodes	12848
Total Elements	6567
Maximum Aspect Ratio	69.988
% of elements with Aspect Ratio < 3	33.3
% of elements with Aspect Ratio > 10	32.8
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	ADMIN-PC



Resultant Forces

Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-456.772	3527.26	-2500.78	4347.88

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N-m	0	0	0	0

Appendix C

Since the spa lift is operated on the cart but not fixed, a tipping over analysis must be done for the safety issue. The spa lift must withstand at least 450lb without tipping over while it is operated. The point of the analysis is to find maximum and minimum tipping over weights. If the minimum tipping over weight does not exceed 450lb, the team will reinforce the design. Putting counter weight and the extended arms on the cart can be a good solution. In order to find the maximum and minimum tipping over weight, the spa lift position in figure 20 and 21 will be analyzed.

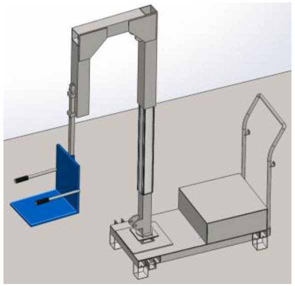


Figure 20: The lift in full extension.

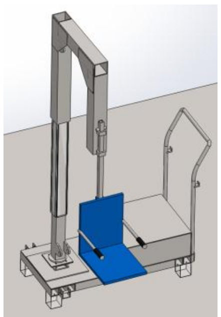


Figure 21: The lift in the loading position

The team expected it will tip over with 450lb load on the chair without a counter weight on the cart. To save some time for the analysis, the team put 450lb on the cart for the counterweight. It is a reasonable weight considering the max load on the chair is 450lb.

The spa lift position in figure 20 is expected to load more and in figure 21 less. It is very likely to tip over with 450lb on the chair. Both hand calculation and Solidworks motion study simulation showed negative results even though there is a counter weight on the cart. The spa lift could not withstand tipping over at 450lb in position in figure 21. Extended arms on the cart are needed to prevent the tip over.

Formulation Section

Given

For Figure 20

Weight of the spa lift : 750lb

The counter weight on the cart : 450lb

The distance between a center of mass and a tipping over line : 14.73in

The distance between the counterweight and the tipping over line : 37.75 in

The distance between the load and the tipping over line : 36.5in

For Figure 21

Weight of the spa lift : 750lb

The counter weight on the cart : 450lb

The distance between a center of mass and a tipping over line : 5in

The distance between the counterweight and the tipping over line : 10.5 in

The distance between the load and the tipping over line : 32in

Find

How much load can the spa lift withstand without tipping over in Fig.1 and Fig.2

Assumption

The wheels on the cart are square boxes.

The most of the material in the spa lift is plain carbon steel.

Static analysis

Slow loading of weight on the chair

Solution

For Figure 20

∑M=$(750 * 14.73) + (450 * 37.75) - (36.5 * x) = 0$

$$x = \frac{(750 * 14.73) + (450 * 37.75)}{36.5}$$

$x =$ 768lb

Theoretically, the spa lift can hold weight up to 768lb without tipping over. The Solidworks motion study simulation verified it with close range number of 705lb.

For Figure 21

∑M=$(750 * 5) + (450 * 10.5) - (32 * x) = 0$

$$x = \frac{(750 * 5) + (450 * 10.5)}{32}$$

$x =$ 264.84lb

Theoretically, the spa lift can hold wight up to 264.84lb without tipping over. This number is not acceptable so the team decided to attach extended arms so that it can support the cart. Counter weight is already 450lb so adding additional counter weight is not a good solution.