Optimal Design Report

Swimming Pool and Hot Tub Lift

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1.1 Introduction

Our client, Mr. Ronald Hiller, is a 56 year old adult male with Multiple Sclerosis (MS) who requires access to his backyard swimming pool and hot tub. Ronald has lost the ability to walk and uses a motorized wheelchair to navigate his house and backyard. His muscle coordination and strength have been severely diminished by MS. He has asked us to build a lift device for him so that he may be lifted up and over the rim of both his pool and hot tub. When he is done swimming, the lift will need to raise him from the water and return him to his wheelchair. The hot tub will use the exact same lift design, except it will lift him from a porch by his house directly to the hot tub adjacent to the porch. Flowchart 1 below depicts the likely sequence of events for our client using the lift system.

Flowchart 1 – Sequence of Events for Lift

The lift will be made of carbon steel and then sprayed with a stainless steel coating to make it resistant to weather corrosion. It will stand around 10 feet tall and be placed as close as possible to the pool/hot tub while also being adjacent to their respective porches. It will sit on a large concrete base for stability, and extend upward 8 feet until it reaches a nylon bearing that will allow the remaining 2 feet of steel shaft to rotate. This will allow the boom to swing over the water. There will be a locking mechanism for the rotating shaft so that it can lock in place while Ron gets into and off of the lift. An electric winch system and a series of pulleys extending up the cylindrical shaft and over the boom will be responsible for raising and lowering Mr. Hiller in the vertical direction. The mesh chair that will hang off of the end of the boom will be detachable. This will allow Ron to place it on the seat of his wheelchair and sit on top of it when he gets ready to go outside. Once at the pool, the chair can be attached to the boom and Ron will not have to try to navigate into the chair. After swimming, it will be easy to get into from the water, and then he can be raised and placed back into his wheelchair. Figure 1 below shows the lift in its entirety. The mesh chair is not depicted, but will hang down from the end of the boom.
This design was chosen as the optimal design over the other alternative designs for safety and economic reasons. It is better to have the point of rotation as close to the top as possible so that the bearing will be moving the minimum weight possible. This design is much more safe than a design that rotates at the bottom of the lift, and will also be easier to access if maintenance ever needs to be done with the bearing or the rotation shaft. For example, if more lubricant was needed, or if the bearing eventually wore out, it would be simpler to remove just the boom and rotating shaft.

Economically, this design also lowered the cost of materials by rotating near the top because the stationary shaft that acts as the axis of rotation doesn’t need to be very long. If rotation occurred at the bottom of the lift, this stationary shaft would need to extend relatively far up into the lift and wouldn’t provide any extra benefit for the extra cost. Another alternative design suggested having the lift go through the porch, but this would cost large amounts of money to have the porch torn apart and then put back together around the lift. The only extra benefit would be that the porch would provide extra stabilization for the lift, but our optimal design has a huge concrete base (weighing 4,400 lbs) so it should already be very stable.
1.2 Subunits

The lift was broken down into two subunits: a mechanical frame subunit and lifting mechanism subunit.

1.2.1 Lift Frame

1.2.1.1 Concrete Base

In order to secure the lift into the ground a cement block will be laid into the ground. The dimensions of this block will be 36x36 (in) (.9144m x .9144m) on the top and 42 (in) (1.066m) deep as seen in Fig. 1 above. State law mandates that any support pylon must go at least 42 inches into the ground in order to avoid damage from permafrost. The block of cement is a simple part but requires a lot of work to create. First, either through a contractor or backhoe rental a 42 inch hole must be dug out. In order to make this hole, 1.7 cubic yards (1.299 cubic meters) of dirt must be removed and then filled with an equal amount of concrete. This will be the support to keep the weight of the lift with Ron from sinking into the ground as well as preventing the torsion from pulling the lift out of the ground and flipping. While the cement is still wet there will be four j-hooks placed near the corners. This will allow the metal plate to be attached to the cement at any time, even months later.

In order to lay the concrete base the volume of concrete needed needs to be removed from the ground. In order to remove this must dirt that deep a power tool is needed. Either a backhoe or pylon digger will be required. In order to safely do this a contractor will most likely be needed. Due to the state requirements even if the width and length of the block was made smaller there still needs to be power tools to dig that deep. Another factor to consider is that we will be placing a perfectly flat sheet of metal on top of this block of concrete. This means that in order for our lift to be perfectly upright the top of the cement block needs to be flat and not at an angle. An experienced hand will make this much easier. An online calculator determined that we will need 55, 80 pound bags of concrete. This will cost approximately 5 dollars per bag and with two holes we need 110 bags which will cost 550 dollars not including transport.
1.2.1.2 Metal Plate

In order to connect the shaft to the cement we will be using a metal plate. The main reason we don’t just place the shaft into the cement is that by using this system we can build the lift in the lab and then attach it to the cement using j-hooks. All that needs to be done on site now is put the cement into the ground and insert the j-hooks. This can then sit there until we have assembled the lift. Doing it the other way would require us to insert the shaft into the cement which includes welding more parts together now. This design will also allow us to change what happens above ground instead of being stuck with one design. The metal plate will have four holes drilled in it which are aligned with j-hooks that will be placed in the wet cement. The j-hooks will be bolted down and maybe even welded down to the metal plate in order to secure the base. The metal plate will be a quarter inch thick. The dimensions will be 36x36 (inch) (.9144m x .9144m) to match the concrete support and can be seen in Fig. 2 above. In the machine shop the plate will be welded to the shaft as well as the supports. This combined piece can be placed on the cement at any time. The plate will be coated like the rest of the lift with weather and rust resistant paint.

The density of the carbon steel is .2826 lb/in$^3$ (7.91g/cm$^3$). The volume of this piece of metal is 324 in$^3$ (5309.4 cm$^3$). The weight of this component is 91 lbs. (41.27 kg). The weight of the shaft is also going to be included in the weight we need to move because they will be welded together.
1.2.1.3 Long Main Shaft

The largest piece of metal in this assembly will be the shaft, which will give the lift most of its height and strength. The metal being used in carbon steel. The dimensions of the tube are 8 ft long with circular dimensions of 4x3.5x.25 inches. Where 4 inches is the outer radius, 3.5 in. is the inner radius, and .25 in. is the wall thickness. The bottom of the shaft will be welded to the metal plate at the machine shop as can be seen in Fig. 3 above. The cost of this part without shipping is 275 dollars. The weld to the metal plate is an important point of strength but there will be support beams to help with the torsional strain. At the top of the shaft there will be a smaller metal tube inserted to deal with the rotational aspect of the lift as well as a bearing sitting on the top ring edge of the shaft. With the weld at the bottom and this up top no water should be able to get into the shaft. The outside will be coated like the rest of the lift with a weather and rust proof paint.

The density of the carbon steel is .2826 lb/in$^3$ (7.91g/cm$^3$). The volume of this piece of metal is 282.7 in$^3$ (4632.6 cm$^3$). The weight of this piece will be 80 lbs. (36.23 kg). Combined with the steel plate these two parts will weigh 170 lbs. (77.11 kg). The surface area of this shaft is 100 in$^2$ which needs to be coated once all the welds are in place.

Figure 3: Solidworks Diagram of the Concrete Base + Metal Sheet + Shaft
1.2.1.4 Support Legs

![Solidworks Diagram of the Concrete Base + Metal Sheet + Shaft + Support Beams](image)

In order to stabilize the lift from torsional strains encountered when Ron uses the lift there will be two (at minimum maybe 3 if we chose to allow the lift to rotate more than 90 degrees) support shafts welded to both the base and the shaft. The horizontal view of the shaft looks like a trapezoid. The shafts will be 23 inches long on the bottom, 26 inches on the top (2 inches off on the shaft side and 1 inch off on the plate side), 1 inch wide, and 1 inch thick and a solid piece of carbon steel. The end being welded to the shaft will be angled at 26 degrees (to the bottom) and the end being welded to the plate will be angled at 64 degrees (to the bottom) as seen in Fig. 4 above. This will allow a flat contact between the supports and both the shaft and plate. The supports will be placed facing the pool. The reason for this is when Ron is in the chair for the lift; his weight being applied at the end of the boom will tend to rotate the lift towards the pool. In order to counteract this, the supports will need to be facing the correct direction. The supports as well as the weld between the shaft and plate will be the resistance to rotation.

The density of the carbon steel is .2826 lb/in$^3$ (7.91g/cm$^3$). The volume for these pieces of metal is 51.27 in$^3$ (840.16 cm$^3$). The weight of each support is 14.45 pounds (6.55 kg).
1.2.1.5 Nylon Bearing:

The bearing is a critical component of the lift system. It provides the axial rotation necessary for the top 2 feet of the lift and the boom to swing out over the pool and back again. It is placed on top of the 8 foot stationary shaft and directly underneath the upper 2 foot rotating shaft as shown in Figure 5 above. It has an outer diameter of 4 inches (10.16 cm), and an inner diameter of 3.5 inches (8.89 cm), which makes the bearing a ¼ inch thick ring. It is a ½ inch (1.27 cm) in height, but will compress slightly once the rotating shaft is placed on top of it. Its uncompressed volume is 1.47 cubic inches. The type of nylon is NSM nylon. This product has solid lubricant additives that give it superior wear resistance, causing it to last up to ten times longer than standard Type 6 nylon. NSM nylon has an approximate density of 0.04155 lbs per cubic inch, and therefore the bearing weighs about 0.0611 lbs. It has a compressive strength of 14,000 PSI for 10% deflection, and the bearing itself has a top surface area of 2.95 inches squared [2,3]. Therefore the total compression of the nylon bearing shouldn’t be more than 1/20 of an inch. Since this number is so tiny in comparison to the height of the 120 inch (3.05 meter) lift, the compression of the nylon bearing is not subtracted from the total height.

1.2.1.6 Short Stationary Shaft
The short stationary shaft is essential as a support for the rotation, and also acts as the axis of rotation for the upper section of the lift. The placement of this shaft can be seen in Figure 6 above. The outer rotating shaft as well as the boom and other upper components have been removed from the figure so that the inner stationary shaft may actually be seen. This shaft also extends about six inches into the large hollow shaft that is below the bearing. It is positioned this way in order to provide a strong support for the rotation of the boom around it. It will be welded in to the large hollow shaft below to firmly secure the pieces together, causing them more evenly distribute weight from the boom.

This short shaft has a 3.5 inch (8.89 cm) outer diameter, a 3.0 inch (7.62 cm) inner diameter, and is 24 inches (60.96 cm) tall. These dimensions give it a volume of 61.26 cubic inches. This short stationary shaft is made of carbon steel, which has a density of 7.84 grams/ cubic centimeter, which converts to 0.2826 pounds per cubic inch. Therefore, using the volume of the shaft multiplied by its density, the stationary shaft weighs 17.312 pounds (lbs). [1] This weight will be distributed directly down onto the long hollow shaft and base plate underneath that. A lubricant may be placed on the outside of this cylinder where it comes into contact with the rotating shaft in order to ease friction and give an overall easier glide from one position to the next.

1.2.1.7 Short Rotating Shaft
This short rotating outer shaft is also essential for rotation purposes. It rotates around the short stationary inner shaft, and the boom is attached to the very top of it so that it rotates when the shaft rotates. The placement of the shaft can be seen in Figure 7 above. It is directly under the end corner of the boom and directly on top of the bearing, with the short stationary shaft inside of it. The lower end of the boom support attaches to this shaft at the bottom of it, directly above the bearing as seen in Figure 7 above. The boom as well as the boom support will be welded to this rotating shaft so as to provide the most secure connection possible.

This short shaft has a 4 inch (10.16 cm) outer diameter, a 3.5 inch (8.89 cm) inner diameter, and is 24 inches (60.96 cm) tall. These dimensions give it a volume of 70.8 cubic inches. This short stationary shaft is made of carbon steel, which has a density of 7.84 grams/ cubic centimeter, which converts to 0.2826 pounds per cubic inch. Therefore, using the volume of the shaft multiplied by its density, the stationary shaft weighs 20.008 pounds (lbs). This weight will be distributed directly down onto the bearing underneath it, and then onto the long hollow shaft and base plate underneath the bearing.
1.2.1.8 Boom

The boom, also made out of carbon steel, is another essential piece of the chair lift. The boom supports the client being lifted and lowered into the pool. The boom also extends the client’s position to be over the pool. On one end of the boom, the shaft is welded onto the bottom side of that end of the boom. The other end has a single fixed pulley attached to it. A winch is also attached to the top of the boom, located at the middle of the boom.

The boom is a square hallow carbon steel tube. The tube is $\frac{1}{4}$ inch (0.635 cm) thick. The ends of the tube are welded shut by $\frac{1}{4}$ inch (0.635 cm) thick carbon steel plates. The boom has a length of 60 inches (152.4 cm), a width of 4 inches (10.16 cm), and a height of 4 inches (10.16 cm) as can be seen in Fig. 8 above. The volume of the boom is calculated to be $231.125 \text{ in}^3$ (3787.46 cm$^3$). With the carbon steel density to be 0.2826 lbs/in$^3$ (7.845 g/cm$^3$), the weight of the boom is calculated to be 65.32 lbs (29.6 kg). This weight along with the weight of the chair and the client is supported by the cylindrical shaft and the boom support.
1.2.1.9 Boom Support

The boom support, made out of carbon steel, is one of the most essential parts of the chair lift. It supports the boom and helps secure the boom in place. The boom support also alleviates the heavy forces acting on the boom when the client is being lifted or lowered into the pool.

The boom support is a solid trapezoidal prism. One end is angled at 23.2 degrees and the other at 66.9 degrees. The long base of the trapezoid side has a length of 60.9 inches (154.686 cm). The short base of the trapezoid has a length of 58.14 inches (147.676 cm). The boom support has a width of 2.0 inches (5.08 cm) and a height of 1.0 inch (2.54 cm) as seen in Fig. 9 above. By using these measurements the volume of the entire boom support is calculated to 119.042 in$^3$ (1950.75 cm$^3$). The density of carbon steel is 0.2826 lbs/in$^3$ (7.845 g/cm$^3$) so the weight of the boom support comes out to 33.64 lbs (15.3 kg).

The boom support has two faces of unequal value in length. The face at the 23.2 degree angle has a length of 2.54 inches (6.45 cm) and the face at the 66.9 degree angle has a length of 1.09 inches (2.77 cm). The face with the length of 2.54 inches (6.45 cm) connects with the free side of the boom while the face with the length of 1.09 inches connects to the shaft just above the nylon bearing.
1.2.1.10 Hand Rotation Shaft

The hand rotation shaft is an essential part of the chair lift. It allows the user to rotate the chair lift around the nylon bearing. By rotating the chair lift around the nylon bearing using the hand rotation shaft, the user helps the client be situated above the pool by using the rotation shaft to rotate the boom from being situated above the ground to being over the pool when the client needs to get into the water. When the client needs to get out of the water, the user uses the rotation shaft to rotate the boom from being situated above the water to being situated over the ground. One end of the rotation shaft attaches to the side of the boom where the boom connects with the cylindrical shaft. The rotation shaft also connects the side of the boom directly adjacent to that cylindrical shaft/boom connection. The other end of the rotation boom is free. The figure can be seen in Fig. 10 above.

The hand rotation shaft is a solid carbon steel rectangular prism. The prism has a height of 2 inches (5.08 cm), a width of 2 inches (5.08 cm), and a length of 24 inches (60.96 cm). The volume is calculated to be 96 in$^3$ (1573.16 cm$^3$). With the density of carbon steel to be 0.2826 lbs/in$^3$ (7.845 g/cm$^3$), the weight of the shaft is calculated to be 27.13 lbs (12.3 kg).
The hand arc is an important piece of the chair lift. This piece completes the rotational mechanism along with the hand rotation shaft. Both the hand arc and hand rotation shaft help assist in rotating the boom between situating over the water or over the ground. The hand arc also keeps the hand rotation shaft in place and helps relieve some stress on the rotation shaft. The arc connects at one end to the rotation shaft while the other end attaches to the boom as seen in Fig. 11 above.

The hand arc is a solid carbon steel arc. The radii of the arc are 20 inches (50.8 cm) from the inner arc and 20.5 inches (52.07 cm) from the outer arc. The angle which the arc traces out is 90 degrees. Therefore the inner arc length is calculated at 31.42 inches (79.81 cm) and 32.2 inches (81.79 cm). The height of the hand arc is 2 inches (5.08 cm) and from observing the difference between the two radii, the width of the arc is 0.5 inches (1.27 cm). Therefore the volume of the hand arc is calculated to be 31.81 in$^3$ (521.27 cm$^3$). With the density of carbon steel to be 0.2826 lbs/in$^3$ (7.845 g/cm$^3$), the weight of the arc is 8.99 lbs (4.08 kg).
1.2.2 Lifting Mechanism Subunit
1.2.2.1 Winch

In order to lift Ron from his wheelchair into the pool we will be using an electrical lift. The lift we have chosen has a 2000 Lb. pulling capacity. The winch requires 12 volts. In order to supply the power wiring from the pool electronics can be used. The winch will be attached to the boom of the lift or the shaft, either way pulleys will be used to run the cable over the end of the boom to allow for straight up and down motion. The winch is water proof so there is no need for housing the winch itself. There is a need to secure the winch to the lift. In order to attach the winch supports will be welded to the shaft and the winch will be bolted to these supports. The winch comes with an installation kit which can be attached to ATVs or cars which is why the supports are needed to modify the lift to allow a safe and strong attachment. The winch has controls with long wires which will need some form of housing to keep them dry and accessible to Ron. The controls will need housings on both the deck in order to allow access to the controls depending on where he is. The winch is rated to move at 6 feet per minute which is slow enough to be safe.

The dimensions of the winch are: 12 x 3 x 4 inches. It weighs 10 lbs. and the cable in the winch can either be metal or synthetic nylon. The nylon costs more but it is less likely to get kinks and has better water resistance values for both weather and being in the chlorinated pool.
1.2.2.2 Pulleys

The pulley is lightweight, 4 inches (100mm) diameter deep groove aluminum sheave, with stainless steel plates. The minimum break strength is 10,000 lbs (44 kN) and it weighs 2.5 lbs (1.13 kg).

The pulley is attached to the free end of the boom at the top corner as in Figure 14 above. It is positioned there because the rope would not get caught at the corner of the boom which would cause some damage to the rope and the boom as well as cause unnecessary friction as the winch moves the chair up and down. By putting a pulley at the corner removes that friction and damage. The position of the pulley can be seen in Figure 13 above.

The pulley set up for the chair lift is a single fixed pulley system in order to change the direction of the force applied to the chair from the winch. With this setup, the winch must apply a force equal or greater the weight of the client and the chair, which is about 300 lbs (1320 N). Since the pulley can handle up to 10,000 lbs (44 kN) and the winch can pull up 2000 lbs (8800 N), this pulley system is perfect for the chair lift.
1.2.2.3 Seat

The seat for the lift is an important factor contributing to durability, ease of use, and comfortability of the pool and hot tub lifts. The chair used will be an AliMed Full Body Seat Sling, model number 78251, shown below. AliMed, Inc is a medical supply company based in Dedham, Ma.

Because Ron Hiller is not a particularly small man, a size large seat will be used. Its dimensions are 47- ¾” wide by 58- 1/4” long. The seat has a weight capacity of 450 pounds, which will more than account for the weight of Ron Hiller, which is 250 pounds. The 450 pound weight capacity will also allow for the extra weight that will be added to the seat and Mr. Hiller when both are soaked with water from the pool, which will add a significant amount of weight.

Figure 15. AliMed Full Body Seat Sling

The Full Body Sling Seat is lightweight and mesh, which will make the lift more water compatible because of its quick drying ability. By not holding water for a long period of time, the seat will be more durable and have a longer product life. The seat also features a head rest that will be more comfortable for Mr. Hiller and will give better stability as the lift is in motion. This stability will be a good safety feature for the lift by eliminating the possibility of whiplash while the lift is raised, lowered, or rotated.

The seat has four chains on each corner that are used to connect the seat to the lift. Because the seat will be detachable, Mr. Hiller will be able to slide the seat under himself while still seated in the wheelchair and then connect the seat to the lift. This will also allow only one seat to be needed for both lifts. This will cut the budget for the seat in half as opposed to a permanently attached chair or rigid seat that is featured in many other pool lifts. The two chains on the left will be connected using one carabiner while the two chains on the right will be connected using a second carabiner.

The cost of the mesh seat is $94.50 with a shipping and handling charge of $13.49. This gives a total budget for the seat of $107.99. AliMed guarantees shipping within the next business day by way of FedEx or UPS. Shipment is also insured against loss or damage.

1.2.2.4 Carabiners

The carabiners mentioned above will be Black Diamond Quicksilver2 Screwgate Carabiners, shown in fig # below. The carabiners will be purchased from REI, which is
an outdoors sports and camping store chain. The carabiners have item #710222 on REI.com.

![Black Diamond Quicksilver2 Screwgate Carabiner](image)

**Figure 16. Black Diamond Quicksilver2 Screwgate Carabiner**

The carabiner has a weight of 56 grams, or 0.12 lbs., so the weight for each carabiner is essentially negligible on the lift. When the screw gate is closed, the carabiner has a strength of 25 kN, or 5620 lbs. Thus, the carabiners will be strong enough to lift a 250 pound man. The gate has an open clearance of 17 mm. The screwgate is a safety feature that allows the carabiner to lock into the chains on the seat without the chance that the chains would become unhooked while the lift is in operation.

Both carabiners can then be hooked onto the cable of the winch for lifting, rotating, and lowering. They can then be easily released once in the pool or wheelchair. The screwgate is user friendly because it is easy to twist, but dependable to not become open during use. Even if by some small chance the carabiner does open, it has an open gate strength of 8 kN, or 1798 lbs, so accidental opening would not cause failure of the seat or lift.

This carabiner was chosen because it has a locking screwgate, user reviews all recommended the use, and they are inexpensive. Each carabiner costs $7.95, and two carabiners will be required. Shipping costs $5.99. The total cost will be $21.89. Cost of shipping can be eliminated if the carabiners are ordered to a specific store location and picked up. That would give a total cost of $15.90.

### 1.2.3 Analysis

To analyze the beam, it will need to be considered as a truss. Since the mass of the truss can’t be considered insignificant compared to the forces acting on it, half of the weight of each beam can be applied on the two end joints [4]. Therefore the diagram of the truss with the forces acting on it would look like Figure 17 below.
Beam AC represents the rotating shaft, beam AB represents the boom, and beam BC represents the boom support of the lift. Since the rotating shaft (beam AC) is fixed in the truss example, the weight on this axis doesn’t need to be considered in calculations. Therefore the total weight hanging off of the end of the beam at point B can be calculated by equation 1 below. The total weight was found to be 350 lbs (1.56 kN).

\[
Total \ Weight = 300 \ lbs + 0.5 \times W_{Boom} + 0.5 \times W_{Boom \ Support} \quad [1]
\]

\[
= 300 \ lbs + 0.5 \times 65.32 \ lbs + 0.5 \times 33.64 \ lbs \approx 350 \ lbs
\]

Then the sum of the forces can be taken in the x and y directions as seen in equations 2 and 3 below. All force references can be found in Figure 17.

\[
\sum F_x = 0 = R_{Ax} + R_{Cx} \quad [2]
\]

\[
\sum F_y = 0 = R_{Ay} + R_{Cy} - 350 \ lbs \quad [3]
\]

All reaction forces are still unknown at this point, so the sum of the moments at point A is taken in equation 4 below. The x-direction reaction force at point C is found directly, and the x-direction reaction force at point C is found using equation 2 above.

\[
\sum M_A = 0 = 58 \ in \times 350 \ lbs - R_{Cx} \times 24 \ in \quad [4]
\]

\[
Therefore \rightarrow R_{Cx} = 845.83 \ lbs \quad and \quad R_{Ax} = -845.83 \ lbs
\]
With the use of force triangles, it was possible to determine the force experienced by each member of the truss. It was also possible to find the reaction forces in the y-direction. Figure 18 below shows the force triangle used to solve for $F_{BC}$ and $F_{AB}$. The angles were found by using trigonometry and the lengths given in Figure 17 above.

![Force Triangle for Truss](image)

**Figure 18: Force Triangle for Truss**

From this force triangle, $F_{AB}$ and $F_{BC}$ are found using equations 5 and 6 below.

$$F_{AB} = 350 \text{ lbs} \times \tan(67.52^\circ) = 845.81 \text{ lbs} \quad [5]$$

$$F_{BC} = \frac{\cos(67.52^\circ)}{350} = 915.37 \text{ lbs} \quad [6]$$

Therefore, the force in the boom member of the truss ($F_{AB}$) is 845.81 lbs (3.76 kN). The boom is in tension, so therefore the boom experiences 845.81 lbs of tensile force. The force in the boom support of the truss ($F_{BC}$) is 915.37 lbs (4.07 kN) and is in compression. Hence the boom support experiences 915.317 lbs of compressive force.

Knowing this, the sum of the y-direction forces can be taken Point C (as seen in Figure 10 above). The sum of the forces equation at Point C is:

$$\sum F_y = 0 = R_{Cy} - F_{BC} \times \cos(67.52^\circ) \quad [7]$$

Substituting in the value for $F_{BC}$ yields:

$$R_{Cy} = 350 \text{ lbs}$$

Therefore, using equation 2 from above:

$$R_{Ay} = 0 \text{ lbs}$$

All of the reaction forces are now known, but the forces that the boom and boom support experience are the most important. They can be compared to the tensile and yield strength in order to determine if the lift will collapse. The tensile strength of the steel is 75,129 psi (518 MPa) and the yield strength is 51,241 psi (353.3 MPa).
2 Realistic Constraints

2.1 Engineering Standards
For the construction of the lifts, all of the standards for building and safety such as patents and state regulations had to be taken into consideration. When digging for cement placement, the composition of the land beneath and angles of the terrain must all be incorporated. When considering ramp construction, state regulations for measurements must be followed or the ramp will be deemed a violation, preventing it from use. More specifically, for engineering purposes, all of the designs and any sketches had to be documented. Several values were obtained from calculations, lengths, weight angles and materials which were all recorded for future reference and verifications.

2.2 Economic
With regards to funding, the price that the lift designed will likely cost far surpasses the amount we will be allotted. This creates a bit of an issue because we have planned to build beyond our means. Essentially, we had to and still need to make some alterations to our design to incorporate cheaper parts or cut out non-essential ones. For example, we did not have money to build the ramp so we had to build from the ground up, adding on our own height with a platform. Tasks such as digging holes, movement of the hot tub and so on is beyond our capabilities, so outside help with costs may be needed. The cost for the cement, tubing, coatings, pulleys, the seat and other components must all be added up and accounted for. This is excluding the very possible occurrence of malfunction of parts during testing or any error which could require an increase in spending.

2.3 Environmental
For the most part, our project is not really of concern for environmental considerations. The lifts will be electric so we are not really using anything harmful to the environment. As for the materials used, we want those which can extend the lifetime of the lift but will not bring any harm to its surroundings. We will be using a mesh seat, steel coatings, a cement base, pulleys and carbon steel tubing which are all environmentally friendly. We also need to take into consideration weather conditions while trying to create these lifts. Building year round is not permissive for outside work, due to rain, snow and just extremely low temperatures which could damage parts and make digging and cement lying very challenging. The bottom part of the lift, which will be submerged in the ground, is composed of cement and must be laid before the ground becomes frosted and the soil hardens, making it difficult to dig through the permafrost layer to create holes for cement base.

2.4 Sustainability
In building the lifts, we have incorporated materials which can hold up through various weather conditions, water damage, weight and so on. Since these lifts are for a pool and hot tub, they will be exposed to a great deal of water containing chlorine. Chlorine is a strong chemical which can easily break down the durability and quality of materials if the wrong one is applied. Keeping this in mind, we have decided to use a mesh seat which will hold up and allow the water to pass through with ease. The choice of steel coating and carbon steel tubing for the rest creates a durable and resistant device which will hold up while outside. The real stability of the lifts will come from the 36 in. x 36 in. x 42 in. cement base which will be placed inside the ground. This cement base is where the actual lift will be anchored which creates a great strength for the weight the lift will have to sustain.
2.5 Manufacturability

Time and resources, or capabilities are the major manufacturing issues for the lifts. In order to complete certain parts, assistance will be needed. The timing factor is important because the process of building lifts which can hold up under the conditions we desire takes time and attention. The material and money we have to work with is a determinant in the way we must go about building the lift. Ideally, we would use all of the best materials used, but due to limitation of funding we must choose wisely. Often times, the same job and a functional safe device is possible without spending a ton of money which is what we are trying to accomplish. We want to create a cement bottom which will need to be laid down prior to building the rest of the lift so that needs to be planned out and set in place in a timely fashion. Welding of the materials will need to occur at every joint, or connection of metals, on the device. This is also something that needs to be completed in timely and orderly manner. This welding needs to occur in the machine shop which creates restraints on time and place of the construction.

2.6 Health and Safety

A device that does not create health or safety hazards for Ronald Hiller is crucial and steps of prevention must be integrated into the design of the lifts. One concern is ensuring the equipment remains sterile at all times, even when exposed to the harsh outside air. The metal will likely be resistant and hold up through any change in weather and moisture, so that is not a major issue. The seat however, will be exposed to water and moist conditions which can leave room for microbial growth. The chlorine in the pool and hot tub acts as a disinfectant, killing off bacteria when the seat is exposed to it. However, health conditions when the seat is not in the water must be considered. The device must be able to handle the stress and strains which it will be placed under. Since our client is a relatively heavy man, the seat and lift need to be able to hold him securely and without risk. This will require testing to take place to ensure stability and strength. We will use materials and such that will last through these conditions, but actual thorough testing cannot occur until the construction is completed. The seat must be attached in a manner which does not run the risk of falling off or breaking, causing injuries. The lift itself must be secure because running the risk of failure is a factor we want to minimize. Also, we must make sure the lift does not swing uncontrollably and at dangerous angles so no falling of the client or damages to the device will occur.

3 Safety Issues

Several safety issues play a role in the construction and entire operation of the lifts.

3.1 Electrical

Failure of the winch is a definite electrical concern. If the winch fails, we need to make sure that our client will not be dropped uncontrollably, which could cause extreme injuries or even death. Another addition would be a safety stop to ensure that the winch, if failure occurs, would eventually stop going up.

3.2 Mechanical

The mechanical safety concerns for the lifts include the rotation of the lift and the attached seat. If the bearing runs out, uncontrollable movement may occur. Without proper lubrication, the opposite could occur and the lift could become stuck and malfunction.
3.3 Biological Hazards
Water diffusion into the components of the lift could potentially create algae buildup, which would eventually need to be tended to. A simple algicide from a pool store could be used to remove this possible growth.

3.4 Decontaminations
The steel coating and carbon steel will not need to be decontaminated. The seat however, will need to be safe of germs and bacteria. During cold weather when the seat is not in the water, bacterial growth is not as likely to happen because of the weather. However, in the hot and moist conditions of the summer, decontamination must be considered. With the chlorine in the water, each time the seat is submerged it will be disinfected. However, regular cleaning is essential and will prevent any growth when not in use.

3.5 Chemical hazards
The chlorine in the water of the pool and the hot tub, although a great disinfectant, could also potentially cause corrosion of the seat and parts. The material of the seat and the steel coating of the lift itself cannot guarantee that no damage will occur. However, using the materials we have chosen will increase resistance and create a longer lasting device.

3.6 Radiation
The pool and hot tub outside will be under great heat exposure from the sun. The UV radiations could be of concern because it could potentially degrade the bearings and welding. Since UV radiation does not affect anything other than surfaces, internal damage will not be of concern.

4. Impact of Engineering Solutions

These two lifts will greatly impact the life of Ronald Hiller and the people he enjoys spending time with. Mr. Hiller’s Multiple Sclerosis has advanced enough to confine him to a wheelchair, rendering him as what society deems “disabled.” The positive attitude Ron has has given him confidence in most aspects of his life despite his inability to walk. One area of his life that he has had to change in the years he has been in a wheelchair has been the use of his pool and hot tub. As he used to spend his summers with his wife entertaining friends in his pool and hot tub, in recent years he has been able to only use his hot tub with the help of a friend physically lifting him in and out of it, but as Mr. Hiller and his friends age, this task is an unrealistic option. Mr. Hiller has become completely unable to use his pool because he cannot get up on his deck that has stairs rather than a ramp. The lift will allow him not only to be lifted in and out of the pool, but also Building two lifts, one for the pool and one for the hot tub, will give Mr. Hiller happiness and ability to do more of the things he enjoyed before his MS advanced so much.

These lift designs could also affect the market for pool and hot tub lifts. Currently, most pool lifts are sold to health clubs and/or public pools, but these lifts have been designed to be incorporated at a home, which could create a whole new market for lift devices if a cheaper way to manufacture and sell pool lifts could be found.

Now, on the market, most pool lifts are designed for in-ground pools. This lift will be one of few options for an above ground pool lift. Also, most pool lifts have the functionality of two locking positions where the lift can be set in the position for loading
and the position in the pool. This pool lift will have a third locking position on the rotation that will let Mr. Hiller get in or out of the pool either on the ground next to the pool, or on top of his deck. This eliminates the need of a ramp to be built for his deck.

The hot tub lift design would impact the market also because many hot tub lifts are manufactured for indoor hot tubs. These are able to use walls and ceilings as supports for the lift. This lift will be outdoors and will rely mainly on the support of the cement base.

Many lifts on the market are also designed for lighter people or children, whereas these lifts will be lifting an overweight, middle-aged man. This means that designs already on the market would need to be altered to consider the additional weight that will be applied to it.

Environmentally, the lifts will provide a structure that needs not to be removed for the winter months. The lifts will be permanent structures that would only be taken down by removing the whole apparatus from the cement in the ground. This is an improvement on similar models that are typically used for indoor pools. While there are many lifts that are used outdoors, few can deal with the weather of the harsh New England winter.

Many pool and hot tub lifts are designed as mass produced lifts that can be used for many different people, but these lifts are designed specifically for Mr. Hiller. This could open doors economically by more companies designing unique lifts built to fit a person in particular.

5. Life-Long Learning

The knowledge acquired through the design of this project have included a smorgasbord of valuable lessons stretching across a broad variety of subjects. First, the client, Ron Hiller, has opened our minds to become more involved with multiple sclerosis and its effects on people. Mr. Hiller has been rendered unable to do some of the things he loves and it has given us a real life example of this incurable disease as opposed to just hearing about the symptoms and its effects. We have now seen many of the ways that MS forces people to adjust their everyday behaviors as simple as driving a car, entering and exiting a home, or mowing the lawn. Mr. Hiller has also shown us that just because something affects your life negatively, it does not mean it has to end your life completely. Mr. Hiller is still just as involved as he was before he became confined to a wheelchair, as he still volunteers for “The Hole in the Wall Gang,” a summer camp that serves children dealing with cancer and other various illnesses. Mr. Hiller has such a positive attitude about life that he even has told us he does not consider himself to be disabled. This has taught us that it is trivial to worry and complain about small things such as tests when people who have had to deal with huge issues can still look at life in an optimistic manner.

This project has opened our eyes to the realities of what goes into manufacturing a large mechanical device. Every step of the design process is vital and requires careful planning and research. The lift we have designed has gone through several alterations before production has even begun. So many factors contribute to the final design. Measurements, materials, environmental properties, availability of resources and workspaces all must be considered and must work in compliance with each other to
create a successful final product. This project also has demonstrated that engineering is not always necessarily about designing a brand new product, but can involve the incorporation of existing devices as well as the modification of pre-existing devices to improve their use.

Working together on this project has taught us the importance of teamwork. Teamwork and communication are the most important aspects that will lead to the success of designing, ordering parts, building, and implementing of these lifts. The teamwork necessary for this design has expressed to us how important each department or level of manufacturing is to the success of a company and its products. We have found through this project that it is vital to be able to put aside differences to achieve a common goal as we have seen that we are all very different people from different backgrounds but we can get along and work together to help Ron Hiller regain the use of his pool and hot tub.

From the mathematical analysis of this design, we have learned that in the real world, we will not have an answer we have to achieve where we will be told if we are right or wrong, but rather we must look at the problem and try to find a solution on our own, without knowing the correct answers. While analyzing the statics of our lifts, we realized that if we are not correct in the mathematical parts, we will not know because unlike in a class where if you do a problem wrong, you will be corrected and told the correct answer, there are no solution manuals to check our analysis.

Our computational skills have improved with this project. The designing of these lifts has required us to obtain knowledge in SolidWorks and other CAD programs. Without this project, most of us would probably not have taken the time to learn how to use SolidWorks, which as it turns out after going through the tutorials and using it to “build” our lifts, is extremely helpful when compared to hand-drawing schematic pictures of the lifts. Another program we were introduced to is Dreamweaver which has allowed us to become familiar with creating and uploading to websites.

Finally, this design process has demonstrated to us the importance of money. Design has weighed heavily on the availability of money, which has shown us the importance of budgeting as well as eliminating components that are not entirely necessary. It is now clear to us that money is in fact a very limiting factor in industry and every aspect of life. It is key that you do not try to live a lifestyle that is more expensive than what you can afford. Budgeting is a vital skill to have to live a successful life without overspending.
References


