Decompression Chamber

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Problem Statement:

Since 2003, the Oklahoma Aquarium has educated the men, women, and children of Oklahoma on the wonders of the ocean, rivers, and lakes. As one of the only aquariums in Oklahoma, the Jenks-based non-profit provides a glimpse into the magical world under the water. Due to the aquarium's status as a non-profit organization, the aquarium has suffered from a tight budget. With a diverse grouping of fish and aquatic animals, the aquarium has experienced a wide range of problems in their pursuit of keeping all of the fish happy and healthy. An affliction called exophthalmia, or bulging eyes, has become a growing problem for the aquarium. This affliction is caused by a buildup of nitrogen in the fish's bloodstream. This phenomenon is similar to the "Bends" which is caused by nitrogen buildup in a human's bloodstream. Just like the bends can be treated with a stay in a decompression chamber, the best treatment for a fish suffering from exophthalmos is a stay in a decompression chamber. Currently, the aquarium does not have a decompression chamber which results in less than ideal solutions to correcting exophthalmia. The aquarium will often have to either drain the fluid from the eye or remove the eye altogether. Both of these solutions will end with the fish becoming blind in one eye. This affliction often affects the rockfish and other cold-water fish at the aquarium. Although it is possible to buy another fish, it is not only more cost-effective, but it is also more environmentally friendly to rehabilitate the afflicted fish.

With a desire to correct exophthalmia within a tight budget, we have been tasked with the creation of a moderately sized, lightweight, decompression chamber that can hopefully serve as an educational tool when it is not in use as medical equipment. This mid-sized pressure vessel will need to be able to withstand two atmospheres of pressure and allow for the occupant to be viewed without any loss of pressure. This chamber will need to be large enough to hold a young adult rockfish, but it also must be capable of being moved on a cart through the current doorways.

Project Requirements

During the development of the project, the Oklahoma Aquarium outlined the requirements of creating a decompression chamber for medical use. The first requirement was to create a tank able to withstand two atmospheres of pressure or 29.39 psi. This was the absolute maximum pressure that the device was to be operated at. The pressure vessel needs to be able to house a fish, most commonly a rockfish, which ranges in size between six and ten inches. Although there would only be one occupant at a time, the chamber was to be between ten and twelve inches in width and have a volume of at least twelve gallons. The most common occupant of the tank will require saltwater which in turn will require the tank to be made of durable and corrosion-resistant materials. It was recommended by the aquarium to use stainless steel or titanium wherever the tank will come into contact with water. To allow for the most flexibility on patient location, the tank is required to fit through standard doorways and be portable.

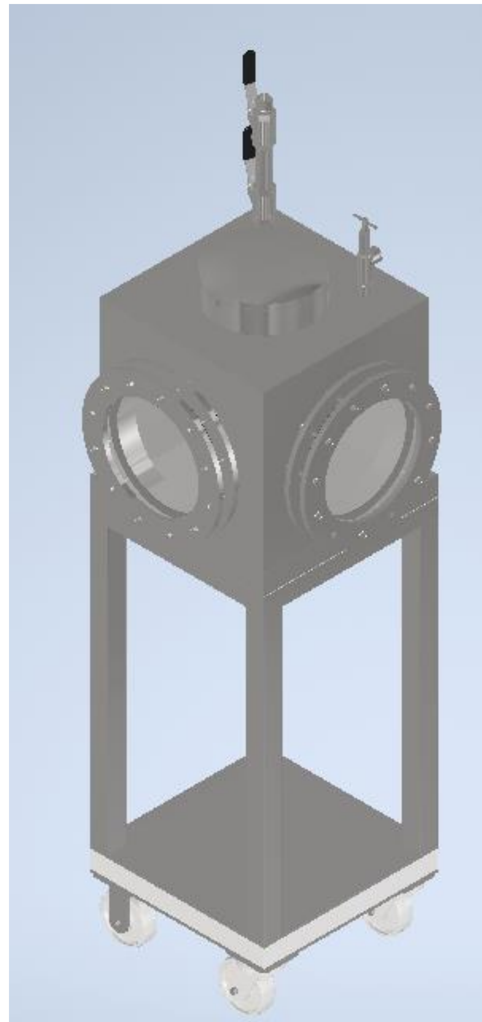


Figure 1 – Final Tank Design

Since the fish will need to be seen without releasing any of the pressure inside the tank, the aquarium required at least one view window and a way to feed and medicate the fish without pressure loss. A large hatch was needed as a way to allow the fish into and out of the tank, and as a way to allow for someone to clean the inside of the tank with ease. Along with easy cleaning, there was to be a drain port on the bottom of the tank at least ½ inch in diameter to allow for most of the large particles to leave the tank with little effort. To keep the fish at optimal health inside the decompression chamber, the aquarium required the water to be circulated at least twice every hour, and a pressure relief valve to be installed to monitor the pressure inside the tank.

Along with all the required design components, the aquarium had some additional design constraints that, if at all possible, they would like to see with the decompression chamber. Since exophthalmia only affects a few fish per year at the aquarium, they have requested that the tank be designed with optional use as an educational tool for the general public when it is not in use as medical equipment. When the chamber is in use with a sick fish, there must be a way to view the fish. The aquarium has requested a way to light the inside of the tank to view the fish, but also let the fish stay in darkness most of the time. With the Oklahoma Aquarium being a non-profit organization, there is no set budget for the projects. They recommended that our design be less than $10,000 in the final cost to better persuade possible sponsors into supporting the project.

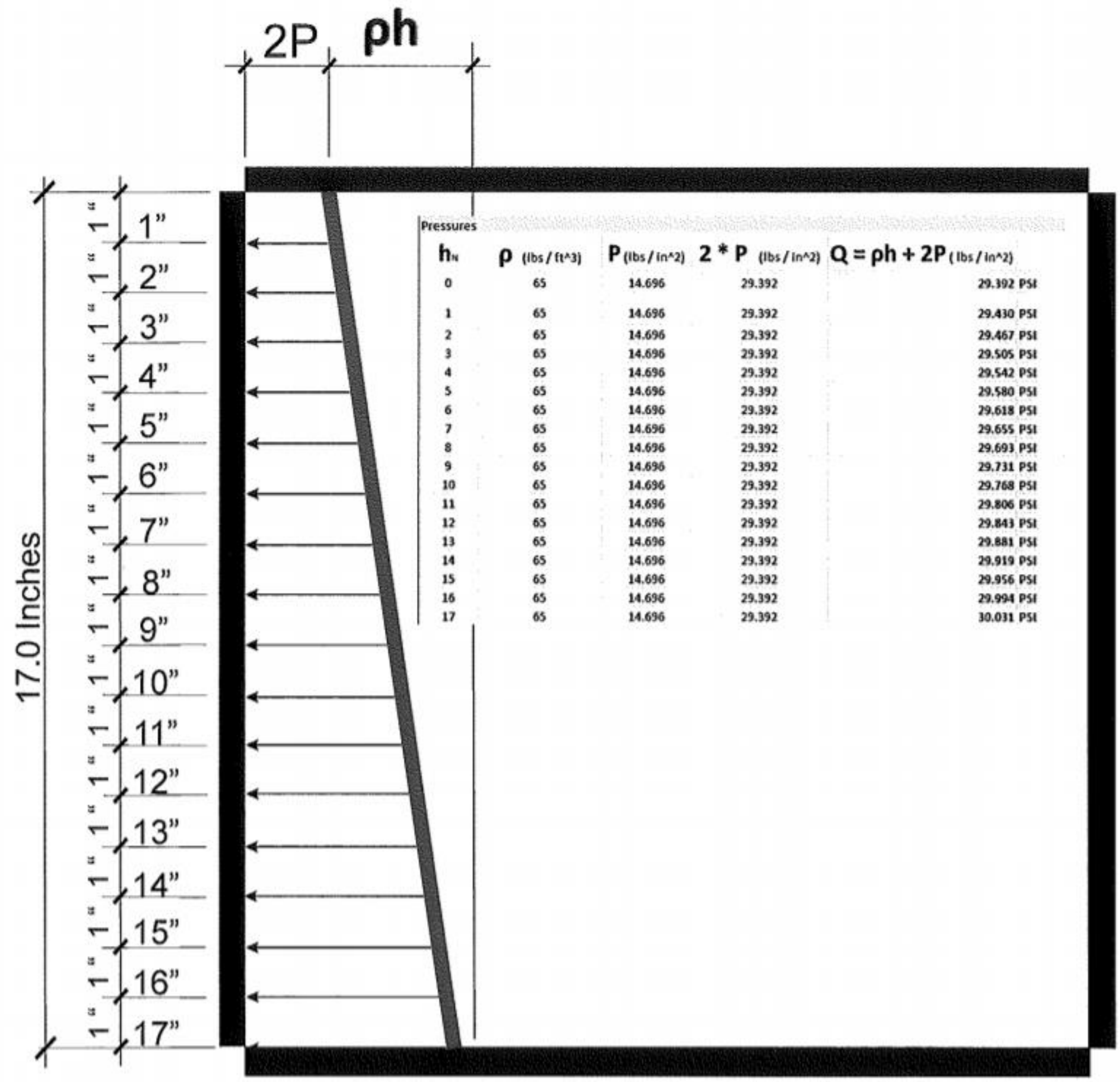
Following the completed final design, the aquarium will receive a packet of all the drawings created, a finalized parts list, and quotes for the project. These drawings will include the manufacturing and assembly drawings for each part of the tank and cart designs. The aquarium will also be receiving all of the 3-D parts and assemblies required to create the finalized design, and the FEA model done on the final assembly. As part of the deliverables, the aquarium will be receiving all of the background information that determined the design choices of the final design, such as ASME codes and standards, and previous design research.

Approach

For the design process, the first thing we needed to understand was what we were trying to solve. For this project, the site visit to the aquarium was required to determine what needed to be completed in this project and what type of budget this project would have. In these first weeks, we determined the general size requirements, the required capabilities of the tank, and the budget for the project. With this knowledge, we started gathering information to design the best tank for the aquarium.

After determining the parameters of the decompression chamber, we designed four different pressure vessels. These designs consisted of a carbon fiber sphere, an acrylic cube, a stainless steel cube, and a PVC cylinder. Out of these four designs, the stainless steel cube was chosen to be the final design. This was determined using a design matrix that had shown that the stainless steel cube would produce the best design for strength, material compatibility, and manufacturability.

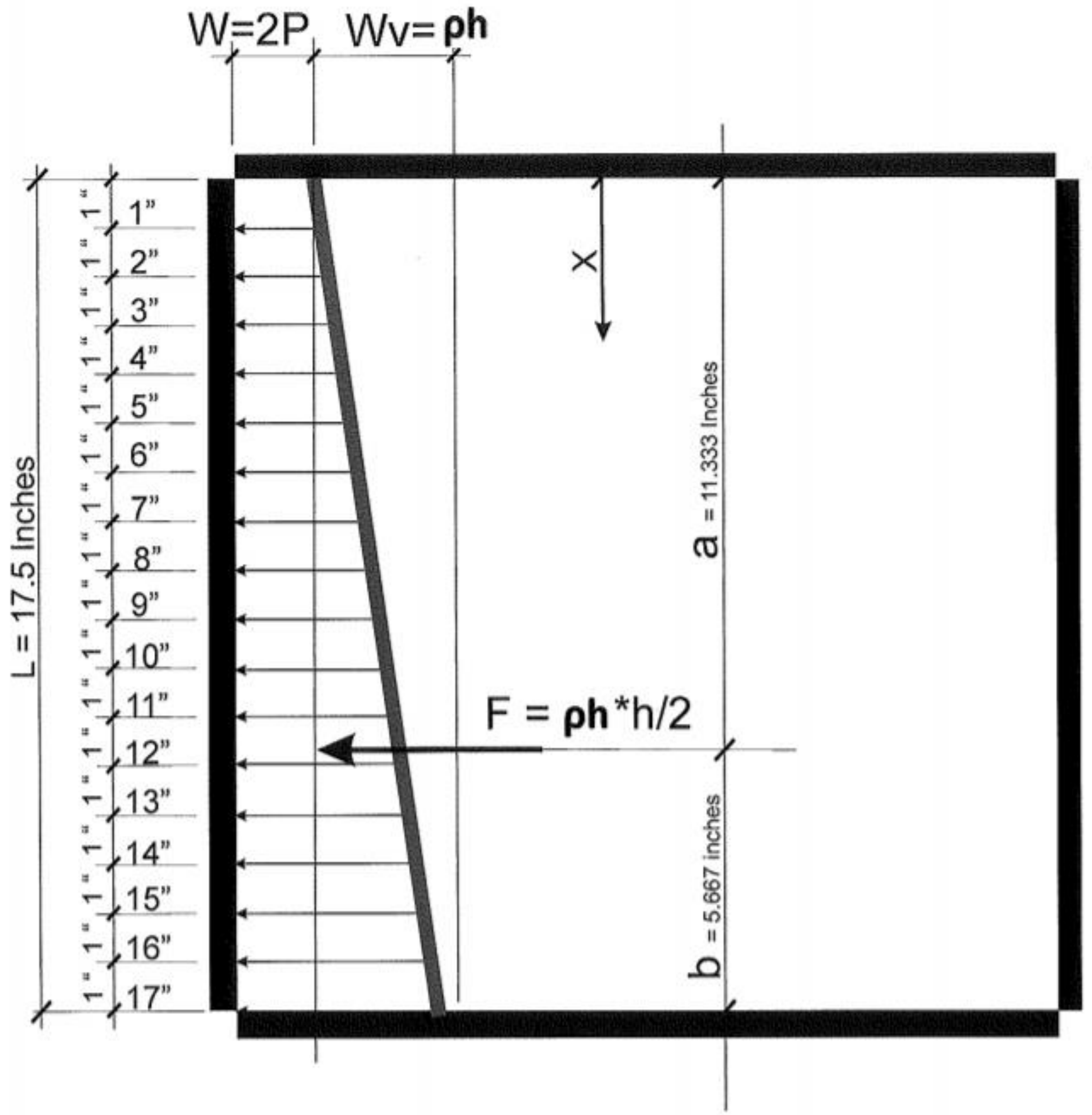
Using the base idea of a stainless steel cube, we worked on developing the final model of the tank. This includes finalizing the overall dimensions of the tank and the locations where additional inserts would go. Most of the dimensions were determined by previously set parameters, such as the tank must fit through a standard doorway, or calculations done by hand. These calculations determined the thickness of the tank and the overall pressure and forces on the tank. Along with the tank calculations, there were many different calculations done on the cart design to determine wall thickness and approximate weight.



Pressures

h_N	ρ (lbs / ft^3)	P (lbs / in^2)	2 * P (lbs / in^2)	Q = ρh + 2P (lbs / in^2)
0	65	14.696	29.392	29.392 PSI
1	65	14.696	29.392	29.430 PSI
2	65	14.696	29.392	29.467 PSI
3	65	14.696	29.392	29.505 PSI
4	65	14.696	29.392	29.542 PSI
5	65	14.696	29.392	29.580 PSI
6	65	14.696	29.392	29.618 PSI
7	65	14.696	29.392	29.655 PSI
8	65	14.696	29.392	29.693 PSI
9	65	14.696	29.392	29.731 PSI
10	65	14.696	29.392	29.768 PSI
11	65	14.696	29.392	29.806 PSI
12	65	14.696	29.392	29.843 PSI
13	65	14.696	29.392	29.881 PSI
14	65	14.696	29.392	29.919 PSI
15	65	14.696	29.392	29.956 PSI
16	65	14.696	29.392	29.994 PSI
17	65	14.696	29.392	30.031 PSI

Figure 2 – Hydrostatic Force and 2*Atmospheric



Max Deflections assuming fixed ends Max Deflections at midspan using 1/2 inch 316 Stainless Steel

Uniform Load W = 2P E = 29,000,000 PSI I = 0.01042 in^4 / in

Δ_U = WL^4/(384EI) = 0.02116 in approx 3/128 inch

Point Load F = **ρh***h/2 a = 11.333 in b = 5.667 in x = 8.50 in E = 29,000,000 PSI I = 0.01042 in^4

Δ_F = Fb^2x^2/(6EIL^3)(3aL-3ax-bx) = 0.00036 in approx 0 in

$\Delta_U + \Delta_F$ = 0.02152 in approx 3/128 inch

Figure 3 - Calculated Deflection

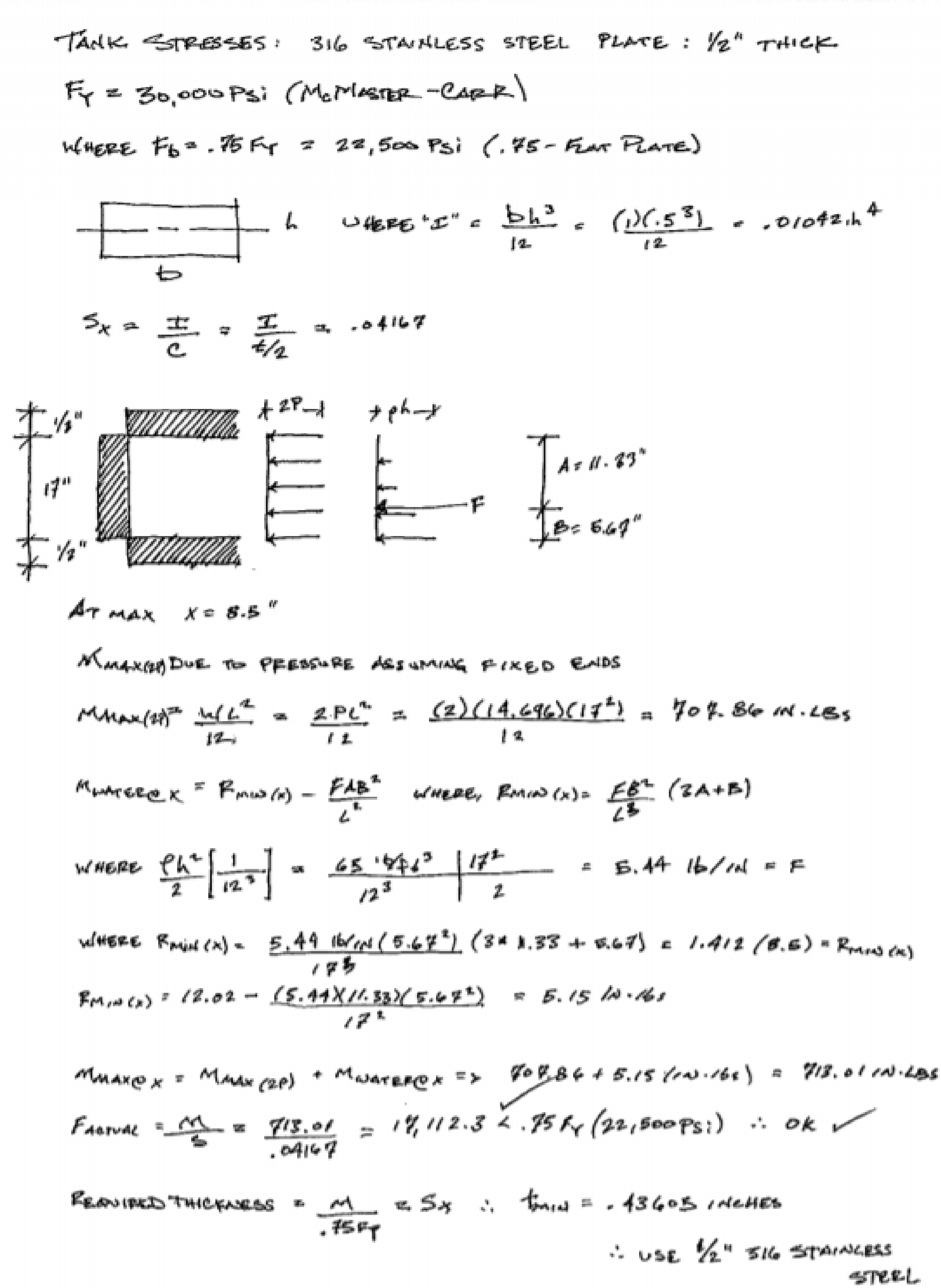


Figure 4 - Decompression Tank Side Wall (Forces)

TANK STRESSES: 316 STAINLESS STEEL PLATE : 1/2" THICK

$F_Y = 30{,}000$ PSI (MC MASTER-CARR)

WHERE $F_b = .75F_Y = 22{,}500$ PSi (.75 - FLAT PLATE)

- CHECK BOTTOM SIDE OF TANK

(FROM SIDE TO BOTTOM $M_{MAX(2P)}$ WILL REMAIN THE SAME)

$\therefore M_{MAX(2P)} = 707.86$ IN-LBS

$$M_{WATER\ lbs} = \frac{65\ lbs}{ft^3} \cdot \frac{17\ IN}{12\ IN} \cdot \frac{1\ ft^2}{144\ IN^2} = .6395\ lb/IN$$

$$M_{WATER\ lbs} = \frac{wL^2}{12} = \frac{.6395\ lb}{IN} \cdot \frac{17^2\ IN^2}{12} = 15.04\ lb\text{-}IN$$

$\therefore$ BASE DESIGN CONTROLS $\therefore M_{DESIGN} = 707.86 + 15.04$ lb-IN $= 722.9$ lb-IN

$$F_{ACTUAL\ (BOTTOM/BASE)} = \frac{M}{S} = \frac{722.9\ lb\text{-}IN}{.04167} = 17{,}348.21 < .75F_Y\ (22{,}500) \therefore OK$$

$$\text{REQUIRED THICKNESS} = \frac{M}{.75F_Y} = S_x \therefore t_{min} = .43906 \text{ INCHES}$$

$\therefore$ USE 1/2" 316 STAINLESS STEEL

Figure 5 - Decompression Tank Base (Forces)

TANK STRESSES: POLY CARBONATE - VIEW WINDOW

TENSILE STRENGTH : 9500 PSI = F_Y WHERE $F_b = (2/3)(F_Y)$

$\therefore F_b = 6{,}333.\overline{3}$ PSI

WHERE $\dfrac{M}{\frac{I}{C}} = F_b = 22{,}500$ PSI (316 STAINLESS STEEL)

WHERE $\dfrac{M}{\frac{I}{C}} = F_b = 6{,}333.\overline{3}$ PSI (POLY CARBONATE)

$$S = \frac{I}{\frac{t}{2}} = \frac{bt^2}{12}$$

$$I = \frac{bt^3}{12}$$

$$C = \frac{t}{2} \text{ (DISTANCE TO THE EXTREME FIBER)}$$

$$\therefore = S = \frac{bt^2}{6} = \frac{M}{F_b}$$

WHERE, $\dfrac{713.01 \text{ IN-lbs}}{6333.\overline{3} \text{ PSI}} = \dfrac{(1\text{-IN})(t^2)}{6}$

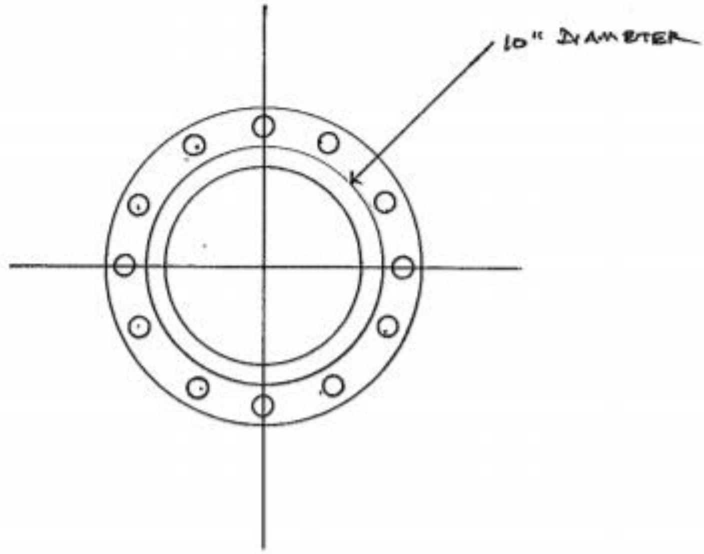
$\Rightarrow .8218799 = t^2 \therefore t = .82" \therefore$ USE 1" NOMINAL POLYCARBONATE

TO BE CODE, ASME STATES $\dfrac{\text{THICKNESS}}{\text{DIAMETER}} => .08$

$\therefore \dfrac{1"}{12"} = .083\overline{3} > .08$ ✓, THEREFORE USING 1" THICK POLYCARBONATE IS TO CODE. ✓

TANK STRESSES : POLY CARBONATE - VIEW WINDOW

BOLT ANALYSIS



WHERE TOTAL AREA = $\pi R^2 = \pi (5")^2 = 78.54 \text{ in}^2$

* CENTERED WINDOW (APPROX 8" FROM TOP OF TANK P = 29.639 PSI

WHERE TOTAL FORCE ON VIEW WINDOW = 29.639 PSI (78.54 IN²)

$= \dfrac{2327.847 \text{ lbs}}{12 \text{ Bolts}} = 194.07 \text{ lbs / bolt}$

* ALLOWABLE TENSILE STRENGTH ON A BOLT = 36,000 PSI (.33) = F_{AC}

$\therefore F_{AC} = 11,880 \text{ psi}$

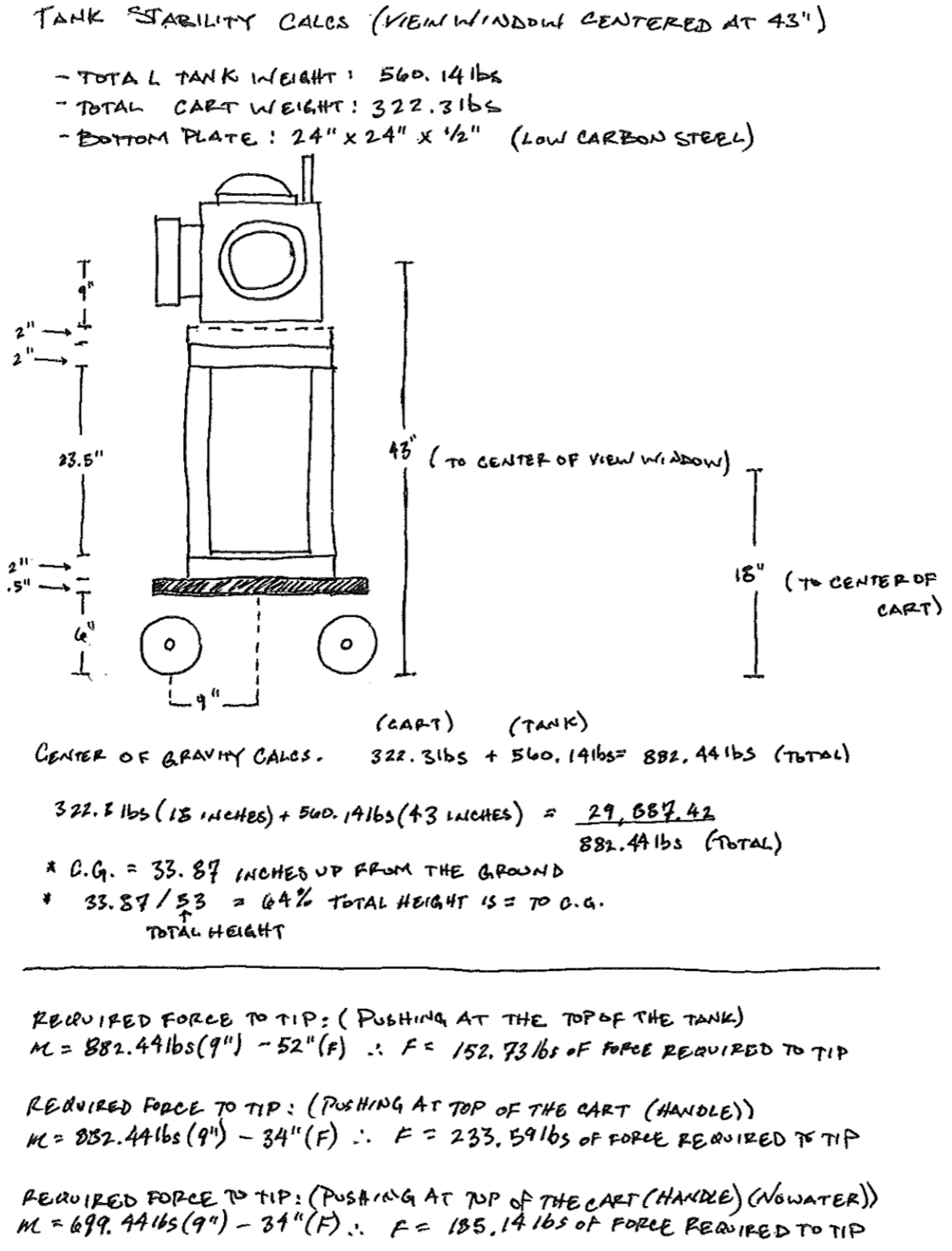
$\dfrac{194.07}{11,880} = .016336 \text{ in}^2$ (REQUIRED BOLT X-SECTIONAL AREA)

$.016336 = \pi (R^2) \quad \therefore R = .07211 \text{ in} \therefore D = .14422 \text{ in}$

(VERY SMALL BOLT, ∴ USE SAFETY FACTOR OF APPROX. 3 - 3/8" BOLT)

– 3/8" DIA BOLT × 12

Figures 6 and 7 - View Window Calculations


TANK STABILITY CALCS (VIEW WINDOW CENTERED AT 43")

- TOTAL TANK WEIGHT: 560.14 lbs
- TOTAL CART WEIGHT: 322.3 lbs
- BOTTOM PLATE: 24" x 24" x 1/2" (LOW CARBON STEEL)

CENTER OF GRAVITY CALCS. (CART) 322.3 lbs + (TANK) 560.14 lbs = 882.44 lbs (TOTAL)

$$\frac{322.3\text{ lbs}(18\text{ inches}) + 560.14\text{ lbs}(43\text{ inches})}{882.44\text{ lbs (TOTAL)}} = \frac{29{,}887.42}{882.44}$$

* C.G. = 33.87 INCHES UP FROM THE GROUND
* 33.87 / 53 (TOTAL HEIGHT) = 64% TOTAL HEIGHT IS = TO C.G.

REQUIRED FORCE TO TIP: (PUSHING AT THE TOP OF THE TANK)
M = 882.44 lbs(9") − 52"(F) ∴ F = 152.73 lbs OF FORCE REQUIRED TO TIP

REQUIRED FORCE TO TIP: (PUSHING AT TOP OF THE CART (HANDLE))
M = 882.44 lbs(9") − 34"(F) ∴ F = 233.59 lbs OF FORCE REQUIRED TO TIP

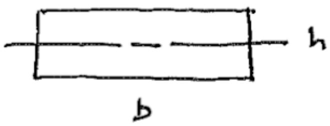
REQUIRED FORCE TO TIP: (PUSHING AT TOP OF THE CART (HANDLE) (NO WATER))
M = 699.44 lbs(9") − 34"(F) ∴ F = 185.14 lbs OF FORCE REQUIRED TO TIP

Figure 8 – Tank Stability Calculations

MAXIMUM PRESSURE CALCS. 316 STAINLESS STEEL PLATE : 1/2" THICK

F_Y = 30,000 PSI (McMASTER – CARR)

WHERE $F_b = .75 F_Y = 22{,}500$ PSI (.75 – FLAT PLATE)



WHERE "I" $= \dfrac{bh^3}{12} = \dfrac{(1)(.5^3)}{12} = .01042 \text{ in}^4$

$S_x = \dfrac{I}{c} = \dfrac{I}{t/2}$ (DISTANCE TO THE EXTREME FIBER)

$\Rightarrow \dfrac{.01042 \text{ in}^4}{.5 \text{ in}/2} = .04168 \text{ in}^3 = S_x$

$M_{WATER @ x} = R_{MIN}(x) - \dfrac{FAB}{L^2}$ WHERE, $R_{MIN}(x) = \dfrac{FB^2}{L^2}(3A+B)$

WHERE, $\dfrac{\rho h^2}{2}\left[\dfrac{1}{12^3}\right] = \dfrac{65 \text{ lb/ft}^3}{12^3} \cdot \dfrac{17^2}{2} = 5.44$ IN-lbs $= M_{WATER}$ (SIDEWALL)

$M_{WATER\ lbs} = \dfrac{65 \text{ lbs}}{ft^3} \cdot \dfrac{17 \text{ IN}}{12 \text{ IN}} \cdot \dfrac{1 ft^2}{144 \text{ IN}^2} = .6395$ lb/IN

$M_{WATER\ lbs} = \dfrac{wL^2}{12} = \dfrac{.6395 \text{ lb}}{1 \text{ IN}} \cdot \dfrac{17^2 \text{ IN}^2}{12} = 15.40$ IN-lbs $= M_{WATER\ lbs}$ (BOTTOM SIDE)

* MOMENT "M" FOR WATER IS GREATEST ON BOTTOM ∴ USE 15.40 IN-lbs

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$M_{MAX(2P)}$ DUE TO PRESSURE ASSUMING FIXED ENDS

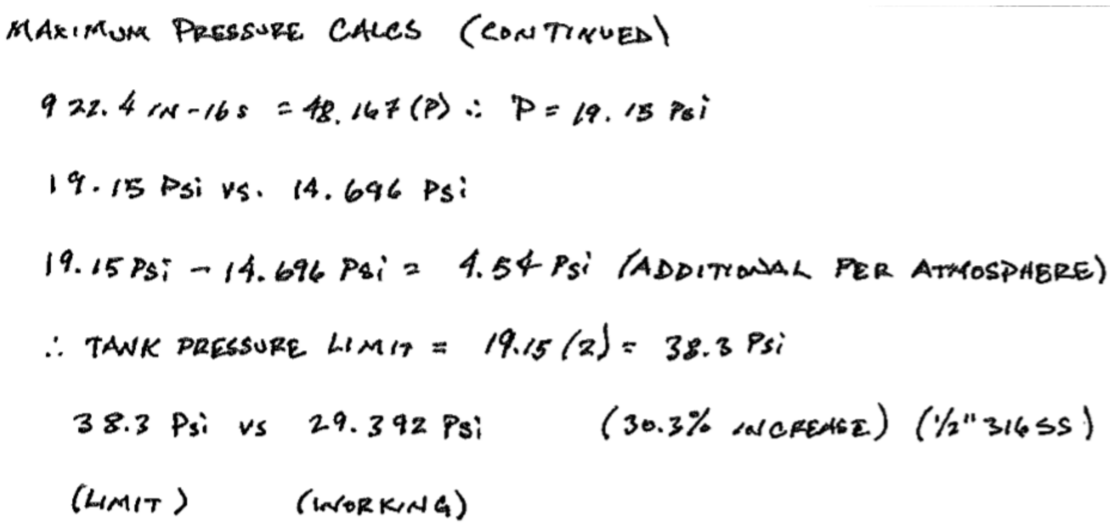
$M_{MAX(2P)} = \dfrac{wL^2}{12} = \dfrac{2PL^2}{12} = \dfrac{(2)(P)(17^2)}{12} = 48.167(P)$

$\dfrac{M}{.75 F_Y} = S_x \therefore \dfrac{M}{22{,}500 \text{ PSI}} = .04168 \text{ in}^3 \Rightarrow M = 937.8 - M_{WATER\ lbs}$ (BOTTOM SIDE)

$M = 937.8 - 15.4 = 922.4$ IN-lbs (MAXIMUM MOMENT)

$M_{MAX(2P)} = M$

$\Rightarrow 922.4$ IN-lbs $= 48.167(P) \therefore P = 19.15$ PSI


MAXIMUM PRESSURE CALCS (CONTINUED)

922.4 in-lbs = 48.167(P) ∴ P = 19.15 Psi

19.15 Psi vs. 14.696 Psi

19.15 Psi − 14.696 Psi = 4.54 Psi (ADDITIONAL PER ATMOSPHERE)

∴ TANK PRESSURE LIMIT = 19.15(2) = 38.3 Psi

38.3 Psi vs 29.392 Psi (30.3% INCREASE) (½" 316SS)

(LIMIT) (WORKING)

Figure 9 and 10- Maximum Pressure Calculations

With all the variables defined, the 3-D modeling began on Autodesk Inventor 2020. This modeling service was used to show all the parts required to complete the tank to the aquarium's specifications. While most of the larger parts were designed and built in Inventor 2020, most of the smaller parts were modeled by McMaster-Carr, the seller of the parts. We used readily available materials where possible; most of which came from McMaster-Carr's online distribution site. With all parts accounted for, the price list was the next thing developed. Using the parts list, vendors were contacted for quotes of parts and labor. McMaster-Carr contained the largest selection of parts and was used extensively to create a working price list.

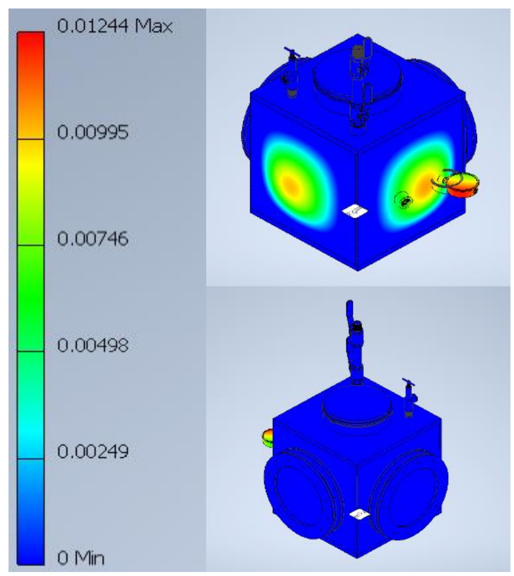


Figure 11- FEA Model

Nearing the end of the design phase, we worked on completing shop drawings, design optimizations, and an FEA model showing decompression tank stresses using Inventor 2020. These design optimizations included calculations to determine the tipping force on the cart design, and the modifications needed to raise that value. This was also the phase where we created a final report and presentation, and a final cost analysis.

Cost Analysis

During the last weeks of this semester, we further expanded the cost analysis based on the increasingly developed parts list, availability of labor quotes, and material and shipping costs. Since this design requires metal to come into contact with salt water, more corrosive resistant materials had to be selected. The best candidate was determined to be 316 stainless steel as it has excellent corrosion resistance although it is costlier. To develop the tank in the shortest timeline, we determined that laser cutting would be the better option as it allows for more precise cuts and smoother edges.

For this design, the labor costs to laser cut the thick ½” 316 stainless steel sheeting was estimated to be $1,100.00, quoted from Central Tube and Bar in Tulsa, Oklahoma. The assembly of the decompression chamber was estimated to be $1,200.00 at $75 per hour shop rate. This will take approximately 16 hours or two full workdays. These values were determined by a verbal quote of an associate of Central Tube and Bar and should not be taken as a set value.

Another feature of our design is a hatch that allows the patient to enter and exit the chamber easily and simply. West Coast Engineered, a company in Wyoming that produces pressurized and non-pressurized hatches, was contacted for inquiries on their quick-access hatches. The two options presented were 8” and 10” diameter hatches using both 304L and 316L stainless steel alloys. For our decompression chamber design, the 10” diameter 316L stainless steel hatch was chosen due to its larger access hole for the patient to enter and exit, as well as for ease of cleaning. The 316L alloy contains less carbon and is easier to weld while keeping the great corrosion resistance that 316 stainless steel is known for. The downside to this design is the higher price. This hatch design cost about $2,004.18 with a $75.00 shipping fee. Along with an access hatch, this decompression chamber design needs a pump. The pump found for this design was a self-priming SEAFLO 51 Series DC Diaphragm pump priced at just $109.99, which is one of the cheapest components of this design. This pump will allow for the required two cycles per hour and is compact enough to be attached to the bottom plate of the cart to remain mobile. This pump can also be used for seawater as well as freshwater. This is not the only pump that would work for our design, but this is the best fit that we found. Although there are several other components to this design, the main components with their cost and benefits have been described above. A full list of all parts and their associated prices can be found on the budget table.

Key Decisions

To complete our design, any flaws or weaknesses must be addressed accordingly. Therefore, identifying the correct problems and executing feasible decisions is a crucial part of our design process. The overall design process consisted of multiple key decisions that helped our team make the appropriate selections for designing parts and finding suitable materials. For the preliminary designs, the primary key decisions that drove our team toward choosing the “Stainless Steel Cube” design was the size, portability, ease of tank access port, and the view windows. These important key decisions were mainly used to address the design requirements from the Oklahoma Aquarium. Continuing toward the final design aspects, calculations for the strength of materials, deflections, hydrostatic forces, and the initial weight of the tank were major key decisions that helped our team to choose the appropriate materials. Material selection of 316 stainless steel plates and parts was used all around the tank to address the corrosion issues that come in with contacting saltwater. These calculations also help to determine how well the design fits with the ASME standards, and how to change the design to match the requirements of the codes and standards. Another important issue was concerning the potential safety hazards that the cart design posed. This was addressed appropriately by shortening the height of the cart and increasing the base of the cart to reduce the possibility of tipping. These crucial processes in defining our design problems helped us in addressing it accordingly to ensure the design would be constructed following the requests and requirements of our sponsor, the Oklahoma Aquarium, and meet ASME standards where possible.

Final Design Detail

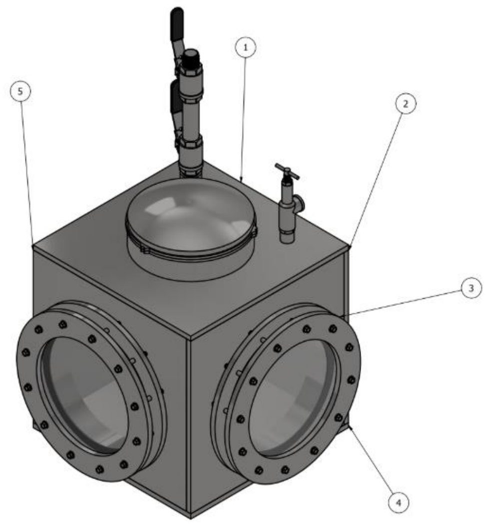


Figure 12- Decompression Chamber Drawing

The final decompression tank design has seen many changes throughout the semester. It has morphed several times ultimately ending up as an 18" x 18" x 18" 316 stainless steel cube that is situated on top of a rolling cart for mobility. The tank holds approximately 21.3 gallons of saltwater and is large enough dimensionally to accommodate a wide variety of fish. To supply the saltwater to the tank, there is a small self-priming pump located on the bottom shelf of the steel cart that supports the decompression chamber. The height of the 10-inch diameter view window is approximately 45 inches off of the ground to the center of the view window, and careful consideration was taken when selecting this height. This height was determined using information from ADA.gov to confirm that the center of the view window would, on average, be eye level of a wheelchair user. This height and dual view window configuration allow for the decompression chamber to be better utilized as an educational device. The tank sits high enough to display fish and other objects to a grade school field trip class or an occupant sitting in a wheelchair. As per the Oklahoma Aquarium decompression chamber requirements, the chamber must be able to pressurize to a maximum of 2 atmospheres. To control this pressure in and out of the tank, there is an adjustable pressure relief valve added to the side of the decompression chamber. It can be set to a pressure of approximately 30 psi (2 atmospheres) while still allowing for the water to circulate and turn over twice per hour. For use in conjunction with the pressure relief valve, there is a large dial pressure gauge located inches away from the pressure relief valve which makes small pressure adjustments very intuitive. Along with the side instrumentation, there are multiple pieces of equipment located on the top of the chamber. These instruments include the feeding tube and the 10-inch diameter hatch. The hatch has a large enough diameter that a net can be inserted into the tank if needed by the staff to aid in removing the treated fish, or to aid in cleaning the tank. Near the hatch, there is a large feeding tube that allows for approximately 4.712 cubic inches of fish pellets and medicine pills to be inserted into the tank by way of a two-part valve configuration. Both the hatch and feeding tube are located approximately 52 inches off the ground which should allow for a comfortable working height when the aquarium staff member is tending to the fish being treated.

Along with the decompression chamber design, our team designed and developed a low carbon cart to move the tank when needed. Located at the base of the cart, there are four casters (2 rigid and 2 swivels) that allow for increased mobility when moving the decompression chamber from aquarium exhibit to aquarium exhibit. These four casters are six inches in diameter and three inches wide. The larger diameter wheel will allow the staff member to use the decompression chamber to move and position the cart with much less effort, and less damage to the floors. The cart has been designed to have a large handle placed on the back of the cart. This should allow for the cart to be maneuvered with more ease.

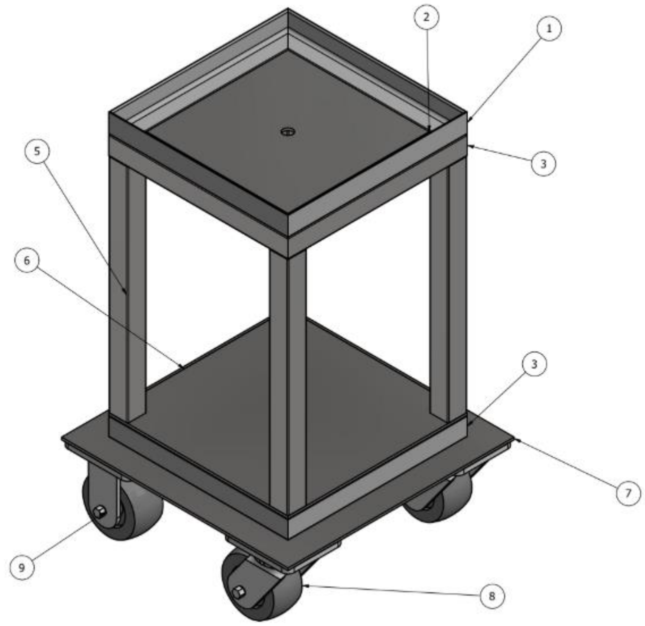


Figure 13- Cart Drawing

Evaluation of Final Design

The final decompression chamber design has been optimized over the last few weeks of the semester. This proposed 316 Stainless steel cube is designed to be very strong, corrosion-resistant, compact, and long-lasting. We have designed this tank to meet the requirements laid out by the Oklahoma Aquarium to treat fish suffering from exophthalmia. The designed decompression tank displays many unique and user-friendly design. This would include features such as easy access 10-inch-wide top hatch, a maneuverable cart, an easily adjustable pressure regulator, two large view windows, and a user-friendly feeding tube capable of supplying both food and medicine to the occupant.

However, there are a few negative design aspects that are associated with our decompression chamber. 316 stainless steel does weigh a bit more than regular carbon steel (0.3 lbs/in^3 vs. 0.283 lbs/in^3) and has the final tank design reaching an approximate 900 lbs when filled with water. Due to the requirements of the tank, there was no way for the chamber portion of the design to be made of carbon steel. The same could not be said for the cart design. Since the cart should not come into constant contact with salt water, it was determined that the cart could be made of low carbon steel and then powder coated for durability. Another issue with the design is that during normal operations the design would be top-heavy. This was addressed with the addition of a wider base plate at the bottom of the cart, and a reduction in the overall height of the cart by about six inches. Both of these changes increase the stability of the cart and increase the force needed to topple the completed design. The Oklahoma Aquarium requested that lighting of some kind be incorporated into the tank. Using our design, we do not believe that there will need any additional lights needed to see into the tank. With that assumption, we added an optional feature of a light shade to filter the lighting for when there is an occupant inside the tank. Many great design features of this decompression tank were left uncovered as the larger items were addressed. On the chance this decompression tank is selected, it will be a great addition to the already impressive Oklahoma Aquarium.

Recommendations for Future Work

The goal for this project was to deliver a finalized decompression chamber design that could be implemented at the Oklahoma Aquarium to treat exophthalmia in fish and be used as an educational tool for visitors. The finalized decompression chamber design that group 1C has submitted, if implemented, is fully capable of meeting and exceeding all requirements set forth by the Oklahoma Aquarium. With major critical decisions already addressed, recommendations for future work mainly consist of optional enhancements and modifications. Some examples of optional future work the Oklahoma Aquarium could opt to add to the design could be internal illumination such as submersible LEDs. This would allow the aquarium to use the LED's to light the tank instead of relying on ambient lighting as we intended with the final design. The aquarium could also develop a smaller scale prototype based on our design to prove the design's effectiveness before full-scale manufacturing. Finally, the final design made strength, fish accessibility, fish visibility, and safety requirements with very few compromises. With that in mind, one aspect that could be altered by the aquarium if they're willing to accept potential tradeoffs in other areas would be to reduce the combined weight of the pressure vessel and cart by opting for lighter-weight materials. Although there are always possibilities for future work that can still be decided upon, the finalized design has taken many factors into account and strikes a good balance of cost and features as is.

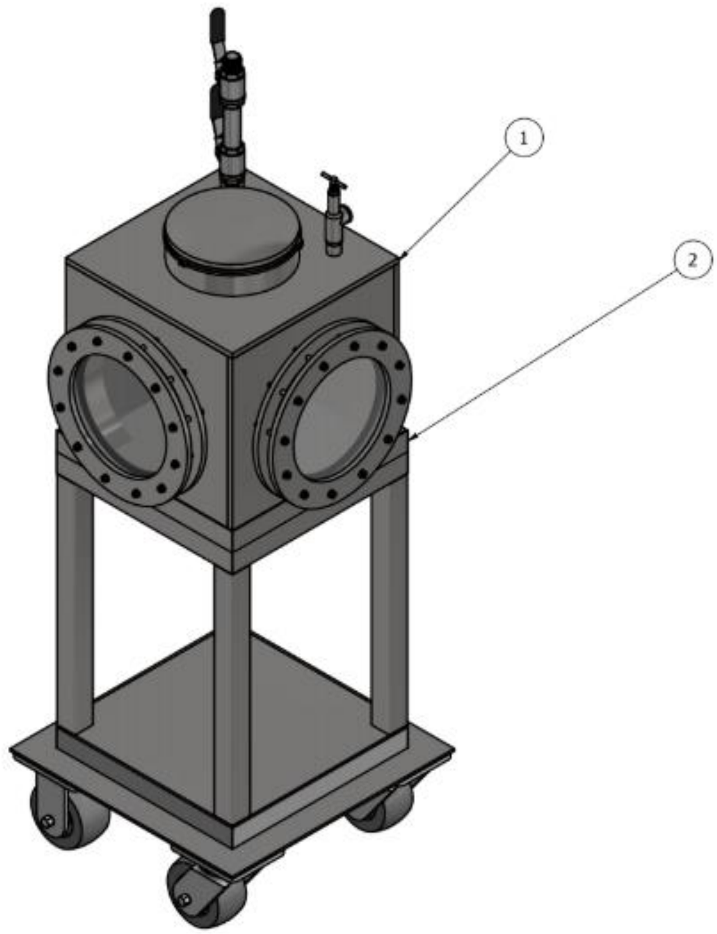


Figure 14- Final Assembly Drawing

Revised Gantt Chart

A Gantt chart is an essential part of any group project in just about any field imaginable. The Gantt chart was created at the beginning of the semester and has kept the group on track for both tasks and due dates for the semester. Due to the changing nature of group projects, it can be seen that the Gantt chart has adapted to better fit the expectations of the group as the project develops. Many of these changes have been small and only changing when parts of the design were added or dropped off, or when extraneous circumstances prevented the original due dates to stay unchanged. As with the last two versions of the Gantt chart for group 1C, the dates of when the tasks were started and completed are shown along the top, and the tasks needed to be fulfilled are listed on the left from top to bottom. These tasks correspond to a colored bar on the right showing the dates when they should be started and completed by, and their level of importance to the final design. As shown in Figures 1 and 2, the group has reached the end of the semester and the end of the project. Overall, the group has been successful at closely following the Gantt chart for the entirety of the decompression chamber design project.

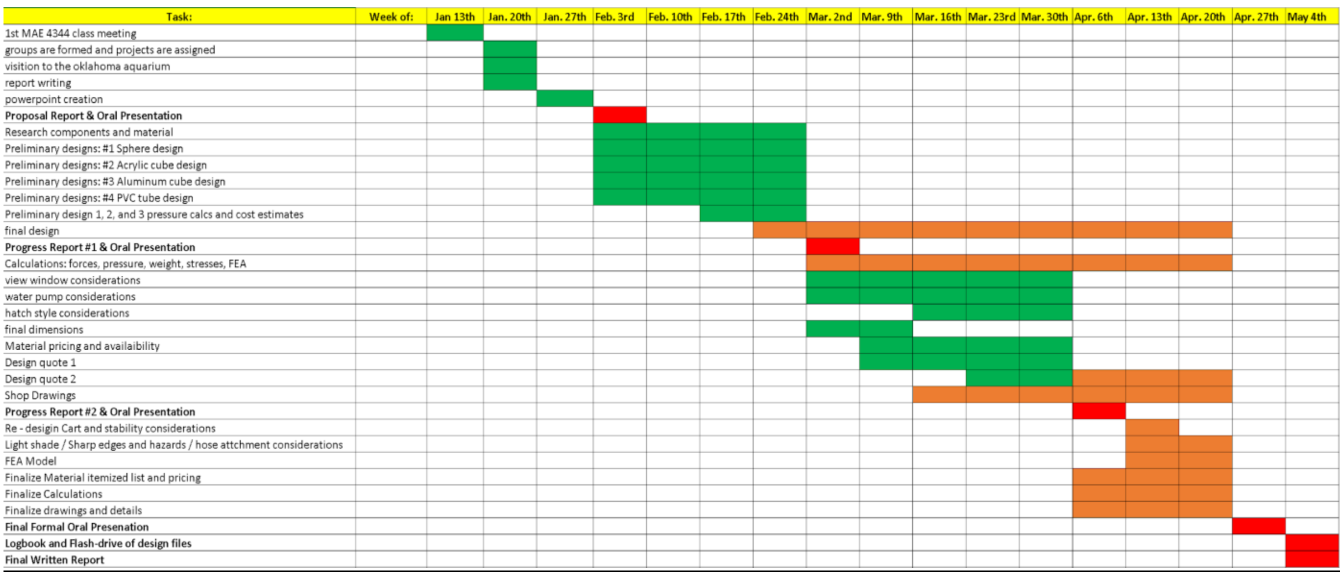


Figure 15 - Gantt Chart showing progress from the beginning of the design to the end

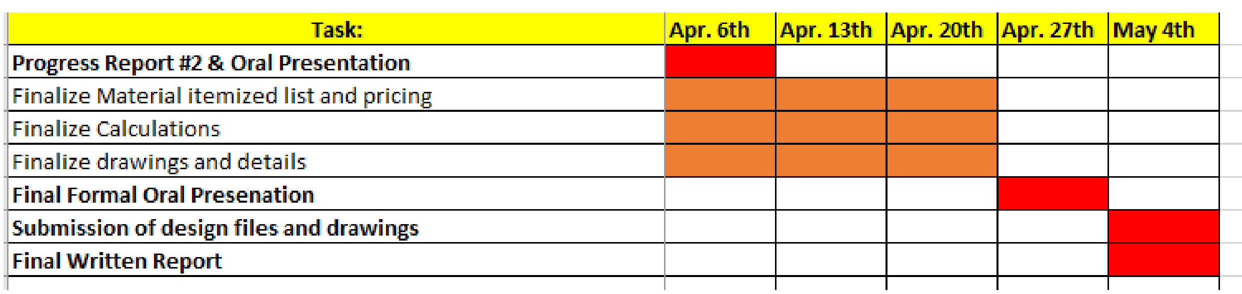


Figure 16 - Gantt chart snip showing work completed since Progress Report #2

Revised Budget Table

The Oklahoma Aquarium assigned a maximum budget of $20,000.00. However, it was stated that the more favorable budget was in the $5,000.00 to $10,000.00 range. To better acclimate to this budget, several design changes were made. The original cost of this design was well over the $10,000.00 budget, but changing the cart components from 316 stainless steel to low carbon steel lowered the cost drastically. In Table 1, a revised budget table consisting of part descriptions, part numbers, quantities, and prices, can be viewed below. These items are necessary for the assembly and construction of the decompression chamber design. The final design has been broken down into sections with each section having the parts required listed along with their prices. The majority of these parts were collected from McMaster-Carr. Other companies that supply more specific parts have been listed in the table as well. This includes the pump and hatch manufactures. The 10" 316L stainless steel quick access hatch was supplied by West Coast Engineered. The Seaflo 51-Series Self-Priming Pump is one of the cheapest components as it is only $109.99. Shops that could perform the fabrication and assembly of the chamber are also listed within the table along with estimated time and labor costs.

The total cost of the entire project is at the bottom of the table and comes out to be $9,896.38. This total is just under the recommended budget of $10,000.00 as advised by the Oklahoma Aquarium.

Table 1: Revised Budget Table of Parts Required for Design and Prices

Part Description, Price, Part Number, & Quantity (#)	Cost ($)
Salt Water Pump & Hoses:	
Seaflo 51-Series Water Pump PN - SFDP1-030-060-51 (1)	$109.99
Medium Pressure (0 - 400 psi) Male to Female ½" NPT Ends PN - 53075K98 (1 - 5ft Segment, 2 - 10 ft Segments)	$113.93
Decompression Tank Wall Material, Cart Gussets, &	**View Window Flange:**
Plate Material ½" 316 Stainless Steel PN - 9195K77 (3)	$2,797.65
Decompression Tank Hatch:	
10" Closure Assembly Type 316-L Stainless Steel, 6" Long x ¼" Thick Weld Ring, Zinc Plated Steel Bolting and Neoprene Gasket Company: West Coast Engineered	$2,004.18

PN - 031920-4	
Shipping Cost of Hatch	$75.00
View Window:	
Flange Head Stainless Steel Bolts (⅜-16 - 3” Long) PN - 90166A134 (12)	$39.60
Standard ⅜”-16 Nut PN - 92673A125 (1 - 25 Nuts per Package)	$2.35
Standard ⅜” Washer PN - 92147A031 (1 -50 Washers per Package)	$5.81
12” x 12” Polycarbonate Sheets 1” Thick PN - 8574K4 (2)	$527.26
⅛” Thick Water Resistant EPDM Gasket Material (800 psi Max) PN - 852T67 (1)	$6.33
Weld Bungs for Attachments:	
Bung, Weld-In 316 Stainless Steel 1” NPT Female PN - 4443K676 (1)	$18.09
Bung, Weld-In 316 Stainless Steel ½” NPT Female PN - 4443K674 (3)	$22.83
Bung, Weld-In 316 Stainless Steel ¼” NPT Female PN - 4443K672 (1)	$5.23
Cart Material:	

2” x 2” ¼” Wall 90 Degree Low Carbon Steel (1 - 72” Segment, 1 – 36” Segment) PN – 9017K694	$62.86
2” x 2” ¼” Wall Low Carbon Steel Square Tubing (4 - 36” Segments, 3 - 72” Segments) PN – 6527K614	$381.71
24” x 24” ¼” Low Carbon Steel Flat Plate (2 - 24” x 24” Pieces) PN – 1388K181	$449.90
24” x 24” ½” Low Carbon Steel Flat Plate (1) PN – 1388K381	$311.77
3.1875” Total Height, 2” Diameter Wheel Steel Casters (300 lb. capacity) (2 - Rigid) PN – 2407T25	$25.44
3.1875” Total Height, 2” Diameter Wheel Steel Casters (300 lb. Capacity) (2 - Swivel) PN – 2407T12	$28.44
Powder Coating Decompression Cart	$100.00
Drain, Feeding Tube & Instrumentation:	
Adjustable Pressure Relief Valve for Water PN - 9763K11	$66.44
1” NPT 2” Long Stainless Steel 316 Straight Pipe (Male to Male) PN - 4548K223 (3)	$19.14

1” NPT 6” Long Stainless Steel 316 Straight Pipe (Male to Male) PN - 4548K228 (1)	$13.90
Ball Valve (Drain) 316 Stainless Steel PN - 46495K23 (3)	$205.05
4” Dial Diameter Corrosion Resistant Pressure Gauge PN - 4066K61	$91.18
Fabrication & Assembly:	
Labor for laser cutting plate material into 6 pieces at 18” x 18” dimensions and all access holes/ports Quoted Shop: *Central Tube and Bar Tulsa, Ok*	$1,100.00
Shop time to assemble decompression tank ($75 per hour shop rate, 16 hours/2 full workdays approximation)	$1200.00
Threaded connectors 1” male x male 316-stainless NPT McMaster Carr PN- 4548K225 (2)	$17.48
Drain valve 1” NPT 316-stainless steel PN - 46495K23	$78.15
Ambient light filter fabric 63x40x0.25” PN - 51736	$33.17
Velcro strips to attach light filter fabric 24”x0.75” PN - 91878 (2)	$11.94
Total:	**$9,896.38**