Retractable Pool Cover

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Team 12

Project Proposal
Document

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Introduction

Our team has been hired to assist our client, Brian Herzog, with his problem. Brian is a retired engineer who started his own company out of his garage. After a few years as the CEO of Frontline Energy Services, he retired. He now resides in Flagstaff, AZ spending time at his home with family and friends. He is looking for a pool cover to go over his indoor, in-ground infinity pool. Additionally, he is looking for this pool cover to support the weight of multiple people walking on top of it and be affordable enough for the consumer of the product. He has informed us that the closest product that he found to fit his problem costs about $50,000. However, there is nothing currently on the market that meets his need and is at a more reasonable cost. In addition, our team will develop a product that suits our client's needs, in order to have this product marketed and possibly developed and sold on a mass scale.

A problem that the design will encounter is the weight of the pool cover. By increasing the ability to withstand a higher weight on the cover, this will lead to an increase in the required yield strength of the system, which will cause an increase in the overall weight of the system. Also, the design has to be rigid enough to hold people crossing over the cover. The design must have a motor, as the client has requested that the cover is automated. Another objective is to consider the number of parts for the design. This is essential, as the number of parts changes how easily maintainable the design is.

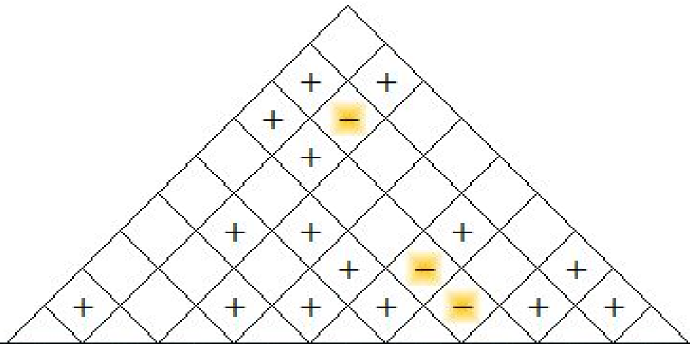
When our team met with Mr. Herzog, he instructed us that he would like the pool cover to be strong enough to support at least 827 kPa of pressure. This is an important constraint as it protects not only the product, but more importantly it protects the individuals who are walking on top of it. The cover must span the entire area of the pool, which is about 16 ft long by 9 ft wide. If the cover does not completely cover the pool, items could be dropped into the pool and damaged, but more importantly someone could get injured if there is a gap between the flooring and cover. Another requirement is to create this product significantly under $50,000. If this product can be created at about one third the cost, it will likely be a success in the market. He is also looking for the design to be automated and can fully operate in one direction in one minute. The final requirement is that it must be easily maintainable as any sort of mechanical system near water needs to be checked and taken care of as to not corrode and break.

Quality Function Deployment & House of Quality

The Quality Function Deployment (QFD) represents the relationships between the customer requirements and the engineering requirements which are needed to design the retractable pool cover. This method is used to have a better understanding of the client's needs and hence addresses the problem through the engineering design requirements. Mr. Herzog has specified the design requirements for the pool cover and the engineering requirements must meet these specifications. Therefore, the QFD matrix employs fundamental requirements for the design and then illustrates the amount of importance to the customer requirements. When a customer requirement and an engineering requirement have a relationship it is denoted with a marker, which can be seen below in Figure 1.

Our QFD contains two markers, a full dot and an empty dot, each representing a strong relationship and a lesser relationship, respectively. The customer requirements are then rated based on the number of correlations it has to the engineering requirements. Customer requirements with the most correlations are the most important as it becomes a very essential way that we are to design our cover. Therefore, the ability to sustain weight is the most important factor due to the fact that it has six relationships and most of these are strongly correlated.

The House of Quality (HoQ), which is the half diamond on top of the QFD in Figure 1, displays the relationships between the engineering requirements for the pool cover. The relationships are signified by two icons, symbolizing a positive or negative correlation. Similar to the QFD, the relationships between the engineering requirements are signified and rated by the number of relationships they share. However, because some of the relationships will impact others negatively these must be closely monitored to come up with a design that still satisfies the functionality of the cover system. The factor of safety has the most negative correlations. If an electric motor is used the factor of safety decreases because we have an electrical component near water. Additionally, if the factor of safety increases too much due to making the components too large, it will require a larger hub to house the cover. This then leads to a bulkier system which may not be able to work for the designated install area.



Column #	1	2	3	4	5	6	7	8	9
Customer Requirements (Explicit and Implicit) / Functional Requirements	Yield strength	Weight (Load Capacity)	Electrical Power	Self-Maintenance	Size (Volume)	Electric Motor	Factor of Safety	Max Deflection (Cover)	Material
Easy to Maintain				●					
Easy Installation and Removal	●		○	●	○	●			
Automated Retraction			●	●		●			○
Able to Sustain Weight	●	●			○		●	●	●
Fit Within Alloted Space					●	●			○
Aesthetically Pleasing		●			●		●		●
Non-Corrosive			●			●	●		●

Figure 1: *QFD and HoQ showing relationships between requirements*

Functional Diagram

In order to come up with different concepts for the pool cover design, our team first had to make a functional diagram to understand the different operations that will occur within the automated pool cover. The basic operation for the automated pool cover are shown below in Figure 2.

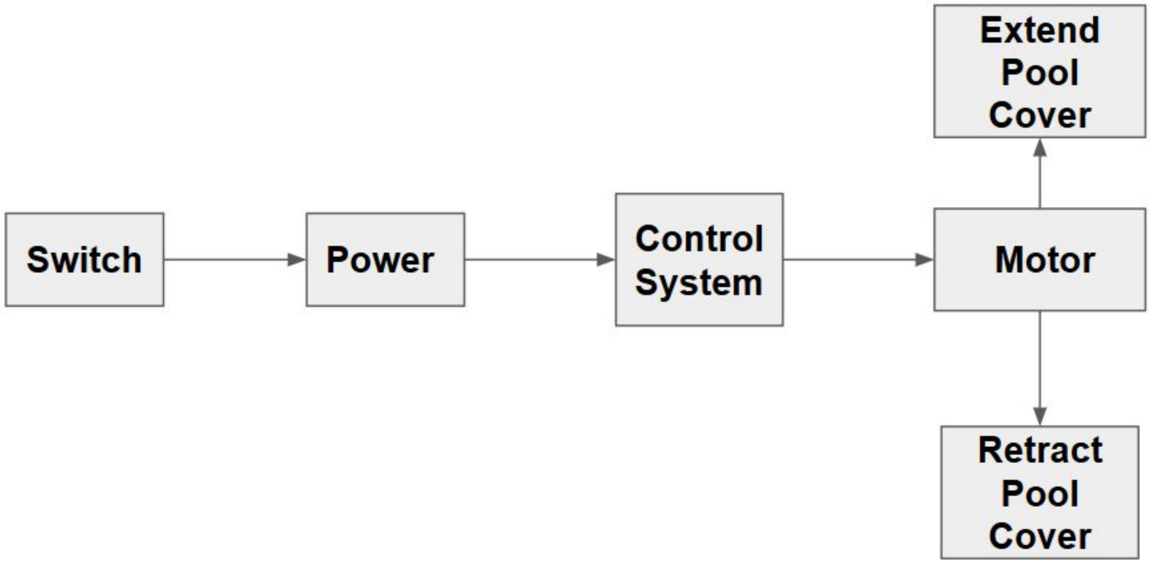


Figure 2: *Functional diagram for automated pool cover*

Each box represents a different functionality for the pool cover design; it is a useful tool when coming up with different conceptual designs. The main functionalities that the team focused on for the project design are the switch, the power, the control system, and the motor. Another design aspect that the team had to focus on was the housing for the pool cover because there is a maximum volume that our design is constrained to. The next task that our team focused on was the criteria for each functionality which is important in evaluating the different conceptual designs.

Criteria

Our team came up with different criteria in order to evaluate the different designs for the motor, the design for the pool cover itself, the control system, and the materials used in building the pool cover.

For the motor, our team came up with the following criteria:

- Power output
- Safety
- Price

- Lifespan
- Manufacturability

The power output of the motor that goes into the final design has to be enough to extend and retract the pool cover. The pool cover itself will be exposed to a large amount of water and the motor will be within close vicinity of the pool. There will have to be a properly enclosed housing unit that is safe enough to not have any electrical problems or cause injury. The price of the motor must be reasonable to stay under the total budget of $50,000 that Mr. Herzog set out for our team. With the goal being to take the design to market after it is completed, both ease of manufacturability and lifespan need to be optimized for mass scale production and long term usage.

For the design for the pool cover, our team came up with the following criteria:

- Volume
- Ease of retraction
- Maintainability
- Manufacturability

The pool cover must fit within the space at the end of Mr. Herzog's infinity pool, and the cover has to easily retract and extend to be used with the motor that the team chooses. The pool cover will ideally have minimal maintenance required, and if a problem occurs it should be easy to access the pool cover and remove it for inspection. The manufacturability for the final design is important because of the mass scale production for selling the product to consumers.

Our team came up with the following criteria for the control system:

- Response time
- Ease of use

The control system will be what the user operates to extend and retract the pool cover. Mr. Herzog gave our team a requirement that the cover must extend or retract within 1 minute. The controls must also be simple enough for anyone to operate the pool cover.

In order to evaluate the materials for building the final design of the pool cover, our team came up with the following criteria:

- Price
- Water resistance
- Yield strength

The price of the material is important because there will be a large amount of material used for the pool cover. The material chosen has to have high water resistance and be non-corrosive, because the pool water is filled with chemicals that will cause corrosion in certain metals. In order to support the weight of multiple people, the material will have to have a high enough yield strength in order to resist bending or deformation.

Concept Generation

Our team brainstormed different concepts for each functionality and then evaluated them further in the report using decision matrices.

Motor

For the motor, our team decided to either use an electric motor or a hydraulic motor to power the extension and retraction of the pool cover. Either choice should have enough torque to rotate the pool cover out on the guide rails to cover the pool. The main differences between the two choices are the price and safety criteria that our team chose to evaluate them with. The two choices are evaluated further on in the decision matrix section of the report.

Pool Cover Design

The team came up with four different conceptual designs for the pool cover which include stacking, rolling, garage door, and a meet in the middle design. The stacking design is an idea that includes different sized slabs that stack back and forth on top of each other inside the housing unit, and when extended, each unstack and unroll out to cover the pool in one solid piece. The rolling design consists of having the pool cover be able to roll up into the housing unit, and that will be a challenge if the material used is metal because the volume that the housing can take up is more rectangular than square, and having metal roll up will turn out to be more square than rectangular. The garage door idea involves using a garage door motor with a pool cover that will be built into a sliding area on the side of the pool, but building this design will require additional construction around the pool area to hold the pool cover as one unit. Having a meet in the middle design will require two motors with housing units at each end of the pool, essentially cutting the volumes for each housing unit in half.

Control System

For the pool cover to retract and extend, it needs a control system telling it to either open or close. Our designs that we came up with include a key start, a remote start, a button/switch, or a lever start. The key start is connected directly to the motor and could be installed near the pool on the side of the wall and works with a key that will either turn the motor on and extend in one direction or retract in the other. The remote start will be more challenging to design electrically, but will allow the user to turn the automated pool cover on and off from anywhere within the pool house. The button/switch idea will be a simple on or off button/switch on the wall near the pool that controls the pool cover that way. Building the lever design will be challenging as well because it will operate based off the user pushing it up and extending or pulling it back and retracting.

Materials

The materials chosen for the final design will be what the pool cover is made out of. Our choices for materials that we came up with include stainless steel, aluminum, brass, some sort of polymer, and fiberglass. The criteria used in evaluating the materials and the final choice for the pool cover can be found further in the decision matrix section. The main two criteria that have to be met for the material choice are the water resistance and the yield strength.

Decision Matrices

Our team developed four decision matrices for each component of our design based on the criteria chosen. The criteria for each component was scored and given a weight which is shown in the column left of the criteria. Each concept is given a number on a 1-10 scale, 1 being the worst and 10 being the best, and the team rated each concept for each component on which best suits that specific criteria. The scaled value and the weight for each criteria for the specific concept is multiplied to get a final weighted score for the criteria. These are all added up to get a final score for the concept; the highest scored concept for each component is chosen as best suitable for our design based on the decision matrices. Tables 1-4 show the decision matrix for the motor, pool cover design, control system, and material, respectively.

Table 1: *Decision matrix for motor*

Motor					
		Electric		**Hydraulic**	
Criteria	Weight	Scale	Weighted Scale	Scale	Weighted Scale
Power output	0.245	10	2.45	10	2.45
Safety	0.4118	4	1.647	8	3.294
Price	0.1015	7	0.711	6	0.609
Lifespan	0.1128	7	0.79	7	0.79
Manufacturability	0.1289	8	1.031	8	1.031
Sum	**1.0**	**36**	**6.629**	**39**	**8.174**

Table 2: *Decision matrix for pool cover design*

Design									
		Stacking		**Rolling**		**Garage Door**		**Meet in Middle**	
Criteria	Weight	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale
Volume	0.3662	7	2.563	7	2.563	9	3.296	4	1.465
Ease of retraction	0.2783	7	1.948	7	1.948	5	1.392	8	2.226
Maintainability	0.2056	9	1.85	8	1.645	7	1.439	6	1.234
Manufacturability	0.1499	9	1.349	7	1.049	6	0.899	4	0.6
Sum	**1.0**	**32**	**7.71**	**29**	**7.205**	**27**	**7.026**	**22**	**5.525**

Table 3: *Decision matrix for control system*

Control System									
		Key Start		**Remote Start**		**Button/Switch**		**Lever Start**	
Criteria	Weight	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale
Response time	0.5915	10	5.915	9	5.234	9	5.234	9	5.234
Ease of use	0.4085	9	3.677	10	4.085	10	4.085	8	3.268
Sum	**1.0**	**19**	**9.592**	**19**	**9.319**	**19**	**9.319**	**17**	**8.502**

Table 4: *Decision matrix for materials*

Materials											
		Aluminum		**Stainless Steel**		**Brass**		**Polymer**		**Fiberglass**	
Criteria	Weight	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale	Scale	Weighted Scale
Price	0.2165	8	1.732	4	0.866	6	1.299	4	0.866	5	1.083
Water resistance	0.2461	8	1.969	9	2.215	7	1.723	9	2.215	10	2.461
Yield strength	0.5374	9	4.837	9	4.837	8	4.299	6	3.224	10	5.374
Sum	**1.0**	**25**	**8.538**	**22**	**7.918**	**21**	**7.321**	**19**	**6.305**	**25**	**8.918**

The best suitable concept for each component is highlighted in yellow in the decision matrices. Based on the criteria, respective weights, and score of the concepts, the best-suited components for our pool cover are: a hydraulic motor, a stacking design, a key start control system, and fiberglass as the material. However, the group has made slight ideal changes to the choices determined by two of the decision matrices. The decision matrices in question are for the control system and materials.

For the control system, although the key start design was selected, the remote start and button/switch designs are close in value to the key start design. This means that if we wanted, we could implement either of these designs, whether the design is more related to what Mr. Herzog desires or is more manageable to fabricate. Additionally, the same can be said for the materials decision matrix.

We have decided to choose aluminum over fiberglass for use on the plates. Again, as the values generated from the decision matrix are close, we are using our own discrepancies on the project. Our team believe that aluminum would still be sufficient enough in the yield strength and water resistance factors to switch materials. Also, the price would be significantly reduced for the cost of the material.

Prototype

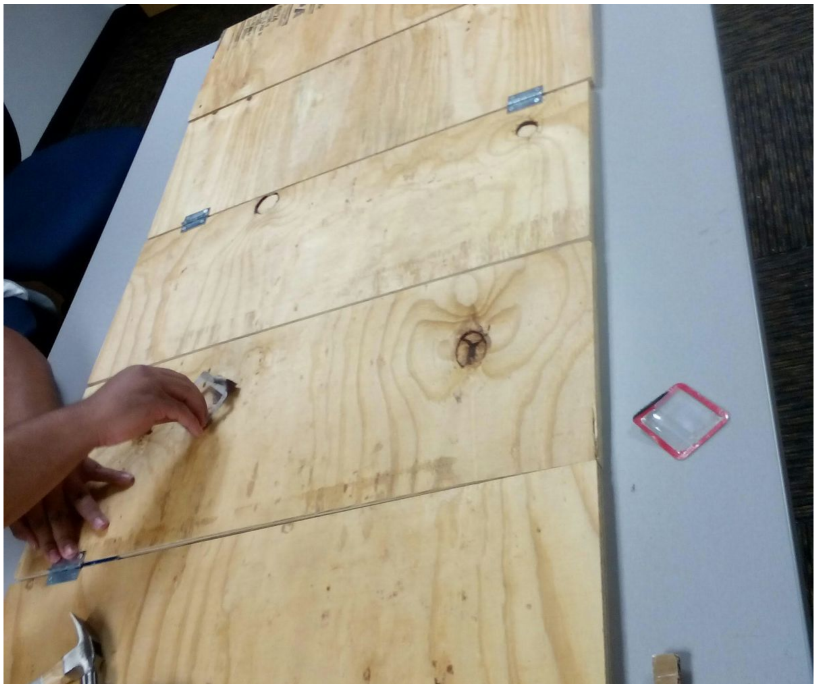


Figure 3: *Fully extended plates*

Figure 4: *Vertical stacking of plates*

Our team has built an initial prototype which will show our proof of concept for our preliminary designs. Our goal of the prototype was to find out if there are any difficulties in the system and also to test our methodology of solving the stacking system problem. Our major focus was on the pulley system, wheels, and hinges. The pulley task is to pull the first wheel attached to first plate while closing or opening. Unfortunately, we did not have a motor so could not test whether the force applied via the motor is significant to the friction force. Instead, our team applied pulling force and continued testing for the other tasks. The hinges worked well and let the plates collapse vertically, but while trying to close, the plates could fail due to the downward facing hinges not having any spring action to allow for vertical motion to close the cover. The other difficulty that we encountered were the wheels and railing system. We need to have some sort of vertical motion to close the cover, exactly the same as the hinge issue. Our team has thought of the "bump theory" which will be further explained in the railing system section. A small bump will be placed on the railing so that it allows the wheels to have vertical motion and buckle to stack vertically.

Plate Design

The design of the plates involves the safety of people crossing the pool cover. The plates have to withstand multiple people standing on them, which means they have to be strong enough to hold the amount of weight applied on it. However, the plates need to be lightweight so that the force required to push the plates open or pull the plates closed is as minimal as possible. Our team has designed plates that have a high factor of safety and at the same time is lightweight. A thin sheet of metal that can be supported by a frame will satisfy our need of a strong plate. The thin sheet will be made of aluminum and the frame will have multiple bars so that the load can be distributed among the entire plate. The dimensions of an individual plate are l ft wide by 9 ft long. Our system will contain 16 identical plates hinged together to form the pool cover.

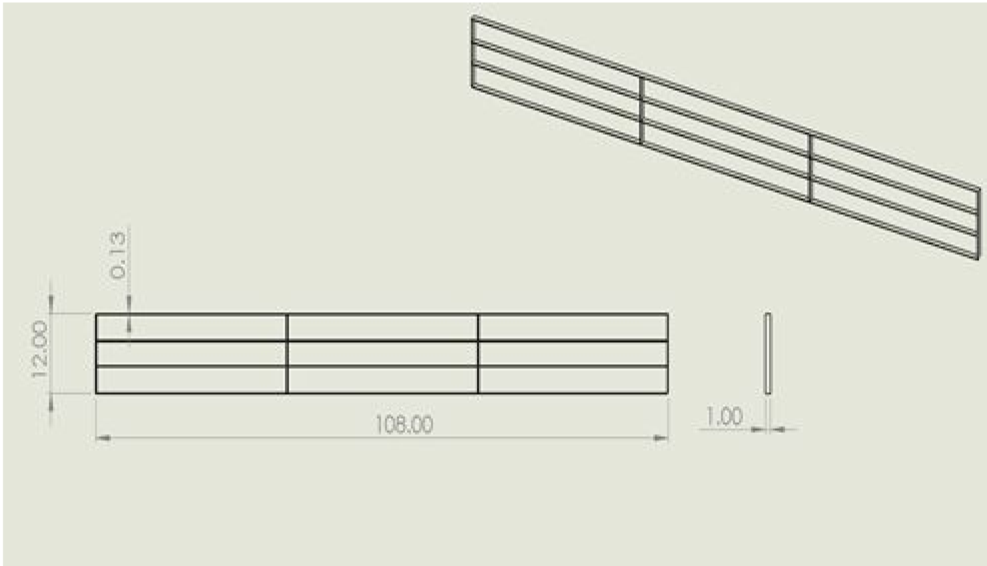


Figure 5: *Illustrates the shape of frame that will become a plate*

The calculation of stresses was done based on the shape illustrated by the figure. By looking at the shape, the maximum bending stress will occur if the weight is applied in the middle of frame. This is because if the weight is applied close to either supports, the bending stress decreases due to the decreasing of the bending moment of the frame. Assuming a person stands in middle and has a weight of 250 lbs, the two bars in the middle will experience the most weight compared to the other bars. Since, most of the weight will be on these two bars, analyzing one of these two bars is significant to the others.

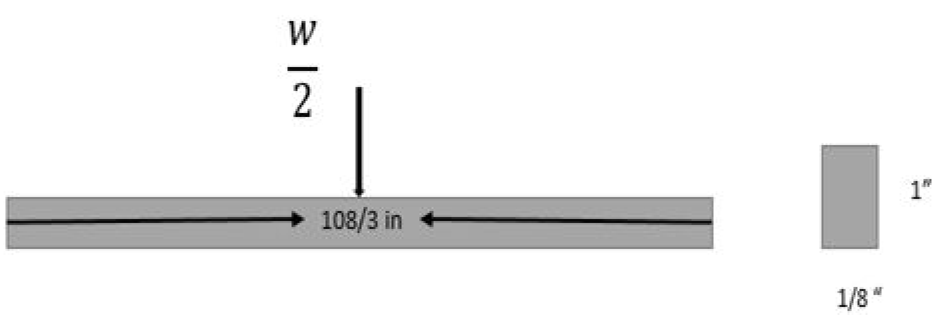


Figure 6: *Free body diagram of one beam in the frame*

$$Average\ weight\ of\ a\ person = 250\ lb$$

$$\sigma = \frac{MC}{I} = \frac{\left(\frac{35.92}{2}\right)\left(\frac{250}{2}\right)(0.5)}{\frac{1}{96}} = 10.8\ ksi$$

$$\sigma_y = 35\ ksi\ \rightarrow Aluminum$$

$$n = \frac{\sigma_y}{\sigma} = \frac{35\ ksi}{10.8\ ksi} = 3.2\ \rightarrow Factor\ of\ Safety$$

Figure 6: *Calculations of the max stress and factor of safety*

σ = bending stress (ksi)

M = bending moment (lb-in)

C = neutral axis (in)

I = moment of inertia about neutral axis (in^4)

σ_y = yield strength of aluminum (ksi)

n = factor of safety

<u>Hinges</u>

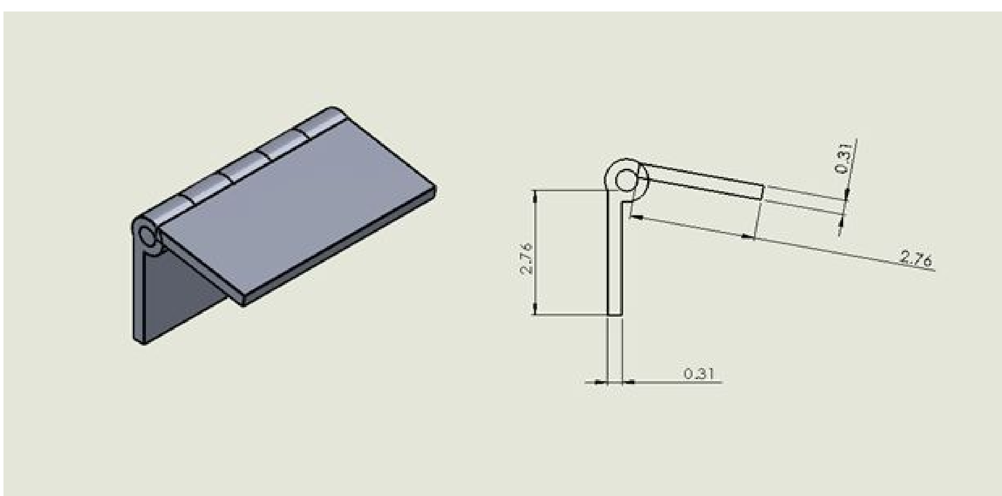


Figure 8: *Hinge dimensions*

Hinges are required to connect the plates together. The first task of the hinge is pulling the next plates to either close or open. The second task is to allow the plates to collapse vertically while closing and extend the plates while opening. In our case, two hinges between plates should be enough to do both tasks. In total, 30 hinges will be needed for all the plates. These hinges can be found at Home Depot or on McMaster-Carr. We have tested the hinges and found them to be strong enough for both tasks.

Table 5: *Bill of materials for the plates*

Material	**Quantity/Dim.**	**Price**
Aluminum Frame	64 long beams (9' X 0.125" X 1")	$252.80
Aluminum Frame	64 short beams (1' X 0.125" X 1")	$45.44
Aluminum Sheet	16 (1' X 9' X 0.125")	$1530.72
Hinges	30	$102
Total Price	-	**$1828.96**

Motor Design

As seen from the decision matrices above, our team has chosen to use a hydraulic motor. The motor we chose is an Extreme Hydraulics IHI-BMPH-160-H4-K-S. This is a high torque, low speed hydraulic motor with a maximum of 159.72 HP. The motor is roughly 8 in long, so it is small enough to be placed in the bottom of the housing, but strong enough to extend or retract the pool cover. The power to weight ratio is roughly 1.06 HP/lb. The price of this motor is about $155 and can be found at www.internationalhydraulicsus.com/. A CAD model is shown below with a fully dimensioned drawing.

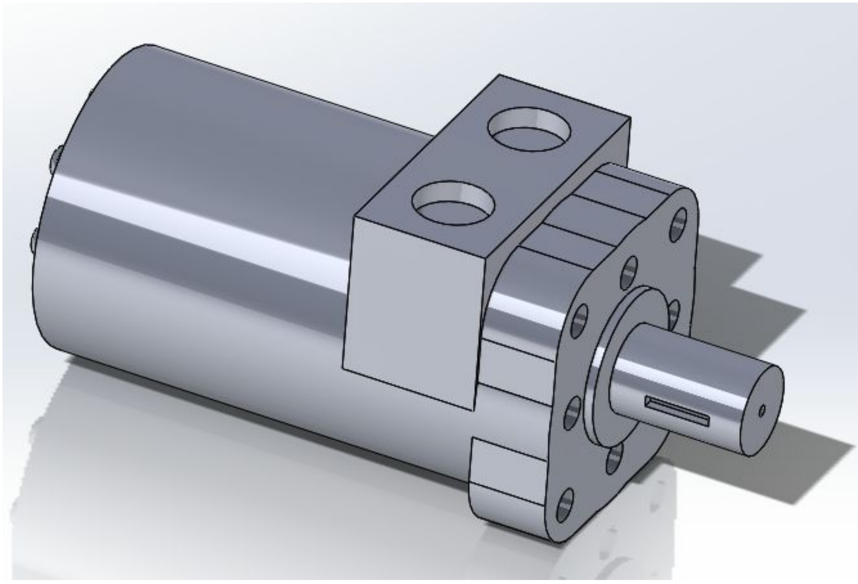


Figure 9: *CAD model of the motor*

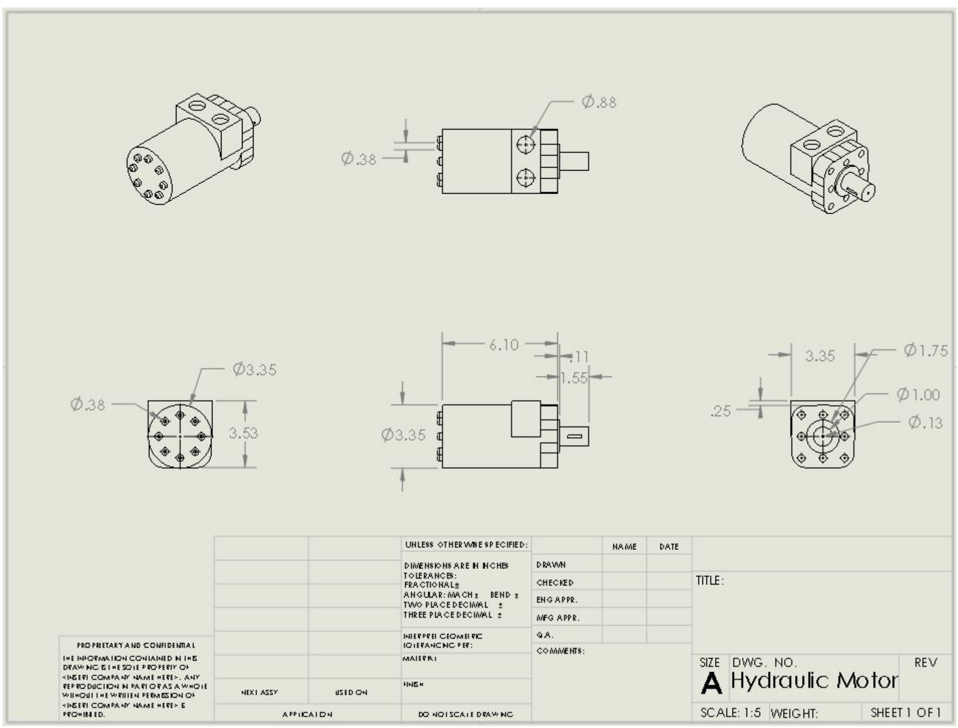


Figure 10: *CAD drawing of the motor with dimensions*

Our team still has to design a hydraulic system to go with the motor and figure out how to provide power to the motor. We have done research and it seems that attaching a reel to the end of our shaft in order for the cable to roll up on would work well. There would need to be a reel on each end of the motor, therefore an intermediate shaft will connect the motor shaft to a larger shaft that will have a reel on each end. This larger shaft will probably lie beneath the motor. When this system is figured out and properly set up, the power supply must then be figured out.

Railing System

The railing system chosen can be seen in the figure below. This system is ideal because it is commercially available. This negates the need to manufacture our own rails in house. The railing system has a very low profile. This is ideal for the application because a low profile allows for a more aesthetically pleasing design and is less of a hazard when entering and exiting the pool. The product can be manufactured in either steel or stainless steel. As seen in Table 6, stainless steel is very expensive, and although steel is less expensive, it is not as strong or non-corrosive. The strength of the material is not of utmost importance since the stresses the rail sees will be distributed along its length. However, since the rails will be very near the water, an anti-corrosive material would be best. If the price of stainless steel is too high, an anti-corrosive paint or spray can be applied to the rail system in order to prevent corrosion and drastically reduce the price. The rail design also has a C-clamp shape in order to secure the wheels. However, in the enclosure the wheels need to come out of the rail when it folds. This means the rail system needs to be modified for the section in the enclosure, the top of the C can be removed to solve this.

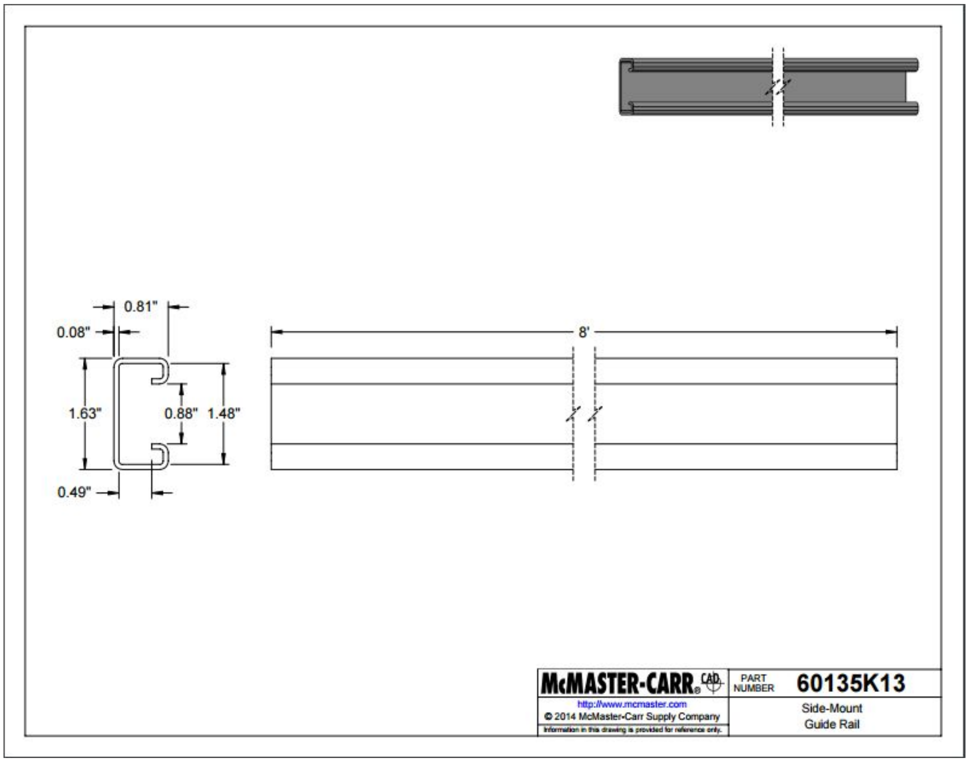


Figure 11: *McMaster-Carr rail drawing*

Table 6: *Price comparison for different railing materials*

	Steel	**Stainless Steel**
Length Needed (ft)	32	32
Price per foot ($/ft)	9.86	34.16
Total Price	$315.52	$1093.12

The “bump theory” still needs to be tested for our rails. The bump theory is a theory that if “bumps” are placed along the rail, it will introduce a small amount of vertical motion to the system during retraction. This vertical motion will disengage the hinge and allow the plates to fold. This addresses the problem that occurred during our prototype demonstration. The fashion in which the rails are installed on the sides of the pool also needs to be addressed. It is likely that the most reasonable method would be screwing the rails into place. The only concern with this method are the strength of the fasteners.

Wheel Design

The wheels chosen for the design are also sold by McMaster-Carr. These wheels are designed to work with the selected railing system. These wheels are also available in both steel and stainless steel. The material of the wheels is not as critical as the railing system. It is not expected that the wheels will see very much moisture, however there is always a possibility. The price differential of stainless steel and steel, for the wheels is not as large as the rails. The stainless steel wheels would not be a bad option. If neither of these wheels seem to work, there are also many rubber options. Rubber would eliminate the corrosivity concern and it would likely roll much smoother than a metal on metal system. This is an option to keep in mind.

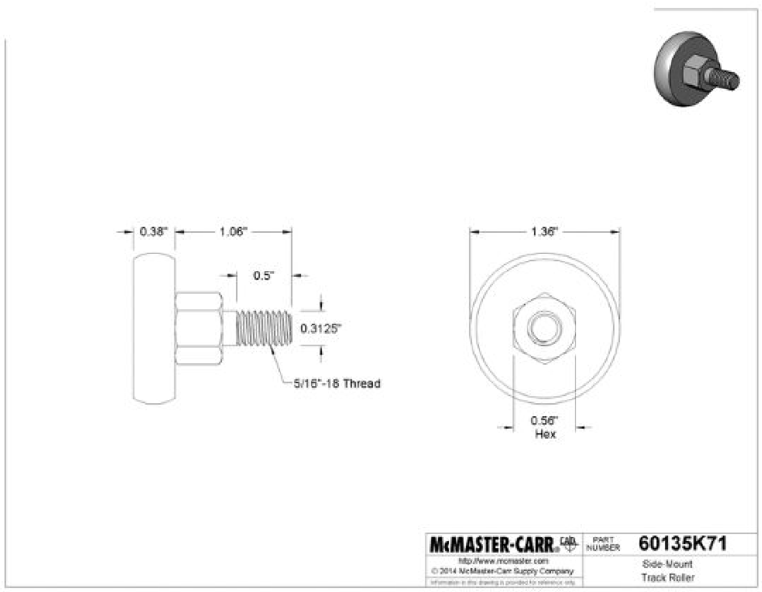


Figure 12: *McMaster wheel drawing*

Table 7: *Price comparison for different wheel materials*

	Steel	Stainless Steel
Units Needed	16	16
Price Per Unit ($/unit)	20.04	36.65
Total Price	$320.64	$586.40

The only thing left to decide for the wheel design is the fashion in which they are fastened to the plate. There will need to be a bracket that the thread of the wheel screws into and is either attached to the plates by fastener or by means of welding. These brackets need to be of very high strength, the joint will be a high stress concentrator.

Housing Design

The complete housing design can be seen in the figure below.

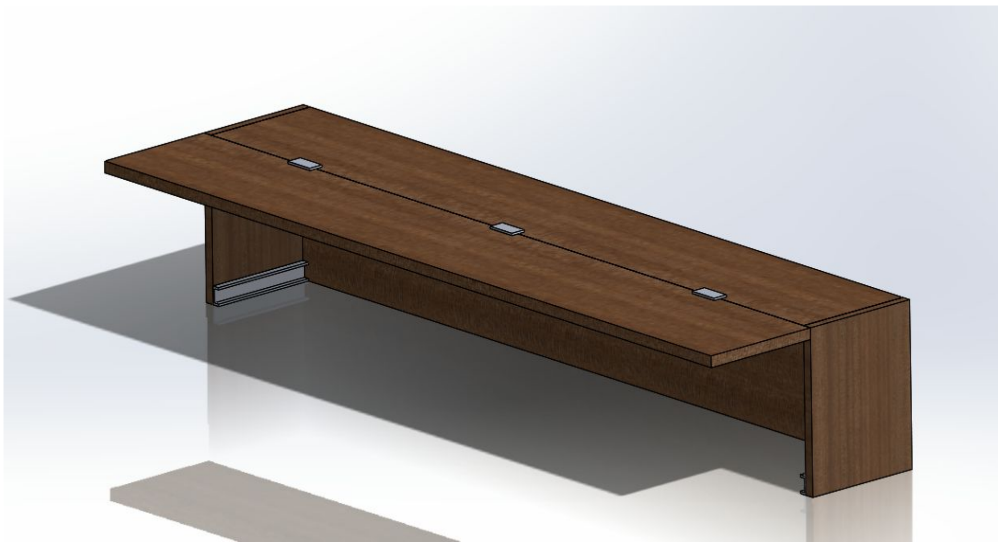


Figure 13: *CAD model of the housing design*

Each panel is made out of wood, and was designed to be 18” wide on the side, 16” tall, and 9’ across the front. There is enough clearance room to allow for the rails to be installed and to insure that the panels can completely fit inside once completely stacked. Different types of wood can be chosen if the red oak plywood does not fit within the pool house design, and the wooden panels will have to be stained to make them water resistant. The front panel will be hinged and will automatically open and close with the extension and retraction of the pool cover with the help of a stepper motor. The stepper motor will provide the torque needed to lift the front panel from vertical to horizontal. An open bottom will be needed to allow the motor component to be installed below the housing. Once built, the housing will look and function like a bench that is installed at the end of the infinity pool. The next step for the housing is to build the panels, design the electrical system to operate the front hinged panel, and check to make sure that the dimensions of the housing will fit within the space allowed at the end of the pool. The full build of materials list for the housing is shown below.

Table 8: *Bill of materials for the housing design*

Material	Quantity	Price
Red Oak Plywood (4'x9')	4	$159.80
Wood Finish (1 quart)	3	$23.31
Hinges	3	$22.98
Stepper Motor	1	$35.50
Total Price	**-**	**$241.59**

Bill of Materials

Our team has totaled up a final bill of materials for our entire designed system as seen below in Figure 9. We have used stainless steel prices for the rails and wheels, the price for two motors, and an expensive thin sheet of aluminum. With that in mind, our total estimated cost comes out to $4138.70, which is well within a reasonable range. Our cost will still rise because the system is not completely designed and every aspect in not yet accounted for. If the pool cover system's total price is less than $15000, then if successful, it should be well below comparable market prices that Mr. Herzog found to be around $50000.

Table 9: *Total bill of materials for pool cover system*

Materials	Quantity/Dimension	Price
Motor	2	$309.94
Rails	2	$1093.12

Wheels	16	$586.40
Aluminum Frame	64 long beams (9’ X 0.125” X 1”)	$252.80
Aluminum Frame	64 short beams (1’ X 0.125” X 1”)	$45.44
Aluminum Sheet	16 (1’ X 9’ X 0.125”)	$1530.72
Hinges	30	$102
Housing Materials	-	$241.59
Total Price	-	**$4138.70**

Conclusion

Our final design consists of the previous subsystems integrated with one another. The final price for the materials at this moment is just over $4100. However, there are still some things that need to be cleared up before we can begin the fabrication process. A hydraulic system must be determined before the motors can be used to extend and retract the pool cover. Additionally, for the railing system the bump needs to be tested in order for the plates to fold correctly. For the wheels, we need to determine the best course of action for how to fasten these to the plates whether it is through the frame or an extension. We are also looking into a different material to cover the framework of the pool cover, instead of aluminum, to help reduce the price of the product. Although, the new materials that we look at still need to provide support to any weight on it. This means that the deflection still needs to be low and any of the stress we believe to be present during normal circumstances will be within the elastic region of the material. Finally, for the housing system we will look into using two motors to control the opening hatch of the frame work. With the addition of a second motor, the reliability of the system working will increase as we will only look at motors that could open the door on their own. This is a precautionary measure, that way if one of the motors fails, the system can still operate. Next semester, our team will look into addressing what still needs to be done and then start to begin the fabrication process.