Christmas Ornament Display Structure

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Engineering Analysis

Document

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INTRODUCTION

The client, My Star of Bethlehem LLC, indicated that they do not have an aesthetically pleasing way to easily display their Christmas ornaments when marketing their products locally. Presently, when the company is promoting their products they use a square four legged tent with three tables setup underneath in a U-shaped configuration. The Christmas stars are both displayed on these tables and hung from the top of the tent frame.

The goal is to design a better way to display the Christmas ornaments when My Star of Bethlehem LLC is marketing their products to potential customers. This design will provide an effective means to display their products at trade shows, private properties, shopping malls etc. Currently, this display stand is being designed for promotional applications, however; it may also have potential consumer applications depending on cost and other design criteria.

MODIFICATIONS TO PREVIOUS DESIGN

Initially, the display stand was being designed to accommodate one star. The client mentioned from the beginning that the structure would only display one ornament at a time and to design accordingly. Based on feedback received from the presentation on concept generation and selection, it was asked of the client if having multiple stars hung at the same time from the same ornament stand had ever been considered. The client responded positively and thought having the ability to hang multiple ornaments would make the stand more versatile and would be a better use of resources. The design was quickly modified to accommodate 3 ornaments and underwent several changes.

The first and obvious change was to create two other holes on the underside of the arch so that two additional electrical cords could be threaded through the hollow cross section. The rectangular geometry of the arch was changed to a square cross section for reasons discussed in the next section. The circular base was cut in half to increase portability and allow both sections to be completely separated when not assembled. This did not necessarily decrease the overall weight of the base but rather facilitated the carrying of both halves separately. Two hinges will be welded on to the base and secured with a locking pin when assembled. This locking pin can be easily removed for disassembly. Another hinge was added that attaches the bottom of the arch to the circular base itself. This hinge facilitates rotation of the arch so that it can be setup on the ground longitudinally and pivoted into a vertical position where it will be secured to the circular base. Three studs fasten the hinged plate to the bottom of the arch and another two studs fasten the hinged plate to the circular base. The bottom of the arch is extruded downward to provide additional support to the arch itself as seen in Appendix A.

MATERIALS AND GEOMETRIES CONSIDERED

The only materials considered for this design were steel and aluminum. Strength, weight and cost heavily influenced the material selection as they were all factors listed in the project objectives and constraints. In general, aluminum is more expensive than steel, about 7 times as much as of March, 2011, except in the case of stainless steel which contains chromium and sometimes nickel. Both are relatively rare elements when compared to aluminum and therefore more costly. From a cost perspective, steel was more attractive; however, steel is about 3 times heavier than aluminum. Because the project budget is flexible and because light weight is one of the constraints, aluminum seemed to be the better choice. Aluminum provides the stiffness required (steels modulus of elasticity is about 3 times as much), the corrosion resistance needed, is much lighter than steel, and readily available with the most significant downside being cost. It was determined that the advantage of aluminum outweighed the disadvantages and was decided on over steel with the project objectives and constraints in mind.

Several geometries were considered for the different components of the arch and base. These geometries include square, rectangular and circular cross sections. The circular section was initially ignored because the square and rectangular cross sections were thought to be more visually appealing. Another reason the square and rectangular sections were more favored was because a hinge could more easily be attached due to a flat surface. After talking with the client about the three possible cross sections, preference was given to the rectangular geometry. However, if there was a significant difference in cost between square and rectangular geometries and the cheaper one would be favored. After doing some price comparisons online between the 3 similarly dimensioned aluminum cross sections using the same websites for each one, it was found that the rectangular and square tubing was either cheaper or not significantly different than the round tubing [4]. Significantly different in this case means greater than $30.00. Between the rectangular and square cross sections, it was found based on some research that aluminum square geometries are cheaper to manufacture and therefore purchase [6]. For this reason, a square cross section for the arch was chosen made of 6063-T6 aluminum for its lightweight, corrosion resistance and formability.

For the base itself only square and circular geometries were considered due to user safety and aesthetics. With a circular base, there would be no pointed edges and visually, it looked more appealing. The square base was not chosen for these reasons. The base was selected to be made out of 3003-H14 aluminum due to its excellent weldability, formability, good corrosion resistance and a smooth shiny finish.

ENGINEERING ANALYSIS

To analyze the display stand, a full-scale model in SolidWorks was designed that could then be used to find the mass properties of the entire structure. Through SolidWorks, the center of mass and the moments of inertia were generated which aided in finding the reaction forces at the base. From these forces, the stresses induced in each section of the structure due to loading can be found. A static analysis of the structure, neglecting the force of the wind, was performed which involved summing moments about the base to find the reaction force. The surface area of one side of each arch section was found based on the dimensions of the tubing used to construct the arch. This will become important when analyzing the force due to wind on the stand which will be a maximum when the wind is impacting the stand perpendicularly from either of the two symmetric sides, assuming that the wind will only impact one side at a time. The structure is divided into four sections and each section contributes to the reactions at the base relative to the section weight and the location of that section with respect to the base. For this analysis, three of the largest ornaments were considered (assuming the worst-case scenario) to approximate the maximum static load that this structure will experience. This type of scenario is not anticipated due to the client's intention of only displaying one of each size ornament at any given time. The values obtained from the SolidWorks model are listed below.

Some of the assumptions considered in the analysis of this structure are:

- Unidirectional wind flow
- Wind speed will not exceed 50 mph
- The aerodynamic analysis will model the ornament as a sphere
- Ambient temperature will not exceed 100 ˚F
- Maximum of three ornaments displayed at any one time
- Uniform thermal expansion due to uniform material thickness and composition
- Force due to wind acting on the base is negligible

<u>Center of mass measured from the center of the base</u>

With x being the horizontal coordinate and considered positive moving towards the curve of the arch in the latitudinal direction, the center of mass COM_x location is 11.32 inches away from the center of the base.

With y being the vertical coordinate and considered positive moving longitudinally towards the tip of the arch, the center of mass COM_y location is 17.52 inches above the center of the base.

With z being the depth coordinate and considered positive when pointing away from the arch when the concavity opens to the right side, the center of mass location COM_z is 0.00 inches as it is symmetric about the vertical plane which intersects the arch halfway through the cross section of the tubing.

<u>Top Section of the arch structure</u>

Force due to weight (including the 3 largest ornaments) F_{wt} = 28.5 lb
Distance from the force due to weight to the center of the base D_{fwt} = 63.68 in
Surface area of one side A_{st} = 185.44 in^2

<u>Middle Section of the arch structure</u>

Force due to weight F_{wm} = 4.92 lb
Distance from force due to weight to the center of the base D_{fwm} = 72.22 in
Surface area of one side A_{sm} = 129.33 in^2

<u>Bottom section of the arch structure</u>

Force due to weight F_{wb} = 21.12 lb
Distance from force due to weight to the center of the base $D_{fwb} = 70$ in
Surface area of one side A_{sb} = 192.52 in^2

<u>Base of the entire structure</u>

Force due to weight F_{wbase} = 52.49 lb
Diameter of base $D_{base} = 47.75$ in
Surface area of the base bottom A_{base} = 1825.64 in^2

In performing the static analysis of this structure, the weight of the ornament acting directly above the center of the base will not cause a moment and therefore was neglected in the moment Equation 1.1. Summing the moments about the origin located at the center of the base, where clockwise is considered positive, the following equation was obtained.

$$\sum M_o = F_{wt}(D_{fwt}) + F_{wm}(D_{fwm}) + F_{wb}(D_{fwb}) + R_{base}(D_{base}/2) = 0 \qquad (1.1)$$

All of the values in Equation 1.1 are known with the exception of R_{base}, R_{base} can be found by solving Equation 1.1 which is the reaction of the base at the outermost edge located directly behind the extrusion on the base of the arch. This edge will provide the reaction force needed to stabilize the structure and is found to be.

$$R_{base} = 60.9806 \text{ lb}$$

This force resists the tendency of the arch to rotate about the center of the base assuming that the base of the structure can withstand the stress induced by this force. If this is true, then the base design is sufficient. This stress will be calculated using the following Equation 1.2.

$$\sigma = \frac{M(y)}{A(e)(r_n - y)} \qquad (1.2)$$

Where:
σ = stress
M = moment
y = distance from the neutral axis to the outer fiber of the cross section
e = distance from the neutral axis to the centroidal axis
A = cross sectional area
r_n = distance from the origin to the neutral axis

Many of these values are not yet known but will be found as more of the analysis is completed and data is gathered. Once the stress induced on the structure is calculated at different locations, it can be determined whether or not the current material will withstand the loading that will occur. In the event that the current material is not strong enough to withstand the forces it will be subjected to, a stronger material will need to be selected that may have a higher density and or cost more.

Another important engineering analysis that must be considered is one that involves the environmental effects on the structure during use. The effects considered in the analysis are wind, temperature and precipitation. The primary focus of the environmental effects will be on the forces due to wind as the selected material is resistant to corrosion. Also, because the structure is composed of the same material throughout the stresses induced due to varying temperature will be neglected as mentioned in the assumptions.

To analyze the force due to wind, the surface areas of the sides of the arch sections were considered as these sections will experience the most force and cause the most stress in the structure. The force will be approximated assuming that a maximum wind speed of 50 mph. This maximum wind speed was found from data provided by the National Oceanic and Atmospheric Administration (NOAA) for Flagstaff, Arizona [3]. This location is assumed to be sufficient for all of Northern Arizona as it is within a 60 mile radius of the primary usage area. The force due to wind is calculated using Equation (1.3).

$$F_w = A(P)C_d \tag{1.3}$$

Where:
F_w = force due to wind
A = surface area
P = pressure due to wind
C_d = drag coefficient

To perform this analysis the entire surface area of one side of the sections of the arch must be summed because the wind will impact the entire surface. Based on this analysis the force was found to be.

$$F_w = 22.54622\ lb$$

When the forces are analyzed using the same method that was used to find the reaction force for the weight of the arch, an equation similar to Equation 1.1 can be implemented to find the reaction force, R_w, necessary to prevent instability. Using SolidWorks to find the centroid of the arch with x being the horizontal coordinate and considered positive moving towards the curve of the arch in the latitudinal direction, the center of mass COM_{xa} location is 27.65 inches away from the center of the base.

With y being the vertical coordinate and considered positive moving longitudinally towards the tip of the arch, the center of mass COM_{ya} location is 17.81 inches above the center of the base.

To find the distance from the centroid of the arch to the center of the base the Pythagorean Theorem, Equation 1.4, can be used.

$$D_{ca} = \sqrt{COM_{xa}^2 + COM_{ya}^2} \quad (1.4)$$

Where clockwise is considered positive, Equation 1.5 can be used to solve for R_w.

$$\sum \mathrm{M_o} = \mathrm{F_w}(D_{ca}) + \mathrm{R_w}(\mathrm{D_{base}}/2) = 0 \quad (1.5)$$

Where:

D_{ca} = the distance of the centroid of the arch to the center of the base

R_w = reaction force that the edge of the base

The reaction force is found to be.

$$R_w = 31.22247\ lb$$

The same equation, Equation 1.2, can be used to find the stress induced by this force which will be used to determine whether or not the material and dimensions selected are sufficient.

COST ANALYSIS

Table 1: Cost estimates for the arch and base components

Qty	Item Description	Size (w x h x t)	Length	Price Each	Total Cost
2	6063-T52 Square Aluminum Tube	2 x 2 x 0.125	96	$62.80	$125.60
1	6063-T52 Square Aluminum Tube	2 x 2 x 0.125	72	$47.10	$47.10
2	3003-H14 Aluminum Plate	24 x 48 x 0.25	48	$171.04	$342.08
1	3003-H14 Aluminum Plate	12 x 24 x 0.25	24	$42.76	$42.76
				Shipping	$5.24
				Final Cost	$562.78
All dimensions are in inches					
Due to the company (www.metalsdepot.com) being located in Kentucky no sales tax is charged					

Table 1 does not represent the costs for all materials used in the ornament stand, but does account for the majority of the costs which will come from the material used to construct the base and arch components (not including the locking pins or hinges). The first 2 rows in Table 1 represent the square aluminum tubing that will be used in the arch sections. Two 8 foot sections and one 6 foot section was considered for a total of 22 feet which is 16.67% more than what is needed. Additional tubing was accounted for to allow for mistakes that may occur during the manufacturing stage. The third row represents the aluminum plates that will be used to construct the 2 halves of the base. Buying 2 smaller plates as opposed to one larger plate which would require further modification was found to be less expensive for the base material. The fourth row represents the aluminum plate that will be used to connect the bottom of the arch to the base itself.

PROJECT TIMELINE

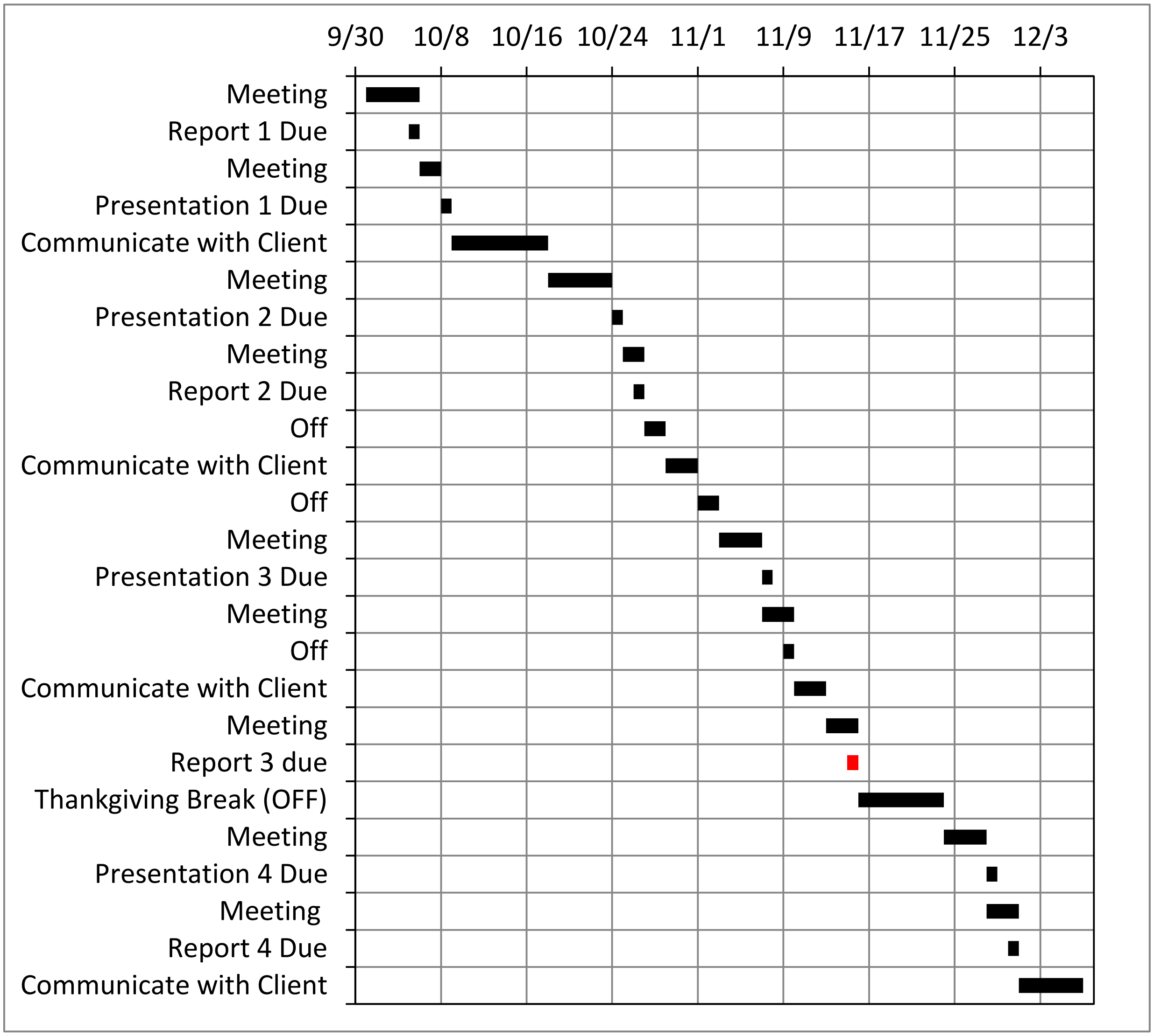

Figure 1: Project plan timeline

The project timeline in Figure 1 represents the milestone events that occur throughout the design process. This graphical representation of a project timeline can be referred to throughout the design process and serves as a guide, ensuring that tasks are accomplished within the corresponding timeframe. The timeline features the aforementioned milestone events on the left column with their corresponding timeframe in chronological order on the right. The longer bars represent a duration over which an event takes place while the shortest bars represent deadlines. The dates are represented at. the top of this chart in a time scale of 8 day increments.

Some changes have been made in the last few weeks to the project timeline worth noting. First, there was a meeting scheduled just after the second presentation initially slated for 5 days. However, it was cut back to 2 days because the additional time was not needed and the focus was on report 2. These two days provided ample time to complete what was necessary. The second change resulted from scaling back the time scheduled to communicate with the client from 5 days to 3 days shortly after report 2 was due. Again, the 3 days provided all the time that was needed to both email and physically meet with the client in order to obtain the necessary information for presentation 3. The extra two days were taken off; one day before and one day after communicating with the client. The meeting before presentation 3 was cut back from 6 to 4 days to focus on presentation 3. Because the deadline for report 3 was pushed back a week to November 16th, 2012, the time scheduled to communicate with the client beginning on November 10th, 2012 and the meeting directly following were cut back from 5 days to 2 days as they were scheduled to occur after the original report 3 deadline. Lastly, Friday, November 9th, 2012, the date report 3 was initially scheduled to be due, was taken off because a break was needed due to a hectic testing week. The red square represents where the project is at in terms of the timeline.

CONCLUSION

The client, My Star of Bethlehem LLC, requested that a display stand be constructed to assist them in showcasing their products at various marketing locations. A preliminary design was generated based on the criteria set in place by the client. Based on feedback from the client, the design was modified. Once the modifications were completed, material chosen and geometry selected, the engineering analysis could be performed. To perform this analysis many assumptions were made in order to make the calculations more manageable. When performing the analysis the focus was on the stresses that would be induced in the structure during use. Based on these stresses, the success or failure of the structure operating under normal conditions can be determined. The cost analysis indicated that the major cost for this project exists in the materials used. To perform this material cost analysis, a quote was obtained from a reputable online source from whom the material could be purchased. Changes that have been made to the project timeline primarily include shortened meetings and time to communicate with the client. Due to the postponement of report 3 and shortened meetings, some additional days were taken off.

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APPENDIX A: DISPLAY STAND FIGURES

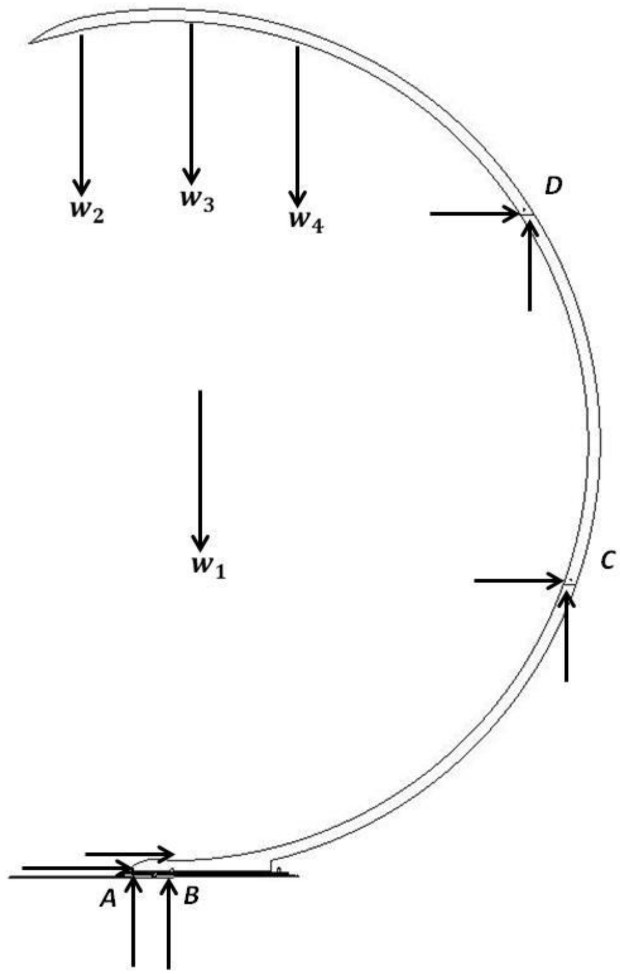

Figure 2: Free body diagram of display stand

The two forces at A and B represent the reactions of the hinge plate/arch fastening studs and the hinge plate/base fastening studs. The location C represents the reactions at the pin attaching the bottom section to the middle section of the arch. The location D represents the reactions at the pin attaching the middle section to the top section of the arch. The weights of the ornaments are shown by the vectors at the top of the arch as w_2, w_3, and w_4. The overall weight of the display stand is represented by w_1 which originates at the centroid of the entire structure.

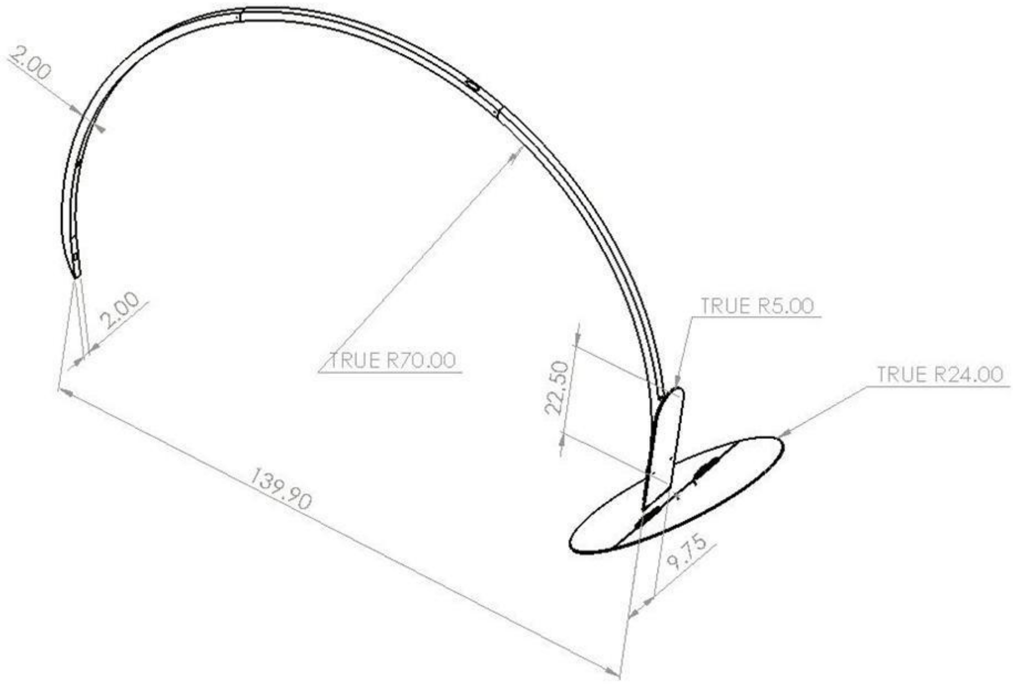

Figure 3: Display stand during arch assembly with dimensions

All dimensions shown are in inches. The center of the base plate which was referred to throughout the report includes both male and female halves when assembled as shown in Figure 3.