Twelve Days of Christmas Mechatronic Display
Final Design Report

Prepared For:
Cambria Pines Lodge

Prepared By:
Michael Beltran
Christine Hagerman
Katie Ruhm

Team Contact Info: frenchhens12@gmail.com

Table of Contents

Introduction 1

Statement of Disclaimer 1

Executive Summary 1

Research and Background 2

Objectives 7

Method of Approach 8

Design Development 9

Management Plan

- Responsibilities 17
- Project Milestones 18
- Communication 18

Final Design

- Detailed Descriptions Days 1-4 19
- Detailed Descriptions Days 5-8 29
- Detailed Descriptions Days 9-12 37

Control System

- Timing and Music 42
- Individual Days 42

Recommendations

- Safety Considerations 43
- Material Selection 43
- Maintenance and Repair 44

Electronic Maintenance and Troubleshooting 44

Manufacturing Processes 46

Prototype vs. Original Design 49

Recommendations for Future Manufacturing 50

Design Verification and Testing 51

Conclusion 56

Appendix A

Quality Function Deployment

Concept Decision Matrix

Failure Mode Effects Analysis (FMEA)

Design Verification Plan &Report (DVP&R)

Appendix B

Gantt Task List

Appendix C

Vendor Information

Material/Component Specification Sheets

Appendix D

Material Cost Analysis

Electronics Cost Analysis

Appendix E

Engineering Analysis

Programs

Appendix F

Artistic Drawings

Part Drawings

Electronic Schematic and Wiring Diagram

Appendix G

Material Specification Sheets

Adhesive Specification Sheets

Electronics Specification Sheets

Introduction

The Twelve Days of Christmas Display is a large mechatronic, light display that will be incorporated into the current Cambria Christmas Market. This project will benefit the visitors and community of Cambria, California. The display will be funded directly by the Cambria Pines Lodge, but Shana McCormick and Lee McFarland will be considered the co-sponsors and the primary contacts for the project. Throughout this report, we will be referring to the sponsor/customer as a general group and the requirements/needs will come from all of the different customers that will be interacting with the display (e.g. Shana, Dirk Winters, Cambria community). The project will require our team to design and construct a light display that will span about sixty feet of the path that winds through the Cambria Christmas Market, held at the Cambria Pines Lodge. Within this display, there will be twelve separate scenes, one for each day in the iconic Christmas song, *The Twelve Days of Christmas*. Each animated scene will be created to depict one verse from the American version of the song. The animation will incorporate moving parts (i.e., gears, shafts, and motors) and lights, both timed to the music. The motions present in the scenes will be simple but eye-catching and exciting, per the request of our sponsor. This project is meant to improve the festive Christmas Market tradition by adding a fun, new attraction.

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

Executive Summary

The Twelve Days of Christmas prototype is a moving light display based on the popular Christmas song, *The Twelve Days of Christmas*. Cambria Pines Lodge commissioned the design and construction of the display in an effort to expand their annual Christmas Market, hosted outdoors. The display was built and installed at the Cambria Pines Lodge in Cambria, California. The complete display spans approximately fifty feet in length and is divided into twelve individual displays, each depicting a singular day of the Twelve Days of Christmas. For example, the first scene includes a partridge in a pear tree, while the second day represents two turtledoves, and so on.

Each of these individual displays is four feet wide and two feet deep, while the height varies between two and four feet. The displays were constructed using a variety of materials including plywood for the base structure, acrylic plastic for the detailed features (e.g., partridge, maids, etc.), and thicker resin panels for larger elements in the display (e.g., four foot heart in Day 2). A variety of manufacturing processes were used to bring the display to life, including laser cutting acrylic into intricate shapes and using standard shop tools to assemble each display. Detail was added to the acrylic and resin panel pieces using acrylic paint, and plywood was painted using exterior paint in a variety of colors to depict appropriate scenes for each display. The displays sit on top of twelve wooden platforms arranged in semi-circular pattern for ease of viewing.

For the mechanical aspect of the display, small DC motors are used to drive mechanisms on six of the individual displays. Some of the mechanisms incorporate chains, while others incorporate linkages to produce the desired motion. LED lights were added to each display, totaling over a thousand individual light bulbs for the complete display. Holes were drilled through the plastic elements in each display and caulking was used to fix the lights in the holes. The motors and lighting elements in the display are controlled by a series of microcontrollers and relays, used to time the lights and motion to the song *The Twelve Days of Christmas.*

Research and Background

Given the complexity of the project requirements, we conducted a wide range of research to fully understand the customers' needs. We investigated the *Twelve Days of Christmas* song and theme, basic motion including four bar linkages and crank systems, parade float designs, and motor and material specifications. While there will be continuing research as the project progresses, we began with these preliminary searches.

- Theme: Twelve Days of Christmas
    - Inspired by the song "Twelve Days of Christmas"
    - Many variations of the song, but we will follow the most popular, American version as it will be seen by mostly American patrons.
        - en.wikipedia.org/wiki/The_Twelve_Days_of_Christmas
- Mechanisms and Animation
    - Researched different ways to create motion from a rotary motor
    - Simple animation for each day
        - Cam Motion
            - Figure 1 -http://www.youtube.com/watch?v=ESRsd1TeOSg

This mechanism and motion idea is very creative. It takes a cam driven system and creates a stair step motion. The ball starts at the bottom of the ramp and as the wood blocks move up and down, it a stair step fashion, the ball moves from one block to the next until it reaches the top. When it comes to the top it is then sent down the ramp to being the journey again.

- Figure 2 – http://www.youtube.com/watch?v=iWq304sq7Ak&list=PL34D1722560A8DF8
  Figure 2 depicts a second cam driven system. The system is a combination of several different kinds of motion, it is a great example of the many different motions that can be created by cams. The individual blocks either rotate, move up and down or do both.

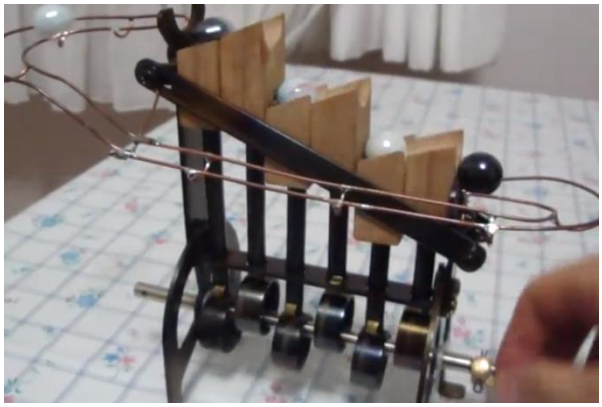


Figure 1. Cam motion for a ball moving device

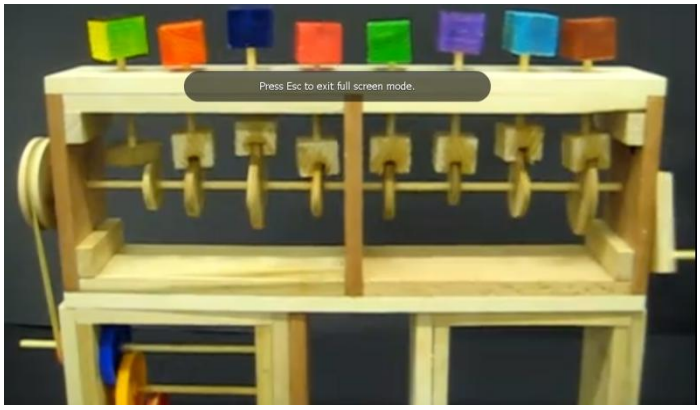
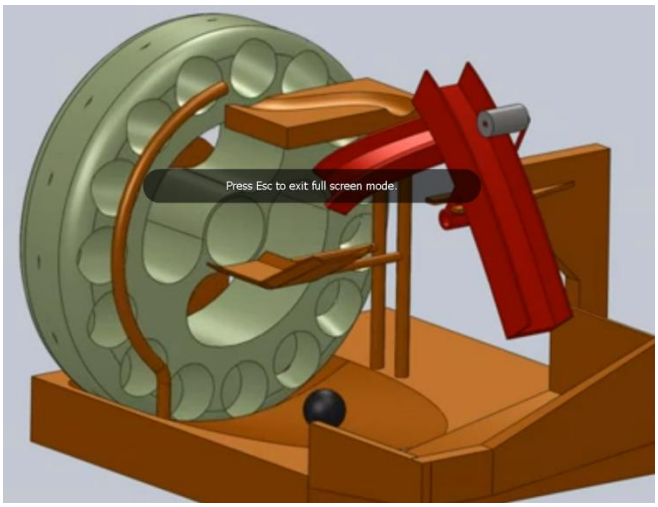


Figure 2. Use of cams for different motions off of one motor

- Rotary Motion
  - Figure 3 - http://www.youtube.com/watch?v=jHuoEeqGEYY



This mechanism is very similar to a ferris wheel. The ball "gets on" at the bottom of the wheel and is taken to the top, being kept in by the guard placed in front. However, when it gets to the top, the guard is removed and the ball rolls out. When it rolls out, it goes down a chute that takes it back to the bottom. The cycle is then repeated.

Figure3. Ferris wheel type mechanism for a ball return device. Uses purely rotary motion

- Rotary to Linear Motion
  - Figure 4 - http://www.youtube.com/watch?v=BoMeqKnLVj0&list=PLBB561A50AFDD75D9
    The value of Figure 4 is that it shows how rotary motion can be translated into linear motion. As the motor turns, the silver bar is also turned. Since this silver bar is connected to the brown bar by a slot, as the silver bar turns it is forced to slide up and down the brown slot. This forced motion causes the brown bar to follow the silver bar's rotary motion is its own linear motion as it slides across the gold slot

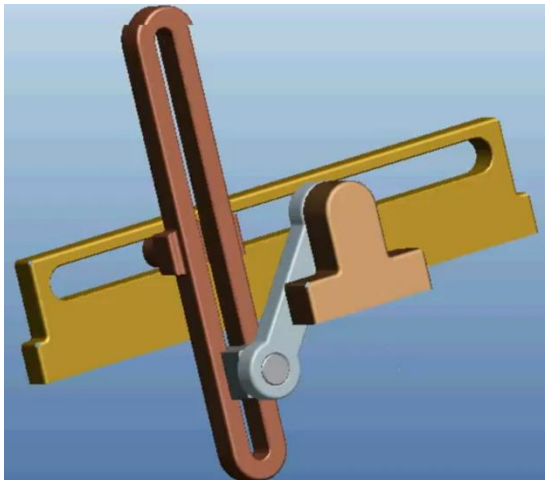


Figure 4. Changing rotary motion to a sliding, linear motion

- Figure 5 - http://www.youtube.com/watch?v=EoBKVKQLBD0
  Figure 5 is a real world example of how rotary motion can be turned into linear motion. There is a motor attached to a series of shafts, that when connected correctly allow the dolls arms to move up and down as if he were drumming.

Figure 5. Rotary motion used to make arms drum on a drum

- Linkages
    - Figure 6 - http://www.youtube.com/watch?v=9jGHAL5ZRkA
      A linkage is a prime example of how to turn rotational motion into a linear motion. The motor is attached to the crank (red bar). As the crank rotates it forces both the coupler (blue bar) and the follower (green bar) to move. By configuring different geometries, many different motions, both linear and rotational, can be accomplished.

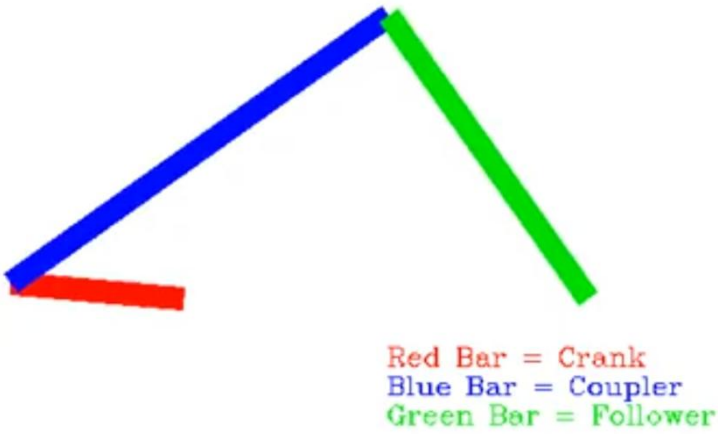


Figure 6. Example of a simple four bar linkage, turns rotary motion to linear motion

- Parade float animation
    - $100 is a typical cost of a small mechatronic device on a parade float
    - Type of motion accomplished by each mechanism
        - Simple motion – pure rotation
        - Complex motion – four bar linkages
- Disneyland/Imagineers
    - Disneyland's "It's a Small World" has achieved a much larger version of our goal.
    - It's a Small World is a great example of many different scenes and displays meshing together as one. This is done by creating continuity between the different elements, such as the style of the people. This simple link between the different scenes helps the display as a whole feel connected.
    - It utilizes small, fast and fun mechatronics that coordinate with music and lights.

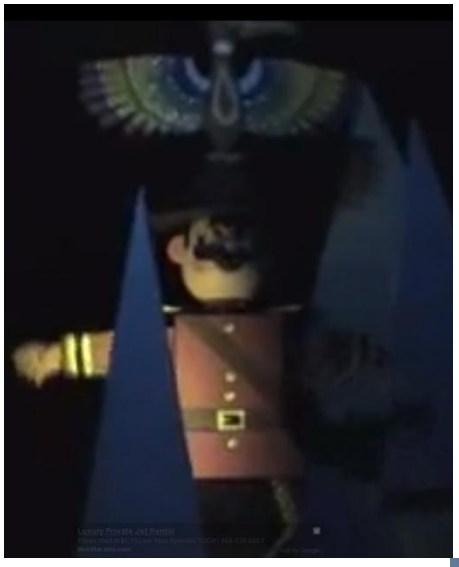


Figure 7. The guard has a combined motion that moves his mouth and arms up and down.

Figure 8. Cancan dancers in it's a small world move their legs and rotate side to side

Figure 9. The outside of It's a Small World utilizes many simple moving gadgets.

- Motors
    - Motors and Materials
        - www.mcmaster-carr.com
            - AC and DC gear motors
                - $40-55 per motor
                - Will need at least one motor per scene (12 motors)
            - Standard steel and plastic costs
- Power Supply
    - Net Energy Metering

        - Supply power to the grid during the day, but use "extra" power during the evening when the display would be on.
        - www.pge.com search "net energy metering"
    - AC/DC power supply
        - $200-250 for the entire display
        - We can go with either two large power supplies or an individual supply for each scene.
- Other Hardware
    - Home Depot/Hardware store
        - Foam, wood, paint
            - About $200 will be spent on the materials needed to build the mechanisms and scenes.

Objectives

As a team, our goal is to design and build a moving display that meets the specific requirements of our sponsor, as well as provide a professional quality product that blends well with the current Christmas display. Our focus will be to design the aspects of the display that are involved with the motion of the elements as well as the timing of the motion, lights and music. We will be contributing aesthetic and artistic ideas to the project, but will be working with an artist or graphic communications student to help us execute these designs with professional quality.

Per the sponsor's objectives, the display must be bright, vivid, and eye-catching with light and color. It should blend well with the already vibrant Christmas Market. The display cannot be harmful to the environment and should promote Cal Poly Mechanical Engineering (i.e., small sign describing our team).

In order to meet the requirements of our sponsors and their customers (i.e., Cambria Market patrons), we used a Quality Function Deployment (QFD) system to analyze customer needs. The format for the QFD is referred to as a "House of Quality" and can be found in Appendix A. We first identified customer needs and then the technical requirements corresponding to these needs. Each of the technical requirements was given a target value that depends on how each requirement is measured (e.g., target value for storage size is 120 square feet). The customer needs/requirements are weighted according to the importance to the customer and completion of the project. There is a section that identifies the stakeholders (i.e., owner, sponsors, and user) and prioritizes each customer need as high, medium, or low with respect to each stakeholder. The technical requirements were then matched and weighted with respect to each customer requirement. Also included in the QFD House of Quality is a category in which our product is compared to

existing, similar products and ranked based on their satisfaction of each customer requirement. The House of Quality includes a set of legends that explain how to read the rankings and values correctly.

Specifications				
Spec #	**Specifications from QFD**	**Requirement/Target**	**Compliance**	**Risk**
1	Height of moving parts	2.5 - 4.5 ft	A	L
2	Display size	2 x 4 x 5 ft	A, I	L
3	Weight of each day	< 60 lbs	A, T	M
4	Storage size	120 sq. ft	A, I	L
5	% viewable mechanisms	90%	I, S	M
6	Weather resistant	yes	T, I, S	M
7	Enclosed mechanisms	yes	I, S	L
8	Power draw	3000 watts	T	M
9	Drop test	survives	T, I	M
10	Push test	survives	T, I	L
11	On/off cycle test	98%	T, I	L
12	Motion	yes	T, I	L
13	Cost	< $15,000	A	L

The specifications table is a derived from the QFD. This table more clearly states the requirements, the risk and how those needs are going to be tested and measured. In this table, the compliance column is specified by letters:

A (analysis)

I (inspection)

T (testing)

S (similarity to existing designs)

These letters explain how the requirements will be tested and are further defined in the appendix. The risk column has a ranking of H (high), M (medium) or L (low), relating to the risk of that requirement not being met by the projects end. We do not have any high risk requirements and are confident that all requirements will be accomplished. Also, we do not specifically have a long life test in our technical requirements even though the total life of each mechanism is very important. The main reason for not having this test is that if we were to test the life length of a mechanism we would have to build a second one, since the first would be extremely fatigued and more likely to fail after the testing.

Method of Approach

This is the process that we will use to create a well-designed display.

- Background Research
    - Artistic theme ideas
        - Whimsical (Willy Wonka, Alice in Wonderland, bright colors, fun)
        - Traditional (homey, simple)
        - Retro (circus, big lights, bright)
    - Motions
        - Use YouTube to find examples of simple motions
        - Cam systems
        - Linkages
        - Rotation
- Brainstorm motion ideas and aesthetic design
    - Based on the characters in the scene, we came up with motions that would be complimentary
- Select desired motions for each day
    - Propose the different scene and motion ideas to our sponsor
    - They will decided on the final motion and artistic scene
- Determine ways to achieve motions
    - Create quick mockups of different mechanisms
- Make prototypes
    - Work with simplified versions of the mechanisms to make sure that it is the motion that we want
- Create dimensioned drawings of mechanisms
    - Use solid works to create a working CAD model of the mechanism
    - Proof of concept
    - Allows easy order of materials needed
- Order materials
    - Use McMaster and hardware stores to obtain the materials needed for each mechanism
- Build mechanisms
    - Work in the shops to put each mechanism together
- Test mechanisms
    - Based on the QFD specifications and requirements
- Add aesthetics to mechanisms
    - Work with the artist to create the façade that will go on top and around the mechanism
    - Look for interference zones and work around them

- Set up display in Cambria

Design Development

Figure 10. Traditional aesthetic theme

In deciding on a concept design, we focused first on the selection of a theme for the display, or how the *Twelve Days of Christmas* will be presented. Three major concept themes were debated throughout the selection process- traditional, whimsical, and vintage/retro. The traditional concept, Figure 10, was inspired by the style of a classic children's book with warm pastel coloring and rosy-cheeked, inviting characters. The cheerful feel of the set would include more simple art and motion. This theme concept would encapsulate a common Christmas display with no wacky designs or unordinary art. Concept ideas for the whimsical theme (Figure 12) included bright colors, fluid geometry, and playful motion. We were inspired by popular movies such as *Alice in Wonderland* and *Charlie and the Chocolate Factory*. The set of our display would include a more "wacky" take on the *Twelve Days* song including intriguing geometric backgrounds, neon colors or lights, and more intricate and unusual motion. Lastly, the vintage/retro design concept would incorporate classic, retro features such as old fashioned light bulbs, gum-ball machine motion, and smiling faces as in vintage advertisements. This theme was inspired by the classic Coca-Cola Santa Clause advertisements, old style motel signs with filament light bulbs, and the brightly colored imagery as seen at a circus or county fair (Figure 11).

We chose our theme by deciding which theme would best meet the needs and wants of our customer. Of the three designs, we feel that the "Whimsical" theme will best suit the requirements of this project. As our sponsors have indicated, the display should be bright, vivid, and attention-getting. The whimsical concept idea can incorporate color and intricate motion, while also presenting the *Twelve Days of Christmas* in a new and exciting way. Our hope is to provide a display that is interesting yet

F t eme

Figure 12. Whimsical aesthetic theme

different from the traditional Christmas display. We will be able to easily incorporate exciting motion and mechanical devices into this theme. As seen in *Charlie and the Chocolate Factory,* Willy Wonka's factory was filled with interesting devices and moving parts that can be imitated in our design. Whimsical motion and pictures will bring a more modern take on Christmas and will be attention-getting for both children and adults at the event.

Day 1: Partridge in a Pear Tree

The subject of the display for the first day is a partridge and a pear tree, as the song describes. To give the impression that the partridge is emerging from the pear tree, we came up with a few motion possibilities. First, seen in Figure 13, we considered a stationary tree with a window, from which the partridge would emerge with a jerking motion (e.g., a cuckoo clock). The second consideration was a bit more complicated, incorporating motion of the tree as well as motion of the bird. The tree would consist of a trunk and two branches, which would separate and reveal a stationary partridge in the center (Figure 14). Our third design was a combination of these two designs, incorporating motion of both the partridge and the tree branches. We determined that since the first day of the display would be highlighted twelve times throughout the duration of the song, we would need to have an eye-catching design. For this reason, we chose to implement the second design, in which the partridge is stationary and the tree branches move. The tree branches will separate as if hinged in the center, and the partridge will reveal itself (Figure 15).

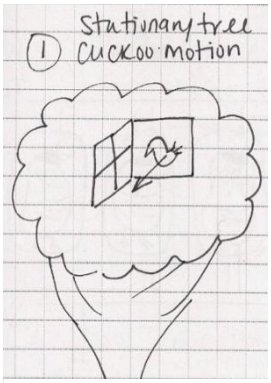


Figure 13

Figure 14

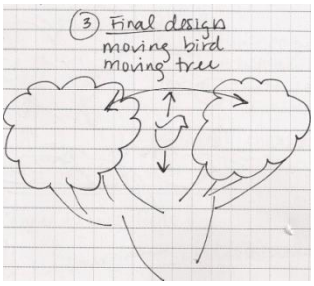


Figure 15

Day 2: Two Turtle Doves The second day of the display will focus on a pair of turtledoves. As with the first display, we had multiple possibilities for motion design. One option was to design a wire system around a stationary heart (Figure 16). The doves would be attached to the wires and rotate about the heart with a type of floating, bouncing motion. The second option, shown in Figure 17, was to create the illusion that the doves are kissing by raising the birds' until their beaks touched. As soon as their beaks touch, a series of hearts formed by lights would light up in

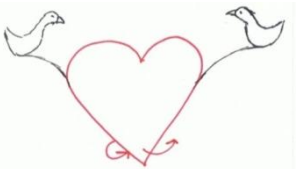


Figure 16

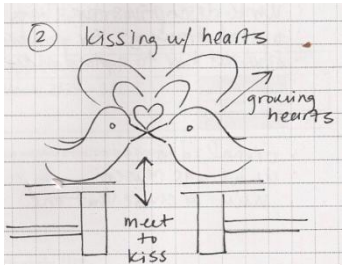


Figure 17

progression behind them, each heart larger than the one before it. We then decided that an interesting addition to the display would be to add a silhouette feature. This addition helps with the "lovebird" theme of this section. Our final design is much like the second design option, with the simple addition of a silhouette screen—two turtle doves meeting in a kiss behind a silhouette screen in the foreground, signaling the progression of light up hearts in the background (Figure 18). We chose this design because it includes interesting motion that keeps with the theme of "lovebirds" that is consistent with the common imagery of turtle doves.

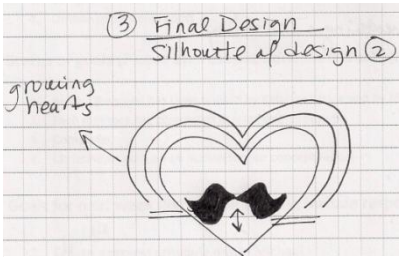


Figure 18

Day 3: Three French Hens

The theme of day three of the display will be based on the "French" theme implied by the name. The background will include an Eiffel tower made of metal wiring, outlined by large, old fashioned light bulbs, while the foreground will contain a series of three French hens painted with French-style costumes. In deciding what type of motion would be used for the hens, we had a few possibilities. First, we considered a simple bobbing and tilting motion in which the birds would move up and down as well as pivot at the base to create random motion (Figure 19). Second, we considered a pecking motion, seen in Figure 20 where the birds would rotate simultaneously to give the illusion that the hens were pecking at the ground. A third design was considered in which the birds would be hinged on a bar and a lever arm would rotate about a shaft and disturb the hanging birds in succession (Figure 21). We chose to use the pecking motion in our final design because it is a simple motion that is consistent with the behavior of hens. Each of the hens in the foreground will be highlighted by a spotlight to enhance the French costume features.

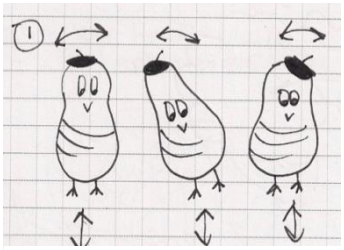


Figure 19

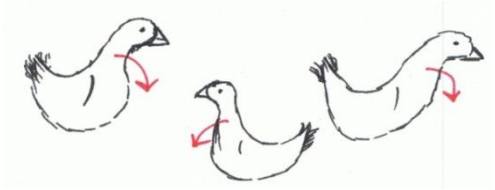


Figure 20

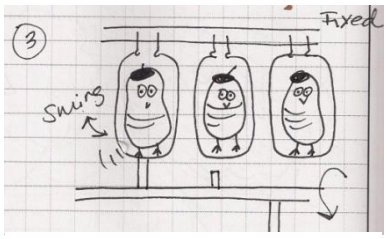


Figure 21

Day 4- Four Collie Birds

A collie bird is a standard, sometimes black, bird. For this display, we considered implementing a type of bird cage, as this is a common theme in bird imagery and will make for an interesting element in the overall display. The bird cage would have a door that would open and shut, revealing a collie bird with a cuckoo bird motion (Figure 22). The remaining three collie birds will be stationary, inside the bird cage. Another consideration was that the bird cage could contain all four stationary birds, but the bird cage itself would move in a circular pattern (Figure 23). A third option, shown in Figure 24, included a series of four birds in a row attached to a system that would cause each bird to flap its wings. For this option, the birds' wings would be separate from the body of the bird so that the wings could create a flapping motion. We decided to implement a design that has four separate bird cages. Each cage will have a separate bird in it and they will be lit up with spot lights. The cages themselves will be lit with LED strands.

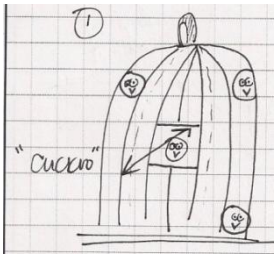


Figure 22

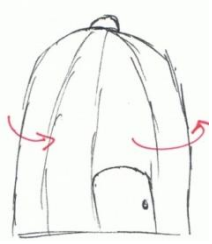


Figure 23

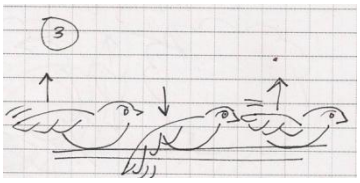


Figure 24

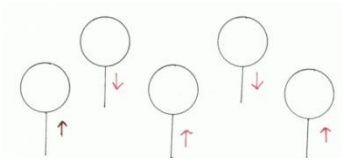


Figure 25

Day 5: Five Gold Rings

The focus of the fifth day is the gold rings. For the gold rings we have a vision of a big focal point as it is the "pause" in the middle of the song. We want to see every ring made from gold LEDs so they shine bright. From this focus, we were able to come up with many different motion ideas. The first idea was to have the 5 rings in two rows. These rows will alternate up and down causing a bobbing like motion (Figure 25). A second motion idea was having the rings intertwined with one another. As seen in Figure 26 they would then rotate in opposite directions of the rings next to them. A third idea was to have the rings placed in a circle and then each ring would rotate in place (Figure 27). This idea was decided against because it is extremely hard to notice when a round element is spinning unless there is a reference spot, which all gold rings would not have. Our fourth idea, as seen in Figure 29, is the one that we are going with. It is similar to the first motion option in that the rings are in two staggered rows. But instead of the

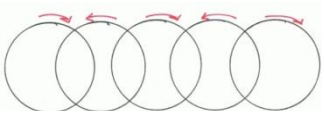


Figure 26

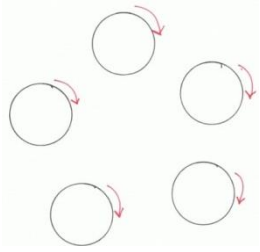


Figure 27

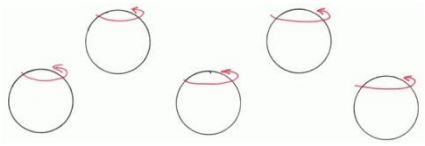


Figure 28

rings moving up and down they will be rotating, one row opposite the other. We thought that this concept was the most eye-catching of the options as it is bright, colorful and full of big motion.

Day 6: Geese – A – Laying

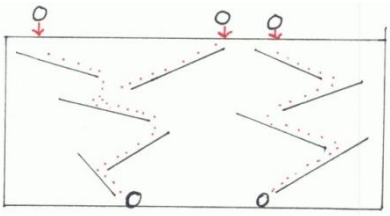


Figure 29

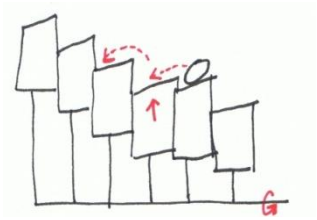


Figure 30

When thinking about this day, we thought that it would be really cute for a goose to actually lay an egg. The remaining ideas we came up with were based on this concept. The first idea, shown in Figure 29, was to do a "gum ball" type drop of the eggs. The eggs would be laid and then proceed to roll down a series of shoots until they reached the bottom. We found that this concept allowed for a fun, visual interaction between the audience and the scene. Another idea we had was to involve a stair step motion (Figure 30). The goose would lay her egg which would then roll down a track. When the egg reached the bottom of the track, it would be returned to the top by a cam driven stair step mechanism. The third idea we had was inspired by the lights already present at the Christmas Market. This idea is a combination of LEDs and our first idea. We thought that it would be fun to have the "egg" be a series of lights that cascaded down the ramp sequence instead of having an actual egg roll (Figure 31). We chose this third concept because we felt that it fit very well with the overall theme of the existing light display.

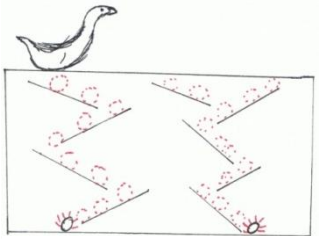


Figure 31

Day 7: Swans – A – Swimming

The seventh day, depicting seven swimming swans presented a couple very fun motion ideas to us. The first concept was to have the swans attached to a belt which would turn around and around like a conveyor belt (Figure 32). This scene would have a front façade of water, outlined in blue LEDs, so it would look as if the swans were actually swimming. The second idea we had, shown in Figure 33, would also have a front façade of water but instead of swimming, the swans would be bobbing up and down in the water. A third idea we had was for the water façade to move back and forth as if it were actual waves. We went with this idea because it was fun and interactive.

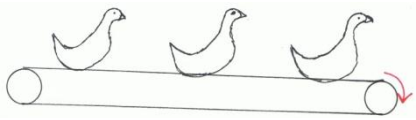


Figure 32

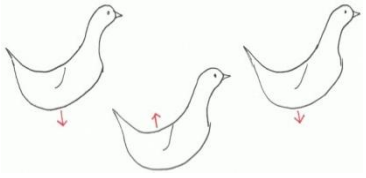


Figure 33

Day 8: Maids – A – Milking

Maids – a – milking typically lends itself towards a display of a lady milking a cow; however we wanted to go in a different direction. We envision a background that both roaming cows and cows being milked. The forefront of the display will be 3-4 maids holding buckets of milk (Figure 34). These maids will have their skirts swinging back and forth to the beat of the song. We also had the idea of having the maids on a platform that would rotate in a circle (Figure 35). This would be a simple motion that would allow all 8 maids to be seen. We chose the first motion idea we had because it is a more interactive and fun motion.

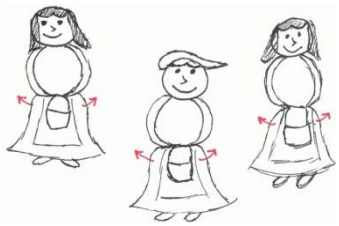


Figure 34

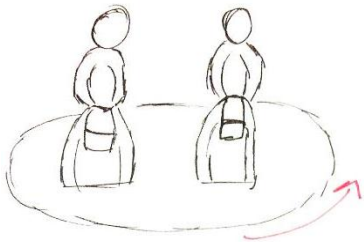


Figure 25

Day 9: Ladies Dancing

For the ninth day we thought of the different dancing motions possible. The first idea was to have the ladies spin individually (Figure 36). Another concept we had was to have multiple circular tracks above each other that have the ladies moving in a circle (Figure 37). We decided to scale back the tracks to a single layer and combine that motion with our first idea. The ladies would move in a circle while simultaneously spinning individually. This made the motion simpler to do compared to having multiple tracks, but still have an interesting motion.

Figure 36

Figure 37

Day 10: Lords – A – Leaping

The tenth day is lords a leaping. We thought about different jumping motions and motion arcs. Our first idea was to have straight vertical motion up and down for each lord (Figure 38). Another idea to add on to that is to have the limbs of each lord move as they moved up and down (Figure 39). We decided not to do this because of the high number of lords. Instead, we simplified it to a rotating wheel with the lords mounted on pins to create an arcing motion (Figure 40). This motion fits the leaping action more because it is more like jumping forward instead of jumping straight up.

Figure 39

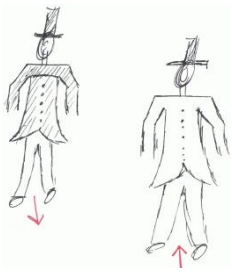


Figure 38

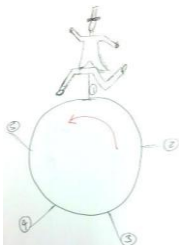


Figure 40

Day 11: Pipers Piping

Eleven pipers piping was more difficult to create a motion for. Our first idea was to have them sway their upper body similarly to the Maids – A – Milking display (Figure 34). Another idea is to have party blowers at the ends of the pipers' pipes to visualize them blowing into their instruments (Figure 41). When looking into this motion, we had a difficult time finding a material that would be able to be flexible enough to roll and unroll and also survive the elements. Because of this, we decided to have these "party blowers" be lights. This will be very much like the geese-a-laying egg drop. We decided to do the light up party blowers because it fit the bright and colorful whimsical theme very well.

Figure 31

Day 12: Drummers Drumming

For the twelve drummers drumming our first concept was to have the drummers arms move up and down to hit drums with drumsticks (Figure 42). We also looked into having just drums, outlined and defined completely in LEDs, drumming in this scene. However, we thought that this would be a little too abstract for this application. A third idea considered was having the drummers march as they moved their arms to hit the drum (Figure 43). We decided to just have the arms move because of the high number of drummers and the short amount of time that the higher number days will be running in the overall display. To accent the drums and brighten them up, we took part of our second idea and are going to detail the drums with lights. This addition of lights will help the scene tie in with the existing display.

Figure 42

Figure 43

Management Plan

While all members will be contributing to the project, each team member will be in charge of a specific part. We also have many big deadlines during the design and build process; these milestones are as follows. These deadlines can be seen as a fluid calendar in our project gantt chart, which is in Appendix B. This gantt chart is important because it has laid out the rest of the project timeline and is a great visual on when certain parts of the project need to be started or completed and also on what sections rely on other aspects of the project.

Responsibilities:

I. Background Research
   a. Twelve Days of Christmas history and lyrics - All
   b. Parade Floats – Christine
   c. Basic Mechatronics – Katie
   d. Four-Bar Linkages – Michael
   e. Motor specifications – Katie

II. Communication
   a. Sponsor – Katie
   b. Disneyland/Imagineers – Katie

III. Project Planning and Documentation
   a. Team Contract
   b. Project Proposal – Katie
   c. Conceptual Design Report – Christine
   d. Conceptual Design Review – Michael

IV. Brainstorming, Idea Generation
   a. Basic, aesthetic motion
   b. Motion into mech/animation design
      i. Days 1-4 – Christine
      ii. Days 5-8 – Katie
      iii. Days 9-12 – Michael
   c. Creative, artistic design

V. Build
   a. Days 1-4 – Christine
   b. Days 5-8 – Katie
   c. Days 9-12 – Michael
   d. Back drop – Christine
   e. Aesthetic façade – Katie
   f. Electrical components – Michael

VI. Testing Plans
   a. Height – Christine
   b. Display Size – Michael
   c. Weight – Katie
   d. Storage Size – Michael
   e. Viewable Mechanisms – Christine
   f. Weather Resistance – Katie
   g. Enclosed Mechanisms – Katie
   h. Power Draw – Michael

i. Drop Test – Christine
j. Push Test –Christine
k. On/Off Cycle Test – Katie
l. Sponsor Approval – Shana, Lee

Project Milestones:

1. Conceptual Design Review	Week of March 18
2. Critical Design Review	First week of May
3. Project Update Memo to Sponsor	October 4
4. Product test run	October 28
5. Senior Project Expo	November 21
6. Displays go live at site	November 28

Communication:

As the project has progressed, we have realized particular strengths and weaknesses within our group. One area that we have struggled as a team is proper communication. To improve this element of our team, we have agreed to communicate more clearly. The build stage of our project will occur over the summer months (June-September). We have agreed to email twice a week to communicate the status of the project build. At least once a month, all three team members will be in the San Luis Obispo area to construct the project. The agreed upon dates can be found in the project schedule in Appendix B.

Final Design

Design Descriptions Days 1-4

Day 1: A Partridge in a Pear Tree

A layout of this scene is shown in Figure 1 and a side view can be seen in Figure 2. In the foreground, there will be a set of bushes made of brightly colored polycarbonate plastic. These bushes will be fixed to the plywood base using spacing studs and acrylic cement. Directly behind the bushes will be a tree trunk made of 3-Form resin panel with a wood grain appearance (Figure 3). Details about 3 Form panels can be found later in Appendix D. The trunk may also be made of dark stained wood, depending on the preference of sponsor. A set of four tree bushes will be attached to the trunk using acrylic cement. The tree trunk will be attached to a standard “2x4”post that will be inserted into slots in the base (Figure 4 and 5). The large tree bush indicated in Figure 1 will also be attached to a 2x4 wood post and inserted into the base for support. The following figures identify components in multiple views and material selection.

Note: Day 1 will include moving components when the mechanism is fully analyzed. The above detailed description describes a stationary version of Day 1.

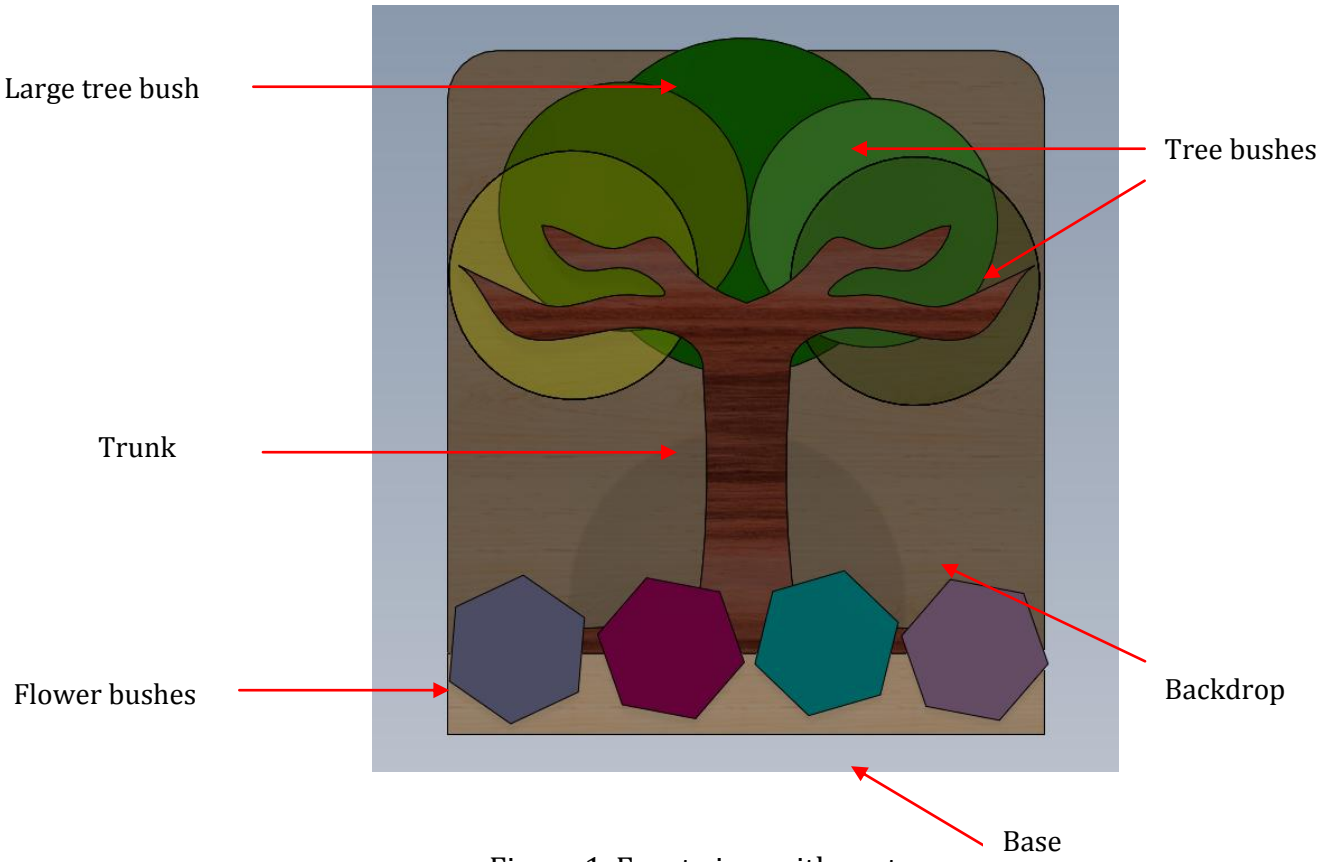


Figure 1. Front view with part name

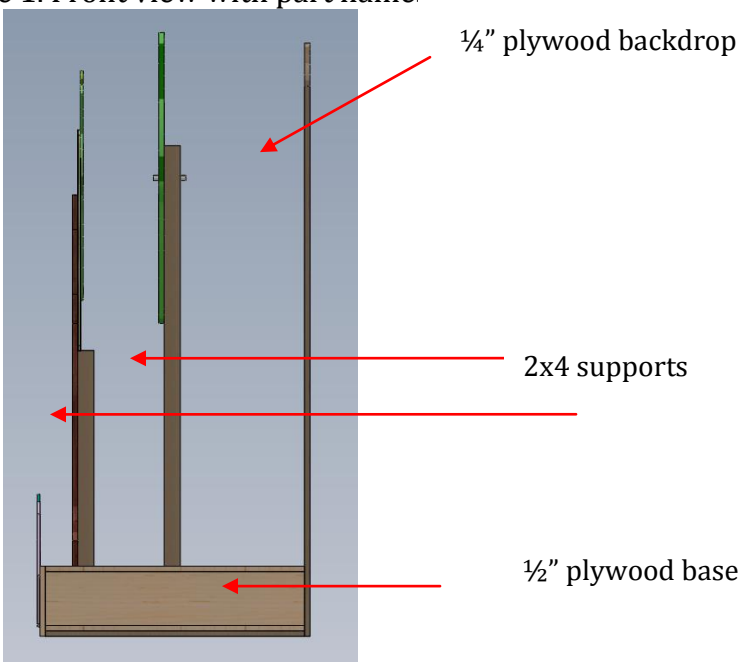


Figure 2. Right side view of Day 1 scene.

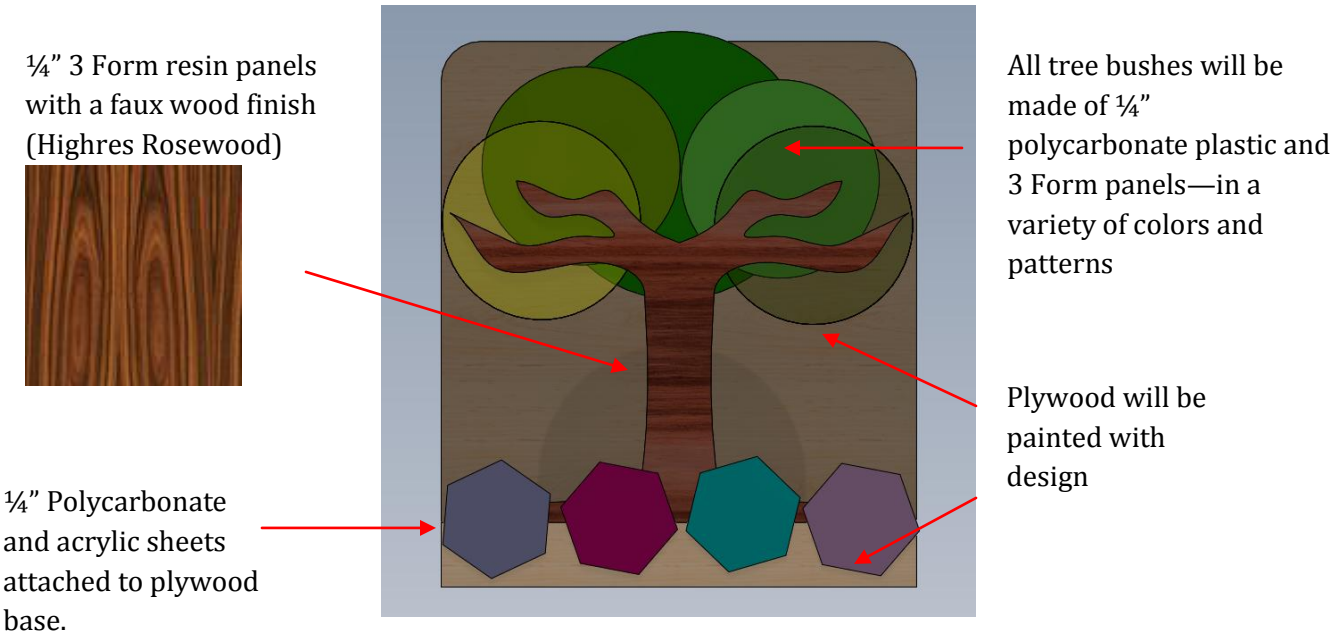
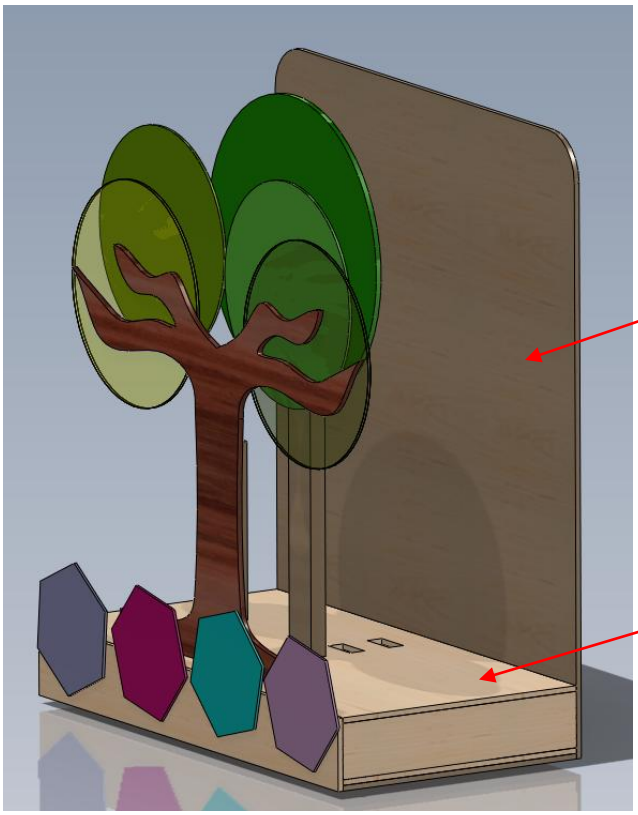


Figure 3. Material selection for each component.



Backdrop will be painted and lights will be added.

Plywood base with 2x4 slots for placement and support. The trunk and rear tree bush are held into the base using 2x4 posts.

Figure 4. Isometric view of Day 1 scene with notes.

Base with slots for 2x4 supports. There are multiple slots so that pieces can be adjusted when moving arms are added.

½" plywood for all pieces

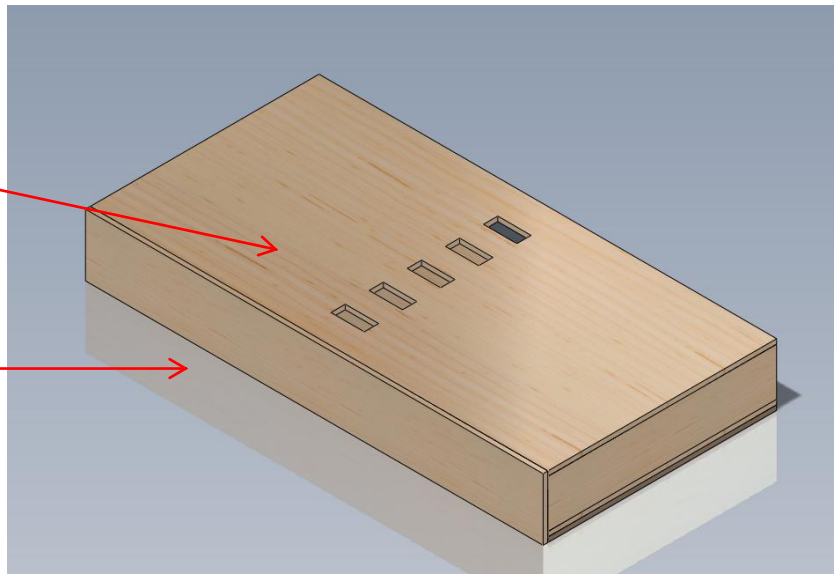


Figure 5. Day 1 base with slots.

Day 2: Two Turtle Doves

Day 2 has no moving components. The foreground includes a set of randomly sized hearts. These hearts will be fixed to the plywood base as indicated in Figure 6. The hearts will be made of acrylic and fixed together using acrylic cement. Two of the larger hearts will be fixed to the plywood base with screws for additional support. Behind the set of hearts will be a large heart made of transparent polycarbonate plastic. This heart is placed in a slot and supported by two angle brackets (Figures 8 and 9). Spotlights will be fixed to the platform in the rear so light will shine through the large transparent heart (Figure 7). This will give the birds a silhouette appearance. The base will be left open in the back to store electronic components, but a cover may be added when the design is complete (Figure 10). The cover would be removable so that technicians may have access. Lights will be placed on the scene, but location of the lights has not been determined.

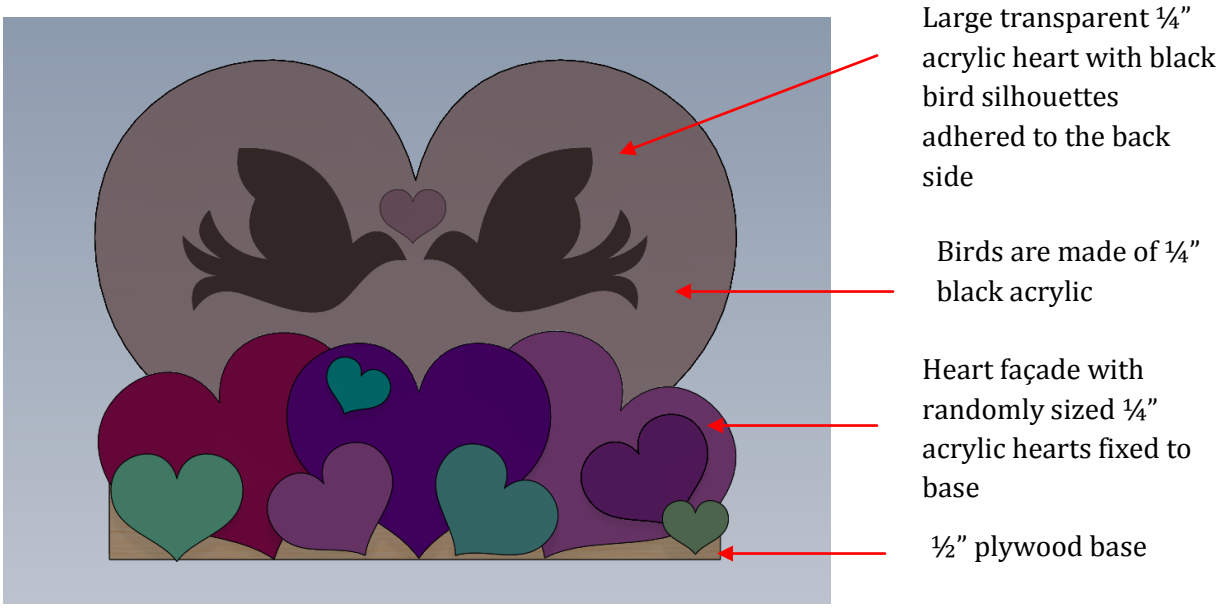


Figure 6. Front view of Day 2 with material selection

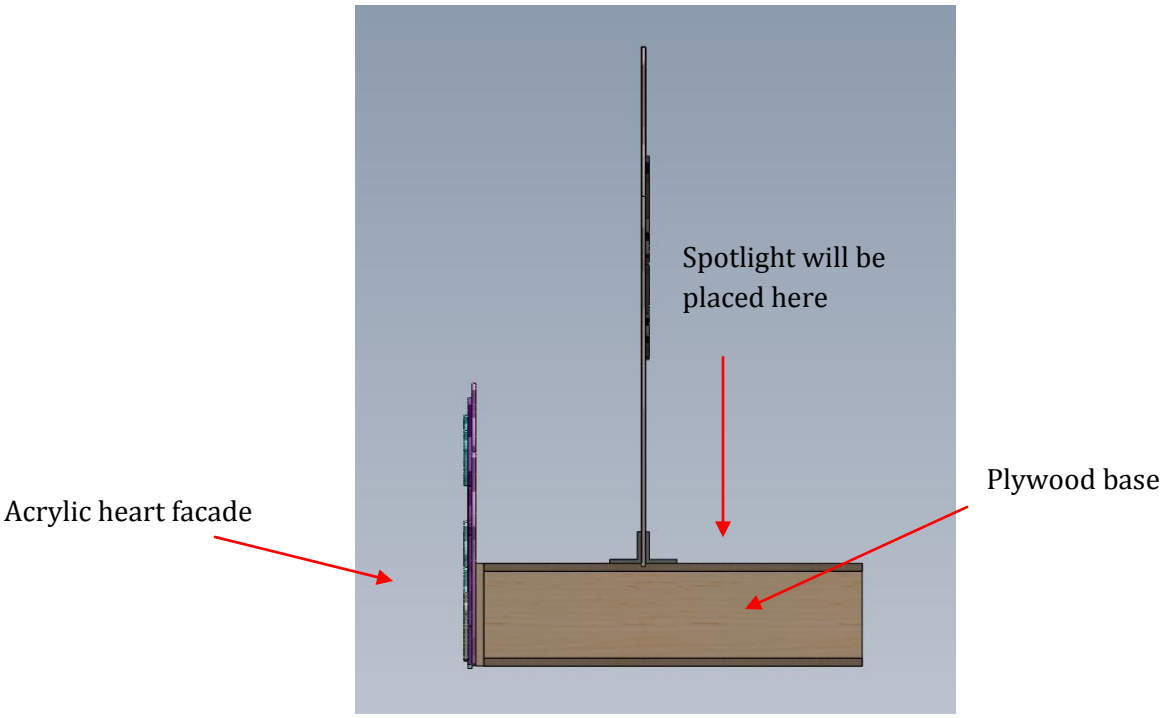


Figure 7. Side view of Day 2 indicating placement of components.

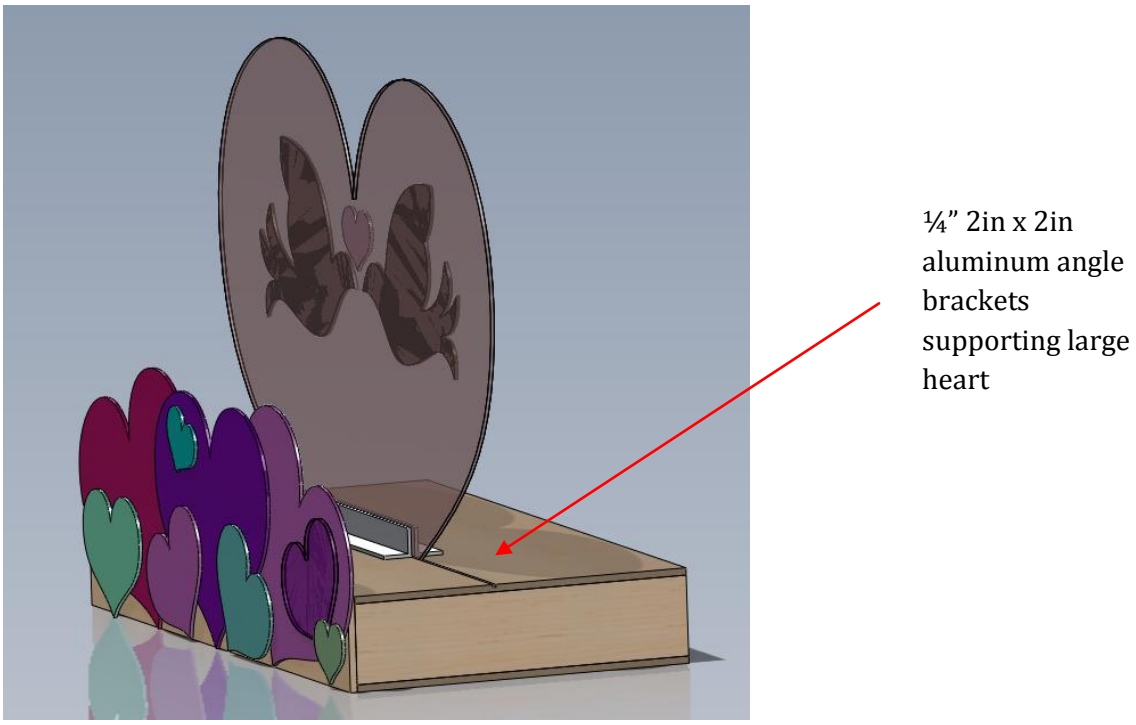


Figure 8. Isometric view of Day 2 indicating material selection and fixtures.

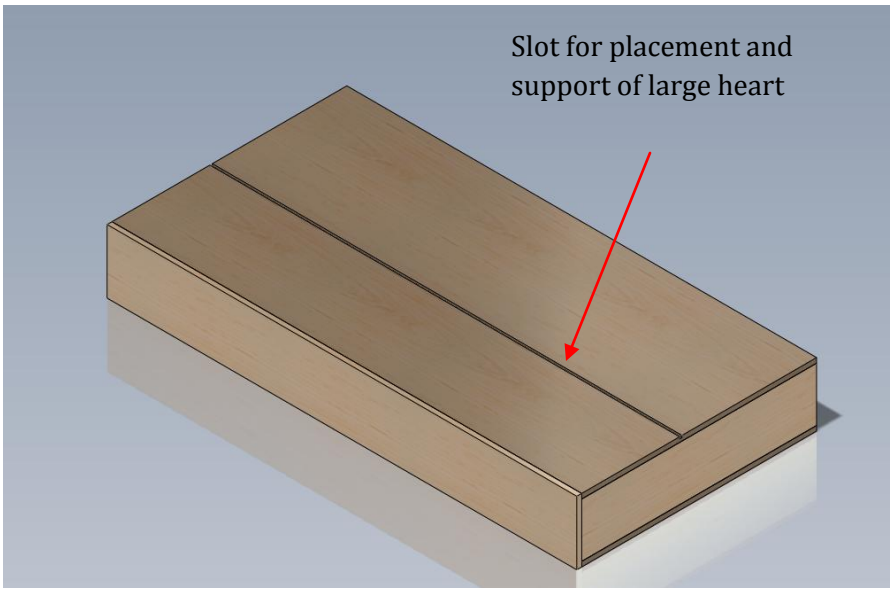


Figure 9. Base for Day 2 with supporting slot.

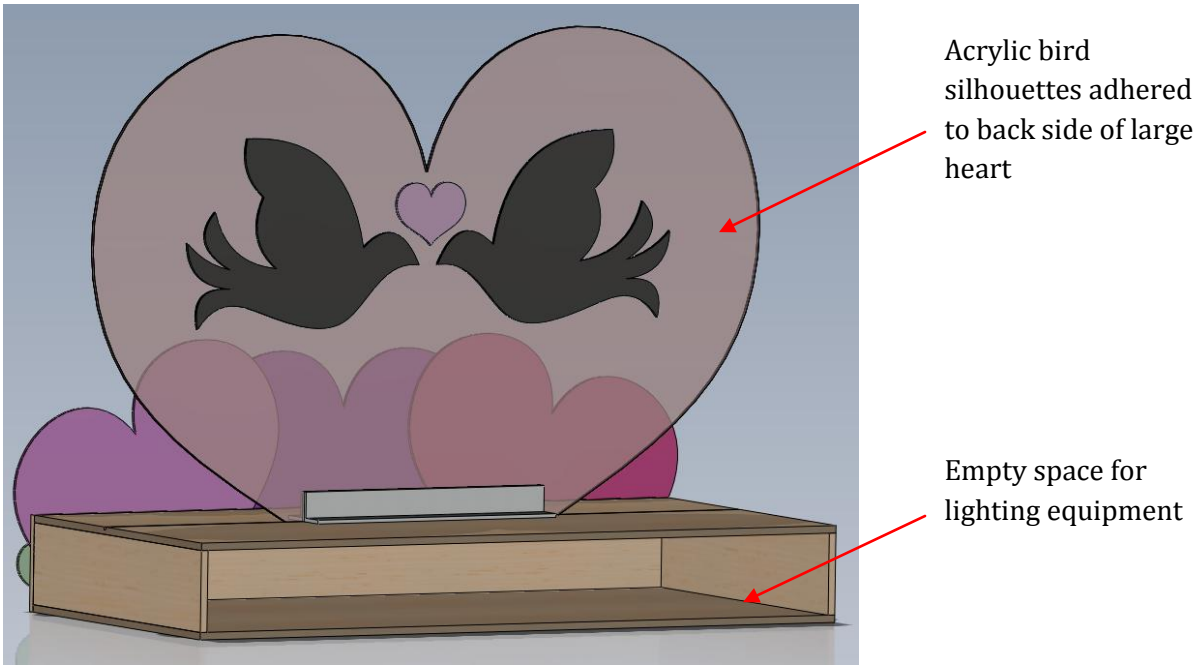


Figure 10. Rear view of Day 2 showing base.

Day 3: Three French Hens

This display representing, the three French hens, has a linkage mechanism made of aluminum (Figure 11). The linkage takes the motor's rotary motion and turns it into a pivot motion in order to make the hens look like they are pecking at the ground. The motor is connected to an ABS plastic sheet that makes up the front face of the display base. The crank is then attached to the motor and held in place with a shaft collar. As the motor spins, the crank spins with the coupler and main bar following its path. This causes the vertical connector bars, attached from the main bar to the hens, to pivot back and forth.

The hens in the display are an element that will be laser cut out of white acrylic and then painted with more detail. Like the swans in day 7 and the maids in day 8, they are supported by two inch aluminum angle. The Eiffel tower, not displayed in these models, will be a three dimensional structure made from pencil steel and wrapped in lights. The display is 48 inches long by 18 inches deep by 48 inches tall.

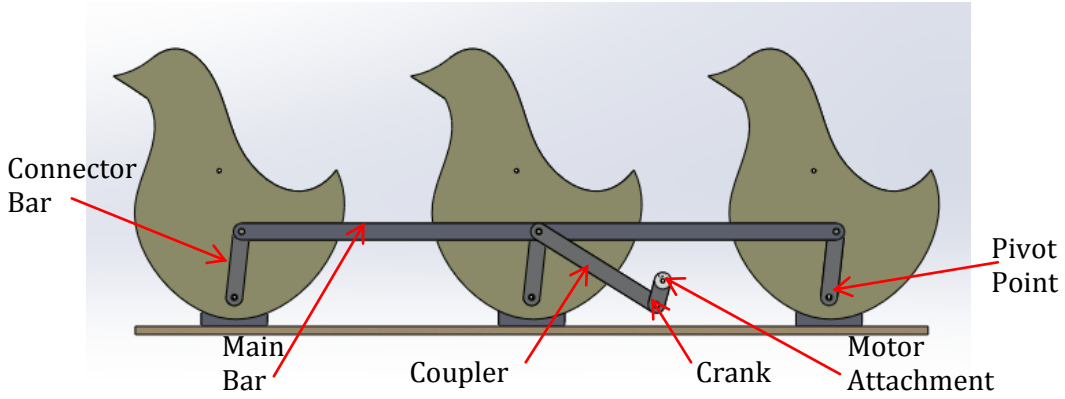


Figure 41. Day 3 linkage

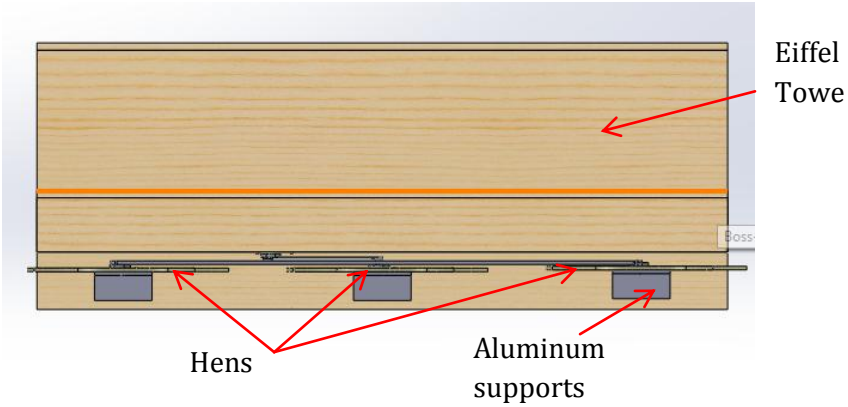


Figure 12. Day 3 top view

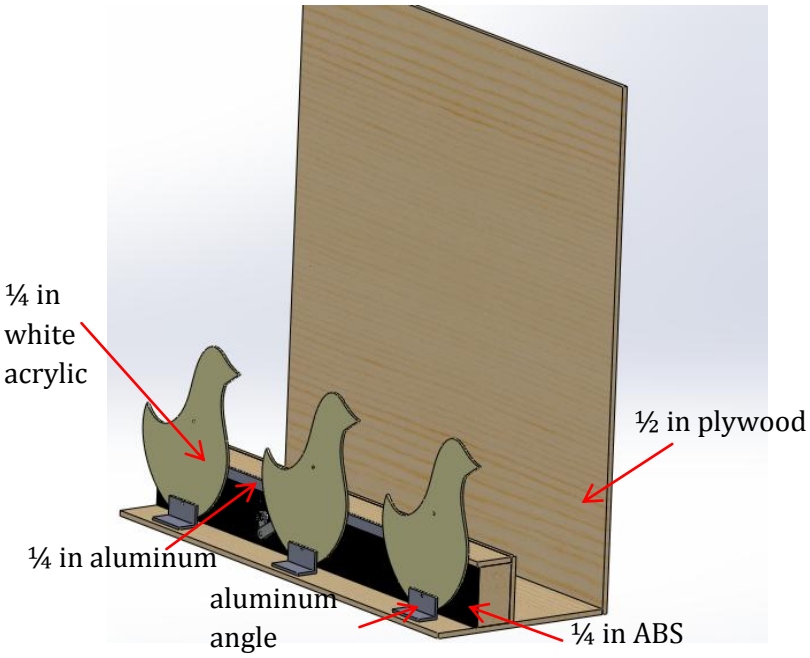


Figure 13. Day 3 material selection

Day 4: Four Collie Birds

The scene for Day 4 is completely stationary. Four bird cages of random size and style will be placed at a variety of heights as indicated in Figure 14. The bird cages will be purchased at low cost and coated in brightly colored spray paint. Lights will be wrapped around the cages for added flare. A set of four birds will be outlined and cut out of acrylic sheet. The acrylic birds will be placed randomly on each bird cage. The acrylic will be painted or coated in vinyl with a cartoon image of a bird. The base will be made of plywood and contain a set of four holes on the top. These holes will be the guides for the aluminum shafts (Figures 14 and 15). Detailed drawings for each component and artistic drawings can be found in Appendix B.

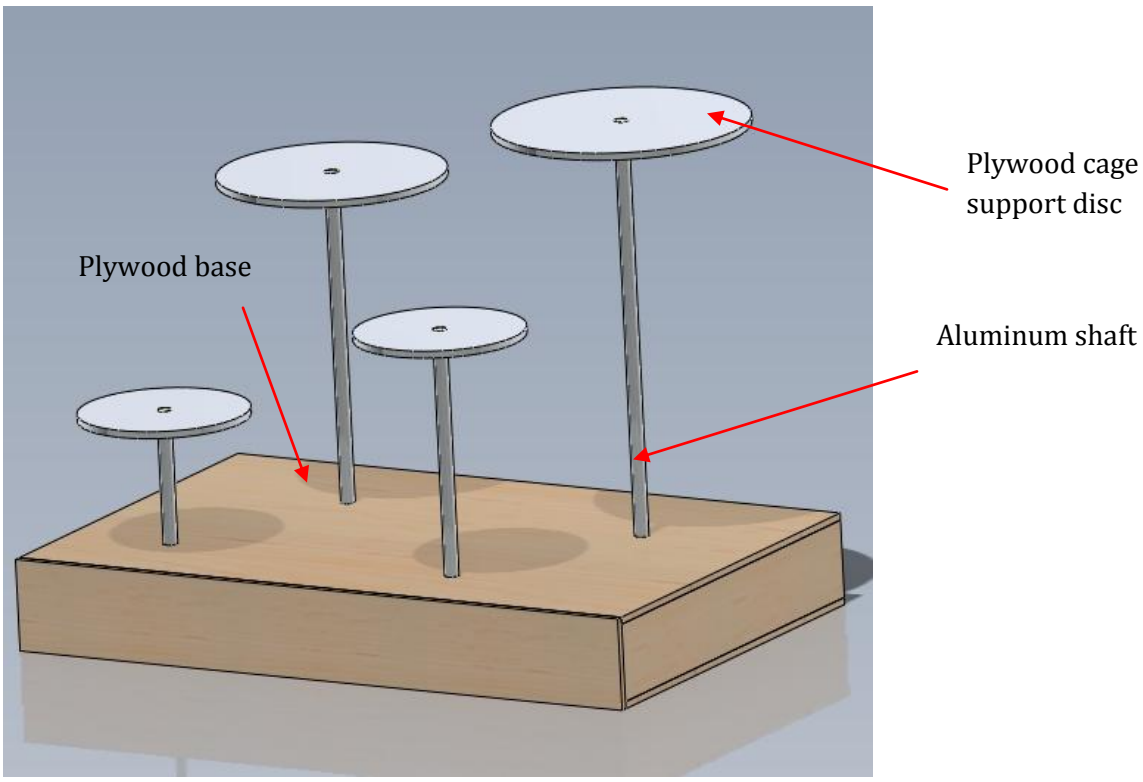


Figure 14. Isometric view of Day 4 setup

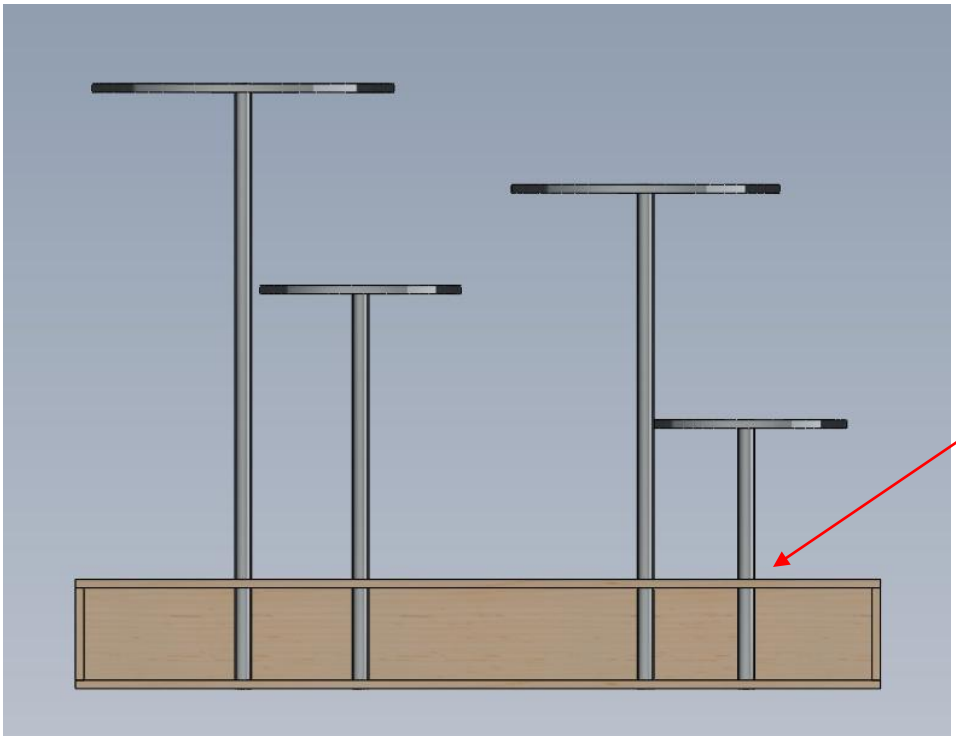


Figure 15. Rear view of Day 4 showing shaft supports.

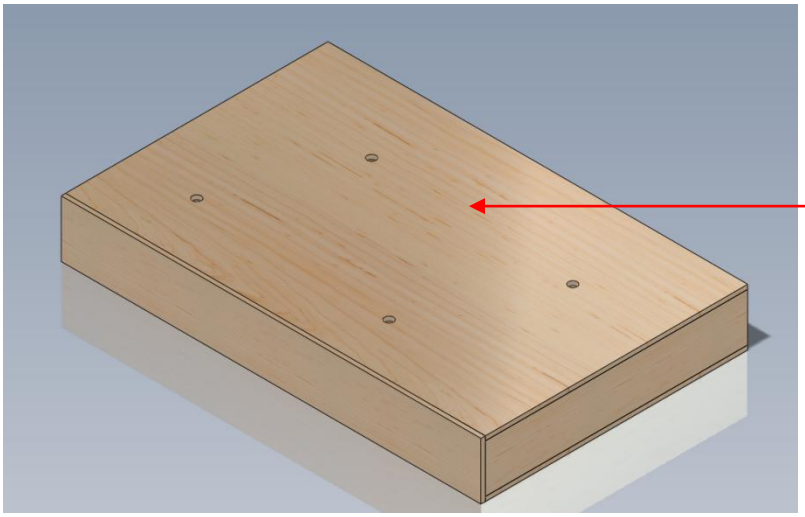


Figure 16. Isometric view of Day 4 base

Design Description Days 5-8

Day 5: Five Golden Rings

The mechanism for five golden rings, seen in Figure 1, is a gear and chain system. The first ring shaft will be attached to the motor and also to the second ring shaft through two separate sprocket and chain sets. The second shaft is then also attached to the third shaft, the third to the fourth and the fourth to the fifth. With this there are 5 separate sprocket and chain sets. Since there is no speed reduction, all of the sprockets will be the same size with 28 teeth, a one inch bore and a 2.37 inch outer diameter. The chain being used is #25 standard roller chain. There will also be floating chain tensioners, seen in Figure 2, implemented to keep the chains at a proper tension. The shafts will be supported through the top base with a purchased flange bushing and at the bottom base with a machined thrust bearing. This lower support will help keep the shaft from deflecting, which is important because the sprockets must stay in line for the chain to work properly. There is also a nylon spacer placed on the fifth shaft the length of a sprocket to ensure that the fifth shaft sprocket is in line with its mate on the fourth shaft. The motor shaft has a 5/16 bore, 1 in outer diameter nylon adapter placed on it so that the same sprocket can also be used at this connection. Each shaft also has a shaft collar to prevent the shaft from sliding up out of the bottom support. These shaft collars also ensure that the sprocket and chain pairs will stay in line with each other. Shaft placement is outlined by the diagram in Figure 3.

Material selection for each component is shown in Figure 4. The rings in this display are made of two different colored acrylic type plastics (Figure 5) and will be cut on the laser. The shafts used are 1 inch diameter aluminum. The thrust bearings are made of acetal and the flange bushing is made of nylon. The chain tensioner is also made of acetal. This material was chosen for the thrust bearings and chain tensioner because it is a low coefficient of friction. Most of the base is made of half inch plywood with the top and the motor mount made of quarter inch ABS plastic. The use of ABS is due to the fact that it does not warp after being exposed to the elements. The total display is 48 inches long and 24 inches deep with the rings reaching a height of 40 inches.

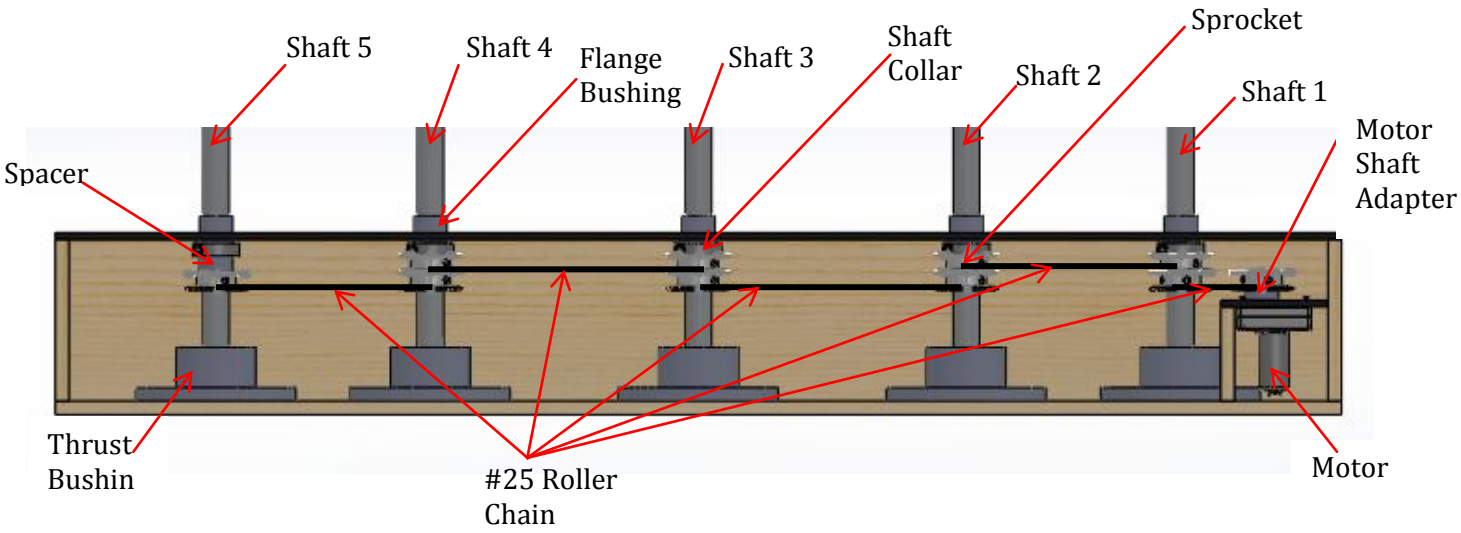


Figure 1. Day 5 mechanism description

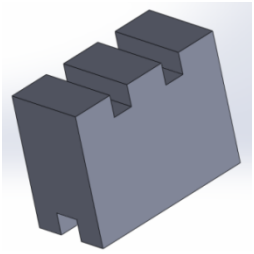


Figure 2. Floating chain tensioner

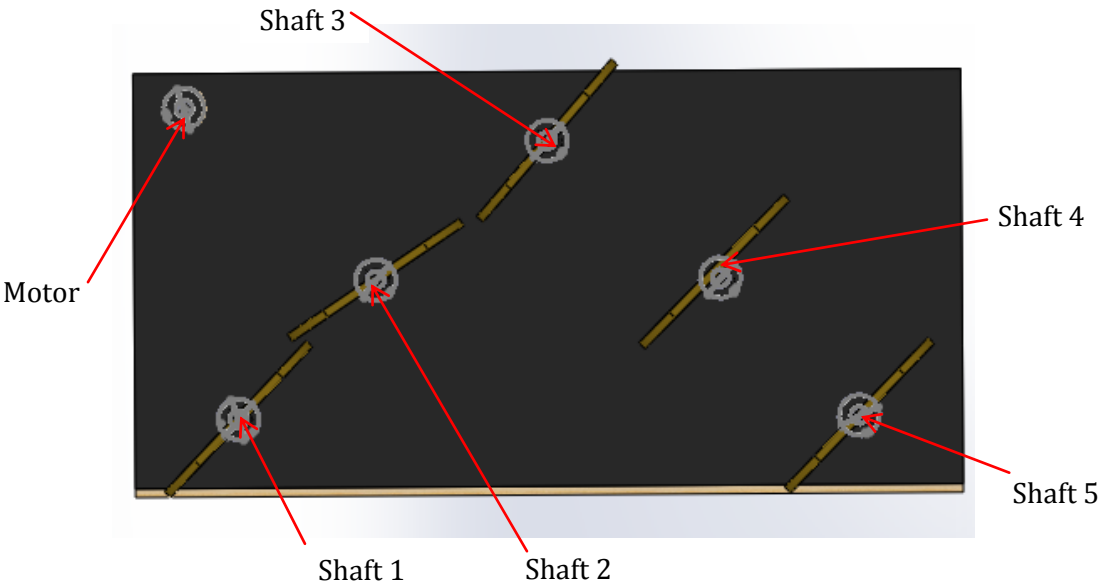


Figure 3. Top view of Day 5 for shaft layout

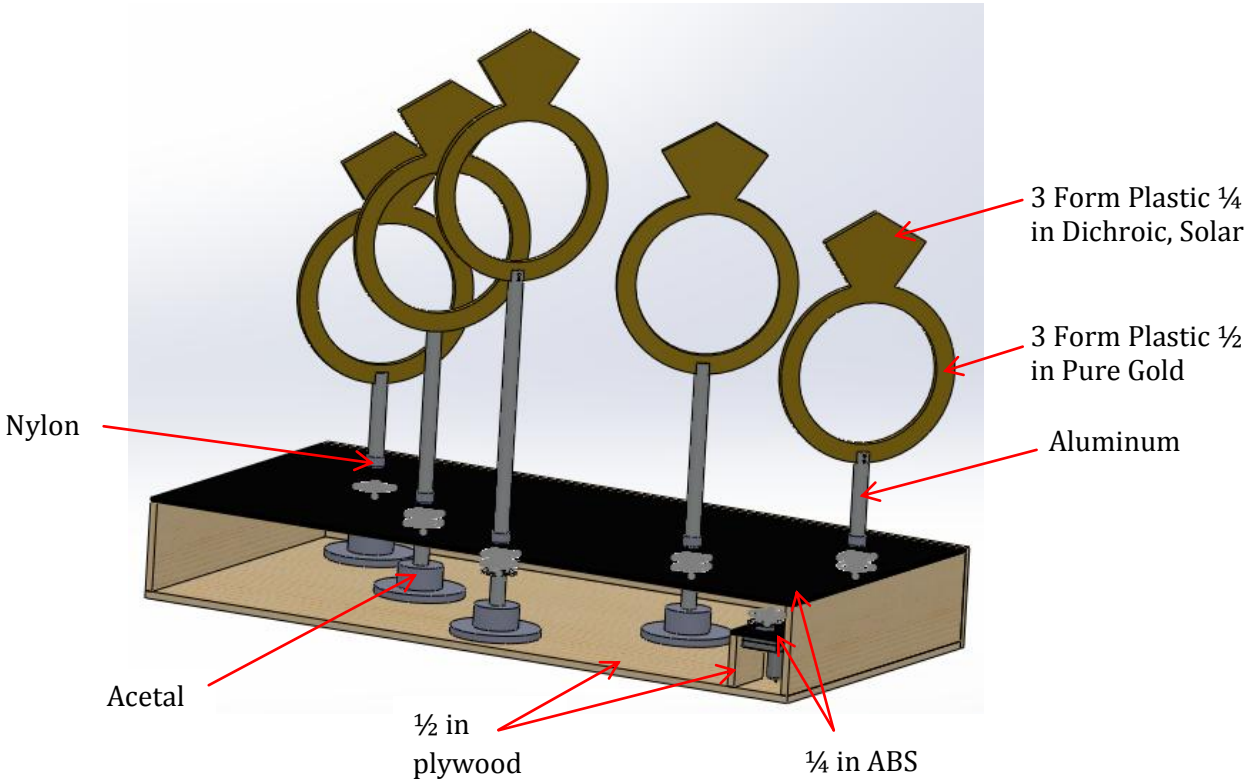


Figure 4. Material selection for Day 5

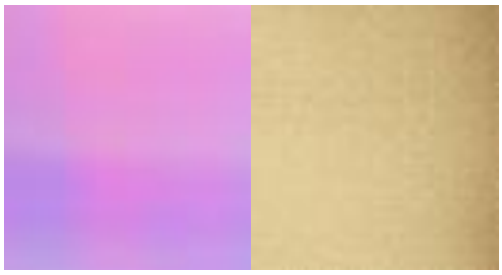


Figure 5. 3-Form material for diamond (left) and gold ring (right)

Day 6: Six Geese-a-Laying

The display for six geese-a-laying does not have any moving mechanism. Instead, it has a "moving" light mechanism. Figure 7, shows the outline of how the "eggs" will roll down the ramps to the bottom of the display. These are not physical eggs, but are instead LED lights placed in the shape of an egg. Each egg will turn on and off, in order from top to bottom, to make it seem as if the eggs are rolling down the ramps. This will be done by controlling each light egg with the microcontroller explained in controls section.

In this display, the geese will be laser cut from white acrylic and painted and will be supported with two inch aluminum angle. The base is made of half inch plywood and the ramp pieces are made of quarter in plywood pieces. These pieces will be painted in order to seal them from the elements. The eggs will be LED lights. This is a simple display that is 36 inches tall, 48 inches wide and only 4 inches deep.

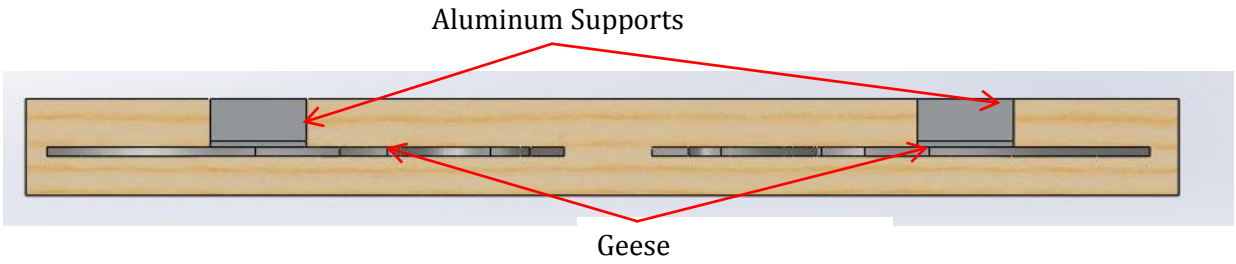


Figure 6. Top view of day 6

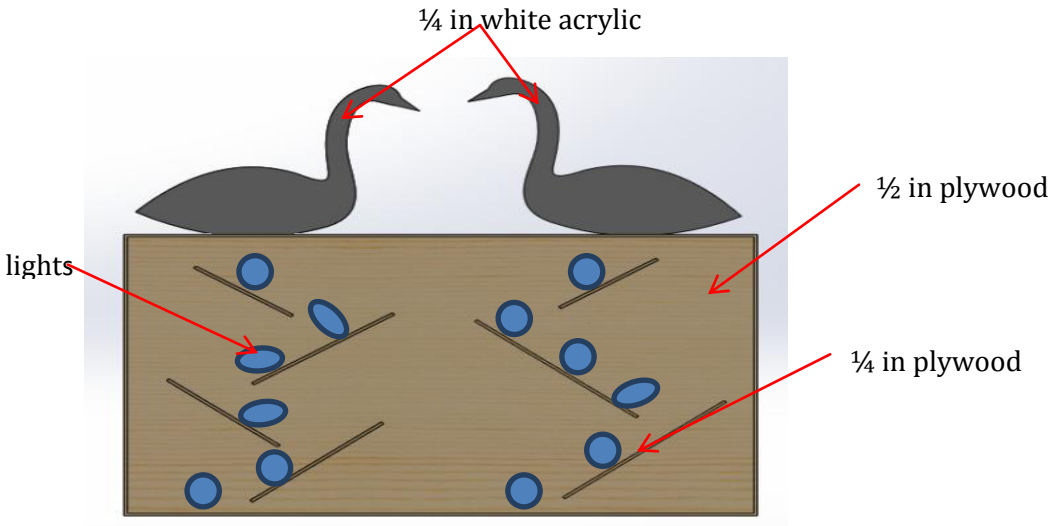


Figure 7. Material selection for day 6

Day 7: Seven Swans-a-Swimming

A linkage mechanism is being used for the display representing the seven swans-a-swimming. The linkage is made of acrylic and produces a sliding motion to make it seem as if the water is moving. The motor is mounted to an ABS sheet that makes up the front face of the display base and is connected directly to the crank on the linkage. The crank is held onto the motor shaft by a shaft collar. The linkage, composed of the crank and coupler, is attached to the back wave façade which is connected to a track and carriage system. This track and carriage pair provides the constraint needed to create the sliding motion from the rotary motion produced from the motor.

The swans will be laser cut from white acrylic and painted. The waves and front grass façade will also be laser cut from an acrylic like plastic, seen in Figure 11. The linkage and washers will be made from acrylic sheet. Both sets of waves and swans are supported by two inch aluminum angle. The base of the display is made primarily of half in plywood with the front motor mount being made from quarter inch ABS sheet. This display is 48 inches long by 18 inches deep and the swans measure about 25 inches tall.

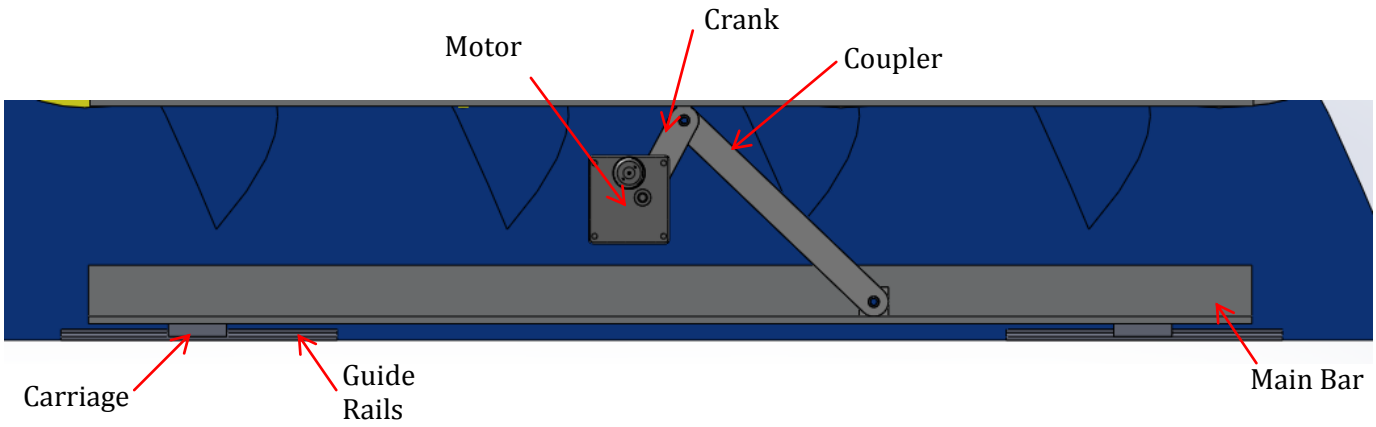


Figure 8. Mechanism view for day 7

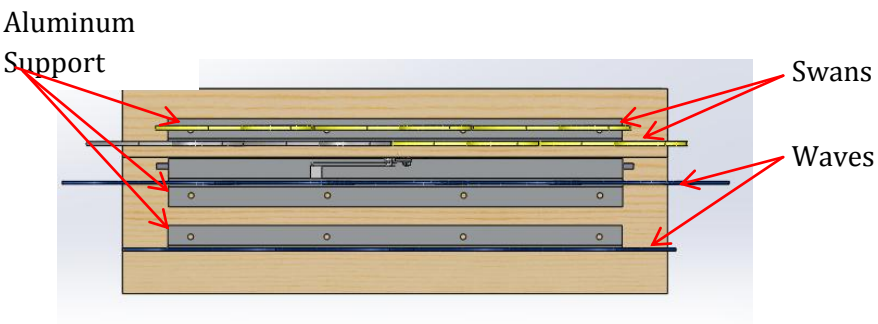


Figure 9. Top view for day 7

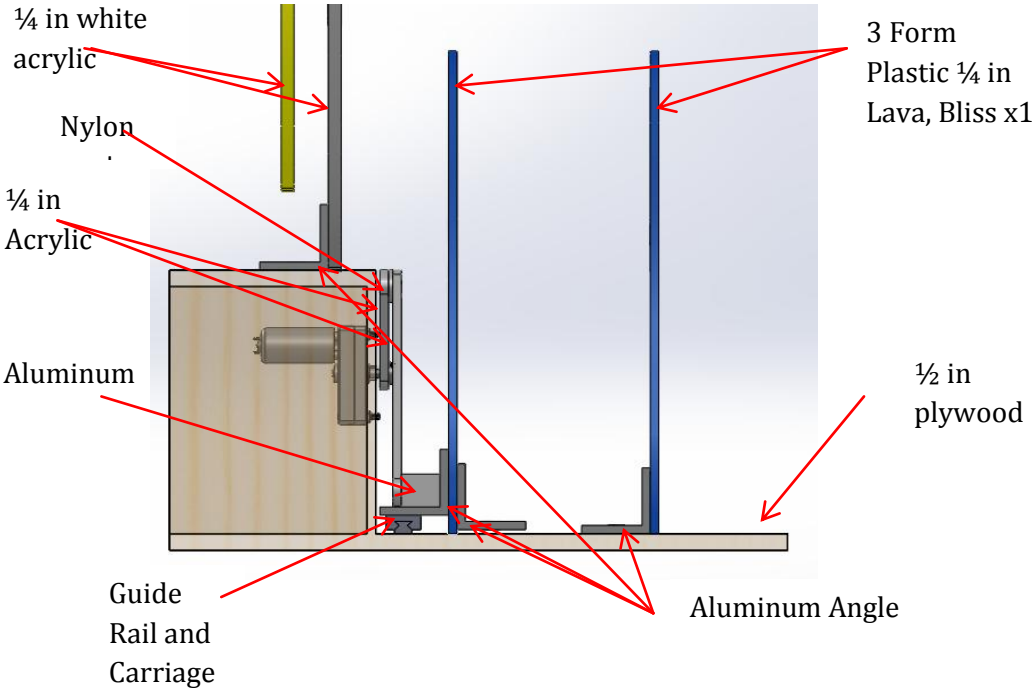


Figure 50. Material selection for Day 7

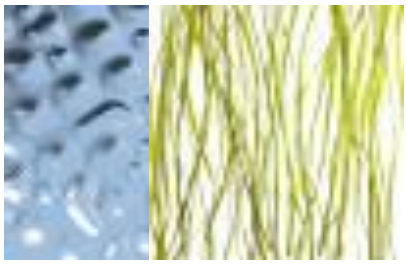


Figure 11. Water and grass plastic material (3Form)

Day 8: Eight Maids-a-Milking

The mechanism layout can be seen in Figure 12 below. The linkage mechanism is made of acrylic. The linkage takes the motor's rotary motion and turns it into a pivot motion in order to make the maids look like they are swaying back a forth. Similarly to day 7, the motor is connected to the ABS sheet that makes up the front face of the display base. The crank is then attached to the motor and held on with a shaft collar. As the motor spins, the crank spins with the coupler and main bar following its path. This causes the vertical connector bars, attached from the main bar to the maids, to pivot back and forth. A top view of this display is shown in Figure 13. The maids in the display are another element that will be laser cut out of white acrylic and then painted. Like the swans, they are supported by two inch aluminum angle. The hills will be cut out of green acrylic and attached to a base of half inch plywood which will be painted. The display is 48 inches long by 15 inches deep by 48 inches tall. Material selection is shown in Figure 14.

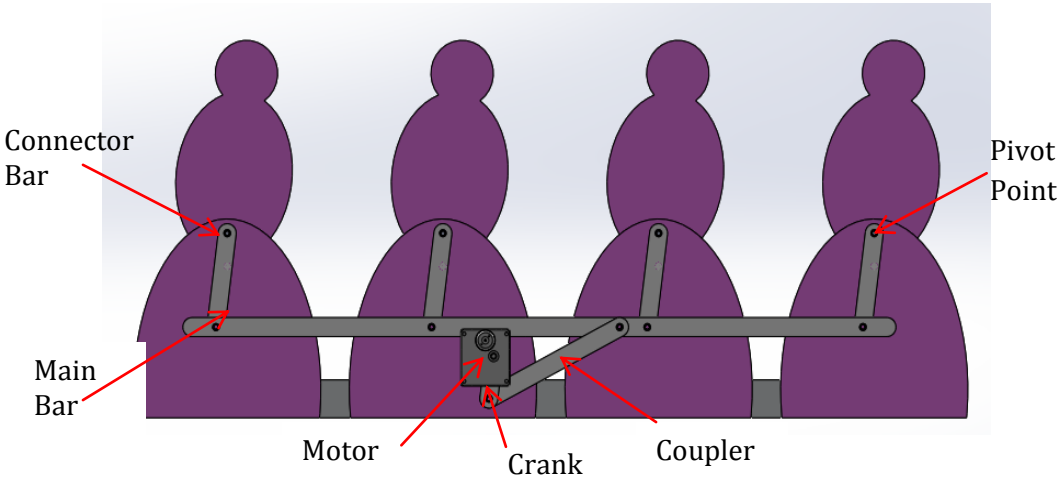


Figure 16. Mechanism view for Day 8

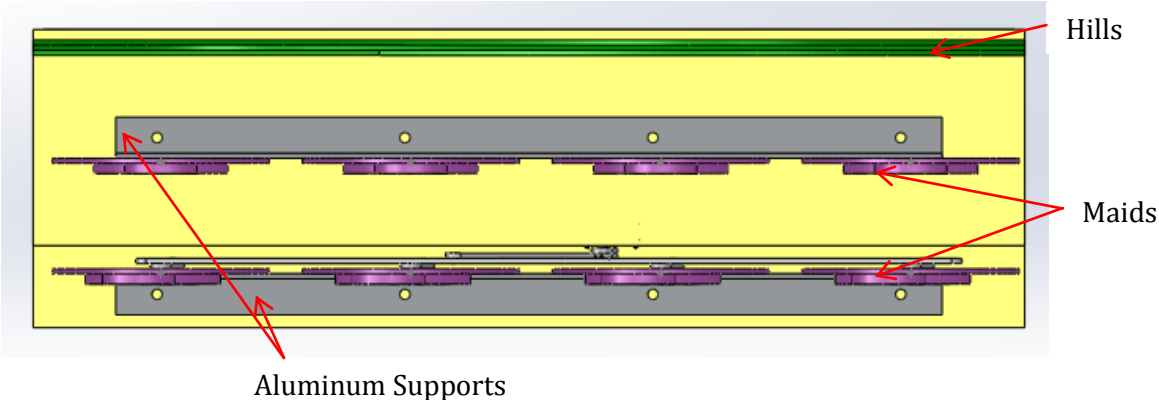


Figure 13. Top view of Day 8

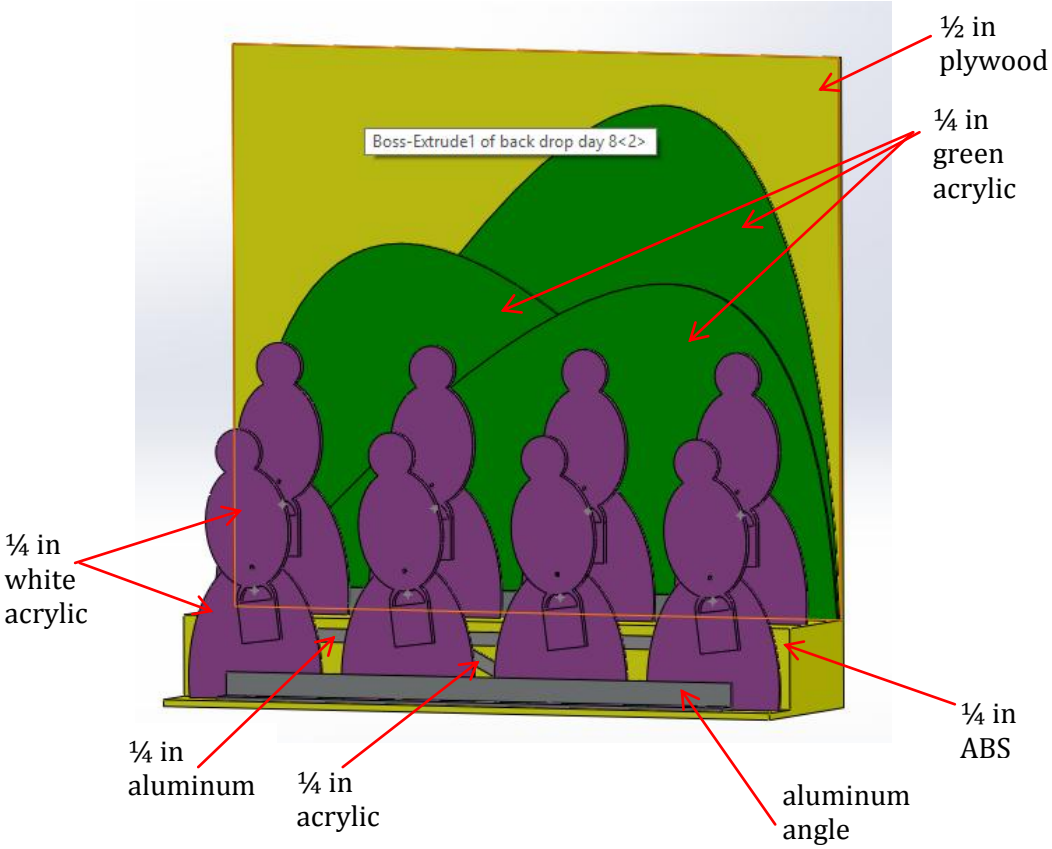


Figure 14. Material selection for Day 8

Detail Description Days 9-12

Day 9: Nine Ladies Dancing

The mechanism for nine ladies dancing is similar to the mechanism for five golden rings. It will use a chain and sprocket system. Instead of five shafts, there will be only three shafts. The motor will be attached to the shaft 1 using two separate sprock and chain sets. Then shaft 1 will be attached to shaft 2 and shaft 2 will be attached to shaft 3 in a similar matter. Each shaft has a half inch diameter. All the shafts will rotate at the same speed so they will use the same sprocket sizes. The sprockets on the shafts have 14 teeth, a half inch bore, and a ## inch outer diameter. The sprocket on the motor will have to be machined to fit the 5/16 inch diameter and a set screw will have to be added to secure it to the motor shaft. Floating chain tensioners will be used to keep the chains engaged with the sprocket teeth. The shafts are supported through the top base with nylon flange bushings and the bottom will be supported by acetal thrust bearings.

There is a platform on top of each of the three shafts. At the end of all the shafts there will be a flat side that will match the hole in the middle of the platform. This will let the platform rotate with the shafts and prevent it from slipping. The platforms will be attached with a removable shaft collar to make them easy to remove and replace. Each platform will have three ladies on top. The platforms and ladies will be made of white acrylic which will be glued together using acrylic cement and then painted. The top base of the dsiplay will be made of quarter inch thick ABS plastic because it will not warp when exposed to the weather. The rest of the base will be made of half inch thick plywood.

Refer to the following figures for more detail.

Note: Figure numbers restart.

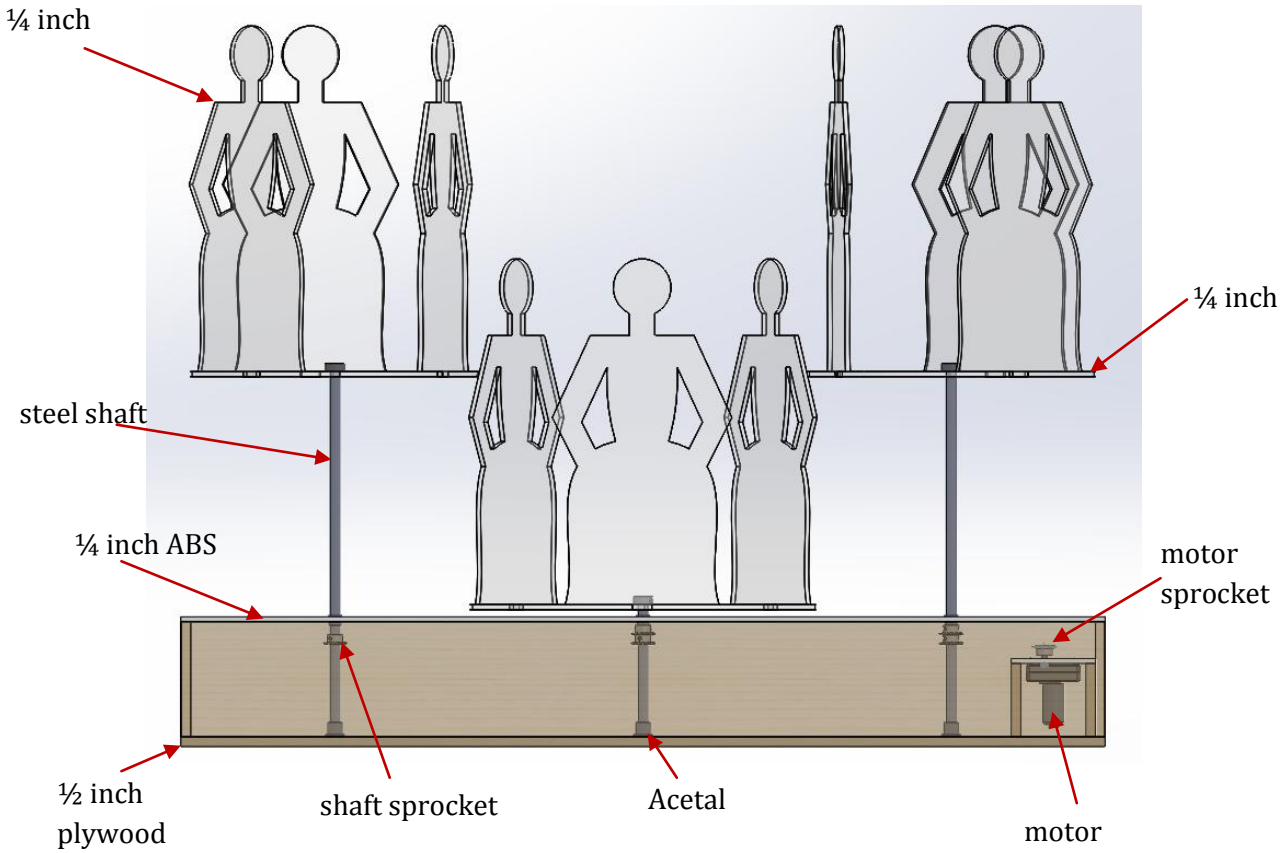


Figure 1. Rear view of Day 9 with material selection

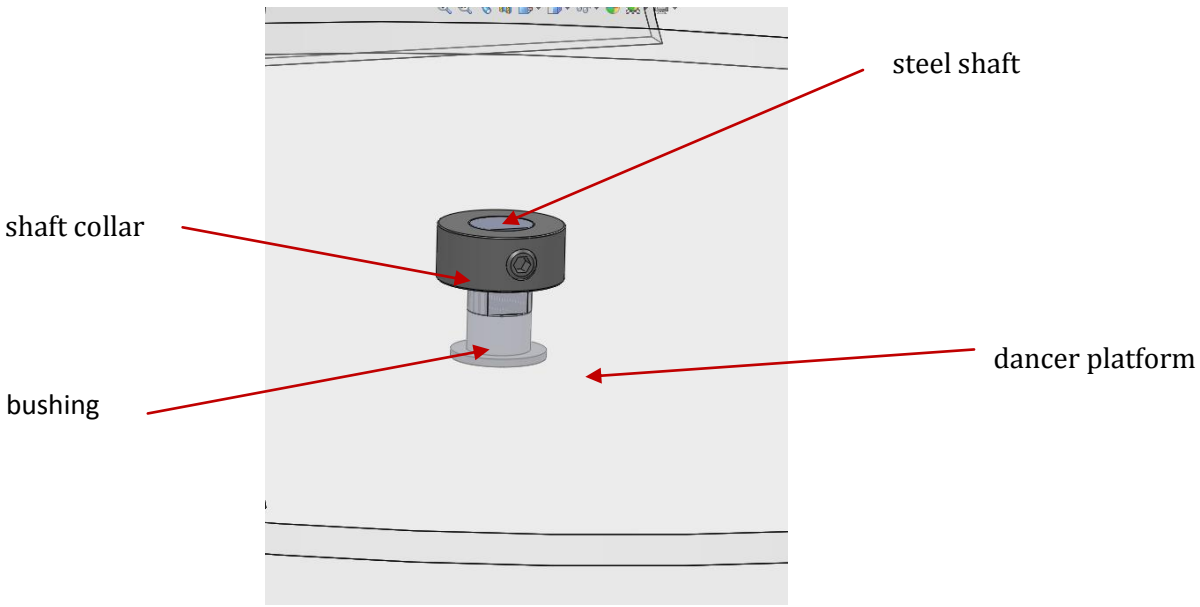


Figure 2. Close up view of shaft connection

Day 10: Ten Lords-a-Leaping

The mechanism for ten lords a leaping is a wheel with the lords cut out that is attached directly to the motor shaft. The wheel will be mounted on the shaft and secured using a shaft collar. A spacer will be added behind the wheel so that it does not grind against the threaded rods used for mounting the motor. The motor will be mounted on 1/8 inch thick aluminum bar stock that will be bent to a 90 degree angle. It will then be mounted on a base made of half inch thick plywood with a slot cut out for the wheel.

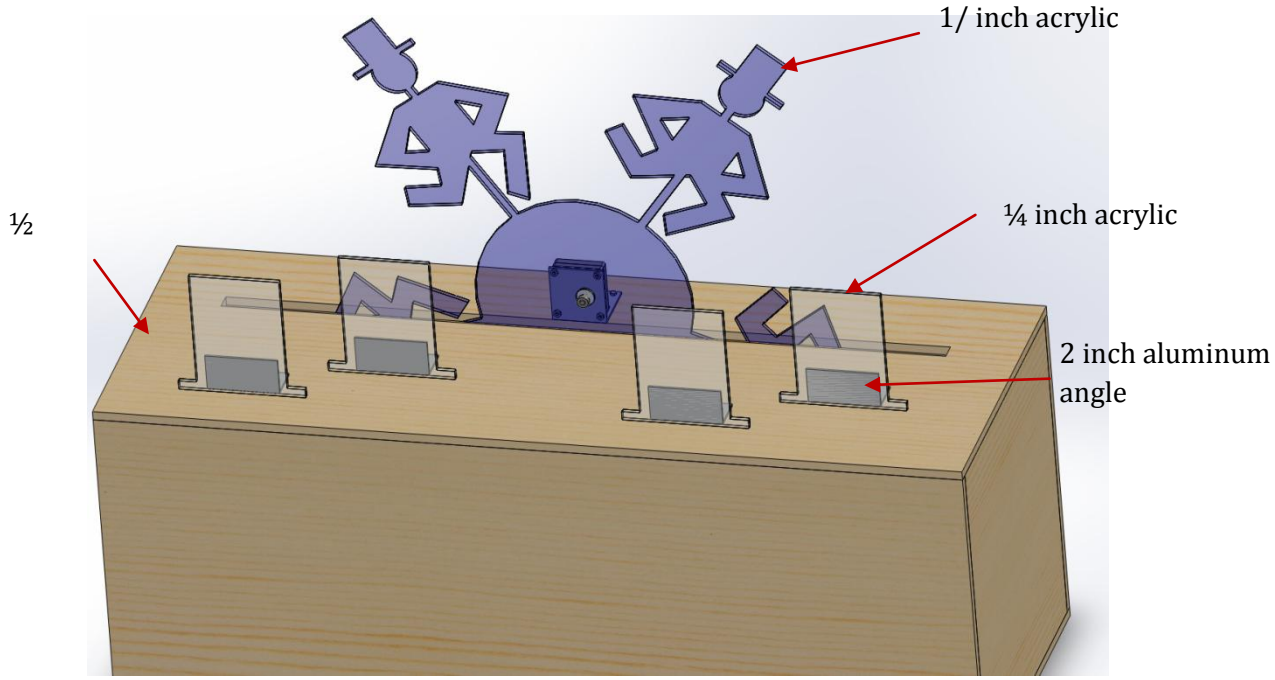


Figure 3. Isometric view of Day 10 with material selection

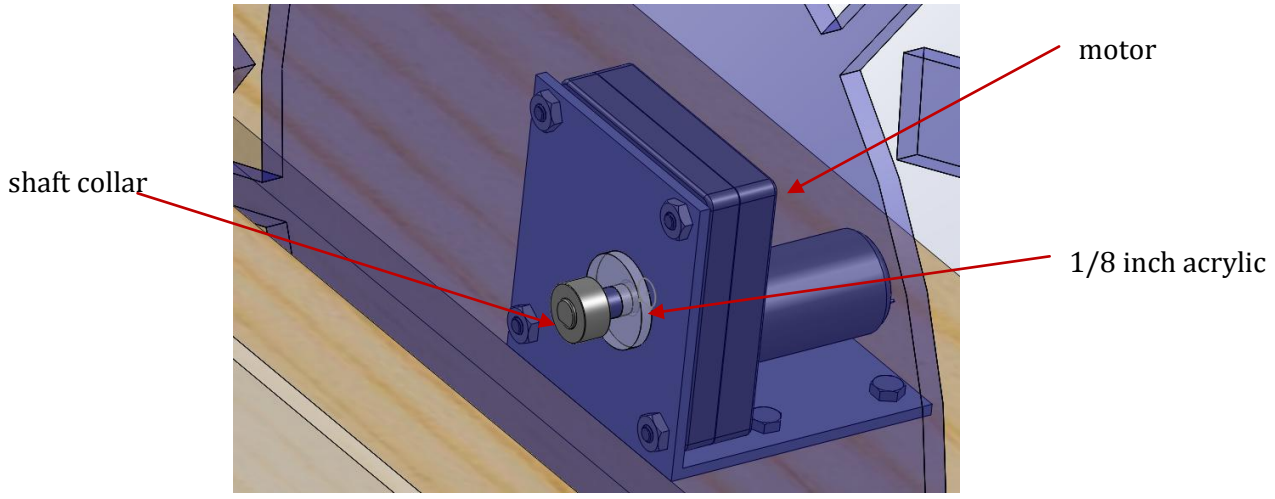


Figure 4. Close up view of motor connection

Day 11: Eleven Pipers Piping

The display for eleven pipers piping does not have a moving mechanical display. Instead it will have light up notes in the backdrop that will flash. The base will be made of half inch plywood with a quarter inch ABS backdrop. The backdrop will have a rectangle cut out for a 1/8 inch thick black opaque acrylic sheet to be mounted with the musical notes cut out with the laser cutter. Transparent colored acrylic sheets will be glued behind the musical not cut outs using acrylic cement to give them color and allow them to light up with LEDs. The pipe instrument infront of the backdrop will be made out of quarter inch acrylic and supported by two inch aluminum angle bar.

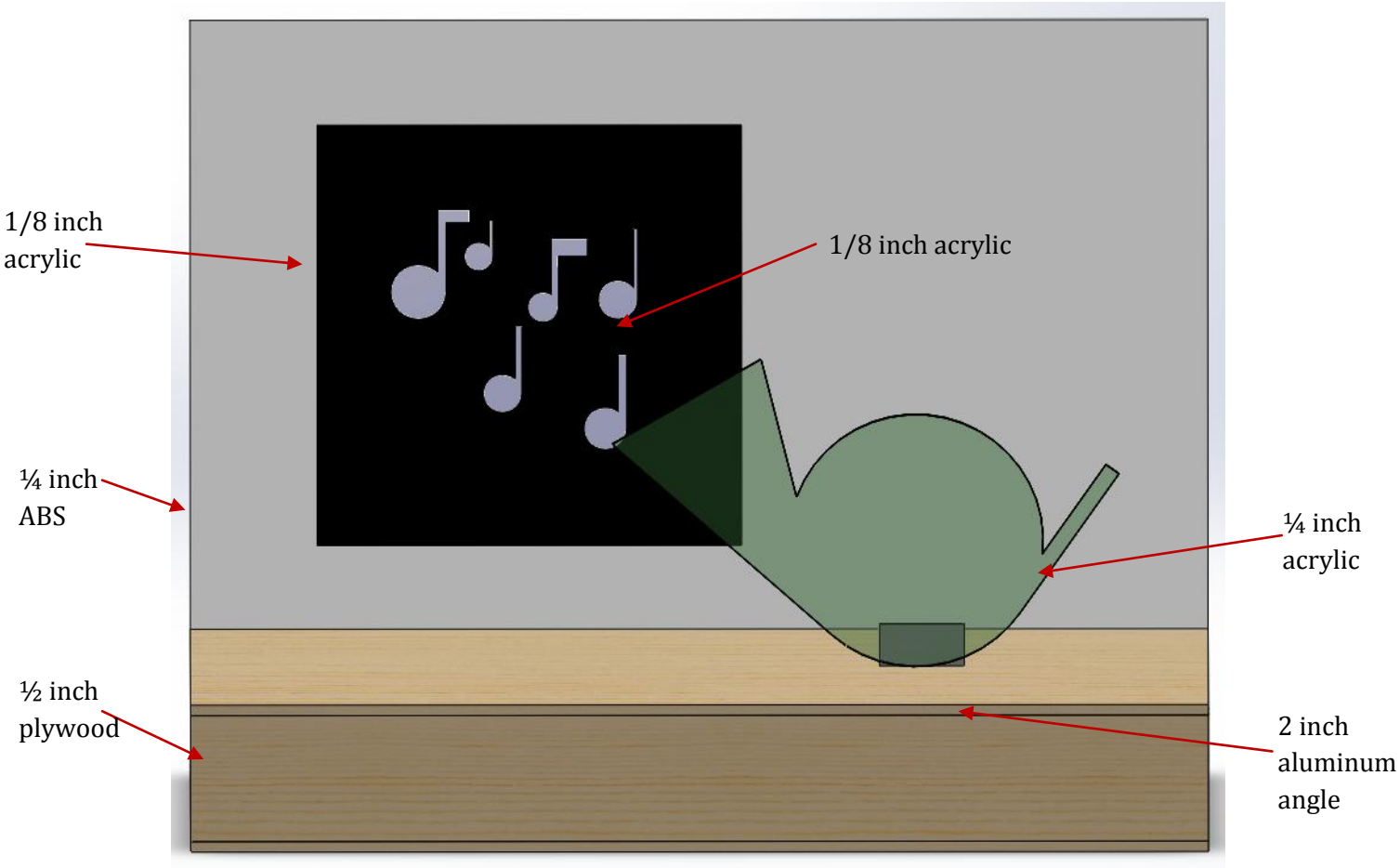


Figure 5. Day 11 front view with material selection

Day 12: Twelve Drummers Drumming

The display for twelve drummers drumming does not have a moving mechanical display. The drummer and drums will be cut out of quarter inch acrylic and mounted to the base using two inch aluminum angle bar. The base will be made out of half inch plywood.

Control System

Timing and Music:

A Raspberry Pi board will be used to play the song and send signals to the individual days to sync them to the music. The Raspberry Pi is a small, low-powered computer that can be programmed in several languages. It has 8 general purpose input and output pins. Shift registers will be used to increase the number of pins to allow it to control all twelve days.

Individual Days:
An Arduino will be used in each day to control the motors and lights. It will turn on and off motors and light sequences based on the signals from the Raspberry Pi. To control the stepper motor in Day 1, a stepper motor driver will be used. This allows the Arduino to easily control the number of steps and the direction the motor rotates. A limit switch will be added to Day 1 to allow the controller to know the relative position of shaft. Days 3, 5, 7 8, 9, and 10 will use a normal motor driver. Motor drivers can control the speed and direction of the motors. The LED lights will be controlled using Darlington Drivers. Each Darlington Driver contains 8 channels that can be turned on and off using the output pins of the Arduino. Each channel can control around 33 LED lights.

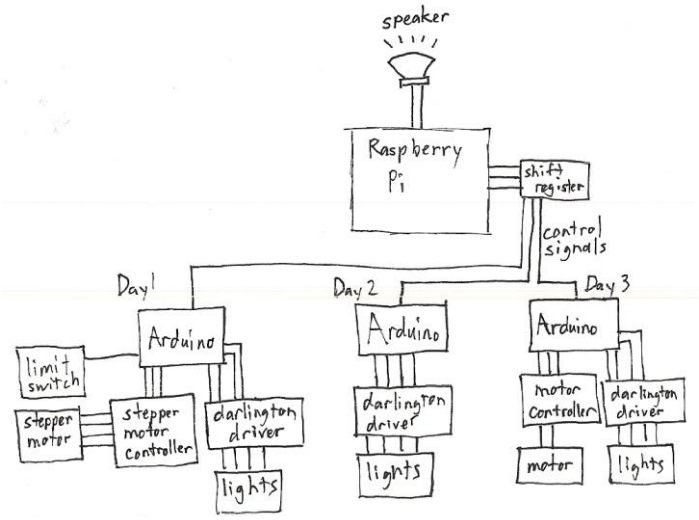


Figure 47. Control System Setup

Conclusions and Recommendations

General Safety Considerations

When handling this display, there will be many different safety matters to take into consideration. One such matter is that many of the displays have pinch points while they are in motion and also while they are being moved. We have attached a picture of each display with their specific pinch points labeled and ask you to be aware of these pinch points in order to avoid coming in contact with them as the display runs. Another safety consideration is that these displays are heavy and difficult to carry. Because of this, we suggest that two people carry each display as they are being transported. A third safety consideration is that the plastic pieces on the display, as well as the lights, are delicate and must be handled with care otherwise they may break as the displays are moved around. Electrical safety is another safety concern. Circuit boards and controllers are required to run the motors and lights in each of the scenes. Electronic components will be enclosed, but it is important to ensure that no moisture contacts the electronic devices used in the display. It could be unsafe for anyone handling the electronics and could cause damage to the display and surrounding objects. Additionally, when the displays are set up, it is crucial that they are fixed securely. The displays are heavy and if they are not secured to the platform, they may tip and become a hazard to anyone nearby.

Material Selection

Each of the twelve displays incorporates a combination of materials. The displays will include polycarbonate plastic, acrylic, aluminum, steel, and wood. The aluminum supports were chosen because they are light and have the strength and durability needed for an element support. Wood will be used for the base because it is inexpensive and easy to replace when necessary. Acrylic plastic was selected for many of the elements because it will not warp, is UV resistant, and for its appearance. The other specialty plastics were chosen in order to reduce the amount of painting required. They are more durable than painted wood and will reduce replacement costs during the life of the display. Please see the Appendix A for a material selection chart and Appendix F for a complete list of the materials being used.

3 Form Reclaimed Material

3 Form has a “reclaim” department in which a selection of unused material has been reclaimed and is resold at lower cost. We will take advantage of this department and purchase pieces from this selection. Since the selection is limited and constantly changing, some of the listed 3 Form materials may be substituted for different materials found in the reclaim department.

Maintenance and Repair

To maintain the display, we recommend covering all sections of the display with a tarp during non-operational hours. Although we have chosen UV resistant materials, it is still recommended that the display not be exposed to extreme heat or direct sunlight unless necessary. This will ensure a long life of the display and maintain the appearance of the plastics and other materials. Paint should be reapplied to detailed acrylic pieces (e.g., maids, partridge, hens, etc.) to ensure that the quality of appearance is at its best. The mechanisms should require little maintenance, but over time the parts will wear and need to be replaced. For part information or to contact vendors please see the appendices in the back of this report.

Electronics Maintenance and Troubleshooting

Refer to Appendix F for wiring schematics and diagrams

Issue: None of the displays are turning on with the music

Possible Solution:

- Open the Timing Box and make sure the peripherals are plugged into the Raspberry Pi GPIO pins

Issue: Music is not playing

Possible Solution:

- Check if the boombox is turned on
- Check if the audio plug is plugged into the amplifier
- Check if the amplifier is turned on
- Check if the amplifier is plugged into the audio cable coming out of the Timing Box
- Open the Timing Box and check if the audio cable is plugged into the 3.5 mm jack of the Raspberry Pi

Issue: An individual day is not turning on

Possible Solution:

- Check if the display is plugged in
- Check if the signal wire is properly connected to the Timing Box and the Controller box

Issue: The motors on Days 3, 5, 7, 8, 9, and 10 or the LED lights in Days 6 and 11 are not turning on

Possible Solution:

- Check if the 12V power supplies are plugged in
- Check that the motors and LED lights are properly connected to the controller box

Issue: String lights and spotlights are not turning on

Possible Solution:

- Check that the relay cord is plugged in
- Check if the string lights are spotlights are plugged in
- Unplug the display, open the controller box and check if the relay cord is properly connected to the relay

Manufacturing Processes

Manufacturing was a significant element in the production of the Twelve Days display prototype. In order to produce the many small features and moving components required for the display, a few crucial manufacturing processes were necessary. Among these processes are laser cutting, machining, and CNC milling. These processes made the production of linkage and chain mechanisms possible as well as making the fabrication of intricate acrylic figures simple and efficient. The linkage used in Day 7 to guide the waves in front of the swans can be seen in the Figure 1 to the left. The laser machine is able to cut out intricate shapes by operating like a printer, shown in Figure 2. The machine reads files from the program Adobe Illustrator and cuts the image with a laser onto a variety of materials. For this prototype, the laser was used to cut images from 18"x32" sheets of ¼" acrylic plastic. The laser cutting machine made it possible to mass produce the various acrylic pieces, including the tree bushes, maids, pears, hats, dancers, and hearts, to name a few. The production of this prototype relied heavily on the use of the laser machine, as every unit of the twelve-piece display has parts created with the laser.

Figure 1. Day 7 mechanism with linkages shown

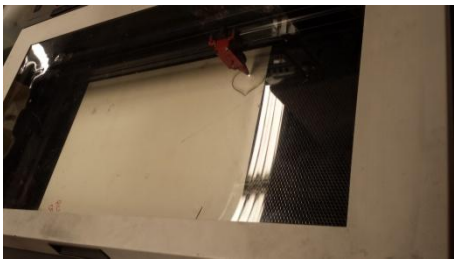


Figure 2. Laser machine cutting heart.

Figure 3. Linkage used for Days 3 and 8

Figure 4. Shaft with sprocket and collar for Day 5.

In order to produce the mechanisms required for the moving components of the display, the CNC mills and lathe machines were used to make parts for the linkages in Days 3, 5, 7, 8 and 9.The mill was utilized to make the aluminum linkages for Days 3, 7 and 8, by removing material from the edges to create rounded features and by drilling holes for joints, as seen in Figure 3. The linkages for Days 3 and 8 have a d-slot used to secure them to the hens and maids, respectively, as well as connecting them to the motor shaft. The manual mill was used to modify shoulder bolts into d-shafts for use on Days 3 and 8 to ensure the hens and maids mimic the motion of the linkages. Additionally, the manual mill was used to create counter bore features on screw holes in order to make the screw head flush with the surface of the acrylic part. This was necessary given the aesthetic requirements of the prototype. The lathe was used to make the round tensioners for the chains as well as the flange bushing for the shafts in Day 5 and 9 (Figure

4). The shafts were made by cutting stock lengths of aluminum and steel and notching the ends using an endmill, in order to insert and secure the rings and ladies' platforms. The jig saw was used manually for cutting out large pieces that could be made using the laser machine; these pieces include the tree trunk in Day 1 and the large heart in Day 2. Support features such as brackets and hinges were purchased in bulk and attached where necessary. Aluminum angle was purchased in large quantity and cut to the appropriate length and used to support large and medium sized acrylic elements including the tree in Day 1, the heart in Day 2, geese in Day 6, swans in day 7, Maids in Day 8, and the piper in Day 11. Other support elements such as the shaft collars were made out of delrin plastic using the CNC mill, also seen in Figure 4.

Figure 6. Hinges for doors.

Figure 5. Enclosure for electronics on Day 11.

The bases for every day were constructed out of plywood and assembled using wood glue and screws, and sealed with exterior paint in a variety of colors. The plywood was purchased in 8'x4' sheets and cut to length on a table saw. Each of the pieces were designed based on the needs of the day and are configured differently for each display. Every base has a door cut into it to ensure access to the motors and control boxes that are enclosed to protect from weather and moisture (Figure 5). The doors were attached using small hinges and screws purchased at a hardware store (Figure 6). For each day, the support requirements varied; for example, Day 1 needed more structural support due to the height and weight of the acrylic plastic tree, so wire was attached to screws in four locations on the tree and fixed to the base with metal loops. Some days did not require this type of support, so standard screws were used to fix the acrylic directly to the plywood base. For example, the eggs in Day 6 were fixed using one screw through a thru-hole cut into the acrylic plastic. For most days of the display, elements were attached to the bases using aluminum angle brackets cut to length from a large stock size, shown in Figure 7. These aluminum brackets were screwed to the base and the acrylic parts were attached to the brackets. Before any of the acrylic elements were attached to the brackets, and subsequently to the bases, they had to be painted. In order to achieve the desired image, Cal Poly art students drew the image on with pencil,

Figure 8. Acrylic painted eggs for Day 6.

Figure 7. Aluminum angle brackets painted in black exterior paint.

and acrylic paint was used to paint over the detail, shown in Figure 8. After the paint dried, a clear spray sealant was used as a final protecting effort against rain and other moisture.

Attaching lights to the display was the final step in the manufacturing process for the prototype. Standard LED strands of Christmas lights were used in the display and attached behind the plastic elements, hiding the unattractive wires and plugs. In order to attach the lights to each of the days, 7/16" holes were drilled into the acrylic plastic so that the bulb could be seen from the front side while hiding the wires on the back side as seen in Figure 9. A handheld drill was used to make the hundreds of holes in each of the days. After the holes were drilled, the light bulbs were carefully placed in the holes and a clear adhesive caulking was applied to the rear side for both weather proofing and fixture purposes, also seen in Figure 9.

Figure 9. Lights behind acrylic, held in by caulking.

All of the electronic circuits were soldered together and enclosed in project boxes to protect them from the weather. The circuit boards were attached to the lid of the project box using double sided foam tape to keep them in space and prevent them from moving around in the box. Slots were cut into the project boxes using a dremel to connect power supplies and peripherals to the circuits. Screw terminals were used to connect the signal wire, motors, and LEDs to the controllers. Extension cords were cut and hooked up to the relays to control the AC current used to power the string lights and spotlights.

Figure 10. LED light circuit for Day 11.

For days that required LED lights, soldering was necessary to attach the LEDS in sequence. Each of the individual LED lights were attached to each other in groups of three, soldered positive end to negative end. Each set of three was soldered to a resistor that was then wired back to connect with other resistors to be controlled by a microcontroller. Soldering is a tedious and time consuming process, but was necessary in order to achieve lighting small elements in sequence for Days 6 and 11 (Figure 10). These LEDs and wiring are not weather proof and are kept within an enclosure made out of plywood as seen previously in Figure 5.

Other miscellaneous tasks included using a grinder to remove excess material from screws that were too long and protruded from the plywood, and using a staple gun to fix the lights

to the plywood bases. At the display site, the displays were mounted to the provided deck on 1 inch risers so that air and water could flow under the displays and they would not sit in stagnant water.

Prototype vs. Original Design

The final prototype was consistent with our design in most aspects. However, in some areas we changed the design during the manufacturing process as we saw fit. For example, we had not originally designed doors for the bases, but realized they would be necessary for access to the motors and electronic components. Changes that were made during manufacturing are expressed below:

Day 1

The design included acrylic bushes to be fixed to the front side of the base, but instead we decided to staple green lights to the plywood base.

Day 2

Originally, the design called for three separate acrylic hearts to be attached and back lit, but we decided to paint three different hearts on one piece of plastic and have the day spot lit.

Day 3

We had designed a pencil steel Eiffel Tower to be attached to the base, but instead an Eiffel tower was cut out of acrylic plastic, painted with detail, and attached to the plywood backdrop.

Instead of using the individual LEDs for the twinkling stars, we used string lights with a twinkling pattern because it was cheaper than using an Arduino to control the lights and easier to wire.

Day 6 and Day 11

The design did not include an enclosure for the LED lights, but the prototype has a plywood case that keeps the wiring protected from weather.

Day 7

Instead of using the individual LEDs for the twinkling stars, we used string lights with a twinkling pattern because it was cheaper than using an Arduino to control the lights and easier to wire.

Day 9

For the ladies dancing, the original design had them on empty platforms but after putting it together we thought that the display needed something more. Due to this, we bought 3 tensile Christmas trees to add as center pieces on the platforms for the ladies to dance around.

Day 12

The design for day 12 originally had the drummers drumsticks as moving lights to mimic the drumming motion but we decided to go with a completely stationary display. To make the display more fun, we also added tensile Christmas trees.

Recommendations for Future Manufacturing

For future manufacturing of this project, we would make a few suggestions:

1. Chain driven mechanisms should be switched to belt driven. The belts are easier to work with, especially since adjustment is needed after transportation at the display site.
2. Improve adhesive strength for the bushings in the linkages. The epoxy used for this prototype caused the bushings to pull out occasionally.
3. Use a more durable material for painting surfaces. Acrylic paint will scratch off and requires many touch-ups after weather has damaged the surface.
4. Improve sealant strength- current sealant is a spray on clear coat. Acrylic paint reacts badly to moist weather and given the outdoor nature of the display, a stronger sealant, such as an acrylic clear coat, would be ideal.
5. Use better connectors to wire the controller boxes to the timing box. The screw terminals would sometimes need to be reconnected because they wires come loose when the box is moved.
6. Have all base doors be on the back of the display. Some of the doors were placed on the side which made it difficult to access the inside of the base after the display has been set up. The displays are arranged side by side, blocking the access door. This made it harder to place and hook up the electronics.
7. Add a start and stop button to make it easier for the user to control the display. Currently the timing box needs to be unplugged to stop the display from running.

Design Verification – Testing

For testing descriptions and the DVPR checklist refer to the testing plan in Appendix A.

Results:

Figure 71. Final set up of display showing visibility and size.

Test Overview

Test A Viewability – Each display is easily viewable. The deck provided for the display mounting is the perfect height and distance from the path the visitors walk on. (Figure 11)
Test B Size – Each display is within the size requirements of 2 feet deep, 4 feet wide and 5 feet tall.
Test C Weight – None of the displays were actually weighed, however they are easily carried by two people or a dolly.
Test D Weatherproof – The display was assembled on site and immediately sat through a rain storm. The only damage from this storm was some running paint. This was solved by putting on a better clear coat over the painted elements.
Test E – The power draw from each display has not yet been determined.
Test F and G – All of the displays that have mechanical motion were tested as they were completed. The entire display was assembled on November 25th and has run for a total of 24 hours. Within these 24 hours, many kinks and bumps were worked out and fixed with the mechanical displays and everything now works as planned.

Test F Display Reliability

Objective

To test the reliability of each of the displays and make sure all the lights, motors, and mechanisms work consistently

Procedure

All the displays were connected to their controller boxes, which are connected to the timing controller. Each day is plugged in to run with the timing controller and unplugged if any issues arise.

Results and Troubleshooting

All Days

Issue: Some days would stop turning on

Cause: The signal wire from the timing box to the controller box would get loose and need to be reconnected

Solution: The screw terminals were tightened to make a more solid connection between the timing box and the controller boxes

Result: All the controller boxes receive signal from the timing box

Arduino Controlled LED Lights Days 6 and 11

No Issues

Result: All the LEDs flash with the desired pattern

4-bar Mechanism Days 3 and 8

Issue: The motor is loud and struggles to turn the mechanism

Cause: The plastic on the hens and maids rubs against the backing of their mount causing excess friction

Solution: Washers were added to the back of the hens and maids to lessen the area of the surface that rubs against each other

Result: The motor is quieter in operation

Chain and Sprocket Days 5 and 9

Issue: The shafts do not rotating smoothly and make loud noises as they turn

Cause: The corners of the tensioner would get caught in the chains

Solution: The corners were chamfered and sanded down to make a mother transition for the chain to enter the tensioner

Result: The chain does not get caught in the tensioner anymore

Issue: The chain would jump off the sprocket

Cause: The chain and sprocket were misaligned

Solution: The sprocket was lowered to the same level as the chain

Result: The chain stays on the sprocket

Wheel Day 10

Issue: The lords interfere with the slot causing the motor to stall

Cause: The wheel the lords are mounted on is misaligned

Solution: The slot was cut wider to fit the wheel

Result: The wheel spins freely without interference from the slot

Test G Controller Box Reliability

Objective

To make sure the timing board stays in sync with the song during each playthrough and is able to turn on and off all the lights and motors.

Results and Troubleshooting

Signal Wire for All Days

Issue: Some days would stop turning on

Cause: The signal wire from the timing box to the controller box would get loose and need to be reconnected

Solution: The screw terminals were tightened to make a more solid connection between the timing box and the controller boxes

Result: All the controller boxes receive signal from the timing box

Relays for All Days

Issue: The string lights and spotlights on some days would stop functioning

Cause: The connection from the extension cord to the relay would come loose and need to be reconnected

Solution: The extension cord wire was tinned with solder to make a more solid connection between it and the screw terminal on the relay

Result: All the relays work and turn on and off reliably

Timing Controller

Issue: When the song is first played after the controller turns on, the song randomly pauses at around 30 seconds and then resumes. This causes the song to be out of sync with the display during the first run.

Cause: When the computer starts up it immediately runs the code to play the music with the timing. Right after start up, the computer is slower than it normally is and this causes the music to stutter during playback.

Solution: A 45 second delay was added to the startup so that the computer has enough time to completely turn on without lag when the song starts.

Result: The timing of the board successfully keeps sync with the music after running it over the course of a day.

Issue: Halfway through the song, the displays start to flicker on and off and then turn off when more than 5 displays are switched on at once.

Cause: The power supply for the relays and motor controllers does not provide enough current to switch on all the components at once during the song. The original power supply used was a 12V 1A supply with a 5V voltage regulator to bring the voltage down to 5V

Solution: The original supply was replaced with a 5V 2A supply to provide more current

Result: All the displays are able to be turned on at once by the timing board

Conclusion

The 12 Days of Christmas Display was set up at the Cambria Pines Lodge on November 21st. The display was worked on, on site until opening night on November 29th. The display has had a very warm reception from the visitors to the lodge. Below are pictures from the display at night.

Appendix A

Quality Function Design Chart
Decision Matrices
Failure Mode Effects Analysis (FMEA) Chart
Design Verification Plan & Report
Testing Plan

Table 1. Quality Function Design Chart

Customer						Engineering Requirements (HOWS)												Benchmarks				
Cambria Community	Dirk Winter - Owner	Shana - Sponsor	George Marshal - Event Coord	12 Days of Christmas Customer (Step #1) Requirements (Whats)		Weighting (Total 100)	Height of moving parts	Display Size	Weight of Each Day	Made with stock parts	Storage Size	% Viewable Mechs	Weather Resistance	Enclosed Mechanisms	Power draw	Drop Test	On/Off Cycle Test	Sponsor Approval	Very Bad	Bad	Neutral	Good	Very Good
H	H	H	H	Customer Requirements (Step #2)	Festive	8												9			×		★ ○ ☺
L	M	M	M		Professional	4												9			★	× ☺	○
H	M	M	M		Motion	6	3	1										9	★				× ○ ☺
M	H	H	M		Energy Efficient	6			1						9				×		★ ○	☺	
H	H	H	H		Safe	8				1				9								★ ○ ☺	
L	H	H	H		Long Life	7				3				3								★ × ☺	○
L	H	H	H		Durable for transport	5			3	3			3	3		9						○	★ × ☺
L	L	L	L		Collapsable	3		3			9								○	×	☺		★
L	M	H	H		Repairable	6				9				3							×	★ ☺	○
H	M	H	M		Education	6	3					9		3				9	★	× ○			☺
L	H	H	H		Waterproof	8							9	9								★	× ○ ☺
L	M	M	M		Wind Stability	8		3	9				3									★	× ○ ☺
H	H	H	H		Easily Viewable	7	9							3							★	× ○	☺
M	H	H	H		Reliable	6				3			1	1		3	9				×	★ ○ ☺	
L	H	H	H		Cost	7		3	1	3					9					○	★ ×	☺	
L	H	M	M		Storable/Transportable	5		3	9		9								○	×		★	☺
					Units		ft	ft	lb	y/n	ft	%	y/n	y/n	watt	y/n	%	y/n					
					Targets		2.5 - 4.5	5 x 4.5 x 4	<40	y	120	90	y	y		y	98	y					
					Benchmark #1																	★	Existing Display in Cambria
					Benchmark #2																	×	Floats
																						○	Disneyland
				● = 9	Strong Correlation																	♦	Holiday Displays
				○ = 3	Medium Correlation																	☺	Target
				Δ = 1	Small Correlation																		
				Blank	No Correlation																		

Table 2. Decision Matrix for Days 1-4 Concept Design

Decision Matrix Pros and Cons			
Day	**Idea**	**Pro**	**Con**
Partridge in a Pear Tree	Cuckoo Partridge	keeps with bird theme	doesn't make sense in a tree
			too busy
			bird not easily visible
	Moving Branches	simple motion	not continuous motion
		bird is easily visible	
	Moving Branches and Partridge	interesting	complicated scene
			not continuous motion
Two Turtle Doves	Spinning Heart	simple motion	not interesting enough
		easy to do	not enough room for a large circle
	Kissing Doves	cute image	hard to maintain
		keeps with love bird theme	complicated motion
	Silhouette Doves	easy to do	not very exciting
		fun light interaction	
		keeps with love bird theme	
		different from other scenes	
Three French Hens	Bobble Hens	cute motion	busy motion
			complicated mechanism
			more moving parts (maintenance)
	Pecking Hens	easy to integrate into scene	complicated motion
		hens do pecking motion	
	Swinging Hens	different from other scenes	doesn't make sense
		interesting	complicated
Four Collie Birds	Cuckoo Bird	fun motion	too busy
		not used in other bird scenes	only focuses on one bird
	Spinning Cage	simple motion	can't see the birds as well
	Flapping Birds		complicated motion
			not exciting or cute
	Lit Cages	can see all birds	no motion
		great light integration	

Table 3. Decision Matrix for Days 5-8 Concept Design

Decision Matrix Pros and Cons			
Day	**Idea**	**Pro**	**Con**
Five Gold Rings	Bobbing Up and Down	easy to do	more complicated motion
			not as fun
	Spinning in a Circle	easy to do	can't see spinning
	Spinning Intertwined	interesting	can't see rings spinning
	Spinning About Vertical Axis	can see motion	more complicated mech.
		easy to accomplish	
		"awe" looking	
Six Geese-a-Laying	Egg Drop	fun motion	complicated return system
		keeps with "whimsical" theme	
	Egg Stairs	cool mechanical motion	complicated system
			high maintenance
	Light Egg Drop	cool light integration	
		simulations motion easily	no actual motion
Seven Swans-a-Swimming	Conveyor Belt	cute image	more complex system
			not as environmentally hardy
	Bobbing Swans		busy
	Moving Waves	easy to do	not as eye catching
		cool effect	
		less moving parts	
Eight Maids-a-Milking	Skirts Swinging	can get all 8 maids in scene	lots of moving parts
	Platform Spinning	easy to do	too busy
			can't get all maids in scene

Table 4. Decision Matrix for Days 9-12 Concept Design

Decision Matrix Pros and Cons			
Day	**Idea**	**Pro**	**Con**
Nine Ladies Dancing	Single Platform Spinning	easy to do	can't see all ladies in one turn
			repeated motion
	Multiple Platforms Spinning	can see all ladies more easily	more moving parts
	Individuals Spinning	all ladies are visible	more moving parts
Ten Lords-a-Leaping	Limbs Moving	inspired by sponsor's ornament	more moving parts
			high maintenance
	Moving Up and Down	easy to do	repeated motion
	Leaping Over 10	Imitates actual leaping	
		Single wheel--simple motion	
		Incorporates Number	
Eleven Pipers Piping	Light up Pipe	different from other scenes	no actual motion
		no motion--easy to maintain	
Twelve Drummers Drumming	Arms Moving	inspired by sponsor's ornament	smaller moving parts
			higher maintenance
	Marching	typical of actual drummers	smaller moving parts
		different from other scenes	
	Drumsticks Moving--Lights Only	interesting	no actual motion
		no motion--easy to maintain	

Table 5. Failure Mode Effects Analysis (FMEA) Chart

FMEA NO.	1	Prepared By		K.R.		Page 1 of 1
Machine Name	Entire Display	Product/Service Application		12 Days of Christmas Display		FMEA Date: 04/17/2013
Design Responsibility	K.R.	Review Date				Core Team: 3 French Hens
Function and Performance Requirement	**Potential Failure Mode**	**Potential Effects of Failure**	**Severity**	**Potential Cause of Failure**	**Occurrence %**	**Current Design and Machinery Controls**
shafts	fatigue failure	display needs to be fixed	10	poor shaft alignment	1	checked during istallation
		shaft shears	10	poor shaft alignment	1	high safety factor used
	impact failure	Display does not run	10	display got dropped during storage	3	aesthetic pieces made of (relatively) durable material
		shaft needs to be replaced	10	display gets pushed off of display deck	2	aesthetic pieces made of (relatively) durable material
	warping	excessive vibration	6	load is too heavy	1	high safety factor used
		gear teeth don't mesh anymore	8	shaft is not manufactured corectly	1	checked during istallation
		shaft imbalance	5	shaft improperly installed	1	checked during istallation
gears	teeth wear	decreased efficiency	4	nonconstant forces	1	following proper instuctions
		gears don't mesh as well	4	not aligned/mounted correctly	2	checked during istallation
				gears analyzed incorrectly	1	checked during design process
				shaft out of round/misalignment	1	checked during istallation
	teeth fracture	display stops working	10	interference	2	checked during istallation
-	-	damage to gears, shafts, or motor	8	impact forces	2	following proper instuctions
-	-	-		to much load	1	following proper instuctions
-	-	-		display gets dropped	3	proper handling
batteries	leaking	damage to the display	10	too much current drain	1	following proper instuctions
		non-ideal voltage	6		1	-
	over drained	battery doesn't work	10		2	checked during istallation
-	overheating	decrease in power	8		1	-
bearings	seizing	shaft damage	8	ball bearings wear out	1	following proper instuctions
		display stops working	10	shaft speed is too high	1	following proper instuctions
		less efficient	6	overheat	1	
		gear damage	8		1	
motor	overheating	motor fails	10	run over the max rpm many times	1	regular maintenence
		display stops working	10		1	
		less efficient	6		2	

		reduced motor life	6		2	
	shorting	failure in wires	7	poor assembly	2	checked during istallation
		too much current draw	6	poor contact with necessary components	2	checked during istallation
				water damage	1	regular maintenence
wiring	pinching	shorting out	10	display being imporperly handled	3	following proper instuctions
	insulation failure	shorting out	10	excessive heat	1	checked during installation
				errosion	1	regular maintenence
				normal wear and tear on the wire	2	regular maintenence
				imporper human handling	3	following proper instuctions
controller	water damage	microcontroller breaks	10	controller box is not waterproof enough	1	seal controller box
				box is left open to the elements	1	following proper instuctions
	shorting	displays do not function	10	water damage	1	insulate wires
	overvoltage	microcontroller breaks	10	not properly connected to the power source	1	iscolate controller from high voltages
				improperly wired	2	checked during istallation
decorative façade	impact damage	figurines on display break	10	something falling on display	2	make display study enough for impact
		back panel of display breaks	10	people touching display	3	barriers
				display gets dropped during storage	3	aesthetic pieces made of (relatively) durable material
	weathering	paint needs to be redone	8	sun/rain damage	2	drawings provided for creating new aesthetic elements
		elements need to be replaced	10	warping/delaminating wood	3	drawings provided for creating new aesthetic elements
				plastic becomes brittle	3	aesthetic pieces made of (relatively) durable material
		display falls over	10	wind forces	3	aesthetic pieces made of (relatively) durable material

Table 6. Design Verification Plan and Report (DVP&R) Chart

ME428/ME481 DVP&R Format

Report Date	12/5/2013	Sponsor	Cambria Pines Lodge				Component/Assembly			REPORTING ENGINEER:	
TEST PLAN									**TEST REPORT**		
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Easily Viewable	Measure the height of the aesthetic display from groundlevel	Between 3ft and 5ft	Katie	PV	12	C	11/15/2013	11/15/2013	display within bounds	Yes	-	The deck built for the display is easily viewed
2	Display Size	Measure the overall height, width, and depth of each display	Within 2ft x 4ft x 5ft	Katie	PV	12	C	11/15/2013	11/15/2013	display within bounds	Yes	-	None of the displays are bigger than 2ft x 4 ft x 5 ft
3	Weight of Display	Weigh each display	Below 60lbs	Katie	PV	12	C	11/25/2013	11/25/2013	45-65 lbs	Yes	-	None of the displas were individually weighed but they are easily carried by two people or with a dolly.
4	Weather Resistance	Spray display with water while running	Continues to run	Christine	PV	12	C	11/20/2013	12/4/2013	works	Yes	-	The display was set up and st through two different storms.
5	Power Draw	Measure power usage of each display	Below 3000 watts	Christine	PV	-	C	-	-	-	-	-	This test has not yet been performed
6	Durable for Transport	Drop the display from # height	Survives	Michael	PV	-	C	-	-	-	-	-	None of the displays were dropped as a test. They were transported in a van and had no damage done to it
7	Reliability	Turn on and turn off display # times	Successfully runs 98% of the time	Michael	PV	24 hrs	C	11/20/2013	12/4/2013	works	Yes	-	Each of the indivudal displays were tested as the mechanisms were finished. The entire display has been run and watched for 28 hours and all kinks have been worked out.

Table 7. Material Decision Matrix- Pro/Con List

Material	Pro	Con
Acrylic	laserable	brittle
	trasparent	
	less expensive	
ABS	Machinable	soft
	durable	more expensive
Polycarbonate	machinable	not laserable
		expensive
Wood	cheap	not weather resistant
	easy to work with	
	easy to paint	
	easy to replace	
Steel	less expesnive	not weather resistant
		heavy
Aluminum	weather resistant	
	relatively easy to machine	
Stainless Steel	weather resistant	heavy
		expensive
		hard to work with

Testing Plan

A) Specification: Easily Viewable
Test Description: Measure height of the aesthetic portion of the display from ground level
Criteria: Between 3 feet and 5 feet
Required Tools: Tape measure
Location: Mustang 60 Shop

B) Specification: Display Size
Test Description: Measure the overall height, width, and depth of each display
Criteria: Within 2ft x 4ft x 5ft
Required Tools: Tape measure
Location: Mustang 60 Shop

C) Specification: Weight
Test Description: Weigh each display
Criteria: Below 60 lbs
Required Tools: Weighing Scale
Location: Mustang 60 Shop

D) Specification: Weather Resistance
Test Description: Spray displays with water while running them
Criteria: Displays continue to function
Required Tools: Power, Hose
Location: Mustang 60 Shop

E) Specification: Power Draw
Test Description: Measure the power usage of each display
Criteria: Below 3000 watts
Required Tools: Power, Power meter
Location: Mustang 60 Shop

F) Specification: Display Reliability
Test Description: Run each display with on off cycles for a full day
Criteria: The displays do not fail
Required Tools: Power
Location: Mustang 60 Shop

G) Specification: Control Box Reliability
Test Description: Run all twelve days in time with music for a full day.
Criteria: The displays consistently run with the correct timing
Required Tools: Power
Location: Mustang 60 Shop

Appendix B

Task List
Gantt Chart

Table 8. Task List with Summer Timeline

WBS	Task Name	Start	Finish
1	**Concept Model**	**Wed 2/20/13**	**Thu 2/28/13**
2	**Concept Design Report**	**Tue 2/26/13**	**Fri 3/22/13**
3	**Detailed Design**	**Fri 4/19/13**	**Thu 6/6/13**
3.1	**Rough Drawings**	**Fri 4/19/13**	**Tue 4/23/13**
3.2	**Analysis**	**Wed 4/24/13**	**Fri 5/10/13**
3.3	**Detailed Drawings**	**Fri 5/10/13**	**Thu 5/23/13**
3.4	Make Bill of Materials	Wed 5/15/13	Tue 5/21/13
3.5	Find Suppliers	Wed 5/15/13	Tue 5/21/13
3.6	Make Testing Plans	Tue 5/21/13	Thu 5/23/13
3.7	Rough Draft of Report	Fri 5/24/13	Mon 5/27/13
3.8	Practice Critical Design Review	Tue 5/28/13	Tue 5/28/13
3.9	Revise	Wed 5/29/13	Mon 6/3/13
3.10	Critical Design Report	Tue 6/4/13	Tue 6/4/13
3.11	Critical Design Review	Thu 6/6/13	Thu 6/6/13
4	**Build**	**Mon 6/10/13**	**Wed 9/25/13**
4.1	Order Parts	Mon 6/10/13	Thu 6/20/13
4.2	**Independent Build (Katie and Michael)**	**Mon 6/24/13**	**Sat 7/13/13**
4.2.1	Laser cut images for Day 1		
4.2.2	Laser cut images for Day 2		
4.2.3	Laser cut images for Day 3		
4.2.4	Place lights Days 5-8		
4.2.5	Place lights Days 9-12		
4.3	**Independent Build (Christine)**	**Mon 6/24/13**	**Sat 7/20/13**
4.3.1	Purchase Day 4 bird cages		
4.3.2	Purchase Day 4 spray paint		
4.3.3	Purchase shafts and supports if necessary		
4.3.4	Place lights Days 1-4		
4.4	**Group Build 1**	**Sat 7/20/13**	**Mon 7/22/13**
4.4.1	Assemble Day 1		
4.4.2	Assemble Day 2		
4.4.3	Paint eiffel tower and backdrop	Mon 7/22/13	Mon 7/22/13
4.4.4	Assemble Day 3	Tue 7/23/13	Tue 7/23/13
4.4.5	Paint cages	Sat 7/13/13	Sat 7/13/13
4.4.6	Assemble Day 4	Mon 7/22/13	Mon 7/22/13
4.5	**Independent Build (Katie and Michael)**	**Sat 7/20/13**	**Sat 8/17/13**
4.5.1	Laser cut images for Day 5		
4.5.2	Laser cut images for Day 6		
4.5.3	Laser cut images for Day 7		
4.5.4	Laser cut images for Day 8		
4.6	**Group Build 2**	**Sat 8/17/13**	**Mon 8/19/13**

4.6.1	Assemble Day 5		
4.6.2	Assemble Day 6		
4.6.3	Assemble Day 7		
4.6.4	Assemble Day 8		
4.7	**Independent Build (Katie)**	**Mon 8/19/13**	**Wed 9/18/13**
4.7.1	Laser cut images for Day 9-12		
4.8	**Independent Build (Michael)**	**Mon 8/19/13**	**Wed 9/18/13**
4.8.1	Continue work on controls/lighting		
4.9	**Independent Build (Christine)**	**Mon 8/19/13**	**Wed 9/18/13**
4.9.1	Mechanism Analysis--Day 1		
4.9.2	Work on Manufacturing Plan		
4.9.3	Continue work on final report (Fall '13)		
4.10	**Group Build 3**	**Wed 9/18/13**	**Fri 9/20/13**
4.10.1	Assemble Day 9		
4.10.2	Assemble Day 10		
4.10.3	Assemble Day 11		
4.10.4	Assemble Day 12		
4.10.5	Day 1 Mechanism Construction		
4.10.6	Begin attaching lighting		
4.11	**Group Build 4**	**Sat 9/21/13**	**Sun 9/22/13**
4.11.1	Attach lighting (all 12 days)		
4.11.2	Additional painting		
4.11.3	Miscellaneous tasks		
4.11.4	**Fall Quarter Begins**	**Mon 9/23/13**	
4.12	**Electrical Parts**	**Mon 9/23/13**	**Wed 11/27/13**
4.12.1	Wire Motors	Mon 9/23/13	Fri 10/4/13
4.12.2	Wire Lights	Mon 9/23/13	Fri 10/4/13
4.12.3	Controllers	Mon 10/7/13	Fri 10/11/13
4.12.4	Project Hardware Demo	Tue 10/15/13	Tue 10/15/13
4.12.5	Test Displays	Wed 10/30/13	Tue 11/12/13
4.12.6	Test Controller	Wed 11/13/13	Tue 11/19/13
4.12.7	Sync To Music	Wed 11/20/13	Tue 11/26/13
4.12.8	Senior Design Expo	Thu 11/21/13	Thu 11/21/13
4.12.9	Set up Display in Cambria	Thu 11/21/13	Wed 11/27/13
4.12.10	Display Goes Live	Thu 11/28/13	Thu 11/28/13
5	**Turn in Final Report**	**Fri 12/6/13**	**Fri 12/6/13**

Appendix C

Vendor Contact Information
Vendor Specification Sheets

Table 10. Vendor Contact Information

Vendor Information					
Category	Vendor	Website	Email	Phone	Contact
Material	3 Form	www.3-form.com	curtis.page@3-form.com	(801) 649-2576	Curtis Page
	Bakersfield Plastics	www.bakersfieldplastics.com	info@bakersfieldplastics.com	(661) 325-5310	
	Tap Plastics	www.tapplastics.com	info@tapplastics.com	(800) 246-5055	
	Home Depot	www.homedepot.com		(805) 596-0857	Store #1052
	McMaster	www.mcmaster.com	cle.sales@mcmaster.com	(330) 342-6100	
	Acrylite	www.acrylite.net			
	ePlastics	www.eplastics.com		(800) 474-3688	
	OnlineMetals	www.onlinemetals.com		(800) 704-2157	
Lighting	Target	www.target.com			
	McMaster	www.mcmaster.com	cle.sales@mcmaster.com	(330) 342-6100	
Electronics	Sparkfun Electronics	www.sparkfun.com	customerservice@sparkfun.com	(303) 284-0979	
	Mouser Electronics	www.mouser.com	sales@mouser.com	(800) 346-6873	
	Torrance Electronics			(310) 328-2501	

Appendix D

Summary Material Cost
Summary Electronics Cost

Key	
MC	McMaster Carr
HD	Home Depot
A	Acrylite
EP	ePlastics
3F	3 Form
OM	Online Metals

Day 1: Partridge in a Pear Tree Cost Summary					
Part	**Subpart**	**Vendor**	**Quantity**	**Price**	**Qty. Price**
Tree Trunk	Trunk	HD	1	$ 50.00	$ 50.00
	Finish	HD	1	$ 30.00	$ 30.00
Bush	Medium	A	4	$5.20/sqft	$ 20.80
	Large	A	1	$5.20/sqft	$ 26.50
Flower Bushes	All	3F	4	$61/unit	$ 61.00
Platform	Base	HD	1		
	Front	HD	1		
	Side	HD	2		
	Total	HD	1	$ 46.00	$ 46.00
	Posts	HD	2	$ 5.50	$ 5.50
Supports	Brackets	MC	4	$ 4.49	$ 17.96
	Spacing Studs	MC	6	$ 2.55	$ 15.30
	Nuts	MC	12	$ 6.74	$ 6.74
				Subtotal	$ 279.80
			Tax 8.00%	**Total**	**$ 302.18**

Day 2: Two Turtle Doves Cost Summary					
Part	**Subpart**	**From**	**Quantity**	**Price**	**Qty Price**
Bird Cages	Cage 1	Various	1		
	Cage 2	Various	2		
	Cage 3	Various	3		
	Cage 4	Various	4		$ 200.00
	Spray Paint	HD	6	$ 20.00	$ 20.00
Base					
	Base		1		
	Front		1		
	Side		2		
	Total	HD		$ 46.00	$ 46.00
Supports	Aluminum Shafts				
	12 in	MC	1	$ 29.05	$ 29.05
	18 in	MC	1	$ 43.57	$ 43.57
	24 in	MC	1	$ 58.10	$ 58.10
	36 in	MC	1	$ 81.33	$ 81.33
	Plywood Discs	HD	1	$ 14.00	$ 14.00
	Shaft Supports	HD	4	$ 20.00	$ 20.00
				Subtotal	$ 512.05
			Tax 8.00%	**Total**	**$ 553.01**

Day 3: Three French Hens Cost Summary					
Part	**Subpart**	**Vendor**	**Quantity**	**Price**	**Qty Price**
Main Hearts	Tier 3	A	1	$5.81/sqft	$ 92.96
	Tier 2	A	1	$5.81/sqft	$ 52.29
	Tier 1	A	1	$5.81/sqft	$ 23.24
Façade Hearts	Medium	3F	3	$67.12/unit	$ 67.12
	Small	A	1	$5.81/sqft	$ 5.81
	Small	A	1	$5.81/sqft	$ 5.81
	Small	3F	1	$61/unit	$ 61.00
	Smallest	A	2	$5.81/sqft	$ 11.62
Platform	Base	HD	1		
	Front	HD	1		
	Side	HD	2		
	Total	HD	1	$ 46.00	$ 46.00
Fixtures	Spacing Studs	MC	6	$ 2.55	$ 15.30
	Nuts	MC	12	$ 6.74	$ 6.74
				Subtotal	$ 387.89
			Tax 8.00%	**Total**	**$ 418.92**

Day 4: Four Collie Birds Cost Summary					
Part	**Subpart**	**Vendor**	**Quantity**	**Price**	**Qty Price**
Hens	Body	A	3	$5.81/sqft	$ 39.22
	Paint/Detail				
Eiffel Tower	Body	A	1	$5.81/sqft	$ 46.48
Moon	Body	A	1	$5.81/sqft	$ 23.24
Backdrop	Starry Sky with Holes	HD	1	$ 39.97	$ 39.97
Façade	Grass	HD	1	$ 151.80	$ 151.80
Platform	Base	HD	1		
	Front	HD	1		
	Side	HD	2		
	Total	HD	1	$ 46.00	$ 46.00
Fixtures	Aluminum Angle Brackets	MC	1	$ 38.65	
	Spacing Studs	MC	6	$ 2.55	$ 15.30
	Nuts	MC	12	$ 6.74	$ 6.74
Motor		MC	1	$ 42.03	$ 42.03
				Subtotal	$ 410.78
			Tax 8.00%	**Total**	**$ 443.64**

Days 5-8 Cost Analysis								
Material	**Day**	**Item**	**Required Size**	**Quantity**	**Stock length**	**Part Number**	**Stock price**	**Total price**
Aluminum Angle (2"x2")								
	6	geese support	4	2	96	OM 2x2x.25x96	$34.97	$139.88
	7	front wave support	40	1				
		back wave support	40	2				
		front swan support	40	1				
		back swan support	6	3				
	8	front support	40	1				
		back support	40	1				
Aluminum Rod (1" OD)	5							
		ring shaft	12	2	1x6	8974K37	$35.17	$35.17
		ring shaft	18	2				
		ring shaft	24	1	1x3	8974K133	$19.34	$19.34
Aluminum Bar (1x1.5)	7							
		linkage block	2	1	1x1.5x12	OM 1x1.5	$8.23	$8.23
Aluminum Bar (1x1/4)	7	crank	10	1	1/4x1x48	OM 1/4x1x48	8.23 (for 8 ft)	$8.23
		coupler	4	1				
	8	crank	2.75	1				

		coupler	8.75	1				
		connector bar	6	4				
		main bar	40	1				
1/2 in Wood	5	base bottom	24x48	1	1/2x48x96		$20	$60
		base side	6x24	2				
		base front	6.5x48	1				
		base back	6.5x48	1				
		motor mount side	3.5x4	1				
		base back	30x48	1				
	6	bottom	3.5x48	1				
		top	3.5x48	1				
		side	3.5x25	2				
		bottom	18x48	1				
	7	side	5.5x7.5	2				
		top	6x48	1				
		base	18x48	1				
	8	back	48x48	1				
		top	10x48	1				
		side	5.5x9.5	2				
1/4 in Wood	6	small ledge	2x9	3	1/4x48x48		$10	$10
		medium ledge	2x13	2				
		large ledge	2x16	2				

White Acrylic	6	geese	21x18	2	1/4x48x96	015-2 (P-95)	$20	$20
	7	swan	15x17	7				
	8	maid top	6.5x15.75	8				
		maid skirt	10.5x10.5	8				
ABS	5	base top	24x48	1	1/4x24x48	ABSBLK0.250HC24X48	$62.02	$124.04
		motor mount	4x4	1				
	7	base front	7.5x48	1				
	8	base front	5.5x48	1				
Green Acrylic	8	front hill	25x48	1	1/4x48x96	6C028	$7.43/sqft	$132.01
		middle hill	27.5x48	1				
		back hill	38x48	1				
Wave Acrylic	7	front wave	15x49	1	1/4x48x96	splash, bliss x1	$19/sqft	$213.75
		back wave	15x59	1				
Gold Ring Acrylic	5	gold rings	12x12	5	1/4x48x96	regency gold (reclaim)	$19/sqft	$95
Grass Acrylic	7	grass front façade	4x48	1	1/4x48x96	seaweeds (reclaim)	$23/sqft	$31
Diamond Acrylic	5	diamond	6x7.5	5	1/4x48x96	dichroic, solar	$34/sqft	$53.13
Motor	5	motor	12V DC	1		6409K14	$42.03	$126.09
	7	motor		1				
	8	motor		1				
Motor Shaft Collar	7	motor	5/16x5/16	1	5/16x5/16	6435K52	$1.71	$3.42
	8	motor	5/16x5/16	1				

Motor Shaft Washer	7	motor		1		95611A029	12.92 (pack 100)	$12.92
	8	motor		1				
Shaft Collar	5	ring shafts	1x1.75x.5	5	1x1.75x.5	6157K18	$3.76	$18.80
Linkage Bushings	7	linkages		3		6389K352	$2.83 (pack of 5)	$11.32
	8	linkages		17				
Sprockets	5	ring shafts	#25, 1in bore, 28 teeth	10	#25, 1in bore, 28 teeth	2737T216	$12.73	$124.30
Chain	5	motor-1	#25 x 45"	1	#25, 1/4 in pitch	6261K171	$3.73/ft	$52.20
		1 to 2	#25 x30"	1				
		2 to 3	#25 x30"	1				
		3 to 4	#25 x30"	1				
		4 to 5	#25 x30"	1				
Top Shaft Bushing		flange bushing	1x1.25x1	5		6389K559	$17.27 (pack of 5)	$17.27
Shaft spacers	5	motor shaft adapter	1.25x1	1		8572K23	$7.02/ft	$7.02
	5	shaft sprocket spacer	1.25x.63	1				
Tensioner	5	chain tensioner	1x1.5x2	5	1x1.5x24	8739K49	$14.80/ft	$29.60
Bottom Shaft Bushing	5	shaft support	3x2, 1 in bore	5	3x24	8572K34	$39.60/ft	$79.20
Dowels	7	swan support	1/4x2	12	1/4x2	97195A419	$4.67 (pack of 100)	$4.67
Guide Rails	7	wave track	1/2x9.5	2	1/2x19	9728K8	$2.61/in	$49.59

Carriage	7	wave carriage	1x9/16x1.25	2	1x9/16x1.25	9728K51	$29.94	$59.88
Clevis Pin	7	linkage pin	1/4x7/8	1	1/4x7/8	92735A230	$7.05 (pack of 5)	$21.15
	8	linkage pin	1/4x7/8	10	1/4x7/8			
Set Screws	5	ring to shaft set screws	#10-32	10	#10-32	92158A367	$4.75 (pack of 10)	$4.75
Carriage Set Screws	7	carriage mounting	M4x10	8		92605A115	$7.86 (pack of 50)	$7.86
					TOTAL			**$1,579.49**

Electronics Cost Analysis			
Part	Days Used	Cost	Total Cost
Stepper Motor	1	?	
Stepper Motor Controller	1	$19.95	$19.95
Lights	All	?	
Arduino Board	All	$15.00	$180.00
Raspberry Pi Model A	Control	$25.00	$25.00
Darlington Driver	All	$1.76	$21.12
Motor Controller	3, 5, 7, 8, 9, 10	$8.95	$53.70
		Total:	299.77

Appendix E

Engineering Analysis

Day 5 and Day 9 EES Beam Deflection Calculator

Day 5 and Day 9 Beam Deflection Calculator

From Shigley Table A-9 10

$L = 6.5$ [in] Distance between bushings

$a = 12$ [in] Overhang length

$F = 30$ [lbf] Loading force

$E = 3 \times 10^{7}$ [psia] Modulus of Elasticity

$D = 0.5$ [in] Diameter

$$I = \pi \cdot \frac{D^{4}}{64}$$ Moment of Inertia of Rod

$$R_1 = F \cdot \frac{a}{L}$$ Reaction at bottom bearing

$$R_2 = F \cdot \left[\frac{L + a}{L}\right]$$ Reaction at top bearing

$$\theta_A = F \cdot a \cdot \frac{L}{6 \cdot E \cdot I}$$ Angle deflection at bottom bearing

$$\theta_B = F \cdot a \cdot \frac{L}{6 \cdot E \cdot L} - 3 \cdot F \cdot a \cdot \frac{L}{6 \cdot E \cdot I}$$ Angle deflection at top bearing

$$Y_C = -1 \cdot F \cdot a^{2} \cdot \left[\frac{L + a}{3 \cdot E \cdot I}\right]$$ Deflection at top of rod

Day 5 Short Beam Deflection Analysis Results

Unit Settings: Eng F psia mass deg

a = 12 [in]	D = 1 [in]	E = 1.000E+07 [psia]	F = 30 [lbf]
I = 0.04909 [in^4]	L = 6.5 [in]	R_1 = 55.38	R_2 = 85.38
θ_A = 0.0007945	θ_B = -0.002378 [rad]	Y_C = -0.05427 [in]	

Day 5 Medium Beam Deflection Analysis Results

Unit Settings: Eng F psia mass deg

a = 12 [in]	D = 1 [in]	E = 1.000E+07 [psia]	F = 30 [lbf]
I = 0.04909 [in^4]	L = 4 [in]	R_1 = 90	R_2 = 120
θ_A = 0.0004889	θ_B = -0.001461 [rad]	Y_C = -0.04694 [in]	

Day 5 Long Beam Deflection Analysis Results

Unit Settings: Eng F psia mass deg

a = 24 [in]	D = 1 [in]	E = 1.000E+07 [psia]	F = 30 [lbf]
I = 0.04909 [in^4]	L = 4 [in]	R_1 = 180	R_2 = 210
θ_A = 0.0009778	θ_B = -0.002922 [rad]	Y_C = -0.3286 [in]	

Day 9 Beam Deflection Analysis Results

Unit Settings: Eng F psia mass deg

a = 12 [in]	D = 0.5 [in]	E = 3.000E+07 [psia]	F = 30 [lbf]
I = 0.003068 [in^4]	L = 6.5 [in]	R_1 = 55.38	R_2 = 85.38
θ_A = 0.004237	θ_B = -0.01271 [rad]	Y_C = -0.2894 [in]	

Appendix F

Artistic Drawings
Part Drawings
Electronic Schematics
Wiring Diagram

Section 1. Artistic Concept Images, prepared by Ashie Fong (Graphic Arts Student, Cal Poly)

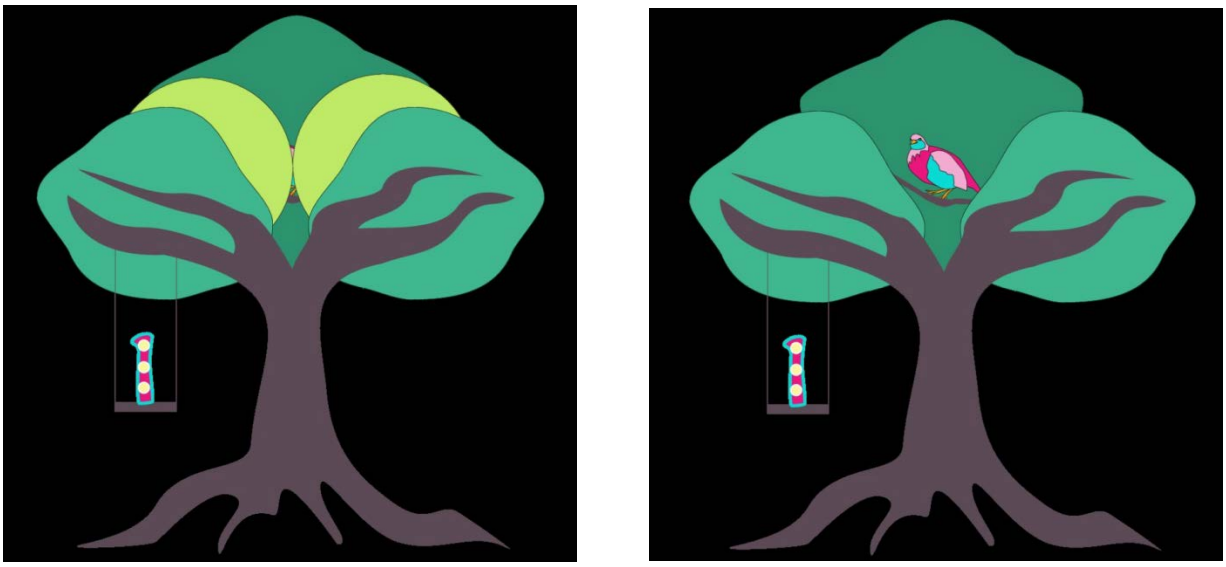


Figure 1. Day 1 Partridge in a Pear Tree

Figure 2. Day 2: Two Turtle Doves

Figure 3. Day 3: Three French Hens

Figure 4. Day 4: Four Collie Birds

Figure 5. Day 5: Five Golden Rings

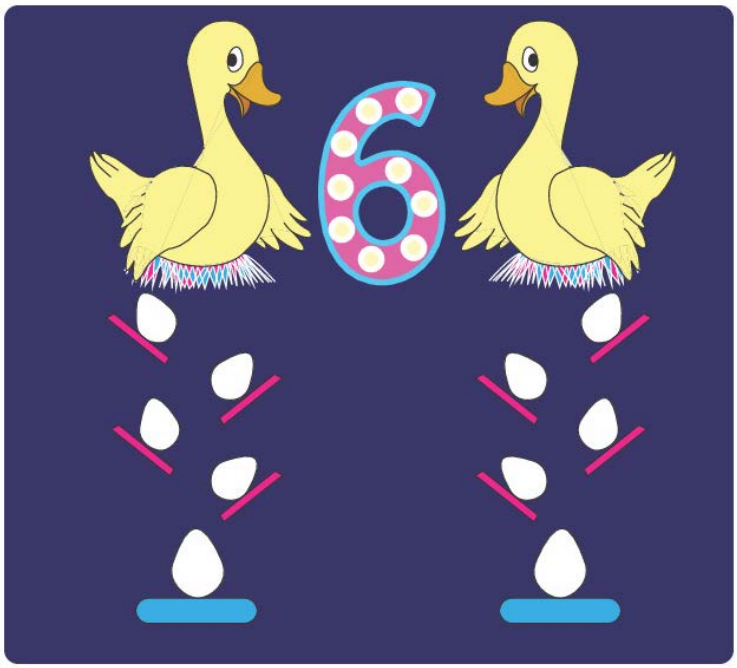


Figure 6. Six Geese-a-Laying

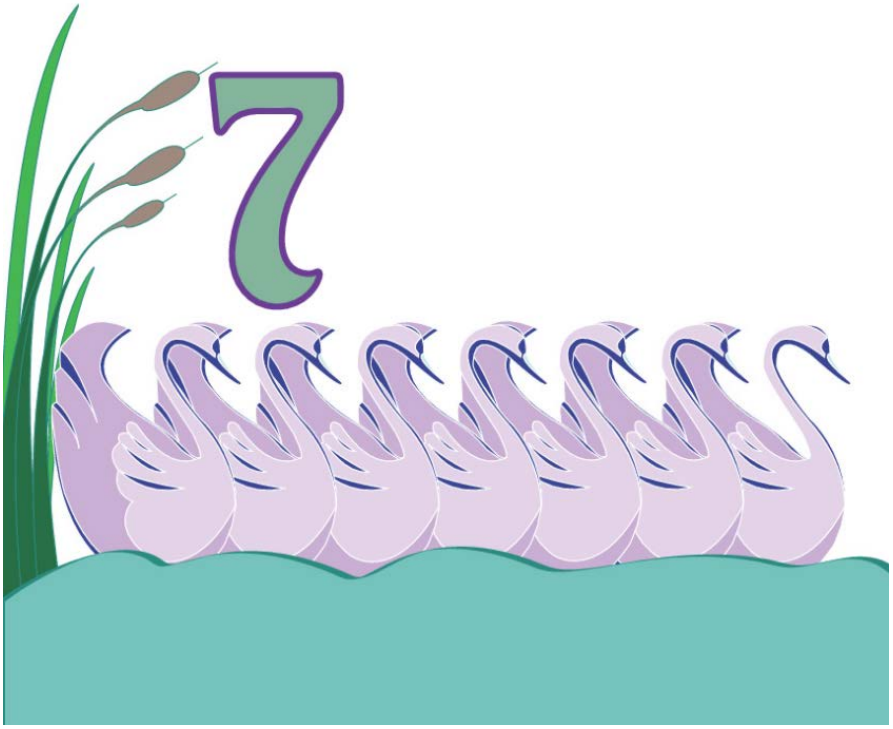


Figure 7. Seven Swans-a-Swimming

Figure 8. Day 8: Eight Maids-a-Milking

Figure 9. Day 9: Nine Ladies Dancing

Figure 10. Day 10: Ten Lords-a-Leaping

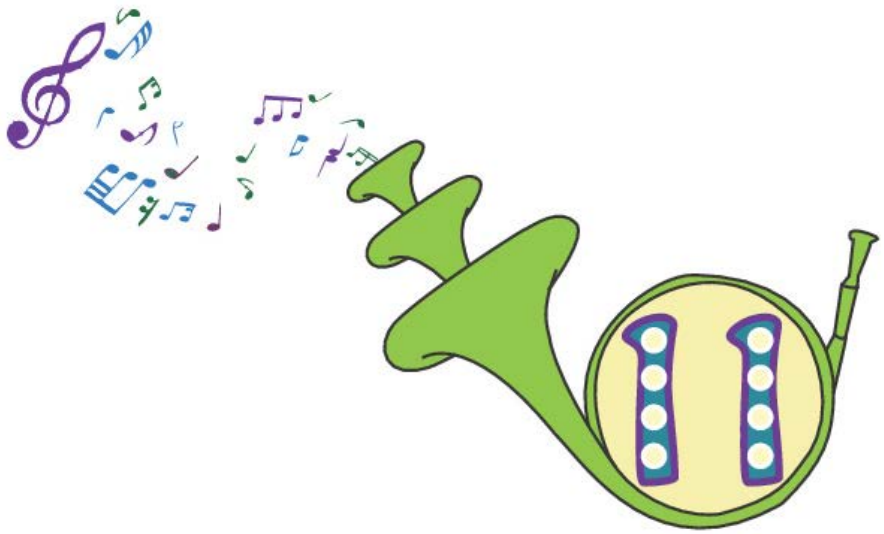
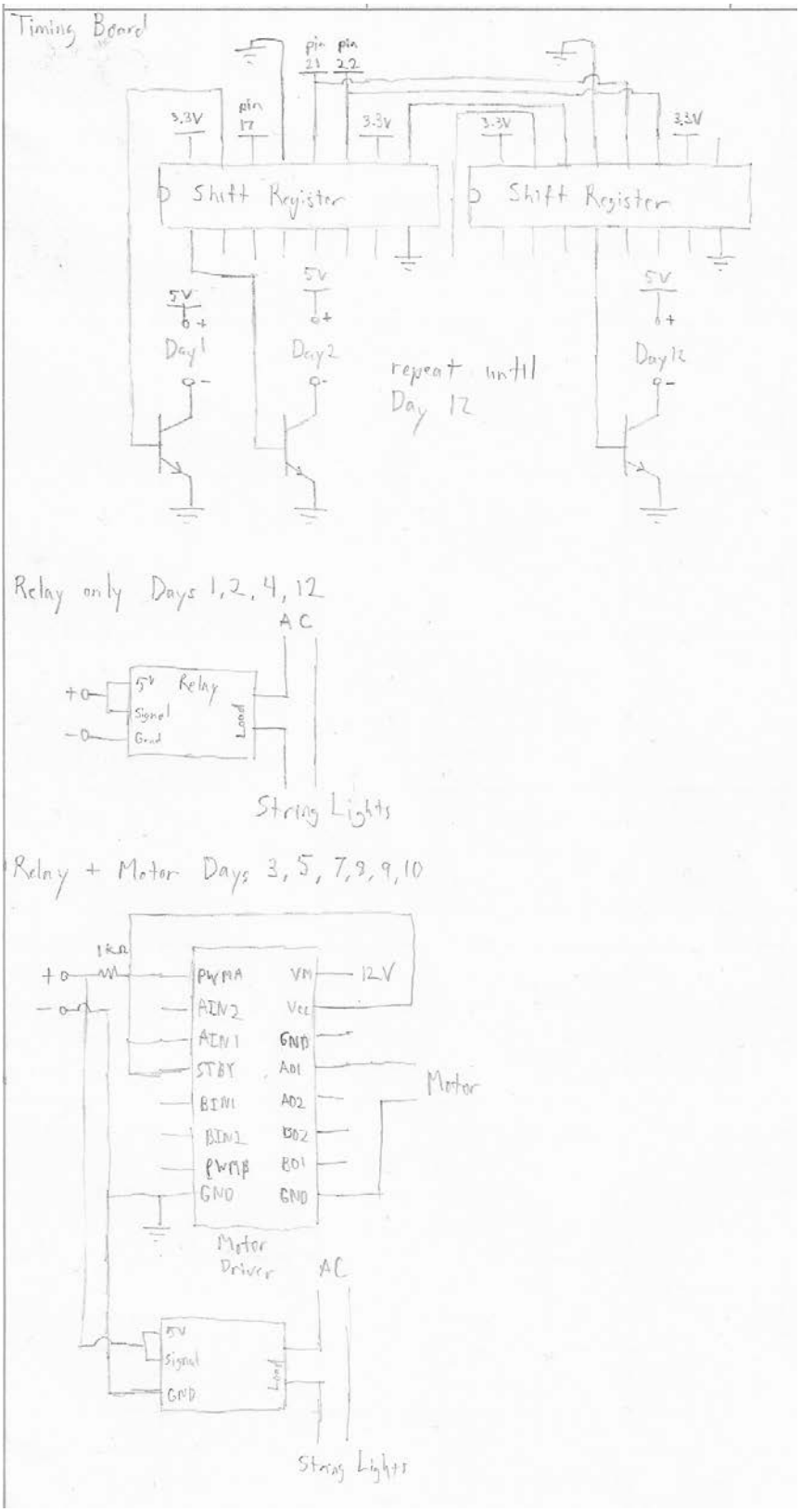


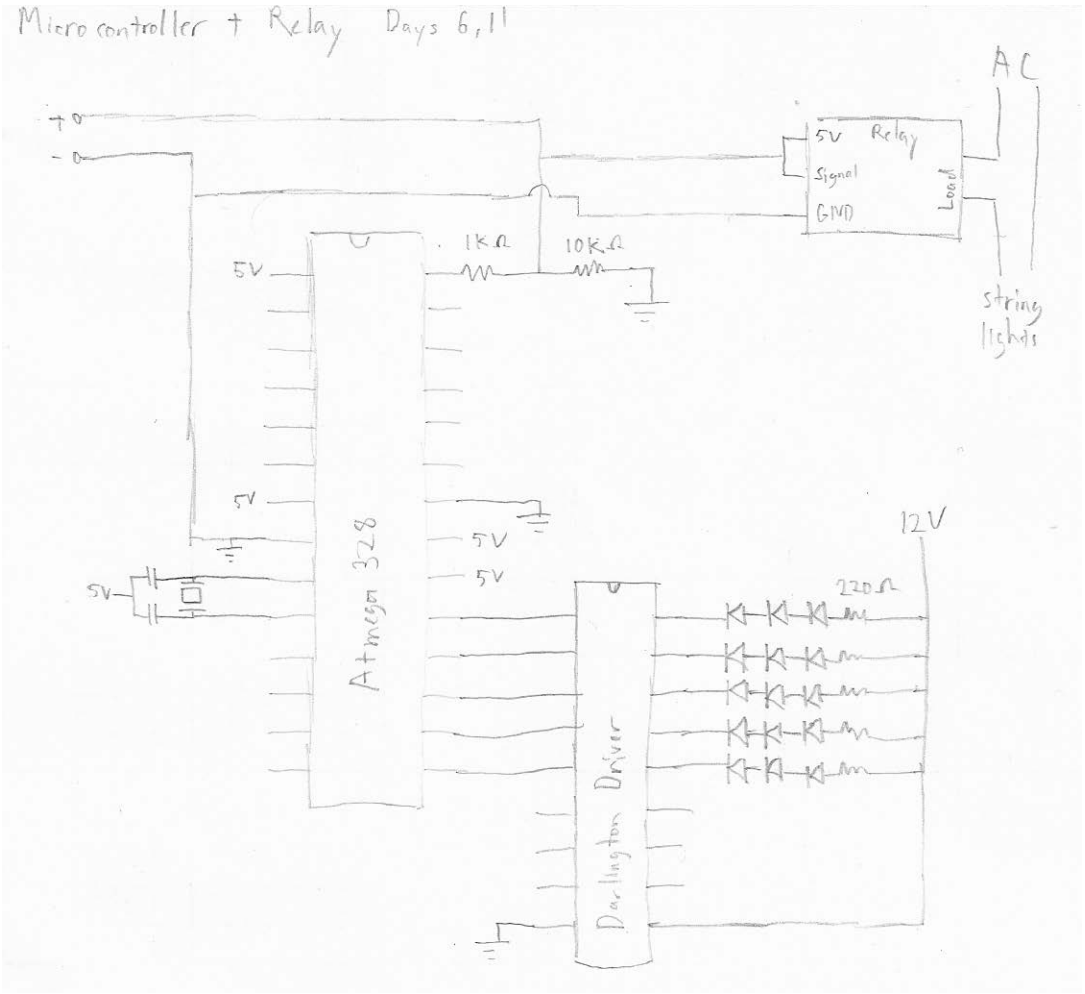
Figure 11. Day 11: Eleven Pipers Piping

Figure 12. Day 12: Twelve Drummers Drumming

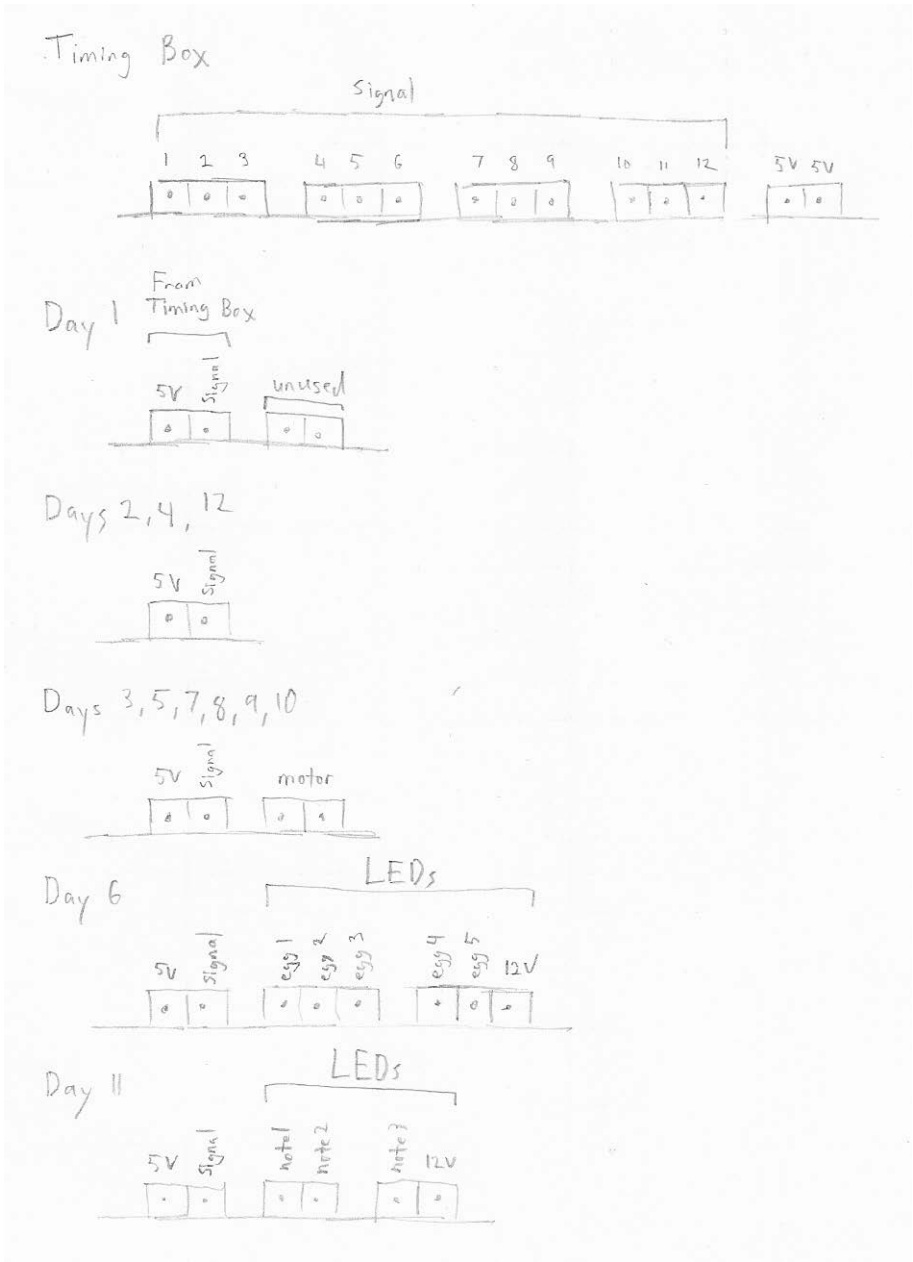
Electronic Schematic



Microcontroller + Relay Days 6, 11



Wiring Diagram



Appendix G

Material Specification Sheets
Adhesive Specification Sheets
Electronics Specification Sheets

3form® varia ecoresin®

Product Description

3form Varia Ecoresin is a dynamic interlayer system with design possibilities as diverse as your imagination. By allowing you to custom-select the color, pattern, texture, interlayer and finish of your material, Varia Ecoresin transforms into the perfect medium for your architectural application. Varia Ecoresin XT can be specified for vertical applications in exterior environments. Reflect, Dichroic™, Wood™ and Timber are also part of the Varia Ecoresin product line.

An award-winning 3form product, Varia Ecoresin has the added benefit of being made from a specially-formulated co-polyester resin that combines performance with environmental responsibility. Ecoresin incorporates 40% pre-consumer recycled content without compromising aesthetics or overall physical properties, is compatible with one of the largest post-consumer recycle streams, and is GREENGUARD® Indoor Air Quality Certified.

FEATURES AND BENEFITS

- Produced on an individual order basis, allowing for creative design and product selection (minimum order quantity – ONE sheet!)
- Post-formable into virtually any shape or size for eye-catching installations
- SCS-certified recycled content helps achieve LEED® credits for building sustainability
- Very tough, allowing for easy fabrication and maximum installed durability
- Extremely versatile which enables designers to achieve full design potential
- Lightweight, half the density of glass, which makes for easier installation and reduces structural support requirements
- Excellent chemical resistance which reduces potential harm incurred by cleaning agents
- Varia Ecoresin is GREENGUARD Indoor Air Quality Certified
- Varia Ecoresin is Underwriters Laboratories registered

AVAILABLE COLORS

Varia Ecoresin is available in a variety of standard woven colors.
Visit www.3-form.com/materials-varia.com for all available options.
Use the C3 Color Matching System to create over 10,000 custom colors.

DICHROIC

Lunar	**Solar**

TIMBER

Mocha	**Natural**

WOOD

Rosewood	**Zebrano Chevron**	**Walnut**

Available laser-cut patterns (wood only):

Array	**Burrow**	**Flicker**
Flora	**Halftone**	**Pulse**
Sequence	**Custom designed**	

TEXTURES/PATTERNS/FINISHES

Varia Ecoresin includes a wide range of textures and patterns from our Organics*, Moderna, Play, Texture, Color, Wood, Dichroic, Reflect, Timber and Graphic collections.

*The Varia Ecoresin system panels utilizing natural products as a decorative interlayers may change in appearance over time. Natural materials are also subject to inherent inconsistency in color, texture and shape.

Each product in the Varia Ecoresin collection comes standard with both a front and back finish. Additionally, 3form provides the option of substituting between five standard finishes. In most cases, you can even pick different front and back finishes. Finishes include:

- **Patent** - A high gloss finish with highest light transmittance
- **Patina** - A non-glare finish with smooth appearance
- **Sandstone** - A more durable finish with a subtle texture
- **Stucco** - A durable finish with a pebbled texture
- **Supermatte** - A frosted matte finish for maximum light diffusion

*Dichroic and Reflect are only offered in Sandstone and Supermatte finishes, but can be ordered with the SFX Frost applied finish.
*Wood is only offered in Patent, Patina, Sandstone and Supermatte finishes.

Additionally 3form low-VOC functional coatings may be applied to the surface of 3form Varia Ecoresin. Finishes include:

- **Titanium** - Smooth, silver, mirror-like finish on the backing of a panel
- **Markerboard Plus** - High gloss finish with dual purpose dry-erase board capability
- **Screen** - Frosted finish with dual purpose projection screen capability
- **Patina Plus** - Non-glare finish with slightly frosted appearance
- **SFX Frost** - Applied frosted finish with paper-like appearance

PANEL SIZES AND TOLERANCES

Varia Ecoresin panels are offered in 4' x 8' (1.2 m x 2.4 m) and 4' x 10' (1.2 m x 3 m). All dimensions and squareness are subject to a 3/16" (4.7 mm) tolerance. 5' x 10' (1.5 m x 3 m) is also available, though some restrictions apply.

Varia Ecoresin is available in gauges from 1/16 inch to 1 inch. Dichroic, Reflect and Wood are not available in 1/16 inch gauge. Timber only available in 3/8" thickness.

SHEETS WITH ONE WOVEN COLOR

NOMINAL THICKNESS GAUGE	MINIMUM ALLOWANCE GAUGE	MAXIMUM ALLOWANCE GAUGE
1/16" (1.5 mm)	0.050"	0.070"
1/8" (3.1 mm)	0.104"	0.132"
3/16" (4.7 mm)	0.168"	0.192"
1/4" (6.3 mm)	0.212"	0.260"
3/8" (9.5 mm)	0.324"	0.384"
1/2" (12.7 mm)	0.436"	0.508"
3/4" (19 mm)	0.648"	0.768"
1.0" (25.4 mm)	0.850"	1.060"

NON-EMBOSSED SHEETS, DICHROIC, REFLECT, TIMBER* & WOOD

NOMINAL THICKNESS GAUGE	MINIMUM ALLOWANCE GAUGE	MAXIMUM ALLOWANCE GAUGE
1/8" (3.1 mm)	0.098"	0.138"
3/16" (4.7 mm)	0.155"	0.205"
1/4" (6.3 mm)	0.196"	0.306"
3/8" (9.5 mm)*	0.304"	0.434"
1/2" (12.7 mm)	0.412"	0.562"
3/4" (19.0 mm)	0.618"	0.798"
1.0" (25.4 mm)	0.850"	1.090"

*Timber only available in 3/8" (9.5 mm)
**Add +/- 1/32" (+/-0.8 mm) to the above tolerance for hint textured sheets.
**Add +/- 3/16" (+/-4.7 mm) to the above tolerance for all embossed texture sheets.

Sheet tolerance readings are based on an average of several measurements along both long edges of each panel. These measurements are taken 2-3 inches (50-75 mm) from the edges of the panel.

Linear patterns in Varia Ecoresin panels have a skew tolerance of 1/4" skew over 48". Panels containing a pattern (Capiz, Timber, etc.) will not match up from sheet to sheet. If the sheets are intended to match, they should be field cut on-site to a smaller final sheet dimension.

FLATNESS TOLERANCE

Varia Ecoresin panels shall not have distortion in the form of a wrinkle, twist or scallop along the perimeter of the sheet. Overall warp extending across the sheet is permitted to a maximum of 9/32" (7.14 mm) for each 48" (1.2 m) or fraction thereof. Panel is to be measured when laying horizontally under its own weight on a flat continuous surface.

Specifications

FLAMMABILITY & SMOKE TEST RESULTS –
BUILDING CODE APPROVALS

Varia Ecoresin panels (a polyester-based material), have been independently tested and meet the criteria for approved interior finishes and light transmitting resin materials as described in the 2009 International Building Code®.

TEST	3FORM VARIA ECORESIN	RESULT
ASTM D 2843 Smoke Density	71.6%	PASS Less than 75
ASTM D 635 Flame Spread	Self extinguishing	PASS CC1
ASTM D 1929 Self-ignition Temperature	716°F	PASS Greater than 650°F
UL94	Flame Class - HB	PASS
UPITT Mortality Test	PASS	Not more toxic than wood
ASTM E84 Flame Spread, 3/16" thickness Smoke generated	 26 250	 Class B: 26-75 <450
ASTM E84 Flame Spread, 1/4" thickness Smoke generated	 65 425	 Class B: 26-75 <450
ASTM E84 Flame Spread, 1/2" thickness Smoke generated	 55 400	 Class B: 26-75 <450
ASTM E84 Flame Spread, 3/4" thickness Smoke generated	 35 450	 Class B: 26-75 <450
ASTM E84 Flame Spread, 1" thickness Smoke generated	 20 250	 Class A: 0-25 <450
NFPA 286 1/4" thickness (walls only or ceilings only) 3/8" thickness (walls in standoff configuration or ceilings only)	 Pass Pass	 Class A Class A

Due to their specialty construction, 3from Dichroic, Reflect and 3form Wood have their own unique set of fire performance results.

TEST	3FORM DICHROIC/REFLECT	RESULT
ASTM D 2843 Smoke Density	47.5%	PASS Less than 75
ASTM D 635 Flame Spread	17.4 mm/min	PASS CC2
ASTM D 1929 Self-ignition Temperature	716°F	PASS Greater than 650°F
ASTM E84 Flame Spread, 1/4" thickness Smoke generated	 65 450	 Class B: 26-75 <450

TEST	3FORM TIMBER	RESULT
ASTM E84-03 Flame Spread, 3/8" thickness Smoke generated	 75 450	 Class B: 26-75 <450

TEST	3FORM WOOD	RESULT
ASTM D 2843 Smoke Density	68.5%	PASS Less than 75
ASTM D 635 Flame Spread	16.7 mm/min	PASS CC2
ASTM D 1929 Self-ignition Temperature	716°F	PASS Greater than 650°F
ASTM E84 Flame Spread, 1/4" thickness Smoke generated	 70 400	 Class B: 26-75 <450

PANEL WEIGHT

THICKNESS (INCHES)	WEIGHT FLUX (LB/FT²)
1/16" (1.5 mm)	0.4 lb/ft² (2.0 kg/m²)
1/8" (3.1 mm)	0.8 lb/ft² (3.9 kg/m²)
3/16" (4.7 mm)	1.2 lb/ft² (5.9 kg/m²)
1/4" (6.3 mm)	1.7 lb/ft² (8.3 kg/m²)
3/8" (9.5 mm)	2.5 lb/ft² (12.2 kg/m²)
1/2" (12.7 mm)	3.3 lb/ft² (16.1 kg/m²)
3/4" (19.0 mm)	5.0 lb/ft² (24.4 kg/m²)
1.0" (25.4 mm)	6.6 lb/ft² (32.2 kg/m²)

EXPANSION/CONTRACTION ALLOWANCES

Like all resin products, 3form Varia Ecoresin will expand and contract nominally with fluctuations in temperature. The following formula provides allowances that should be made in framed or fitted applications:

- Longest length of panel (inches) x temperature change of the sheet (°F) x 0.00004 = Amount of Linear Expansion/Contraction (inches)

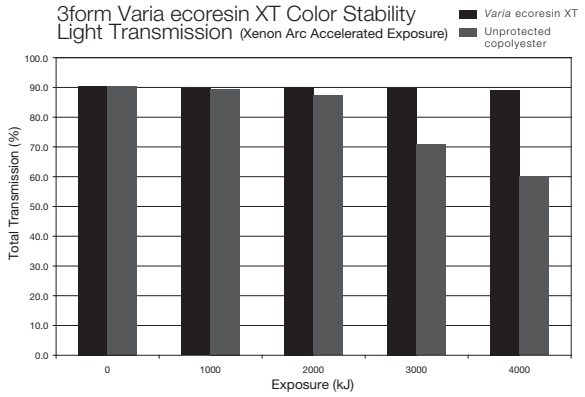
EXAMPLE:

- 48" x 96" panel that experiences a 50°F temperature change will expand/contract: 96 inches x 50 degrees x 0.00004 in/in ºF =

0.192 inches (expansion)

Installers should take extra precautions if installation is occurring before the HVAC systems are operational. Allowances should also be made in the following situations:

- Fastening points
- Channel depths in frames
- Holes for standoffs and other hardware



- Meeting points for multiple sheets of 3form Varia Ecoresin

EXTERIOR PERFORMANCE

UV stabilizers, when incorporated with 3form Varia Ecoresin XT panels, have proven to be very effective in maintaining the integrity of the panels with extended exposure to UV radiation.
*3form Wood is not to be used for exterior applications as the wood interlayer is susceptible to swelling or cracking over time.

*3form Dichroic and Reflect are not to be used for exterior applications.

COLOR STABILITY

The above chart illustrates the effectiveness of the UV stabilizers incorporated into 3form Varia Ecoresin XT panels. Following 4,000 kJ of exposure (representing approximately 5 years outdoor Florida exposure), the 3form Varia Ecoresin XT exhibits excellent performance and maintains consitent light transmission.

USAGE LIMITATIONS

VARIA ECORESIN XT

3form Varia Ecoresin XT is not intended for horizontal exterior applications. Dark colors should be avoided if possible as they absorb excessive heat which can lead to permanent distortion or warping. Varia Ecoresin XT is not recommended for extreme high temperature environments (eg, Arizona, New Mexico, Texas, etc.)

DO NOT use cyanoacrylate or solvent type thread locking materials with Varia Ecoresin. To more permanently secure hardware, use the recommended products from the 3form adhesives matrix."

REFLECT

3form Varia Reflect interlayer is very delicate, it is not recommended for use in exterior applications.

When using Varia Reflect in pressure fitting applications, such as stand-off supports, use a pressure distribution plate or neoprene gasket to prevent localized panel separations.

Varia Reflect cannot be heat formed.

DICHROIC

3form Dichroic has an inherent linerarity running parallel to the panel length. The 3form Dichoic interlayer is very delicate, it is not recommended for use in exterior applications.

When using Dichroic in pressure fitting applications, such as stand-off supports, use a pressure distribution plate or neoprene gasket to prevent localized panel separations.

Dichroic panels will have a smaller finished size after heat forming. See the heatforming section for details.

CRUSH/MICA/RIVER ROCK

Rocks and Glass Inserts may have areas of cracked or crushed material.

ORGANICS

Varia Ecoresin Panels utilizing natural or organic materials (ie. leaves, branches or twigs) my change in appearance over time. Natural materials are also subject to inherent inconsistency in color, texture and shape. Small areas of delamination are also to be expected, especially near saw cut edges.

METALLICS

Varia Ecoresin panels utilizing metallic interlayers (ie. Hollywood, Electra, Itemba, Mirror print) may change in appearance over time due to antiquing of the metallic materials.

WOOD & TIMBER

Because 3form Wood is produced from natural wood pieces, it is not recommended for use in high moisture or exterior applications. Natural wood is very responsive to environmental conditions (moisture, humidity, temperature changes) and therefore is restricted to interior applications. Wood pieces in Timber may contain knots, imperfections, dark spots, stains and color variation. 3form Wood is made using a veneer and provides a one-sided aesthetic which will vary in color, appearance, grain size and width from your sample. 3form Wood may also contain knots and other minor imperfections.

The edges of Timber do not have to be sealed or treated, however if the edges are to be visible, the following treatments improve the edge aesthetics.

Natural: Sand edges with 220 grit sandpaper and carefully wipe the edges with Weld-On 3 (or MEK) making sure not to get any of the chemical on the face or back of the sheet.

Mocha: Sand edges with 220 grit sandpaper and carefully wipe the edges with Minwax Special Walnut 224 stain.

OTHER

Birch will sometimes bleed and cause small amounts of yellowing while being manufactured. In addition, due to the manufacturing press process, birch bulbs may be dispersed within the sheet, some of which will be trapped in clear areas for the Birch Grove pattern.

Structured Bamboo is a one-sided product

Pinapple weave panel width is 45 inches.

FABRICATION

The minimum distance from any edge of the panel to the nearest point on the rim of a hole or cutout must be 2x panel thickness.

EDGE SEALING

Certain Varia Ecoresin designed layers (organics, papers and fabrics in particular) can have a tendency to wick moisture over time if the edges become wet and are not adequately sealed. These Varia Ecoresin products should not be exposed to water or wet conditions without first

applying an approved edge sealing treatment. Varia Ecoresin produced using C3 or HighRes do not require edge sealing. These are good options to use as an alternative to Woven Colors and Organics. Edge sealing is required on all exposed edges (including any holes that are created to allow for stand-off fastening). There are some designed Varia Ecoresin Woven Colors that do not exhibit wicking behavior and therefore do not need to be edge sealed. If you have additional questions or concerns regarding edge sealing of 3form products please contact the 3form Technical Help Desk at 877-649-2670.

DEFLECTION

3form Varia Ecoresin will exhibit different amounts of deflection given a variety of factors: fastening techniques, loads, gauges and panel dimensions to list a few. The 3form Technical Help desk can assist you with general deflection guidelines for your application. You may also consult the Varia Deflection Charts technical white paper. If your application has specific engineering requirements, please contact the 3form Product Technology team for additional direction.

HEAT FORMING/COLD BENDING

Varia Ecoresin can be cold bent for simple bends and curved areas. As a rule, a minimum radius of 100 times thickness is acceptable for Varia Ecoresin (will depend on interlayer material). A minimum radius of 250 times thickness should be used for Dichroic. A minimum radius of 200 times thickness should be used for Wood.

Heat formed Dichroic panels will have a finished size 6” less on each dimension than the standard size sold.

STANDARD SIZE	SIZE AFTER FORMING
48” x 96”	42” x 90”
48” x 120”	42” x 116”

PANEL THICKNESS	MINIMUM COLD BEND RADII		
	VARIA ECORESIN	DICHROIC/REFLECT	WOOD
1/16" (1.5 mm)	7" (178 mm)	-	-
1/8" (3.1 mm)	12" (305 mm)	32" (813 mm)	24" (610 mm)
3/16" (4.7 mm)	19" (483 mm)	47" (1194 mm)	37" (950 mm)
1/4" (6.3 mm)	25" (635 mm)	63" (1600 mm)	50" (1270 mm)
3/8" (9.5 mm)	37" (940 mm)	94" (2388 mm)	75" (1905 mm)
1/2" (12.7 mm)	50" (1270 mm)	125" (3175 mm)	100" (2540 mm)
3/4" (19.0 mm)	75" (1905 mm)	188" (4775 mm)	150" (3810 mm)
1" (25.4 mm)	100" (2540 mm)	250" (6350 mm)	200" (5080 mm)

Because of its low thermoforming temperature, Varia Ecoresin is easy to line bend or drape form. For specific details on line bending and heat-forming please consult the 3form Varia Ecoresin Fabrication Manual.

The special construction of 3form Dichroic and Wood introduces challenges in terms of heat forming. Because both are rigid interlayers, complex curvature is not possible. Simple curves and bends may be accomplished. Timber can only be heat-formed in simple curves, perpendicular to the direction of the wood.

For highly complex shapes and curves, consult with or employ the services of the experts in 3form Fabrication.

EDGE FINISHING

Edges of 3form Varia Ecoresin panels are able to be machined or routed into a variety of different forms. In addition to a straight edge, edges may accept beveling, rounding, etc. Additional finishing, such as sanding or polishing, can also be provided to some edges.

Selected Mechanical and Physical Properties for 3form Varia Ecoresin

Values reported for Varia Ecoresin with no decorative inserts. Decorative inserts may increase or may decrease specific test results. Should your application require specific test values, consult the 3form Product Technology Department.

		TYPICAL VALUE			
		0.118" (3 MM)		0.236" (6 MM)	
PROPERTY*	ASTM METHOD	SI	U.S.	SI	U.S.
GENERAL					
Density	D 1505	1,270 kg/m³	79 lb/ft³	1,270 kg/m³	79 lb/ft³
Water Absorption	D 570 23° C (73° F), 24h immersion	0.2%	0.2%	0.1%	0.1%
MECHANICAL					
Tensile Stress @ Yield	D 638	53 MPa	7,700 psi	53 MPa	7,700 psi
Tensile Stress @ Break	D 638	26 MPa	3,800 psi	26 MPa	3,800 psi
Elongation @ Yield	D 638	4.8%	4.8%	5.0%	5.0%
Elongation @ Break	D 638	50%	50%	40%	40%
Tensile Modulus	D 638	2,200 MPa	320,000 psi	—	—
Flexural Modulus	D 790	2,100 MPa	310,000 psi	2,000 MPa	290,000 psi
Flexural Strength	D 790	77 MPa	11,200 psi	83 MPa	12,000 psi
Shear Strength	D 732	62 MPa	9,000 psi	62 MPa	9,000 psi
Shear Modulus	—	793 MPa	115,000 psi	—	—
Rockwell Hardness	D 785	115	115	117	117
Safety Glazing	ANSI 97.1	PASS		PASS	
Izod Impact Strength, Notched	D 256 @ 73°F D 256 @ 32°F D 256 @–22°F	88 J/m 66 J/m 39 J/m	1.7 ft·lbf/in. 1.2 ft·lbf/in. 0.7 ft·lbf/in.	62 J/m — —	1.2 ft·lbf/in. — —
Impact Strength, Unnotched	D 4812 @ 73°F D 4812 @ 32°F D 4812 @ –22°F	NB** NBB NBB	NB** NBB NBB	NB** — —	NB** — —
Impact Resistance—Puncture, Energy @ Max. Load	D 3763 @ 73°F D 3763 @ 32°F D 3763 @ 14°F D 3763 @ –4°F D 3763 @ –22°F	33 J 40 J 42 J 43 J 47 J	24 ft·lbf 30 ft·lbf 31 ft·lbf 32 ft·lbf 34 ft·lbf	71 J 93 J 96 J >100 J >100 J	53 ft·lbf 69 ft·lbf 71 ft·lbf >74 ft·lbf >74 ft·lbf
THERMAL					
Cont. Max Use Temperature -Varia	–	65ºC	150ºF	65ºC	150ºF
Cont. Max Use Temperature - Dichroic/ Reflect	–	60ºC	140ºF	60ºC	140ºF
Cont. Max Use Temperature - Wood	–	60ºC	140ºF	60ºC	140ºF
Heat Deflection Temperature	D 648 @ 264psi	70ºC	157ºF	73ºC	164ºF
Vicat Softening Temperature	D 1525 @ 1 kg	83ºC	181ºF	—	—
Forming Temperature	—	138-160ºC	280-320ºF	—	—
Thermal Conductivity	ASTM D 5930	0.205 W/ m·K	0.118 Btu/ hr·ft²·ºF	0.205 W/ m·K	0.118 Btu/ hr·ft²·ºF
Coefficient of Thermal Expansion	ASTM D 696	$7x10^{-5}$ mm/ mm/ºC	$4x10^{-5}$ in/ in/ºF	$7x10^{-5}$ mm/ mm/ºC	$4x10^{-5}$ in/ in/ºF

*Unless noted otherwise, all tests are run @ 73°F (23°C) and 50% relative humidity, using specimens machined from extruded sheeting with a thickness as indicated.

**Nonbreak as defined in ASTM D 4812 using specimens having a thickness as indicated. Properties reported here are typical of average lots. 3form makes no representation that the material in any particular shipment will conform exactly to the values given.

REFINISHING

It is possible for Varia Ecoresin to become damaged by scratching. Patent is the only Varia Ecoresin finish that may be repaired, and requires use of a flame polishing technique*.

*Not possible with Varia Ecoresin XT.

Light scratches and scuffs on the sandstone surface finish can be repaired with a plastic polish. The majority of 3form products have a surface finish that would be ruined by buffing.

SOUND TRANSMISSION CLASS (STC) VALUES FOR VARIA ECORESIN

Measurement protocol: ASTM E 90 - Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

THICKNESS	STC VALUES
1/8" (3.1 mm)	25
3/16" (4.7 mm)	29
1/4" (6.3 mm)	31
3/8" (9.5 mm)	34
1/2" (12.7 mm)	34
1" (25.4 mm)	39

THERMAL INSULATION VALUES FOR VARIA ECORESIN

Insulative values are a function of both the convective properties (U-values and shading coefficients) and the conductive properties (thermal conductivity).

Measurement protocol: ASTM E 903 - Standard Test Method for Solar Absorbance, Reflectance and Transmittance of Materials Using Integrating Spheres. ASTM E 891-87 - Tables for Terrestrial Direct Normal Solar Spectral Irradiance Tables for Air Mass. ASTM E 408-71 - Standard Test Method for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques.

VARIA ECORESIN CLEAR THICKNESS	WINTER U-VALUE (BTU/HR-FT²-°F)	SUMMER U-VALUE (BTU/HR-FT²-°F)
1/4" (6.3 mm)	0.97	0.93
3/8" (9.5 mm)	0.90	0.87
1/2" (12.7 mm)	0.83	0.80

Chemical Resistance of 3form Varia Ecoresin to Select Compounds

365 DAY FULL IMMERSION TESTING @ 73°F (23°C)

Polymer materials are affected by chemicals in different ways. Changes in performance or appearance can be attributed to fabrication methods, exposure conditions, concentration of chemical substances or exposure duration. Such factors can even influence the final effect of substances that 3form Varia Ecoresin is considered "Resistant" to under test conditions. Further details are explained below:

FABRICATION

Stresses generated from sanding, grinding, drilling, polishing, machining, sawing and/or forming (hot or cold).

EXPOSURE

Exposure duration, stresses imparted during the application life-cycle due to loads, temperature changes, heat, environments, etc.

APPLICATION OF CHEMICALS

Application from contact, rubbing, wiping, spraying, soaking, etc. Also having an affect is the relative concentration of the chemical in question.

The following data is based on complete immersion of Varia Ecoresin in the chemical or reagent shown. Samples remained immersed and were stored at 73ºF (23ºC) for a period of one year. Following the test period the samples were removed from immersion and inspected.

The following table provides indicative performance of the chemical resistance characteristics of Ecoresin. The following codes are used to describe the chemical resistance characteristics:

R = RESISTANT

3form Varia Ecoresin is able to withstand the identified compound for long exposure periods up to 120ºF (7 days, full immersion)

LR = LIMITED RESISTANCE

3form Varia Ecoresin is only resistant when in contact with this compound for short periods at room temperature. It is advised that further determination of the effect of the substance be further tested in your particular application.

NR = NOT RESISTANT

3form Varia Ecoresin is not resistant to the compound. The material will swell, craze, haze, dissolve or experience some physical change when exposed to this substance.

REAGENT	RESULT	REAGENT	RESULT
Acetic Acid, 5%	R	Acetic Acid, conc.	NR
Acetone	NR	Ammonium Hydroxide, conc.	NR
Antifreeze, Automotive Ethylene Glycol Type	R	Benzene	NR
Brake Fluid, DOT3	R	Brake Fluid	LR
Carbon Tetrachloride	NR	Chromic Acid, 40%	R
Citric Acid, 10%	R	Cottonseed Oil	R
Deionized Water	R	Detergent, Alconox (0.25%)	R
Di (2-Ethylhexyl) Phthalate	R	Dibutyl Sebacate	R
Diesel Fuel	LR	Dimethyl Formamide	NR
Ethanol, 50%	R	Ethanol, 100%	R
Ethyl Acetate	NR	Ethylene Dichloride	NR
Gasohol, 10% Ethanol	LR	Gasohol, 10% Methanol	LR
Gasoline, Base for Gasohol	LR	Gasoline, Premium Unleaded	LR
Gasoline, Regular	R	Gasoline, Regular Unleaded	LR
Grease, Automotive	R	Hand Cleaner, Waterless Jergens SBS30	R
Hexane	R	Hydrochloric Acid, conc.	NR
Hydrochloric Acid, 10%	R	Hydrogen Peroxide, 3%	R
Hydrogen Peroxide, 28%	R	Isooctane	R
Kerosene	R	Lacquer Thinner	LR
Methyl Alcohol	LR	Mineral Oil	R
Motor Oil	R	Nitric Acid, conc.	NR
Nitric Acid, 10%	R	Nitric Acid, 40%	LR
Oleic Acid, 83%	R	Olive Oil	R
Penetrating Oil, Liquid Wrench #1	NR	Phenol, 5%	NR
Silicone Spray Lubricant	NR	Soap Solution, 1%	R
Sodium Carbonate, 2%	R	Sodium Carbonate, 20%	R
Sodium Chloride, 10%	R	Sodium Hydroxide, 1%	R
Sodium Hydroxide, 10%	R	Sodium Hypochlorite, 3.5%	R
Sulfuric Acid, conc.	NR	Sulfuric Acid, 3%	R
Sulfuric Acid, 30%	R	Tapping Oil	R
Toluene	NR	Transformer Oil	LR
Transmission Fluid, Auto	R	Turpentine	LR

Cleaning Instructions

3form Varia Ecoresin, like all thermoplastic resin materials, should be cleaned periodically. A regular, seasonal cleaning program will dramatically help prevent noticeable weathering and dirt build-up. 3form recommends the use of the following common cleaning products: Windex, Formula 409, Simple Green, Fantastik, Virex, 10:1 Water/Bleach Solution.

Rinse the sheets with lukewarm water. (Be careful not to expose edges of organic or fabric interlayers to water) Remove dust and dirt from Varia Ecoresin with a soft cloth or sponge and a solution of mild soap and/or liquid detergent in water. A 50:50 solution of isopropyl alcohol and water also works well. Rinse thoroughly with lukewarm water.

Always use a soft, damp cloth to blot dry. Rubbing with a dry cloth can scratch the material and create a static charge. Never use scrapers or squeegees on Varia Ecoresin. Also avoid scouring compounds, gasoline, benzene, acetone, carbon tetrachloride, certain deicing fluids, lacquer thinner or other strong solvents.

DO:

- Keep edges dry and free of liquids
- Apply cleaning solution or water to a clean cloth and wipe resin clean

DO NOT:

- Use a squeegee.
- Use strong solvents, highly alkaline or abrasive cleaning agents.
- Clean in hot sun or at elevated temperatures.
- Rub with a dry cloth.
- Do not completely saturate panel with cleaning solution or water
- Expose organic or fabric interlayers to water or cleaning solution

PRESSURE WASHING

Pressure washing can also be an effective way to remove miscellaneous debris from surfaces of 3form Varia Ecoresin installations that are in exterior or hard-to-reach places.

Pre-soak panels with a light water spray to loosen and remove incidental surface debris.

It is recommended that the water pressure for cleaning Varia Ecoresin panels be 1,500 psi or less. 3form Varia Ecoresin is a tough material but can be damaged if high pressure is concentrated in a single position too long. Use a gradual sweeping motion over the application. Never concentrate water spray in a single position. Pressure nozzle should never be positioned closer than 8 inches (203 mm) from the panel surface.

Test a portion of the sheet first before spraying. If test piece shows any sign of material fatigue, abrasion or delamination – discontinue pressure washing and proceed with manual cleaning instructions as described above.

Coated or painted parts are not suitable for pressure washing as finish may be stripped off. Pressure washing is also not suitable for Varia Ecoresin panels that have been edge sealed or seamed. If using detergent, use mild detergents only. Rinse sheet with light water spray after washing.

DO NOT:

- Concentrate spray in single position.
- Use more than 1,500 psi pressure.
- Position pressure nozzle closer than 8" (203 mm) from panel.
- Proceed with pressure washing if test piece shows detrimental effects to panel.
- Pressure wash Varia Ecoresin panels that have been painted or coated to maintain coating integrity.
- Pressure wash Varia Ecoresin panels with sealed edges to ensure edge seals remain in tact.

If debris or dirt is not removed by pressure washing attempt to clean with manual procedures described in preceding section.

IMPORTANT

If a cleaning material is found to be incompatible in a short-term test, it will usually be found to be incompatible in the field. The converse, however, is not always true. Favorable performance is no guarantee that actual end-use conditions have been duplicated. Therefore, these results should be used as a guide only and it is recommended that the user test the products under actual end-use conditions.

For more information, please visit 3-form.com or call 877-649-2670.

WELD-ON
IPS CORPORATION

PRODUCT BULLETIN
4™
ACRYLIC PLASTIC CEMENT

SUBSTRATE RECOMMENDATIONS:
WELD-ON® 4™ is formulated as a blush-resistant cement for bonding acrylic (poly-methyl methacrylate) to itself. It will also form strong bonds with other thermoplastics such as polystyrene, CAB (cellulose acetate butyrate), and polycarbonate to themselves. It is not recommended for cross-linked acrylic.

BONDING RECOMMENDATIONS:
WELD-ON 4 is used extensively in sign fabrication for cementing acrylic letters to flat acrylic presentation panels and trim-capping of cut out acrylic letters. Strong butt joints are made with flat sheets by using the soak method. WELD-ON 4 is also widely used in many applications e.g. fabrication of display and presentation cases, medical equipment assembly, the bonding of plastic containers and pre-forms, and in the manufacture of numerous solvent welded structures and subassemblies using the capillary method.

GENERAL DESCRIPTION:
Weld-On 4 is a water-thin, somewhat flammable cement formulated to quickly develop very clear and high strength bonds for many thermoplastic substrates. The bond is achieved by first softening the surfaces to be joined and then fusing them together with the dissipation of the solvent. The initial bond forms within a matter of minutes and is followed by a significant and continual increase in bond strength over the next several hours. WELD-ON 4 may be preferred by some plastic fabricators because it is less likely to leave white marks (commonly called blushing). For similar applications but faster setting cement, WELD-ON® 3™* is recommended.

*WELD-ON 3 is not available for use in areas regulated by California's South Coast Air Quality Management District (SCAQMD).

TYPICAL BOND STRENGTH†:

SUBSTRATE MATERIAL	Aged Bond Strength, lbs/in² (kg/cm²)		
	2 Hours	24 Hours	1 Week
Acrylic (Cast & Extruded)	800 (56.3)	2000 (140.6)	2500 (175.8)
Polycarbonate	750 (52.7)	1600 (112.5)	2400 (168.7)
Polystyrene	400 (28.1)	1300 (91.4)	2000 (140.6)

† Substrate thickness: 0.25 inch (0.64 cm). Bond area: 1.0 in² (6.45 cm²)

ADHESIVE PROPERTIES AND CHARACTERISTICS:

COLOR:	Clear
VISCOSITY:	Water Thin
TIME TO REACH 80% OF ULTIMATE BOND STRENGTH:	72 hours
SPECIFIC GRAVITY:	1.12 ± 0.04

DIRECTIONS FOR USE:
- **GENERAL** – surfaces to be joined must be clean, dry, and fit intimately without forcing. Apply cement with syringe, eyedropper or brush. Assemble while parts are still wet. If cement is applied to one surface, let the two surfaces be in gentle contact for a few seconds to allow the cement to soften the dry surfaces, then press parts together in firm contact. Initial bonds form very quickly. 65 – 80% of the ultimate bond strength will be obtained within 24 – 72 hours. Strength will continue to increase for several weeks.
- **CAPILLARY METHOD** – Parts are placed lightly together and cement is applied to the edge of the joint with syringe or eyedropper. By capillary action, the cement will flow a considerable distance (approximately 0.25 inch (0.64 cm) between two such surfaces. Allow a few seconds for the cement to soften the surfaces. Press parts firmly together.
- **SOAK METHOD** – vertically dip surfaces until softened (approximately 2 to 5 minutes), then join pieces firmly together.
- Although development of Weld-On 4 bond strength is slightly slower than that of WELD-ON 3, ultimate bond strength will be the same. If crazing is a problem, we suggest you consider annealing before cementing.

AVAILABILITY:
This product is available in 4 oz., pint, quart and gallon metal cans. For detailed information on containers and applicators, refer to the current Product Catalog and Price List.

SHELF LIFE:
2 years in tightly sealed containers. The date code of manufacture is stamped on the bottom of the container. Stability of the product is limited by the evaporation of the solvent when the container is opened. Evaporation of solvent will cause the cement to thicken and reduce its effectiveness. Adding of thinners to change viscosity is not recommended and may significantly change the properties of the cement.

QUALITY ASSURANCE:

Weld-On 4 is carefully evaluated to assure that consistent high quality is maintained. Fourier transform infrared spectroscopy, gas chromatography, and additional in depth testing ensures each batch is manufactured to exacting standards. A batch identification code is stamped on each can and assures traceability of all materials and processes encountered in manufacturing this plastic cement for its intended specific application.

SHIPPING:

For One Liter and Above

Proper Shipping Name: Flammable liquid, toxic n.o.s (Methyl Acetate, Dichloromethane)

Hazard Class: 3 with subsidiary risk 6.1

Identification Number: UN 1992

Packing Group: II

Label Required: Flammable Liquid & Toxic

For Less than One Liter

Proper Shipping Name: Consumer Commodity

Hazard Class: ORM-D

SAFETY AND ENVIRONMENTAL PRECAUTIONS:

This product is a flammable, moderately fast evaporating solvent cement. It is considered a hazardous material. In conformance with the Federal Hazardous Substance Labeling Act, the following hazards and precautions are given. Purchasers who may re-package this product must also conform to all local, state, and federal labeling, safety and other regulations. VOC emissions do not exceed 250 grams per liter.

DANGER! FLAMMABLE. VAPOR HARMFUL.
MAY BE HARMFUL IF SWALLOWED. MAY IRRITATE SKIN OR EYES.

Keep out of the reach of children. Do not take internally. Keep away from heat, spark, open flame and other sources of ignition. Contact with hot surfaces may produce toxic effects. Keep container closed when not in use. Store in the shade below 80ºF (27ºC). Use only in adequate ventilation. Avoid breathing of vapors. Atmospheric levels should be maintained below established exposure limit values. See Sections II and VIII of MSDS. If airborne concentrations exceed these limits, use a supplied air respirator. Do not use a chemical cartridge respirator. For emergencies and other conditions where short-term exposure may be exceeded, use an approved positive pressure self-contained breathing apparatus. In confined areas, use a positive pressure self-contained breathing apparatus (SCBA). Do not smoke, eat or drink while working with this product. Avoid contact with skin, eyes, and clothing. May cause eye injury. Protective equipment such as gloves, safety goggles, and impervious apron should be used. Carefully read Material Safety Data Sheet and follow all precautions.

Contains Methylene Chloride (75-09-2), Methyl Acetate (79-20-9) and Methyl Methacrylate Monomer (80-62-6). Methylene Chloride is considered a cancer causing material. OSHA has established special requirements for work place monitoring and protection. Extent of health risk depends on level and duration of exposure, as well as individual sensitivity. Do not use this product for other than intended use.

“Proposition 65 Warning”: This product contains chemicals known to the State of California to cause cancer.

“Title III Section 313 Supplier Notification”: This product contains toxic chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-To-Know Act of 1986 and of 40CFR372. This information must be included in all MSDS’s that are copied and distributed for this material.

FIRST AID:

Inhalation: If overcome with vapors, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call physician.

Eye Contact: Flush with plenty of water for 15 minutes and call a physician.

Skin Contact: Wash skin with plenty of soap and water for at least 15 minutes. If irritation develops, get medical attention.

Ingestion: If swallowed, give 1 or 2 glasses of water or milk. Do not induce vomiting. Contact physician or poison control center immediately.

IMPORTANT NOTE:

This product is intended for use by skilled individuals at their own risk. These suggestions and data are based on information we believe to be reliable. Users should verify by test that this product, as well as these methods, is suited to their application.

WARRANTY:

IPS® Corporation (“IPS Corp.”) warrants that all new IPS Corp. products shall be of good quality and free from defects in material and workmanship for the shelf life as indicated on the product. If any IPS Corp. product becomes defective, or fails to conform to our written limited warranty under normal use and storage conditions, then IPS Corp. will, without charge, replace the nonconforming product. However, this limited warranty shall not extend to, nor shall IPS Corp. be responsible for, damages or loss resulting from accident, misuse, negligent use, improper application, or incorporation of IPS Corp. products into other products. In addition, any repackaging of IPS Corp. products also shall void the limited warranty. IPS Corp. shall not be responsible for, nor does this limited warranty extend to, consequential damage, or incidental damage or expense, including without limitation, injury to persons or property or loss of use. Please refer to our standard IPS Corp. Limited Warranty for additional provisions.

IPS CORPORATION®

455 W. Victoria Street
Compton, CA 90220 USA
Tel (310) 898-3300
Toll Free (800) 421-2677
Fax (310) 898-3390

202 Industrial Park Lane
Collierville, TN 38017, USA
Tel (901) 853-5001
Toll Free (800) 888-8312
Fax (901) 853-5008

www.ipscorp.com

WELD-ON 16

ACRYLIC PLASTIC CEMENT

SUBSTRATE RECOMMENDATIONS

WELD-ON 16 is especially formulated to bond acrylic plastic. It can also be used for bonding styrene, butyrate, PVC and polycarbonate, as well as other plastics and porous surfaces.

BONDING RECOMMENDATIONS

WELD-ON 16 is recommended as an excellent general purpose, high strength acrylic cement. It is especially useful where fast cure and high strength are desired for applications such as large housings, signs, plastic letters, industrial fabrications, display items, lenses and models.

GENERAL DESCRIPTION

WELD-ON 16 is a very high strength, clear, medium bodied, fast curing, bodied solvent-type acrylic cement. Applied to cast, molded or extruded acrylics, it will effect initial bonds within minutes and form strong joints within hours.This product may be thinned with WELD-ON 3 by approximately 10%. Initial bond forms very quickly so some parts may be handled within a few minutes of application. Bond strength continues to develop very rapidly reaching a substantial level within hours. Joints are water and weather resistant and will generally have similar physical and chemical properties to acrylic plastic.

BOND STRENGTH DATA

The following strength data was obtained with compressive shear loading at 0.05”/min.The materials tested were ¼” acrylic lap joints of 1 sq. in. bonding area.

SUBSTRATE MATERIAL	24 HOURS	1 WEEK
Acrylic	1700 PSI	2200 PSI
Polycarbonate	1000	1700
Styrene	900	1700

ADHESIVE PROPERTIES AND CHARACTERISTICS

COLOR:	Clear		
VISCOSITY:	800 cps		
WORKING TIME:	2 – 3 minutes		
FIXTURE TIME:	5 – 6 minutes		
80% STRENGTH:	16 hours		
SPECIFIC GRAVITY: 1.02 ± .040			
COVERAGE:	10mil:	28sq. ft./Pint	224 sq. ft./Gallon
	20mil:	14sq. ft./Pint	112 sq. ft./Gallon

DIRECTIONS FOR USE

- Parts to be joined should be clean and fit without forcing.
- Apply WELD-ON 16 to one or both surfaces with brush, polyethylene squeeze bottle or gun.
- If cement is applied to one surface, bring the two surfaces in gentle contact for several seconds to allow the dry surfaces to be softened.
- Assemble with firm pressure while parts are still wet.
- Hold or clamp assembled parts firmly until initial set. Joint strength will increase greatly in 24 hours. Thereafter, strength will continue to increase gradually for some weeks.

SHELF LIFE

Two years expectancy in tightly sealed containers. Stability of the product is limited by the permanence of the container and the evaporation of the solvent when container is open. Evaporation of solvent will cause the cement to thicken and reduce the effectiveness of the cement.

SHIPPING

Shipping Information for Individual Containers Larger than One Liter: DOT Shipping Name: Flammable liquid, toxic, n.o.s. (Methyl Ethyl Ketone, Dichloromethane). DOT Hazard Class: 3 with subsidiary risk Hazard Class of 6.1. ID #: UN1992. Packaging Group: II. Label: Flammable Liquid & Toxic.

Shipping Information for Less than One Liter: No packaging or shipping exceptions available. May not be shipped as Consumer Commodity/ Limited Quantity/ ORM-D

SAFETY AND ENVIRONMENTAL PRECAUTIONS

WELD-ON 16 is a flammable, fast evaporating solvent cement and is considered a hazardous material. In conformance with the Federal Hazardous Substances Labeling Act, the following hazards and precautions are given. Purchasers who may repackage this product must also conform to all local, state and federal labeling, safety and other regulations.

DANGER - EXTREMELY FLAMMABLE - VAPOR HARMFUL - MAY BE HARMFUL IF SWALLOWED - MAY IRRITATE SKIN OR EYES

Keep out of reach of children. Do not take internally. Keep away from heat, spark, open flame and other sources of ignition. Contact with hot surfaces may produce toxic effects. Keep container closed when not in use. Store in the shade below 80°F. Use only in well ventilated area. Avoid breathing of vapors. Atmospheric levels should be maintained below established exposure limits. See Section II and VIII of the Material Safety Data Sheet. If airborne concentrations exceed those limits, use a supplied air respirator. Do not use a chemical cartridge respirator. For emergency and other conditions where short-term exposure guidelines may be exceeded, use an approved positive pressure self-contained breathing apparatus (SCBA). Do not smoke, eat or drink while working with product. Avoid contact with skin, eyes and clothing. May cause eye injury. Protective equipment such as gloves, goggles and impervious apron should be used. Carefully read Material Safety Data Sheet and follow all precautions. Contains Methyl Ethyl Ketone (78-93-3), Methylene Chloride (75-09-2) and Methyl Methacrylate Monomer (80-62-6). Methylene Chloride is a possible human cancer hazard based on test results with laboratory animals. Risk to your health depends on level and duration of exposure, as well as individual sensitivity. Do not use this product for other than intended use.

"Proposition 65 Warning": This product contains chemicals known to the State of California to cause cancer.

"Title III Section 313 Supplier Notification": This product contains toxic chemicals subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 and of 40CFR372. This information must be included in all MSDS's that are copied and distributed for this material.

FIRST AID

Inhalation: If ill effects from inhalation, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call physician.

Eye or Skin Contact: Flush with plenty of water for 15 minutes. If irritation persists, get medical attention.

Ingestion: If swallowed, do not induce vomiting. Contact physician immediately.

QUALITY ASSURANCE:

Every batch of this cement is checked to assure that consistent quality is maintained. An infrared absorption curve is recorded for each batch to ensure that this cement is properly formulated. Samples are taken from all batches and kept for a period of at least one year. A batch identification code is stamped on each can.

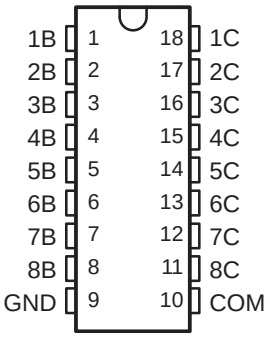
IMPORTANT NOTE:

This product is intended for use by skilled individuals at their own risk. These suggestions and data are based on information we believe to be reliable. Users should verify by test that this product, as well as these methods, are suited to their application. Since specific use, materials and handling are not controlled by IPS, our warranty is limited to the replacement of defective IPS products.

SLRS049C − FEBRUARY1997 − REVISED AUGUST 2004

- **500-mA Rated Collector Current (Single Output)**
- **High-Voltage Outputs . . . 50 V**
- **Output Clamp Diodes**
- **Inputs Compatible With Various Types of Logic**
- **Relay Driver Applications**
- **Compatible with ULN2800A Series**

DW OR N PACKAGE
(TOP VIEW)



description/ordering information

The ULN2803A is a high-voltage, high-current Darlington transistor array. The device consists of eight npn Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of each Darlington pair is 500 mA. The Darlington pairs may be connected in parallel for higher current capability.

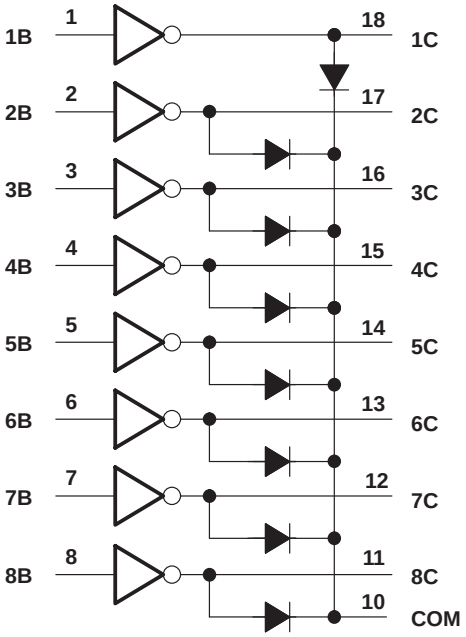
Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED and gas discharge), line drivers, and logic buffers. The ULN2803A has a 2.7-kΩ series base resistor for each Darlington pair for operation directly with TTL or 5-V CMOS devices.

ORDERING INFORMATION

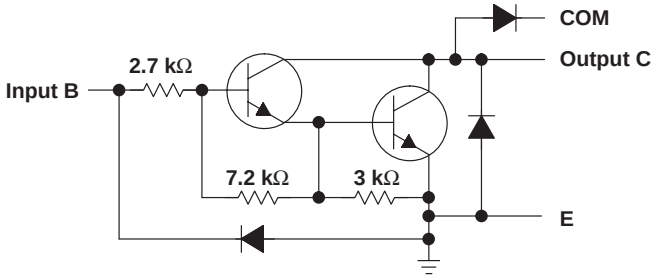
T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
−40°C to 85°C	PDIP (N)	Tube of 20	ULN2803AN	ULN2803AN
	SOIC (DW)	Tube of 40	ULN2803ADW	ULN2803A
		Reel of 2000	ULN2003ADWR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

logic diagram



schematic (each Darlington pair)



absolute maximum ratings at 25°C free-air temperature (unless otherwise noted)†

Collector-emitter voltage . . . . . 50 V
Input voltage (see Note 1) . . . . . 30 V
Continuous collector current . . . . . 500 mA
Output clamp diode current . . . . . 500 mA
Total substrate-terminal current . . . . . −2.5 A
Package thermal impedance, θ_{JA} (see Notes 2 and 3): DW package . . . . . TBD°C/W
N package . . . . . TBD°C/W
Operating virtual junction temperature, T_J . . . . . 150°C
Storage temperature range, T_{stg} . . . . . −65°C to 150°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltage values, unless otherwise noted, are with respect to the emitter/substrate terminal GND.
2. Maximum power dissipation is a function of $T_J(max)$, θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.
3. The package thermal impedance is calculated in accordance with JESD 51-7.

electrical characteristics at 25°C free-air temperature (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
I_{CEX}	Collector cutoff current	V_{CE} = 50 V, See Figure 1	I_I = 0,			50	µA
$I_{I(off)}$	Off-state input current	V_{CE} = 50 V, T_A = 70°C,	I_C = 500 µA, See Figure 2	50	65		µA
$I_{I(on)}$	Input current	V_I = 3.85 V,	See Figure 3		0.93	1.35	mA
$V_{I(on)}$	On-state input voltage	V_{CE} = 2 V, See Figure 4	I_C = 200 mA			2.4	V
			I_C = 250 mA			2.7	
			I_C = 300 mA			3	
$V_{CE(sat)}$	Collector-emitter saturation voltage	I_I = 250 µA, See Figure 5	I_C = 100 mA,		0.9	1.1	V
		I_I = 350 µA, See Figure 5	I_C = 200 mA,		1	1.3	
		I_I = 500 µA, See Figure 5	I_C = 350 mA,		1.3	1.6	
I_R	Clamp diode reverse current	V_R = 50 V,	See Figure 6			50	µA
V_F	Clamp diode forward voltage	I_F = 350 mA,	See Figure 7		1.7	2	V
C_i	Input capacitance	V_I = 0 V,	f = 1 MHz		15	25	pF

switching characteristics at 25°C free-air temperature

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
t_{PLH}	Propagation delay time, low- to high-level output	V_S = 50 V, C_L = 15 pF,	R_L = 163 Ω, See Figure 8		130		ns
t_{PHL}	Propagation delay time, high- to low-level output				20		
V_{OH}	High-level output voltage after switching	V_S = 50 V, See Figure 9	$I_O \approx$ 300 mA,	V_S − 20			mV

PARAMETER MEASUREMENT INFORMATION

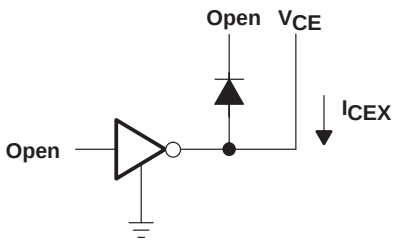


Figure 1. I_{CEX} Test Circuit

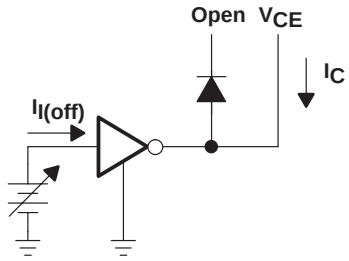


Figure 2. $I_{I(off)}$ Test Circuit

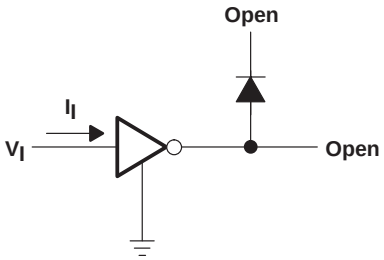


Figure 3. $I_{I(on)}$ Test Circuit

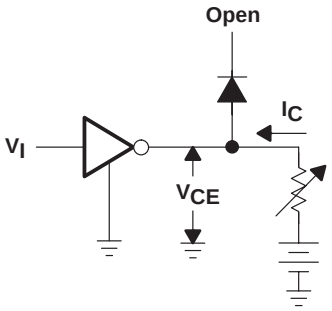


Figure 4. $V_{I(on)}$ Test Circuit

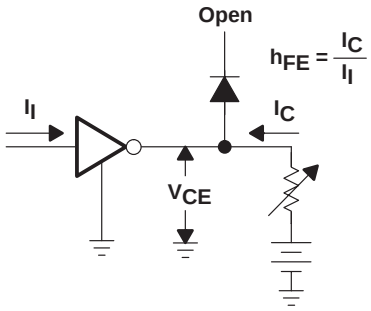


Figure 5. h_{FE}, $V_{CE(sat)}$ Test Circuit

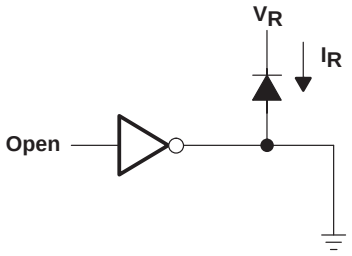


Figure 6. I_R Test Circuit

PARAMETER MEASUREMENT INFORMATION

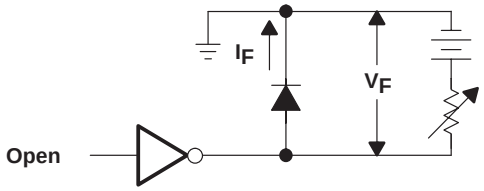
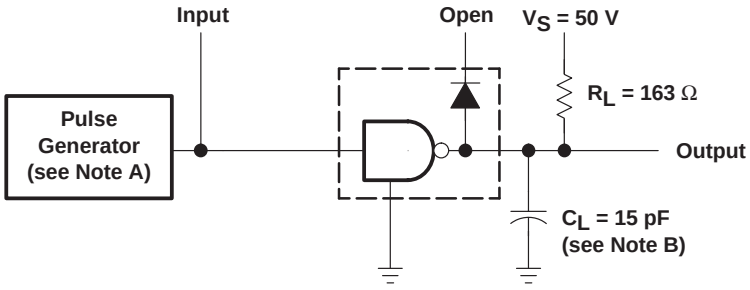
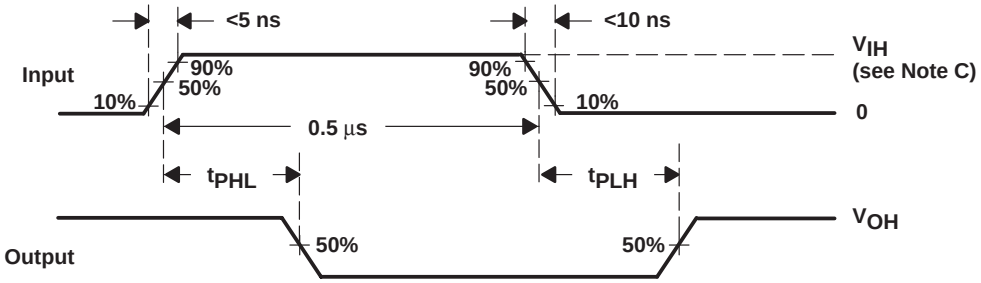


Figure 7. V_F Test Circuit



Test Circuit

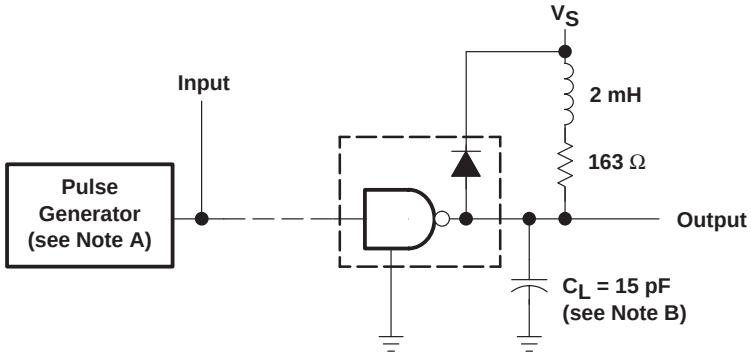


Voltage Waveforms

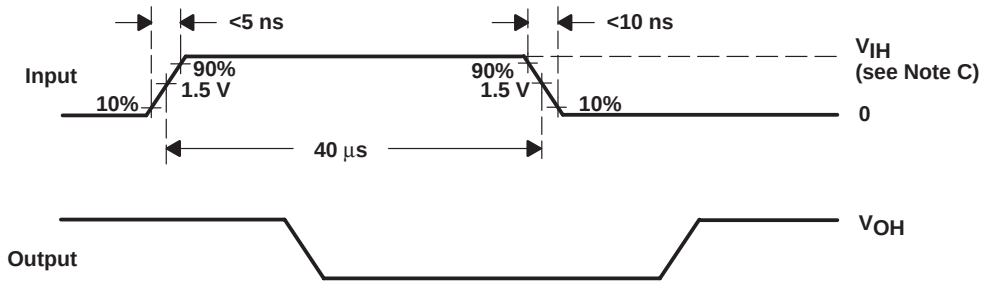
NOTES: A. The pulse generator has the following characteristics: PRR = 1 MHz, Z_O = 50 Ω.
B. C_L includes probe and jig capacitance.
C. V_{IH} = 3 V

Figure 8. Propagation Delay Times

PARAMETER MEASUREMENT INFORMATION



Test Circuit

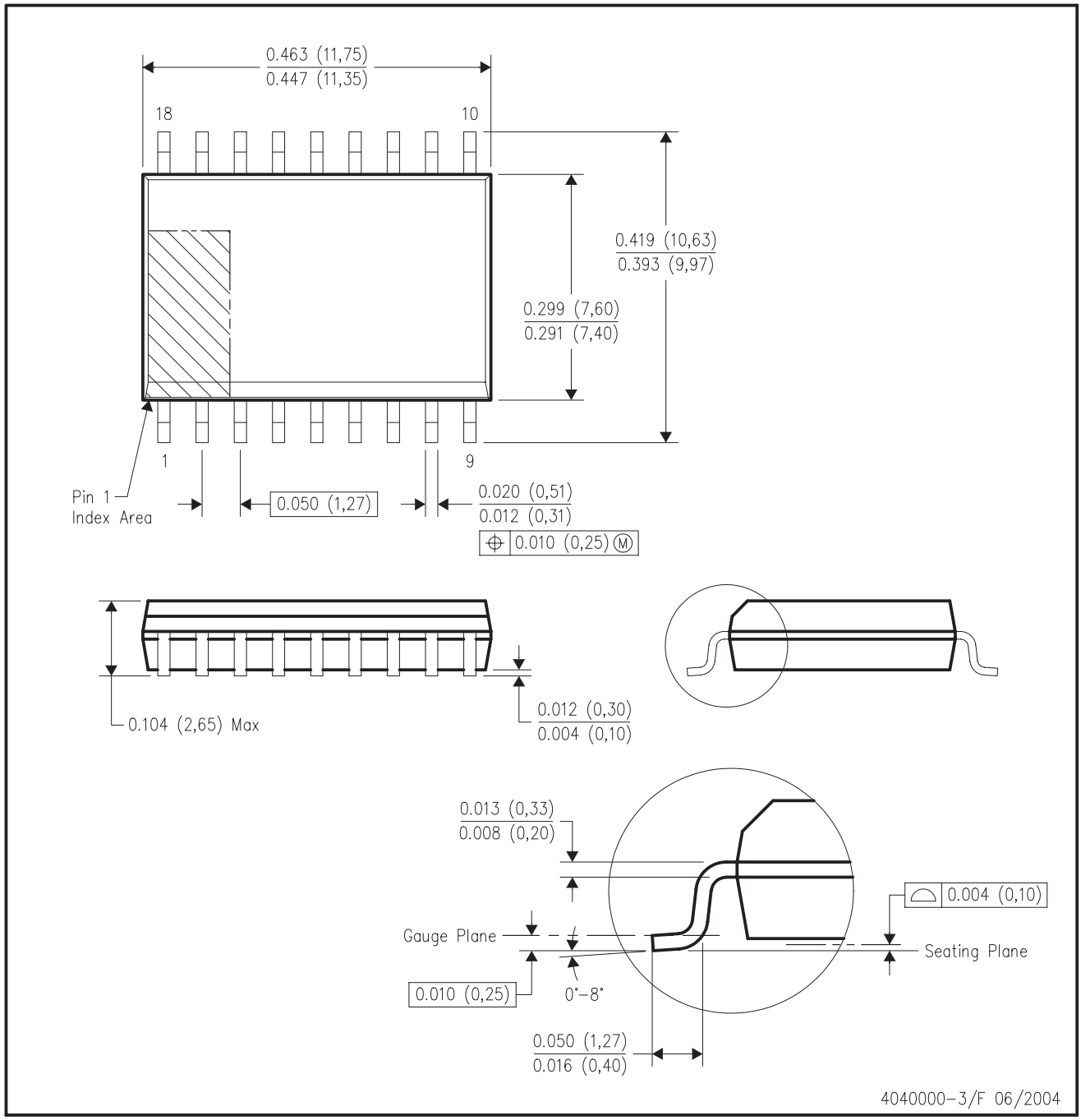


Voltage Waveforms

NOTES: A. The pulse generator has the following characteristics: PRR = 12.5 KHz, Z_O = 50 Ω.
B. C_L includes probe and jig capacitance.
C. V_{IH} = 3 V

Figure 9. Latch-Up Test

DW (R–PDSO–G18) PLASTIC SMALL–OUTLINE PACKAGE

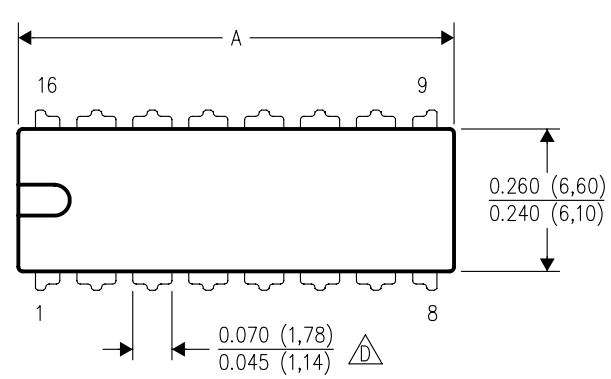


NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. Falls within JEDEC MS–013 variation AB.

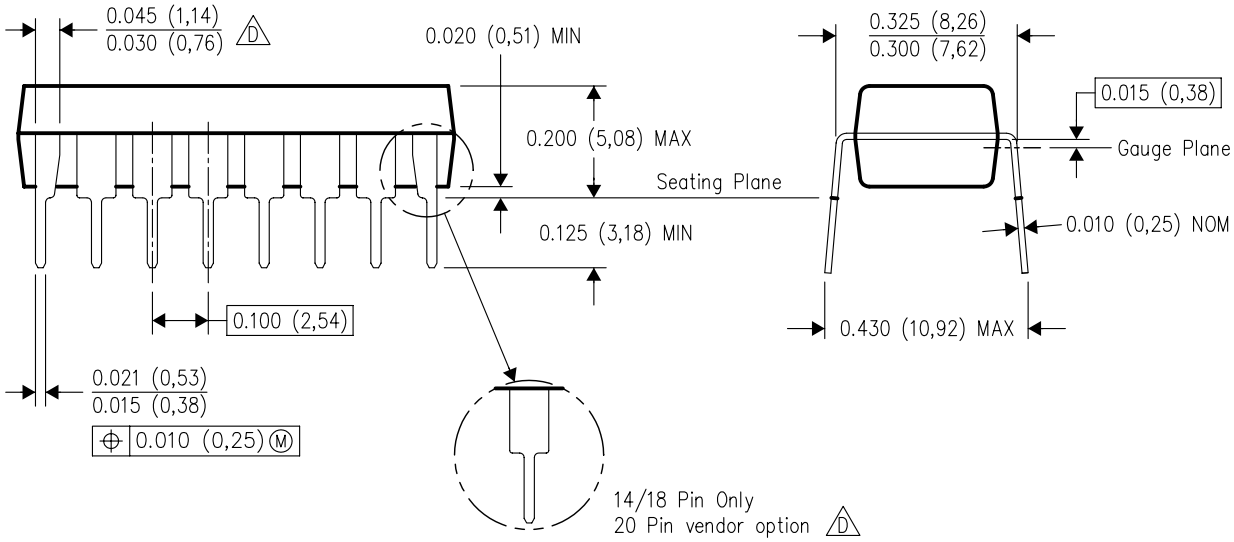
N (R–PDIP–T**)

PLASTIC DUAL–IN–LINE PACKAGE

16 PINS SHOWN



DIM \ PINS **	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
MS–001 VARIATION (C)	AA	BB	AC	AD



4040049/E 12/2002

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001, except 18 and 20 pin minimum body length (Dim A).
D. The 20 pin end lead shoulder width is a vendor option, either half or full width.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265