AUTOMATED EXPANDING CHRISTMAS TREE

FINAL DESIGN REPORT

PREPARED FOR:

Bret Clark, Representative for Civic Ballet of San Luis Obispo

Clint Bryson, Stage Crew Lead for the Cal Poly Performing Arts Center (PAC)

PREPARED BY:

Zoey Camarillo – zcamaril@calpoly.edu

Ben Mosemann – bmoseman@calpoly.edu

Xiomara Medina – xnmedina@calpoly.edu

Will Tedone – wtedone@calpoly.edu

Mechanical Engineering Department
California Polytechnic Department
San Luis Obispo
June 2024

Statement of Disclaimer

Abstract

The Civic Ballet of San Luis Obispo (SLO) needs a new expanding Christmas tree for their 2024 production of *The Nutcracker*. This Final Design Review Report outlines pertinent information regarding the Cal Poly Mechanical Engineering Senior Project of Team F14 ("D.R.E.I.D.E.L.S."), who was tasked of designing and building the new expanding Christmas tree frame. Our team's name, "D.R.E.I.D.E.L.S.," stands for Design and Research of Expansion Integrated Dramaturgy Ergonomic Leveraging Systems. We thought this would be a fun, creative, and ironic name for our team.

In this report, our team will discuss how we procured the materials required and manufactured and assembled our design. Furthermore, it will detail the results found from the test procedures and inspections from our Design Verification Plan in Appendix D. These results helped us understand the strength and physics of the structure, the ergonomics and transportability of the design, and necessary constraints such as expansion time and low noise level.

Contents

Introduction

Our Senior Project is to design and build an expanding Christmas tree prop that will grow about 2.5 times its original size while maintaining the aspect ratio of a healthy tree. Bret Clark from the Civic Ballet of SLO and Clint Bryson from the Cal Poly Performing Arts Center (PAC) are the primary sponsors for this project. The Cal Poly PAC puts on a yearly production of *The Nutcracker*, and we intend to complete this project in time for their 2024 production. The completed Christmas tree frame will be handed off to a team of Cal Poly stagecraft students who will decorate the frame over the summer. The following Final Design Review (FDR) Report is divided into three major sections: Design Overview, Design Implementation, and Design Verification.

The Design Overview section will outline the final design description and note any changes made to the design since the Critical Design Review (CDR). The Implementation section will take up the main bulk of this report and includes information regarding procurement of materials, manufacturing, and assembly of the final design. The Design Verification section will review the specifications of the final design and mention if they have been met or not. This will be supported by the Testing & Results subsection which will review the tests that were conducted on our final design and the results that we found from said tests. In total, the FDR Report should give a good overview of the outcome of the Senior Project of Team F14.

Design Overview

1.1 Design Description

Our final design for the expanding Christmas tree consists of two major subassemblies: the scissor lift and the base platform. The scissor lift is constructed from square aluminum tubing and solid steel rods. The scissor lift is expanded by two 3” bore pneumatic pistons that squeeze the bottom two rods together. These pistons are powered from a 5-gallon air tank and are controlled manually by a single operator. It is important that the operator follows the steps laid out in the User Manual in **Appendix A** so that they reduce exposure to the risks detailed in our Risk Assessment in **Appendix B**. As the scissor lift expands vertically, it also expands the tree horizontally by pushing out D-shaped rings that are attached on one end to the scissor lift rod and slotted on the other. The scissor lift is attached to a wheeled plywood base, fixed at one end, and rolling on a wheel for the other.

Implementation

1.2 Procurement

Our team procured the materials through various commercial vendors. Due to the large number of materials required for this project, we had determined that buying from warehouse vendors would be best. All metal parts (i.e. aluminum links and steel bars) were purchased from a local metal company, Ventura Steel. Ventura Steel was the best option to buy this material from as they had low prices for the stock sizes. This allowed us to purchase stock-sized material in bulk, and Ventura Steel was able to cut the materials to our desired sizes and ship them to us.

For the rest of our materials, we considered multiple vendors both in person and online, all of which are identified in the final project budget in **Appendix C**. We decided to purchase most of our materials from McMaster Carr due to their low bulk prices and fast shipping time. McMaster also provided us with multiple options for our materials and we were able to purchase them all from one place knowing that they would all be shipped quickly. For other items such as nuts, bolts and plywood, we purchased from Home Depot since only a few of each were required.

1.3 Manufacturing

All the manufacturing required for our expanding Christmas tree was completed on campus in the Cal Poly Machine Shops. Both the scissor lift and base sub-assemblies required a large amount of manufacturing, but most of it was single repeated actions. During the design stages of this project, we were concerned about the time it would take to manufacture and assemble everything, but we were successful in keeping on schedule.

The scissor lift links were made from 1.5" square aluminum tubing which was cut from the stock length into equal lengths of 48" long each. Each link has three drilled holes (one near each end and one in the middle). This process, shown in **Figure 1** on the next page, took the longest for us to complete as there were so many links that needed to be manufactured. One of the drilled scissor links is shown below in **Figure 2**.

Figure 1. Drilling holes into the scissor lift links.

Figure 2. Cut and drilled scissor lift link.

The D-ring links were also made of 1.5" square aluminum tubing, but the links were cut to various increasing lengths with the largest link being 66" long and the shortest link being 48" long. Ventura steel cut the stock material for us before shipping it to us. Each D-ring link had holes drilled at each end and an 18" long slot which matches the stroke length of the pneumatic pistons. We used a manual mill to create the slots as shown below in **Figure 3.** As mentioned earlier, the slots allow the Christmas tree frame to horizontally expand while simultaneously vertically expanding.

Figure 3: Manual Milling Slots into D-ring Links

The second step of the D-ring manufacturing required us to bend round aluminum tubing of various lengths into quarter circle arcs. The various lengths of the tubing were relative to the various lengths of the D-ring links, meaning that the longer the D-ring link, the longer the tubing. Despite the varying lengths of the tubing, the arc angle of each bent tube was designed to be the same. They were bent partially with a manual pipe bender and then adjusted by hand as needed.

Once the D-ring links had been drilled and milled and all the tubing had been bent, we handed the material off to Kevin "Kevo" Williams, a welding instructor who works at Cal Poly. The final step of manufacturing the D-rings was to weld the round aluminum tubing to the D-ring links and we trusted Kevin with completing this task. The completed D-ring links and the scissor lift links are shown below in **Figure 4.**


Figure 4: Completed Manufactured Scissor Lift and D-ring Links.

The manufacturing of the base began after the scissor lift and D-ring links were completed. Ideally, we had wanted to begin the manufacturing of the base at the same time but were delayed by shipping delays for the aluminum required.

The plywood that makes up the base was first sized down at Home Depot and then cut down to the final dimensions of 36” x 52” using the table saw in **Figure 5** on the next page. Then four holes were drilled into each corner to bolt the caster wheels in **Figure 6** to the plywood.

Figure 5. The table saw used to cut plywood base and waste material for scale.


Figure 6. Swivel caster wheel bolted in the corner of the plywood base.

To provide points for the scissor lift to attach the base platform, we manufactured both the base anchors and the V-groove wheel tracks. The two base anchors were machined by making rough straight cuts into a block of aluminum, facing the surfaces on a manual mill, and drilling the bolt holes also on the manual mill. An image of a completed base anchor is shown in **Figure 7** below.

Figure 7. Complete base anchor next to the vise and mill setup used.

The V-groove wheel track was manufactured from pieces of two different sizes of aluminum angle cut on the metal saw seen in **Figure 8** on the next page and welded together by Kevin Williams. The V-groove wheel track after welding is pictured in **Figure 9**.

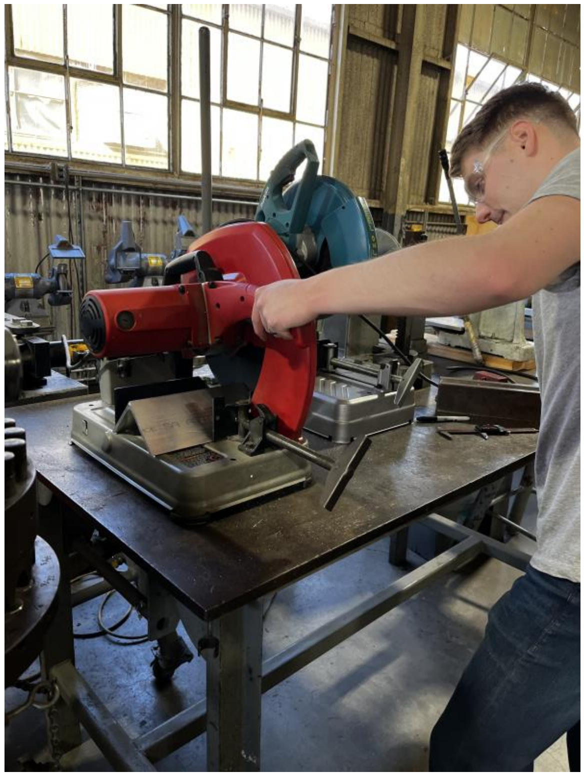

Figure 8. Cutting the aluminum angle on the hot metal saw in the Aero Hangar.

Figure 9. Close-up of V-groove track weld

Additionally, to connect the piston rod end to the steel rod in the scissor lift that would have the V-groove wheels attached to it, our team needed to modify the threaded piston clevis that we purchased from McMaster-Carr. To produce the exact piston stroke length required, we drilled a new hole in the clevis using a drill press, the result of which can be seen in **Figure 10**.

Figure 10. Modified piston clevis next to the drill press set up used.

1.4 Assembly

Once manufacturing of all parts was completed, we could begin assembling the Christmas tree frame. We assembled the scissor lift and the base separated from each other before attaching them together in the end. The bulk of the scissor lift was assembled first as we were still waiting on parts for the base. Assembling the scissor lift involved multiple repeatable processes that needed to be completed in a certain order. **Figure 11** on the next page shows an assembly diagram that we used to guide the scissor lift assembly. As shown in the diagram, the retaining rings were placed on both sides of each scissor lift link and D-ring lift to ensure that they would not move on the steel rods. Slipping the retaining rings onto the steel rods proved to be more difficult than we had originally predicted, however we were able to manufacture a custom tool that would help make the process easier for us. The tool helped the same as a lever arm would allow us to produce more force on the retaining rings. This was especially useful because we had so many retaining rings to fasten.

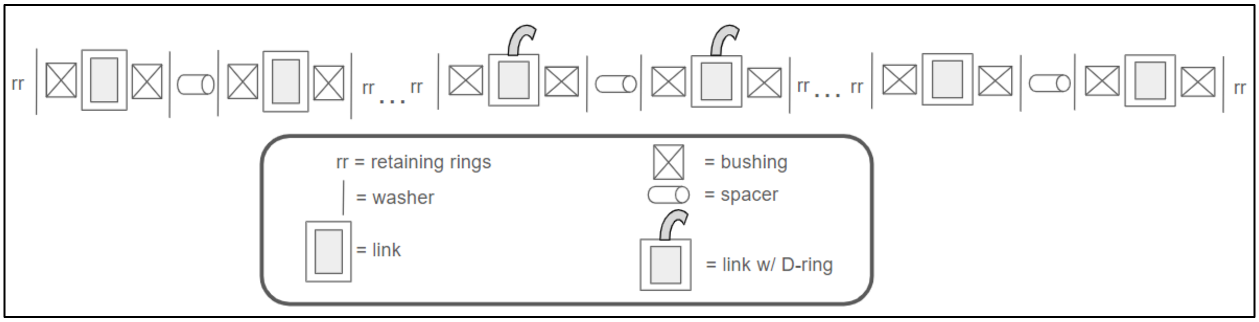

Figure 11. Diagram of Outer Shaft Assembling Method

We had a notation that we used when assembling the scissor lift to ensure we were placing all the links in the right order. We had "outside links" and "inside links" that needed to be attached to each other in an alternating pattern. We started by assembling the scissor lift on its side to make it easier for us to place the links on the rods. The "outside links" needed to be placed down on the ground before the "inside links" could be added on top of them. Once half of the scissor lift had been assembled, we then added the D-rings to their designated spots. **Figure 12** shows the bulk of the scissor lift assembly on its side. As seen, only half of the scissor lift was built first because we needed to attach the base to the scissor lift before we could assemble the second half of the scissor lift. **Figure 13** shows the scissor lift assembly and the base assembly side by side.

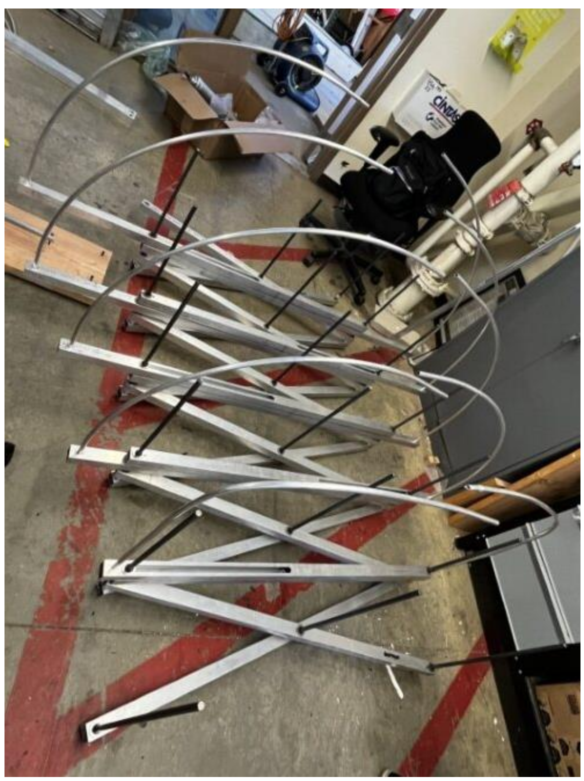

Figure 12. Half of the scissor lift assembly and the D-ring links.

Figure 13: The scissor lift assembly and base assembly side by side.

Once the base and one half of the scissor lift were complete, we could attach them together. To do so, we lifted the scissor lift onto tables as shown in **Figure 14**. This was done because the base platform is wider than the scissor lift. When the scissor lift is elevated however, two of our team members could lift and hold the base platform in place while the other two put on the retaining rings, washers, and spacers as seen in **Figure 15**.

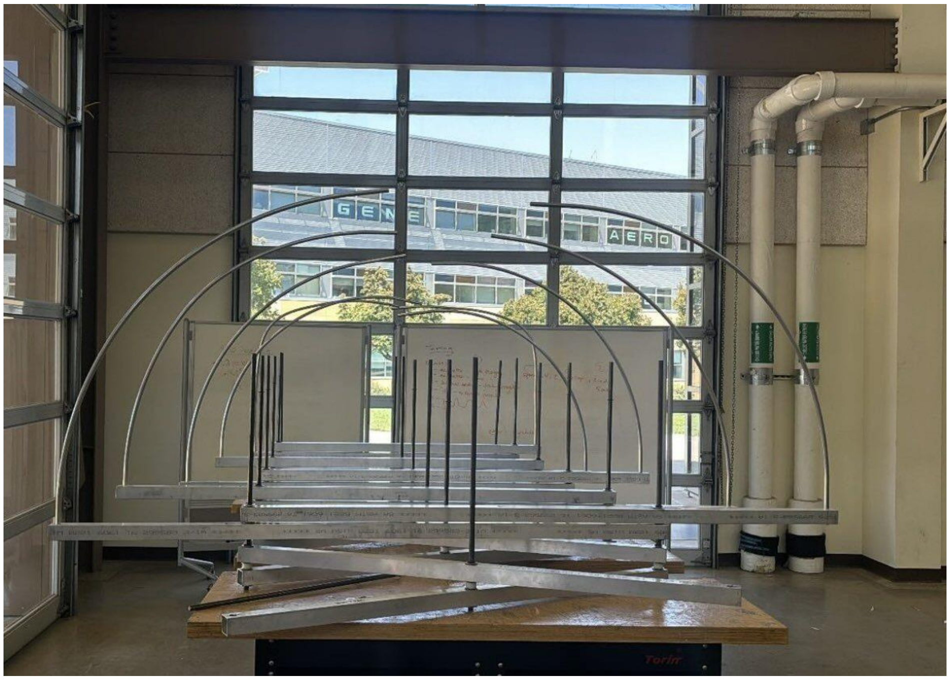

Figure 14. Scissor lift on high bay tabletops.

Figure 15. Attaching the scissor lift to the base platform assembly.

Once the scissor lift and base were attached to each other, we began assembling the second half of the scissor lift. Then once everything was completed, we were able to turn the Christmas tree off its side so that it stood up vertically. The completed Christmas tree assembly is shown in **Figure 16**.

Figure 16. Completed Christmas tree frame assembly.

Design Verification

1.5 Specifications

Table 1 below summarizes the design specifications that our team identified together and that agreed with those our sponsor outlined for our project. Any specification that was not outlined is labeled "Not Outlined By Sponsor" (NOBS).

Table 1: Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Weight	250 lbs.	± 50 lbs.	H	A, I, T
2	Minimum Height	8 ft. tall	Max	L	A, I
3	Maximum Height	25 ft. tall	22 - 25 ft	M	A, I
4	Aspect Ratio	3:1 (height to diameter)	N/A	M	A, I
5	Ease of Repair	NOBS	N/A	M	T
6	Ease of Transportability	Tree must be built on platform with wheels	N/A	L	I
7	Cost	$2500	± $100	M	A
8	Expansion Noise Level	100 dB	N/A	L	T
9	Expansion Time	< 10 seconds	± 1 sec	L	T
10	Branch Deflection	Maintain a deflection of less than 2 inches	5%	M	T
11	Number of Operator Actions	1	Max	L	A, I
12	Number of Separate Pieces	0	Max	L	A, I

*Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1.6 Testing and Results

All the testing for our project was performed in Bonderson High Bay. The five test procedures outlined in **Appendix E** were followed, which included tests for weight, time to replace a link, noise level, D-ring deflection, and time to expand. We followed the specifications outlined in **Table 1** for each of the tests. Each test was performed individually, and all data is recorded in **Appendix E** under the appropriate test procedures. Testing was originally going to be done via floor scales provided by the Cal Poly Racing Team. However, this idea was rejected due to constraints of locations for both the scales and the lift itself. To complete the weight test, the CAD file was utilized for the lift. Material data was input, and we were able to get an estimated weight of 246.5 pounds which met the specification outlined in **Table 1**. Changing the link was a specification NOBS for the lift. As there was no specification, we outlined in the test procedure that the test would fail if one scissor lift link took 1 hour to remove. The removal of one link took 23 minutes, so we passed this test.

Noise level testing was NOBS, so we determined that the average must be equal to or less than 100 dB (about the noise level of a large speaker). While we could not expand our Christmas tree, we reasoned that the loudest sound produced would be when the air is released from the air tank. When we released the air as quick as possible, we resulted with a 94 dB reading which passed this test. The plot of our decibel reading is pictured in **Figure 17**.

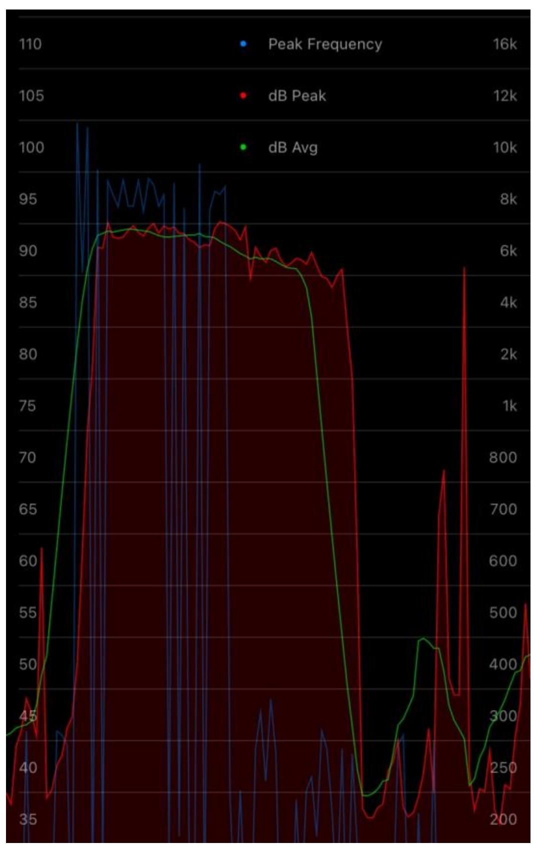

Figure 17. Decibel reading of air release.

The D-ring deflection test was originally outlined as 5% of the maximum lift height, however this became difficult to account for, so we determined the revised specification to be no more than 2 inches of deflection. For this test a 2.5 lbs. point load was applied to the D-rings which resulted in an average of 4 inches of deflection per D-ring which failed the test. The test set up is pictured in **Figure 18.** The data for each D-ring and its uncertainty can be found in **Table 2**, while further information on the formulas used can be found in **Appendix E**.

Figure 18. Applied 2.5 lb weight to edge of D-ring.

Table 2. Branch deflection data and uncertainty.

D-Ring #	**1**	**2**	**3**	**4**	**5**	**6**
Deflection (in)	4.75	4.75	4.75	4.5	2.0	3.5
Uncertainty U_y (in)	0.0313					
Dimensionless Uncertainty u_y	0.0066	0.0066	0.0066	0.0070	0.0157	0.0089
Length (in)	35.25	34	31.75	32.5	27.5	27
Uncertainty U_L (in)	0.031					
Dimensionless Uncertainty u_L	0.0009	0.0009	0.0010	0.0010	0.0011	0.0012
Deflection Ratio	4.76 ± 0.01	4.94 ± 0.01	5.29 ± 0.01	5.08 ± 0.01	4.58 ± 0.02	5.62 ± 0.02

We also intended to perform an expansion time test specified to be less than 10 seconds. This test could not be performed fully due to the lift failing during expansion which resulted in the lift becoming nonfunctional. From the test, the lift expanded 8 inches in 2 seconds, which was used to determine that full expansion would be complete in 44 seconds, which fails.

Of the five total tests, we passed three of the specifications and failed two. The two failed tests were the most vital for the lift's functional operation. The results of the five tests are summarized in **Table 3**.

Table 3. Summary of test results

Spec. #	Specification Description	Requirement	Test Result	Pass/Fail
1	Weight	< 250 lbs	247 lbs	Pass
5	Ease of Repair	Remove link in less than 1 hour	23 minutes	Pass
8	Noise Level	< 100 dB	94 dB	Pass
9	Expansion Time	< 11 sec	44 sec	Fail
10	Branch Deflection	< 2 in	4 in	Fail

All our other specifications were evaluated through analysis and inspection. The pass/fail results from these are summarized in **Table 4**.

Table 4. Summary of specifications met.

Spec. #	Specification Description	Pass/Fail
1	Weight	Pass
2	Minimum Height	Pass
3	Maximum Height	Pass
4	Aspect Ratio	Pass
5	Ease of Repair	Pass
6	Transportability	Pass
7	Cost	Pass
8	Noise Level	Pass
9	Expansion Time	Fail
10	Branch Deflection	Fail
11	# of Operator Actions	Pass
12	# of Separate Pieces	Pass

Discussion & Recommendations

1.7 Discussion

While our design does not pass all 5 critical tests, there are actions that can be taken to correct this, and the main structure is identifiably useful. There are the mechanical problems as well as some physical ones discussed in the next section, but in the next section we will give our solutions that should eliminate both problems while maintaining the main structure and components of the tree.

1.8 Recommendations and Next Steps

Our team has outlined four main recommendations and next steps for our sponsors. We have had multiple discussions with our sponsors regarding what could be done and what should be done. Our sponsors are fully aware of these recommendations and have their own ideas of how to move forward after the Christmas tree frame has been handed off to them.

The first recommendation is to fully disassemble and reassemble the structure and ensure that when the scissor lift is reassembled, the front and back faces are parallel to each other. Originally when we assembled the scissor lift, there were errors in the assembly process which resulted in the front and back faces of the scissor lift to not be parallel, and this caused the scissor lift to tilt forward instead of standing up straight. We would recommend that the entire structure be taken apart and reassembled to ensure proper assembly.

The second recommendation could be done with or without disassembling and reassembling the scissor lift. We spoke about this with Kevin Williams and our sponsors, and everyone agrees that this may be a good solution to the current structure. To eliminate the leaning of the scissor lift, we recommend creating a column that sits at the back of the scissor lift that will act as a guide as the scissor lift expands and collapses. The guide column would act like a vertical track or a funnel that will keep the scissor lift standing straight.

The third recommendation is a direct result of the failed Expansion Test. When we tested the expansion of the scissor lift, the ½" diameter steel bar on wheels deflected. We recommend that this bar be sized up to 1 in. diameter to prevent this from happening again. Currently, the deflected steel bar has been cut up so that it may be removed from the scissor lift. This part needed to be replaced anyway, so we cut the bar to make it easier for our sponsor to replace. We further suggest that the scissor lift be supported via wood blocks or other mediums before taking out the rest of the steel bar. If not followed, the scissor lift may fall on the person removing the steel bar.

Our final recommendation is to add structure and rigidity to the D-rings. The D-rings are not as strong as we had originally intended them to be, so we would recommend adding a form of support to them that will allow more weight to be held on each D-ring. This could be done in a few ways, such as a tether to cantilever the D-rings off the main structure of the scissor lift, or by welding / adhering physical supports on the D-rings themselves. We spoke with our sponsors, and they have already identified a few other ways this could be done. We believe this recommendation will come last after our first recommendation of disassembling and reassembling the scissor lift. Instructions on how to disassemble and reassemble the tree are included in our user manual in **Appendix A**.

Conclusion

Our project achieved the successful assembly of our expanding Christmas tree design. The product has the potential to expand approximately 2.5 times its original size while maintaining a healthy aspect ratio, being transportable, and operating quieter than its predecessor. However, our prototype failed the mechanical tests regarding the deflection of the D-rings and the bottom steel rod of the scissor lift deflected a critical amount while expanding. Therefore, our prototype is unfortunately unusable in its current condition. Despite this, our design did manage to achieve 10 out of the 12 specifications that we established in the beginning.

Our team has included the suggested fixes and test criteria to prove that new additions or design changes to the tree should be adhered to prove it will work without failure of the Civic Ballet of SLO and their next performance for *The Nutcracker*.

References

No outside references were used in this document.

Appendices

Appendix A – User Manual

User Manual – Expanding Christmas Tree

Written By: Team F14 "D.R.E.I.D.E.L.S."
Zoey Camarillo, Xiomara Medina, Ben Mosemann, Will Tedone

Safety

The expanding Christmas tree is a tall and wide structure that undergoes rapid change during operation. Extreme caution should be exercised when operating and/or standing near it, even when the tree is not being operated.

- **Hazard #1:** The tree is top heavy when it expands. This should be mitigated by placing stage weights on the base platform after being installed onto the stage.
- **Hazard #2:** The tree involves moving parts. Operators should not stand in the line of horizontal expansion if the tree is actuated.
- **Hazard #3:** The system is pressurized. Air hose lines and pneumatic components should be inspected for leaks before operation.

> Warning: Before disassembly, bleed pneumatics so there is no built-up pressure in the pistons, or the tank.

Personal Protective Equipment (PPE):

- Anyone operating the tree and/or standing within 4 feet are required to wear safety glasses.
- Closed-toed shoes are recommended for operators.
- Leather gloves are recommended when assembling, disassembling, or replacing parts.

Operation

This section outlines how to operate the expanding Christmas tree.

Steps:

1. Fill the 5-gallon air tank to a minimum of 100 psi. When filling, read the dial pressure indicator in **Figure 1A** to ensure the pressure is correct and does not exceed 120 psi.

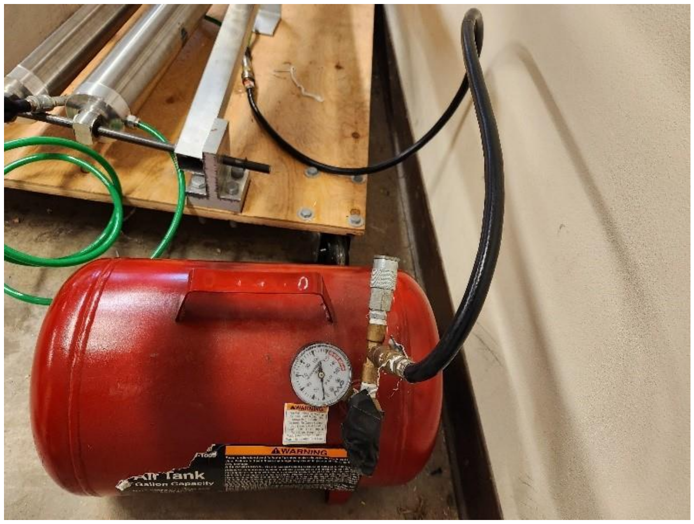

Figure 1A: 5-gallon air tank with dial pressure indicator.

2. Connect the air tank to the tree pneumatic system using the quick connector in **Figure 2A**.

Figure 2A: Pneumatic quick connector.

3. Rotate the silver valve handle in **Figure 3A** perpendicular to the pipe to release the airflow into the two pistons. This will cause the Christmas tree to expand. The speed of the expansion can be slowed by rotating the silver valve handle to less than 90 degrees.

Figure 3A: Silver valve handle used to control the airflow into pistons.

4. When the Christmas tree needs to be collapsed, turn the pressure relief valve on the exit side of pistons in **Figure 4A** to release the air. Note: this must be done in a slow controlled manner otherwise the Christmas tree will collapse rapidly and unsafely. Ensure the dial indicator on the air tank reads zero so that all the pressure has left the system.

Figure 4A: Fully open position of the pressure relief valve.

Assembly/Maintenance

Explanation of Retaining Rings

These retaining rings are highlighted in **Figure 5A**. The purpose of them is to keep the links from sliding out of position. The rings accomplish this with teeth that bite into the steel rod and face one direction, which make them directional. Because they are made of steel, cutting them off requires the use of tin snips.

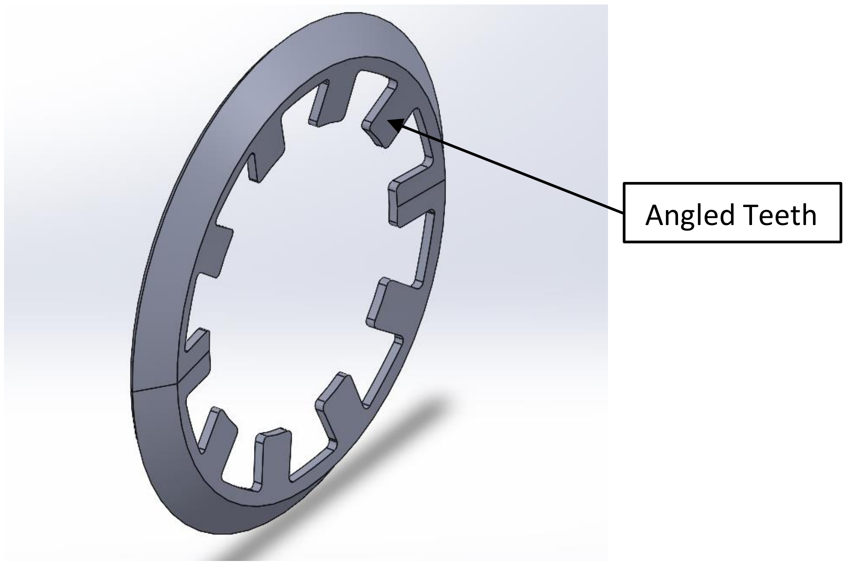

Figure 5A: Retaining rings diagram.

Replacing a Scissor Lift Link

This section is more abstract than the rest of because there are many different configurations of links that can be taken off. If replacing a link, some thinking/planning will need to be done. The following is to be used as a guide to help you plan your individual needs. Items to be discussed are:

- Summary of assembly/disassembly
- Explanation of retaining rings
- Recommendations for how to support the main structure during disassembly.
- How to identify the order of disassembly.
- How to use the disassembly tools.

Summary of Disassembly

Figure 6A shows a diagram of the method of assembly used to put the scissor lift together. Extra care was taken to ensure the links were not crossing or parallel to each other, something which should be considered when assembling or disassembling.

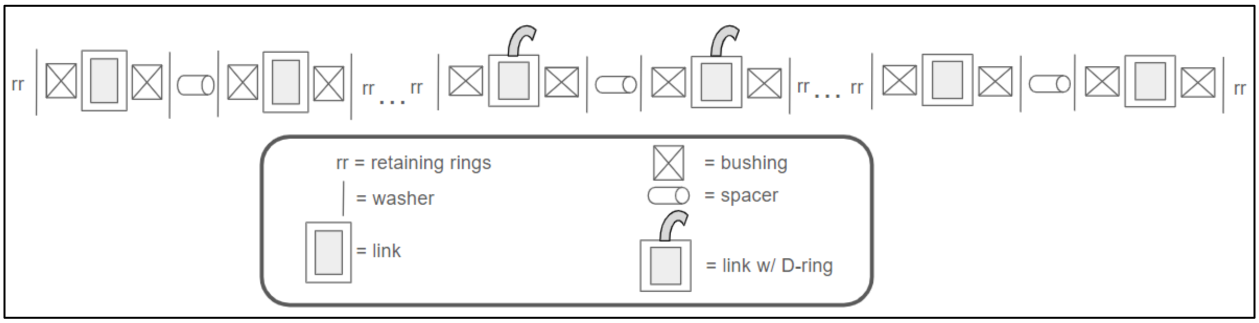

Figure 6A. Diagram of outer shaft assembling method.

The first step in disassembling a link is to identify the links that need to be removed to get to the link that needs to be replaced. Notice that the retaining rings are one directional facing the back. This means if the link you want to take off is in the front, you will have to take off many more from the back. Also notice that the front and the back are symmetric, meaning if you are taking of a front link, you will have to take off the same links in the front.
Supporting the structure may be a problem because each link supports the above steel rods. We suggest that you place 2x4 wood pieces underneath each steel rod affected to vertically support the structure while you are replacing the link.
Next you will need to clip the retaining rings towards the back side of the link you are trying to detach with tin snips. After ensuring the wooden supports are rigid enough to support, you can pull off the links.

Part List w/ Sources for Replacements

Part #	Part Name	Quantity	Est. Cost	Dimensions	Notes	URL
110000	Scissor Lift					
111000	Links and Bushings					
111100	Link Sq Tubing 1.5"x1.5"	6	$252.00	20' long, 1.5"x1.5", 1/16" wall	Cut to forty-eight, 4' links	(805)644-2100 (Ventura Steel)
111200	Nylon Bushings 0.5" ID	168	$157.92	1/2" ID, 5/8" OD	Order in exact amount	https://www.mcmaster.com/6389K623
112000	Rods					
112100	Steel Rod 0.5" dia.	2	$38.00	20' long, 0.5" dia.	Cut to twenty-four, 2' links	(805)644-2100 (Ventura Steel)
112200	Nylon Spacer	2	$39.30	1" OD, 1/2" ID, 0.5" Lg	Buy two packs of 25, need 44 total	https://www.mcmaster.com/94639A876/
112300	Steel Washer	2	$23.98	1/2" ID, 1.125" OD	Buy two packs of 100, need 192 total	https://www.mcmaster.com/92141A032/
112400	Retaining Ring	2	$23.80	1/2" ID, push on	Buy two packs of 100, need 124 total	https://www.mcmaster.com/98430A138
113000	D-Rings					
113100	Sq Tubing, 1.5"x1.5"	3	$216.00	20' long, 1.5"x1.5", 1/8" wall	Cut to various lengths for each D-ring	(805)644-2100 (Ventura Steel)
113200	Round Tubing 1/2" dia.	2	$50.00	24' long, 1" dia.	Cut and bent to various lengths for each D-ring	(805)644-2100 (Ventura Steel)
114000	Pneumatic System					
114100	Pneumatic Piston 3" Bore 18" stroke	2	$661.34	Mcmaster		https://www.mcmaster.com/6498K706/
114200	Clevis Rod End	2	$49.02	Part# 6071K21	OPTION 1	https://www.mcmaster.com/6071K21/
114300	Push-to-Connect Tube Fitting 3/8 Tube OD, 3/8 NPT Male	4	$88.72			https://www.mcmaster.com/7610N121/
114400	Polyurethane Tubing for Air and Water 3/8 OD - 10ft	10	$13.10			https://www.mcmaster.com/5648K26

114500	Wye Connector, 1/4 NPT Male Thread to Tube	2	$34.40			https://www.mcmaster.com/5779K628
120000	Base Platform					
120100	V-Groove Wheel 4in	2	$76.28	4" dia, 800 lbs rating		https://www.mcmaster.com/2310T66
120200	Swivel Caster Wheel	4	$102.20	4" dia, 200 lbs rating		https://www.mcmaster.com/2407T21
120300	V-Groove End Stop	1	$29.65	1' long, 4"x4", 1/4" thick	Cut to four, 3" pieces	https://www.mcmaster.com/8982K63/
120400	Angle Alum Track 1in	1	$13.33	4' long, 1"x1"	Cut to two 22.5" pieces	https://www.mcmaster.com/8982K4/
120500	Base Anchor Stock	1	$95.51	3" x 4", 1/2 ft length	Cut into two pieces	https://www.mcmaster.com/8975K282/

Appendix B – Risk Assessment

designsafe Report

Application:	F14	Analyst Name(s):	
Description:		Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1	All Users <None>	<None>						
2-1-1	Engineer Common Tasks	mechanical : lack of shoring / structural strength Design for Strength and Stiffness is not correct	Catastrophic Unlikely	Medium		Catastrophic		
2-1-2	Engineer Common Tasks	mechanical : Binding Too much friction (causes immovable machine)	Serious Unlikely	Medium		Serious		
2-1-3	Engineer Common Tasks	mechanical : head bump on overhead objects Overhanging props / tree parts	Moderate Unlikely	Low		Moderate		
2-1-4	Engineer Common Tasks	mechanical : machine instability Tipping	Catastrophic Unlikely	Medium		Catastrophic		
2-2-1	Engineer misuse - (add description)	mechanical : lack of shoring / structural strength Shaking and sitting causes breaks	Catastrophic Unlikely	Medium		Catastrophic		
2-2-2	Engineer misuse - (add description)	mechanical : crushing Falling crushes person	Catastrophic Remote	Low		Catastrophic		
2-2-3	Engineer misuse - (add description)	mechanical : cutting / severing Sharp edges while running next to tree	Minor Unlikely	Negligible		Minor		
2-2-4	Engineer misuse - (add description)	mechanical : unexpected start Operator lets in air too early	Moderate Unlikely	Low		Moderate		
3-1-1	Machinist Drilling	mechanical : stabbing / puncture Safety of operator	Moderate Remote	Negligible		Moderate		
3-2-1	Machinist Fixturing	mechanical : lack of shoring / structural strength Too tight a vice causes failure	Moderate Unlikely	Low		Moderate		
3-2-2	Machinist Fixturing	mechanical : machine instability Mill breaks down	Minor Remote	Negligible		Minor		
3-2-3	Machinist Fixturing	mechanical : Squeezing Too tight a vice after beginning slots creates uneven edges by squeezing	Minor Likely	Low		Minor		
3-3-1	Machinist Milling	mechanical : lack of shoring / structural strength Finished Product creates too thin of walls and will hurt final product	Serious Likely	High		Serious		
3-3-2	Machinist Milling	mechanical : cutting / severing Bend creates uneven cuts means splitting the beam	Catastrophic Remote	Low		Catastrophic		
4-1-1	Supervisor / Foreman train personnel	mechanical : crushing Using structure as a support to get up	Serious Unlikely	Medium		Serious		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
4-1-2	Supervisor / Foreman train personnel	mechanical : head bump on overhead objects Unfamiliarity with procedure	Moderate Unlikely	Low		Moderate		
4-2-1	Supervisor / Foreman inspect property	material handling : instability Pre or post sand bags	Minor Unlikely	Negligible		Minor		
4-2-2	Supervisor / Foreman inspect property	material handling : excessive weight Decorations or our final product	Moderate Likely	Medium		Moderate		
4-2-3	Supervisor / Foreman inspect property	fluid / pressure : high pressure air	Serious Remote	Low		Serious		
5-1-1	Laborer Common Tasks	mechanical : Binding During Production, it does not work	Serious Unlikely	Medium		Serious		
5-1-2	Laborer Common Tasks	mechanical : stabbing / puncture Getting into position	Minor Likely	Low		Minor		
5-1-3	Laborer Common Tasks	mechanical : unexpected start Opens valve too early	Serious Remote	Low		Serious		
5-1-4	Laborer Common Tasks	mechanical : head bump on overhead objects Getting into position	Minor Unlikely	Negligible		Minor		
5-1-5	Laborer Common Tasks	ergonomics / human factors : repetition Opening and closing valves	Catastrophic Unlikely	Medium		Catastrophic		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
5-1-6	Laborer Common Tasks	noise / vibration : loss of hearing acuteness Pneumatics	Moderate Remote	Negligible		Moderate		
5-1-7	Laborer Common Tasks	confined spaces : confined spaces Depends on location of valve	Minor Remote	Negligible		Minor		
5-1-8	Laborer Common Tasks	fluid / pressure : high pressure air Setting up compressor / tank	Moderate Unlikely	Low		Moderate		
5-2-1	Laborer Setup	mechanical : crushing	Serious Unlikely	Medium		Serious		
5-2-2	Laborer Setup	mechanical : drawing-in / trapping / entanglement	Moderate Unlikely	Low		Moderate		
5-2-3	Laborer Setup	mechanical : stabbing / puncture Ripping fabric while going on/off stage	Minor Likely	Low		Minor		
5-3-1	Laborer clean site after play	mechanical : head bump on overhead objects While cleaning up under tree	Minor Unlikely	Negligible		Minor		
5-3-2	Laborer clean site after play	mechanical : machine instability	Serious Unlikely	Medium		Serious		
5-4-1	Laborer Drop while transporting	mechanical : crushing Falling	Serious Likely	High		Serious		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
5-4-2	Laborer Drop while transporting	slips / trips / falls : trip	Minor Unlikely	Negligible		Minor		
5-4-3	Laborer Drop while transporting	ergonomics / human factors : duration Pulling on/off stage to truck	Minor Likely	Low		Minor		
6-1-1	Welder Fixturing	mechanical : Squeezing	Serious Likely	High		Serious		
6-2-1	Welder weld	mechanical : lack of shoring / structural strength Burning through Aluminum	Catastrophic Likely	High		Catastrophic		
6-2-2	Welder weld	fire and explosions : flammable gas Shielding gas	Serious Remote	Low		Serious		
6-2-3	Welder weld	weather related : rain / wet conditions Rust	Serious Unlikely	Medium		Serious		
7-1-1	passer by / non-user public walk near machinery	slips / trips / falls : falling material / object	Serious Unlikely	Medium		Serious		
7-2-1	passer by / non-user public work next to	slips / trips / falls : falling material / object Falling decorations	Serious Unlikely	Medium		Serious		

Appendix C – Final Project Budget

Material	Dimensions	Supplier	Price per unit	Quantity	Shipping	Total Cost	Date Purchased
6061 Aluminum Square Tubing	1-½" H x 1-½" W x 1/16" wall x 20' L	Ventura Steel	$45.00	6	N/A	$270	2/23/2024
6061 Aluminum Square Tubing	1-½" Ht x 1-½" W x 1/8" wall x 20' L	Ventura Steel	$70.00	3	N/A	$210	2/23/2024
Hor Rolled Steel Rods	½" D x 20' L	Ventura Steel	$13.00	2	N/A	$26	2/23/2024
Hor Rolled Steel Rods	½" D x 8' L	Ventura Steel	$6.00	1	N/A	$6	2/23/2024
6061 Aluminum Round Tubing	½" D x 1/16" Wall x 20' L	Ventura Steel	$25.00	2	N/A	$50	2/23/2024
Light Duty Dry-Running Nylon Sleeve Bearing	1/2" ID and 5/8" OD, 1/2" Long, 3/4" Flange OD	McMaster Carr	$0.94	168	See Below	$158	3/1/2024
Off-White Nylon Unthreaded Spacer	1" OD, 1/2" Long, for 1/2" Screw Size	McMaster Carr	$19.65	2	See Below	$39	3/1/2024
Stainless Steel Washer	7/16" Screw Size, 0.5" ID, 1.125" OD	McMaster Carr	$11.99	2	See Below	$24	3/1/2024
Push-on External Retaining Rings	1/2" OD, Black-Phosphate 1060-1090 Spring Steel	McMaster Carr	$11.90	2	See Below	$24	3/1/2024
Round Body Air Cylinder, Double-Acting, Universal Mount	3" Bore, 18" Stroke Length	McMaster Carr	$330.67	2	See Below	$661	3/1/2024
Clevis Rod End	5/8"-18 Thread, 4-15/16" Shank Center Length	McMaster Carr	$24.51	2	See Below	$49	3/1/2024
Iron V-Groove Track Wheel	4" Diameter x 1-1/2" Wide, for 1/2" Axle	McMaster Carr	$38.14	2	See Below	$76	3/1/2024
Cart-Smart Caster Wheel	4" Diameter 75A Durometer	McMaster Carr	$25.55	4	See Below	$102	3/1/2024
Multipurpose 6061 Aluminum 90 Degree Angle with Round Edge	1/4" Thickness, 4" High x 4" Wide Outside, 1' Long	McMaster Carr	$29.65	1	See Below	$30	3/1/2024
Multipurpose 6061 Aluminum 90 Degree Angle with Round Edge	1/8" Thickness, 1" High x 1" Wide Outside, 4' Long	McMaster Carr	$13.33	1	$66.05	$13	3/1/2024
Push-on External Retaining Rings	9/16" OD, Black-Phosphate 1060-1090 Spring Steel	McMaster Carr	$11.09	2	See Below	$22	4/16/2024
316 Stainless Steel Washer	1/2" Screw Size, 0.531" ID, 1.25" OD	McMaster Carr	$9.72	11	$10.14	$107	4/16/2024
Cardinal Caster	3" Diameter Polyurethane Wheel	McMaster Carr	$11.09	2	$9.69	$22	5/7/2024
					Total (Before Tax)	$1,976	

Appendix D – Design Verification Plan & Report (DVPR)

DVP&R – Ready for Testing

DVP&R - Design Verification Plan (& Report)											
Project:	F14 - Expanding Christmas Tree		Sponsor:	Bret Clark					Edit Date: 5/23/2024		
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/ Equipment	Parts Needed	Responsibility	TIMING Start date	Finish date	Numerical Results	Notes on Testing
1	1	Measure weight of tree assembly	Weight	< 200 lbs	Racing Team	Scales	Will & Xiomara	5/22/2024			
2	5	Time how long it takes to replace one scissor lift link	Time and # of people required	< 3 people < 1 hours	Flat head screwdriver, mallet, makeshift tool, tin snips	Scissor lift link, retaining rings, washers	Will, Ben, & Xiomara	5/2/2024			
3	8	Measure the noise level of tree expansion	Decibel reading	< 100 db	Decibel meter	N/A	Xiomara	5/22/2024			
4	9	Time how long it takes for the tree to expand	Time	< 10 sec	Timer	Compressed air tank, pneumatic plumbing	Zoey, Ben, & Xiomara	5/22/2024			
5	10	Measure the deflection of the D-rings under the weight of the decorations	Deflection (in)	< 2 in of deflection per D-ring	Weights, tape measure	D-rings	Ben & Will	5/2/2024			

Tests not yet completed. To be filled in once done.

DVP&R – Testing Results

DVP&R - Design Verification Plan (& Report)											
Project:	F14 - Expanding Christmas Tree		Sponsor:	Bret Clark						Edit Date:	5/23/2024
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/ Equipment	Parts Needed	Responsibility	TIMING Start date	Finish date	Numerical Results	Notes on Testing
1	1	Measure weight of tree assembly	Weight	< 200 lbs	Racing Team	Scales	Will & Xiomara	5/22/2024	5/23/2024	209.4 pounds	9.4 pounds over, this data was taken from the CAD model. Still within the tolerance limit however.
2	5	Time how long it takes to replace one scissor lift link	Time and # of people required	< 3 people < 1 hours	Flat head screwdriver, mallet, makeshift tool, tin snips	Scissor lift link, retaining rings, washers	Will, Ben, & Xiomara	5/2/2024	5/23/2024	23 minutes	3 people were required, 2 to hold the lift up and 1 to change the link. This test was done on an outer ring.
3	8	Measure the noise level of tree expansion	Decibel reading	< 100 db	Decibel meter	N/A	Xiomara	5/22/2024	5/23/2024	The maximum noise reading from the compressed air tank was 94 decibels. This is within testing limits.	The lift itself made no noise, the compressor was the main noise producer.
4	9	Time how long it takes for the tree to expand	Time	< 10 sec	Timer	Compressed air tank, pneumatic plumbing	Zoey, Ben, & Xiomara	5/22/2024	5/23/2024	We were only able to expand 8 inches in 2 seconds. After interpolating, full expansion will take about 44 seconds. This is not within testing limits.	We were not able to fully expand the scissor lift, so this test was not able to be completed properly anyway. This was also done with the tank only partially opened.
5	10	Measure the deflection of the D-rings under the weight of the decorations	Deflection (in)	< 2 in of deflection per D-ring	Weights, tape measure	D-rings	Ben & Will	5/2/2024	5/23/2024	an average of 4.04 inches vertically per each D-ring	The D-rings were weaker than anticipated, recommendations will be made for how to possibly repair this.

Appendix E – Test Procedures

Test Name: Noise Level Test

Test Date: 5/22/2024

Performed By: Ben Mosemann

Purpose: The purpose of this test is to ensure that the noise of the Christmas tree expansion does not interfere with the music and sounds of the play by measuring the decibel level of the Christmas tree expansion.

Location: Bonderson High Bay

Equipment:

- Design Verification Prototype
- Handheld decibel meter

Hazards:

- Potential loud noise levels

PPE Requirements:

- Earplugs (for all attendees)

Procedure:

1. Ensure the decibel meter reads zero in a quiet room to calibrate it
2. Fully collapse the Christmas tree
3. Fill the air tank(s) with compressor
4. Turn on decibel meter
5. Open valve to expand Christmas tree
6. Record maximum decibel reading
7. Repeat steps 2-6 for a total of 2-5 times

Results: We will record the maximum decibel reading for each run and average them together. The average must be equal to or less than 100 dB, which is the pass/fail criteria that we listed in our DVP&R.

Test Results:

Table 1E: Decibel Reading of Pistons

Run #	Maximum Decibel Reading (dB)
1	94
2	94
Average	94

Test Name: Weight Compared to Simulation

Test Date: 5/23/24

Performed by: Will Tedone

Purpose: Ensure the weight of the entire assembly is less than 250 lbs. See how long it takes to move the assembly 20 feet and find the ramp rate.

Location: Bonderson High Bay

Equipment:

- High weight scale
- Stopwatch
- Ear plugs
- Safety glasses

Test Procedure:

1. Verify all test participants are wearing proper safety equipment.
2. Set up camera to take picture of scale accounting for parallax errors.
3. Set up assembly on the scale and let to settle until the scale is settled.
4. Record data on **Table 2E**.
5. Take a picture of the scale to verify the weight. Record pictures in **Table 3E**.
6. Take off the assembly.
7. Repeat Steps 3-6 for the following trials.

Table 2E: Weight of Final Assembly [lbs]

Trial	Weight
1	
2	
3	

Table 3E: Pictures Weight of Final Assembly [lbs]

Trial	Weight
1	
2	
3	

8. Have the assembly be stationary on flat ground.
9. Push with enough force to start the assembly's movement.
10. Start the stopwatch.
11. When we reach an apparently steady walking speed, lap the stopwatch.
12. After the assembly moves 20 feet, stop the stopwatch.
13. Record this data in **Table 4E**.
14. Repeat steps 8-13.

Test Safety:

Safety Concern	Mitigation
Heavy Lift Items	- The assembly will be on wheels - Dolly will help lift it from the back - 3 man lift < 125 lbs

Test Update: 5/30/2024

We were unable to complete this test according to the test procedure written above due to restrictions of the size of the completed verification prototype. Instead of following the test procedure, we completed an FEA analysis of the completed verification prototype in SOLIDWORKS by assigning materials and weights to each component.

After assembly in SOLIDWORKS, we took the weight of the tree. Each individual piston's weight was added to the part model's mass properties; after checking the weights of the aluminum we had to the theoretical weight in SOLIDOWRKS, we observed the mass properties of the assembly.

The result is a weight of 246.5 lbs.

Test Name: Point Mass Deflection Test

Test Date: 5/9/24

Performed By: Zoey Camarillo, Xiomara Medina, Ben Mosemann, Will Tedone

Purpose: To verify the structure is robust enough to withstand expected loading and ensure that the tree can still expand after loading. We will be testing if the tree structure will hold its form under the weight of the decorations.

Location: Bonderson High Bay

Equipment:

- Completed verification prototype
- Tape measure
- Metal ruler
- Digital level
- 10-pound dumbbells
- Metal wire for attachment

Hazards:

- Dumbbells falling from D-rings
- Prototype tipping over from weight
- D-ring welds fail, and D-rings fall

PPE Requirements:

- Safety glasses (for all attendees)

Facility: The test will take place in Bonderson Room 108

Procedure:

1. Ensure Christmas tree is in collapsed configuration
2. Ensure D-rings are level to begin with by measuring angle with digital level
3. Photograph each D-ring without load, ensuring camera is level and in line
4. Attach dumbbells to endpoint of D-ring pipes
5. Measure vertical deflection at endpoints
6. Photograph deflected D-rings

1. Remove weight from the tree

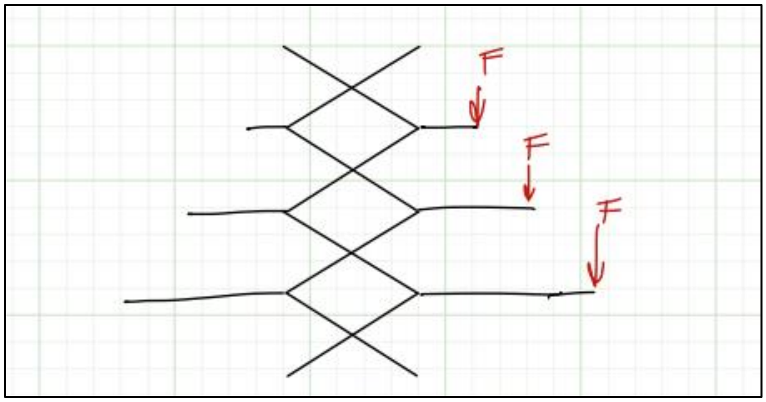

Figure 1E: Diagram of point mass (weight) location on D-rings

Results:

- Pass Criteria: Deflection ratio must be less than **3.00**. The deflection ratio (equation seen below) compares the measured deflection to the D-ring length and is corrected for the cubed relationship between length and deflection for a cantilevered beam. Additionally, it is scaled by 100 to produce a percent.
- Number of samples: 6 D-rings to get 6 values for vertical deflection and 6 horizontal lengths

Equations: $DR = 100 \cdot \frac{\sqrt[3]{y}}{L}$

- Uncertainty Analysis: Resolution certainty will exist for our vertical deflection measurements, a statistical uncertainty will be performed for our population of 6 D-rings samples, and a propagated uncertainty will be calculated using the ratio above which compares measured vertical deflection to the horizontal length of the D-rings. **See the next page for the equations for the uncertainty calculation.**

Data with weight 2.5 lbs. Point load at longest length "L"

D-Ring #	**1**	**2**	**3**	**4**	**5**	**6**
Deflection (in)	4.75	4.75	4.75	4.5	2	3.5
Length (in)	35.25	34	31.75	32.5	27.5	27
Deflection Ratio	4.76	4.94	5.29	5.08	4.58	5.62

Calculations:

1. $u_y = \frac{U_y}{y}$ and $u_L = \frac{U_L}{L}$, where *u* is dimensionless uncertainty and *U* is the uncertainty, and *y* and *L* are the measured deflection and length.
2. The propagated uncertainty of the deflection ratio is as follows:

$$U_{DR} = DR \cdot \sqrt{\left(\frac{1}{3} \cdot u_y\right)^2 + (-1 \cdot u_L)^2}$$

3. Therefore, for each D-ring, there will be a deflection ratio and propagated uncertainty of $DR \pm U_{DR}$.

Test Name: Estimate of Repair Time

Test Date: 5/9/24

Performed by: Will, Xiomara, Ben

Purpose: Estimate the time it takes to replace one link of the scissor lift Christmas tree frame. The goal of this test is to give our sponsors an understanding of how long replacing parts of the scissor lift might take.

Location: Bonderson High Bay

Equipment:

- Completed verification prototype
- Rubber mallet
- Clamps
- Other misc. tools
- Timer
- Containers to store fasteners

Hazards:

- Pinch points within the body of the Christmas tree frame as it is taken apart
- Bumping your head into the parts of the scissor lift frame may be above

PPE Requirements:

- Safety goggles (required for all attendees)
- Work gloves (optional)
- Hard hat (optional)

Procedure:

There are many links that make up the scissor lift Christmas tree frame. Each link is stacked in a staggered pattern, so that means that time it takes to remove and replace a link will vary depending on the type of link that needs to be removed.

There are two types of links that can be placed in different locations of the scissor lift. First are “under” links, which are placed under other links; we will call the other links “over” links. The scissor lift maintains its even shape by alternating “under” and “over” links as the scissor lift builds up. The procedure for removing “under” and “over” links will be slightly different, but we will be able to run a test that can estimate both removal processes simultaneously. As the name implies, “over” links will lay over the “under” links. This means that to remove an “under” link, we need to also remove the “over” links that are on top of each pivot point on the “under” link. This also means that if we need to remove an “over” link, we are free to remove just the link in question, without having to worry about the “under” links that it may be on top of.

We also need to consider the placement of these “under” and “over” links. Looking at the diagram below, links 1, 3, and 5 are “over” links while links 2 and 4 are “under” links. Link 2 we will classify as specifically an “under” end link while link 4 will be called an “under” middle link. Similarly, link 1 is an “over” end link, while links 3 and 5 are both “over” middle links (assuming the scissor lift continues down past link 5).

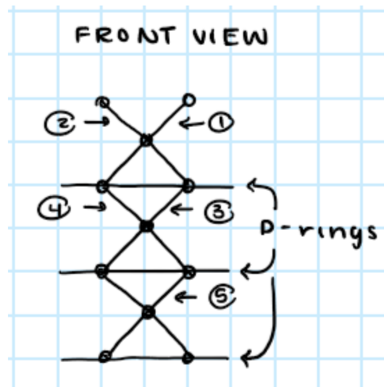

Figure 2E: Front View of Scissor Lift Frame

Removing "over" links is easy because they are not stuck under any other links. However, if we wanted to remove an "under" middle link, we will need to also remove three additional links (one for each pivot point on the "under" middle link). Looking back at Figure 1, if we wanted to remove link 4 (an "under" middle link") we would also need to remove links 1, 3, and 5 in before we can even remove link 4. This means that for each "under" middle link, the removal time is three times that of the removal time for a single "over" link (whether end or middle). For an "under" end link, we only need to remove two additional links. Since we can relate the removal time of a link in terms of the removal of one link, we can estimate how long it might take to remove four different kinds of links from the scissor lift: "under" end links, "under" middle links, "over" end links, and "over" middle links.

Something else to note is that even though the scissor lift has links on both sides (resulting in two X's per one level of the scissor lift), when removing links, we only need to focus on one side of the scissor lift at a time. This will also make it easier to replace parts if we only focus on one side of the scissor lift at a time.

The following steps outline a procedure that will test the time it takes to remove a link from the scissor lift. Additional calculations will be completed after the procedure to estimate the removal time for all four types of scissor lift links.

Turn Scissor Lift on Side: Turn the scissor lift onto one side so that the D-rings are facing upwards (as if on top of the scissor lift as opposed to normally sitting in front of the frame). See Figure 2 below.

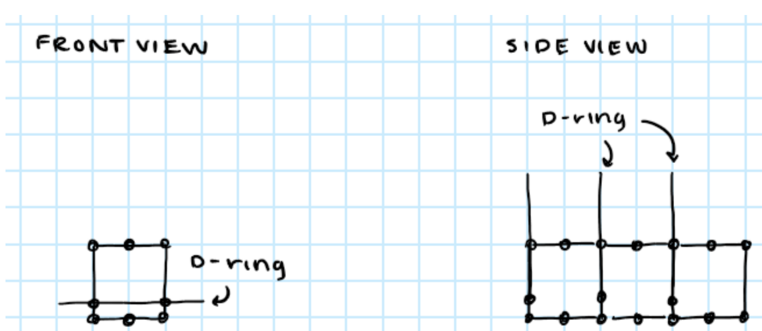

Figure 3E: Front and Side View of Scissor Lift after Step 1 (Turn Scissor Lift on Side)

Remove Scissor Lift Link: Remove the “over” end link located at the top of the scissor lift. This link would be considered link 1 according to Figure 1. Record how long it takes to remove this link.

Fill out **Table 5E**. The removal time of the “over” end link from Step 2 is represented by X.

Data:

Link Type	Total Removal Time
“Over” end link	X
“Over” middle link	X
“Under” end link	X*2
“Under” middle link	X*3

Table 5E: Link Type Removal Time Formulas

Results:

Pass Criteria, Fail Criteria, Number of samples to test, Design analysis equations/spreadsheet with uncertainty. Comment on how Uncertainty Analysis will be completed.

This test seems more like an analysis of the scissor lift; however, our sponsors need to use this Christmas tree frame for many years to come, so one of the specifications for our project was “ease of repair.” If removing the scissor lift links takes longer than the desired time (e.g., 1 hour per link), then we would deem this a Fail. A Fail means that we did not create a design that is “easy to repair.”

Test Update: 5/30/2024

Below are the results of the test. The process took 3 people to complete.

Link Type	Total Removal Time
“Over” end link	23 minutes
“Over” middle link	23 minutes
“Under” end link	23*2 = 46 minutes
“Under” middle link	23*3 = 69 minutes

Table 6E: Link Type Removal Results

We outlined in the test procedure that the test would fail if one scissor lift link took 1 hour to remove. The removal of one link took 23 minutes, so we passed this test.

Test Name: Time to Expand Christmas Tree

Test Data: 5/9/24

Performed By: Zoey Camarillo, Xiomara Medina, and Ben Mosemann

Purpose: To ensure the frame expands and collapses within the required time frame during the Nutcracker performance

Location: Bonderson High Bay

Equipment:

- Completed verification prototype
- Stopwatch

Hazards:

- Exposed pointed edges
- Moving parts

PPE Requirements:

- Gloves
- Safety glasses (for all attendees)

Procedure:

- Ensure all testers follow the safety procedures outlined.
- Set up frame in Bonderson High Bay with appropriate surrounding space.
- Prepare stopwatch to begin as step 4 is being done.
- Once all set up, begin squeezing the base of the frame to expand. Be sure to record the time at this point.
- Once the frame is fully expanded, stop the stopwatch, and record these values in **Table 7E** in the documentation section below.
- While still fully expanded, reset the stopwatch, and prepare it to begin recording at step 7.
- Release force on the frame allowing it to collapse. Record the time again.
- Once the frame is fully collapsed, stop the stopwatch, and record these values in **Table 8E** in the documentation section below.
- Repeat steps 4-8 two more times.
- Once all trials have been completed, average out all the time and record them in their appropriate tables.

Data:

Table 7E: Expansion Time

Trial	Time [sec]
1	
2 UNABLE TO BE PERFORMED	
3	
Average	

Table 8E: Collapse Time

Trial	Time [sec]
1	
2 UNABLE TO BE PERFORMED	
3	
Average	

Test Update: 5/30/2024

The scissor lift was unsuccessful at expanding and failed very early into the expansion. The steel rod on wheels deflected soon after we began actuating the pneumatic pistons. As a result, we were not able to fully expand the scissor lift using the pneumatic pistons. However, before the deflection, we saw a slight expansion. Based on this expansion, we estimated the time it would take to expand fully using the same rate of expansion we saw before the test failed.

The starting height of the scissor lift is 7 ft. 2 in. or 86 in. During the test, before the deflection, the scissor lift expanded to a height of 7 ft. 10 in. or 94 in. We observed an 8 in. vertical expansion in 2 seconds. The full expansion was meant to be 22 ft. or 264 in., so from the collapsed height to the expanded height, the scissor lift should have expanded vertically a total of 178 in. or 14 ft. 10 in. The following calculation below shows how we estimated the expansion time without physically expanding the system.

$$\left(\frac{178\ in.}{8\ in.}\right) * (2\ sec.) = 44.5\ sec.$$

According to this calculation, we estimate that had the scissor lift not failed, it would have taken 44.5 seconds to fully expand to 22 ft.