Final Design Review Report

Automated Expanding Fireplace

Prepared for SLO Civic Ballet, Bret Clark, Clint Bryson

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Statement of Disclaimer

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Abstract

The Final Design Review (FDR) encompasses information regarding the final design verification prototype (FVP), manufacturing, testing, and future recommendations for the Expanding Fireplace Senior Project sponsored by the SLO Civic Ballet. The project aims to create the frame of an expanding fireplace set piece for The Nutcracker production at the Cal Poly Performing Arts Center in December 2024. The current set piece being used has unfavorable features that have been addressed with the new design we have developed. Our sponsors have proposed several notable design changes since the Concept Design Review (CDR). These changes include adding beams across the top of the vertical beams that can slide along one another, allowing the frame to maintain a closed shape when expanding. This allows for more ease in attaching decorations to the set piece. Another proposed change was to place a turntable bearing under each caster wheel, allowing the wheels to act similarly to triple swivel caster wheels, which experience little to no jog when changing directions. This will be useful since the moving base subsystems change their rolling direction during production when transitioning from expanding to contracting. Other changes implemented on our behalf include reinforcing certain aspects of the stationary and moving base subsystems by changing areas that used 2020 extrusions (20mm by 20mm) for 2040 extrusions (20mm by 40mm). Lastly, to support the beams across the top, which our sponsors proposed, we implemented a diagonal support beam on each moving base subsystem. The final design consists of a stationary base, two moving bases on either side of the stationary base, and vertical sliders attached onto each respective moving base. The stationary base serves as a mounting point for the motor, several pulleys, and an overall datum from which the expansion occurs. The two moving bases can move outward, allowing for expansion in the horizontal plane. They are guided out by sliding rails attached to the moving bases and nested into the stationary base. A pulley system directly powered by the winch facilitates this horizontal movement. The moving bases also interface with the vertical sliders. A fixed-length pulley system powers the vertical sliders movement. This allows us to expand vertically as a result of the horizontal expansion by fixing an end of the pulley system on the opposing moving base and another end at the bottom of the vertically sliding beam. Our design eliminates the need for a separate power source for vertical expansion, resulting in the use of a single motor to power the entire expansion of the fireplace. The verification prototype met the major goals of expansion time, low noise output, and desired weight, but it fell short in terms of overall desired expansion. The fireplace expanded roughly four feet in each dimension, but roughly seven feet was desired.

Contents

1 Introduction

The success of a theatre production heavily relies on the quality and creativity of stage background and props. Some solutions for the design of theatre props require the assistance of engineers. For this set design, our sponsors who represent the SLO Civic Ballet, Bret Clark and Clint Bryson, proposed the task of redesigning and delivering an expanding fireplace stage prop that will be implemented into the *Nutcracker* production at the Cal Poly Performing Arts Center (PAC). The current showing of the *Nutcracker* utilizes a stage piece that requires replacement as it achieves little expansion, is heavyweight, and is difficult to transport. Therefore, this project aims to design and construct a piece capable of the desired expansion lengths while being lightweight, simple to operate, relatively inexpensive, easy to transport, and safe.

The following Final Design Report for the Expanding Fireplace summarizes the system design overview, model implementation, and design verification. This includes a complete description of the design components, how they function, and changes made since the CDR. Also, the report outlines material procurement, the manufacturing processes exercised to produce the final prototype, and the testing performed to validate our specifications. Although the Fireplace assembly was finalized, the report additionally covers recommendations to be followed which improve the overall functionality of the project.

2 Design Overview

The following section will go over the design overview of the verification prototype. Section 2.1 will reiterate the design description in the CDR report for the reader's convenience. Section 2.2 will follow by going over the design changes implemented since CDR. This will make it easier for the reader to directly identify what has changed since CDR.

2.1 Design Description

Overall, the design may be broken into five subsystems: the stationary base subsystem (SBS), two moving base subsystems (MBS), the horizontal pulley system (HPS), and the vertical pulley system (VPS). The overall assembly is displayed below in Figure 1 with the subsystems labeled.

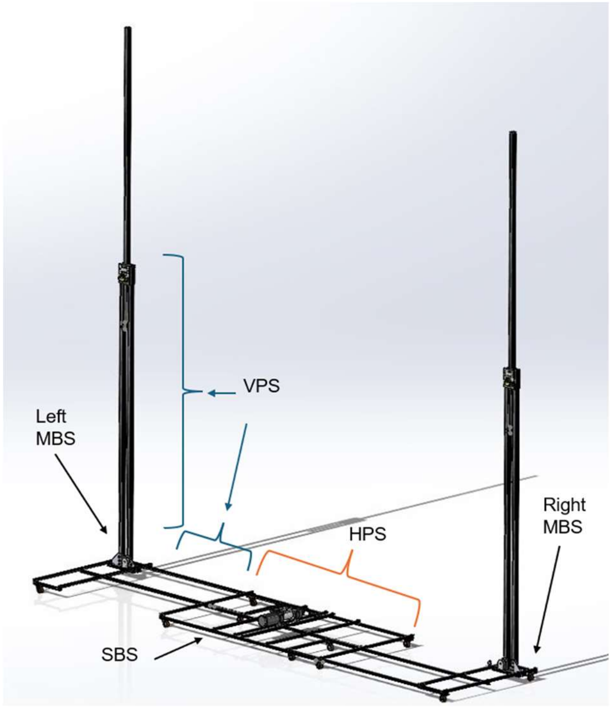


Figure 1. Overall Assembly

2.1.1 Stationary Base Subsystem

The SBS acts as a fixed datum for the moving subsystems of the design. Parts in this subsystem include aluminum extrusions, corner brackets, fasteners, rail slides, pulleys, and caster wheels. Aluminum extrusions are the structural members of the subsystem. The skeleton of the SBS is a rectangular ladder frame parallel to the ground. The overall dimensions of the SBS are 6' x 1000mm (about 3.28 ft) x 6". The stationary base subsystem is shown in Figure 2 below, with the major components labeled.

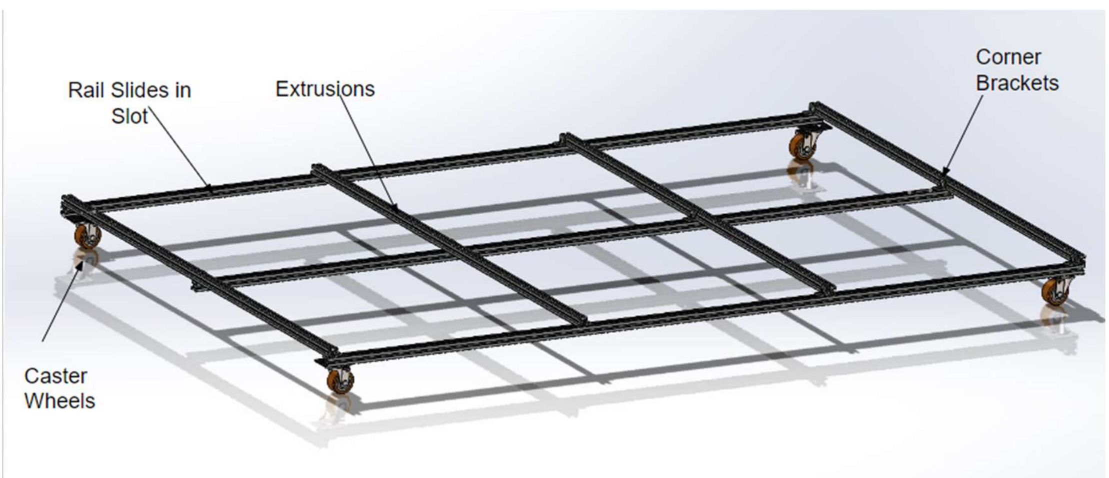


Figure 2. Stationary Base Subsystem (SBS)

Caster wheels are attached to each of the four corners of the SBS and secured directly to the aluminum extrusion skeleton using thread fasteners. The caster wheels have a locking mechanism that is engaged during expansion to prevent movement of the subsystem. The wheels are released when the whole system is transported from the PAC to off-campus storage at Meathead Movers in San Luis Obispo.

We decided to go with T- bolt screws and slide-in T- nuts for fasteners because they are designed to interface with the aluminum extrusion slots. The SBS design consists of three-foot extrusions overlayed onto the six-foot extrusions. This leaves gaps for the moving bases to nest into while the fireplace is unexpanded. The rail slides are inserted and fastened into the slots of the six-foot extrusions, allowing for the fork configuration of the moving bases to slide in and out of the stationary base during the expansion process, which will be covered in more detail in this document.

2.1.2 Moving Base Subsystem

The two moving base subsystems symmetrically interface with the stationary base subsystem. They are both mirrored across their longitudinal planes but are otherwise identical in dimensions and materials. The structural skeletons of the MBS are made of the same materials as the SBS. The fork configuration will interface with the rail sliders housed in the SBS. The flat section of the MBS is shown below in Figure 3.

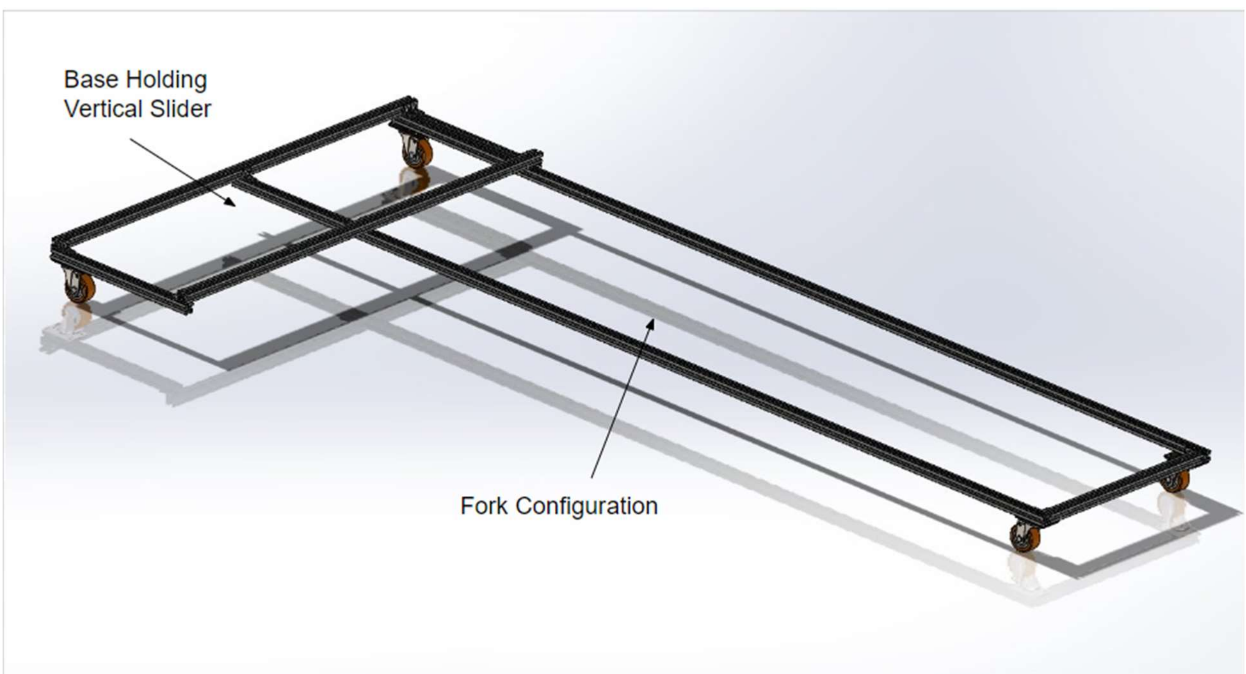


Figure 3. Moving Base Subsystem Frame

The MBS also includes two aluminum extrusions fixed vertically to the outer corners of the subsystem. Another aluminum extrusion of equal length is free to move vertically relative to the columns. The vertically moving beam may slide via linear bearings and has a screw-in D-ring at the bottom that acts as an attachment point for the pulley cord.

2.1.3 Horizonal Expansion

The motor which powers motion is attached to the SBS. The motor interfaces with the two pulley cords of the horizontal pulley system, one for each MBS. Both cords extend from the motor shaft to a pulley at the end of each side of the stationary base. The cord will wrap back around to the D-rings at the end of the fork configuration of each MBS. When the motor wraps each cord in, the HPS will pull out both MBSs to expand the horizontal length of the fireplace.

2.1.4 Vertical Expansion

Vertical expansion will be driven by extending the horizontal distance between the SBS and the MBS. The vertical pulley system consists of a fixed length of cord. The cord attaches to a D-ring on the MBS, wraps around a pulley on the SBS, wraps back to a pulley on the MBS, and back to a pulley on the SBS. This forms a double loop. The cord then wraps around a pulley at the bottom of the vertical extrusion on the MBS. Finally, the cord wraps around a pulley at the top of the fixed vertical beam of the MBS and attaches to a D-ring at the bottom of the sliding vertical extrusion. A simplified schematic of the vertical and horizontal pulley systems is shown in Figure 4.

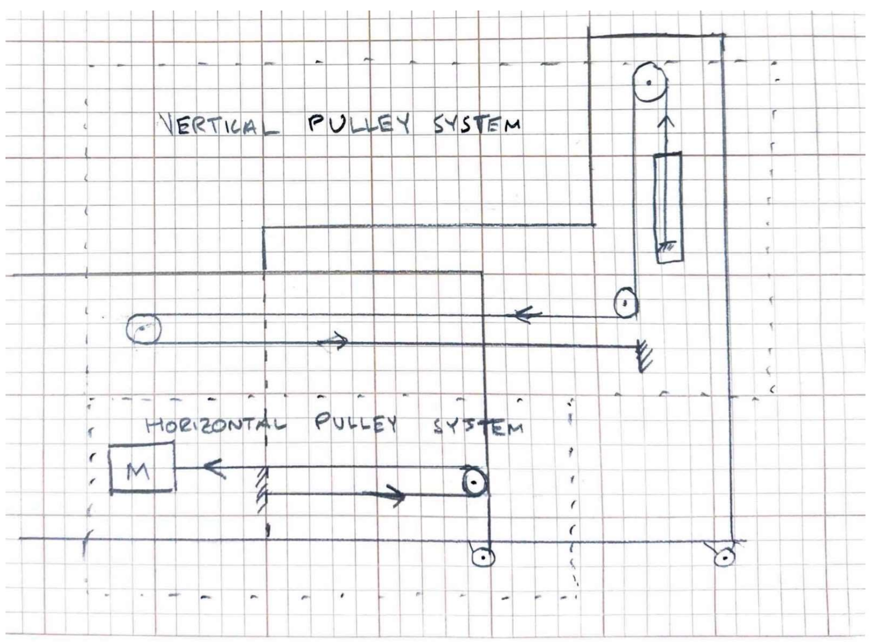


Figure 4. Schematic of Vertical (Top) and Horizontal (Bottom) Pulley Systems

The cord utilized for the vertical pulley system will always be in tension. Because of this, extending the distance between the SBS and MBS will force the vertical extrusion to slide upward. The double looping of the vertical pulley system ensures the correct kinematics of the system. Specifically, both MBSs must have twice the vertical expansion as horizontal expansion. This is crucial to maintaining a proper aspect ratio of the Expanding Fireplace.

2.1.5 Full Assembly

When put together, the full assembly will have two configurations: one for when fully expanded and the other for when contracted. To change between configurations, the user must first ensure all safety measures are in place. These safety measures include weighing down the moving bases, properly tensioning each pulley system, locking the SBS, and clearing the surrounding area. The user manual in Appendix A goes into more detail on the step-by-step operation process. Also, the risk assessment in Appendix B goes over all the potential risks we have identified, such as if the verification prototype were to fail or if proper safety measures were not taken. Once safety measures are in place, expanding and contracting the system will be performed using the motor's attached controller. Figure 5 below depicts the final assembly in its contracted state, followed by Figure 6, which displays the expanded state.

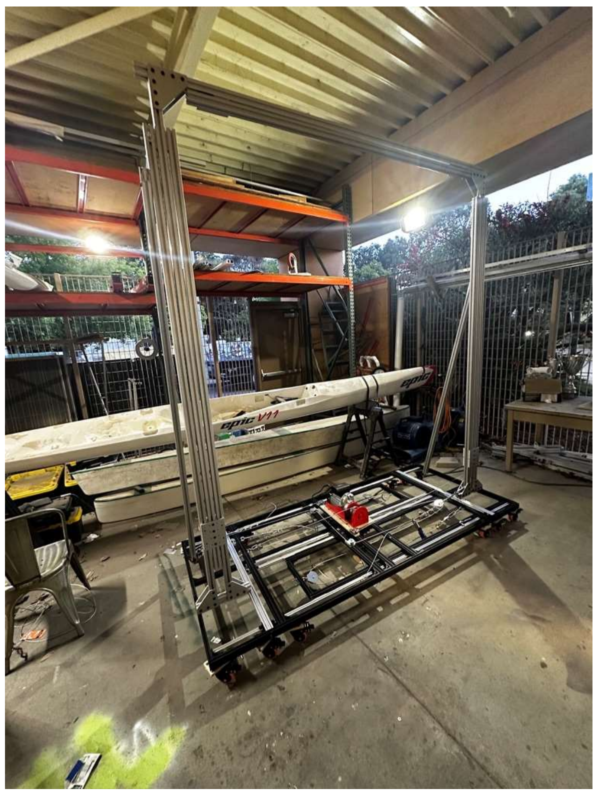


Figure 5. Final Assembly in Contracted State

Figure 6. Final Assembly in Expanded State

2.2 Design Changes Since CDR

Several design changes have been made since the CDR report, both by request of the sponsor and due to design changes made on the fly as a result of our judgment. One of these modifications is the addition of beams that slide along one another across the top of the vertical beams, which enables the frame to keep its closed shape even when it expands. As a result, decorating the set piece can be done more easily. The beams spanning the top of the system are shown in Figure 7.

Figure 7. Addition of Beams Across the Top of the Vertical Beams. This photo has the corner plate bracket detached from the horizontal members to show the joining in more detail.

Another suggested modification was to put a turntable bearing beneath each caster wheel. This would enable the wheels to function similarly to triple swivel caster wheels, which display minimal jog when changing directions. This will be helpful since the moving base subsystems alter their rolling direction during production when they go from expanding to contracting. The altered wheel bearing assembly is shown in Figure 8 below.

Figure 8. Addition of Turntable Bearings Between the Base and Caster Wheels

Additional modifications performed on our behalf include replacing areas utilizing 2020 extrusions (20 mm by 20 mm) with 2040 extrusions (20 mm by 40 mm) to reinforce specific components of the fixed and moving base subsystems. Figure 9 below displays this with side-by-side images of the previous base with the current one. The 2040 extrusions stand out with their black surface finish.

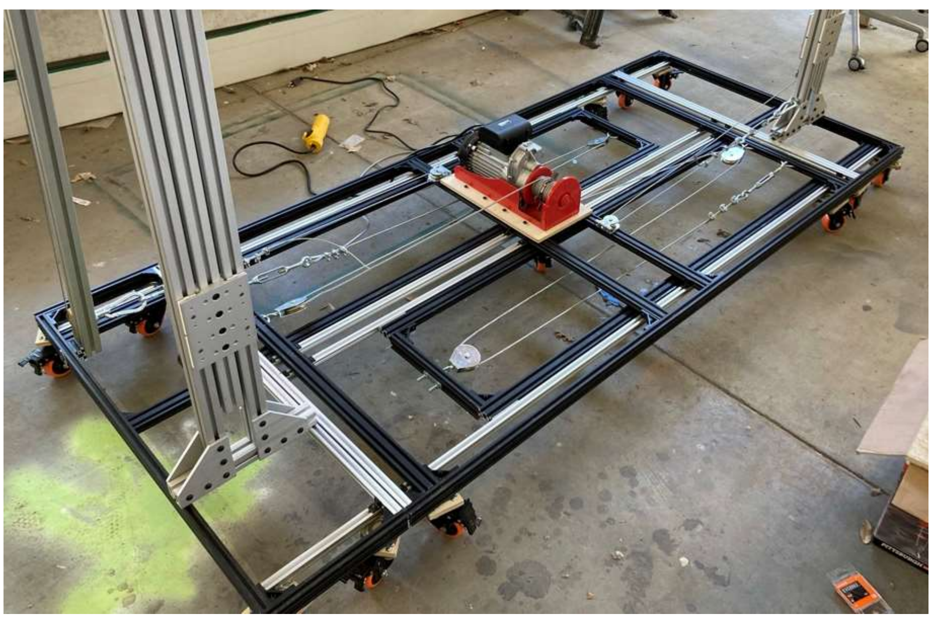


Figure 9. Areas Reinforced with 2040 Extrusions

In the design overview, the vertical pulley system was said to be looped back to the same moving base. This was due to the inconsistent expansion of the moving bases. Given that the previous system moved the vertical pulley system at twice the rate of the horizontal rate of each individual MBS, the effected would be doubled at the top. Since the two sides were now coupled with beams going across both sides, this would cause stress and strain on the rest of the system. To rid ourselves of the worry of unequal expansion, we attached the end of the VPS to the opposing MBS, as opposed to looping back to the same MBS.

Finally, we added a diagonal support beam to each moving base subsystem to support the beams across the top that our sponsors suggested. By having two points in which the vertical beams are fixed to the bases, the system will be much more stable when expanding, especially with the added weight of the beams across the top. The placement of the diagonal beam can be seen below in Figure 10.

Figure 10. Diagonal Support Beams

3 Implementation

The following section will outline the procedures completed to construct the DVP. These procedures will, for the most part, parallel the manufacturing plan described in CDR, with the exception of the design changes mentioned above.

3.1 Procurement

Materials needed to build the Expanding Fireplace are all available at local department stores, online mechanical parts distributors, and general online stores. Components for the pulley systems were obtained from Home Depot. All extrusion components used for building the bases were obtained from T-Nutz, an online store, and Amazon. T-Nutz carries the 1.5-inch extrusions and the components used with them, such as corner brackets, whereas Amazon carries the 20 series extrusions (2020 and 2040) and the corresponding components. Wheels and the turntable bearings for the bases were obtained from Amazon. All fasteners were obtained from both the T-Nutz website, Amazon, and Home Depot. All corner brackets for the 2020 extrusions came with their own fasteners, removing the need to purchase them separately. The linear bearings and rail slides for the vertical sliding system were purchased from 8020, another online store abundant in extrusion components. The rail slides utilized for the horizontal system were bought from Frame Tech. The final major purchase was the motor which was purchased from Harbor Freight. Reference Appendix C to get an overview of the final project budget.

3.2 Manufacturing

After acquiring the necessary materials, the fabrication of the Expanding Fireplace commences. A critical manufacturing task is cutting stock aluminum extrusions to the required lengths. Due to the design changes mentioned in Section 2.2, a few more cuts were performed than initially specified by our cuts list in the design package. All these cuts were performed using the horizontal band saw in Mustang 60'. Another essential manufacturing step was to drill holes through the extrusions for fastening extrusions of different sizes. We also had to drill through several other parts of the assembly, such as the motor mount plate, the caster wheel plates, and the linear rails. All drilling was conducted using a drill press in the Mustang 60' shop and the Aero Hangar. Drilling was also utilized in the motor modification process, allowing the cable to exit through an extra hole. An angle grinder was also used to modify the motor to create side-facing slots through which the rope exits.

3.2.1 Cutting Manufacturing Processes

Both the 1.5-inch and the 20 series extrusions required cutting to a specified length. All 20 series extrusions came in either 2000mm or 1000mm. From the initial stock length of 2000mm, six 2040 and four 2020 extrusions were cut to be 6' in length. Since the 2040 extrusions only came in the 2000mm stock length, we also had to cut down seven extrusions to 1000mm, matching the width of the base. Some 2020 extrusions came at a stock length of 1000mm, not requiring any cutting. Since the width of the MBS is 1', we had to cut down four 2040 and two 2020 extrusions down to that length. For the end of the fork configurations, we had to cut two 2040 extrusions to the spacing between the forks. Due to a complication in the fork configurations not being perfectly symmetrical, we marked the length for these cuts instead of measuring. That concludes all the cuts for the 20 series extrusions. Series 2020 aluminum extrusions are shown in Figure 11.

Figure 11. Aluminum Extrusions

All 1.5-inch extrusions came in a length of 7.5'. We had to cut two mounting beams for the vertical beams on each MBS, each of which was 1' long to match the width of the MBS. We also cut the face of the diagonal support beams flush with the vertical beams' faces. Since we picked an arbitrary angle because it was a design change implemented after CDR, we marked the point at which the beam stuck out and cut along that length. Finally, we cut the size of two more extrusions by 9" for the extrusions running across the top. All the cuts were performed on the horizontal bandsaw in Mustang 60', as we found it to be the only reliable saw in the shops that would cut the ends squarely. It also required the least amount of post-processing, such as deburring and sanding, making it the best saw on campus for our use. The horizontal band saw used is shown in Figure 12 below.

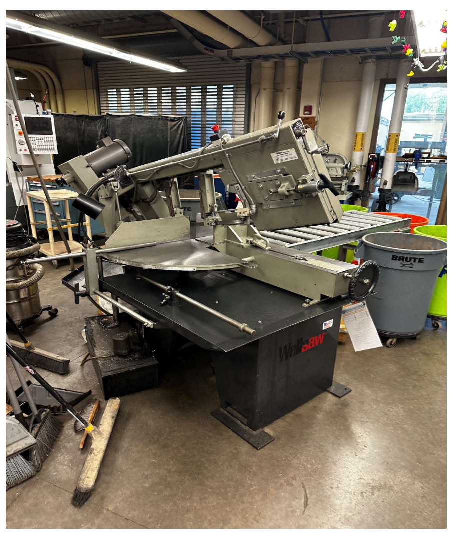


Figure 12. Horizontal Bandsaw

3.2.2 Drilling Manufacturing Processes

The extrusions were drilled to assemble parts that could not use their slots. This included the mounting of the pulleys onto the outside-most vertical beams, where a single 5/16'' hole was drilled to fit a 5/16'' eye bolt to which the pulley could mount. Two 3/16'' holes were also drilled into each non-sliding vertical beam to mount the corresponding linear rails. On the moving bases, a 5/16'' hole was drilled on the two extrusions, one in a 2020 and the other in a 2040, in order to interface the moving base made of 2020 extrusions and the vertical beams made of 1.5'' extrusions. The beam at the end of the fork configuration must also be drilled to attach a pulley using a 5/16'' U-bolt. As for the stationary base, holes were required to mount the horizontal pulley system. This was done through two 5/16'' U-bolts per side, which served as the attachment points for the pulleys. These holes often required post-processing, and some even needed to be milled out. This is due to the variable angle of the U-bolts, which meant varying distances between the holes. All the holes drilled onto extrusions were initialized with center drills, as the non-flat surfaces of the beam made the drill bits wander, and coolant was utilized to avoid deformation. Individual parts of the system that required drilling were the motor mount plate, the linear rail slides, and the caster wheel mounting plates. These were all done on a wood drill press. The linear rail slide drilling gave us several issues, primarily due to poor quality control from the supplier. The 2020 linear rail slides came arched, meaning that it was challenging to fixture them properly. This also meant that the pressure applied to it from the drill press would bend it back straight, but it would try to bow back out during the entire machining process. This made drilling them difficult, as they would chip or flat-out break while drilling. A countersunk hole was also required for them, which would get close to the slot's neck, causing further issues. Thus, the mill was utilized for the 1.5'' sliders to create a slot, eliminating the need for a countersunk hole and placing less stress on the part while machining.

3.2.3 Motor Modification Manufacturing Processes

Modifying the motorized winch to pull from two opposite directions also required manufacturing processes. We started by first unwinding the wire rope wrapped around the cable drum. The next step was to unmount the motor from the motor casing. The components of the motorized winch that required modification were the casing itself and the cable drum. On the portions of the casing that were beside the cable drum, we cut out square sections using an angle grinder, allowing the cables to come out horizontally. The next step involved drilling a 3/16" hole into the drum on the opposite end of where the wire currently comes out from. This will allow us to wrap the wire at the center of its length and have each end come out of a different hole. To separate the drum into two sections for which the wire can spool, we used hose clamps with small metal sheets to create a barrier at the center. The resulting modified motorized winch can be seen below in Figure 13.

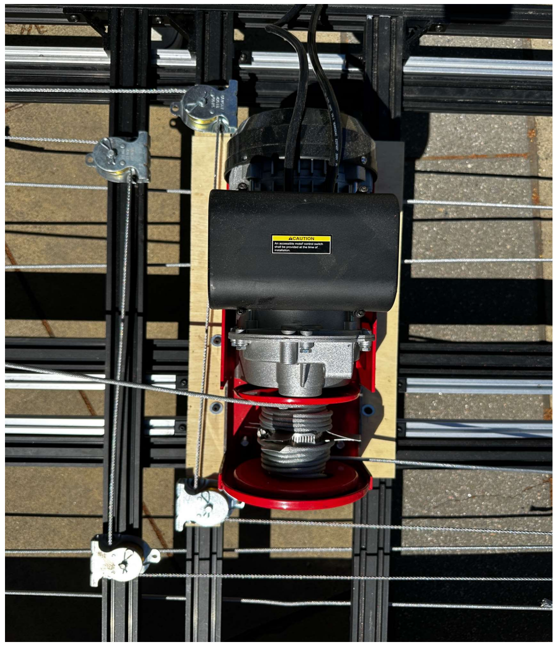


Figure 13. Modified Motorized Winch

3.3 Assembly

The following subsections describe the process of assembling each subsystem.

3.3.1 Stationary Base Subsystem Assembly

The first step of the assembly of any component made of extrusions will be to slide the proper number of slide-in T-nuts into the beams. The improper placement or allotment of them will require disassembly in order to rectify any missing or incorrectly placed ones, thus their placement is a crucial initial step. To connect extrusions to one another, we used corner brackets of three different sizes. These are shown below in Figure 14 with the fasteners they use.

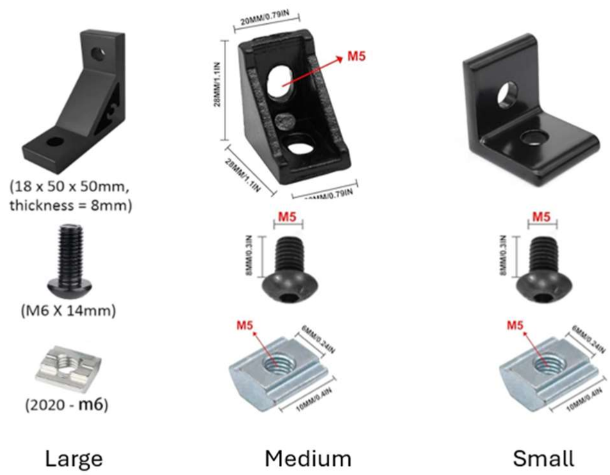


Figure 14. Large, Medium, and Small Corner Brackets with Corresponding Fasteners

All connections involving the large and medium corner brackets are in L-type orientation, whereas all connections involving the small corner brackets are in T-type orientation. The different between these orientations is shown below in Figure 15.

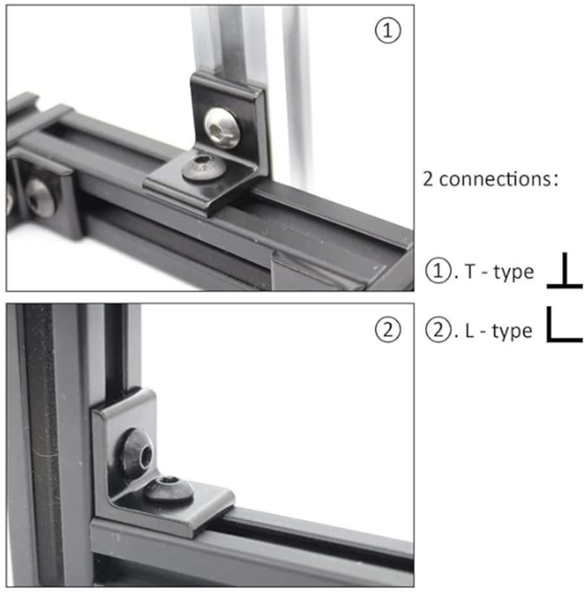


Figure 15. L-Type v. T-Type Connection

To put together the SBS, we first put together the overall rectangular shape with 6ft 2040 extrusions and 1000mm 2020 extrusions. The 2040 extrusions were oriented with the 40mm side going vertically, and we used medium corner brackets to assemble the face of the 2020 extrusion to the top slot of the 40mm side of the 2040 extrusion using an L-type connection. We then added four 6ft 2020 extrusions along the length of the base. These will relate to small corner brackets using a T-type connection to the 2020 extrusions along the width of the base. The placement is dependent on the width of the wheel mounts. Two will be placed a wheel mount width apart from the two outer 2040 extrusions, and the other two will run along the center with the same spacing. Next step was adding 1000mm 2040 extrusions along the width of the base for supporting the pulley mounts and motor mount.

A total of five 2040 extrusions are used with two on each end flush against the corner bracket between the outer corners of the base, two at the center spaced out the distance of the motor. The 2040 extrusions were all placed with the 40mm side laying down flat on the 2020 beams going across the length of the base. Large corner brackets were used to attach the 2040 beams going across the width to the outer 2040 beams, and small corner brackets were placed in T-type to connect the lower support 2020 beams to the 2040 beams. The last 2040 extrusion running along the width is placed to the left of the center extrusions that will hold the motor mount, and it was connected using large corner bracket. Finally, we mounted the motor to the wooden mount, and placed the entire assembled motor with wooden mount on the central motor mount beams, placing it so that the drum was at the center of the base.

The final step in building the SBS was mounting the wheels to the underside of the base. A total of five wheels were used for the SBS, four at each outer corner and one at the very center. First, we needed to make the turntable mounts for the wheels. This involved first attaching the wheels to the wooden caster mounting plate. On this plate, we also attached the turntable bearing. Therefore, our assembled wheels from bottom to top followed the order of wheel, wooden mount, to turntable bearing. The turntable bearings had holes that were used to fasten to the base using screws and T-nuts. Figure 16 below gives an overview of what this looks like.

Figure 16. Assembled Wheel Placements on SBS

Finally, we mounted the motor to the wooden mount, and placed the entire assembled motor with wooden mount on the central motor mount beams, and placed it so that the drum was at the center of the base. The assembled SBS is show below in Figure 17.

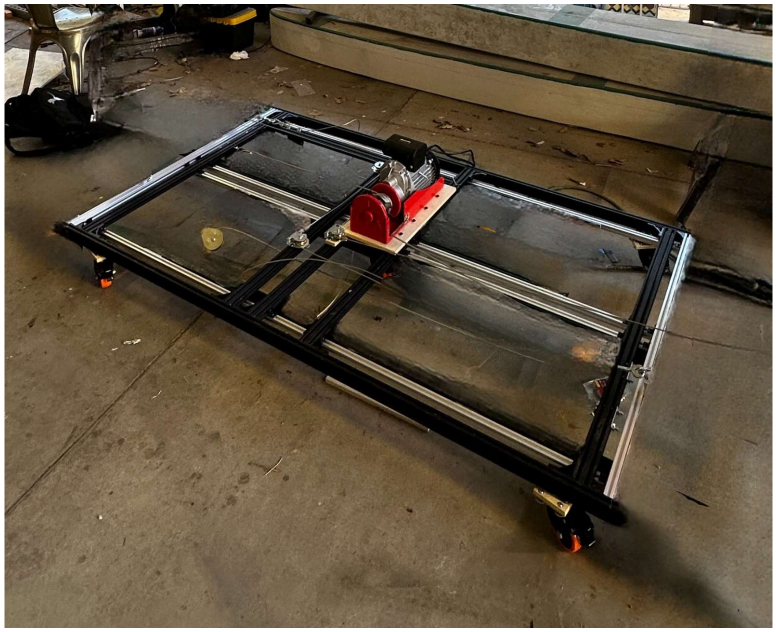


Figure 17. Assembled SBS

3.3.2 Moving Base Subsystem Assembly

To assemble the moving base subsystems, we started off by making the outer perimeter of the base. The 3 outer edges are made with 2040's that have the 40mm side vertically, and the edge that lies against the stationary base is a 2020 beam on the top slot of the 40mm side of the 2040 extrusions, as pictured in Figure 18. Like the stationary base, there will be 2020 extrusions running along the length of the system in order to mount the wheels to, which will be spaced from the 2040's accordingly. Finally, the forks will be placed onto the bottom slots of the 2040 extrusions, running lengthwise into the stationary base. They have mirrored placement on either moving base, so as not cause interference when nested in the stationary base. A 2040 extrusion will be go in between the forks, at the end, with their top-side being flush, and the 40mm side running vertically. A one foot, 1.5'' extrusion will be placed on top of the main portion of the base., utilizing a 5/16'' bolt, running from the bottom upwards. The wheels were then mounted onto this assembly, in the same process as the SBS.

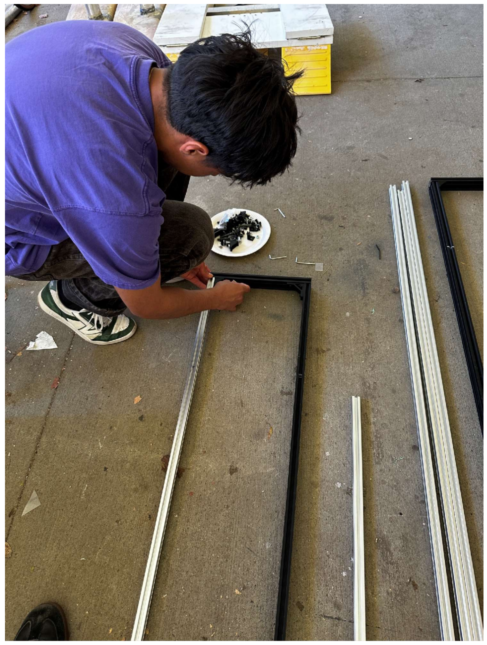


Figure 18. Assembly of the Bottom Plane of the MBS.

The next step will be to assemble the vertical beams separately, as they will attach onto the 1.5'' extrusion once assembled. First, we must place the linear rails at the top of the outer two beams, through the respective holes drilled for attachment. We then attached the linear bearing to the center beam, and then a D-ring is mounted below the linear bearing. This assembly is then slid up, through the bottom of the two outer beams, in a manner that the linear rails, and the linear bearing slides into their respective slots. This assembly was then attached to the mounted 1.5'' extrusion, utilizing four corner plates. The corner plates closest to the outer edge of the system were placed flush with the end, in order to ensure correct placement for the diagonal support and looked like Figure 19. The diagonal support is then placed onto the entire assembly. This is done by first locating the diagonal support with the corresponding hole at the bottom of the base, with a 2040 extrusion being used as a spacer in between the diagonal support and the 2040 extrusion. The top part is then placed in order to obtain the highest placement possible, while still being able to attach the diagonal support to the outermost vertical beam. This entire process will then be repeated for the other moving base.

Figure 19. The Vertical Beams mounted to the rest of the Moving Base Subsystem.

The remaining portion of the moving bases were the two top beams placed horizontally. These were first assembled together, with only one plate of a linear bearing being attached to either the top or bottom beam. This plate will be facing the rear of the system, in order to allow for mounting up front. They are then attached to the middle, vertically sliding beam, utilizing corner plates on both sides of the top beam, and an inner L-bracket between the horizontal and vertical beams. Before fully tightening any bolts, we ensured that the bottom beam does not rest inside the corner plates of the top bracket at the fully contracted position of the set piece, and that the linear sliders are an inch away from the corner plates of the opposing beam. Once this was done, we fully tightened all hardware, completing the assembly of the moving base subsystems.

3.3.3 Horizontal Pulley Subsystem Assembly

To assemble the HPS, we began by fastening a total of six U-bolts at different locations of the SBS. One U-bolt will go at the end of each fork configuration, and two will go along the 2040 extrusions near the end of the SBS in the direction of the fork configuration. Before attaching, we made sure that the U-Bolts and the end of each fork configuration and the U-bolts closest to the center of the base along the 2040 extrusions all had a swivel pulley in place. The U-Bolts on the outer ends all had a turnbuckle in place since they were the end mounting locations for the HPS. Figure 20 below displays the placement of the U-Bolts along the 2040 extrusion, whereas Figure 21 displays the location of the U-Bolt at the fork configuration.

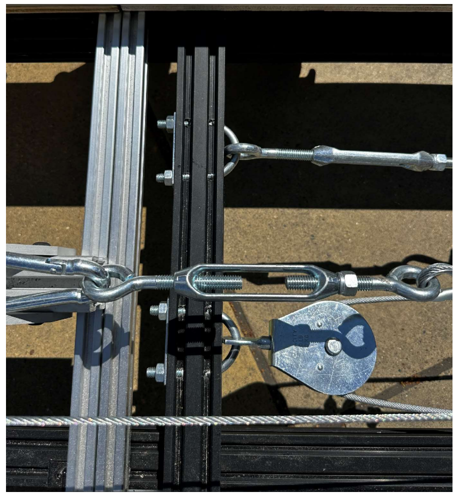


Figure 20. U-Bolts Along the 2040 Extrusion

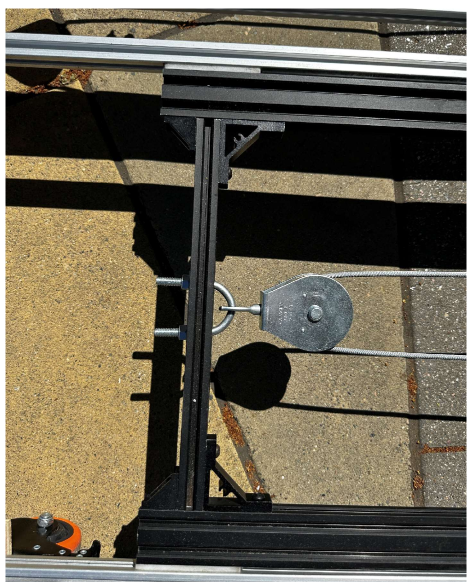


Figure 21. U-Bolt at the End of the Fork Configuration

The next part involved wrapping the wire rope around the pulley from the motor to the end mount at the turnbuckle. To attach to the end mount, we used wire clamps and thimbles to create a tight loop. This is shown below in Figure 22.

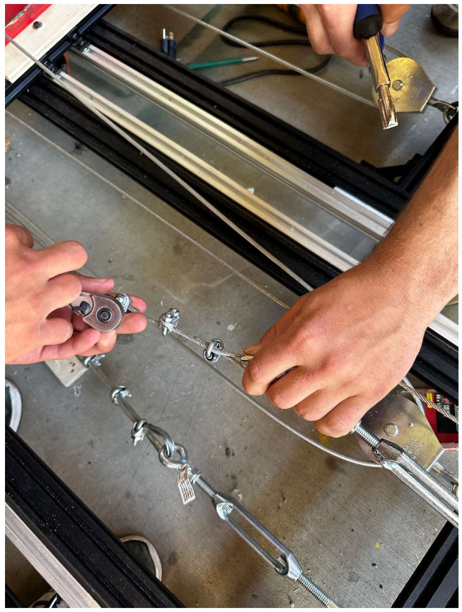


Figure 22. Looping the Wire Rope

Finally, we tightened the turnbuckles to the point of max tension before it would cause the MBS systems to want to roll out of the SBS. The final HPS is shown below in Figure 23.

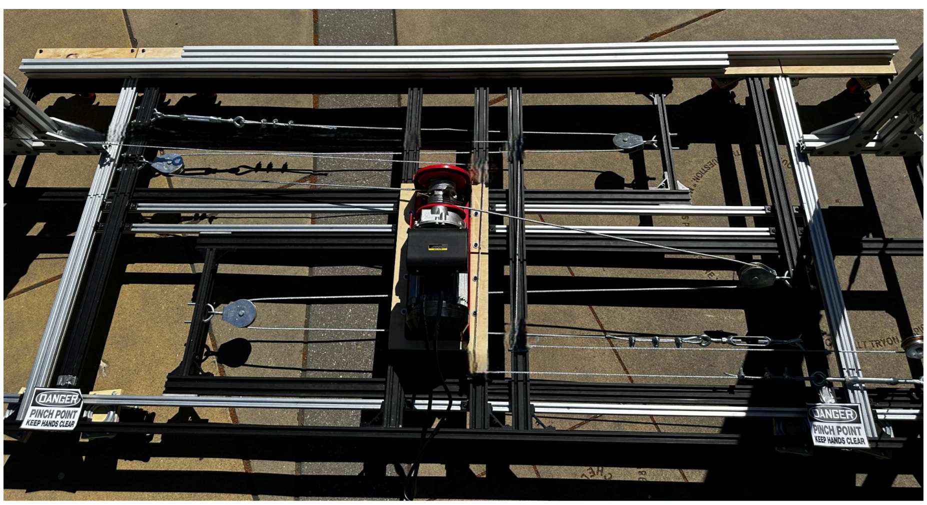


Figure 23. HPS System

3.3.4 Vertical Pulley Subsystem Assembly

The VPS assembly is slightly more complicated than the HPS assembly since both sides are not perfectly symmetrical. To begin the VPS, we first mounted all pull rings, pulleys, eye bolts, and turnbuckles to their corresponding locations. A pull ring was mounted to the bottom end of each vertical sliding extrusion, and it acts as a mounting point for the wire rope. This is shown below in Figure 24.

Figure 24. Pull Ring at Vertical Slider End

At the top of each outer vertical beam, we also added an eye bolt to which a swivel pulley is attached. Figure 25 below displays this. Up until this point, both sides are the same.


Figure 25. Eye Bolt Mount for Swivel Pulley

For the VPS on the lefts side of the system when facing the front, the next pulley mount was placed at the bottom of the diagonal beam. This is shown below in Figure 26.

Figure 26. Left Side Pulley Placement

For the other side, the next pulley is placed directly under the top pulley as shown below in Figure 27.

Figure 27. Bottom Pulley Placement

From there, each pulley system will head to the center of the SBS and zig zag across to the opposite MBS from which the pulley system came from. The pulleys on the SBS are directly mounted to the 2040 extrusions. This is shown below in Figure 28.

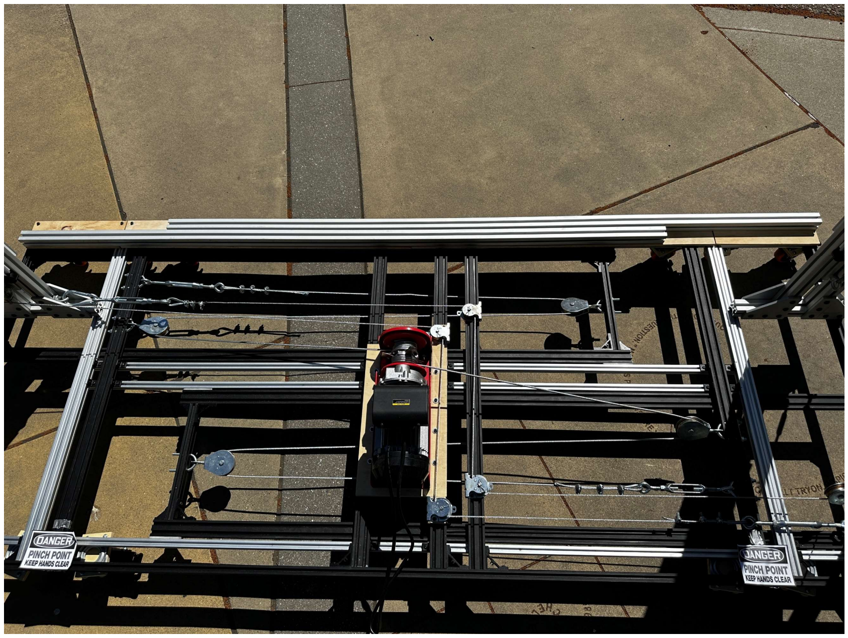


Figure 28. Pulley Systems Entering From Each MBS, Zig Zagging at the Center, and Leading Off to the Opposite MBS

Finally, the wire was wrapped around all the pulleys, and a turnbuckle was placed at the end mount of the VPS. The system was then fully tensioned to the point where the vertical sliding beam will move upward upon any movement of the MBS going outward.

That concludes the assembly of the system. The fully assembled system is displayed below in Figure 29.

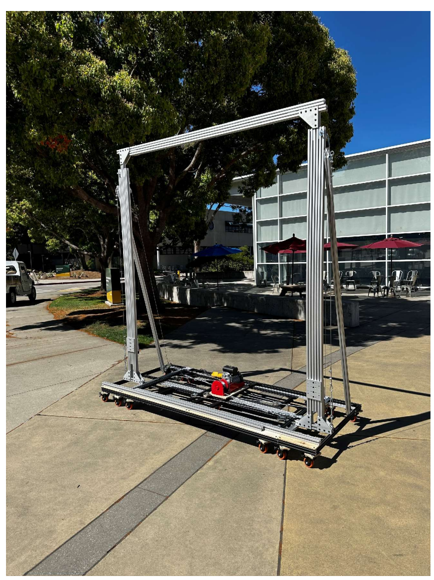


Figure 29. System After Assembly

4 Design Verification

The following section will go over the design specifications and testing performed on the verification prototype to grade its ability to meet our desired specifications.

4.1 Specifications

All the design specifications necessary to meet the desires of our sponsor are listed in Table 1 below. All supporting evidence for this section can be found in Appendix E's Design Verification Plan & Report (DVPR).

Table 1. Specifications List

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Expansion	6 ft H x L	±1ft	H	A, I
2	Initial Dimensions	7.5 ft x 7.5 ft x 4 ft (H x L x W)	±1ft	L	A, I
3	Weight	250 lb.	±100lb	M	A, I
4	Noise	65 dB	Max	L	T, I
5	Cost	$2000	Max	M	A
6	Expansion Time	10 seconds	±2s	M	A, I, T
7	Appearance Survey	7/10	Min	L	I
8	Transport Survey	7/10	Min	L	T
9	Rehearsal/ Operator Survey	7/10	Min	L	I, T

4.2 Testing and Results

The goal of the expansion test was to verify if our system meets the desired size requested by our sponsor. The goal of our sponsor was for the system to double the length and height dimensions. To do this, we measured the unexpanded dimensions using a measuring tape and then obtained the measurements along the length and height after expansion. When measuring the unexpanded dimensions, we got a height of eight feet and two inches and a length of eight feet, all within the target initial dimensions range. When measuring the expanded dimensions, we obtained a height value of twelve feet and two inches and a length value of eleven feet and eleven inches. This was short of the target goal of six feet of expansion because we only expanded roughly four feet along each dimension. Figure 30 and 31 show the team conducting the expansion size test for horizontal and vertical expansion respectively.


Figure 30. Measuring Horizontal Expansion


Figure 31. Measuring Vertical Expansion

Our sponsor set the weight goal to ensure the fireplace would be relatively easy to transport. The target goal set was to be under 250 pounds. To test this, we used corner scales and placed them under the wheels at each corner. Our tests showed that our system was within the target range, weighing 232 pounds. Figure 32 displays the weight test procedure and equipment used.

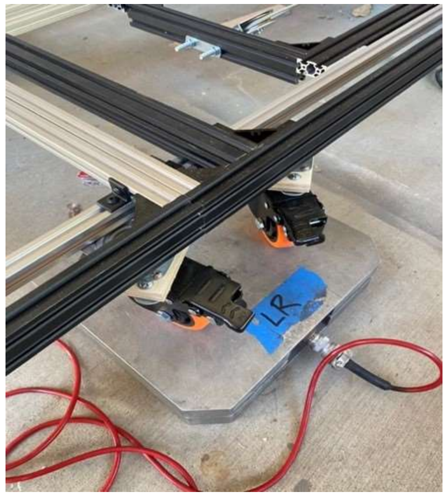


Figure 32. Left Rear Weight Scale for Fireplace

The noise specification was set to ensure that the expansion would not be loud enough for the audience to hear during the production. The goal set for this specification was to be under 70dB when 40 feet away from the fireplace. Someone stood 40 feet away while holding a decibel reader during the expansion process to test this. We were just under the target goal with a peak decibel reading of 64.6 dB. On average, the noise readings were 61.1 dB during the expansion process. The peak reading was mainly attributed to the motor's clicking sound upon initiating and coming to a stop. A screen shot of the smartphone application which measured noise during one of our test trials is shown in Figure 33.

Figure 33. Noise Test Results

The expansion time test was set to ensure that the fireplace could expand within the desired time frame set by the production. Since it will expand at the same time as the expanding Christmas Tree set piece, we needed to ensure that the expansion occurred at roughly the same rates. The goal was to have the expansion happen in under ten seconds. To test this, we conducted multiple trials of timing the expansion process from a fully contracted to an expanded state. Five trials were conducted, and a statistical uncertainty calculation was performed using the collected data. Figure 34 is a photograph of a timing test procedure in progress.

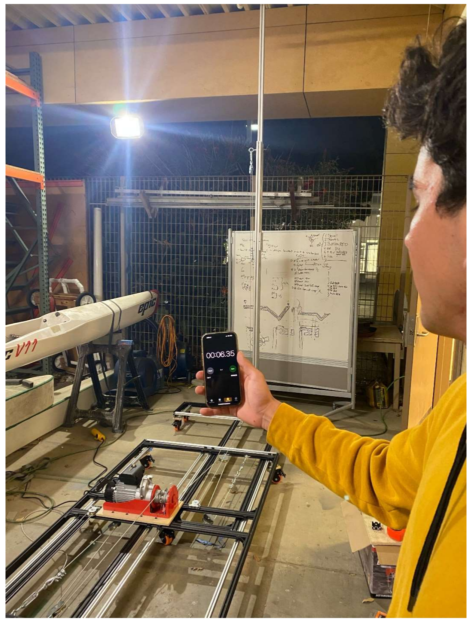


Figure 34. Conducting a Trial of the Expansion Test

The maneuverability test was set to grade the fireplace's ability to move around, which is essential to our sponsors since it will need to make turns, maneuver around obstacles, and rotate in place when moved around the stage and to the storage unit. To test this, we pushed the fireplace from one end of the room to the other while following a random path involving curves and changes of direction. We also rotated the set piece to test its ability to rotate about its center. The last test involved pushing it over a drive-up curb to test its ability to climb over small obstacles. In all cases, the fireplace accomplished the task at hand, giving it passing marks for all tests.

The appearance inspection survey was set to ensure that the overall final assembly had a clean, finished look and met the desired vision of our sponsors. The grading for this inspection was based on the feedback from our sponsors. Being that the final assembly allowed for decoration

Due to an inability to get our verification prototype to the theatre space, we were unable to complete the tests for both the operator/rehearsal survey and the transportation survey. The goal for the operator/rehearsal survey was for our sponsors to conduct the operation process of expanding and contracting precisely as it would in the production. This involves rolling the set piece onto the stage, expanding it in the desired time frame, contracting it in the desired time frame, and finalizing by pushing it off the stage. The goal for the transportation survey was to grade its ability to be loaded into the moving truck, dropped off at the loading deck, and pushed onto the stage.

5 Discussion & Recommendations

The following section will address our observations and recommendations for next steps based on the performance of the verification prototype.

5.1 Discussion

In addressing the performance of our design, several key factors that influence the overall functionality were identified. Through extensive testing and analysis, we observed specific areas where enhancements could significantly improve the system's stability and ease of contraction. The following discussion outlines these areas in detail, providing insights into the potential improvements to optimize the design. Additionally, more drastic steps to significantly change the design's initial dimensions are discussed.

5.2 Recommendations and Next Steps

Throughout the design process, the team recognized that stage weights could be strategically placed on the system during operation to support various design aspects. The DVP requires stage weights at the bottom of each MBS to ensure the outer wheel remains grounded. During testing, we utilized 45 lb rubber plate weights, which were adequate for 4 ft of expansion. However, for more significant expansion, additional weight would be necessary. This requirement arises because the top sliding beams tend to bend towards each other as the system expands, resulting in increased frictional force. Additional weight helps to counteract this leaning tendency.

Improvements can be made to the system's contraction mechanism. In the DVP, the system contracts approximately halfway under its own weight and with the assistance of bungee cords. This process can be enhanced by rearranging the bungee cords to ensure they maintain tension from the fully unexpanded to the expanded state. The team found success by repositioning the cords to different locations, and shorter bungee cords also proved effective. Greater stage weights on the MBS increase the force required to contract the system.

Modifying the initial dimensions of the fireplace presents a more complex challenge compared to the previous adjustments. Dimensioning the system necessitates disassembling the entire structure and cutting dimension-driven beams. As detailed in the Implementation chapter, the assembly and disassembly of the system are not trivial tasks. Nevertheless, it is feasible to reduce the unexpanded size of the entire system.

6 Conclusion

The Final Design Review report focused on capturing the process that transitioned the team toward the completion of the verification prototype, advancing from the structural prototype and Critical Design Review. This transition involved obtaining and processing the required materials as laid out in our manufacturing plan. Apart from the initially proposed development plan, several modifications were implemented that supported the functionality of the project. In order to measure the effectiveness of our design decisions in regard to the specifications set by our sponsors, test procedures were drafted and executed. Ultimately, the finalized verification prototype successfully met the target values set by our specifications. Although the team assembled a quality prototype that satisfied the initial criteria proposed by our sponsors, the development of the Expanding Fireplace proved to be a challenging process. Through this process we managed to adapt to issues that arise during the implementation phase. We are glad to present a safe prototype which can potentially be deployed for theatrical use if recommendations are taken into consideration and the user manual is properly followed.

References

Appendices

Appendix A – User Manual

Required PPE

No special safety equipment is required while operating the system for the play. Gloves are recommended if one is lifting the system into a truck, trailer, etc. for moving long distances.

Operational Steps

Prior to operating the system for the play:

1) Scan the fireplace and ensure that all bolts in the system are properly fastened
2) Verify that the system is in the contracted position by observing if the faces of the moving and stationary bases touch. Tension the pulley system by adjusting the tensioner on the end of each wire rope until you notice that the moving base starts to expand from the tension. Adjust the tensioner so that it has one full revolution of threading before the moving base begins to expand
3) Carefully operate the system to its expanded position and apply lubrication to the sliding components
4) Place weights (45 lbs or more) onto the moving bases above the outside wheels for additional stability so that it is ready to operate in the play

When operating the system for the play:

1) Position the system in the desired location on the stage.
2) Prepare the system for expansion
    a. Chalk or lock the wheels of the stationary base
    b. Align the wheel of the moving base toward the direction of expansion
    c. Ensure the faces between the stationary bases are flush with each other.
    d. Ensure that the area is clear for expansion. This means that all area 4 feet to the left, 4 feet to the right, and 8 feet upward should not obtain any possible obstructions.
    e. Ensure that the motor is plugged in.
    f. Ensure that all supporting weights for the base have been added.
3) When your que comes, hold down the button labeled “expand” until the marked spots on the base align
4) When the curtains are drawn, hold the button labeled “contract” until the surfaces of the moving and stationary base are flush
5) Unplug the electronics
6) Unchalked or unlock the wheels of the stationary base.
7) Push the system off stage

When moving the system long distances (i.e. from storage to the PAC) follow these guidelines:

- Ensure the system is unexpanded, that is the surfaces of the stationary and moving base are flush
- Lift and carry with at least 4 people, 2 in front, 2 in back
- Everyone lift with one hand holding the stationary base and one on a moving base to ensure no sliders are subject to large loads
- Lift with moving straps that go under the stationary base and forks of the moving base

- Avoid any large drops holes or bumps is possible

Repair Procedures
Over time, wire rope may lose tension in both pulley systems from being in a constant state of tension. If this occurs, you can tighten the tensioner on the end of each wire rope by loosening the nuts on both ends and tightening the bolt. You want to ensure that you do not over tension the wire rope either. When tensioning, you will begin with the horizontal pulley system with the fireplace in a contracted state. You will tighten the bolt on the tensioner to the point where you notice the moving base begin to expand outward from the tension. At this point, you will slightly loosen the bolt so that the bases are flush with one another, obtaining the perfect tension for expansion. To tension the vertical pulley system, you will tighten the bolt on the tensioner until you notice the vertical beam begin to move upward. At this point, slightly loosen the bolt until the beam rests on the rubber support, obtaining the perfect tension for expansion.

Appendix B – Risk Assessment

designsafe Report

Application: Fireplace

Analyst Name(s): Fermin Moreno, Eduardo Hernandez, Ben Hoefer, Wilbert Quiterio

Description:

Company: FIRE

Product Identifier: Expanding Fireplace

Facility Location: CAL POLY

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
1-1-1	operator normal operation	mechanical : pinch point pulleys, motor	Minor Unlikely	Negligible		Minor		
1-1-2	operator normal operation	mechanical : unexpected start accidental	Minor Remote	Negligible		Minor		
1-1-3	operator normal operation	slips / trips / falls : trip accidental	Minor Unlikely	Negligible		Minor		
1-1-4	operator normal operation	slips / trips / falls : falling material / object decorations falling, vertical beams failing	Serious Unlikely	Medium		Serious		
1-1-5	operator normal operation	material handling : instability unstable expansion	Moderate Unlikely	Low		Moderate		
1-1-6	operator normal operation	material handling : excessive weight weight of beams suspended at large height	Moderate Unlikely	Low		Moderate		
1-2-1	operator on stage transporting	mechanical : crushing tips over	Moderate Unlikely	Low		Moderate		

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
1-2-2	operator on stage transporting	mechanical : pinch point pulleys/motor	Minor Unlikely	Negligible		Minor		
1-2-3	operator on stage transporting	mechanical : machine instability unstable when pushing around	Minor Unlikely	Negligible		Minor		
1-2-4	operator on stage transporting	slips / trips / falls : slip accidental	Minor Unlikely	Negligible		Minor		
1-2-5	operator on stage transporting	slips / trips / falls : trip accidental	Minor Unlikely	Negligible		Minor		
1-2-6	operator on stage transporting	ergonomics / human factors : excessive force / exertion force needed to push the set piece	Minor Likely	Low		Minor		
1-2-7	operator on stage transporting	ergonomics / human factors : posture Posture when pushing	Minor Likely	Low		Minor		
1-2-8	operator on stage transporting	ergonomics / human factors : lifting / bending / twisting Related to pushing	Minor Likely	Low		Minor		
1-2-9	operator on stage transporting	material handling : instability unstable transportation	Minor Unlikely	Negligible		Minor		
1-2-10	operator on stage transporting	material handling : excessive weight too heavy to push off stage	Minor Unlikely	Negligible		Minor		

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
2-1-1	Design Team transporting	mechanical : crushing	Moderate Unlikely	Low		Moderate		
2-1-2	Design Team transporting	mechanical : pinch point	Minor Unlikely	Negligible		Minor		
2-1-3	Design Team transporting	mechanical : machine instability	Minor Unlikely	Negligible		Minor		
2-1-4	Design Team transporting	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
2-1-5	Design Team transporting	slips / trips / falls : trip	Minor Unlikely	Negligible		Minor		
2-1-6	Design Team transporting	slips / trips / falls : falling material / object	Serious Unlikely	Medium		Serious		
2-1-7	Design Team transporting	ergonomics / human factors : excessive force / exertion	Minor Likely	Low		Minor		
2-1-8	Design Team transporting	ergonomics / human factors : posture	Minor Unlikely	Negligible		Minor		
2-1-9	Design Team transporting	ergonomics / human factors : lifting / bending / twisting	Minor Likely	Low		Minor		

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
2-1-10	Design Team transporting	material handling : instability	Minor Unlikely	Negligible		Minor		
2-1-11	Design Team transporting	material handling : excessive weight	Minor Unlikely	Negligible		Minor		
2-2-1	Design Team normal operation	mechanical : crushing	Moderate Unlikely	Low		Moderate		
2-2-2	Design Team normal operation	mechanical : pinch point	Minor Unlikely	Negligible		Minor		
2-2-3	Design Team normal operation	mechanical : machine instability	Minor Unlikely	Negligible		Minor		
2-2-4	Design Team normal operation	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
2-2-5	Design Team normal operation	slips / trips / falls : trip	Minor Unlikely	Negligible		Minor		
2-2-6	Design Team normal operation	slips / trips / falls : falling material / object	Serious Unlikely	Medium		Serious		
2-2-7	Design Team normal operation	fire and explosions : hot surfaces	Minor Unlikely	Negligible		Minor		

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
2-2-8	Design Team normal operation	material handling : instability	Minor Unlikely	Negligible		Minor		
3-1-1	Dancers/ Performers Bystanding	mechanical : crushing	Moderate Unlikely	Low		Moderate		
3-1-2	Dancers/ Performers Bystanding	mechanical : pinch point	Minor Unlikely	Negligible		Minor		
3-1-3	Dancers/ Performers Bystanding	mechanical : machine instability	Minor Unlikely	Negligible		Minor		
3-1-4	Dancers/ Performers Bystanding	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
3-1-5	Dancers/ Performers Bystanding	slips / trips / falls : trip	Minor Unlikely	Negligible		Minor		
3-1-6	Dancers/ Performers Bystanding	slips / trips / falls : falling material / object	Serious Remote	Low		Serious		
4-1-1	Movers Transporting	mechanical : crushing	Moderate Unlikely	Low		Moderate		
4-1-2	Movers Transporting	mechanical : pinch point	Minor Unlikely	Negligible		Minor		

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
4-1-3	Movers Transporting	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
4-1-4	Movers Transporting	slips / trips / falls : trip	Minor Unlikely	Negligible		Minor		
4-1-5	Movers Transporting	slips / trips / falls : falling material / object	Serious Unlikely	Medium		Serious		
4-1-6	Movers Transporting	ergonomics / human factors : excessive force / exertion	Minor Likely	Low		Minor		
4-1-7	Movers Transporting	ergonomics / human factors : posture	Minor Unlikely	Negligible		Minor		
4-1-8	Movers Transporting	ergonomics / human factors : duration	Minor Likely	Low		Minor		
4-1-9	Movers Transporting	ergonomics / human factors : lifting / bending / twisting	Minor Likely	Low		Minor		
4-1-10	Movers Transporting	material handling : instability	Minor Unlikely	Negligible		Minor		
4-1-11	Movers Transporting	material handling : excessive weight	Minor Unlikely	Negligible		Minor		

Appendix C – Final Project Budget

Number	Item Description	Vendor	Vendor's Part #	Our Part #	Item Cost	Shipping and Tax	Total Cost	How Purchased	Account Used	Date Purchased	Location
1	2000mm T Slot 2020 Aluminum Extrusions	Amazon	2020T	11200	$179.99	$13.05	$193.04	Senior Project Budget	Cal Poly	1/20/2024	Mustang 60'
2	1000mm T Slot 2020 Aluminum Extrusions	Amazon	2020T	11100	$79.99	$5.80	$85.79	Senior Project Budget	Cal Poly	1/20/2024	Mustang 60'
3	2020 Series Profile Connector	Amazon	E2022000011	11500	$23.99	$1.74	$25.73	Senior Project Budget	Cal Poly	3/9/2024	Mustang 60'
4	2020 Heavy Duty Corner Brackets	Amazon	QI-2053	12103	$21.66	$1.57	$23.23	Senior Project Budget	Cal Poly	3/9/2024	Mustang 60'
5	2020 Profile Corner Brackets	Amazon	TGLG-20S-2L	13103	$11.97	$0.87	$12.84	Senior Project Budget	Cal Poly	1/20/2024	Mustang 60'
6	T-Slot Nuts Kit, M5	Amazon	B0B66NNNRT	11400	$13.99	$1.01	$15.00	Senior Project Budget	Cal Poly	1/27/2024	Mustang 60'
7	Caster Wheels 3in	Amazon	CC-PBJL-3	11600	$56.97	$4.13	$61.10	Senior Project Budget	Cal Poly	1/27/2024	Mustang 60'
8	1.5in Swivel Pulleys	Home Depot	44154	15100	$55.79	$4.04	$59.83	Senior Project Budget	Cal Poly	3/13/2024	Home Depot
9	1.5in Mount Pulleys	Home Depot	43364	14200	$37.88	$2.75	$40.63	Sponsor Budget	Sponsor	3/13/2024	Home Depot
10	5/16in U-Bolts	Home Depot	806906	14400	$6.80	$0.49	$7.29	Sponsor Budget	Sponsor	4/10/2024	Home Depot
11	3/8in Eye Bolts	Home Depot	807206	15300	$2.04	$0.15	$2.19	Sponsor Budget	Sponsor	4/10/2024	Home Depot
12	3/8in Turnbuckles	Home Depot	807046	14500	$19.12	$1.39	$20.51	Senior Project Budget	Cal Poly	4/10/2024	Home Depot
13	1/8in Wire Rope	Harbor Freight	61784	14300	$8.99	$0.65	$9.64	Sponsor Budget	Sponsor	4/12/2024	Harbor Freight
14	Electric Hoist 1300lb.	Harbor Freight	62853	14100	$159.99	$11.60	$171.59	Sponsor Budget	Sponsor	4/12/2024	Harbor Freight
15	90in 1515 T Slot Aluminum Extrusions	TNUTZ	EX-1515	13202	$567.60	$100.77	$668.37	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
16	Pull Ring	TNUTZ	PULL-RING	15400	$26.00	$1.89	$27.89	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
17	15 Series 7 Hole 90° Joining Plate	TNUTZ	JP-015-P	13203	$25.20	$1.83	$27.03	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
18	15 Series 5 Hole 90° Joining Plate	TNUTZ	JP-015-H	13206	$39.60	$2.87	$42.47	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
19	5/16-18 Black Button Head Socket Cap Screw 5/8in	TNUTZ	N/A	13204	$9.60	$0.70	$10.30	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
20	Standard T-Nut - 5/16-18	TNUTZ	ST-015	13205	$28.80	$2.09	$30.89	Sponsor Budget	Sponsor	3/6/2024	Mustang 60'
21	15 Series Long - Double Mount Unibearing	8020	6879	13201	$223.12	$16.18	$239.30	Sponsor Budget	Sponsor	4/9/2024	Mustang 60'
22	15 Series T-Slot Insert Linear Bearing Pad	8020	6897	13207	$22.32	$1.62	$23.94	Sponsor Budget	Sponsor	4/9/2024	Mustang 60'
23	20 Series Slider	FrameTech	SLDR06F	11700	$30.00	$2.18	$32.18	Sponsor Budget	Sponsor	4/9/2024	Mustang 60'
	Overall Project Budget	$2,000				Total Amount Spent	$1,830.76				

Appendix D – Design Verification Plan & Report (DVPR)

DVP&R - Design Verification Plan (& Report)											
Project:	Expanding Fire Place		Sponsor:	Bret Clark					Edit Date:	6/7/2024	
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Expansion	Measure the front face in the fully expanded position	Length	5+ ft for both width and height	Tape measure/ladder	None	Ed	5/9/2024	5/23/2024	Expanded Fireplace Measurements: Horizontal Length = 11' 11", Vertical Length = 11' 11" from base height, 12' 5" from floor	Although there is potential for more expansion, we recommend using this length for stability reasons. We are unsure of the effects that the added weight of the decor could have.
2	Noise	Use a sound level meter next to the systems. Also use a sound meter in the closest seeks in the audience in the PAC	Decibels	85 dB max	Sound level meter	Sound Level meter	Ben	5/9/2024	5/23/2024	Average of 61.1 dB, Peak of 64.6dB	The peak sound always occurred when the motor initiated and stopped. Upon initiating and stopping, the motor make a click sound which is the loudest part of the operation.
3	Expansion Time	Time how long it takes for the system to go from unexpanded to fully expanded	Time	10 seconds maximum	Timer	None	Fermin	5/14/2024	5/23/2024	Average expansion time was 6.23 seconds.	All trials were fairly close to one another. Most error in analysis was due to human error caused by reaction time in stopping the expansion at the appropriate distance and starting/ stopping the stopwatch.
4	Transport Survey	Give a survey to Dr. Clark, meat head movers, and others involved in moving the prop to and from meathead movers and the PAC.	Survey	7/10 minimum	Contact with meathead movers	None	Wilbert	5/3/2024	N/A	Not completed. The PAC was unavailable to us, so we were unable to perform this test.	
5	Operator/ Rehearsal Survey	Give a survey to the operator and those who move/directly interact the prop during the show. Provide a survey for them to answer based on the performance of the fireplace and how well it integrates with the production.	Survey	7/10 minimum	Contact with operators	None	Fermin	5/14/2024	N/A	Not completed. The PAC was unavailable to us, so we were unable to perform this test.	

DVP&R - Design Verification Plan (& Report)

Project:	Expanding Fire Place	Sponsor:	Bret Clark		Edit Date:	6/7/2024

TEST PLAN / TEST RESULTS

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
6	Manuverability test	Manuver the prop to simulate the play and other way the system will move	Varies	Varies	Objects and curb	None	Ed	5/14/2024	5/23/2024	Pass	The verification prototype was able to rotate in place, maneuver around obstacles with ease, and complete sharp turns without struggle. This earned it a passing score in all three categories that we tested.
NOT A TEST	Weight	Weight the entire system without the decorations.	Weight	250 lb. max	Large scale	None	Fermin	5/3/2024	5/29/2024	232 lbs	We used corner scales and placed them at the bottom four corners of the verification prototype.
NOT A TEST	Initial Dimension	Measure the front face in the contracted position	Length	7.5 x 7.5 minimum	Tape measure/ladder	None	Ed	5/3/2024	5/23/2024	Horizontal Length = 8ft Vertical Length = 8ft from base height and 8ft 6in from ground height	All obtained using a measuring tape.
NOT A TEST	Cost	Excel sheet to add up all	Cost	$2000 maximum	None	None	Fermin	5/3/2024	6/7/2024	$1,830	Still within budget, especially since $500 was using Cal Poly funds, so only $1,330 of our sponsor's budget was used of the $2000.
NOT A TEST	Appearance Inspection	Give a survey to the stagecraft team to rate how the prop looks before expansion and while expanding.	Survey	7/10 minimum	Contact with stagecraft team	None	Wilbert	5/14/2024	5/29/2024	Pass	Had a clean overall look with decoration attachment points along all the slots on the front face. Sponsors thought it was slightly too tall, however, but they said they can work with it.

Appendix E – Test Procedures

Test Name: Operation Noise Assessment

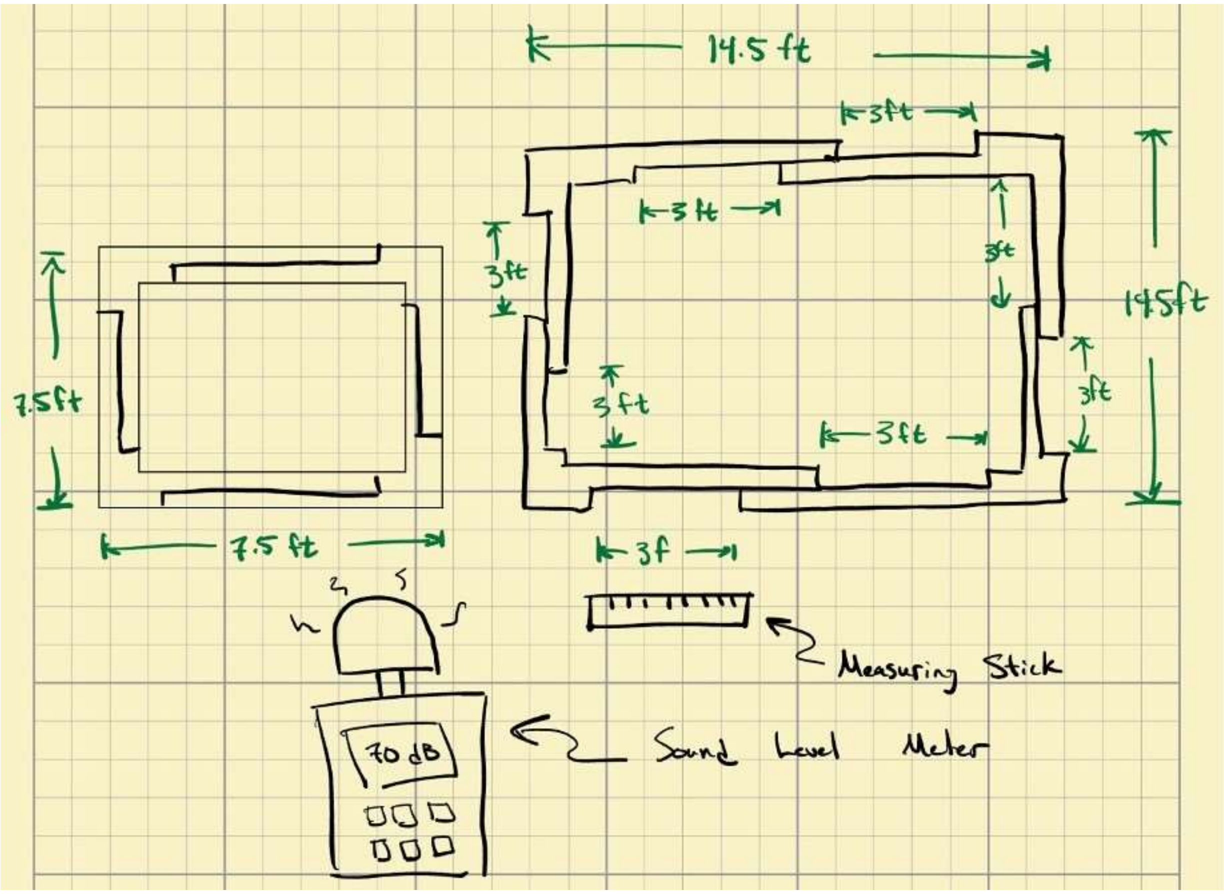
Purpose: This test assesses the noise the system makes when operating on stage. For the prop to be seamlessly integrated into the Nutcracker Production, the expanding fireplace must be quiet enough so the audience cannot notice it.

Scope: The function being tested is "integrating into the Nutcracker Production"

Equipment:

- Sound level meter (application on phone)
- Measuring tape
- Safety glasses

Sketch



Hazards:

- Pinch points
- Tipping

PPE Requirements:

- Safety Glasses
- Normal Shop clothing: long pants, closed toed shoes
- No hanging clothing or hair

Facility:

We will simulate play conditions on the south outdoor area of Mustang ’60. To minimize surrounding noise, we will conduct the test during a passing period Mustang ’60. More details about testing at Mustang ’60 follow in the procedure section.

Procedure:

1) Place the system (in the PAC or outside on the south side of Mustang ‘60) such that there is at least 6 feet of open space to the left and right of the system.

2) Ensure system is “zeroed” by inspecting that all moving faces are touching.

3) Get into position.

3a) One team member will be on the on and off switch of the motor.

3b) One will be next to the outlet ready to pull the plug of the motor.

3c) One team member will be on the front of the fireplace, opposite the motor operator. They must ensure the system doesn’t tip and generally inspect the system as it expands.

3d) One team member will be 40 feet away with the decibel meter in hand.

4) The system will be expanded to full size. A tape measure will be laid out on the ground to reference when full size is achieved, and the motor may be shut off. The member with the decibel meter will measure during system expansion. They shall have the meter set to “maximum” so the meter will display the highest decibel reading over expansion.

5) The motor will be running in reverse with the same positioning of the team members

6) Repeat for a total of 5 trials.

If the test is conducted at Mustang ’60, there will be some ambient noise. If a loud noise happens during the test (likely from the construction in the library or Mustang ’60 shop itself) that trial will be thrown out. We will repeat the trial.

Results:

Pass Criteria

The system expands without a maximum noise level of under 70 dB.

Fail Criteria

The system expands with a maximum noise level which exceeds 75 dB.

Number of samples to test

Five sample tests taken.

Design analysis spreadsheet

Trial	1	2	3	4	5	**Mean,**
Noise	*62.9*	*64.9*	*65.3*	*65.3*	*64.6*	*64.6*

Test Date(s): 5/24/24

Performed By: Fermin, Wilbert

Test Name: Expansion Time Assessment

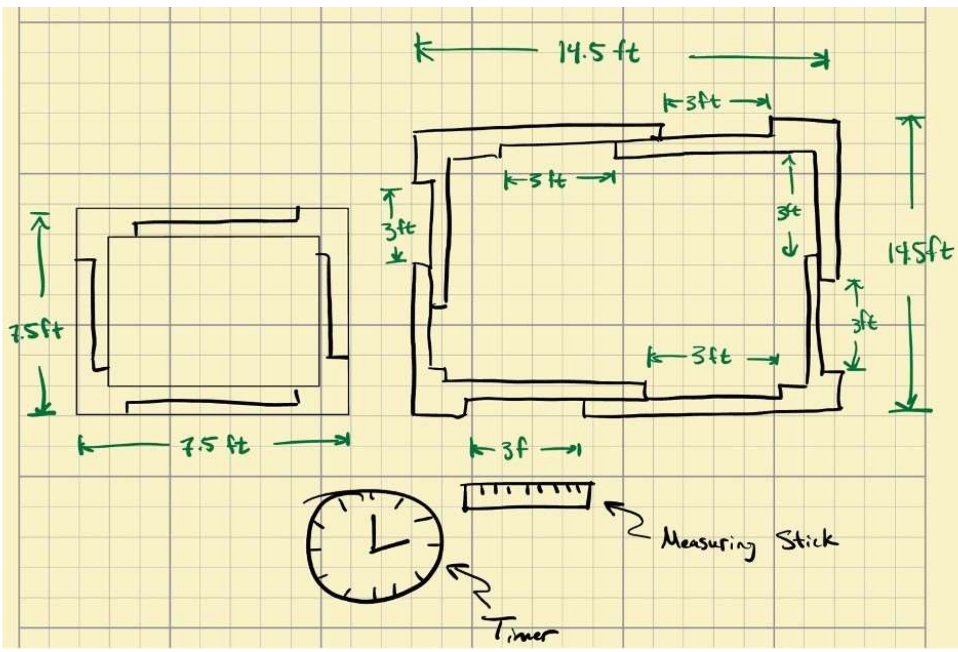
Purpose: To test if our system can expand fast enough (<12 sec) to match our engineering specification. This is to ensure the prop can be implemented into the Nutcracker Production.

Scope: The test is for "Expansion Time" feature.

Equipment:

- Stopwatch (phone)
- Measuring Tape
- Safety glasses
- Work gloves for two member preventing tipping

Sketch



Hazards:

- Pinch Points
- Tipping

PPE Requirements:

- Safety Glasses
- Gloves
- Normal Shop clothing: long pants, closed toed shoes
- No hanging clothing or hair

Facility:

Outdoor concrete pad outside the south side of Mustang 60.

Procedure:

1) Place the system (outside on the south side of Mustang 60) such that there is at least 6 feet of open space to the left and right of the system.
2) Ensure system is "zeroed" by inspecting that all moving faces are touching.
3) Get into position.
   3a) One team member will be on the on and off switch of the motor.
   3b) One will be next to the outlet ready to pull the plug and operate the timer.
   3c) The remaining two team members will be on either side of the system. They must ensure the system doesn't tip and generally inspect the system as it expands.
4) The system will be expanded to full size. The time will be recorded for expansion each trial. Pictures of before and after expansion will be taken.
5) The motor will be running in reverse with the same positioning of the team members
6) Repeat for a total of 5 trials.

Results:

Pass Criteria

The System achieves 6 feet of expansion in both horizontal and vertical directions in 12 seconds or less.

Fail Criteria

The system doesn't reach 6 feet of expansion in both horizonal and vertical direction in 12 seconds or less.

Number of samples to test

Five sample tests taken.

Design analysis equations/spreadsheet with uncertainty

Trial	1	2	3	4	5	**Mean, μ**
Time	*6.23*	*6.17*	*6.18*	*6.35*	*6.27*	*6.24*

Uncertainty calculation will be performed by the following equation. Our goal is to have an uncertainty of less than +/- 1.5 seconds.

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^\wedge 2}{n}}$$

n = 5

Trial	1	2	3	4	5	Mean, μ
Time	6.23	6.17	6.18	6.35	6.27	6.24
$(x_i - \mu)$^2	0	0.005	0.004	0.012	0.001	

$\sigma = 0.074$ seconds

Our uncertainty is well below our goal.

Test Date(s): 5/24/24

Performed By: Fermin, Wilbert

Test Name: Operator/Rehearsal Survey

Purpose: Assess how the system integrates into the production

Scope: The function being tested is “integrating into the Nutcracker Production”

Equipment:

- Fireplace Set Piece
- Safety Glasses

Hazards:

- Pinch Points
- Tipping

PPE Requirements:

- Safety Glasses
- Long Pants and Closed-toed shoes
- No hanging clothing or hair

Procedure:

1) Have the operator simulate the play at the PAC
2) Questions: Rate the following on a scale from 1(poor) to 10(excellent)
    a. The process of positioning and preparing the prop before the play.
    b. The process of expanding the system during the place
    c. The process of contracting the system and moving it off stage during the break

Results:

Pass Criteria
An average score above 7/10 and no score lower than a 5/10

Test Date(s): 6/02/24

Test Results: We weren’t able to access the PAC so this test wasn’t conducted.

Test Name: Transportation Survey

Purpose: Assess how difficult the set piece is to move onto, around, and off the stage

Scope: The function being tested is "transportability."

Hazards:

- Pinch Points
- Tipping

***Warning labels will be present on the fireplace as a cautionary measure

PPE Requirements:

- Safety Glasses
- No hanging clothing or hair

Facility: Mustang 60 – Room 108

Procedure:

1) Unload the fireplace from the moving truck onto the PAC unloading deck
2) Have the operator move the set into the PAC from the unloading deck outside of the PAC
3) Move the fireplace onto the stage from the PAC backstage.
4) Remove fireplace from the stage
5) After the procedure, survey operators on Google Forms: Rate the following on a scale from 1(poor) to 10(excellent)

a. The process of taking the set piece of a moving truck.
b. The process of moving the set piece into the stage, navigating around other set pieces and obstacles.
c. The process of removing the set piece from set in the required time.

Results:
Pass Criteria
An average score above 7/10 and no score lower than a 5/10

Test Date(s): 6/02/24

Test Results: This test wasn't completed due to not being granted access to the PAC

Test Name: Maneuverability Test

Purpose: Verify that the fireplace set piece can be maneuvered around, be moved into and out of an area slightly smaller than its own dimensions, and maneuver over a small curb/elevation change.

Scope: The function being tested is "maneuverability"

Equipment:

- Fireplace set piece
- Movable obstacles (boxes)
- One inch curb
- Stopwatch

Hazards:

- Pinch Points
- Tipping

***Warning labels will be present on the fireplace as a cautionary measure

PPE Requirements:

- Safety Glasses
- No hanging clothing or hair

Facility: Mustang 60 - high bay and side yard

Procedure:

1. Position the fireplace in the center of the Mustang 60 High Bay.
2. Construct a small area with movable objects roughly 3 inches of clearance on every dimension of the fireplace set piece.
3. Maneuver the fireplace set piece into and out of the space as quickly as possible, while timing the time it takes.
4. Rotate the fireplace set piece 90 degrees once out of area, then stop the timer.
5. Roll over small curb/obstacle placed down.

Results:

Test Aspect	Result Evaluation
Maneuver into/out of designated area	Pass
Rotate 90 degrees	Pass
Roll over small obstacle	Pass

Test Date(s): 5/20/24

Performed By: Ben, Fermin, Wilbert, Eduardo