Design and Construction of a Tilting Platform in a Wind Tunnel for Wildfire Testing

A Major Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
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Abstract

The purpose of this project was to create a tilting platform that could be used in the wind tunnel in the UL Fire Protection Engineering Performance Lab at Gateway Park. This was completed by designing a lift mechanism that allowed the platform to elevate to multiple angles, while utilizing non-combustible materials that could last through testing in the tunnel. The lift mechanism required the use of a hydraulic that could support the weight of the platform and any materials that may be used for testing up to an incline of 15 degrees. The platform also had to be designed so that the components would not interfere with the tunnel's airflow. The innermost edge of the platform had to be designed with a hinge that could also support the weight of the platform and two people who may be working on the platform in its horizontal position. This section must also be able to withstand the heat of the burner that is located adjacent to the end of the platform.

Acknowledgements

Our team would like to thank Professor Albert Simeoni for his guidance in organizing our project and assisting in our design process. We would also like to thank Doctor Reza Ziazi, Frederick Brokaw, and others in the Fire Protection Department at WPI for their guidance and assistance in the structural design features of the wind tunnel and our design. We would additionally like to thank Diane Poirier for her assistance in ordering materials and scheduling lab times.

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1.0 Introduction

Evidence has shown that there has been an overall increase in the intensity of wildfires relative to the steady rate of the number of wildfires since 1983 (National Interagency Fire Center, 2023). The increase in size, and rate at which these fires occur has increased their unpredictable nature, making them difficult to contain. In 2022, the US government spent over $3.5 billion to aid in preventing and combating wildland fires (National Interagency Fire Center, 2023). Thousands of firefighters are deployed to California, Washington, and Canada among other locations to limit the devastations these fires cause (Mass.gov, 2023). If more research is conducted on the spread and effects of wildland fires, it may help fire departments to better deploy resources and be able to manage and suppress these fires more effectively.

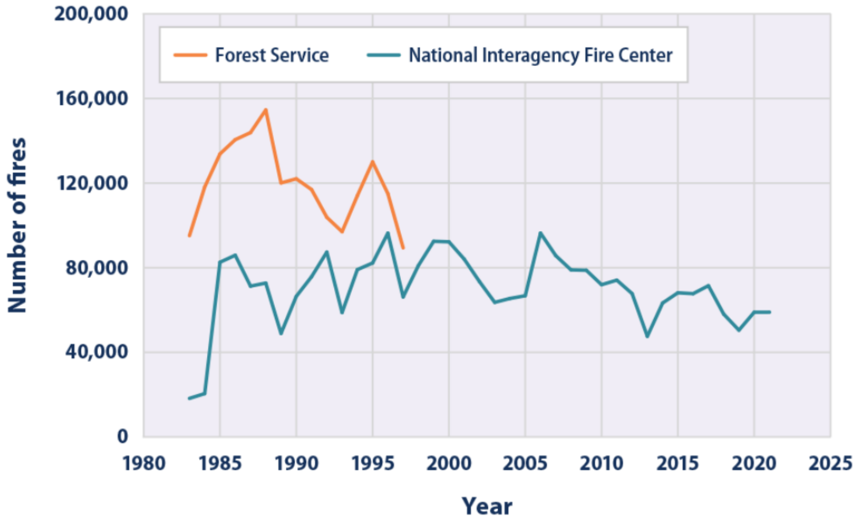

Figure 1: Frequency of Wildfires in the United States (1983-2022) Two Curves are presented in this figure and the next that represent two agencies that tracked data on Wildfires

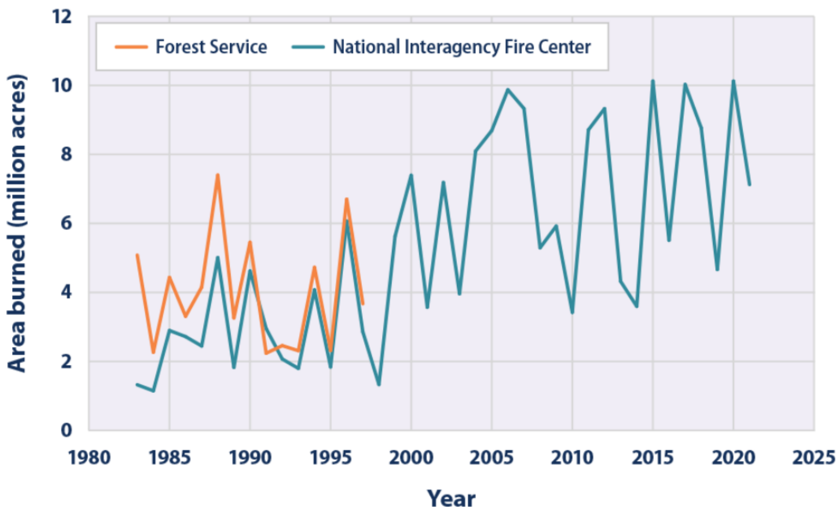

Figure 2: Area burned in Wildfires in the United States (1983-2022)

Wildfires have also become a large contributor to global climate change (California Air Resources Board, 2023). Climate change will continue to worsen if more resources are not allotted for research and fire prevention efforts. Recently, regions in Hawaii, California, and other places around the world have lost entire neighborhoods, and communities due to rapidly spreading wildland fires. Two main contributing factors that affected wildfire growth in these situations were wind velocity and the topography of the land.

The Fire Protection Engineering (FPE) Department at Worcester Polytechnic Institute (WPI) currently houses a large-scale wind tunnel intended to simulate wildfires. This diverges from the conventional applications of wind tunnels, where airflow is directed at an object to analyze its aerodynamic properties. The full-size wind tunnel at WPI has been used for many different research purposes, with a primary focus being on the behavior of wildfires under certain wind conditions. With only a handful of laboratories with similar testing capabilities in the country, the FPE wind tunnel is unique and plays an important role in furthering wildfire research (Grimes, 2018). These tests are currently limited to a flat, fixed platform like the one shown below in Figure 3.

Figure 3: Fire-Testing in the FPE Wind Tunnel

The researchers in the WPI Fire Protection Engineering department are expanding into testing the wildfire spread on sloped surfaces, which this Major Qualifying Project (MQP) intends to facilitate. In addition, to this MQP, the FPE department plans to reconstruct the test section of the wind tunnel. During this remodel, the wind tunnel will have an open jet configuration ,replace the unstable framing that is currently in place, and add a door to access the inside of the testing section. The open jet configuration refers to the plan of swapping the current permanent roof with a removal one. By making this change the pressure inside of the wind tunnel will not be compromised. When the platform is at an angle the crossed section area of the wind tunnel testing segment is reduced causing a decreased airflow and increased pressure experienced inside the wind tunnel. The updated design of the test section frame can be seen below in figure 4. After its construction is complete the FPE department will characterize the fluid dynamic behavior of the wind tunnel and conduct preliminary fire tests with the tunnel. By working through these steps, it is the goal of the FPE department to help accomplish the study of wildfires under realistic wind and different slope conditions.

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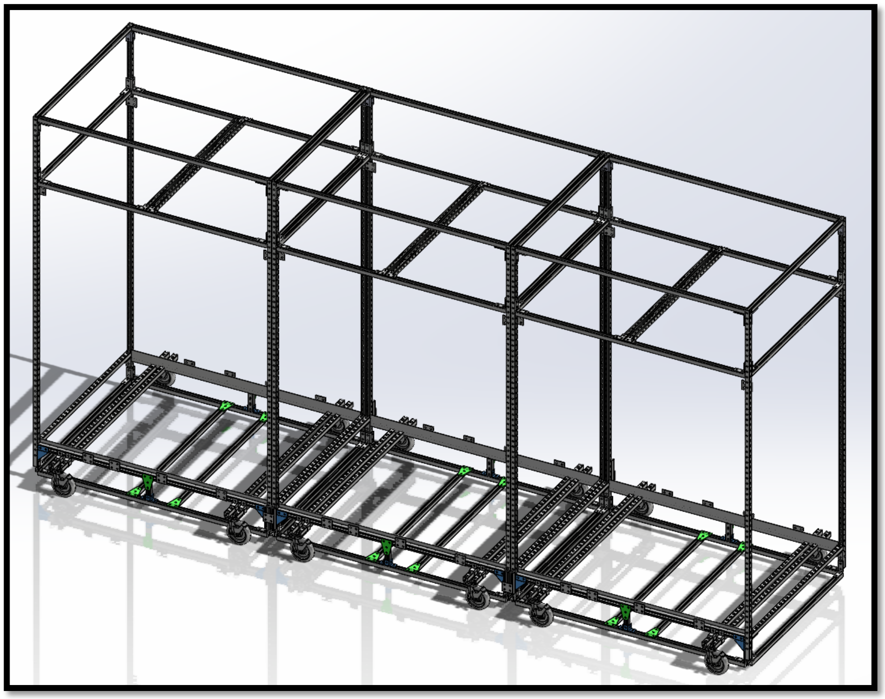

Figure 4: Design of Wind Tunnel Frame Renovation

2.0 Project Scope

2.1 Existing Conditions

The WPI Fire Lab currently has a wind tunnel that they use for various testing. The tunnel is steel construction with Unistrut framing on the bottom that has wheels secured to it for easier transportation and setup. The tunnel is also modular and is set up in sections that measure 39.5 inches in length, and 59.5 inches in width. There are a total of five sections set up this way as well as the wooden conditioning section between the testing section and steel fan section. This conditioning section contains a honeycomb like structure which helps adjust the flow of wind to be near uniform once it reaches the inlet of the testing section. We will not be adjusting any parts of the current conditioning section or fan section. In all five of the testing sections, the ceiling, the floor, and one wall are steel sheets, and one wall is constructed of fire-rated glass which acts as a viewport into the tunnel. Annotated images displaying the tunnel and some of its general dimensions are shown in Figures 4 and 5. Figure 4 is a side-view of the tunnel which shows the side with the glass view port. Figure 5 shows the inside of the tunnel, along with its dimensions. These dimensions will be explained further in other sections. The current floor is also shown in Figure 5. The current floor of each section is steel, which matches the tunnel construction, however there is a second, removeable platform which is constructed of wood and gypsum boards. This floor is currently used for any testing that takes place within the tunnel and remains stationary (no tilting or adjusting).

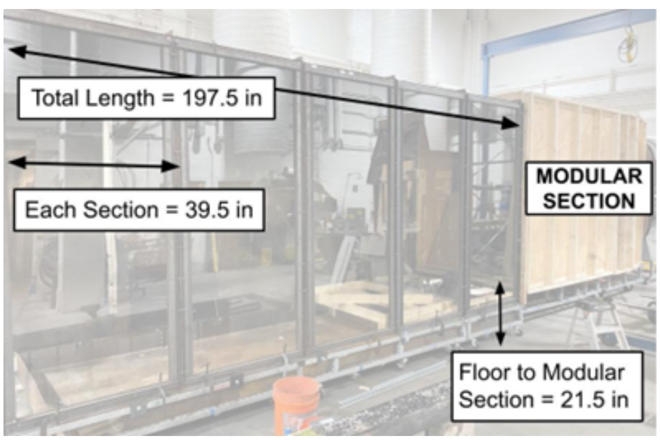

Figure 5: Side-view of the wind tunnel.

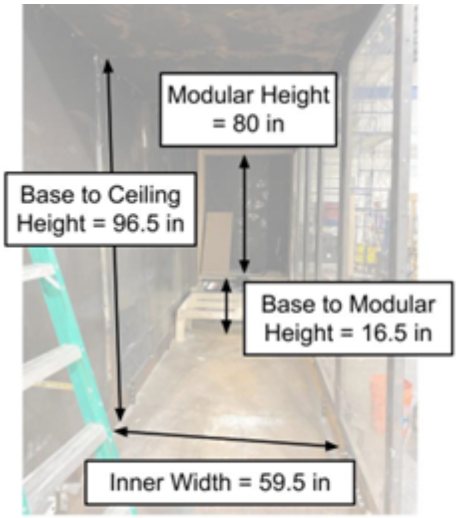

Figure 6: Front-view of the wind tunnel with the interior dimensions

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Dimensions of Wind Tunnel	
Length	197.5 in
Width	59.5 in
Height from floor of tunnel to ceiling	96.5 in
Height from platform to ceiling	80 in
Floor of tunnel to conditioning section	16.5 in
Floor of lab to conditioning section	21.5 in
Length of each testing section	39.5 in

Table 1: Dimensions of wind tunnel in the WPI fire lab.

2.2 Project Goal

The goal of this project is to design and build a tilting platform for the FPE wind tunnel. Replacing the current gypsum and wood platform with a more technical and versatile alternative that allows for more types of testing as well as providing a more permanent solution.

To meet the project requirements, the platform must:

I. Be able to tilt from 0 degrees up to 15 degrees, in increments of 5 degrees.
II. Not interfere with the airflow of the wind tunnel.
III. Be insulated such that no or little heat transfer occurs during tests between the test section and the underside of the platform.
IV. Be able to support the weight of two people while at 0 degrees for testing set-up.
V. Be able to perform multiple tests between routine maintenance.
VI. Be removable from the tunnel by lab staff.

To achieve these goals, we must create a platform that is light enough to be removable, while maintaining good structural integrity, and with the appropriate materials to withstand the long-term effects of fire testing.

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3.0 Design Process

3.1 Constraints and Modifications

Much like any engineering design project, there were several different iterations of this design that we had created over the course of the MQP. This happened due to design flaws, advisor suggestions, and changes in parameters. Throughout the project, there was a total of six design iterations, including our final design. Our initial iterations focused on being cost-effective while still creating a durable design. It is important to note that between iterations 3 and 4 the project parameters underwent a substantial revision enabling us to engineer an improved design. The two pivotal changes were a budget increase from $1,000 to $10,000, and the decision that all materials used must be non-combustible. As a result, we focused more on a durable and effective design with a higher budget and designed for more permanent, long-term use.

3.1.1 Design Iteration 1

The first design iteration of the platform was constructed of wood. Our main goals for this initial design were to be as cost-effective as possible, while also meeting the initial requirements. We were first advised to use wood to construct the platform. During this phase, the platform was required to be under a weight of 300 pounds and to be modular so that it could be taken in and out of the wind tunnel with ease. The design was modeled after a deck, with large vertical boards traveling the length under the platform, similar to an I-beam. There were also several cross-members that supported the long boards and gave more stability to the platform design, to prevent torsion. The top, or the deck, of the platform was designed to be constructed of plywood along with several small boards that would travel along the top of the deck across widthwise. These boards provide further stability; however, their main purpose was to allow for sand to be poured into these areas. This prevents the sand and burning material from sliding down the platform while at an angle. This is labeled in Figure 7.

The major issue with this iteration is that it was designed from a combustible material. Our design plan was to protect the wood with a fire-rated insulating barrier to prevent damaging the platform and any combustible material unrelated to the test from affecting the test data. Using gypsum board to protect any areas on the platform that would be exposed to fire. Over time, the gypsum board would break down and need to be replaced after a handful of tests. Additionally, the wood may be damaged by fire, and by screws when re-attaching new gypsum boards. Overall, this option did not provide a long-term, low-maintenance solution to the problem, and was decided to not be used. Figures 7 and 8 show the CAD drawings of this design, along with the basic dimensions and a label showing where the samples and sand would have been placed.

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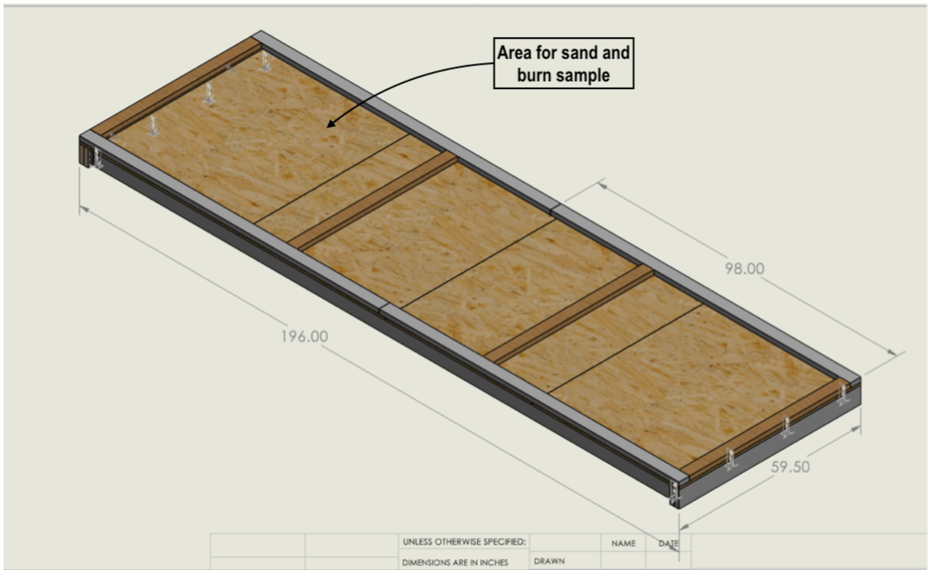

Figure 7: CAD drawing of Iteration 1 platform - top view

Figure 8: CAD drawing of Iteration 1 platform - bottom view

3.1.2 Design Iteration 2

The second design iteration had more of a focus on the lifting mechanism and utilized a similar platform design to iteration 1. There is a large overhead crane in the FPE lab that we planned on using to lift the platform; similar to the one shown below in Figure 9. We planned to use a hook that the crane could attach to and then hoist the far end of the platform to reach the desired angles. One concern that became apparent was the smoke rising to the ceiling would pass over the hoisting mechanism of the crane, and smoke seeping into the mechanism could cause damage which would be unsuitable for long-term use. Aside from potential damage risks by using this mechanism of lifting for the platform, it would also affect the data being produced, because the chain or wire affixed to the end of the platform would disturb airflow within the tunnel. Additionally, the crane is not feasible to hold the structure up in a permanent position during the duration of a fire test and guarantee safety in the lab. For these reasons, we moved away from the idea of using the crane to hoist the platform.

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Figure 9: Overhead Gantry Crane

3.1.3 Design Iteration 3

Our third design iteration was also focused on the design of the lifting mechanism while still being cost-effective and utilizing whatever we could from the lab. This third iteration design was to utilize a forklift that was already in the lab. This is a small stacker forklift and it is rated to lift up to 4000 pounds, which is more than adequate for the intended use. The plan was to have the forklift blades slide under the platform, and then lift the far end to achieve 15 degrees of inclination. However, the blades needed to be flipped upside down to achieve the full height needed to reach 15 degrees. This configuration can be seen in Figure 10 below. The issue with this lifting mechanism is the initial height of the configuration, which is 22.5 inches. The distance from the floor to the surface of our platform to be flush with the wind tunnel is 21.5 inches. Since the blades would be taller than this in their initial position, it would not be possible to get them oriented underneath the platform to lift it safely and effectively. The primary safety concern with this design is that the supports for the platform could not be feasibly attached to the platform at all times, similar to the safety concerns of Iteration 2.

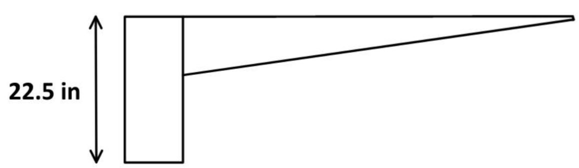

Figure 10: Profile of Forklift Blade Drawing

3.1.4 Design Iteration 4

After finishing iteration 3 of the platform and lifting design, the total available budget had been increased by the FPE department. This unexpected budget change prompted us to create a more durable and more effective design. The fourth iteration of the design does this. It involves the use of a hydraulic system to lift our platform, as well as a new design for the platform which uses metal, instead of wood.

The platform frame was designed to be constructed from 80/20 extrusions which would be light enough to lift with our mechanism and could be removed by the lab staff. We also found that a good lightweight option to cover the top of our platform is vermiculite, as it is lighter than metal and has good thermal insulation. We then purchased a sample piece of 1-inch-thick vermiculite, which after testing under a load, fractured. See figure 11. This led to our conclusion that the vermiculite would not be able to support the weight of two people.

Figure 11: Broken Vermiculite

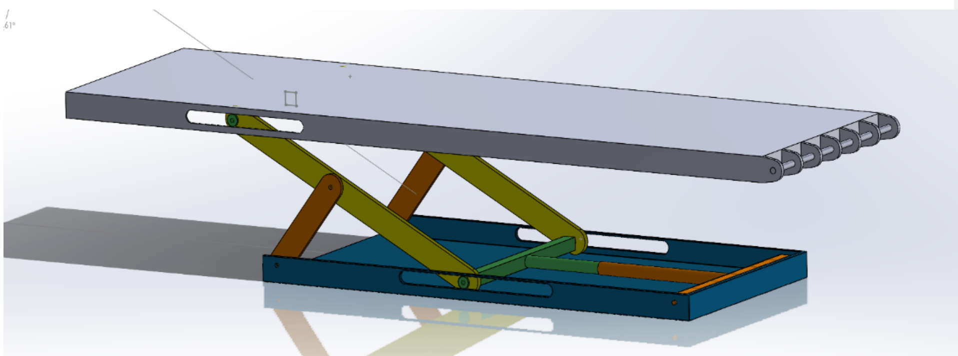

Figure 12: First design of lift mechanism.

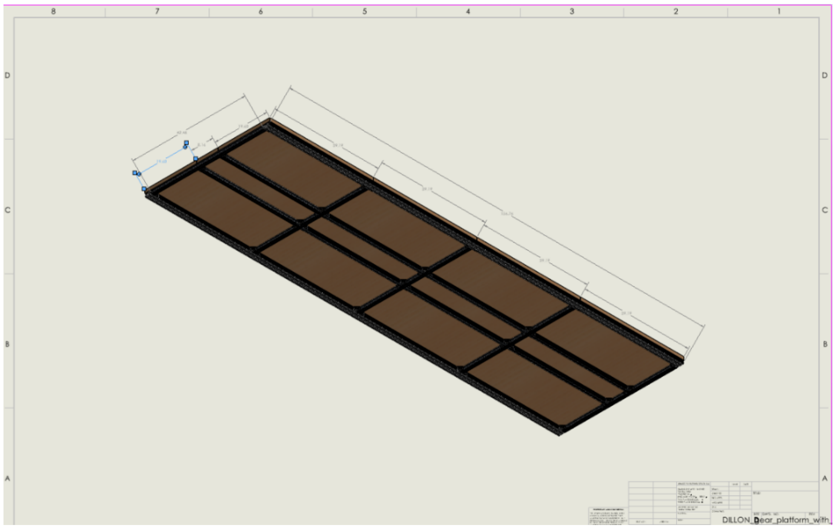

Figure 13: CAD drawing of underside of iteration 4 design.

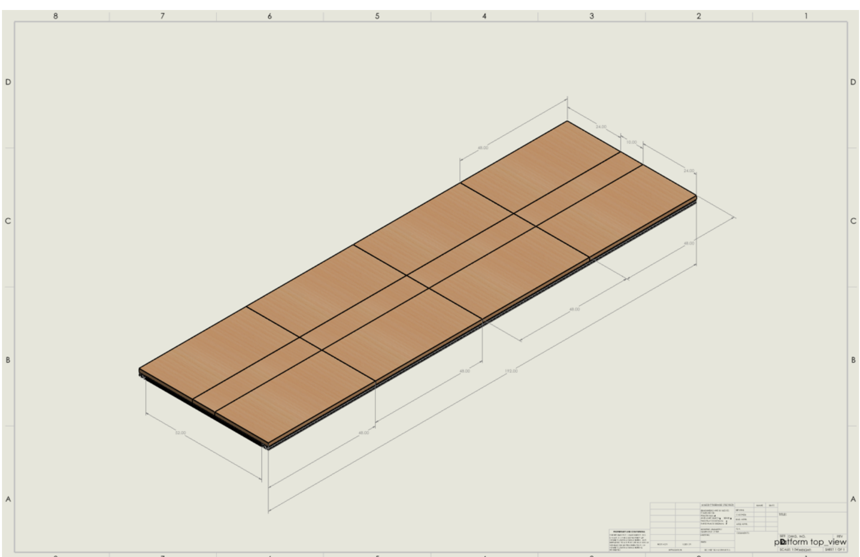

Figure 14: CAD drawing file of top of platform.

3.1.5 Design Iteration 5

The fifth iteration of the platform design contains a different type of structure material, but a similar layout. This model goes back to using Unistrut for the frame, and sheets of 6061-Aluminum on the top of the frame for structural integrity. There were 2 of these sheets to each cover half of the length of the platform, at 96 inches each. We ran a simulation in SolidWorks, applying a uniform distributed load of 2,000 pounds across the entire platform. The results from this simulation are shown below in Figure 15. Further information regarding the finite element analysis (FEA) process can be seen in Appendix B.

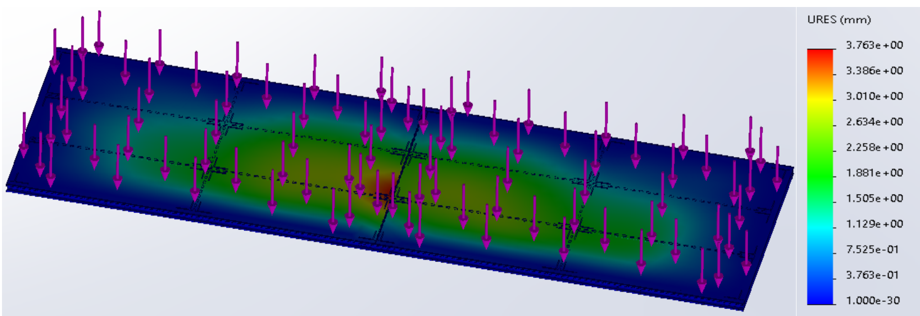

Figure 15: SolidWorks Simulation with Maximum Deformation of 3.763 mm

This shows that the sheets of 6061-Aluminum can withstand well over the necessary weight for a person standing on the platform and any materials being burned. While it holds up the weight needed, each aluminum sheet would cost upwards of $400, and would weigh over 100 pounds each. For these reasons, we decided against using these sheets in our final design.

3.2 Final Design

3.2.1 Platform Design

The final design of the platform incorporates many design aspects of previous iterations. It is to be constructed from 1-5/8" galvanized steel Unistrut members. Following all the previously discussed constraints, the platform is 16 feet long and 5 feet wide. Overall, this configuration of the platform requires 150 feet in length of Unistrut, though an additional 10% in length of Unistrut should be purchased to account for potential mistakes that may be made in the construction process.

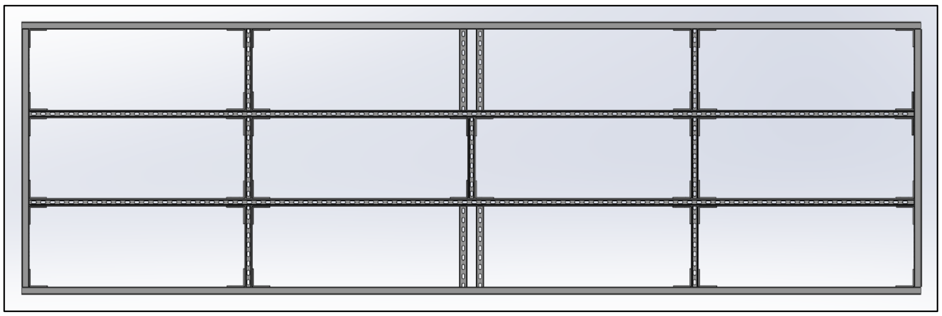

Figure 16: Final platform design, constructed of Unistrut members.

This design of the platform uses 48 L-shaped brackets to attach all the members together. Additionally, the end of the platform closest to the burner section will be attached to a structure using 4 Unistrut hinges. One of the primary benefits of utilizing Unistrut is that it is highly customizable. As such, there are many other types of connections that may be useful in constructing the frame of the platform. For additional structural support that may be needed in certain areas, U or Z-shaped brackets may be useful.

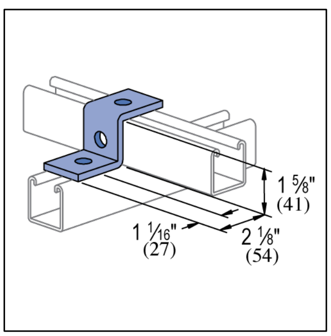

Figure 17: Z-Shaped Unistrut Bracket

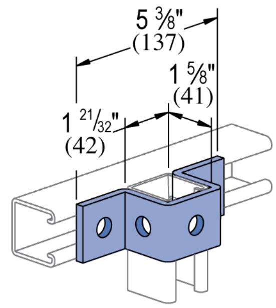

Figure 18: U-Shaped Unistrut Bracket

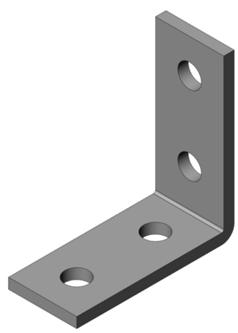

Figure 19: L-Shaped Unistrut Bracket

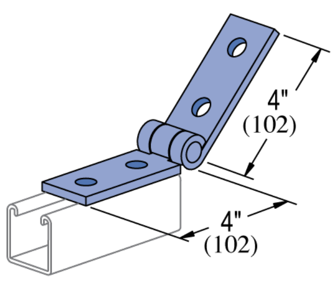

Figure 20: Unistrut P1354 - Adjustable 4-Hole Hinge

3.2.2 Platform Surface

The final design of the platform also saw the addition of cement boards as a replacement for the aluminum which would cover the top of the platform. The cement board is a much more cost-effective solution that also serves as an adequate thermal barrier with enough structural strength to support the weight of two people and the testing components. With just the lower, thicker layer of cement board, the platform will be able to support 200 pounds, which is enough for one person to stand on the platform and place the second layer of cement board. When the second layer of cement board is placed, the platform can hold up to 500 pounds. The deformation simulations can be found in Figure 23. Cement boards, such as the ones our team utilized from Hardie Backer, are commonly used as a component for 1-hour rated fire barrier assemblies. For the purposes of the tilting platform, it was decided that the full assembly required to reach the 1-hour rating of the fire barrier was not necessary, as burning tests in the wind tunnel do not last longer than 5 minutes, on average.

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Board Thickness	K-Value	R-Value
0.25 inches	7.80 $\frac{Btu}{ft^2 \cdot h \cdot °F}$	0.13 $\frac{ft^2 \cdot h \cdot °F}{Btu}$
0.5 inches	20.0 $\frac{Btu}{ft^2 \cdot h \cdot °F}$	0.05 $\frac{ft^2 \cdot h \cdot °F}{Btu}$

Table 2: Thermal Properties of Cement Board

Board Thickness	Compressive Strength	Flexural Strength
0.25 inches	7,000 psi	2,000 psi
0.5 inches	6,500 psi	1,700 psi

Table 3: Mechanical Properties of Cement Board

The platform's surface will consist of two layers of cement board, the bottom layer being 0.5 inches thick and the top 0.25 inches thick. The bottom layer of the cement board would be fastened to the platform's frame, but the top layer would rest on the bottom layer, supported by friction, and pressed against the burner section to keep it from sliding when the platform is angled. With the boards having a friction coefficient of 0.8 between them, it would take a considerable amount of force to move the boards, which is unrealistic in the lab. Having the thinner boards unsupported on the top layer allows them to be easily replaced after repeated testing. The 0.25-inch-thick cement boards weigh about 1.9 pounds per square foot of area, while the 0.5-inch-thick boards weigh about 2.6 pounds per square foot. In total, the surface of the platform will weigh about 360 pounds. With the given arrangement of the boards, each of the top pieces will weigh 28.5 pounds for the 3 by 5-foot sections and 9.5 pounds for the 1 by 5-foot section, both of which can be easily moved around in the lab. The figures below display the configuration of the cement boards on each layer. By overlapping the boards in an offset fashion, we can limit the amount of air and heat that may travel through the small gaps between boards.

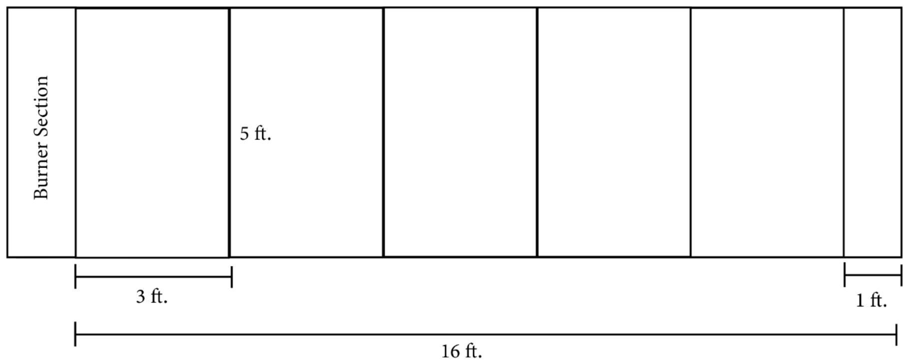

Figure 21: Configuration of the top layer of cement boards.

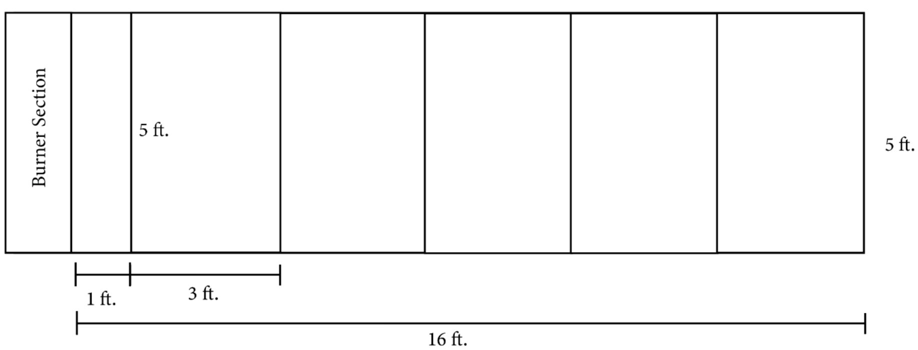

Figure 22: Configuration of the bottom layer of cement boards.

3.2.3 Static Analysis of Platform

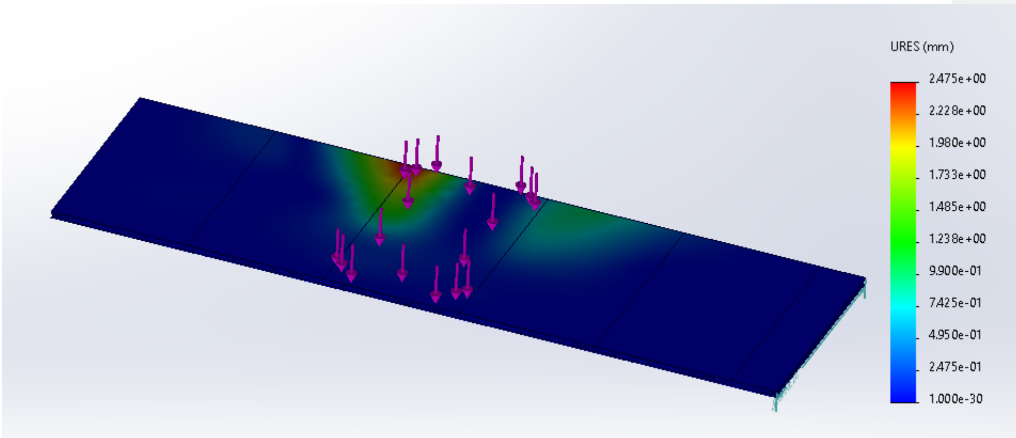

Figure 23: SolidWorks Simulation with Maximum Deformation of 2.475 mm (First Layer of Cement Board)

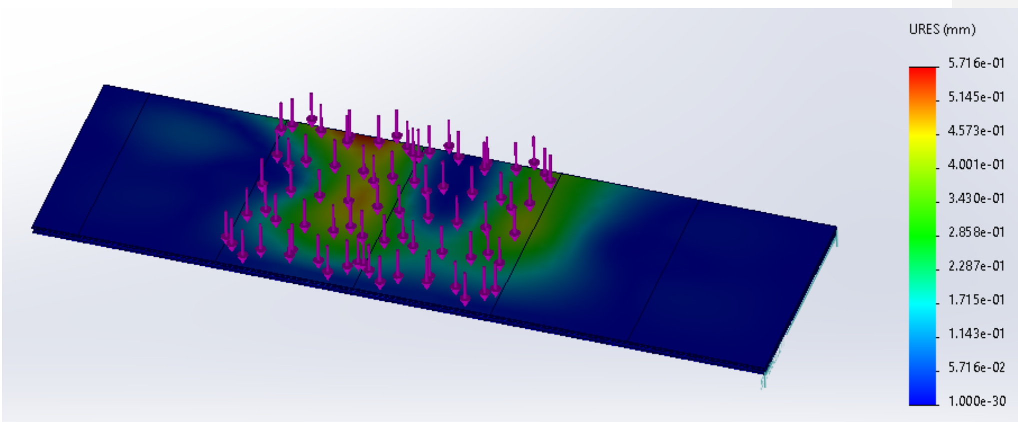

Figure 24: SolidWorks Simulation with Maximum Deformation of 0.572 mm (Both Layes of Cement Board)

The static analysis of the platform with the bottom layer of the cement board is shown above. This analysis was conducted with only the first 0.5-inch layer will have to support the weight of a person who enters the wind tunnel to place the second layer of cement board on top when setting up the fire tests. The first simulation applied a load of 300 pounds on the center piece of cement board; this load was intentionally placed 20 inches from the 16 foot edge where the maximum deformation is seen above. The reason for this placement is because it is expected that someone will not only be in the center of the platform. Additionally, the cement board that the force was applied to is not symmetrically placed over the framing due to the far end of the cement board having to be only a foot wide instead of the standard 3-foot-wide piece. The analysis resulted in various deformations indicated by the deformation scale, and the asymmetrical deformation focused on the areas highlighted by green and red in the figure are due to the placement of the load and the cement board itself. The results are not significantly concerning because the 300-pound load applied is an overestimate of how much weight will be on the platform at once. The next simulation in Figure 24 shows how the platform with both layers deform less than with the one layer, even with an increased load of 500-pounds. The information to create the successful mesh for the simulation can be found in Appendix C.

3.2.4 Lifting Mechanism Design

The lifting mechanism used in the final design of this project utilizes a hydraulic piston. This piston is attached to a joint underneath the platform which allows the hydraulic to pivot at that point while lifting the platform. Our team determined that a hydraulic piston (Figure 25) with a stroke length of 30 inches is required to push the arms of the lift far enough to reach the desired incline of 15 degrees. This hydraulic system will be powered via a DC power unit with a split hose for the purpose of simultaneous lifting. More specifications of the hydraulic cylinder and pump can be found in Appendix E.

Figure 25: MAXIM Hydraulic Cylinder: 30 in Stroke Lg, 40 1/4 in Retracted Lg, 3570 lb., 1 1/4 in Rod Dia.

Figure 26: MAXIM Hydraulic Power Unit: 1.3 gpm, 2,500 psi Max. Pressure, 0.75-gal Reservoir Capacity, 12V DC

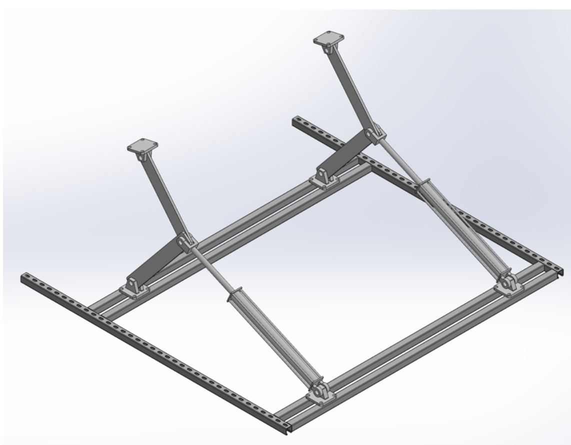

Figure 27: Hydraulic scissor lift design (Note: lengths of the Unistrut members are not to scale)

The figure above shows the assembly of the hydraulic scissor lift in its entirety. In this figure, the Unistrut members are not to-scale, as the lift system is designed to be able to be incorporated directly into the new design of the wind tunnel, shown in Figure 4. The two arms of the scissor lift are .5-inch-thick steel bars. The lower of the two bars are 24 inches in length and 3 inches in width. The upper bars are 21 inches in length and 3 inches in width. All the bars used to construct the arms have a hole 1.5 inches from each end that is 1 inch in diameter, where a clevis pin would be used as a pivot for the platform and the arms.

To allow the hydraulic piston and the scissor arms to pivot, clevis pins with a 1-inch diameter should be used at each of the joint locations. However, to attach the arms to the platform and the hydraulic to the wind tunnel structure, an additional part is needed. Six mount pieces, such as the one shown in Figure 28 should be used to allow for the pivoting movement of the lift assembly. These mounts have a 0.5-inch gap between both upward supports that allow the scissor arms to fit securely, without risk of horizontal motion. The mounts have a 1-inch diameter hole to insert a clevis pin for rotation.

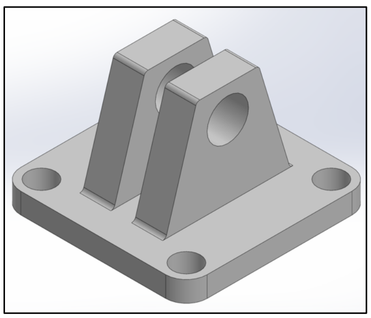

Figure 28: Mount piece used to attach the arms and hydraulic to the platform and tunnel

4.0 Conclusions

In conclusion, there was not enough time to construct the entire platform, however we have organized a list of materials to purchase, as well as a final CAD model to use to assist in constructing the platform later, so that there is the opportunity for fire testing on an incline. The final design for the mechanism, as well as the intended design for the reconstruction of the frame of the wind tunnel use Unistrut parts. This was intentional to aid in the ease of integration between these two structures.

An additional improvement that could be made is for the platform to be able to achieve greater angles of incline. The current design was unable to achieve more than 15 degrees of incline, because if it were to go past this, the end of the platform would hit the ceiling of the wind tunnel. This could potentially damage the structure of the wind tunnel, and as the platform gets closer to the ceiling, the more difficult it is to take temperature measurements at the end of the wind tunnel due to the lack of space available. If the platform were shorter in length, or if the ceiling were modular or could increase in height without comprising the strength of the structure, greater angles of incline could be achieved.

Currently, the platform can achieve an angle of incline with a constant slope. This is not always the case in a real-life situation; topography is not typically a perfect slope and can have slopes that increase or decrease in their angle of incline. If different sections of the platform could achieve various angles of incline to achieve a non-constant slope, this could open the opportunity for a wider variety of fire testing.

Figure 29: Final CAD Assembly of Tilting Platform

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Appendix A: Bill of Materials

Item	Description	Link	Cost (ea.)	Quantity	Cost
Hydraulic Cylinder	Lifting Mechanism	MAXIM30inch	$373.10	2	$746.20
0.25" Cement Board	Platform	HardieBacker	$11.85	14	$165.90
0.5" Cement Board	Platform	HardieBacker	$14.85	7	$103.95
20' Unistrut	Framing cut down to 16' sections	UnistrutOhio	$102.96	5	$514.80
5' Unistrut	Framing across width	UnistrutOhio	$22.98	8	$183.84
Unistrut L-Bracket	4-hole fitting	Unistrut Ohio	$3.75	52	$187.50
Unistrut Hinge	4-hole hinge	UnistrutOhio	$17.42	6	$104.52
Hydraulic Hose	Connects pump and cylinder	Grainger	$384.07	1	$384.07
Hose Fittings	To connect hoses to hydraulic cylinder and pump	Grainger	$8.81	4	$35.24
Hydraulic Pump	12V DC Power	Grainger	$990.46	1	$990.46
				TOTAL	**$3,416.48**

Table 4: Bill of Materials

Appendix B: Finite Element Analysis of Static Structures

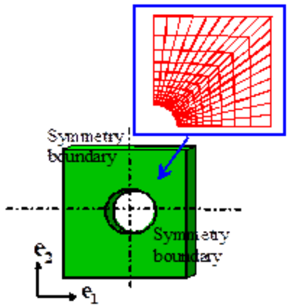

Figure 30: FEA Mesh Example

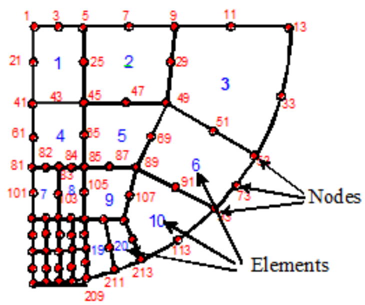

Figure 31: FEA Mesh Elements and Nodes

A plane stress FEA mesh is used to model a plate like solid which is loaded in its own plane. The solid must have uniform thickness, and the thickness must be much less than any representative cross sectional dimension. A plane stress for an FEA mesh containing a hoe is shown above, and an example of nodes and elements associated with those nodes used to specify positions of a three-dimensional object are shown next to it. By constricting the degrees of freedom on the edges of the plates on the top of the platform, an FEA analysis was successfully conducted to determine the deformation from a uniformly distributed force applied on the surface of the plates.

Appendix C: Unistrut P1000T Beam Loading

Beam Loading - P1000T						
Span (in)	Max Allow. Uniform Load (lbs)	Deflection at Uniform load (in)	Uniform Loading at Deflection			Lateral Bracing Reduction Factor
			Span/180 (lbs)	Span/240 (lbs)	Span/360 (lbs)	
24	1,437	0.06	1,437	1,437	1,437	1.00
36	961	0.13	961	961	765	0.94
48	723	0.22	723	646	425	0.88
60	578	0.35	553	408	272	0.82
72	476	0.50	383	289	187	0.78
84	408	0.68	281	213	136	0.75
96	357	0.89	213	162	111	0.71
108	323	1.14	170	128	85	0.69
120	289	1.40	136	102	68	0.66
144	238	2.00	94	68	51	0.61
168	204	2.72	68	51	34	0.55
192	179	3.55	51	43	NR	0.51
216	162	4.58	43	34	NR	0.47
240	145	5.62	34	NR	NR	0.44
Note	NR - Not Recommended					

Figure 32: P1000T Beam Loading and Deflection

Appendix D: Final Design Platform SolidWorks Mesh

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	6.66416 in
Minimum element size	0.333208 in
Mesh Quality	High
Remesh failed parts independently	Off

Table 5: Mesh Information

Total Nodes	898233
Total Elements	448814
Maximum Aspect Ratio	35.207
% of elements with Aspect Ratio < 3	13
Percentage of elements with Aspect Ratio > 10	10.7
Percentage of distorted elements	2.06
Time to complete mesh(hh;mm;ss):	00:00:53
Computer name:	HL230-22

Table 6: Mesh Details

Appendix E: Hydraulic Cylinder Dimensions and Specfciations

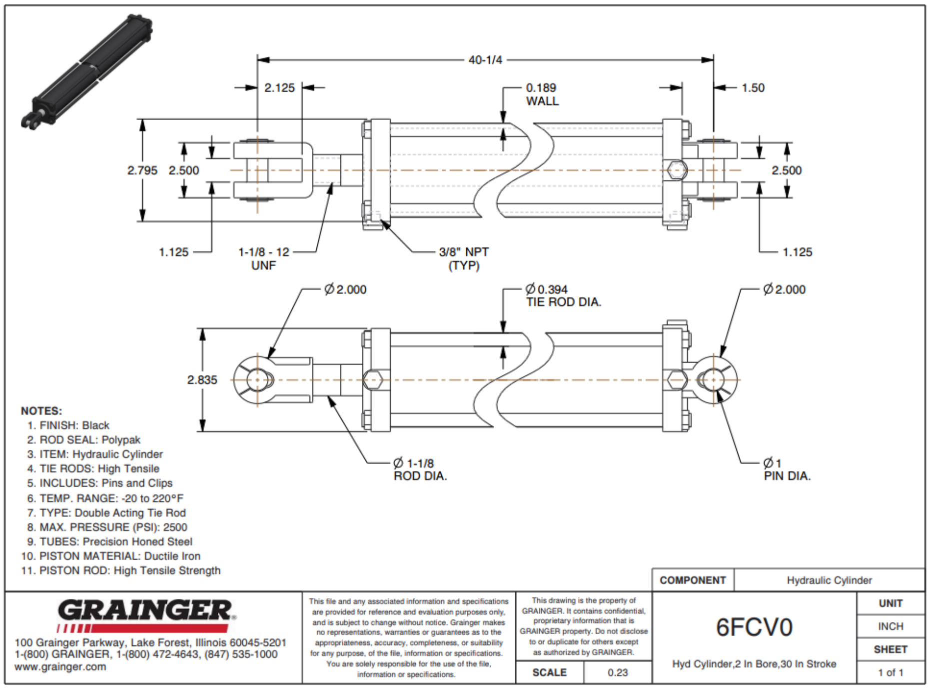

Figure 33: Grainger Hydraulic Dimensional Drawing

Product Details

Catalog Page **2360**

Brand **MAXIM**	Rod Thread Size **1-1/8"-12**
Cylinder Style **Tie-Rod**	Temp. Range **-20° to 220°F**
Duty Rating **Standard Duty**	Piston Material **Ductile Iron**
Bore Dia. **2 in**	Tube Material **Precision Honed Steel**
Stroke Length **30 in**	Tie Rods **High Tensile**
Max. Pressure **2,500 psi**	Rod Seal Type **Polypak**
Retracted Length **40-1/4 in**	Finish **Black**
Rod Dia. **1-1/4 in**	Includes **Pins and Clips**
Port Size **3/8 in NPT**	Pin Dia. **1 in**
Single Acting/Double Acting **Double Acting**	UNSPSC **27121602**
Column Load **3570 lb**	Country of Origin **China (subject to change)**
Extended Length **70-1/4 in**	

Product Description

Standard-duty tie-rod hydraulic cylinders are double-acting steel cylinders rated to 2500 psi. They are slightly smaller than heavy-duty cylinders. They provide power in both push and pull directions, allowing for more precise positioning than single-acting cylinders. The hard chrome-plated case-hardened steel rod provides smooth movement and a long service life.

Figure 34: Grainger Hydraulic Product Details

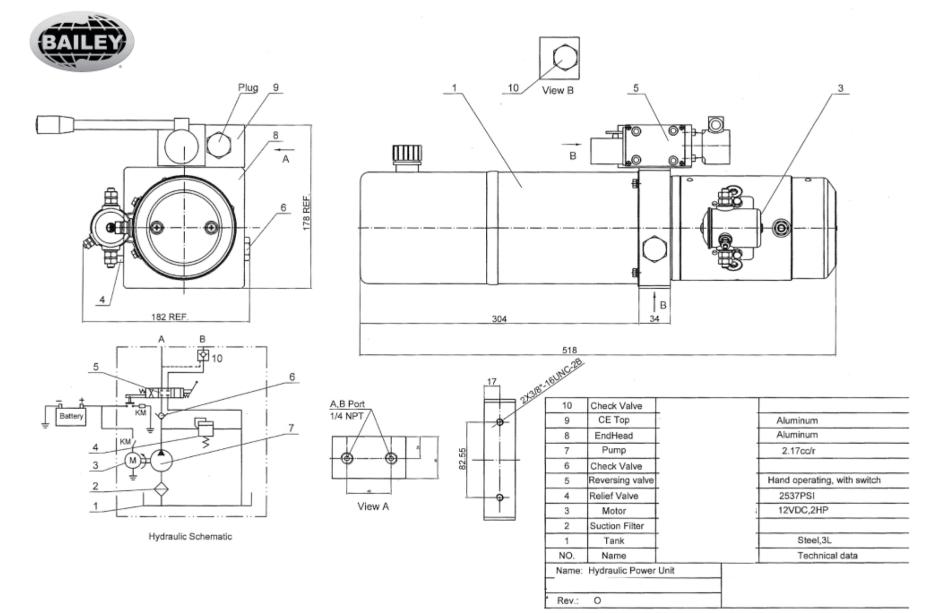

Figure 35: Grainger Hydraulic Pump Drawing

Product Details Catalog Page 2356

Brand **MAXIM**	Flow @ 3000 psi **1.3 gpm**
Manufacturer Part Number **253109**	Duty Cycle **Intermittent**
Frame Design - Hydraulic Power Units **Frame Mount**	Reservoir Capacity **0.75 gal**
Circuit Design **Double Acting**	Overall Length **20-1/2 in**
Power Source - Power Units **DC Power**	Overall Width **9 in**
HP **1.6 hp**	Overall Height **7-1/2 in**
RPM **2,600 RPM**	Mounting Orientation - Power Units **Horizontal**
Voltage **12V DC**	Pressure Port Thread Size **1/4 in NPT**
Full Load Amps **325**	Return Port Thread Size **1/4 in NPT**
Pump Displacement **2.1 cu- in/rev**	Control Valve Configuration **4-Way/3-Position**
Max. Pressure **2,500 psi**	Control Valve Type **Manual**
Nominal Flow **1.3 gpm**	Tank Material **Steel**
Flow @ 500 psi **2.5 gpm**	Cord Length **10 ft**
Flow @ 1000 psi **1.3 gpm**	Built-In Features **Check Valve**
Flow @ 1500 psi **1.3 gpm**	UNSPSC **39121004**
Flow @ 2000 PSI **1.3 gpm**	Country of Origin **China (subject to change)**
Flow @ 2500 psi **1.3 gpm**	

Figure 36: Grainger Hydraulic Pump Details