Tensile Testing Environmental Chamber – Structural

Senior Project Final Design Report
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Statement of Disclaimer

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Abstract

Environmental chambers for tensile testing machines are used to study how a multitude of materials behave in extreme temperatures. These chambers provide the necessary information to innovate cutting edge technology for materials in fields such as aerospace. These chambers are often heavy and expensive requiring a significant amount of time and money just in the installation process alone. This report will serve to outline and define the design and fabrication of an environmental chamber, conducted by a team of four senior mechanical engineering students at California Polytechnic State University, San Luis Obispo. The goals of the project include a low-weight product, accurate and precise temperature changes within the chamber, visibility of the testing area, and ease of installation of the product on the tensile testing machine. This document provides an in-depth definition of the problem and a description of the background research conducted and presents the team's initial design ideas as well as the concept prototype and complete model for the chosen final design. Furthermore, this document lays out additional descriptions of the design verification prototype manufacturing process as well as testing procedures and results used to verify the effectiveness of the design.

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1: Introduction

A tensile test machine is a tool used to study mechanical properties in various materials by applying tensile or compressive force and measuring the material's response. The tensile test machine can be used to develop a stress-strain curve for a material, find the yield strength and modulus of elasticity, and find the ultimate tensile strength. As a material's mechanical properties change with ambient temperature, it is useful to also be able to control the environmental temperature surrounding the specimen while being tested.

Professor Elghandour, the sponsor of this project, heads the Composites Lab at Cal Poly where the tensile test machines are used to test material properties as part of engineering labs and graduate student activities. Marius Jatulis and Abdul-Rahman Mohamed are graduate students who are interested in the prospects of testing materials on the tensile test machines at controlled temperatures and are listed as sponsors for this project.

The model of tensile test machine in the lab is the Lloyd 50 by Ametek [1]. The purpose of the project is to develop an environmental chamber to fit into the current tensile test machine that allows for testing materials at controlled temperatures within the range of 32-410 degrees Fahrenheit. The product should cost less to create than the environmental chambers currently on the market, which are too expensive for the school to purchase. The chamber should also be at a reasonable weight, so that it can be installed and taken off the machine easily in between tests. This project focuses on the design and development of the physical features and the mechanical integration of the heating and cooling components for the environmental chamber.

The team working on this project is Erik Soldenwagner, Michael Ingel, Austin Marshall, and Lauren Schirle, who are fourth- and fifth-year mechanical engineering undergraduate students at Cal Poly in San Luis Obispo, California. Other notable individuals assisting in the development of this project include the four undergraduate mechanical engineering students who compose the separate senior project group heading the controls, heating, and cooling aspects of this project.

2: Background

2.1: Customer Meetings and Observations

Weekly meetings were conducted with Dr. Elghandour, graduate students Marius Jatilus and Abdul Mohamed and the separate senior project group designing controls components throughout fall quarter. The meetings outlined important observations and notes on the project. Concerning machine specifications, The LD50 tensile testing device has a maximum force of 50,000 Newtons when testing in both tension and compression. The bottom jaw that holds the testing sample remains stationary while the top jaw is moved by power screws in two pillars at the sides of the machine. Wide hand cranks are incorporated to tighten the clamps on the testing sample but can be removed after the tightening is completed before testing begins. The clamps themselves are steel, with a depth of roughly three inches.

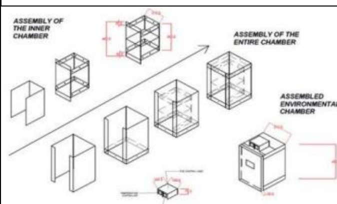
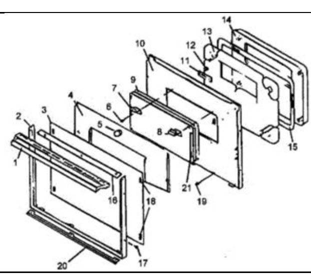
A plexiglass protective shield is also included with the LD50 and cannot be removed according to Dr. Elghandour; this therefore serves as a sizing restriction for environmental chamber designs. Dr. Elghandour also expressed the importance of a clear window into the testing chamber for students conducting experiments can visualize the mechanical failure modes exhibited within the chamber.

2.2: Existing Designs

Currently there are multiple existing environmental chambers for tensile testing machines with wide variety features and unique ways of accomplishing different tasks. In Table 1 below, each machine key features are noted to identify how successful environmental chamber accomplish different steps, i.e., install/uninstall, door/sealing mechanisms, and materials. By identifying successful key features, it provides insight into the future design decisions for this group’s environmental chamber.

Table 1: List of existing products with offered features

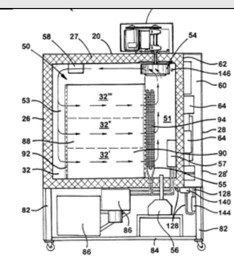
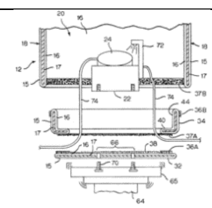
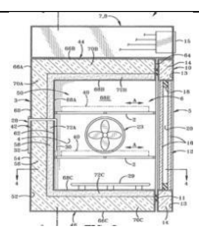
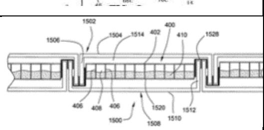
Product/ Company	**Pictures**	**Key Features**
Intron Enivro-Chamber [2]		● Advanced functions include 8-segment ramp/dwell, USB interface, and analog DC output capability ● Removable wedge ports provide quick and easy setup and incorporate instrumentation cut-outs for extensometer cables without interfering with the pull rods ● Triple-pane, optical quality borosilicate glass window with twin cartridge heaters for minimizing frosting and misting. ● Comes with guide rails so that machine can easily be pulled behind tensile testing machine
Ametek/ LD550 Thermal Cabinet [1]		● Actual thermal chamber for the tensile testing machine, Lloyd LD50, that sponsor is using ● Multi-layered glass panel inlaid into to door to provide clear line of sight on test subject ● The cabinets are mounted on wheels on an independent base unit. Normal ambient tests are possible when the cabinet is moved in rear position, clear of the test machine crosshead. ● Comes with guide rails so that machine can easily be pulled behind tensile testing machine
MTS/ Advantage Environmental Chambers [3]		● Specifically designed to allow for a temperature range of -129 to 315 degrees Celsius ● Rails insert or cable insert functions for installing the chamber to the tensile testing machine ● Designed to be specifically compatible for a wide range of materials testing including composites.
Thwing-Albert/ Environmental Test Chamber [4]		● A climate controlled for hot or cold applications. ● The temperature chamber/oven can be affixed or set on roller mounting brackets for easy use. ● Dual Handles on door for easy grip ● A built-in viewing window and internal light enables the operator to view the test in progress. ● The temperature controls of the chamber allow for testing from -100F to 600F ● Bores for slotting the clamps pf the tensile machine

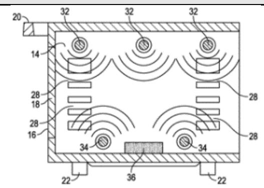
Product/ Company	Pictures	Key Features
Test Resources/ Environmental Test Chambers [5]		● Heated window options for low temperature testing, so you do not have to deal with frost build up on windows ● Fast ramping to set point temperatures ● Forced air convection blower for better thermal homogenization ● Close fit load train port inserts mean fewer thermal losses, better temperature consistency and less thermal gradients ● Temperature compensated load cells, lessen the thermal effects on load readings ● Water cooled pull rod options, that will limit thermal effects on the load cell ● Optional carts for moving the chamber in and out of the load frame when not in use. Eliminating the possibility of operator injuries from lifting heavy equipment
CSZ/ Tensile Test Chamber [6]		● Chamber is designed to minimize the amount of electrical and mechanical components on the top and the bottom of the chamber. ● Two door handles are installed to allow for easy removal of the door. ● An insulated split circular port was used in the top and bottom of the chamber to interface with the user’s load frame and actuator. ● Eyebolts are included to facilitate removal of the chamber from the load frame. ● Robust profile makes it heavy and costly
Kwara State University/ Low Cost Temperature Controlled Chamber Fabricated for Materials Testing [7]		● Low-cost thermal materials testing chamber designed for use in areas with limited power supply ● Makes use of aluminum sheeting and thermocouples to achieve a sturdy environment for heating materials ● Achieved a maximum temperature around 100 degrees Celsius.
Parts for Modern Maid [8]		● Complete diagram of Modern Maid oven door assembly ● Outlines components for integrating window assembly ● Insulation and gasket seal placement included in assembly drawing

2.3: Relevant Patents

When the team researched patents, it was observed that very few chambers on the market are patented environmental tensile testing chambers, as there are many different companies who have essentially the same tensile testing machine products for sale. Instead of trying to find patents for the market machines, the team focused on patents that were relevant to the applications desired and highlighted the key product features of relevance below in Table 2. The first patent listed has interesting documentation for the use of a dual chamber to allow for a testing environment and an environment to direct airflow for cooling and regulation in the test chamber. This split setup could be a way for the team to learn how to isolate the changes around a test sample while effectively cooling afterwards. The second patent features interchangeability of an insulated system to inspire ideation for chamber attachment hardware. The third patent highlights an option to use a phase change medium to heat and cool the chamber as an alternative to maintain temperature. The fourth patent has documentation for the use of different insulation layer wall setups using thermoplastics and aerogel which the team could consider using in the chamber construction. The final patent highlights the heat transfer for a common household device to learn from something that is safe in every home, helping the team determine how to expel heat from the chamber safely while reaching temperatures up to 400 degrees Fahrenheit.

Table 2. List of relevant patents along with key features to consider for future designs.

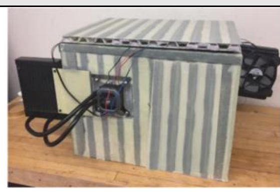
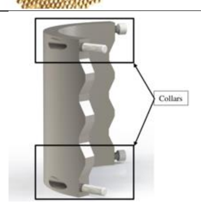
Company/Patent Title	Pictures	Key features
Envirotronics/ Environmental Test Chamber [9]		● Dual Chamber electronic testing setup ● One chamber for testing heated parts and the second for regulating the airflow through the chamber ● Uses pressurized partitions to ensure heat and/or moisture from the first chamber doesn't seep into the second chamber ● The second chamber makes use of an air blower to intake and pressurize the air before going into the main testing chamber
Michael Pickel/Thermal Test Chamber [10]		● Soft sided thermal test chamber designed for attachment to shaker tables ● Used to fully enclose test subject while on the shaker table while running thermal tests ● Makes use of interchangeable centerpiece to accommodate different testing machines
Caron Products and Services/Insulated Chamber with Phase Change Material [11]		● Interior chamber heated using a phase change material between the outer wall and inner wall. ● Makes use of both heaters and cooling devices to change the temperature of the wall along with inserts for the chamber that can induce direct heating/cooling ● Controls for humidity of the chamber included.
Cabot Corp/Insulated Panel and glazing system [12]		● Creation of translucent glazing panels for use of insulation ● Thermoplastic outer walls with internal channel for insulation material ● Uses hydrophobic aerogel particles in the inner channel to provide the insulating properties

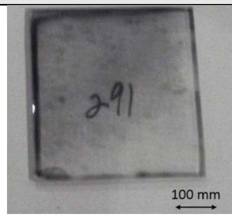
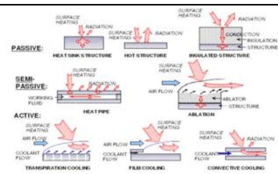
Company/Patent Title	Pictures	Key features
Conair Corp/Toaster and Convection Oven with Variable Controls [13]		● Provides reference for small, heated chamber that can reach up to 400°F with minor heat on outside ● Has insulated design to keep the controls portion of the product safe from the heated chamber ● Layout for wall thickness and heat sinks to cool the chamber

2.4: Relevant Technical Reports

Table 3 below outlines reports relevant to the design considerations and project goals for the environmental chamber. Previous senior projects and industry technical reports include findings related to design for insulation, composites manufacturing processes, weight-saving considerations, and glass-type testing for high-temperature environments.

Table 3. Lists relevant technical reports with useful design considerations.

Report Title	Pictures	Key Elements
Portable Thermoelectric Refrigerator [14]		● Portable thermo-electric cooler that uses Peltier devices to create large temperature differences over short periods of time ● Different corrugated insulation cross-sections are tested for insulation efficacy ● Description on manufacturing for inner and outer chamber walls
Development of 3-D Compression-Molded Composite Primary Structure [15]		● Descriptive procedure on mold creation for composite designs using University facilities ● Design for composite assembly discussed in detail, with pitfalls and successes included in procedure ● Detailed list of assembly information for parts that include composite and non-composite components
Temperature Controlled Packaging Container for Biologics and Pharmaceuticals [16]		● Includes product research into existing thermoelectric chambers, describes elements that are useful to small-scale design ● Describes "common cold chain technology" for information on Peltier device integration within and around chamber enclosure
Additive Manufacturing for Post-Processing [17]		● Comprehensive list of Joining methods for composites that don't include fixed or floating fasteners (e.g. adhesives, shrink fits, etc.) ● Advantageous for materials too brittle for screws and bolts ● Useful in design of chamber exterior wall around insulation and internal components
Mini High Temperature Test Unit [18]		● Design of a portable, light environmental testing chamber ● Weight and size are key specifications in design considerations ● Specifies that chamber that can operate under temperatures reaching 1000 °F ● Total cost less than $3000, outlines important design considerations to keep cost low

Report Title	Pictures	Key Elements
Influence of Thermal Annealing and a Glass Coating on the Strength of Soda-Lime-Silicate Glass [19]		• US Army research involving the strength of glass in transparent armor systems • Rough environment to test clear, strong materials • Discusses desired aspects of glass for high-stress environments • Desirable for testing chamber window
Design Considerations for Thermally Insulating Structural Sandwich Panels for Hypersonic Vehicles [20]		• Identifies key design parameters, material properties and design principles for sandwich panels • Considerations for multilayer panel design in chamber walls • Discusses loads and impacts box may be subjected to and from which locations

2.5: Industry codes

Research was conducted on standard processes of tensile testing of materials at non-ambient temperatures to gain a deeper understanding of the test process. This research included typical order of operations to perform a test, testing modes, and expected testing rates and temperature gradients. This also included understanding safety procedures such as proper securement of the test specimen and safety precautions against flying fragments of broken test specimen. Additionally, research was conducted on standard processes for testing the impact strength of materials, and testing the thermal insulation of materials, for when it is necessary to experimentally validate the performance of the materials used on the product.

3: Objectives

In defining the scope of work for creating the environmental chamber, clear incremental goals for the project were established along with specific criteria to evaluate project aspects and design specifications. Strict deadlines were set for project deliverables to ensure consistent project progression and efficient team time-management.

3.1: Problem Statement

Existing tensile testing chambers are too heavy, expensive, and cumbersome to place on the tensile testing machine. Dr. Elghandour and the Cal Poly Composites Lab need an environmental tensile testing chamber that can perform material and part tests at constant temperatures, ranging from 32 – 410 °F (0-210 °C). The goal is to achieve this temperature performance while keeping the chamber lightweight, easy to install, relatively cheap, and handle impact from material failure. The designed chamber should be easily integrated onto the existing Lloyd LD50 Tensile Testing machine to allow use for future classes or projects for running tension and compression experiments.

3.2: Customer Needs and Wants

Dr. Elghandour outlined several specifications for the environmental chamber that are required to be met for the design. Considering geometry, the chamber must have a maximum height of 37 inches for it to be usable with the LD50's current vise jaws. This dimension would also include any height added to the exterior of the chamber, such as legs for stability. The chamber must also have a maximum width of 17.5 inches, as it is restricted by the position of the LD50's power-screw columns on either side of the testing machine. The chamber depth must fall in the range of 8 to 18 inches; the minimum dimension allows space for the vise jaws to fit inside the chamber and still be tightened, and the maximum dimension ensures the chamber will fit inside the protective splinter shield surrounding the LD50's testing area. The chamber should also allow for 16 inches between the vise jaws within the environmental chamber for full testing range. The Chamber needs to be easily installed by one person, so the weight and installation processes should be manageable. The chamber should be able to be installed around the jaws either by sliding or removing the jaws while maintaining a tight seal during testing. A viewing window is required to observe part failure or record the reaction. The final product must be considerably cheaper than current products on the market to create affordability for school labs. Considering materials, the chamber must be durable to withstand any splintering that may occur from samples being tested within it. The chamber must also be heat resistant to easily handle the temperature changes in the desired 32 to 410 ◦F over many testing cycles.

Dr. Elghandour also outlined several design elements that he would prefer for the environmental testing chamber. The chamber must be well-insulated, with the exterior wall of the chamber not exceeding room temperature during the maximum 410 ◦F (210 °C) internal temperature condition so it can be handled safely by students during and after testing. The viewing window which allows for students to watch the part failure and record it should be as large as possible to allow a clear view of test to reduce the chances of missing details during testing. The chamber would preferably be light, in proximity of 50 lbs, and easy to install to the testing machine. The use of some sort of track to easily position the chamber onto the machine and hold it in place during testing would be ideal.

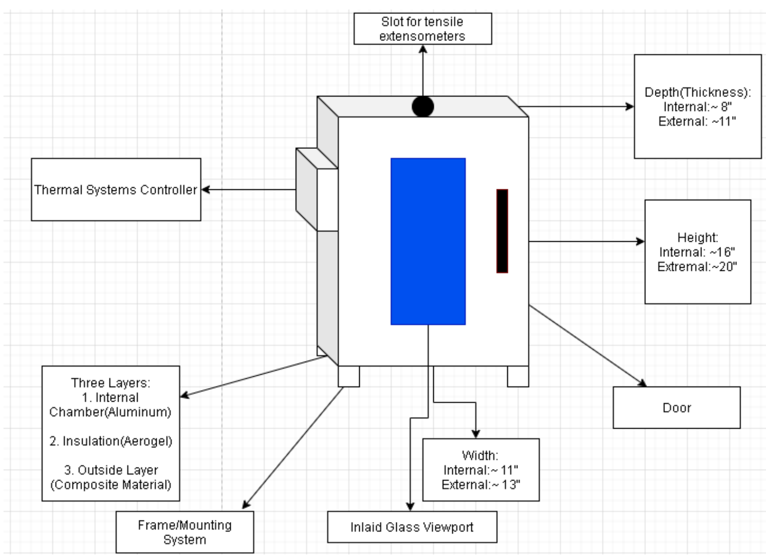


Figure 1. Boundary diagram of the proposed system.

3.3: QFD Process

The QFD process is a method of determining what specifications are needed for the product and how important each one is based on the customer's wants and needs. This relationship was outlined and analyzed using a House of Quality graphic, included in Appendix A.

Using this process, customers such as Cal Poly lab students and groups in industry were identified. Emphasis was placed on Dr. Elghandour as the sponsor and main customer. Corresponding customer requirements were then input, taken from interviews with Dr.

Elghandour and background research on current industry products. Weights for each requirement were selected and applied based on their importance to the customers. Existing products were researched and scored based on how well they met the identified customer requirements, helping to benchmark competition and indicate areas that are open for future designs to improve upon. Engineering specifications were then selected as measurable and verifiable methods for determining whether certain designs meet the customer requirements. The specifications were cross-referenced with the customer requirements to identify any strong relationships between them and determine which specifications could be used to quantify certain wants and needs. Finally, the specifications were given target values based on the input of Dr. Elghandour and comparisons to existing products.

The completed House of Quality identified major specifications such as the chamber dimensions, with a height, width, and depth of 37 inches, 17.5 inches, and 18 inches, respectively. The cost was also specified as having a maximum value of $5000, and the weight as having a maximum of 50 lbf. Full specifications and target values are included in Appendix A.

3.4: Engineering Specifications Table

Table 4 below includes important engineering specifications for the environmental chamber, derived from the QFD house of quality 'Customer Wants and Needs'. Each specification's target value, tolerance, risk level for meeting the requirement, and method of confirming compliance is included below. High, medium, and low risk is indicated with H, M and L in the table, respectively. Compliance confirmation method is indicated with an A for Analysis, T for Test, and I for Inspection in the table.

Table 4. Engineering Specifications Table

Spec#	Specification Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Weight	50 lb	Max	H	A, T, I
2	Width (Exterior)	18 in	Max	L	I, A
3	Width (Interior)	11 in	Min	M	I, A
4	Height (Interior)	34 in	Min	L	I, A
5	Depth (Thickness)(Interior)	7.5 in	Min	M	I, A
6	Depth (Thickness)(Exterior)	20 in	Max	L	I, A
7	Cost	$5000	Max	L	I, A

Measurement Process for Specifications:

Weight: A scale will be used to measure the overall weight of the assembly. The chamber will also be manually lifted to gauge the comfortability of weight distribution.

Geometry: Engineering rulers, calipers, tape measures and height gauges will be used to measure the chamber's inner and outer dimensions. Visual inspection will be used to gauge how well the chamber fits in the LD50 machine.

High Risk Specifications: The weight of the Environmental Chamber must be 50 lbs or less to be lighter than existing products in the market and to be lifted reasonably easily by 1-2 people.

The reason this specification is high risk because in making something more thermally efficient adding material and features will inevitably add weight to the chamber.

4: Concept Design

4.1: Ideation and Functional Decomposition

To begin generating concept ideas for the different aspects of the environmental chamber, the chamber was divided into its key functions and sub-functions in a process called functional decomposition. A function tree was created (Fig. 2) to outline each of the functions in detail, with the branches starting with the main functions and the sub-functions branching down, with each sub-function describing a key aspect to achieve the main function that it is under.

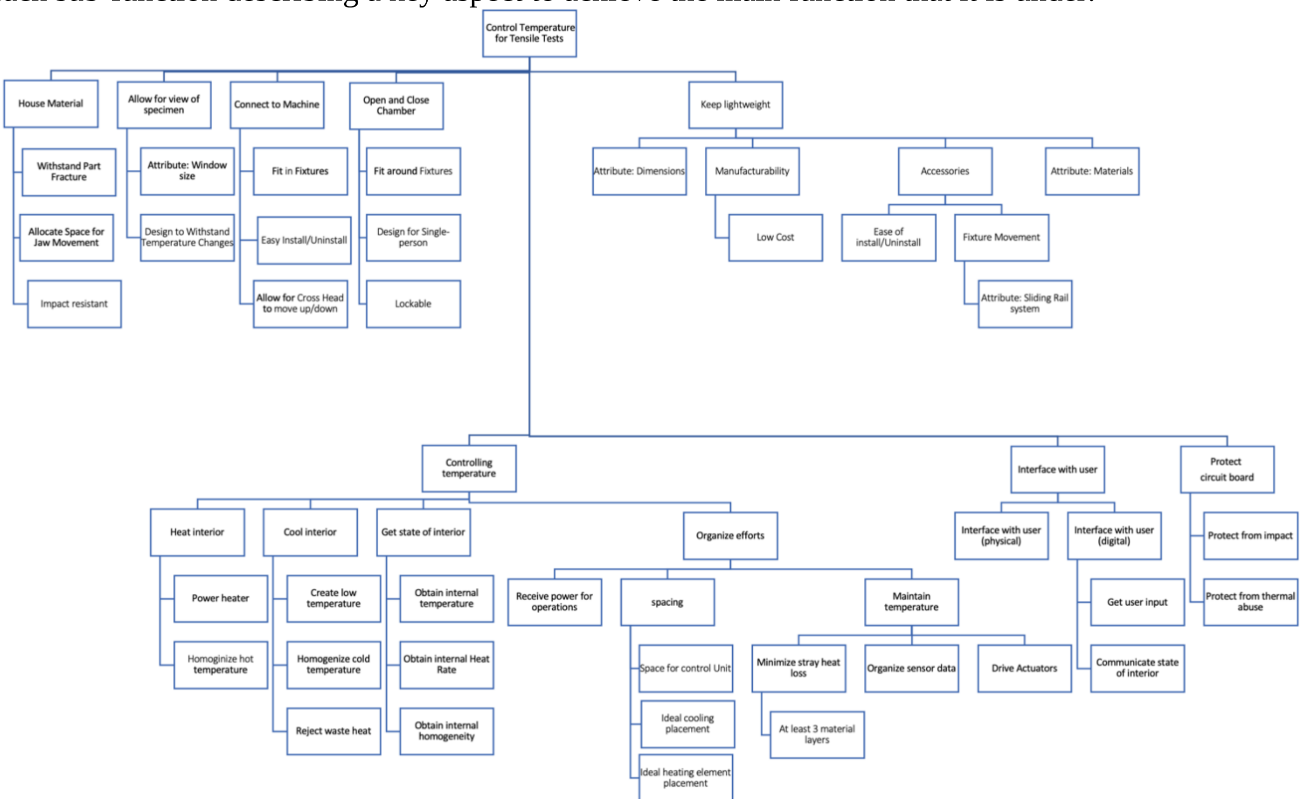


Figure 2. Functional decomposition including structural and controls requirements (this team is only working on the structural requirements seen on the top half of the diagram).

Using the functions outlined in the functional decomposition as a guide, ideas were generated to achieve each sub-function. The goal was to generate at least five separate ideas for each sub-function. Ideas were brainstormed independently by writing or sketching ideas in the logbook, then sharing these concepts with the rest of the team for feedback and additional ideas. From the ideas generated in the logbooks, function prototypes were then developed from home using materials at hand, such as cardboard, foam board, paper, wooden sticks, and glue. These prototypes were made to demonstrate the general concept and feasibility of one single function of the environmental chamber. Images of these concept prototypes are included in Appendix B.

4.2: Concept Selection

The initial concept prototypes directed thinking toward what is more feasible and what could be too difficult to manufacture. With these design limitations considered, the next step was to expand on the ideas for each function by creating Pugh matrices that could then be used to design a morphological matrix. The morphological matrix is used to create multiple combinations of the best ideas from the Pugh matrix to keep design teams from fixating on one solution. The best designs generated from this step were then compared in a weighted decision matrix to help determine which design should move forward as the initial blueprint for the product. This is where the preliminary concept is born and comes to fruition with initial models to direct the direction of the final designs path.

4.2.1: Pugh Matrix and Morphological Matrix

After completing initial ideation and function concept models, the team moved forward to creating Pugh matrices for each of the key functions to determine which ones would perform better. The goal of a Pugh matrix is to compare different function ideas to a base "datum" concept to determine if they would be better (+), worse (-), or about the same (S) to see which ones should be looked into farther. These scores are then added for each idea to see how positive the idea is compared to the datum function. The individual Pugh matrices can be found in Appendix B. The ideas from the Pugh matrix are then listed in a morphological matrix seen below in Table 5.

Table 5. Morphological Matrix

Function	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5	Idea 6	Idea 7	Idea 8
Corrugate Insulation Cross-section	Triangular	Wave	Square	Trapezoidal	Arching	-	-	-
Stuffed Insulation	Fiberglass Roll	Polyeurothane injection	Mineral Wool Sheets	Poured Sand	Air Convection	-	-	-
Installation to Machine	Telescoping rail	Bungee Folding rail	Detachable "plug in" rail	Chamber Legs	Srew in Support	Locking wheels	Fixed rail w/ sliding clamps	-
Sealability	Multi-Level Door (With Sealing strips)	External hinge	Internal Hinge	Cresecent Hinge	Safe lock Mechanisms	Hybrid(half Internal Hinge + Safe lock)	Hybrid(half External Hinge + Safe lock)	Hybrid(half Internal Hinge + Safe lock) + Multi-Level Door (With Sealing strips)
Machine Arm Integration	Front-Back halves attachment	Side-Side halves attachment	Slot for arm from the side	Slot for arm from the top	-	-	-	-
Machine Arm Sealing	Rubber Sliding Bearing	Sealing Foam	Rubber Flaps	O-ring Material	Rubber+foam	-		-

The purpose of the morphological matrix is to list out many of the function ideas to then mix and match different combinations of ideas and functions to create full product concepts. This was done several times to generate many ideas for the full concept and the top 5 combinations are summarized below in Table 6 and sketches of each can be found in Appendix C.

Table 6. Top 5 concepts produced from the morphological matrix.

Function	Concept # 1	Concept #2	Concept #3	Concept #4	Concept #5
Corrugate Insulation Cross-section	Square	Triangular	Trapezoidal	Arching	Trapezoidal
Stuffed Insulation	Mineral Wool sheets	Fiberglass Roll	Mineral Wool Sheets	Polyeurothane Injection	Mineral Wool
Installation to Machine	Detachable "plug-in" rails	Fixed rail w/ sliding clamps	Chamber Legs	Locking Wheels	Fixed rail w/ sliding clamps
Sealability	Multi-Level Door (With Sealing strips)	Safe lock Mechanisms	Hybrid(half External Hinge + Safe lock)	Cresecent Hinge	Hybrid(half Internal Hinge + Safe lock) + Multi-Level Door (With Sealing strips)
Machine Arm Integration	Front-Back halves attachment	Side-Side halves attachment	Slot for arm from the side	Slot for arm from the top	Front-Back halves attachment
Machine Arm Sealing	Sealing Foam	Rubber+foam	O-ring material	Rubber Flaps	Sealing Foam

4.2.2: Weighted Decision Matrix

With main concepts selected, the next step was to create a weighted decision matrix to choose the best concept to move forward with. The weighted decision matrix used the major QFD specifications along with a few additional points, each with assigned weights depending on how important that goal is to determine the best design. The weights were on a scale of 1-5 where 1 is the least important and 5 is the most important. The concept ideas were scored based on a scale from 1-5 where 1 met the specification the worst and 5 met it the best. Once each concept had a score from 1-5, these numbers were then multiplied by the specification weight and added together in the total row. The concept with the highest value for this total was therefore the most ideal design direction, as it outperformed the other concepts. The weighted decision matrix can be seen below in Table 7.

Table 7. The weighted decision matrix with the best design total highlighted.

Specification	Weight [1-5]	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Ease of Installation	5	4	1	1	4	4
Weight	4	4	2	4	4	4
Cost	4	3	3	3	2	4
Manufacturability	3	2	1	4	2	5
Size	1	4	3	4	4	4
Safety	3	2	4	3	0	4
Durability	2	3	3	4	2	3
Insulation	4	3	2	4	1	5
Total	26	76	45	73	62	97

Based off the weighted decision matrix, concepts 1 and 3 were seen to perform well, but concept 5 had the highest total. This showed that concept 5 should be the basis used to create the preliminary design of the environmental chamber. Simple sketches of concept 5 can be seen below in Figure 3 highlighting its main features.

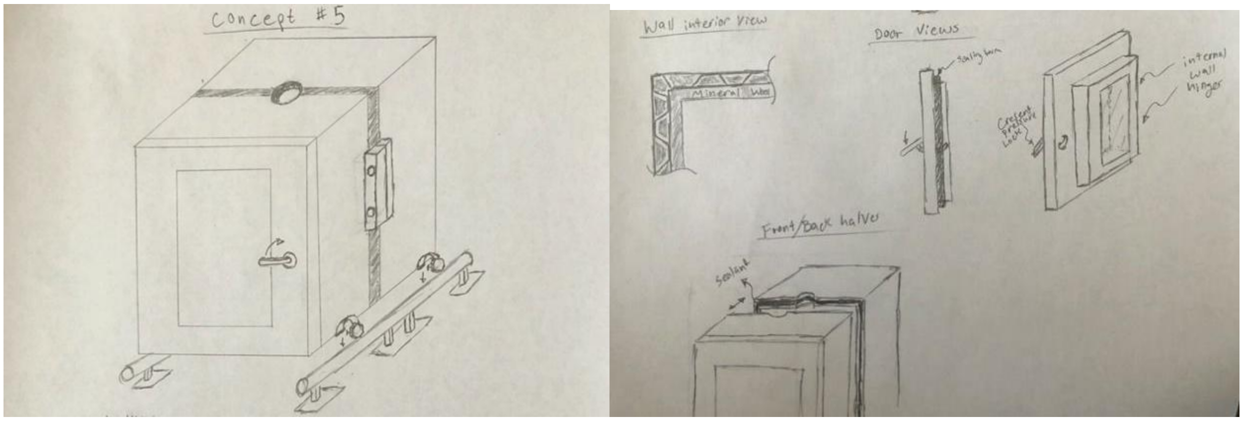


Figure 3. Sketches of key concept 5 features

4.2.3: Preliminary Design

After selecting concept 5 as the design basis, sponsor meetings were held with Dr. Elghandour to get feedback on the design choices. He approved of all the choices except the machine arm integration function. Dr. Elghandour asked the team to shift from attaching two halves of the chamber together to fit around the vise fixtures to creating a removeable slot that would allow the chamber to slide into place easily. The slots on the top and bottom of the chamber would be taken out when installing with the door open and then reinserted once the chamber was in position. With this design change, a concept prototype was built, and CAD model of the final preliminary design was made, seen below in Figures 4 and 5.

Figure 4. Preliminary concept model prototype

The concept prototype was constructed to demonstrate the functionality of all selected design elements when combined into one model. The front-facing door provides simple access to the chamber interior and the side-hinged design allows for the door to be opened while the chamber is mounted on the LD50 machine. The external hinges also avoid interfering with thermal sealing between the door and chamber walls. The front-facing door opening also allows for the top and bottom slots to be accessed easily when the LD50 arms are positioned in the chamber. The chamber rails are used in positioning the chamber and are included on the chamber bottom to avoid obstructing testing.

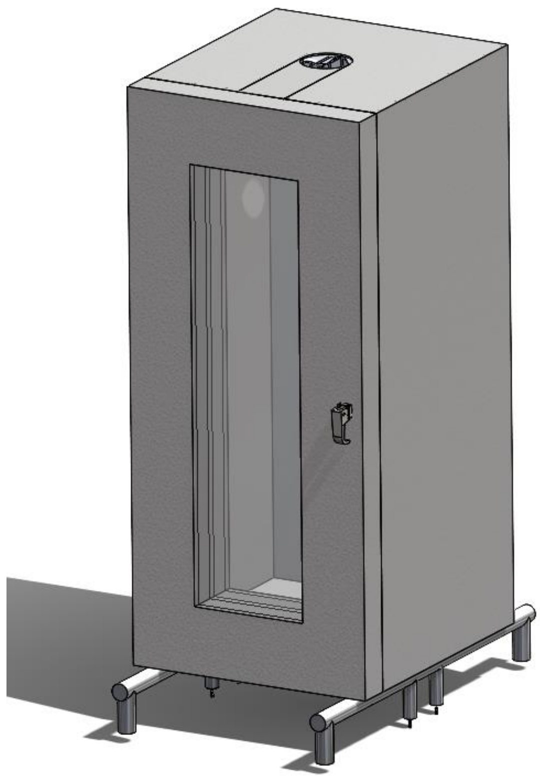


Figure 5. Preliminary CAD model

The model depicted above shown the main structure of the proposed environmental chamber along with the rail system to be used to install the chamber. It should be noted that the machine is installed by first opening the door and removing both slots, then sliding the chamber into place on the rails and tightened to them when in the correct position. Additional views of the model in the orientation it will be installed to the LD50 tensile testing machine can be viewed in Appendix D.

The basic geometry of the box is heavily designed around the necessary internal dimensions. In order to allow the machine to reach a maximum of 16 inches between the two vises, the chamber is 34 inches tall inside. The machine's inner depth is 8 inches, to allow room for a control box to be attached to the back of the chamber. The machines inner width is 11 inches to ensure that there's room to tighten the machines vise grips when a part is inserted. The thickness of the walls will be about 1.5 inches including the inner aluminum ¼ inch wall, the insulation sheet, a corrugate insulated structure, and the composite outer wall shell. See Appendix D for section views of the model depicting these layers of the outer structure.

4.3: Preliminary Analysis

Appendices E and F include rudimentary hand calculations which, based on certain design assumptions, give a brief insight on the relative magnitude of forces that the hinges and corrugate material will experience throughout their life cycles being used in the Composites Lab. Along with this, preliminary composite design work has been performed alongside graduate students Marius Jatilus and Abdul-Rahman Mohamed. An initial fiberglass composite corrugate wall was manufactured using a mold, wet layup, and vacuum seal bag. This unfortunately resulted in a poor surface finish as the vacuum bag was not large enough to sink into the pattern perfectly, so it left some bubbles in parts of the corrugate pattern. Images of the vacuum bag seal and first test result are seen below in Figure 6.

Figure 6. Initial composite wet layup results using a vacuum bag.

After other vacuum bag fiberglass layups on the corrugate mold, it was determined that a composite corrugate structure would be difficult to manufacture as well as take up significant amount of the limited project management plan time frame. Backing the external chamber with corrugate patterns would also take up limited space between the walls that would be necessary for the controls team's components. Dr. Elghandour advised that flat panels epoxied to composite L-brackets would be sufficient for the external chamber structure, making the corrugate pattern unnecessary. Results from composite strength testing, outlined in Chapter 7, supported this design change.

4.4: Challenges and Risks

Certain challenges and risks were emphasized following the development of the concept design. The greatest challenge to the design was keeping the chamber weight below the 50 lbf maximum specified. Though insulation materials are light, the amount required in addition to the inner and outer wall materials and heating and cooling elements fitted to the chamber were considered difficult hurdles to overcome. Another major challenge was to maintain a steady temperature at the maximum of 210 degrees Celsius. This concern considered potential inconsistencies in the insulation that will occur in locations such as the chamber door and slots for the LD50 jaw arms to enter the chamber testing area.

Risks in the design were primarily focused on the high temperatures the chamber will experience during testing. Poor insulation could lead to the chamber exterior becoming hot and harming students using it as well as potentially damaging electrical components used to control the heating and cooling of the chamber testing area. Material samples that fracture during testing may also become dangerous projectiles if not adequately contained by the chamber.

5. Final Design

Following Mustang 60 shop technician consultation and advice from Dr. Elghandour, the final structural design was developed. CAD models for the environmental chamber can be seen in Figures 7 and 8 below. While most components are representative of what was shown in the Concept Design section, other components underwent significant changes, and the complete assembly design is more detailed. Major changes to the initial design include adjustments in the door assembly, details in the rail support design, integration of the heating and cooling components, and cutout details of the inner and outer walls. Furthermore, there were slight adjustments to the overall dimensions of the internal and external structures to allow for more room for controls components. Additional images of the design, including exploded and section views of key sub-systems, can be seen in Appendix I.

Figure 7. Isometric view of final design.

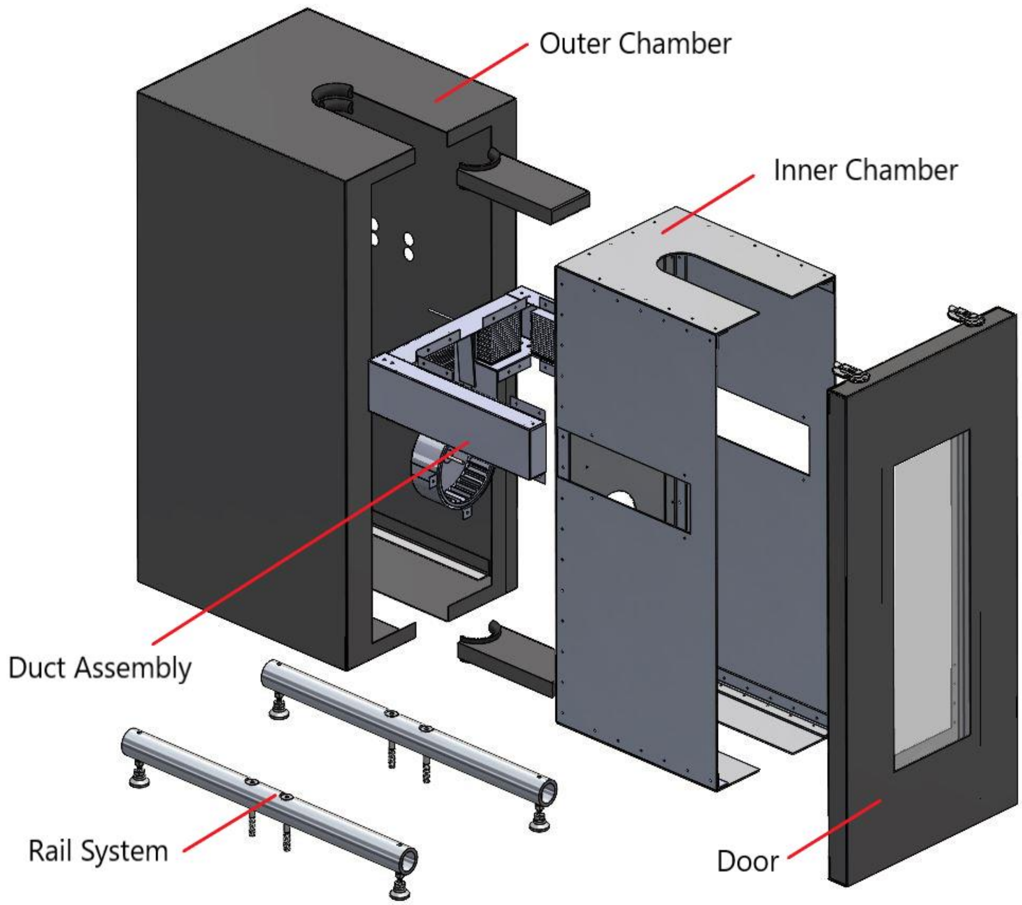


Figure 8. Labelled exploded view of full assembly.

5.1 Inner Chamber design

The inner wall of the chamber was constructed with panels of 5052 aluminum sheet metal, joined into a box shape via riveted aluminum L-brackets on each side. This construction provides stiffness to the shape and ensures minimal bending as the chamber is being handled in construction, as well as when being handled by users. The ductility of the aluminum is also ideal for the inner wall as there is a possibility of specimen parts fracturing and impacting the chamber wall during tensile testing. The aluminum walls include various holes and openings which connect to sheet metal ducting attached to the outer side of the wall, which direct the temperature-controlled air while the chamber is in the process of heating or cooling during use.

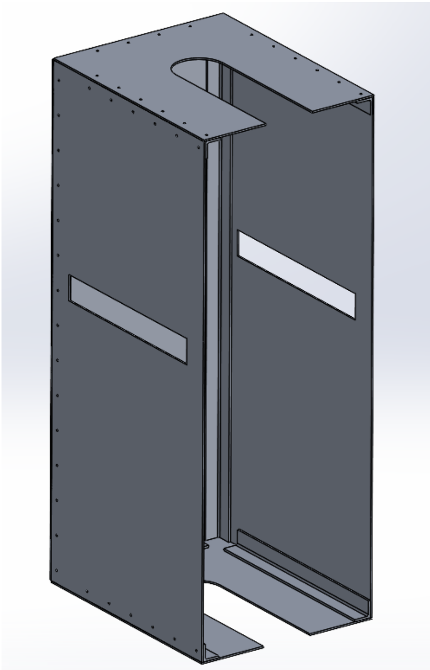


Figure 9. Inner Chamber assembly model.

5.2 Outer Chamber design

The outer wall was constructed with composite and fiberglass composite flat panels. The outer panels are held together via composite L-brackets on each edge of the chamber which attach with Magnolia epoxy adhesive. There is space between the outer chamber composite walls and the inner chamber for insulating material and radiation shielding (not included in the model) to ensure that the temperature inside of the inner chamber walls is fully insulated from the outside environment, and vice versa.

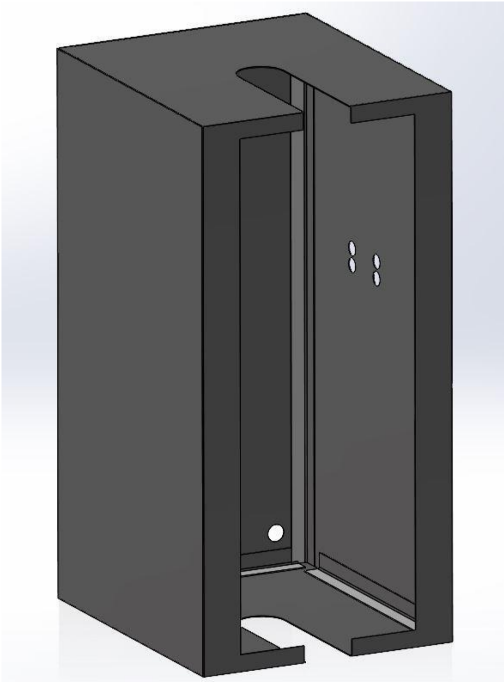


Figure 10. Outer Chamber assembly model.

5.3 Door Design

The door subsystem of the chamber design underwent significant changes since the preliminary design phase to help simplify manufacturing. The biggest design change to the door involved the inclusion of the chamber glass view port and the design for interior overlap to help reduce heat bleed out of the door. The door was updated for simpler manufacturing using an aluminum sheet, similar to the interior chamber walls, and composite carbon and fiberglass sheet on the exterior, with space for insulation and glass mounting hardware in between. Aluminum L-brackets were attached to the aluminum and composite sides to hold two panes in place. The interior and exterior faces of the door were attached together using composite and aluminum L-brackets, which also provided surfaces to mount the latches for attachment. Around the outermost edges of the door, RTV sealant was be used to create a "sticky" film to help the door grip to the walls when latched shut.

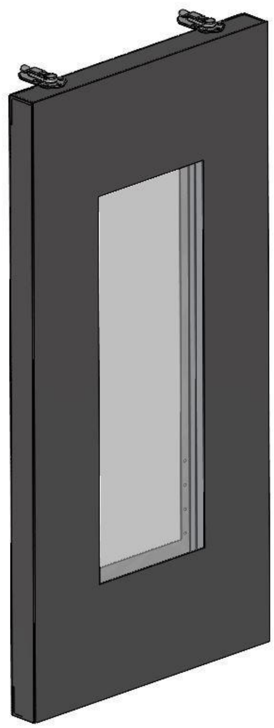


Figure 11. Door assembly model.

5.4 Rail System Design

The rail system design remained roughly the same over design iterations. The system slightly changed to using cheaper components that were more readily available. The main rail bar was made using simple aluminum piping with threaded holes machined to it to allow the ability to attach to the LD50. The machined holes were counterbored to keep the top surface curvature of the piping. On both ends of the pipe used for the rail, leveling mounts with rubber ends were screwed into the rail to create adjustable supports to keep the rail level when inserting the chamber system.

Figure 12. Rail System assembly model.

5.5 Structural Prototype

The structural prototype of the chamber, shown in Figure 13, is a scaled down model of the inner and outer chambers, with a simplified version of the door that does not include a window, handles, or hinges. Furthermore, the outer chamber is constructed out of aluminum sheet metal rather than composite, and the inner chamber was constructed by a single sheet of aluminum bent into shape and riveted together via bent flanges. The purpose of this prototype was to verify the manufacturability of the sheet metal inner wall and to test the effectiveness of different forms of insulating material, as well as to check for heat bleed at the seams of the chamber. Following the manufacturing of this prototype, expected tolerances of bend results from the sheet metal break were found to be too imprecise upon visual inspection. Constructing the box edges with L-brackets rather than bent sheet metal would allow for a stiffer and more tightly-toleranced inner chamber. Furthermore, the group concluded that aluminum rivets were a sufficient method of joining edges of the chamber wall based on analysis of the structural prototype.

General heat transfer from the inner chamber to the outer chamber was also investigated on the structural prototype. Preliminary heat tests were run using a hemp and silicon insulation material provided by Dr. Elghandour. The thin hemp insulation sheet was sandwiched between the back wall of the inner chamber and the back wall of the outer chamber while a heating pad was pressed against the back inner wall of the inner chamber. The goal with heating this part of the chamber was to determine how well a basic insulator prevented heat transfer to the outer chamber wall. This is a very important component of the project, as preventing the outermost surface from being hot enough to harm the user is crucial. The preliminary test was run by attaching a thermo couple to the outer chamber’s back wall in the central location of where the heat pad would be on the inner chamber. The test was started with the heat pad at 190°F where the pad was gradually raised to a temperature of 240°F over 15 minutes. During this gradual increase, thermocouple readings were taken for the outer chamber every minute and found that the exterior wall only increased from 74°F to 76°F. Along with this result, a side of the outer chamber without any insulation was also measured at the end of the test and found that it only raised to 100°F. This confirmed that a basic insulating material will work to insulate the chamber, so when using an insulator with a higher R value, the chamber should perform as desired.

Figure 13. Inner chamber of structural prototype.

5.6 Safety Maintenance and Repair

Main areas of concern for safety and maintenance were centered on the insulation and sealing of the chamber area. Improperly installed insulation around the chamber may lead to significant heat bleed from the internal testing area, leading to poor conditions for material testing when the chamber is used with the LD50. In addition to affecting testing data, significant heat bleed may be a safety hazard. The external walls of the chamber may reach unsafe temperatures and burn the user if they touch it during testing or attempt to open the chamber door soon after testing has concluded.

Other areas of concern include the alignment of the chamber door and chamber system rails, both of which could negatively affect the chamber's ease of installation. Once completed, the chamber assembly will be difficult to take apart for repairs. Achieving a tight thermal seal requires the use of fixed fasteners and bonding epoxies, which can be challenging to remove. RTV heat sealant can be stripped away from chamber components as necessary. All sealants need to be replaced after maintenance to ensure the chamber is resealed. All safety, maintenance, and repair concerns for the environmental chamber from the final design structural prototype analysis are detailed in Failure Modes and Effects Analysis and the updated Design Hazard Checklist. They are included as Appendix K and Appendix G, respectively.

5.7 Cost Analysis

The total system cost for the proposed verification prototype is included below in Table 5, and a more detailed summary is in Appendix M. The team was given a $5,000 budget to build the prototype between money from Dr. E and the CPConnect grant, but most of the money is to be used by the controls team for the heating, cooling, and ducting systems. Due to their need to buy more expensive equipment, the goal is to spend below $1000 on the structural materials. The most expensive parts necessary for the structural components are the aluminum sheet metal, the glass for the viewport, and the radiation shielding. The sheet metal was ordered in one large sheet to help reduce costs. This 4 ft x 8 ft sheet was cut in half for transport and then cut on the waterjet to precisely create all the pieces most efficiently. The glass viewport was created by having two separate panes at 21 in x 8 in. The radiation shielding was bought from McMaster as they are the quickest vendor to acquire high temperature radiation shielding from. The sheet metal total cost totaled to $107.66, the glass for the viewport totaled to $206.44, and the radiation shielding totaled to $405.43. While these parts are expensive, the rest of the necessary parts were affordable, allowing the team to remain under the goal price at a combined total of $859.10.

Table 5. List of key materials needed for the verification prototype.

Sub assembly	Part Number	Component	Supplier	Total Cost
Inner Chamber	111000	Aluminum Sheet 4ft x 8ft	B&B Steel	$107.66
	111100	Aluminum Edging	Home Depot	$23.36
	111300	RTV Heat sealant	Amazon	$25.98
Outer Chamber	121000	Fiberglass + Epoxy	Dr. E	$0
	122200	Radiation Shielding	McMaster	$405.43
	123100	Silicon Gasket	McMaster	$15.25
Door System	131000	Window Ceramic Glass	One Day Glass	$206.44
	131100	Aluminum J Channel	Home Depot	$15.99
	132000	Compression Latches	McMaster	$15.24
Rail System	142000	Rail	Mustang 60	$0
	143000	Bolts	McMaster	$12.80
	144000	Leveling Mounts	McMaster	$24.68
Fasteners	See Appendix J	Other Fasteners	Home Depot	$6.27
Total				$859.10

6. Manufacturing Plan

Upon definition of the Final Design, the verification prototype was constructed to confirm the design's complete functionality. The Manufacturing Plan outlines steps for purchasing materials and components as well as manufacturing steps for each design assembly and subassembly. Final Design component model images can be seen in Appendix I. The manufacturing plan steps below reference these design images. Technical drawings and data sheets of each component for the design can be seen in Appendix N, the Drawing Package.

6.1 Material Procurement

A sizable portion of the materials to be used in the creation of the structural verification prototype were provided by the Cal Poly Composites Lab. The fiberglass, carbon fiber, and resin needed for the outer chamber walls were provided, as well as bonding epoxy and some insulating materials that will be tested within the prototype walls. The composite shell for the chamber door will also be provided.

Non-composite components were ordered from retailers online to procure materials that meet design specifications. The door window is the most expensive component due to its size and heat-resistant properties and was ordered from OneDayGlass.com to source quickly and at a more affordable price. The internal and external chamber aluminum sheeting was sourced from B&B Steel and Supply, ordered based on price per square foot and gage thickness. Component costs will be covered using Cal Poly Reimbursement requests. Additionally, the heat shielding used in the insulation was purchased from Design Engineering Incorporated.

Most other components were small and common parts that were easily sourced from hardware stores. Aluminum L-brackets, rivets, bolts, nuts, hinges, and commercial heat sealant as well as guiding rail components including steel piping and threaded rods and caps will be purchased were purchased from Home Depot or McMaster-Carr as needed. A full breakdown of the complete material procurement plan is included in the Indented Bill of Materials, listed as Appendix J.

6.2 Inner Chamber Construction

The inner chamber was constructed using aluminum sheet metal panels that were cut into the appropriate shapes to rivet the box together. The water jet cutter in Mustang 60 was used in order to ensure a tight tolerance.

Step 1: Used the waterjet to cut out the inner chamber template to ensure a tighter tolerance than cutting by hand. Each of the 5 walls were cut into induvial pieces from the sheet metal to include the top piece, bottom piece, and the 3 side wall pieces.

Step 2: While cutting, the waterjet was used to create the rivet holes on in the appropriate places along the edges and cut out the arm slots. Rivet holes were cut in the aluminum edging to be used to create the inner structure.

Step 3: The top and bottom pieces were riveted to the aluminum edging that matches dimensions, then the side walls were riveted to their matching edges to create the “U” shape of the walls. The top and bottom pieces were placed on the matching wall piece and were riveted to the respective edges. Clecos were used to keep the holes aligned while riveting. In certain cases, extra drilling was necessary to allow a more seamless fit of the rivets and a flusher finish.

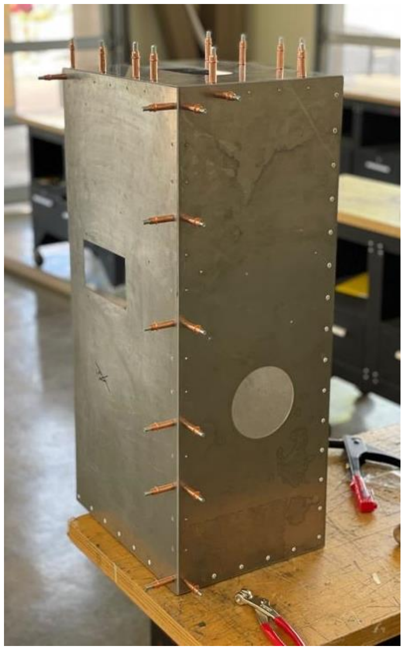


Figure 14: Cleco clamps being used to hold the chamber walls together while riveting the chamber.

Step 4: RTV heat sealant was applied to the outside box edges to ensure there were no heat leaks from the riveted edging connections.

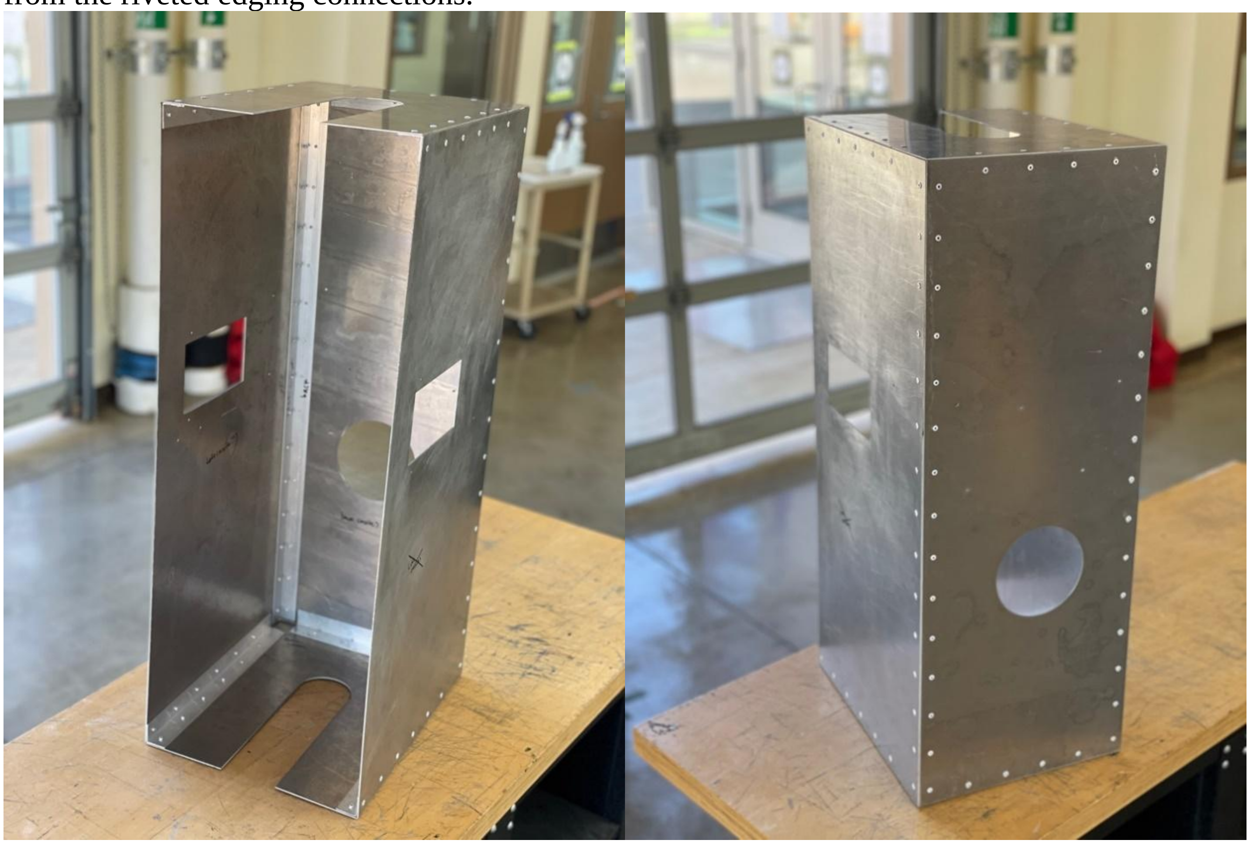


Figure 15: Finished aluminum chamber ready for sealant.

6.3 Outer Chamber Construction

The outer chamber was constructed from multiple flat carbon fiber and fiberglass composite panels joined together with L-brackets. The back panel is removable and held in place using bolts and wing nuts. Additional insulation material was added, fitting in between the outer composite structure and the aluminum inner chamber. Great consideration was used in the placement of this insulating material to avoid regions of space dedicated to heating and cooling components, such as the fan and ducts.

Step 1: The surface was prepared and then vacuum bagging was placed on flat aluminum or steel for the flat panels.

Step 2: The pre-preg carbon fiber and fiberglass material were cut to length. For each panel there are two layers of carbon fiber on the outside faces, and in between are six layers of fiberglass. The fiberglass thread orientation so that the alternating sheets are perpendicular to each other.

Step 3: Wet plies were laid on to the flat metal pieces, with close attention paid to eliminating bubbles and gaps.

Step 4: Peel ply was applied over the top of the laid-up composite, again with close attention paid to eliminating air bubbles and wrinkles.

Step 5: A rectangle of tacky tape was placed on the mold surrounding the composite and apply vacuum bagging material. The end of the vacuum fitting was placed inside the bag and attached to the vacuum hose on the outside before the bag was sealed shut.

Step 6: The vacuum pump was used to apply suction to the part. Extra care was taken to eliminate bridging and gaps. The bags were also checked for air leaks.

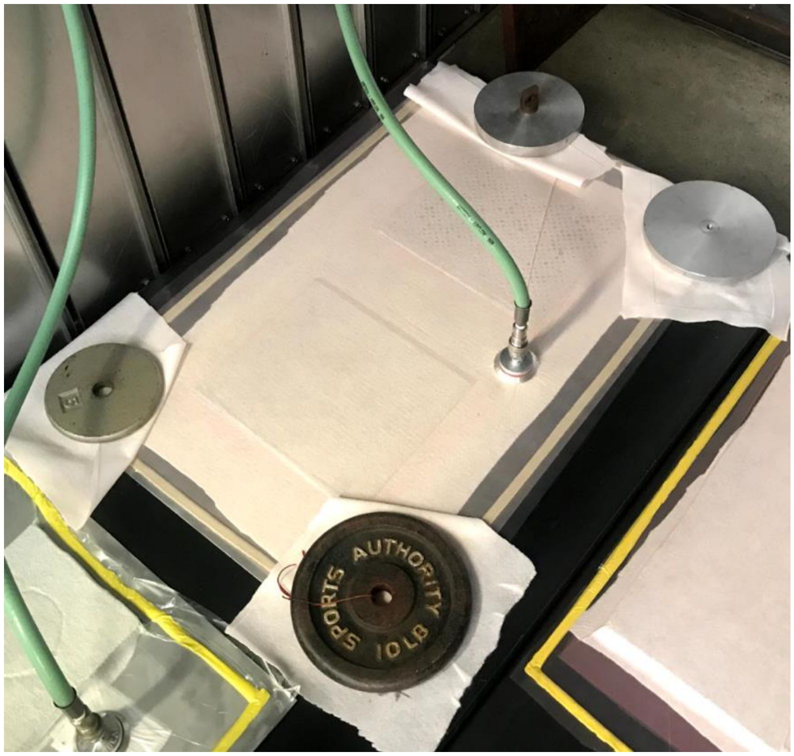


Figure 16: A completed panel layup sealed under a vacuum bag. Weights were placed in the corners to ensure the tacky tape did not lift and let air fill the bag.

Step 7: The layups were cured in the Composites Lab heating chamber. After curing, the vacuum bag and breather were peeled off the composite panels as seen below in Figure 17.

Figure 17: Vacuum bags being peeled off of the shiny surface finish sides of the panels.

Figure 18: Completed composite panels, pictured before being sent to the waterjet for proper sizing and hole cutting.

Step 8: Cured flat panels and brackets were water jetted to the correct size and holes were cut for ducting system routings using the waterjet.

Step 9: 2 sheets of dry carbon fiber were cut and covered with epoxy, this time laid up over long rectangular beams in a u-shape. The beam layup was then vacuum sealed.

Figure 19: (left) L-brackets vacuum sealed and ready for cure cycle. (right) Brackets out of vacuum bag before cutting into L brackets.

Step 10: Once cured, the u-shapes were cut in half to create composite l-brackets. The thinner part was left as u-shapes to be cut and used as structural support for the internal chamber.

Figure 20: 1 inch u-channel used for structural supports.

Step 9: Panels were assembled into box shape by placing the panels against each other at 90-degree angles, using large weights to hold them in place. Using epoxy, all panels were bonded except the back in place using L brackets at the edges after correctly preparing each surface with sandpaper and acetone cleaner.

Figure 21: Composite panels being epoxied together using weights and flat surfaces to ensure perpendicularity and good bonding surfaces.

Step 10: The back chamber wall was aligned with back l-bracket supports of epoxied external chamber and match-drill holes through both. Bolt heads were epoxied and placed through holes with threaded ends facing out of the chamber. The back chamber wall was placed over the bolts to properly align them, with a vacuum bag separating it from the rest of the chamber so the back did not bond to the rest of the assembly.

Figure 22: (left) Inner view of the bolt heads being epoxied to the back flanges. (right) Outer view of the vacuum bag being used to prevent the back panel from sealing to the flanges as the wingnuts hold the bolts in place while drying.

6.4 Door Construction

The door was constructed using aluminum sheet metal, composite lay-up, insulation, and a ceramic glass viewport that were together by rivets, RTV heat seal, and epoxy.

Step 1: The water jet was used to cut the internal sheet of aluminum out of the aluminum sheet metal stock. It also created rivet holes along the edges to be used to connect the aluminum edging to bond to the composite exterior. Rivet holes were cut with the water jet for the aluminum J channel that will hold the glass to the door.

Step 2: The bottom aluminum edge and the J-channels were riveted to the aluminum door sheet. Along with this, the composite flanges were bonded to the sides to create a surface for the composite side of the door to bond to. The side J-channels were epoxied to reduce the number of sharp edges caused by rivets on the ceramic glass.

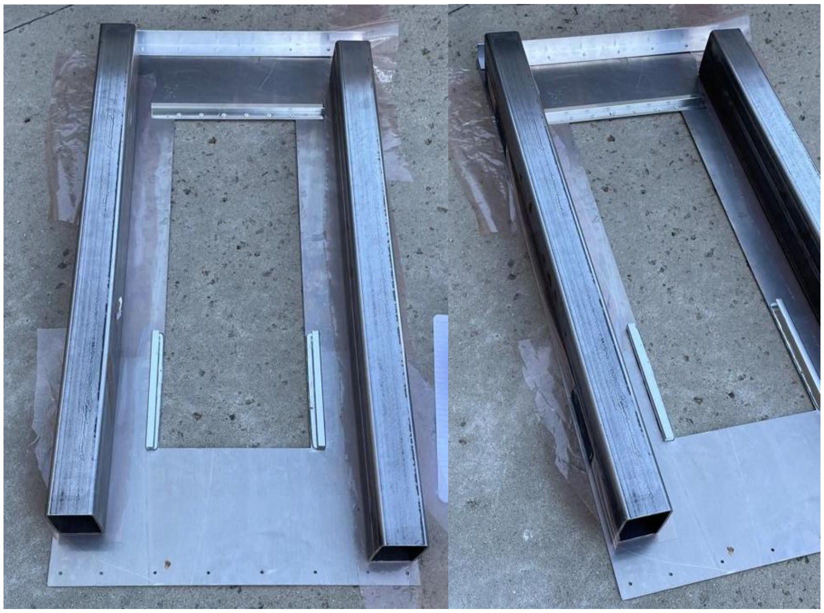


Figure 23: Shows the riveted portions of the door and the composite flanges being epoxies to the door.

Step 3: Before the ceramic glass was slid into the J-channels, high temp weave gasket was secured between the sections of J channel. The glass was then slid into place from the top and RTV was put over the rivets on the bottom J channel and at the edges of the other J-channels.

Step 4: After the glass was in position, the top aluminum edge for the door was riveted onto the aluminum sheet. With all the components done, the aluminum side of the door was flipped over and RTV sealant was placed around the inner edge of the viewport to create a seal on the inside of the chamber.

Step 5: A matching composite sheet was cut to the shape of the aluminum sheet in step 1. 90° composite edges and 2 J-channels were epoxied to the composite so that all the edges had composite lips. Before epoxying the third J-channel, the glass was positioned in the J-channels. After the glass was in place, the last J-channel was epoxied to fix the ceramic glass in place.

Figure 24: (left) Weighed down composite angles while epoxying. (right) Last J-channel being epoxied in the upper left corner with protective plastic over to prevent anything from getting on the glass during the cure time.

Step 5: Insulation wrapped in radiation shielding was placed around the glass viewports.

Figure 25: Shows the radiation shield placed around the viewport. Aerogel insulation is below the shiny surface seen.

Step 6: The aluminum side of the door was epoxied to the composite side.

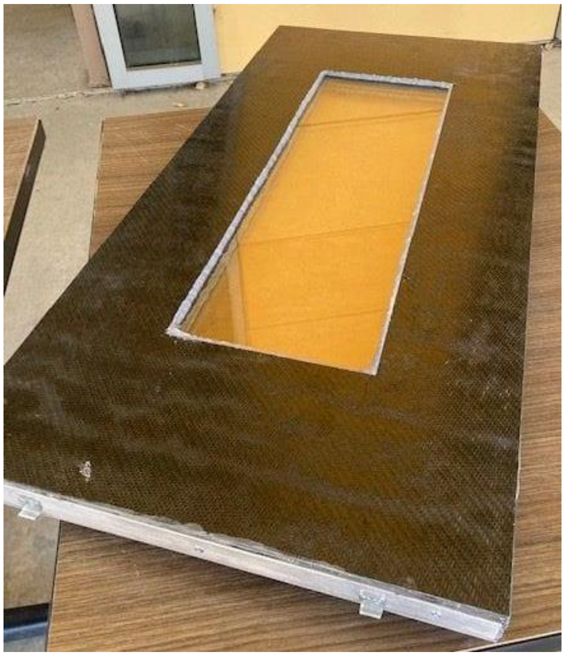


Figure 26: Shows the door after both sides were epoxied together.

Step 7: A power drill and rivets were used to attach the compression latches to the top and bottom of the door.

6.5 Rail System

The rail system will be constructed by using simple 1in diameter steel piping with threads cut into the appropriate locations to attach to the LD50. The middle section of the rails will be screwed into threaded holes located on the LD50. The ends will each have adjustable "stool feet" to provide extra support when moving the chamber on and off the LD50.

Step 1: Aluminum pipe was cut to the appropriate lengths using the metal chop saw and debur the ends using a belt sander.

Step 2: The drill press was used to drill pilot holes for the stool feet and support bolts, with a hand tap used to create the threads on the pipe.

Step 3: The end mill was used to create countersink for bolt holes, so flathead bolt ends did not protrude from rail system. Hand tools were used to create chamfers and remove excess material from the threaded holes.

Step 4: The stool feet were screwed into the ends of the rail as much as possible.

Figure 27: Rails with drilled holes and stool feet installed.

Step 5: Threaded flathead bolts were screwed into the LD50 holes and the pipe rail at the same time.

Step 6: The stool feet were unscrewed until the rubber grips were tight between the machine and the rail. A level was used to ensure both rails would provide an even surface for the chamber to rest on.

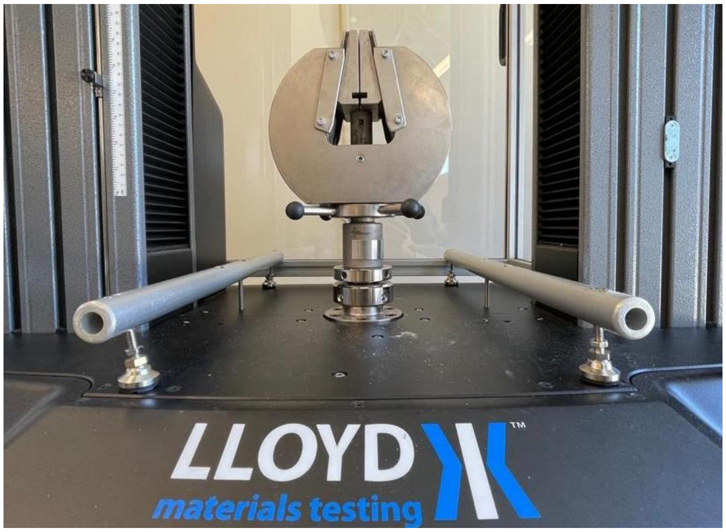


Figure 28: Shows the rails fully installed to the LD50 machine.

6.6 Full Assembly

The main systems put together include the inner chamber, outer chamber, door, and the rail system. While the rail system was already attached to the LD50, all other components needed to be assembled with each other. The general construction of the chamber started by attaching the inner chamber and outer chamber, attaching the door, and then placing the chamber on the rails fixed to the LD50.

Step 0: The Controls team attached their ducting system components to the inner chamber.

Step 1: Aluminum chamber was positioned from the back of the composite chamber when the back wall was unbolted. The aluminum chamber was connected to the composite chamber by using RTV sealant on slot supports. This was used to allow for the aluminum chamber to be able to be taken out by stripping the sealant, rather than having it permanently affixed with epoxy. RTV was applied around the open face of the aluminum chamber everywhere it touched the composite.

Step 2: Removable insulation “pillows” for the back and top of the chamber were created to be easily removable during maintenance. These pillows were made by cutting large pieces of radiation shielding, filling one side with aerogel, and then folding it in half to seal it. An example of one of these pillows being made is seen in Figure 29.

Figure 29: Shows the process of making the insulation pillows from left to right.

Step 3: Aerogel insulation was wrapped in radiation shielding and placed around the ducts on the aluminum chamber. Insulation was also stacked in the bottom of the chamber in layers of radiation shielding and aerogel.

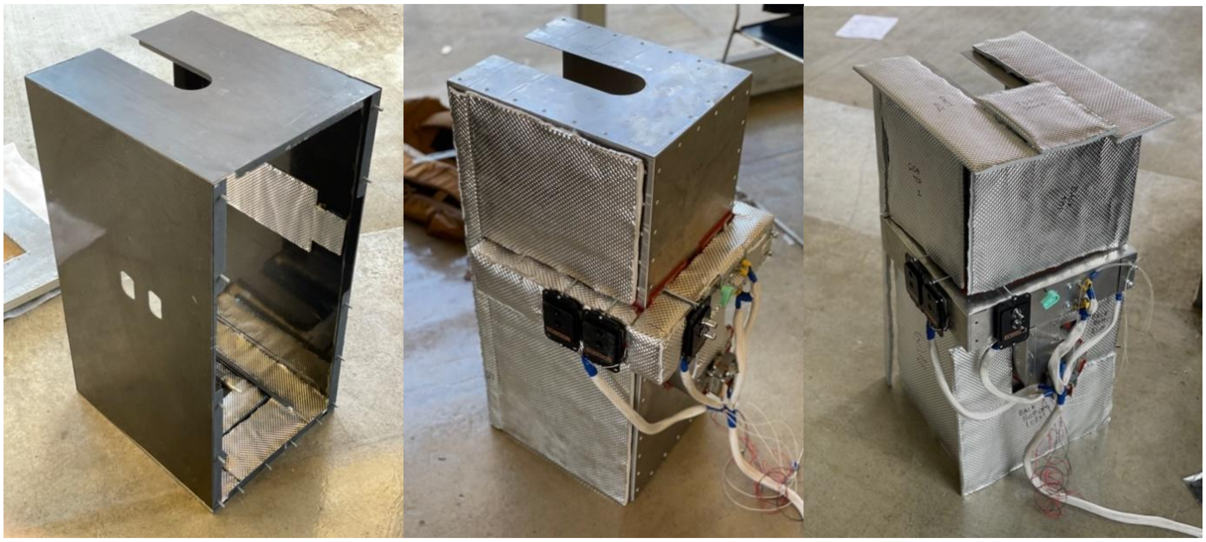


Figure 30: (Left) Insulation & radiation shielding installed to the bottom. (Middle) Radiation shielding around the ducts + permanent insulation pillows. (Right) Removable insulation pillows included.

Step 3: The back wall of the outer chamber was bolted back on the external chamber with wing nuts, the chamber was positioned with the rails on the LD50, and the door was latched to the front of the chamber.

Figure 31: Show the fully assembled chamber on the LD50.

7. Design Verification Plan

The structural design of the inner and outer chamber system was contingent on the use of composite components, as they are used heavily in the design. Strength testing of the composite components was conducted to investigate the properties of the wall panels. The insulating properties of the design are also important to allow the inside of the chamber to reach the specified 210° C internal temperature safely. Full records of specification tests are included in the Design Verification Plan, listed as Appendix J. For details on the test procedures used see the Test Procedures document listed in Appendix R.

7.1 Composite Tests

The strength of the composite was investigated using standard compression testing and tension testing to determine if the fiberglass and carbon fiber sheets that are to be used in the environmental chamber will safely withstand our maximum expected force of 20 lbf (Appendix A: QFD House of Quality). Sample sheets of corrugated fiberglass were made and cut into pieces to be tested.

For compression testing, the corrugate pieces were placed in the LD50 machine found in the Composites Lab. Flat plates were placed in between the jaws and the corrugate for even force application. Force was applied by the jaws until failure is achieved, with the maximum force recorded. Preliminary compression testing was performed by graduate student Marius Jautilus, with Figures 32 and 33 depicting visual results. Figure 34 depicts the graphical results of the preliminary compression tests, indicating that the vertical trapezoidal composite corrugate with the back sheet experienced failure conditions at an applied load of 1800 lbf.

Figure 32: Sample cut piece of fiberglass corrugate to be tested.

Figure 33: Fiberglass corrugate undergoing compression testing. Failure modes can be seen in the fracturing of the trapezoidal corrugate and separation of the back plate.

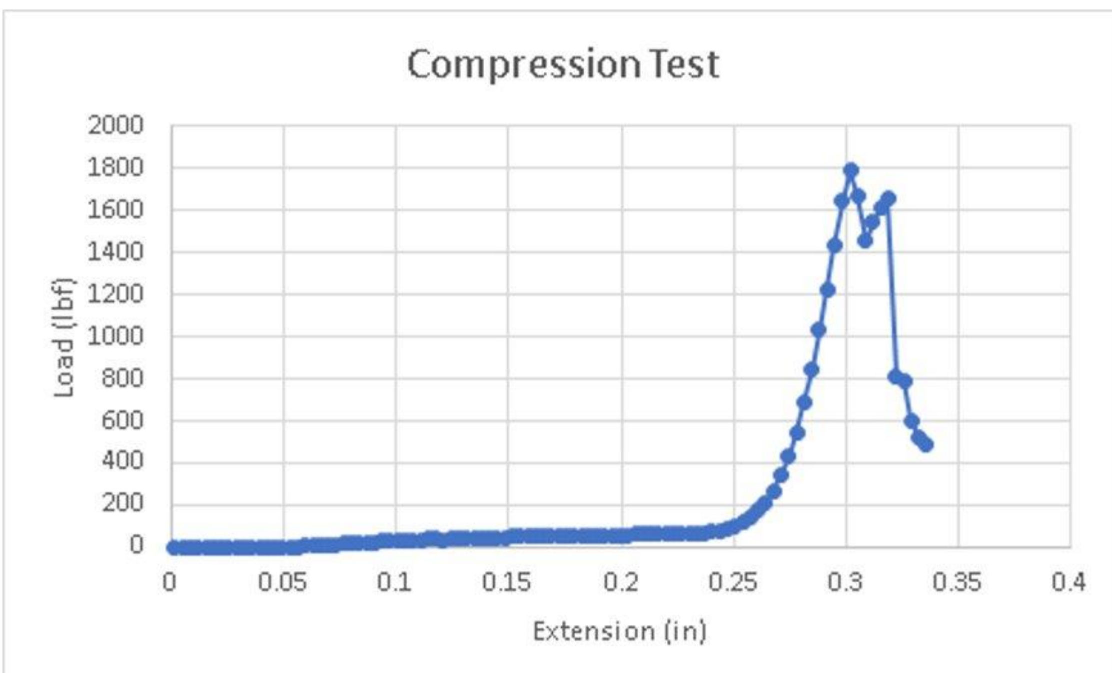


Figure 34: Data from preliminary compression test.

After tests on the corrugated structure resulted in strength significantly beyond our design needs, our team decided it would be worth comparing the performance to a simple flat sheet of composite to optimize manufacturing time and material use. To do this, a sheet of composite was made using 2 layer of carbon fiber with 6 layers of fiber glass. The fiberglass was sandwiched between the two layers of carbon fiber and oriented in a 0-90 pattern. As there were lots of different pre-impregnated carbon fiber in the composite's lab, this procedure was done twice with two different types of carbon fiber which include one manufactured by Boeing and one with the same curing requirements as the Boeing carbon fiber. After these sheets were cured, they were cut into strips of roughly 1 in by 10 in. These were then tension tested in the LD50 machine and the following results were developed.

Table 6: Dry carbon Fiber Lay-Up Sample Dimensions

Test sample	Width [mm]	Thickness [mm]	Height between jaws [mm]	Load at Failure [N]	Load at Failure [lbf]
1	22.7	1.3	167	12,543	2,820
2	22.8	1.2	172	11,613	2,611
3	23.3	1.3	175	11,358	2,553

Table 7: Boeing Carbon Fiber Lay-Up Sample Dimensions

Test sample	Width [mm]	Thickness [mm]	Height between jaws [mm]	Load at Failure [N]	Load at Failure [lbf]
1	22.9	1.6	180.5	14,313	3,218
2	23.0	1.6	180	14,245	3,202
3	22.9	1.6	173	16,255	3,654

These results from Tables 6 and 7 were then plotted against the machine extension to produce Figure 35 below. To view the raw data from these composite tests, view Appendix P. It can be noted that two samples from each of composite layup had two different peaks. This represents an occurrence where the carbon fiber layers broke before the fiber glass layers so there was a small dip before the machine continued to stretch the fiber glass until it failed. The second peaks from these curves can be ignored as the fiber glass layers are used for insulation not material strength. The carbon fiber gives the composite the strength and rigidity desired for the structure of the chamber so the points at which this break is most important. If the carbon fails, then the walls would start to become less rigid weather or not the fiber glass failed, so the carbon is the design fracture peak that the team is concerned with.

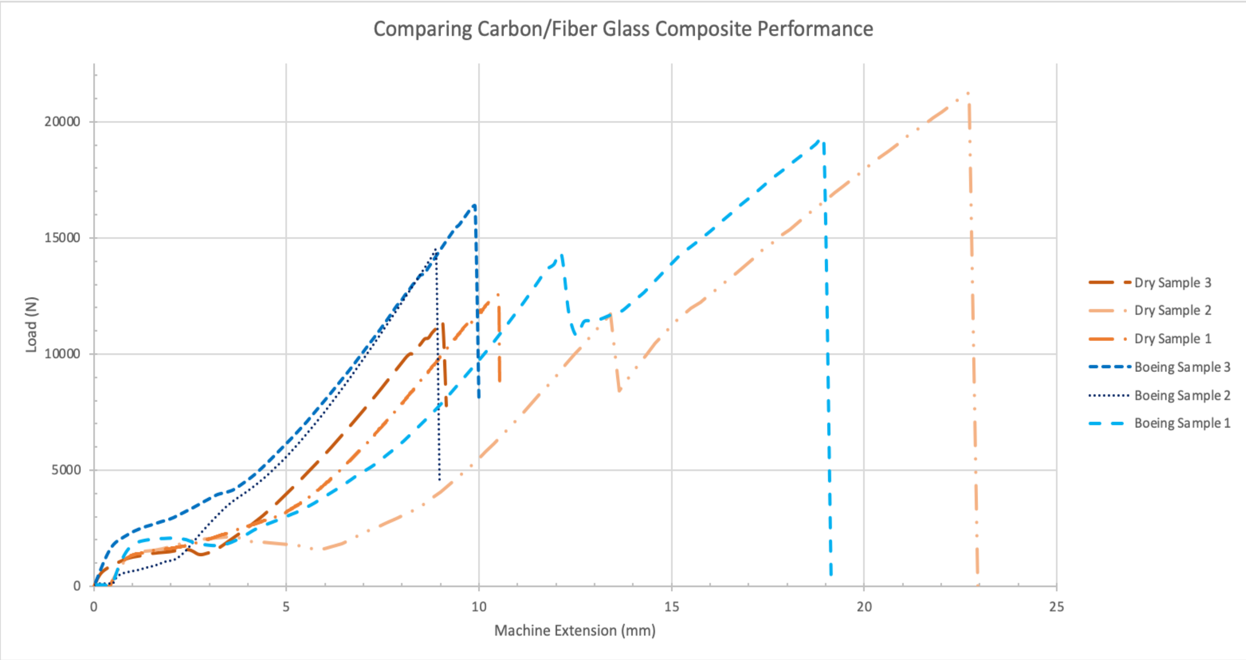


Figure 35: Performance from Composite sample tests.

As seen when observing the first peaks of each set from Figure 35, it was clear that the Boeing carbon fiber had a higher yield strength and ultimate failure loading point than the dryer carbon sample. This helped the team to determine that the Boeing carbon fiber would be the best to use and verified that it would not be unnecessary to go through the rigorous process of manufacturing the corrugated composite panels. While the corrugated panels performed well in loading situations, in order to insulate them well, a flat panel would need to be added to the outside which would result in the same if not more composite material used to construct the chamber. To reduce the amount of composite material used, reduce the total weight of the project, and save the extensive amount of time required to manufacture corrugated panels, the team moved forward in the design using the simple flat plate carbon and fiberglass composite panels instead of the corrugated panels.

7.2 Heat Bleed Test on Structural Prototype

A key aspect of the environmental chamber is its ability to insulate against the heat generated within the internal chamber area. To protect against the 210 °C maximum design temperature in the testing area, Dr. Elghandour has requested that the exterior of the chamber be cool enough to be touched immediately after testing. To meet this specification, the temperature of the external chamber wall must not exceed 60 °C at any location on its surface which is the OSHAA threshold surface temperature for burns.

Preliminary heat bleed testing was first performed on structural prototype to investigate the planned measurement process. This test was performed as a preliminary proof of concept, being built out of thin aluminum sheet metal and insulated with a simple hemp-silicon material. Heat was applied to the internal wall with an electric heating pad set to its maximum temperature of 190 °C and a thermocouple was used to take measurements at the internal and external wall locations. Exterior walls were sampled with either convection, conduction, or a combination of the two to investigate how different conditions affected temperature readings.

Data from the preliminary test was promising, seen in Table 8, showing acceptable temperatures even with suboptimal insulating conditions. The initial testing process highlighted the need for a heating element that could meet the 200 °C testing conditions as well as a safer way to take temperature readings of the walls that would be necessary for testing the verification prototype.

Table 8: Data from preliminary heat bleed test

Measurement Locations		Temp [°F]	Conditions
External	Back Wall	77	Pure conduction
	Right Wall	74	Natural convection
	Left Wall	102	Pure conduction
Internal	Back Wall	135	Pure conduction
	Top wall	165	Conduction/ Convection
	Insulation	92	Pure Conduction

Figure 36: Heat Blead test set up with heat pad inside the internal chamber and thermocouple to verify its temperature and the internal chamber pressed firmly against silicone hemp insulation.

7.3 Heat Bleed Tests on Final Prototype

Following the completion of the design verification prototype, the amount of heat bleed was then tested by heating local areas of the inner chamber wall surfaces to 210°C using a standard heat gun. Upon reaching the target internal temperature, an infrared heat sensor laser was used to measure the local external temperatures of the aluminum sides and the composite sides of the chamber. These readings were taken at the site of the heating element on both sides and maximum temperatures were taken around the box at the end of the test to get a rough idea of overall performance. High temperature vacuum bags were also wrapped around the chamber and the door during testing to help reduce the amount of convection during testing. Images of the testing setup can be seen below in Figure 37.

Figure 37: Testing set up for the heat bleed test on the main chamber.

Figure 38: Testing set up for the heat bleed using a heat gun, laser temperature reader, and high temp vacuum bags to prevent convection.

The testing was done in four main parts of the chamber, and these include the bottom left chamber wall, the bottom right chamber wall, the door frame, and the door glass. The left and right walls of the chamber performed nearly identically where the inside aluminum wall reach temperatures above our desired temperature at roughly 220°C while the composite outer surface of the chamber remained at less than roughly 35°C. A graphic representation of this data can be seen below in Figure 39 where the heating device was shut off at 20 minutes to allow a 5-minute cool off data point to be collected. When heating each wall, at the final heating reading of 20 minutes, the team also took a data point at the top of the wall and the top of the chamber. For the top of the tested wall, the final temperature for both sides was between 40-45°C which lies in a safe temperature range to touch but will feel rather warm. The top of the chamber lied more in the range of 60-65°C which is high enough to minorly burn the user if touched for a while; but after 5 minutes of cooling, the top of the chamber dropped down to 40-45°C which is in a safe touching range again. The team recommends avoiding touching the top of the chamber until either the 5-minute cooling time has passed, or the user is wearing heat protective gloves.

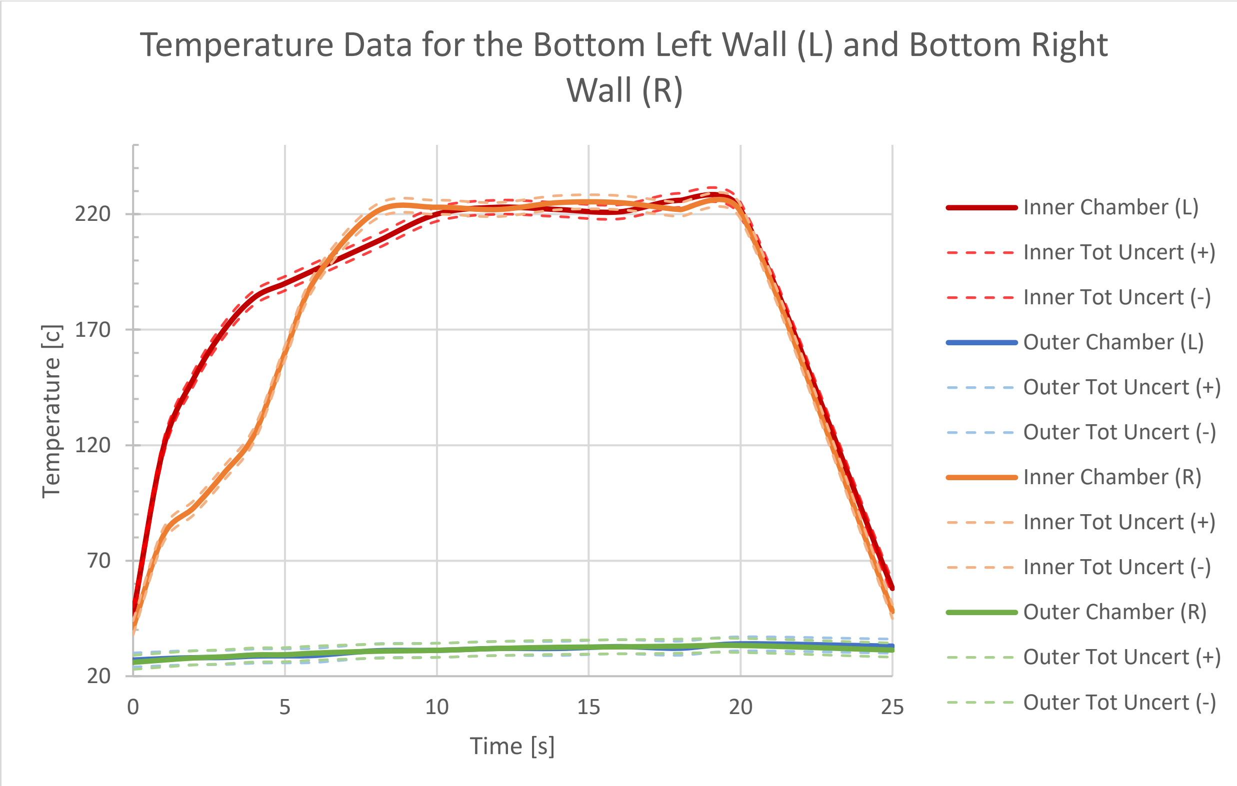


Figure 39: Temperature data for the bottom left wall and bottom right wall, where the inner chamber is the aluminum wall, and the outer chamber is the composite wall. Raw data and additional graphs can be found in Appendix Q.

When testing the door, the team performed two tests using the same set up as the chamber, one test on the door frame and one test on the glass. The test on the door frame was conducted with the heat gun centered on the left frame wall and heated to 190°C (a higher temperature was difficult to reach in the testing conditions we could use). The maximum temperature reached on the composite side of the door was in the range of 45-50°C and dropped to a range of 42-48°C after 5 minutes. In both cases the door is safe to handle when heat is directly applied to the door however it will feel quite warm to the touch so gloves may help a user feel more comfortable handling the door if it needs to be taken off before allowing time to cool. At the end of this first test, the glass closest to the door frame was at a temperature of roughly 77°C and the center of the glass was at a temperature of roughly 58°C. This shows that heat transfers slowly across the glass. The testing of the glass was conducted by placing the heat gun directly under the center of the glass and quickly getting the inside of the glass up 250°C and the then recording the cooling time. The team discovered that the outer pane of glass passes the safe to touch temperature relatively quick and takes roughly 15-20 minutes to return to a safe touching temperature. Due to this fact, we don't believe users should be touching the glass at any time when the machine is being used and should be allowed proper cooling time before directly touching either glass pane. The biggest problem with the door testing is due to the fact that heating elements won't be place directly up to the door so our testing is considered to be a worse case than the chamber would most likely act. Along with this, the glass temperature was measured using electrical tape on the glass panes as our contact point for the laser to read which may not be the most accurate way to get these temperatures. The door performance can be seen below in Figure 40.

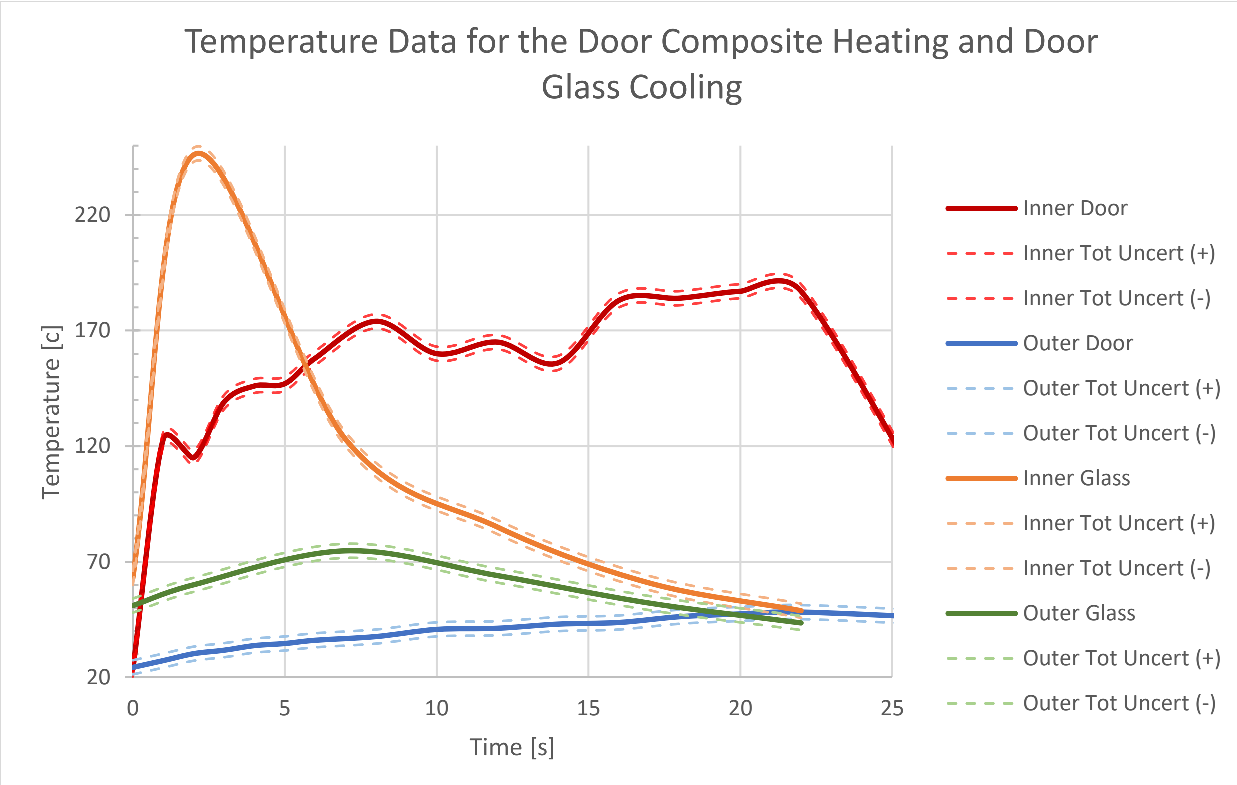


Figure 40: Temperature data for the heating of the aluminum/composite portion of the door and the door glass cooling curve from peak temperature. Raw data and additional graphs can be found in Appendix Q.

Uncertainty propagation was performed on all the heat bleed tests for the final prototype. In Figures 39 and 40, the dotted lines represent the total uncertainty above and below the recorded data taking into account the laser resolution of ± 0.05°C and the estimated laser position uncertainty of ± 3°C. When the infrared laser was being used to record data, it was aimed at the same position on each wall; however, as it's a handheld device, it would easily jump off of the reading point and could vary by roughly 3°C. All the uncertainty data for these tests can be seen in Appendix Q.

The data recorded demonstrates that the insulation of the chamber is sufficient. The maximum temperature reached at any exterior point on the chamber walls during the testing was about 40°C and the maximum temperature on the door frame was about 48°C, which is reasonably safe for users to handle and meets Dr. Elghandour's exterior temperature criteria. However, during tests the top of the chamber reached temperatures approaching slightly dangerous levels but became safe within 5 minutes of cooling; so, it is recommended to avoid touching the top of the chamber without thermal gloves for at least 5 minutes. Along with this, the door frame does get relatively warm but remains under burning temperature so it should be touched with caution or wait for 5 minutes of cooling. The chamber glass should not be touched when the machine is in use as this is the one part of the chamber that could easily burn a user if touched. The door glass takes roughly 15-20 minutes to cool to a safe touching temperature so it should never be touched unless the operator is certain enough time has passed.

7.4 Alignment Tests

Upon assembly of the chamber, the prototype chamber structure and door were tested to ensure that they align sufficiently as to achieve a professional look that can be replicated in the manufacturing of the final design. Any overlapping or mismatched areas were investigated visually to make note of any areas that fail visual inspection. Certain areas of the prototype produced small gaps up to 0.25 inches after assembly, which were then noted and filled with RTV sealant to prevent heat bleed. Upon performing alignment tests on the door interface, additional RTV sealant was applied along the door and chamber interface to reduce gaps. Following these changes, the prototype alignment was verified as sufficient.

Figure 41: The alignment of the door to the main chamber.

The image above shows that the door itself aligns well with the front of the main chamber and any minimal air gaps were easily filled with RTV to ensure and air-tight seal.

Figure 42: The rails inside the LD50 enclosure

The figure above demonstrates that the rails not only secure to the bed of the LD50 but also fit snuggly within the enclosure, about 1/8 in of separation. Additionally, the height of the rails and leveling were also measured to ensure a better, more flush fit of the environmental chamber onto the LD50.

Figure 43: The main chamber on the rails in the LD50

The figure above certifies that the main chamber not only fits within the uprights of the LD50 but also around the arms that will be testing future samples. Furthermore, in the Figure_ below it can be seen that the slots fit onto the arms and in the main chamber.

Figure 44: The main chamber with slots installed placed in the LD50.

Finally, Figure 45 below demonstrates the fully assembled chamber fitting both on the LD50 and within the machine enclosure. Sufficient room was also available for heating and cooling elements used by the controls team for their system design.

Figure 45: Fully assembled chamber inside the LD50 enclosure.

7.5 Ease of Installation Tests

Dr. Elghandour has specified that the completed chamber should be installable by at most two people. The final design chamber should weigh no more than 50 pounds to meet that requirement, and was be measured using a large scale in the Composites Lab.

Figure 46: The external chamber being weighed (in grams).

Meeting the single-person installation target also meant that the chamber needed to be positioned easily within the LD50's protective shield and around the machine's vise jaws. The rail mounting system of the final design assisted in positioning and visual inspection of the chamber's locating features, such as the rail levels, were conducted to ensure that they are effective.

Figure 47: The Environmental Chamber being installed with a two-person team.

For instructions on how to set up the LD50 machine for installation of the environmental chamber, and more details on how to install the chamber, see details in the User Manual in Appendix O.

8: Project Management

The project design process began with the background research of the product and meeting with the project sponsors to fully understand their wants and needs, which was used to define the engineering problem and set the project scope. From here the team went through the ideation process to help envision different solutions to the problem and presented the chosen design that resulted from this step at the Preliminary Design Review. The team then moved forward in the development of the design of the product while creating a functional prototype, which was presented at the Critical Design Review. Upon sponsor approval of the Critical Design, the design verification prototype was manufactured in conjunction with the design constraints and requests set by the controls team on the project. Heat bleed testing, weight testing, and fit and alignment testing was then conducted to confirm that the prototype design would meet design criteria. A more detailed timeline outlining all the intermediate steps and goals can be found in the Gantt chart in Appendix H.

The design process followed throughout the project positively impacted the results from our verification prototype. Defining clear objectives based on sponsor requirements was helpful when working with design changes; and knowing the aspects of the project that needed to be prioritized was important in influencing how challenges were overcome. Ideation strategies used in developing the concept design were also utilized when brainstorming solutions to manufacturing challenges as they arose.

In learning from the Environmental Chamber project, future projects would benefit from earlier communication between interdisciplinary teams. The controls and structures teams worked mostly independently, and infrequent joint meetings led to design and manufacturing challenges that could have been avoided. Future project scheduling would also benefit from increased time spent on concept design and verification prototype manufacturing. Work on the low-cost model would have been helpful in identifying manufacturing problems early in the project; meeting with a knowledgeable shop technician early in design would have been similarly useful. This project also included significant manufacturing down-time, including composite cure cycles and epoxy cure times. Overlapping planned manufacturing weeks with written objectives from earlier in the project process would have been feasible and an effective use of time.

9: Conclusion & Recommendations

This document defines and describes the scope of this project, preliminary design, preliminary analysis, manufacturing/ testing processes and steps and the specs of the final prototype. The purpose of this Final Design Review report is to clarify and identify all design and testing paths for the environmental chamber's structure. The goal of this document is to lay down a clear insight into all design, testing and manufacturing pathways that were taken. Based upon the preliminary findings discovered during the IDR (Interim Design Review) a concept prototype was created and tested to verify current ideas and processes as well as provide ample data to justify certain design changes and paths. Additionally, insights into more ideal manufacturing processes were discovered through conversing with shop techs as well as personal experiences from fabricating the concept prototype. Furthermore, certain design and manufacturing changes occurred during the Manufacturing and Test review. Finally, once the final prototype was assembled final test were conducted to ensure it met the necessary specifications agreed upon. Ultimately, the final prototype met all thermal, structural and safety requirements.

In the case that future innovations or work be performed on the chamber there are several recommendations that this team would make regarding both the LD50 and the environmental chamber. For instance, it is recommended that the LD50 machine be moved in a way that provides easier access to the rear of the machine. Though the environmental chamber is lightweight, and its shape provides ample handholds, the ease of installation is largely hindered by the tight quarters both around the sides and rear of the machine. Additionally, it is recommended that the interface between the slots and the LD50 machine arms be continually lubricated as the rubber gasket provides a noticeable amount of friction. Furthermore, as the RVT sealant on the door and front of chamber will be experience consistent wear during chamber opening and closing, there are certain areas that may require touch ups to maintain proper sealing. It is advised that that a high temp warning be placed on the external glass pane on the door, as the temperatures may reach above OSHA's standard of safety. Additionally, it is recommended that flush handles be mounted onto the front or edges of the door to improve ease of installation and general safety.

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Appendix A: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

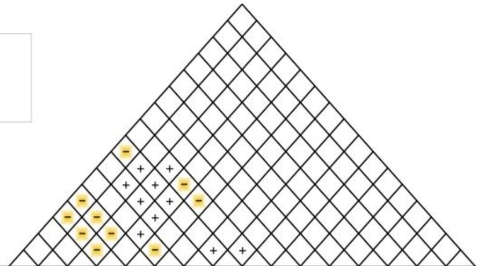
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Tensile Testing Environmental Chamber

Revision Date: 10/6/2020



WHO: Customers

Row #	Weight Chart	Relative Weight	Dr. Elghandour	Lab Students	Industry	Manufacturers	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants)
1		10%	10	9	10	9	9	Tall Enough for Testing
2		7%	9	7	6	6	9	Fit in Shield Width
3		7%	9	7	6	6	9	Fit in Shield Depth
4		9%	10	7	8	9	9	Installation by One - Two People
5		9%	9	7	9	9	9	Heat resistant Walls
6		6%	5	9	5	4	3	View Inside Testing Chamber
7		6%	6	3	6	9	9	Space for Control Unit
8		7%	8	3	7	8	9	Light Outer Wall
9		6%	9	2	7	7	9	Affordable
10		8%	7	7	7	8	9	Simple Installation around Jaws
11		8%	8	6	9	8	9	Well-Insulated/Sufficient Wall Thickness
12		9%	9	8	9	10	9	Withstand Sample Fragment Impact
13		6%	5	8	6	5	9	Quick Temperature Changes
14		0%						
15		0%						
16		0%						

HOW: Engineering Specifications (Tests)

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction of Improvement	◇	▼	◇	▼	▼	▼	▲	◇								
WHAT: Customer Requirements (Needs/Wants)	Chamber Height	Chamber Width	Exterior Chamber Depth	Weight	Heating Times	Cost	Impact Strength	Chamber Level	Interior Chmaber Depth							
Tall Enough for Testing	●	○	○	○	○	○	▽	▽	○							
Fit in Shield Width	▽	●	○	○	○	○	▽	○	○							
Fit in Shield Depth	▽	▽	●	○	○	○	▽	○	●							
Installation by One - Two People	▽	▽	▽	●	▽	▽	▽	○	▽							
Heat resistant Walls	▽	▽	▽	○	○	▽	●	▽	▽							
View Inside Testing Chamber	○	○	▽	▽	○	▽	○	▽	▽							
Space for Control Unit	●	●	●	○	▽	▽	▽	○	●							
Light Outer Wall	○	○	○	●	▽	○	▽	▽	○							
Affordable	▽	▽	▽	●	●	●	○	○	▽							
Simple Installation around Jaws	○	○	○	●	○	▽	○	●	○							
Well-Insulated/Sufficient Wall Thickness	▽	▽	▽	○	●	●	○	▽	▽							
Withstand Sample Fragment Impact	▽	▽	▽	○	▽	▽	●	▽	▽							
Quick Temperature Changes	▽	▽	▽	▽	●	●	▽	▽	▽							
HOW MUCH: Target Values	37 inches	17.5 inches	18 inches	25 pounds	45 minutes	$2,500	20 lbf	0.02 inches	8 inches							
Max Relationship	9	9	9	9	9	9	9	9	9							
Technical Importance Rating	271.4	270.2	272.4	452.7	363.3	331	304.3	234	272.4	0	0	0	0	0	0	0
Relative Weight	10%	10%	10%	16%	13%	12%	11%	8%	10%	0%	0%	0%	0%	0%	0%	0%
Curr. Products: Ametek Tensile Chamber	1	3	4	2	5	2	5	5	4							
Curr. Products: Instron Tensile Chamber	2	3	5	1	5	2	5	5	5							
Curr. Products: Univ. of Llorin, Nigeria Chamber	3	0	4	5	4	5	2	4	4							
Curr. Products: TestResources environmental chamber	4	1	5	4	4	3	4	5	5							
Curr. Products: Twing-Albert Environmental Chamber	5	5	2	1	3	2	4	4	2							
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

NOW: Curr. Products

Ametek Tensile Chamber	Instron Tensile Chamber	Univ. of Llorin, Nigeria Chamber	TestResources environmental chamber	Twing-Albert Environmental Chamber	Row #
10	8	8	2	8	1
5	5	9	0	8	2
5	5	9	0	1	3
2	2	8	1	2	4
9	9	6	9	9	5
8	7	0	9	5	6
9	9	6	9	9	7
2	2	9	1	2	8
2	2	10	1	2	9
7	9	0	7	7	10
9	9	6	9	9	11
9	9	7	9	9	12
6	6	3	5	6	13
					14
					15
					16

Appendix B: Decision Matrices

PUGH MATRIX

CONCEPT / CRITERIA	EXTERNAL HINGES	INTERNAL HINGES	SAFE LOCK MECHANISM	CRESCENT HINGE	SCISSOR HINGE	SUBMARINE DOOR
MANUFACTURABILITY	+	+	+	+	+	−
LOW COST	+	+	+	+	=	−
LIGHT	+	+	−	+	−	−
② INSTALLATION	−	−	+	−	−	+
SEALING ABILITY	S	+	+	+	+	+
STRENGTH	S	S	S	S	S	S
LOCKS DOOR	−	−	+	−	−	+
TOTALS	+0	+1	+4	+2	−4	0

Pugh Matrix – Installation

DATUM – Fixed Rail to machine and table behind (Most common for Industry)

Concept: / Criteria:	1) Telescoping Rail	2) Burger Folding Rail	3) Fully detachable "plug-in" Rail	4) Chamber Legs	5) Screw in supports	6) Locking wheels	7) Fixed rail on machine w/ rail clamps (various types)
Weight	S	S	S	+	+	+	+
Space	+	+	S	+	+	+	+
Cost	+	+	S	+	+	+	+
Manufacturability	−	−	S	+	−	+	−
Sturdiness	S	S	S	S	−	−	+
Ease of Instal	S	S	+	−	−	+	+
Aesthetic	+	+	S	+	−	−	+
Total	2	2	1	4 ★	−1	3	5 ★

SOLO- Pugh Matrix - 10/24

STUFFING PUGH MATRIX

CONCEPT / CRITERIA	(DATUM) loose-stuffed fiberglass	polyurethane foam injection	mineral wool stuffing	sand-filling cavity	air convective cooling
heat-resistant	//	+	+	−	−
light	//	S	S	−	+
affordable	//	−	S	+	−
thickness	//	S	S	−	−
quick temp changes	//	S	+	S	−
safe	//	−	S	+	+
total	0	−1	+2	−1	−2

CORRUGATE PUGH MATRIX (cross-section)

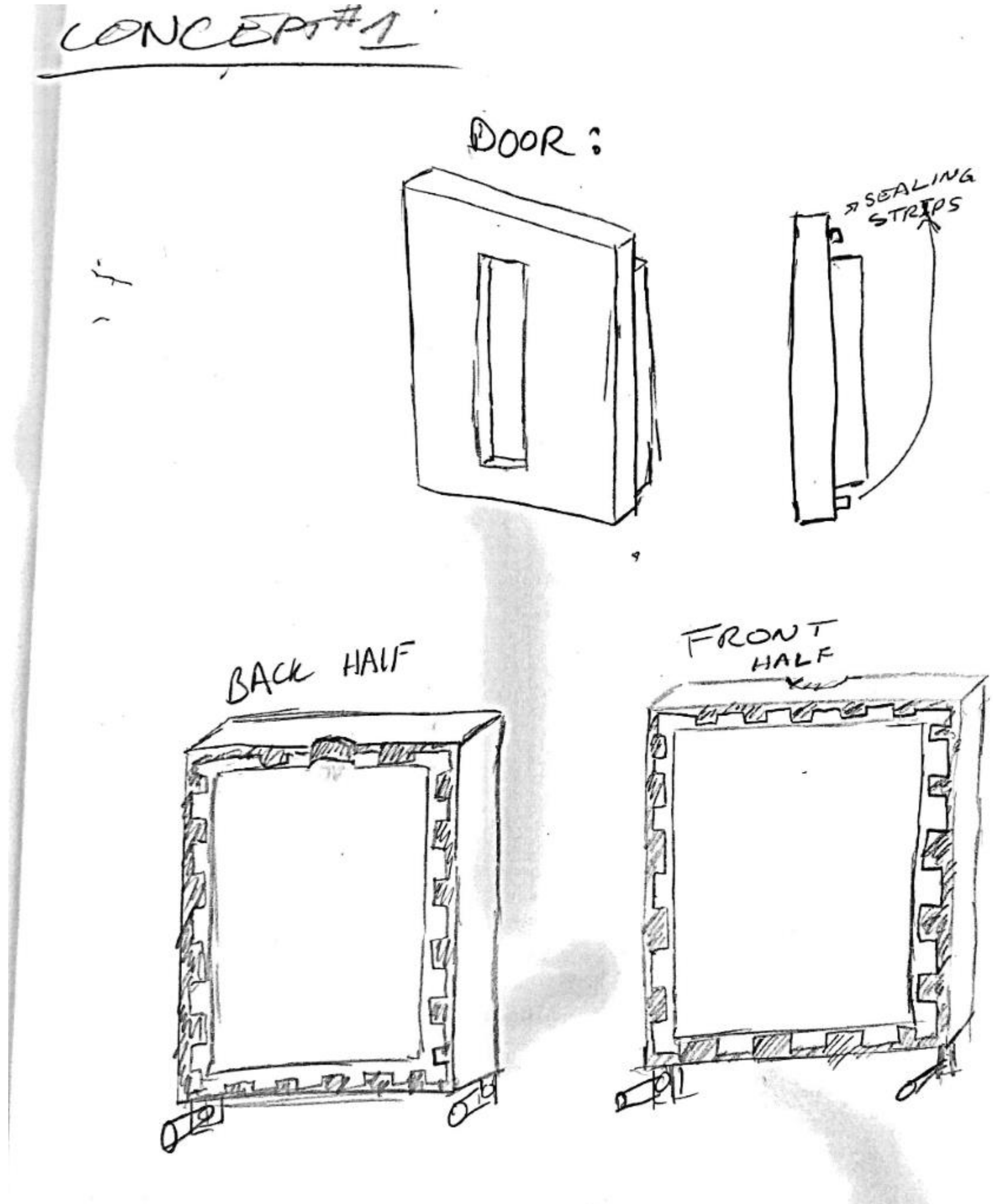
CONCEPT / CRITERIA	triangular (DATUM)	wave	square	trapezoidal	arch
manufacturability	"	S	S	+	−
light	"	S	S	S	S
affordable	"	S	S	+	S
thickness	"	−	+	+	S
installation	"	S	+	+	−
strength	"	−	S	S	−
total	0	−2	+2	+4	−3

	Chamber Assembly	Two Halves: left and right sides (A)	Two Halves: front and back sides (B)	Removable door/back with slot into place (C)	Machine arm/Chamber interface	Rubber Bearing (D)	EPDM Foam (E)	Rubber Flaps (F)	Greased O-ring (G)		
Tall enough for testing		S	S	S		S	S	S	S		
Fit in shield width		S	+	S		S	S	S	S		
Fit in shield depth		S	S	S		S	S	S	S		
Installation by one to two people		S	S	+		S	S	S	S		
Heat resistant materials		S	S	S		S	+	S	S		
View inside testing chamber		S	+	S		S	S	S	S		
Space for control unit		S	S	S		S	S	S	S		
Lightweight		S	S	S		S	+	S	S		
Affordable		S	S	S		S	+	S	S		
Simple installation around jaws		S	S	-		S	S	S	S		
Well insulated to outside		S	S	-		S	+	-	S		
Withstand fragment impact		S	S	S		S	-	-	S		
Quick temperature changes		S	S	S		S	S	S	S		
	Totals:	0	2	-1		0	3	-2	0		
	Rank	2	1	3		2	1	3	2		

Front and back sides attachment method	This method of assembling the box around the machine allows for easier assembly than the side-side idea, because space is constrained on the sides of the machine, but it can be accessed through the front and back after removing the blast shields. It also allows for a larger window in the front if the front section remains one piece. The two halves assembly method also would provide better sealing where the arm comes into the chamber because there is no need for a large gap or slot when sliding on to the machine, the two halves can be snug around the machine arm as they are assembled together.
EPDM foam sealing	This method of sealing the gap between the chamber opening and the machine arm is versatile because the foam is able to squish ad give way for minor adjustments needed, making assembly easy and sealing more ensured. The material is rated for our top temperature and is relatively lightweight and affordable.

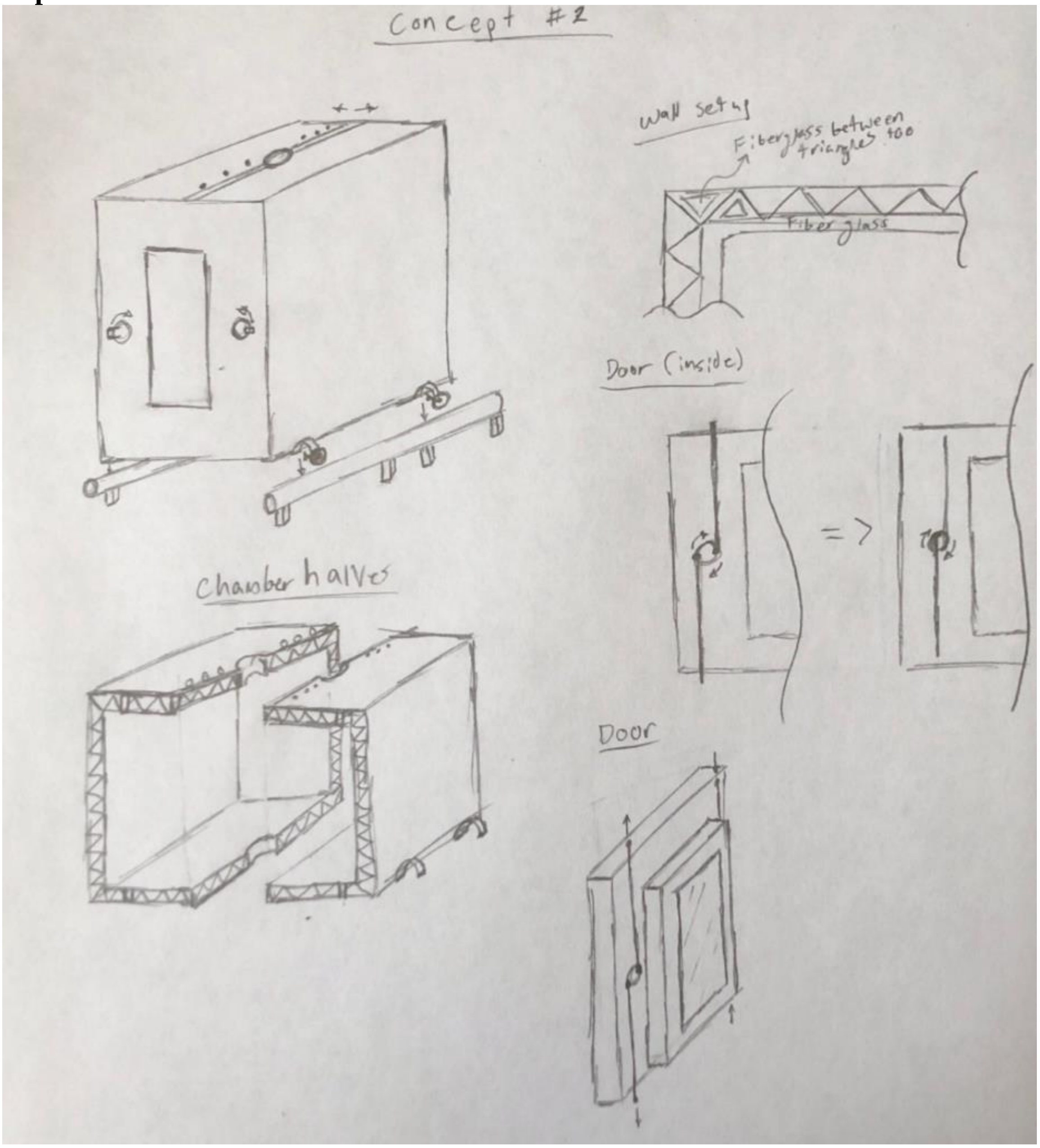
Appendix C: Concept Ideas

Concept 1:



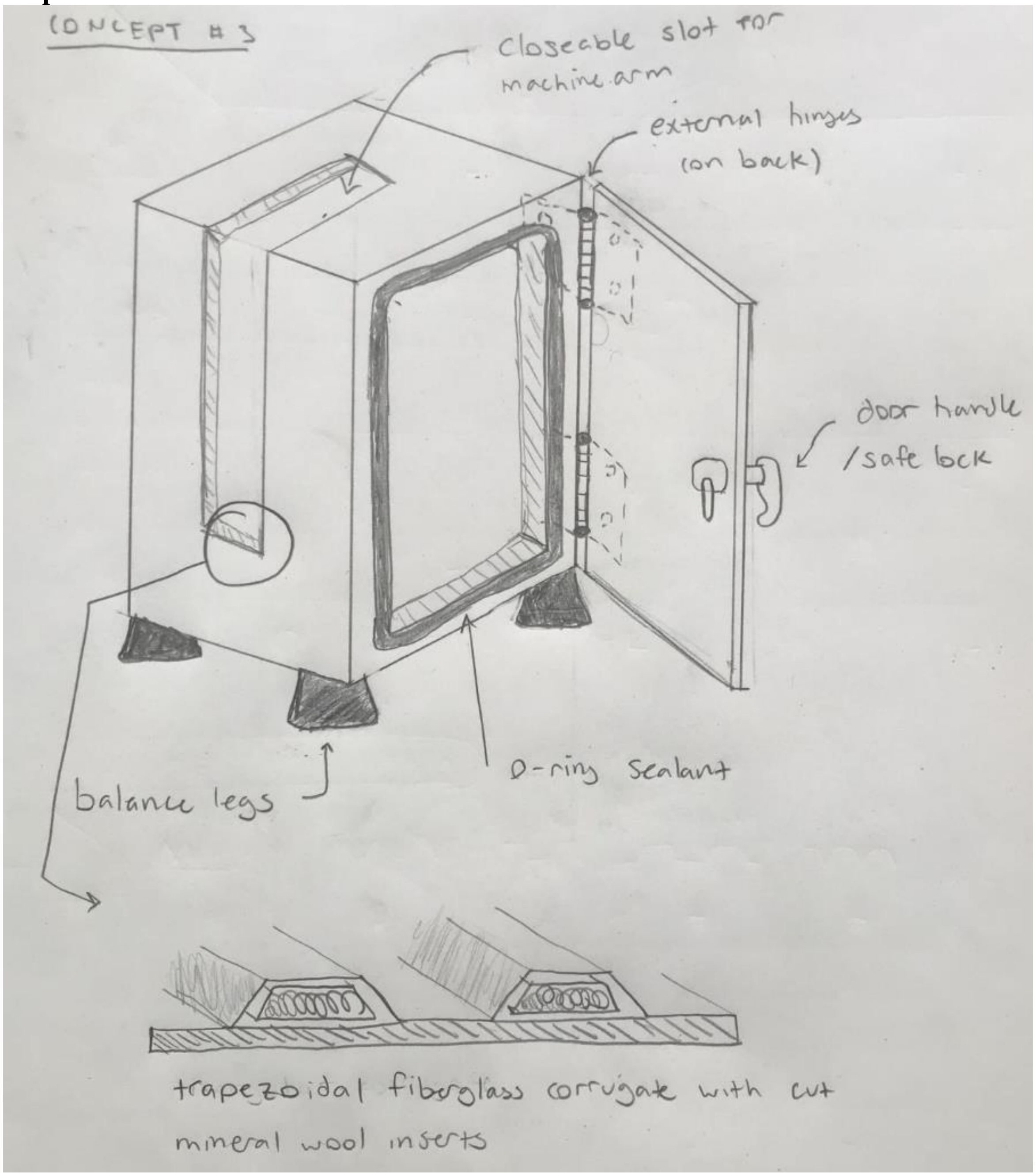
Concept 1 Depicts an enviro chamber split into a front and back half with a multi-level door, with insulation strips. Additionally, the chamber is mounted on detachable," plug-in" rails. For the insulation, the chamber uses a square corrugate which is then packed in with mineral wool sheets. This design addresses the installation issues that have arisen around the fact that the tensile testing machine is surrounded by an impact shield. Additionally, the splitting the chamber into front and back halves allows for an easy installation and a lightweight modularity. The square corrugate is a rather simple shape that would be easy to manufacture and pack with the mineral wool insulation.

Concept 2:



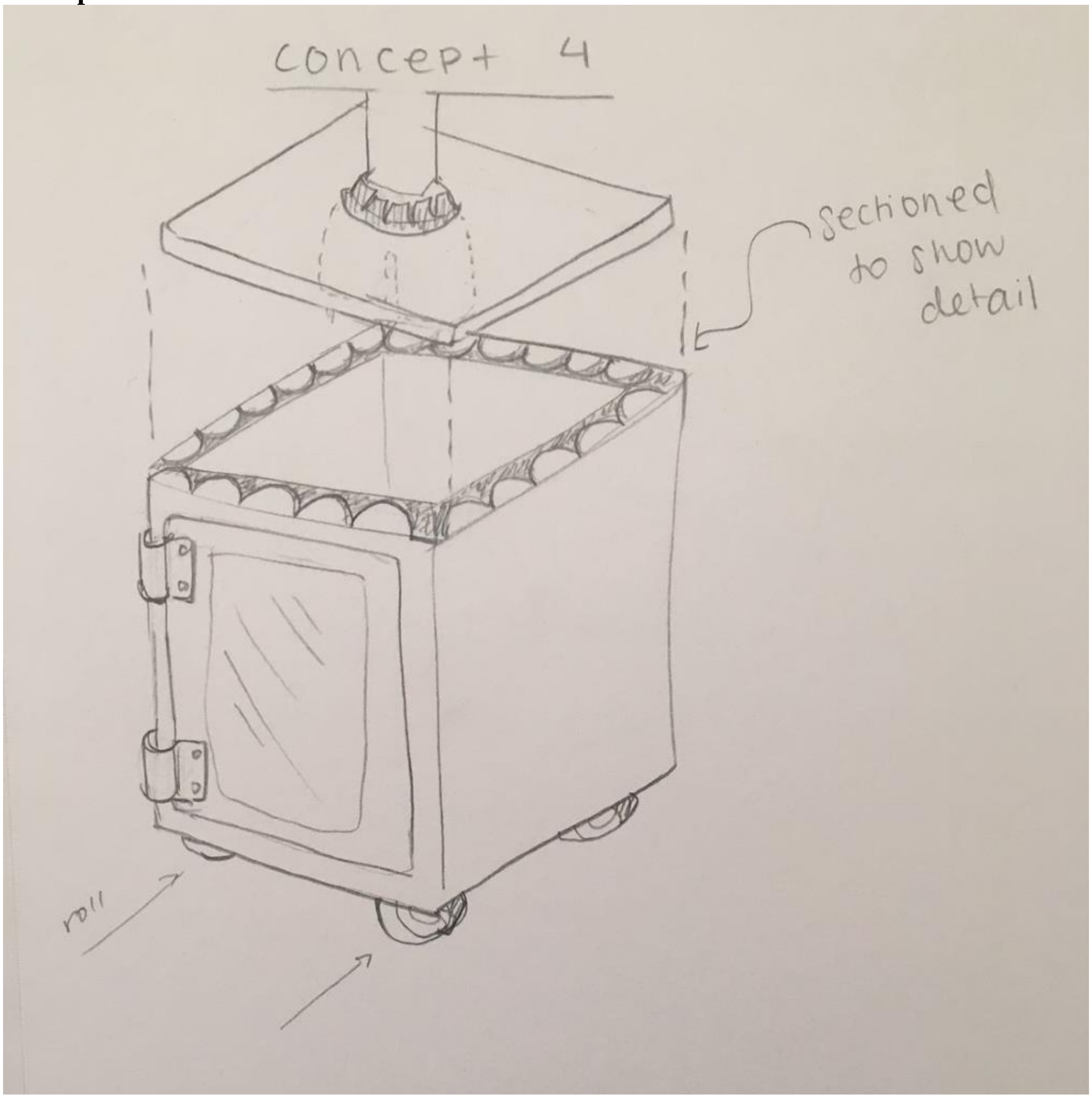
Concept 2 depicts several views of a potential chamber set up. This concept makes use of having a fully removeable door using a pin locking system like you'd see in an industrial safe or submarine door. The door along with the rest of the chamber is structured with a triangular corrugate insulation cross section which is intended to both strengthen the machine and help insulate. This would then have a layer of fiberglass roll on the inner side of the cross section with fiberglass roll stuffed into the air pockets of the cross section. To get the chamber around the vises, it would be able to split in half (side by side) and bolted together when attached to the machine. In order to ensure the chamber stays stationary, there would be an added rail to the LD50 for the halves to slide onto and pressure lock the guides into place so its stationarily connected to the rail and machine.

Concept 3:



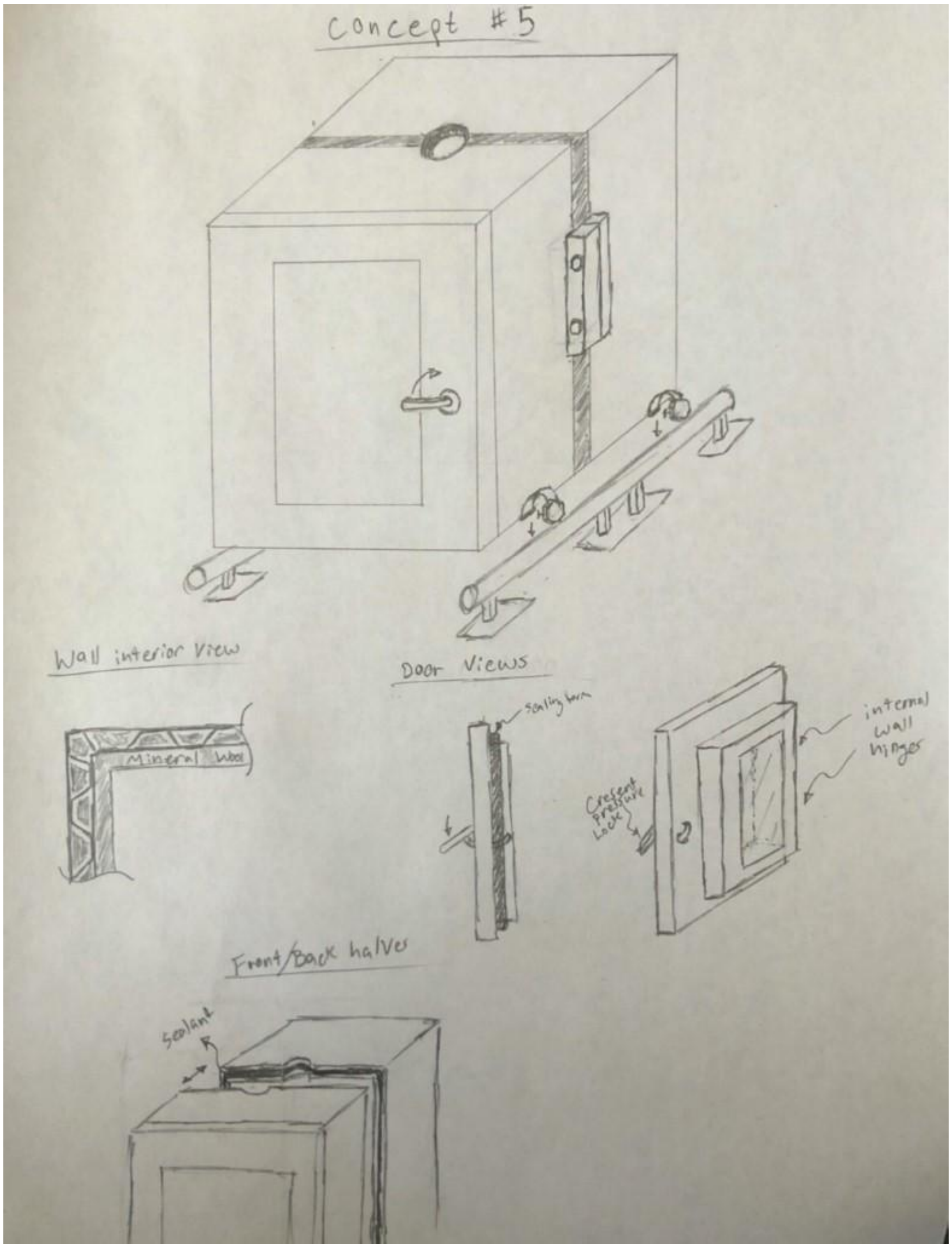
Concept 3 features insulation with fiberglass corrugate in a trapezoidal cross-sectional shape. The open spaces in the cross section between the chamber walls will be filled with mineral wool, which can be cut to shape and inserted without fastening. The chamber is supported by 4 legs on the bottom for stability and positioning. External hinges are matched with a door handle/safe lock to close the chamber door and a closeable slot is included on the side of the chamber for the machine arm to fit through during installation.

Concept 4:



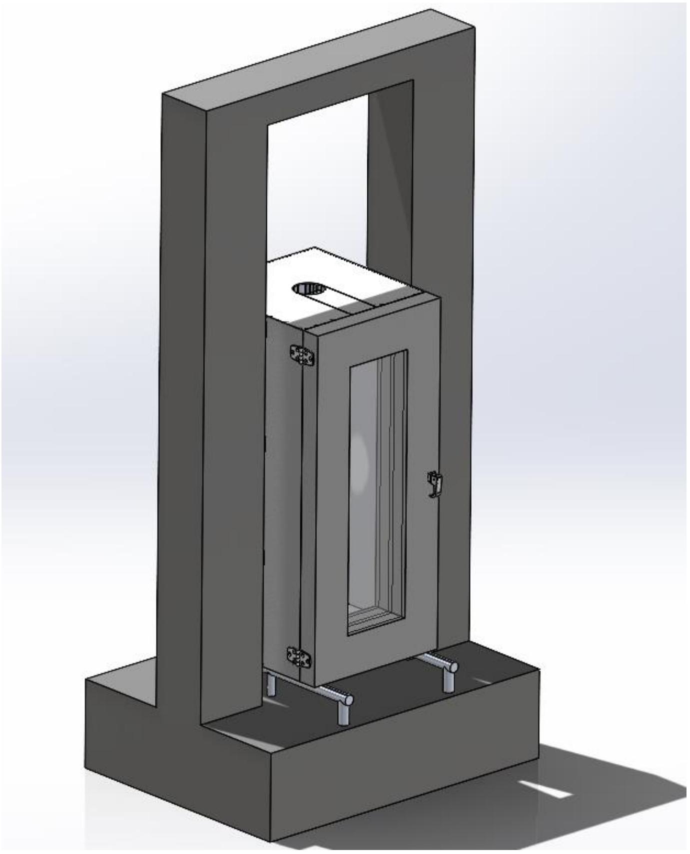
Concept 4 depicts a chamber which installs by rolling forward into place on the bottom floor of the LD50 with locking wheels. The machine arms enter the machine through the top and bottom through enlarged openings, which have rubber flaps to allow for sealing of the chamber after the machine arms are through. There is a single door attached to crescent hinges on the exterior side of the chamber. The door also has an exterior lock and single large window. The insulation is constructed with arching composite corrugate with Polyurethane injection in the gaps to provide insulation.

Concept 5:

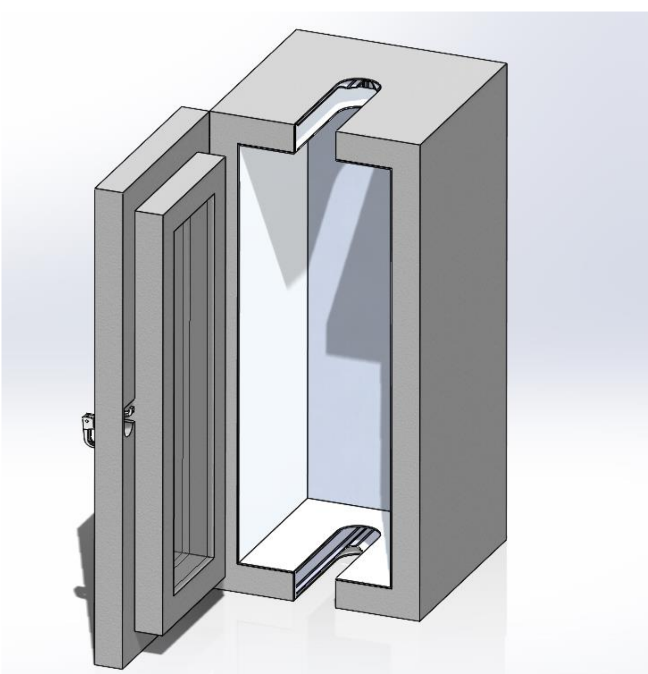


Concept 5 makes use of a rail system installed to the LD50 machine where the two separate halves of the chamber can be slid on from the front and back of the testing machine. When both reach the vise fixtures, the chamber is bolted shut in the middle and the rail sliders are tightened to the rail to ensure the chamber is stationary during testing. Each chamber half uses a sealing foam around its cross-section to ensure a seal is created when both sides are tightened together. For the chamber walls, a trapezoidal cross section is used to provide the best structural support in combination with mineral wool added into the air gaps and coating the inner wall to help insulate the chamber. For the chamber door, it uses inner wall hinges and a crescent safe lock with a lever to pressure seal the door to the chamber. The door has the same sealing foam around the thicker door wall portion enclosing the viewing window.

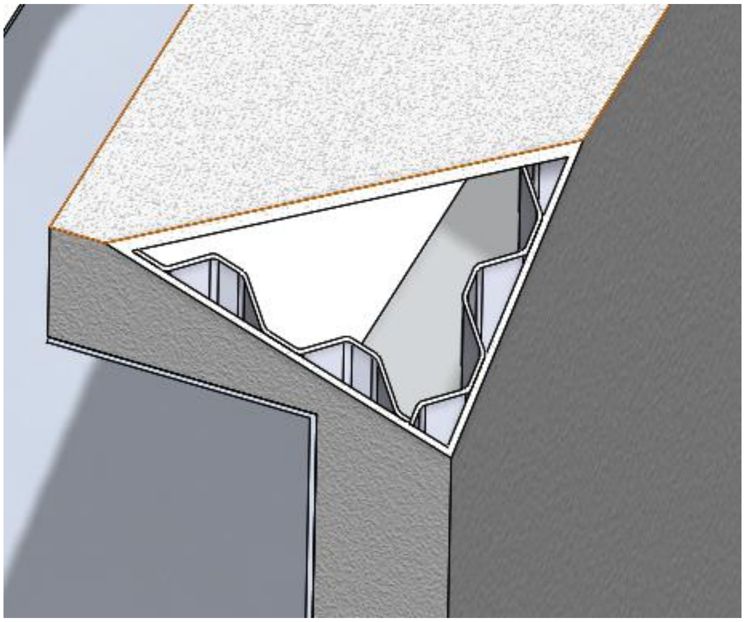
Appendix D: Preliminary CAD Model



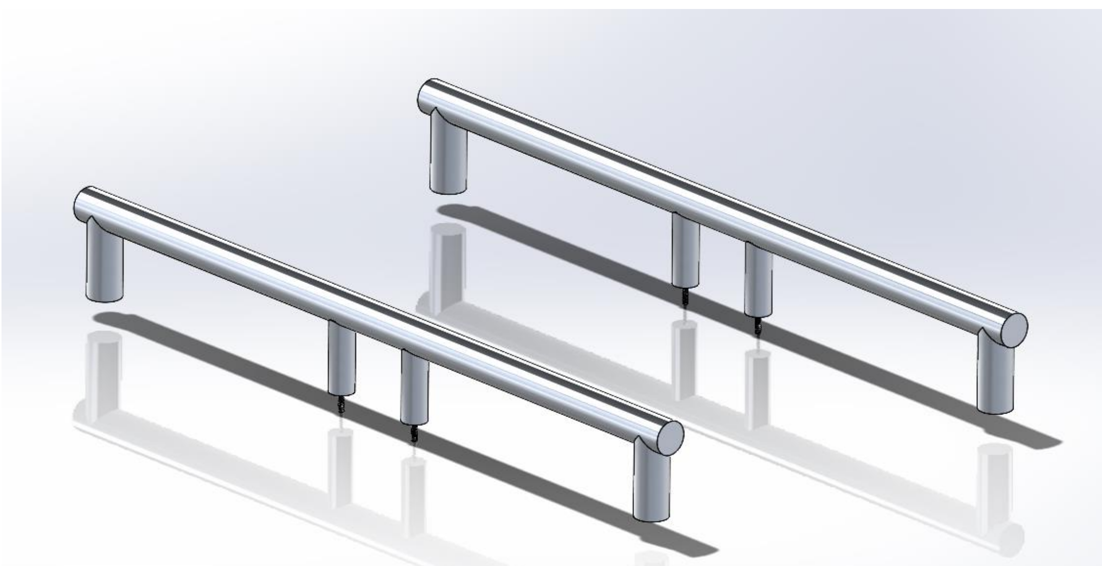
Environmental chamber installed on LD50 block model.



Environmental chamber with door opened (configuration for installing onto the LD50).



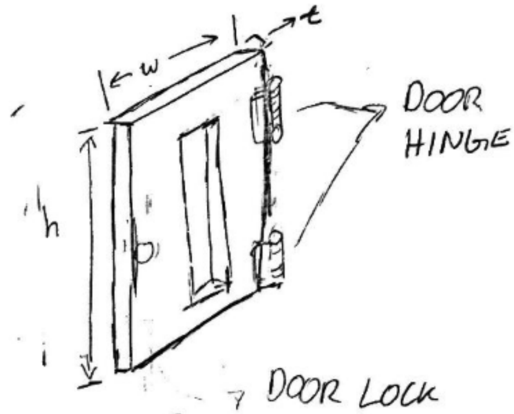
Cutout view of the materials making up the structure of the environmental chamber. The outer layer is composite material bonded to trapezoidal corrugated core. There is empty space for insulating materials and thermal components, followed by the inner wall which is made of aluminum sheet.



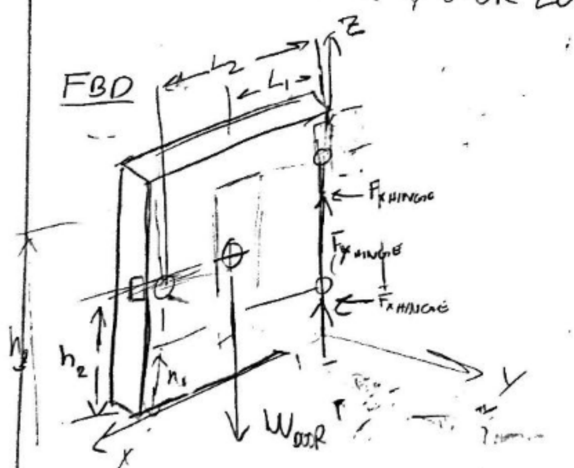
Closer look of the rails to be used in installing the environmental chamber.

Appendix E: Door Hand Calculations

DOOR



FBD



VARIABLES

L_1 : DISTANCE TO COM

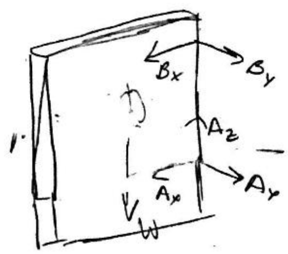
L_2 : DISTANCE TO F_{DOOR} / DOOR HANDLE/LOCK

h_1 : HEIGHT OF 1st HINGE

h_2 : HEIGHT OF COM & DOOR HANDLE/LOCK

h_3 : HEIGHT OF SECOND HINGE

FBD (AGAIN BUT MORE SIMPLE)



ANALYSIS:

$\Sigma F_z =$

$$A_z = W$$

ΣM_{x_A}:

$$-(W)(L_1) - B_y(h_3 - h_1) = 0$$

$$B_y = -\frac{(W)(L_1)}{h_3}$$

$\Sigma F_y = 0$

$$A_y + B_y = 0$$

$$A_y = -B_y \Rightarrow$$

$$A_y = \frac{(W)(L_1)}{(h_3 - h_1)}$$

$\Sigma M_{y@PTA}: = 0$

$B_x(h_3 - h_1) = 0$

$\boxed{B_x = 0}$

$\Sigma F_x = 0$

$A_x + B_x = 0$

$\boxed{A_x = 0}$

ASSUME DIMENSIONS

$W = 8\,lbs$

$h_1 = 9\,in$

$h_2 = 18\,in$

$h_3 = 32\,in$

$w_1 = 9\,in$

$\boxed{A_z = 8\,lb}$

$B_y = \frac{-(8lb)(9in)}{(32 - 9in)}$

$\boxed{B_y = 2.8\,lb}$

$\boxed{A_y = -2.8\,lb}$

∴ ASSUMING USE OF METAL DOOR HINGE WE ARE BELOW SAFETY LIMIT OF DOOR

Appendix F: Epoxy Shear Calculations

PRELIMINARY CALCS - SHEAR

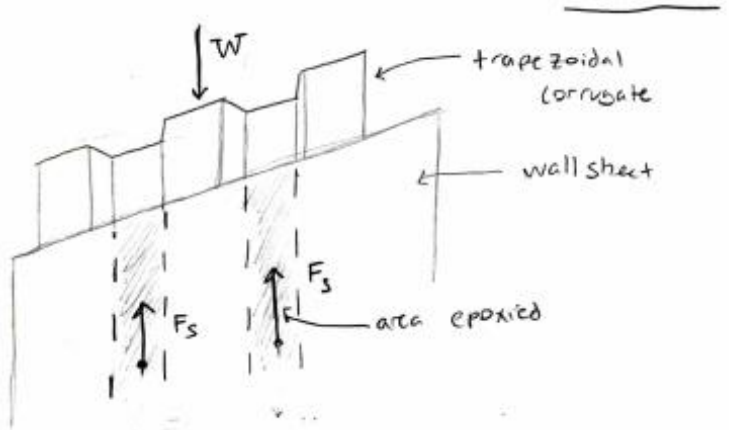
Assume $W_{\text{sheet + mineral wool}} = 4\ \text{lbf}$ (total insulation weight)

Block shear for Loctite epoxy → $\tau_{max} = 1510\ \text{psi}$
(can operate at high temperatures)

Sheet height → $34\ \text{in} = h$

width of trapezoid in contact with epoxy → $w_{tr} = 0.47\ \text{in}$

Schematic



Calculation $\tau = \dfrac{F}{A_{contact}}$ → $A_{contact} = \dfrac{F}{\tau}$

$\dfrac{4\ \text{lbf}}{1510\ \frac{\text{lbf}}{\text{in}^2}} = \boxed{0.0026\ \text{in}^2}$ → minimum epoxied area to hold sheet

$A_{trapezoid} = w_{tr} \cdot h = .47\ \text{in}\ (34\ \text{in})$
$= \boxed{15.98\ \text{in}^2}$ → contact area available for 1 trapezoid

$A_{trap} > A_{contact}$ → only one trapezoid required to hold insulation

Appendix G: Design Hazard Checklist

Preliminary design hazard considerations for construction and operation of the environmental chamber with the LD50 tensile testing machine.

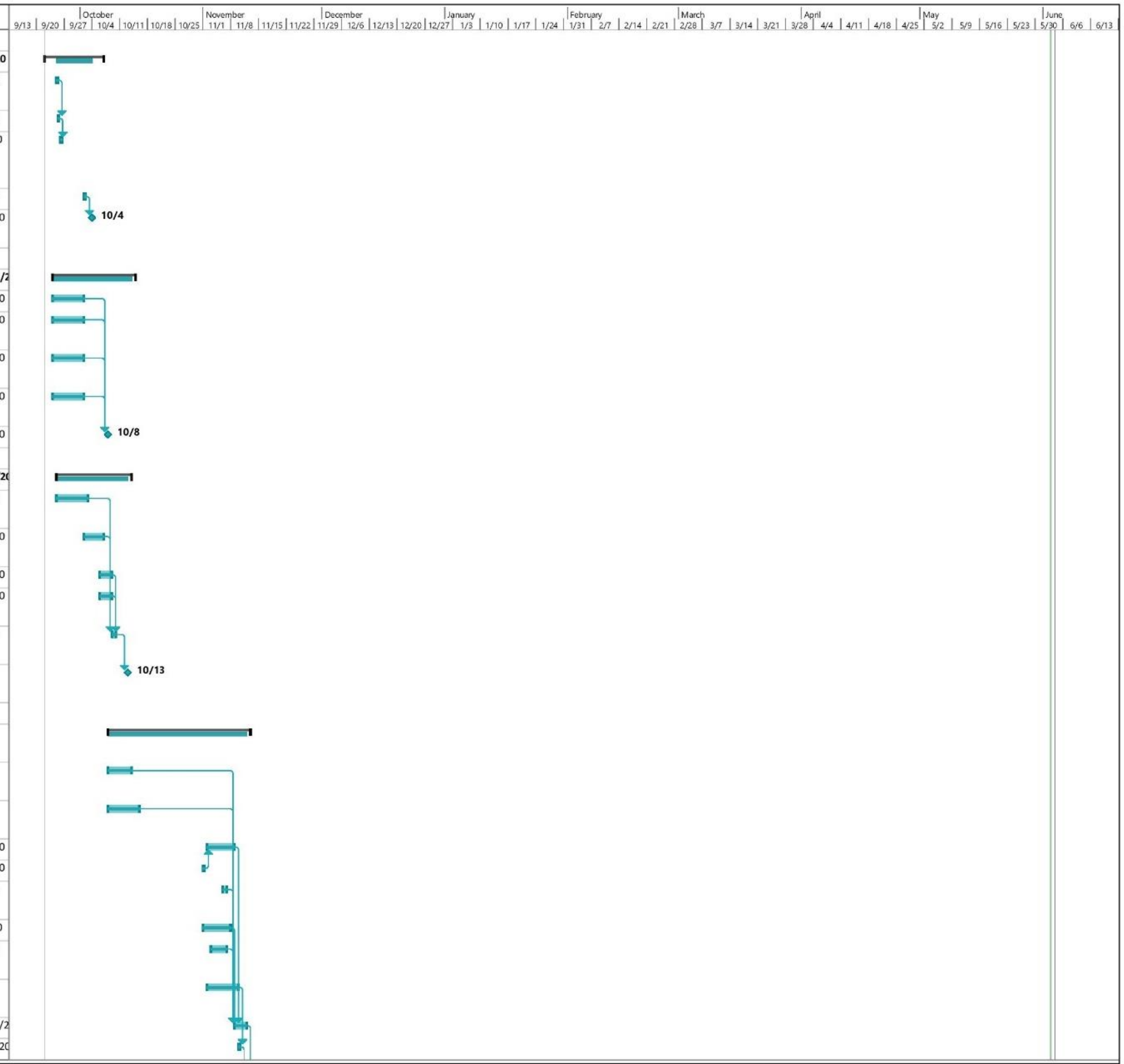
DESIGN HAZARD CHECKLIST

Team: Environmental Chamber Faculty Coach: Dr. Elghandour

Y	N	
☑	☐	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
☐	☑	2. Can any part of the design undergo high accelerations/decelerations?
☑	☐	3. Will the system have any large moving masses or large forces?
☑	☐	4. Will the system produce a projectile?
☐	☑	5. Would it be possible for the system to fall under gravity creating injury?
☐	☑	6. Will a user be exposed to overhanging weights as part of the design?
☐	☑	7. Will the system have any sharp edges?
☐	☑	8. Will you have any non-grounded electrical systems?
☑	☐	9. Will there be any large batteries or electrical voltage (above 40 V) in the system?
☐	☑	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
☐	☑	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
☐	☑	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
☑	☐	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
☐	☑	14. Could the system generate high levels of noise?
☑	☐	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
☑	☐	16. Is it possible for the system to be used in an unsafe manner?
☑	☐	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Appendix H: Gantt Chart

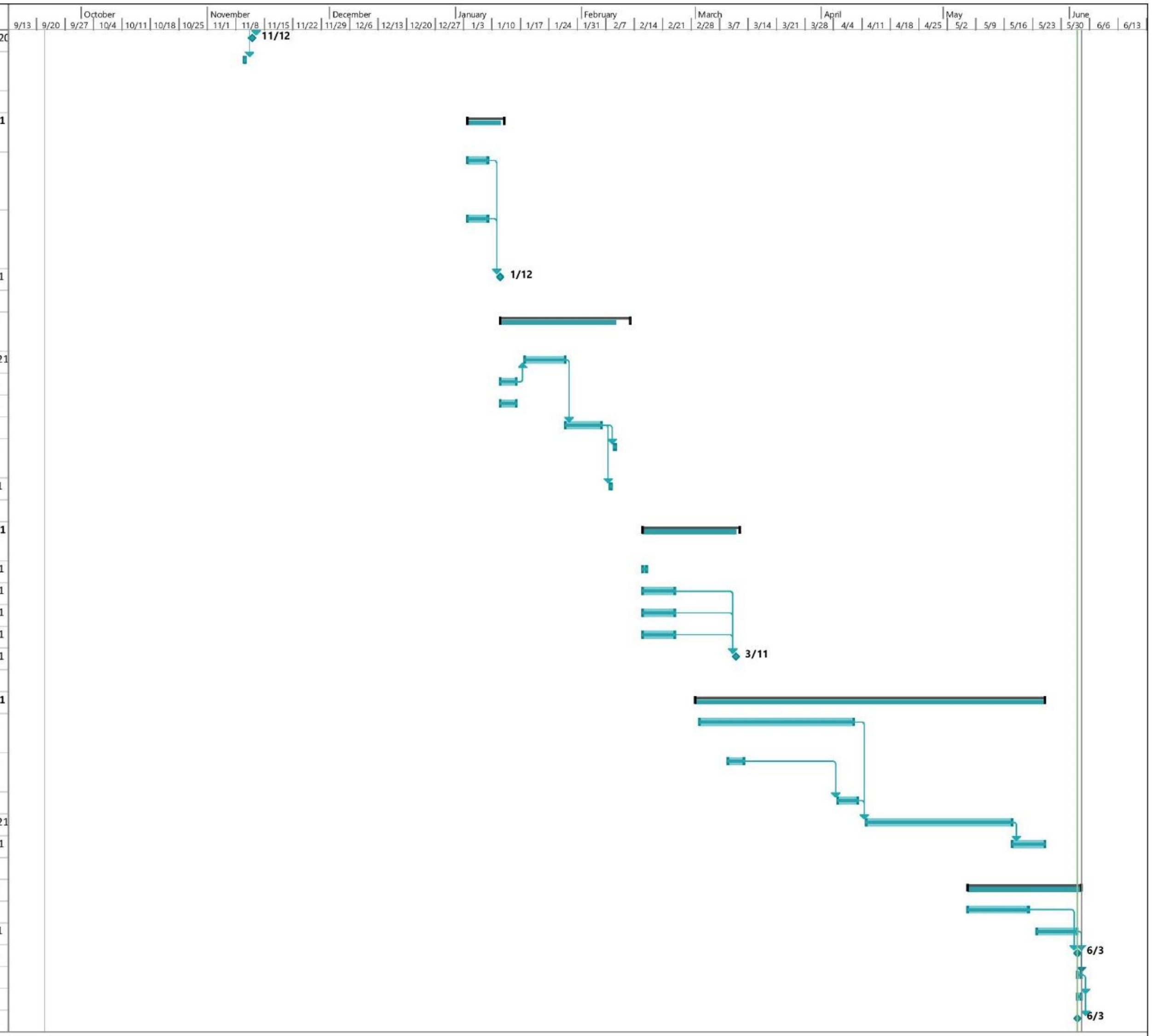
ID		Task Mode	Task Name	Duration	Start	Finish
1						
2	✓		**Problem Statement**	**11 days**	**Tue 9/22/20**	**Tue 10/6/20**
3	✓		Meeting With other Team	2 hrs	Fri 9/25/20	Fri 9/25/20
4	✓		Sponsor Interviews	4 hrs	Fri 9/25/20	Fri 9/25/20
5	✓		Identify Needs/Want of Sponsor	2 hrs	Sat 9/26/20	Sat 9/26/20
6	✓		Boundary Diagram	1 hr	Fri 10/2/20	Fri 10/2/20
7	✓		Problem Statement Complete	0 hrs	Sun 10/4/20	Sun 10/4/20
8						
9	✓		**QFD House of Quality**	**15 days**	**Thu 9/24/20**	**Wed 10/14/2**
10	✓		Patent Search	6 days	Thu 9/24/20	Thu 10/1/20
11	✓		Research Applicable Senior Designs	6 days	Thu 9/24/20	Thu 10/1/20
12	✓		Research Current Products	6 days	Thu 9/24/20	Thu 10/1/20
13	✓		Research Relevant Materials	6 days	Thu 9/24/20	Thu 10/1/20
14	✓		Complete QFD	0 days	Thu 10/8/20	Thu 10/8/20
15						
16	✓		**Scope of Work**	**13 days**	**Fri 9/25/20**	**Tue 10/13/2(**
17	✓		Background Information	6 days	Fri 9/25/20	Fri 10/2/20
18	✓		Customer Requirement Table	3 days	Fri 10/2/20	Tue 10/6/20
19	✓		Objectives	3 days	Tue 10/6/20	Thu 10/8/20
20	✓		Project Management	3 days	Tue 10/6/20	Thu 10/8/20
21	✓		SOW Turned in for Peer Review	1 day	Fri 10/9/20	Fri 10/9/20
22	✓		Final SOW sent to Sponsor	0 days	Tue 10/13/20	Tue 10/13/20
23						
24	✓		**Preliminary Design Review**	**26 days?**	**Thu 10/8/20**	**Thu 11/12/20**
25	✓		Ideation and Brainstorming	4 days	Thu 10/8/20	Tue 10/13/20
26	✓		Incorporating Feasable Fabrication Processes	6 days	Thu 10/8/20	Thu 10/15/20
27	✓		Build Concept Model	6 days	Mon 11/2/2(	Sun 11/8/20
28	✓		Order Materials	1 hr	Sun 11/1/20	Sun 11/1/20
29	✓		Evaluate alternatives and Choose best one	1 day	Fri 11/6/20	Fri 11/6/20
30	✓		Concept CAD Model	7 days	Sun 11/1/20	Sat 11/7/20
31	✓		Build Concept Prototype	4 days	Tue 11/3/20	Fri 11/6/20
32	✓		Prepare Presentation	6 days	Mon 11/2/20	Mon 11/9/20
33	✓		PDR Complete	3 days	Mon 11/9/2(	Wed 11/11/2
34	✓		PDR Presentation	1 hr	Tue 11/10/2(	Tue 11/10/2(



Project: Thermochamber Gantt
Date: Thu 6/3/21

Task · Split · Milestone · Summary · Project Summary · Inactive Task · Inactive Milestone · Inactive Summary · Manual Task · Duration-only · Manual Summary Rollup · Manual Summary · Start-only · Finish-only · External Tasks · External Milestone · Deadline · Progress · Manual Progress

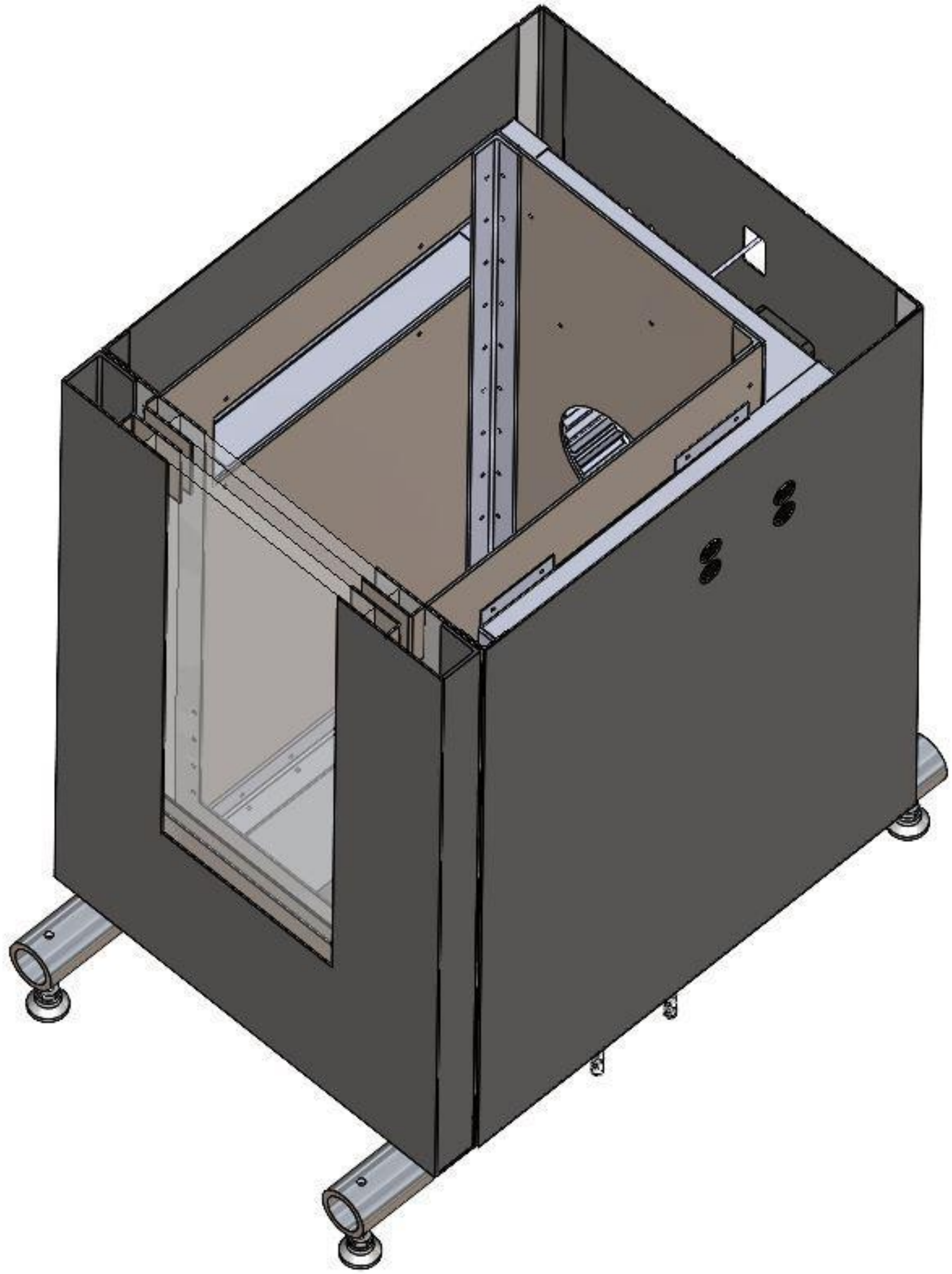
ID	Task Mode	Task Name	Duration	Start	Finish
35		Submit PDR Report	0 hrs	Thu 11/12/20	Thu 11/12/20
36		PDR Presentation to Sponsor	1 hr	Tue 11/10/20	Tue 11/10/20
37					
38		**Interim Design Review**	**7 days**	**Mon 1/4/21**	**Tue 1/12/21**
39		Design Analysis and Calculations (pre-build)	5 days	Mon 1/4/21	Fri 1/8/21
40		Design Analysis and Calculations (post-build)	5 days	Mon 1/4/21	Fri 1/8/21
41		IDR Complete	0 days	Tue 1/12/21	Tue 1/12/21
42					
43		**Concept Design Review**	**24 days**	**Tue 1/12/21**	**Fri 2/12/21**
44		Build Structrual Prototy	8 days	Mon 1/18/21	Wed 1/27/21
45		Final Part Selection	4 days	Tue 1/12/21	Fri 1/15/21
46		Detailed CAD/Manufac	4 days	Tue 1/12/21	Fri 1/15/21
47		Prepare Presentation	7 days	Thu 1/28/21	Fri 2/5/21
48		CDR Presentation to Class	1 hr	Tue 2/9/21	Tue 2/9/21
49		CDR Presentation to S	1 hr	Mon 2/8/21	Mon 2/8/21
50					
51		**Manufacturing and Test Review**	**18 days**	**Tue 2/16/21**	**Thu 3/11/21**
52		Risk Assesment	1 day	Tue 2/16/21	Tue 2/16/21
53		Experimental Design/	6 days	Tue 2/16/21	Tue 2/23/21
54		Test Plan/Operator Ma	6 days	Tue 2/16/21	Tue 2/23/21
55		Manufacturing and Te	6 days	Tue 2/16/21	Tue 2/23/21
56		M&T Review	0 days	Thu 3/11/21	Thu 3/11/21
57					
58		**Verification Prototype**	**62 days?**	**Mon 3/1/21**	**Tue 5/25/21**
59		Composite wall layups	28 days	Tue 3/2/21	Thu 4/8/21
60		Waterjet aluminum chamber	0.8 wks	Tue 3/9/21	Fri 3/12/21
61		Rivet Inner chamber	5 days	Mon 4/5/21	Fri 4/9/21
62		Final Assembly	5.2 wks	Mon 4/12/21	Mon 5/17/21
63		Testing	1.2 wks	Tue 5/18/21	Tue 5/25/21
64					
65		**EXPO**	**20 days**	**Fri 5/7/21**	**Thu 6/3/21**
66		Expo Presentation/Op	11 days	Fri 5/7/21	Fri 5/21/21
67		Update CAD/Drawings	8 days	Mon 5/24/21	Wed 6/2/21
68		Finish FDR Report	0 days	Thu 6/3/21	Thu 6/3/21
69		EXPO Webpage	1 day	Thu 6/3/21	Thu 6/3/21
70		Clean up Work Space	1 day	Thu 6/3/21	Thu 6/3/21
71		Finish up Paperwork	0 days	Thu 6/3/21	Thu 6/3/21



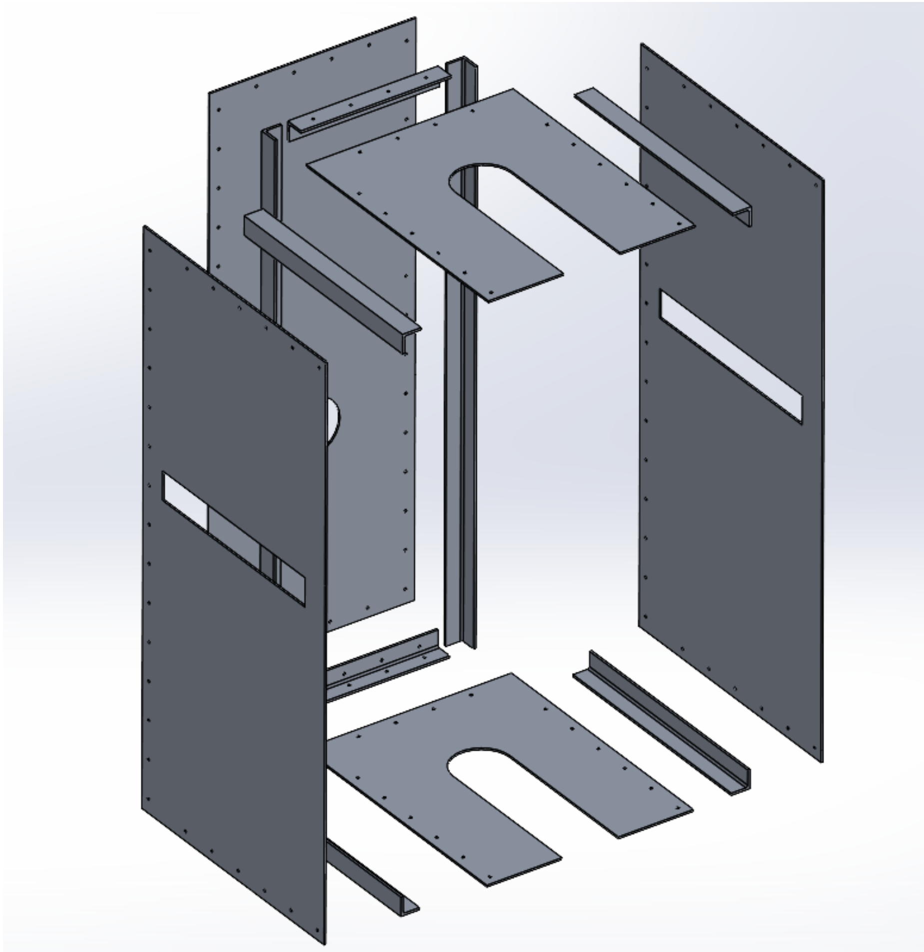
Project: Thermochamber Gantt
Date: Thu 6/3/21

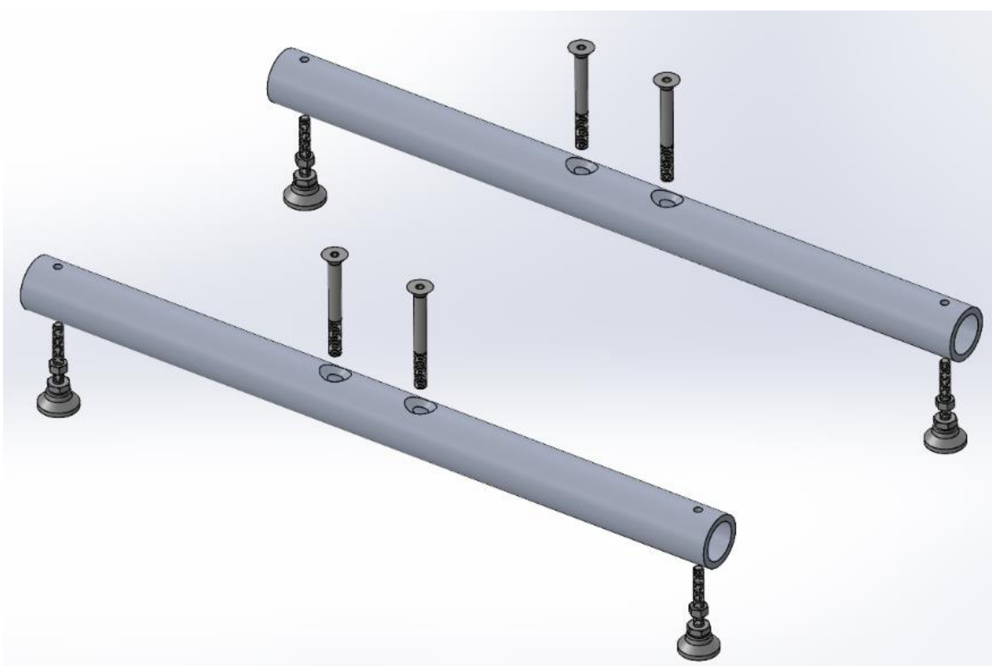
Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

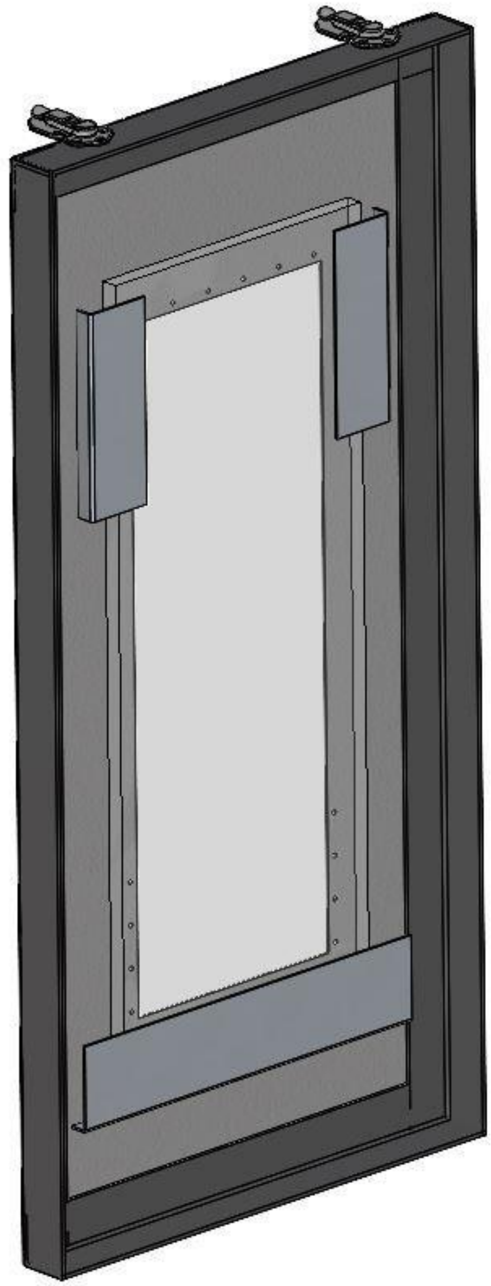
Appendix I: Final Design



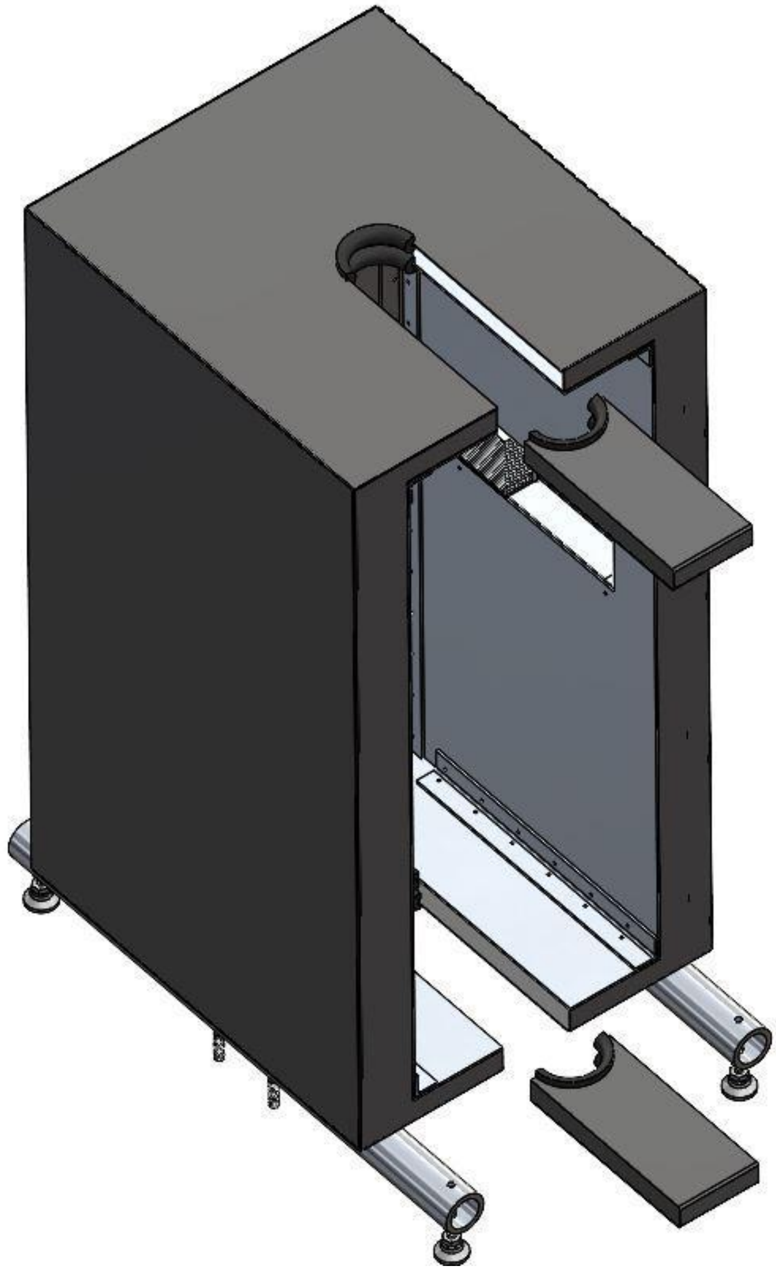
Section view showing space between internal and external chambers.


Exploded view of the Inner Chamber.


Exploded view of the Rail System.



Section view showing the internals of the door, and mounting of the glass panels.



Additional assembly view showing insertion of slot pieces.

Appendix J: Design Verification Plan

DVP&R - Design Verification Plan (& Report)											
Project:	Tensile Testing Environmental Chamber (F42)		Sponsor:	Dr. Elghandour						Edit Date:	5/25/2021
TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Composite Strength	Tension tests - record data when pulling the composite	Mpa /psi	failure @ F>40 lbf for component	Instron machine located in the Cal Poly Composites lab.	Composite panel (SP)	Austin	February	2/25/2021	Pass- Load at Failure conditions exceeds 250 lbf - planned composite layup will work for our design	Tested Boeing prepreg carbon fiber with fiberglass against dry carbon fiber with fiberglass - Boeing samples were stronger and will require less sheets per panel
2	Heat Bleed - Walls	Measure localized external wall temperatures with IR temperature reader while heating internal wall past the design temperature of 200 Celsius	Localized temperature (degrees C)	< 60 Celsius on the outer wall (OSHAA burn hazard compliance	Using a heat gun to heat the walls to 220 Degrees Celsius. External Wall Temps were recorded using temperature gun.	Chamber external and internal wall, insulation and radiation "pillows"	Erik	May	5/24/2021	Pass-At steady state internal wall temps of 200+ degrees Celsius, wall temps stayed constant around 32 degrees Celsius	Top of the chamer reached around 60 degrees Celsius which is dangerous but our slots were not inserted leaving more room for convection. Top wall reduced to safe temps within 5 minutes
3	Heat Bleed - Door Frame	Measure localized external door frame temperatures with IR temperature reader while heating internal door wall past the design temperature of 200 Celsius.	Localized temperature (degrees C)	< 60 Celsius on the outer door frame (OSHAA burn hazard compliance	Using a heat gun to heat the door frame to 210 Degrees Celsius. External door frame Temps were recorded using temperature gun.	Chamber external and internal door frame, insulation and radiation "pillows"	Lauren	June	5/25/2021	Pass- At steady state internal door frame temps of 190 degrees Celsius, temps stayed constant around 48 degrees Celsius	Glass viewport leaves a large gap in surface insulation quality but door frame can still be handled safely at maximum testing conditions
4	Heat Bleed - Door Glass	Measure localized external door glass temperatures with IR temperature reader while heating internal door wall past the design temperature of 200 Celsius. Small squares of electrical tape were placed on each glass panel for IR reader to take accurate measurements	Localized temperature (degrees C)	< 60 Celsius on the outer door frame (OSHAA burn hazard compliance	Using a heat gun to heat the door glass to 210 Degrees Celsius, directly at black tape squares. External glass temps were recorded using temperature gun.	Chamber external and internal door frame, insulation and radiation "pillows"	Michael	May	5/25/2021	Pass- While internal glass temp reached 245 degrees Celsius external hit 60 deg Celsius.	test is not an accurate scenario for heating as in reality glass will not have heat source directly normal to it at a close distance. During use, temperature warning labes will be placed on door and gloves will be recommended PPE

DVP&R - Design Verification Plan (& Report)

Project:	Tensile Testing Environmental Chamber (F42)		Sponsor:	Dr. Elghandour						Edit Date:	5/25/2021
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
5	Alignment Checks	Ensure door closes flush and sealant fills all seams	by inspection (in) - any overlap on top or bottom	pass/fail	N/A	VP	Lauren	May	5/25/2021	Pass- Door is flush on the chamber with minimal overlap/lip	Intial gaps bewteen the door and the chamer were small and esaily filled using use hight temp RVT.
6	Alignment Checks	Ensure completed chamber assembly fits within LD 50 protective shield door size constraints	by inspection (ruler/calipers) (in)	pass/fail	ruler/calipers	VP	Erik	May	5/18/2021	Pass- Chamber Fits withing the LD50 inclosure.	has about a 1 inch clearance between the front of the door and the inside of the protective shield.
7	Ease of install	Weight	[lbs]	<50lbs	Tensile test machine	VP	Michael	May	5/25/2021	Pass-Chamber pieces individual weigh and summed up to be around 48.75 lbs when fully assembled.	When installing the chmaber the door, which weighs 11 lbs, is not attached to the chamber. Thus the actual weight when installing is around 37 lbs.
8	Alignment Checks	Chamber fits and is level on rails	by inspection with level	pass/fail	tensile test machine	VP	Austin	May	5/25/2021	Pass- Chamber Fits perfectly on rails.	Rails to had to be leveled prior to chmaber insertion not recommended to take them off.
9	Ease of install	Rails Fit in inclosure	by inspection	pass/fail	Tensile test machine	VP	Austin	May	5/25/2021	Pass- Rails fit very snuggly inside the LD50 inclosure.	Extremely tight fit but nothing is impacting.

Print Date:

Appendix K: Failure Modes and Effects Analysis

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Access to chamber / View Sample testing	Unable to see test sample	a) Poor data results b) Harder to notice a machine failure / emergency stop	5	1) Window is too small 2) Window fogs up when heating/cooling	1) Size window to be a large portion of door 2) vacuum seal between each pane 3) dry chamber between tests	3	Proper sizing and testing controls system in the chamber thoroughly	2	30						
Access to chamber / Prevent Heat Transfer	incomplete/improper seal	a) Significant heat bleed b) Burn the user	9	1)Lock malfunction 2) Hinge Malfunction 3)Improper mounting of door to chamber 4) Seals rip/ damaged	1) stress analysis 2) fatigue strength 3) check seal placement	5	Proper sizing and testing controls system in the chamber thoroughly	2	90	Heat sealant materials/corrugate insulation and perform compression and tensile testing after heating					
Access to chamber / Safety Lock	Door does not lock	a) Door can be opened during tests b) Heat bleed c) Observers exposed to fragments of specimen in part failure	8	1) Lock can be undone during tests 2) Poor material seals 3) Inner chamber cannot withstand part fractures	1) Full chamber lock during testing (control) 2) tight manufacturing tolerances 3) proper aluminum wall thickness	2	checking manufactured parts thoroughly and testing control "running" lock	2	32	Heat lock at max temperature (w/ quench for some tests) and check strength and operation. Testing running lock during low heat tests to ensure it stay locked while running					
Access to chamber / Easy to Open	Door cannot be opened	a) Inability to access samples b) Damage to door material from force required to open	7	1) Hinged design is obstructed by LD 50 columns 2) Hinges are worn from repeated use 3) Door Lock is damaged in the locked position	1)Checking tolerances and machining quality 2) Full chamber lock during testing (control)	2	Checking the design specifications on hinges and safety lock, performing physical testing on both	1	14						
Enclose Testing Area / Prevent Heat Transfer	Flawed Insulation	a) Significant heat bleed b) Burn the user	9	1) fiberglass layups are too thin 2) selected filler material has too low of an R value 3) slots for door, fans etc. are not sealed well	1) Test fiberglass layup for strength / heat transfer 2) Test sealant and insulation material for heat transfer	3	Material property testing on LD50 for strength and on heating device for heat transfer	3	81	Material testing and further analysis on both the LD50 and heated chamber					
Enclose Testing Area / Endure Part Failure	Breaks as a result of part failure	a) Compromise insulation / heating elements b) Potential sharp broken edges	7	1) Weak choice of material 2) Wall is not thick enough	1) research/test material properties 2) size based on max impact from machine	1	Look up brinell Hardness specs	1	7						
Enclose Testing Area / Fit onto LD50	Does not fit onto LD50	Cannot be used for LD50 testing	10	1) Dimensions too big 2) additional components take sizing out of spec 3) Manufacture of chamber panels expands sizes	1) Make all chamber dimensions relative to the LD50 2) trim materials to fit desired tolerance	1	Measurements throughout manufacturing process and accounting for issues	1	10						
Insert Chamber on Machine / Support Chamber	Support rail bends or breaks	a) Chamber not in the correct position for testing b) Potential sharp edges from broken parts	5	1) Rails are too small 2) Rails are flimsy material 3) Rail threaded mounts are insufficient	1) Stress analysis 2) Fatigue strength 3) Check fastener specifications	1	Material testing on rail stock	2	10						

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Insert Chamber on Machine / Create Easy Install	Difficult to install	a) Waste test time from install effort b) user strains or injures themselves from installing	6	1) Dimensions too big / not enough clearance 2) Lots of friction on the sliding rails 3) Hard to access the clamps / fasteners	1) Check model dimensions compared to LD50 2) Design empty space for hands + necessary tools around clamps and fasteners	2	1)Visiual inspection 2)Physical testing	2	24						
Insert Chamber on Machine / Secure Chamber	C-clamps interfere with rail / cannot tighten	a) Chamber in the incorret position for testing b) Chamber slips or shifts during testing causing damage	6	1) Designed placement for the c-clamps is incorrect 2) C-clamps do not apply enough force 3) C-clamps are the incorrect size and slip 4) C-clamps lose strength after multiple uses	1) Check design specifications on C-clamps 2) Stress analysis	1	Strength testing on C-clamps, fit testing on rail	1	6						
General / Looks Good	poor construction / damaged surface	looks cheap/ unprofessional	3	1) fiberglass has airpockets 2) welds are lumpy 3)surface finish tooling is worn down 4) components don't fit tightly	1) reach out to experinced welders 2) practice manufactuing before final model 3) outsource if necessary	2	Visual inspection	2	12						
General / Safe	lock malfunctions / joint damage	many points of possible injury or customer endagerment	7	1) Lock is heated too much during testing 2) Lock is installed loosely to chamber door 3) Welds/fixturing of chamber components is shoddy	1) Check design specifications of lock and hinges 2) Stress analysis	2	1) Visual Inspection 2) Life cycle testing of hinges	4	56	Extensive testing in lab and thorough analysis of Fatigue and Life Cycle					
General / Durable	lock/hinges/slot malfunctions	a) deteriorates quickly b) in constant need of repair	7	1) Materials selected are worn down by temperature changes 2) Materials selected can't withstand sample impact testing	1) Stress analysis 2) Fatigue strength 3) Check fastener specifications	1	1) Heat testing for locks and hinges 2) Brinell Hardness test for walls	4	28						

Appendix L: Project Budget

Materials Budget for Senior Project

Title of Senior Project:	Tensile Testing Environmental Chamber
Team members:	Michael Ingel, Austin Marshall, Lauren Schirle, and Erik Soldenwagner
Designated Team Treasurer:	Austin Marshall
Faculty Advisor:	Dr. Eltahry Elghandour
Sponsor:	Dr. Eltahry Elghandour, Marius Jatulis, and Abdul-Rahman Mohamed
Quarter and year project began:	Fall 2020
Materials budget given for this project:	$2,470.00

F43-F42 Budget from CP connect

Date purchased	Vendor	Description of items purchased	Transaction amount
02/18/21	B&B Steel	Aluminum Sheet metal for inner chamber + door (4 ft x 8ft 1/16 in thick)	$91.35
02/18/21	B&B Steel	Single sheet metal cut (cut piece in half to fit in car)	$16.31
03/11/21	Home Depot	minum edging for structure) 1 in. x 96 in. Aluminum Angle with 1/16 in. Th	$23.36
03/11/21	McMaster-Carr	High-Temperature Rubber Seal Surface-Mount, Hollow, Plain Back, 5/8" Wide (need black, 5 ft)	$15.25
03/11/21	McMaster-Carr	Swivel Leveling Mount	$24.68
03/11/21	McMaster-Carr	compression latches to seal door	$13.52
03/30/21	Amazon	5 Piece Quick Release Lighting Truss Clamp Small 32-35mm 1 1/4 - 1 3/8 inches Diameter 165 Lb Load Capacity	$39.90
03/30/21	Amazon	Rutland 500-degree RTV high heat silicone seal	$25.98
03/11/21	The Craft	Acetone (1 gallon)	$50.97
03/11/21	The Craft	West System 105 Resin (1 gallon)	$359.96
03/11/21	The Craft	206 Hardener (1 quart)	$171.96
03/11/21	The Craft	sandpaper (320, 400, and 600 grit)	$22.50
03/11/21	The Craft	Sales Tax	$46.92
04/11/21	One Day Glass	2 sheets of Ceramic Glass - Square/Rectangle - 8 in wide and 21 in hieght - 3/16 in Neoceram - seamed edge - added rope gasket - No holes - fedex 2nd day	$206.44
04/11/21	Ace Hardware (online)	Prime-Line Silver Medium Aluminum 40 lb. Mirror J Channel (72 x 9/32 mirror channel)	$15.99
05/07/21	McMaster-Carr	Tight-Hold Draw Latch, Screw on, Zinc-Plated Steel, 2-3/4" Long x 1-3/16" Wide	$15.24
05/14/21	McMaster-Carr	Heat Barrier Sheet 42" Wide x 4 Feet Long, Saturday Delivery and Tax	$405.43
6/3/21	Airtech Intl.	Vacuum bag sealant tapes AT-200Y Economical multi-purpose sealant tape	$692.20
6/3/21	FiberGlast	Battery, 1743-A	$99.90
6/3/21	FiberGlast	Charging Base, 1744-A	$99.90
Additional Items from other Account			
6/3/21	Airtech Intl.	Vacuum valves and hoses Vac Valve 406 TF Threaded base valve with a positive pressure seal (has to be ordered over phone or email)	$279.90
6/3/21	Airtech Intl.	Miscellaneous Air-Roller 232 Hand roller for sealant tape application (has to be ordered over phone or email)	$156.50
6/3/21	FiberGlast	Commercial Electric Cutter Kit, 1740-A	$449.85
6/3/21	FiberGlast	Replacement Blade w/ Shoe, 1742-A	$79.90

Total expenses (CP Connect Account): $ 2,437.76

Total expenses (Other Account): $966.15

	Team F42 - CP Connect Fund	Team F43 - Fund from beginning of the year
budget:	$ 2,470.00	$2,530.00
actual expenses:	$ 2,437.76	$2,493.73
remaining balance:	$ 32.24	$36.27
Total remaining Balance	$ 68.51	

Appendix M: Indented Bill of Materials

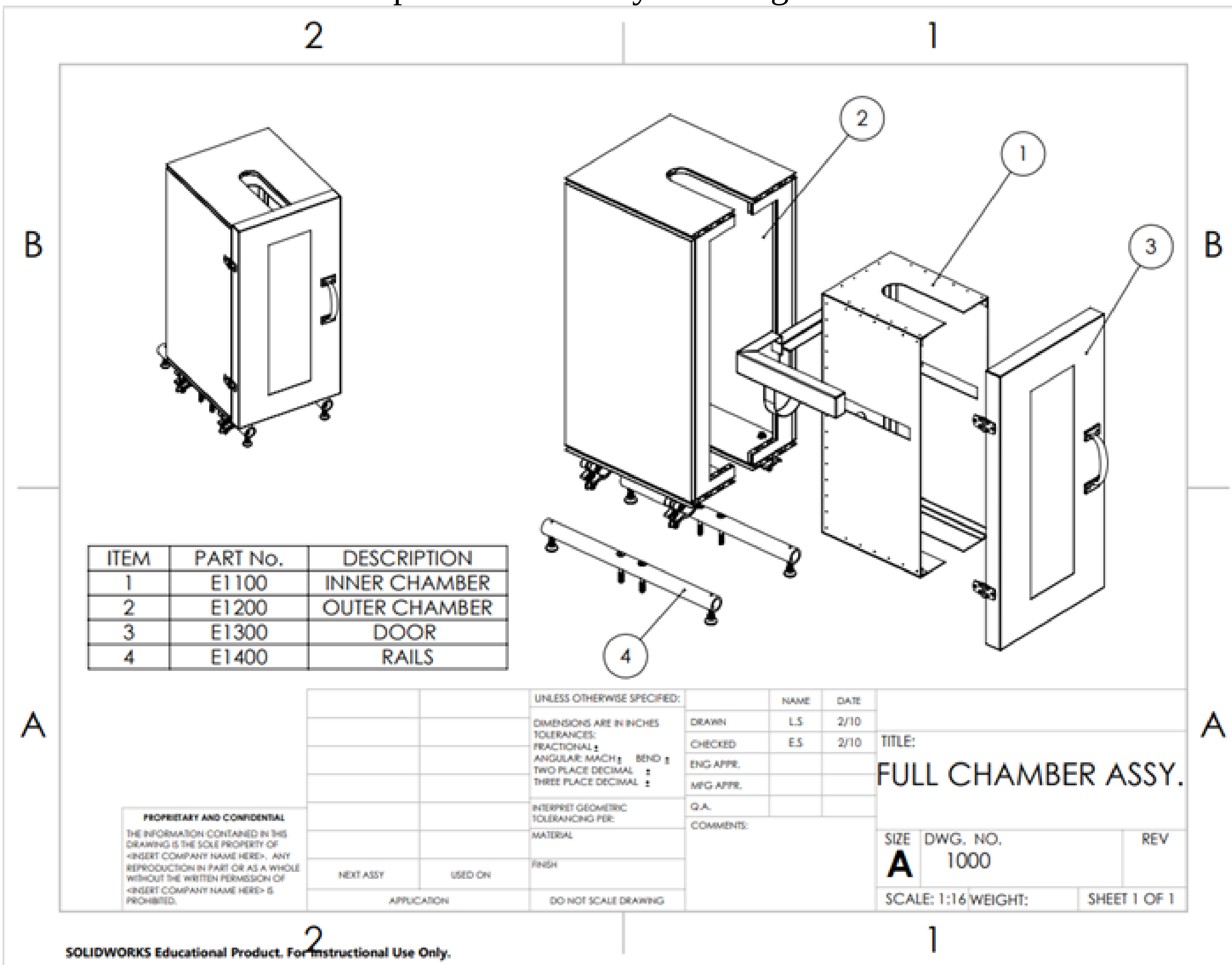
Environmental Chamber - Structures Team

Indented Bill of Material (iBOM)

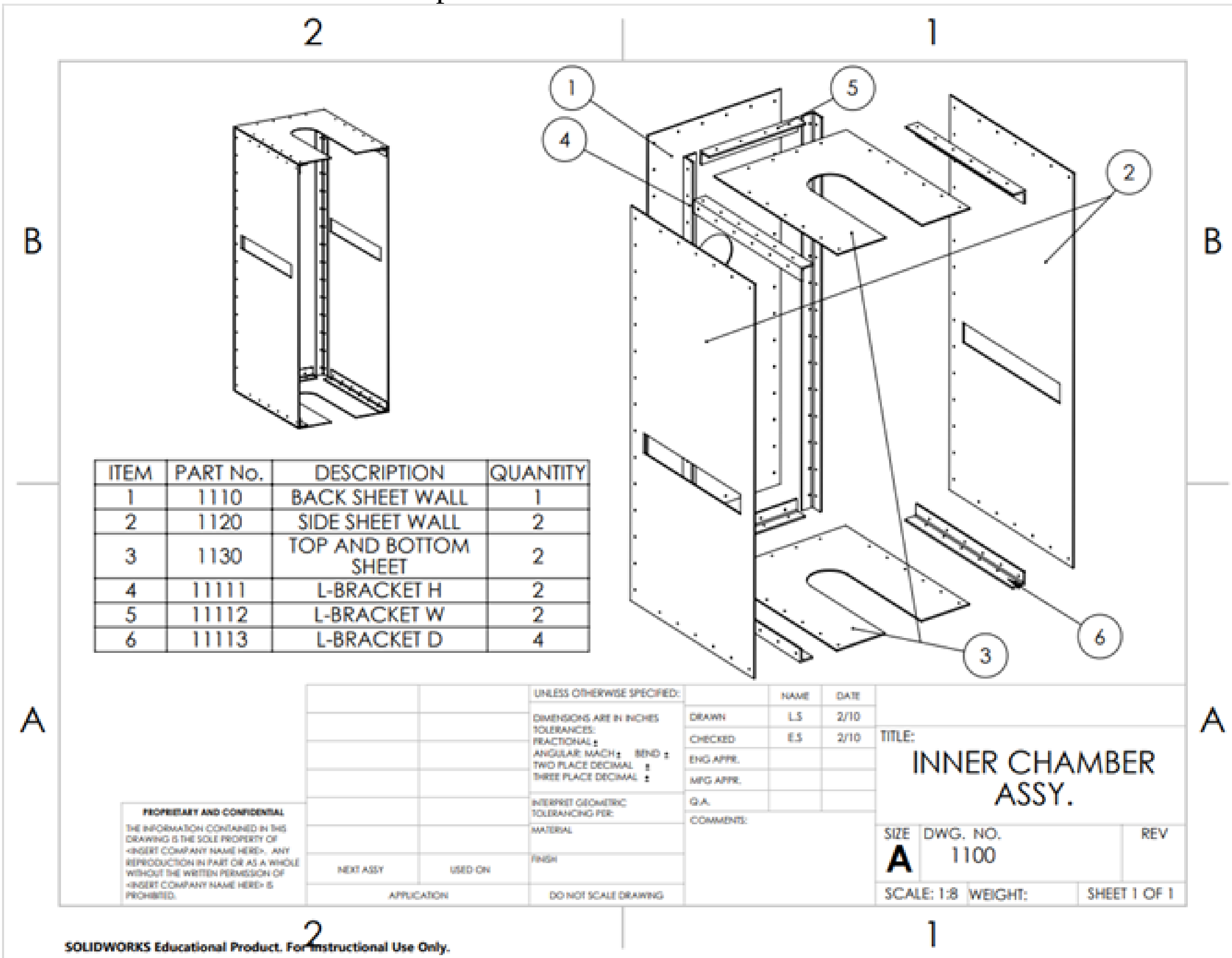
Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4					
0	100000	Final Assy					
1	110000	Inner chamber				------	
2	111000	Aluminum Shell	1	107.66	107.66	B&B Steel	4 ft x 8 ft 1/16 in thick sheet
3	111100	Aluminum Edge	2	11.68	23.36	Home Depot	1 in. x 96 in. Aluminum Angle with 1/16 in. Thick
3	111200	Rivets	1	6.27	6.27	Home Depot	Aluminum box of 100 pcs
3	111300	Heat sealant	2	12.99	25.98	Amazon	RTV
2	120000	Outer Chamber					
2	121000	Composite Shell	1	0.00	0	Provided	Fiberglass + carbon fiber + resin (composites lab)
3	121100	T-Brackets	4	0.00	0	Provided	Fiberglass + carbon fiber + resin (composites lab)
3	122000	Insulation	1	0.00	0	Provided	Aerogel
3	122100	Radiation Shielding	2	202.72	405.43	McMaster	Aluminum + fiberglass radiation shielding
2	123000	Bonding Epoxy	1	0.00	0	Provided	Magnolia magnum bond 56
3	123100	Silicon Gasket	1	15.25	15.25	McMaster	3/8 thick rubber gasket, 5 ft long
1	130000	Door				------	
2	131000	Door Window glass	2	103.22	206.44	Onedayglass	Ceramic Glass
3	131100	J Channel	1	15.99	15.99	Home Depot	40 lb mirror J channel
2	132000	Compression Latches	4	3.81	15.24	McMaster	compression latches to seal door
3	132100	Rivets	1	0.00	0	Home Depot	already paid for in earlier step
2	134000	Aluminum Shell	1	0.00	0	B&B Steel	already paid for in earlier step
2	135000	Composite shell	1	0.00	0	Provided	Fiberglass + resin (composites lab)
1	140000	Rail					
2	142000	Aluminum Pipe	1	0.00	0	Mustang 60	1 in diam, free left over piping
3	143000	Bolts	1	12.80	12.8	McMaster	18-8 Stainless Steel Hex Drive Flat Head Screw, M6 x 1 mm Thread, 75 mm Long
2	144000	Swivel Leveling Mount	4	6.17	24.68	McMaster	
3	144100	locking nut	4	0.00	0	McMaster	included with leveling mount
	Total Parts		**36**	498.6	**859.1**		

Appendix N: Drawing Package

Exploded Assembly Drawing E1000



Exploded Inner Chamber E1100



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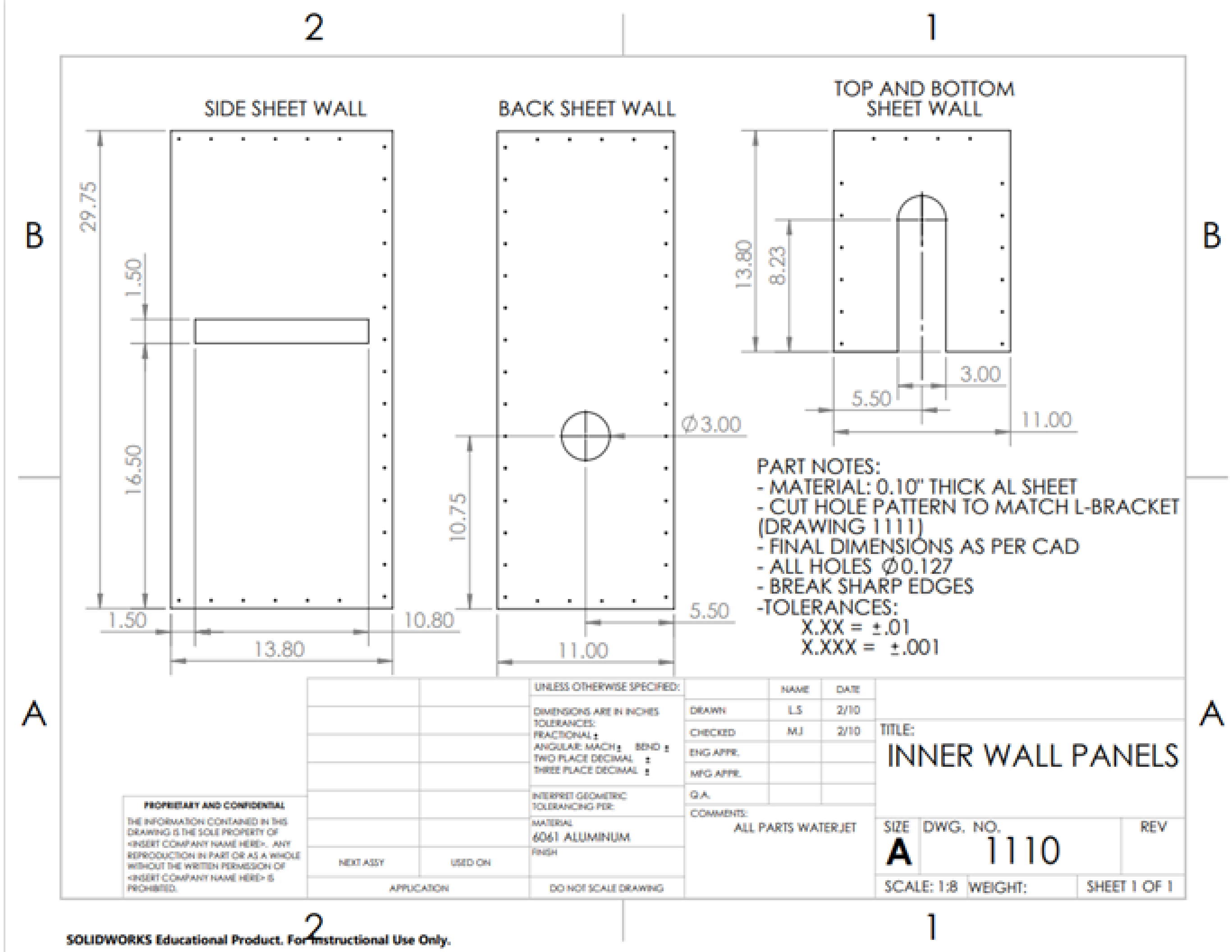
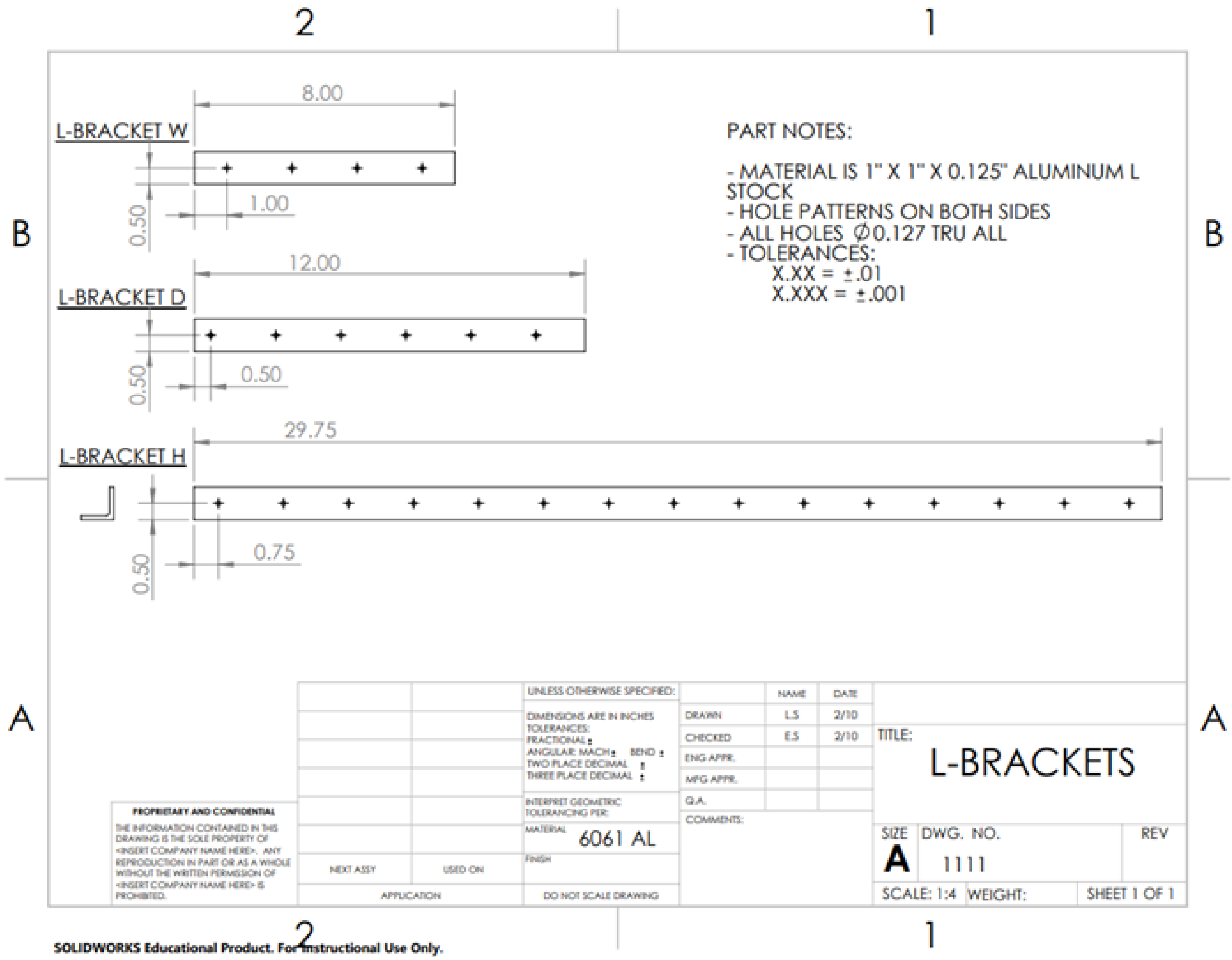
1	1110	BACK SHEET WALL	1
2	1120	SIDE SHEET WALL	2
3	1130	TOP AND BOTTOM SHEET	2
4	11111	L-BRACKET H	2
5	11112	L-BRACKET W	2
6	11113	L-BRACKET D	4

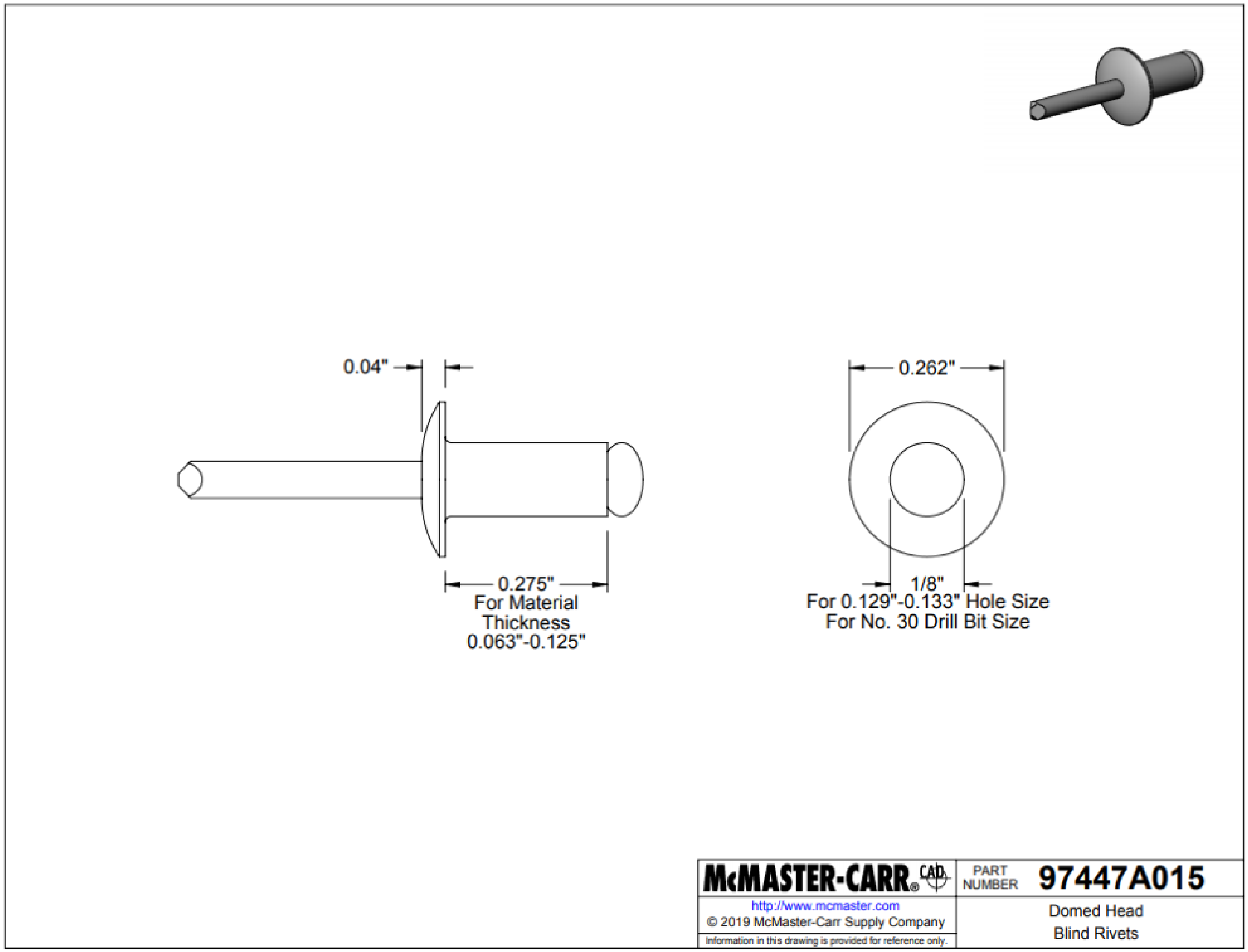
Aluminum Sheet



Aluminum Edge Brackets



Rivets


0.04"
0.262"
0.275"
For Material
Thickness
0.063"-0.125"
1/8"
For 0.129"-0.133" Hole Size
For No. 30 Drill Bit Size
McMASTER-CARR
CAD
PART NUMBER
97447A015
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Domed Head
Blind Rivets

Heat Sealant

Concentration:			
Boiling Point:	Not Available	**Freezing/Melting Pt.:**	Not Available
Flammability:	Not classified as a flammability hazard.	**Flash Point:**	>100 C (>212 F)
Partition Coefficient:	Not Available	**Octanol:**	Not Available
Vapor Pressure:	Not Available	**Vapor Density:**	Not Available
pH:	Not Available	**VOC:**	Not Available
Evap. Rate:	Not Available	**Bulk Density:**	Not Available
Molecular weight:	Not Available	**Auto-Ignition Temp:**	Not Available
Decomp Temp:	Not Available	**UFL/LFL:**	Not Available

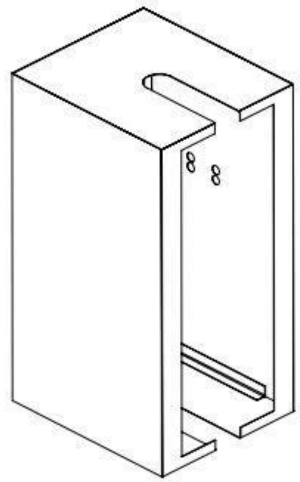
10 STABILITY AND REACTIVITY

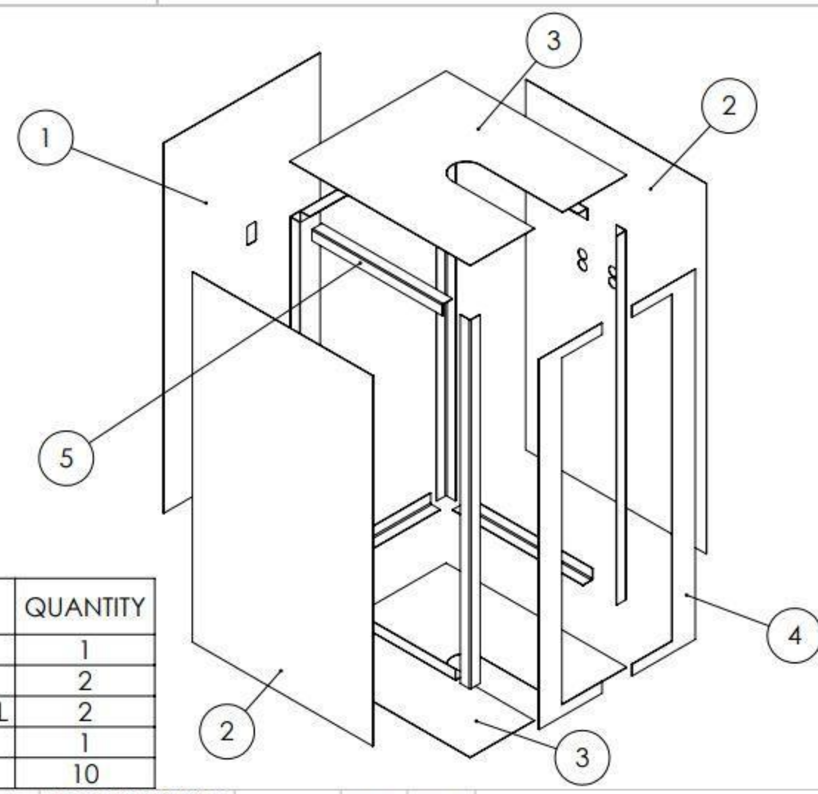
Reactivity:	This product is stable and non-reactive under normal conditions of use, storage and transport.
Chemical Stability:	Product is stable under normal conditions.
Conditions to Avoid:	Premature exposure to air or moisture initiates curing and the release of acetic acid vapors.
Materials to Avoid:	Strong Oxidizing Agents;
Hazardous Decomposition:	Formaldehyde
Hazardous Polymerization:	Will not occur.

Outer Chamber Exploded View E1200

2 1

B





B

ITEM	PART NO.	DESCRIPTION	QUANTITY
1	12101	BACK WALL	1
2	12102	SIDE WALL	2
3	12103	TOP AND BOTTOM WALL	2
4	12104	FRONT WALLS	1
5	12105	L-BRACKET	10

A

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

OUTER CHAMBER ASSY.

SIZE A DWG. NO. 1200 REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

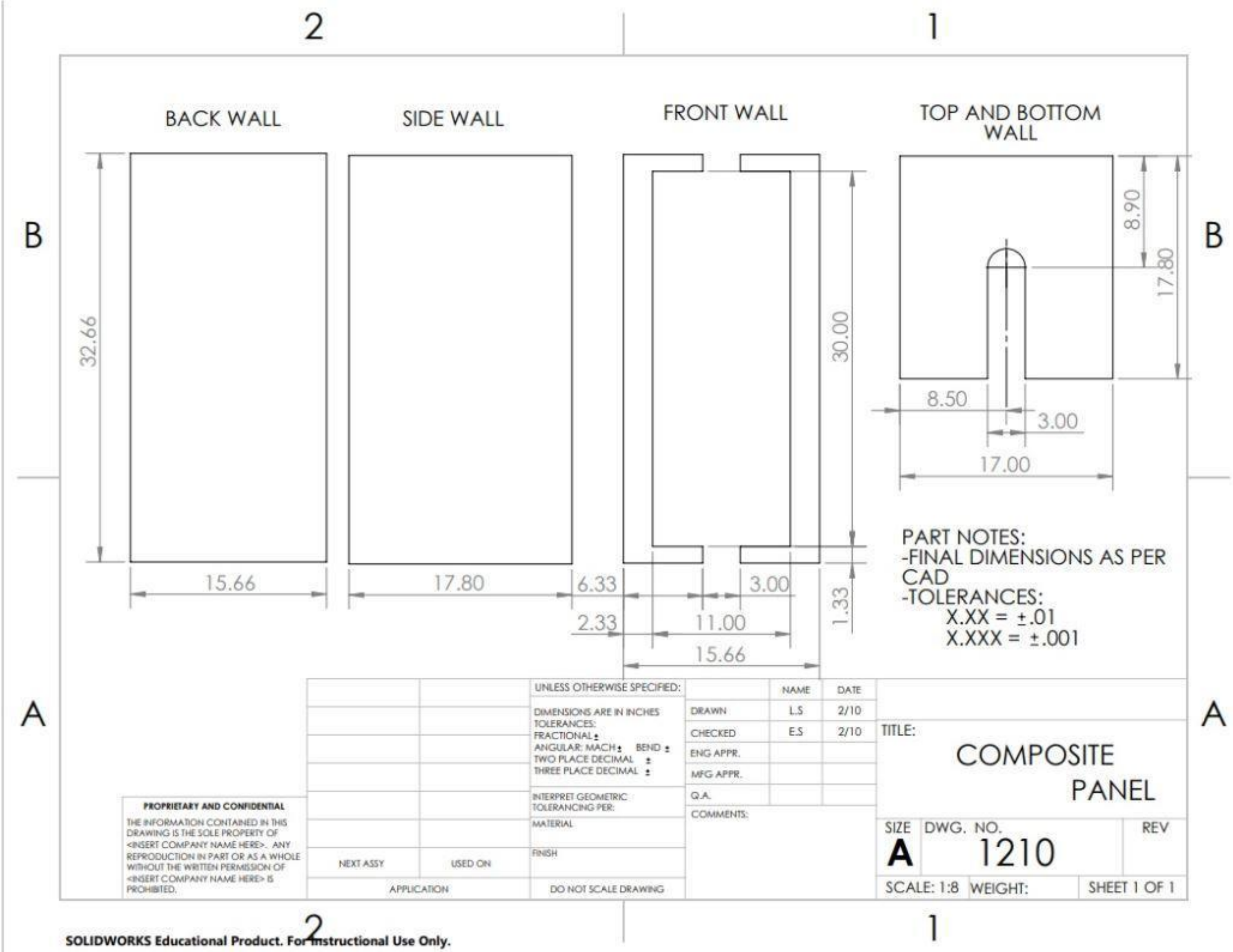
NEXT ASSY USED ON

APPLICATION

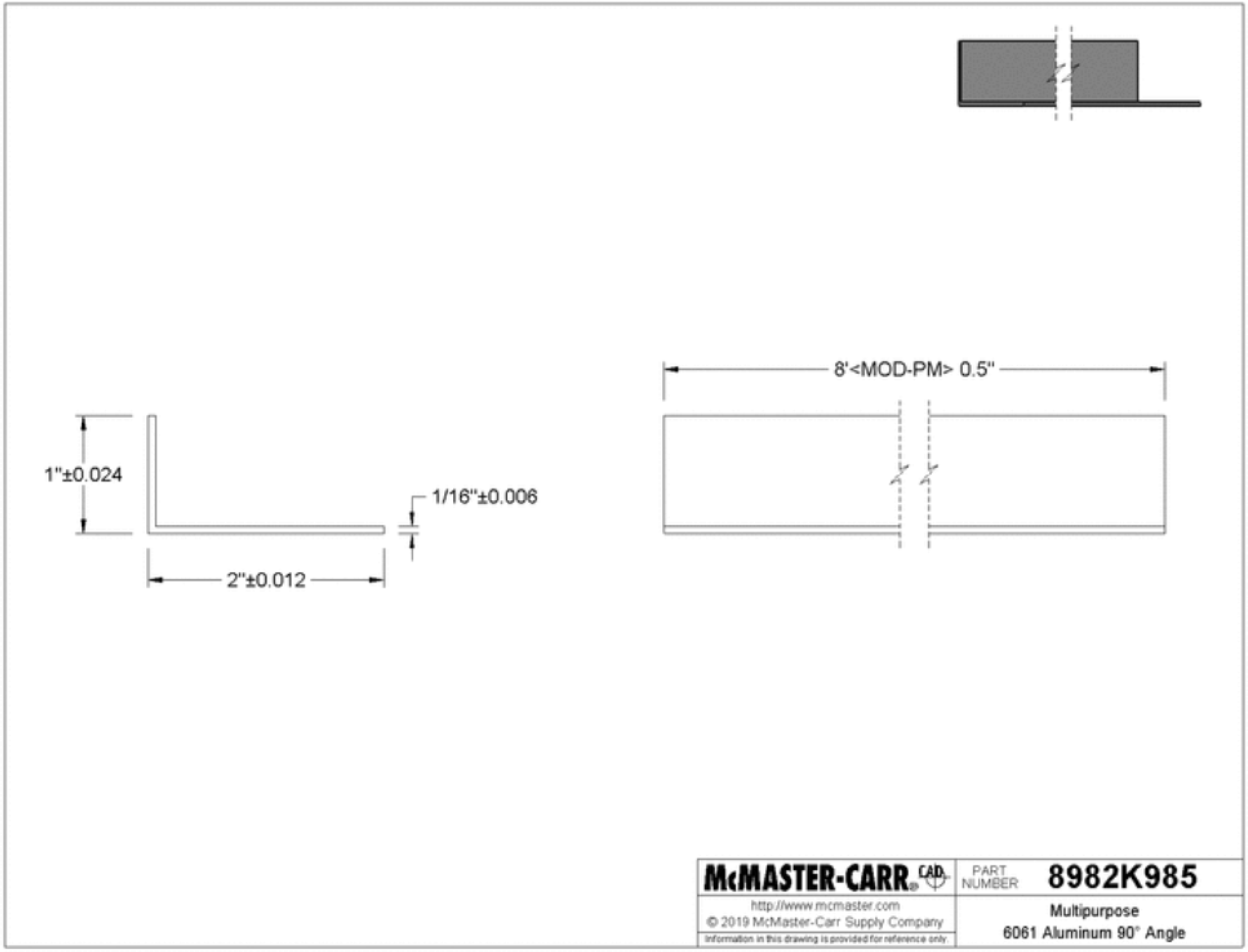
A

2 1

Composite Sheets



L-Brackets

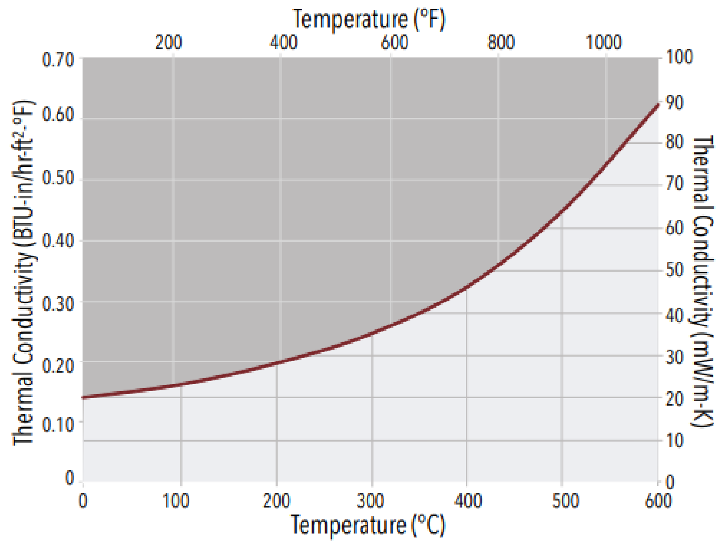

8'<MOD-PM> 0.5"
1"±0.024
1/16"±0.006
2"±0.012
McMASTER-CARR
CAD
PART NUMBER
8982K985
http://www.mcmaster.com
© 2019 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Multipurpose
6061 Aluminum 90° Angle

Stuffed Insulation Aerogel – Pyrogel XTE

THERMAL CONDUCTIVITY†

Tested in accordance with ASTM C177

Mean Temp. °F / °C	***k*** BTU-in/hr-ft²-°F / mW/m-K
32 / 0	0.14 / 20
212 / 100	0.16 / 23
392 / 200	0.19 / 28
572 / 300	0.24 / 35
752 / 400	0.32 / 46
932 / 500	0.44 / 64
1112 / 600	0.62 / 89



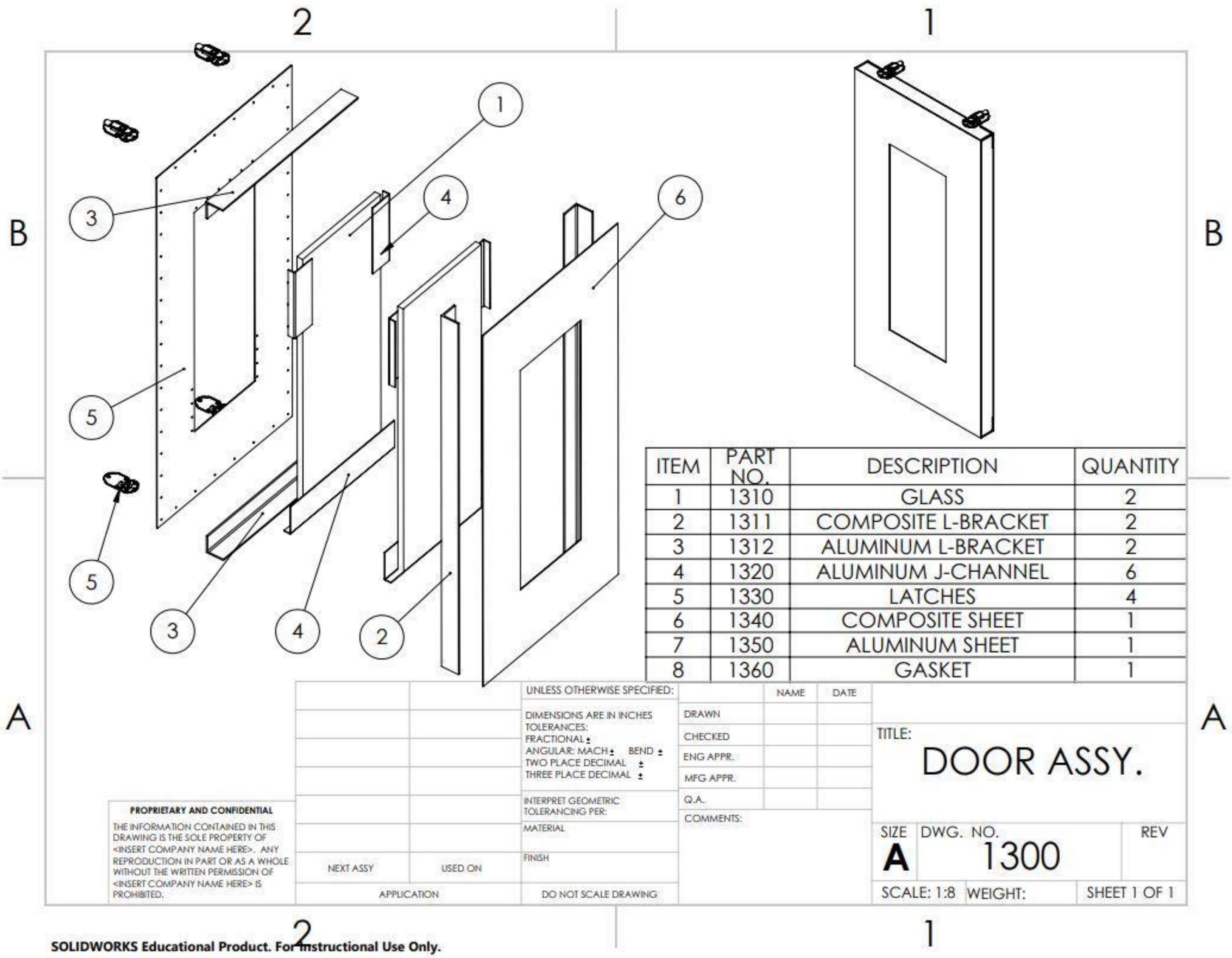
†Thermal conductivity measured at a compressive load of 2 psi.

PHYSICAL PROPERTIES

THICKNESS*	0.2 in (5 mm)	0.4 in (10 mm)
ROLL SIZE*	1,500 sqft Bulk Rolls	850 sqft Bulk Rolls 80 sqft Pony Rolls**
MAX. USE TEMP.	1200°F (650°C)	
COLOR	Maroon	
DENSITY*	12.5 lb/ft³ (0.20 g/cc)	
HYDROPHOBIC	Yes	

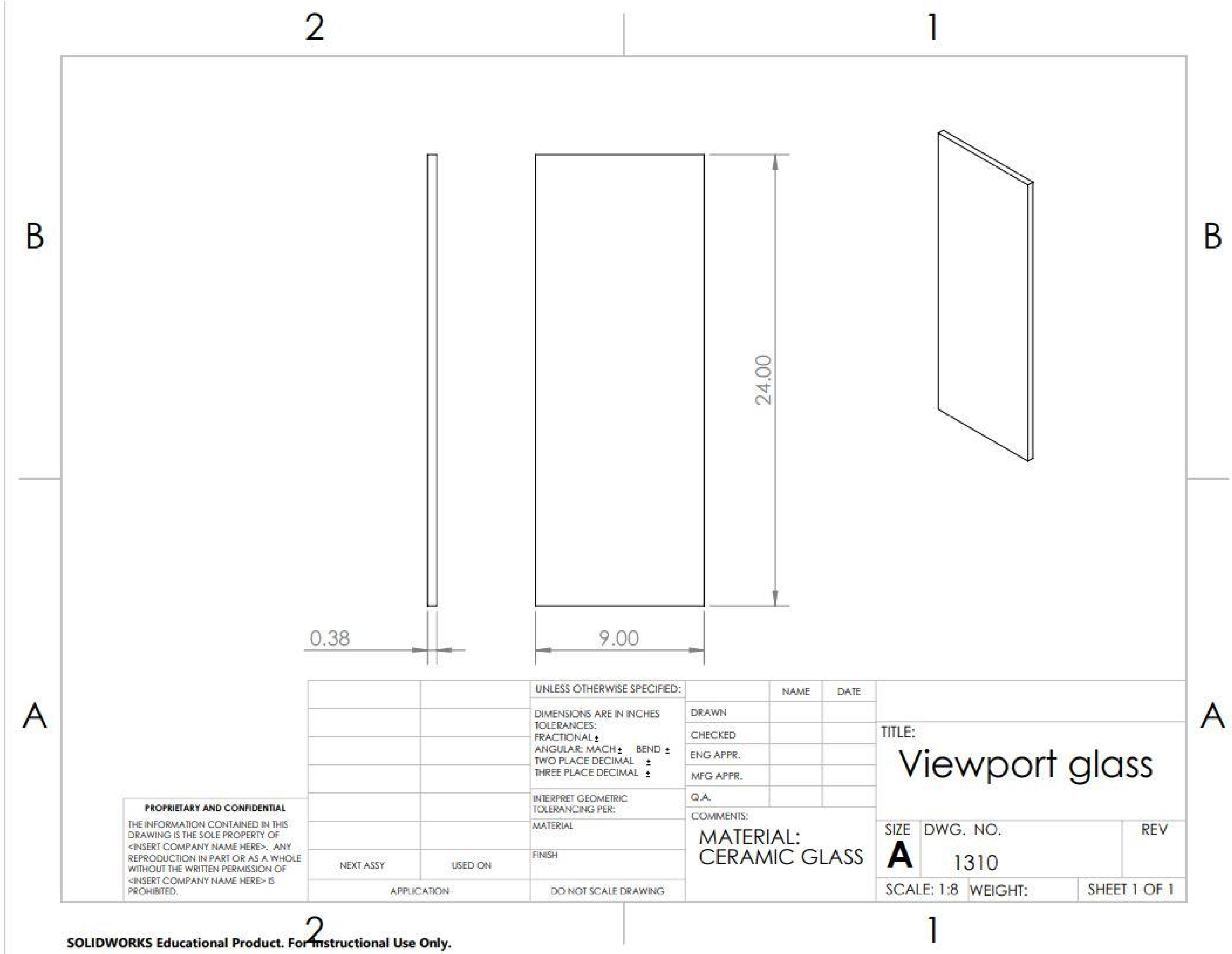
*Nominal Values.
**Pony Rolls are cut from ASTM C1728 compliant material.

Door Exploded View E1300

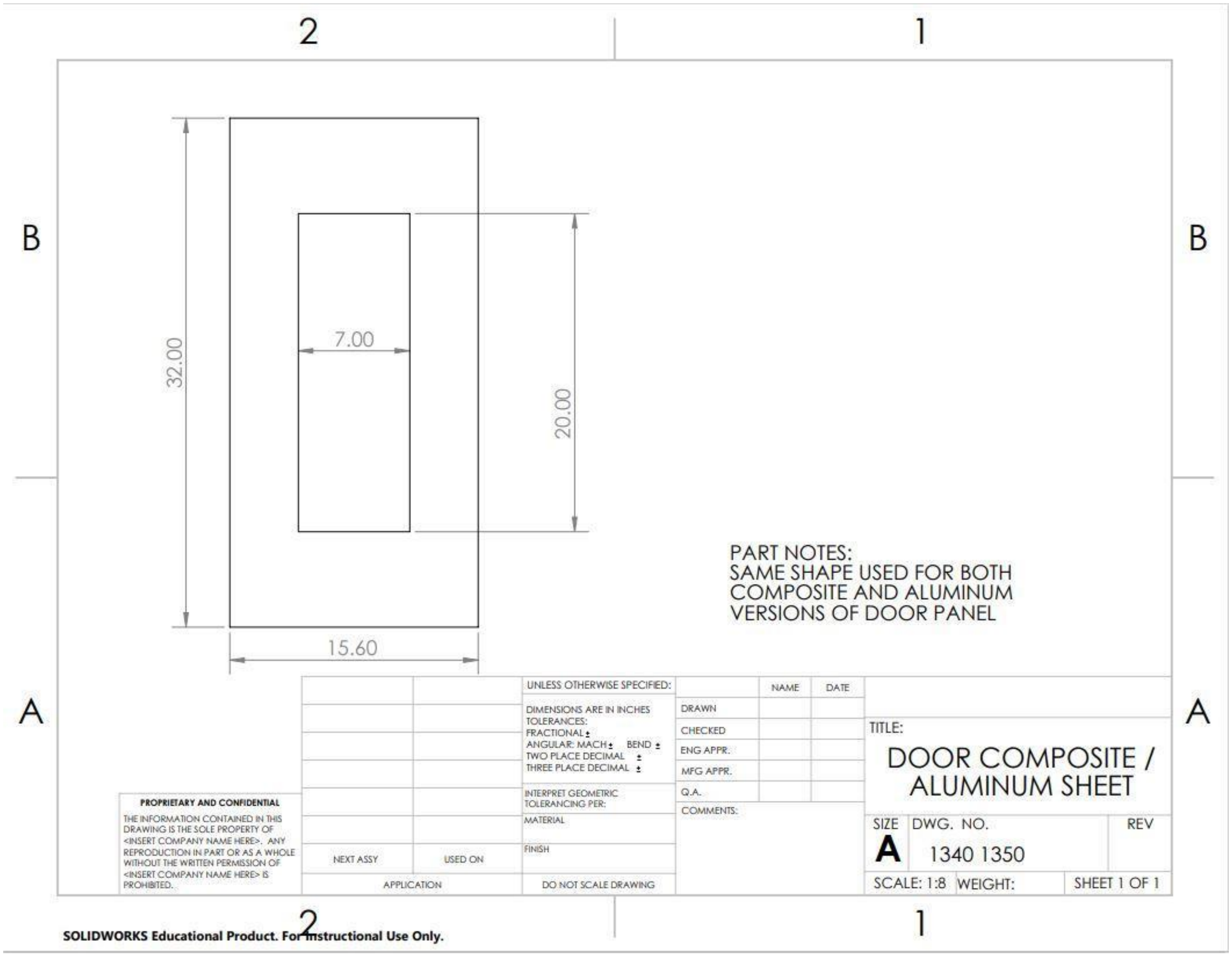


ITEM	PART NO.	DESCRIPTION	QUANTITY
1	1310	GLASS	2
2	1311	COMPOSITE L-BRACKET	2
3	1312	ALUMINUM L-BRACKET	2
4	1320	ALUMINUM J-CHANNEL	6
5	1330	LATCHES	4
6	1340	COMPOSITE SHEET	1
7	1350	ALUMINUM SHEET	1
8	1360	GASKET	1

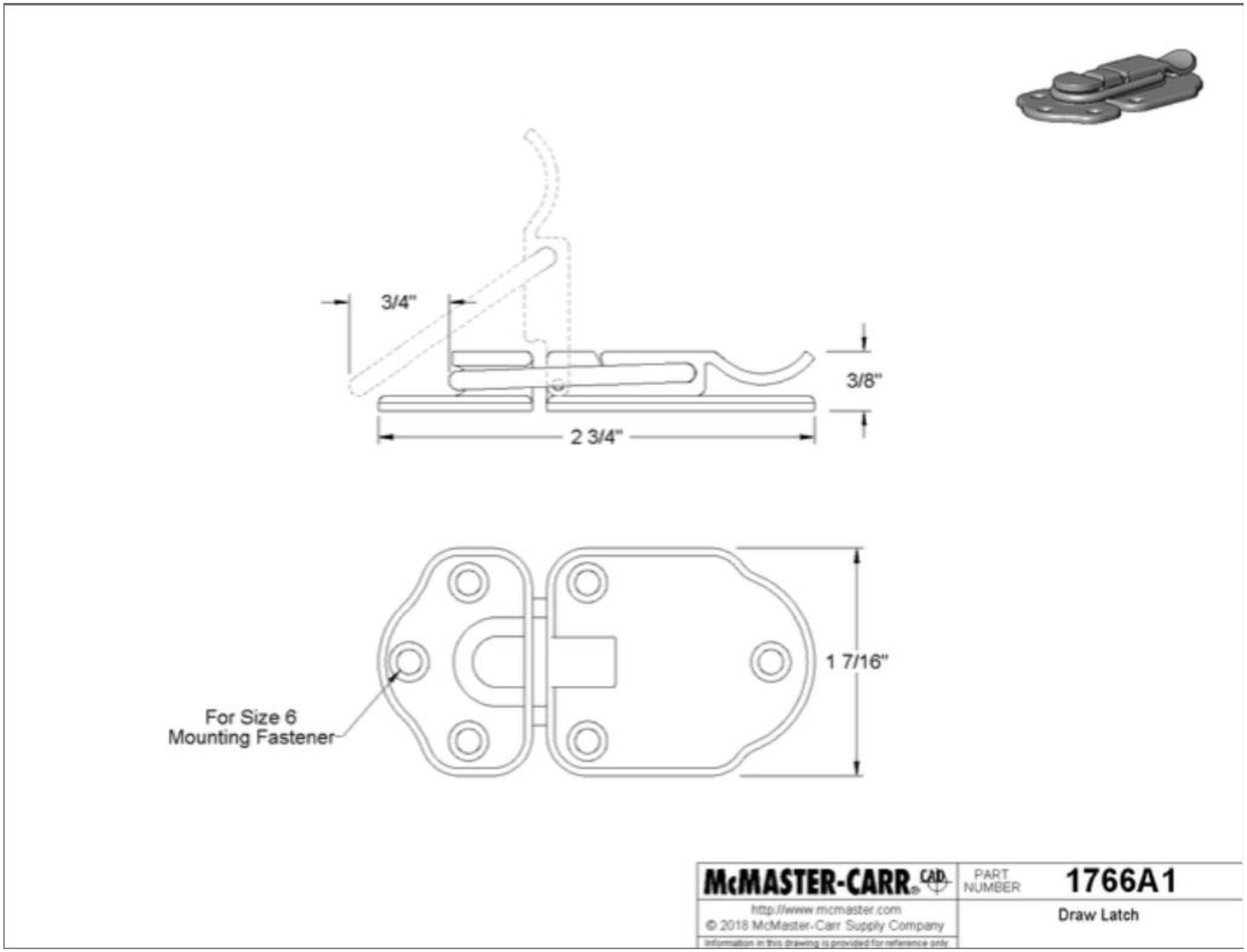
Door Viewport Glass



Door Composite / Aluminum Sheet



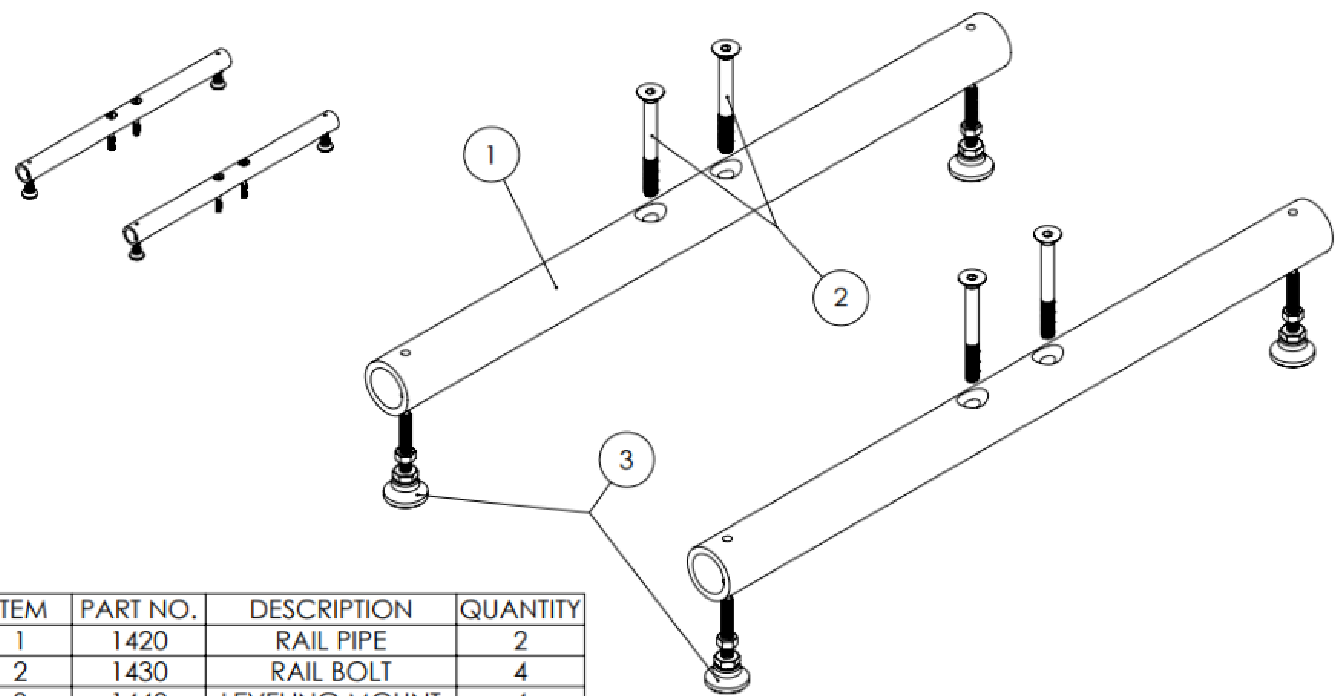
Door Draw Latches



Rail Exploded View E1400

2 | 1

B



ITEM	PART NO.	DESCRIPTION	QUANTITY
1	1420	RAIL PIPE	2
2	1430	RAIL BOLT	4
3	1440	LEVELING MOUNT	4

A

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	L.S	2/10
CHECKED	A.M	2/10
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: RAIL ASSY.

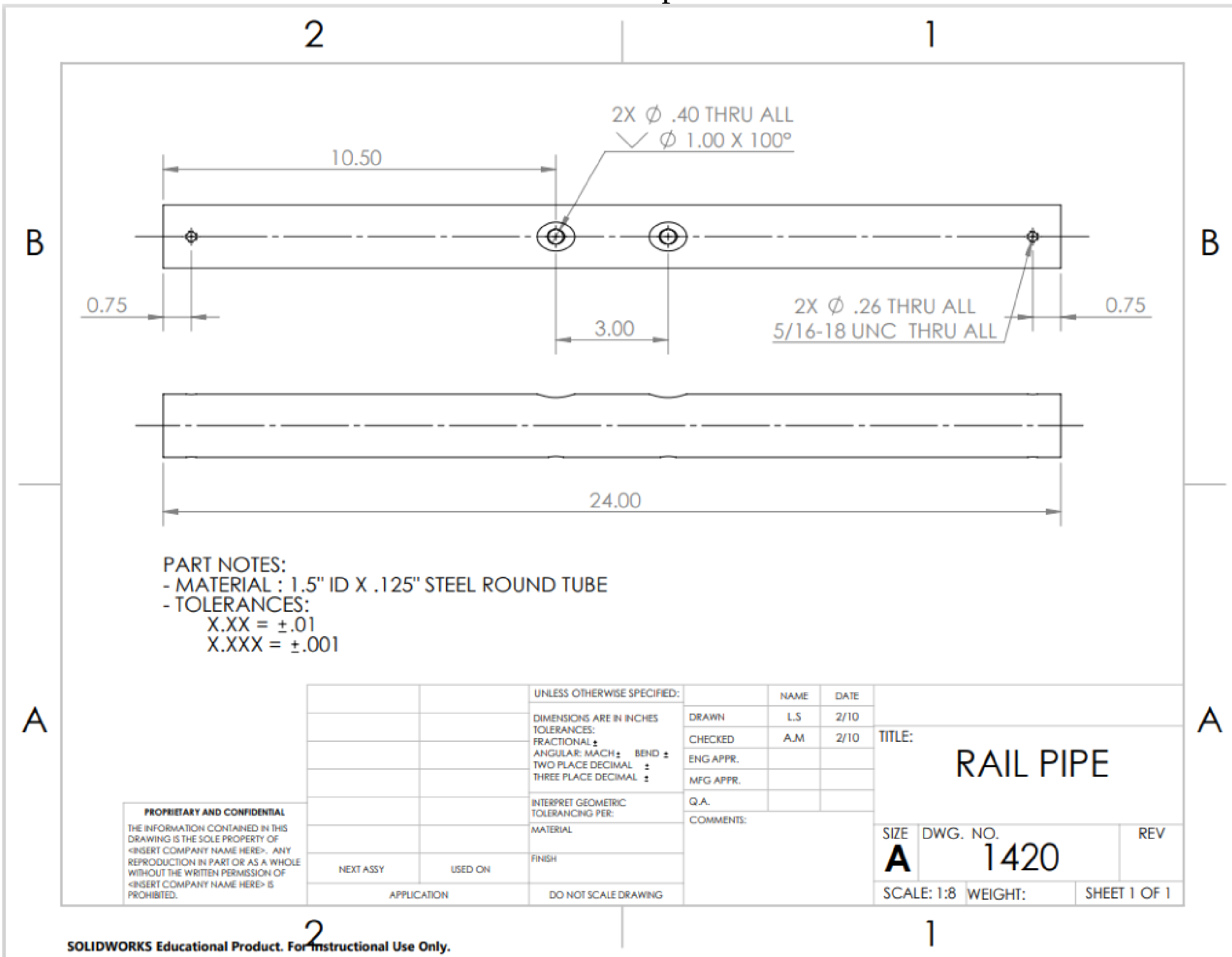
SIZE A DWG. NO. 1400 REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

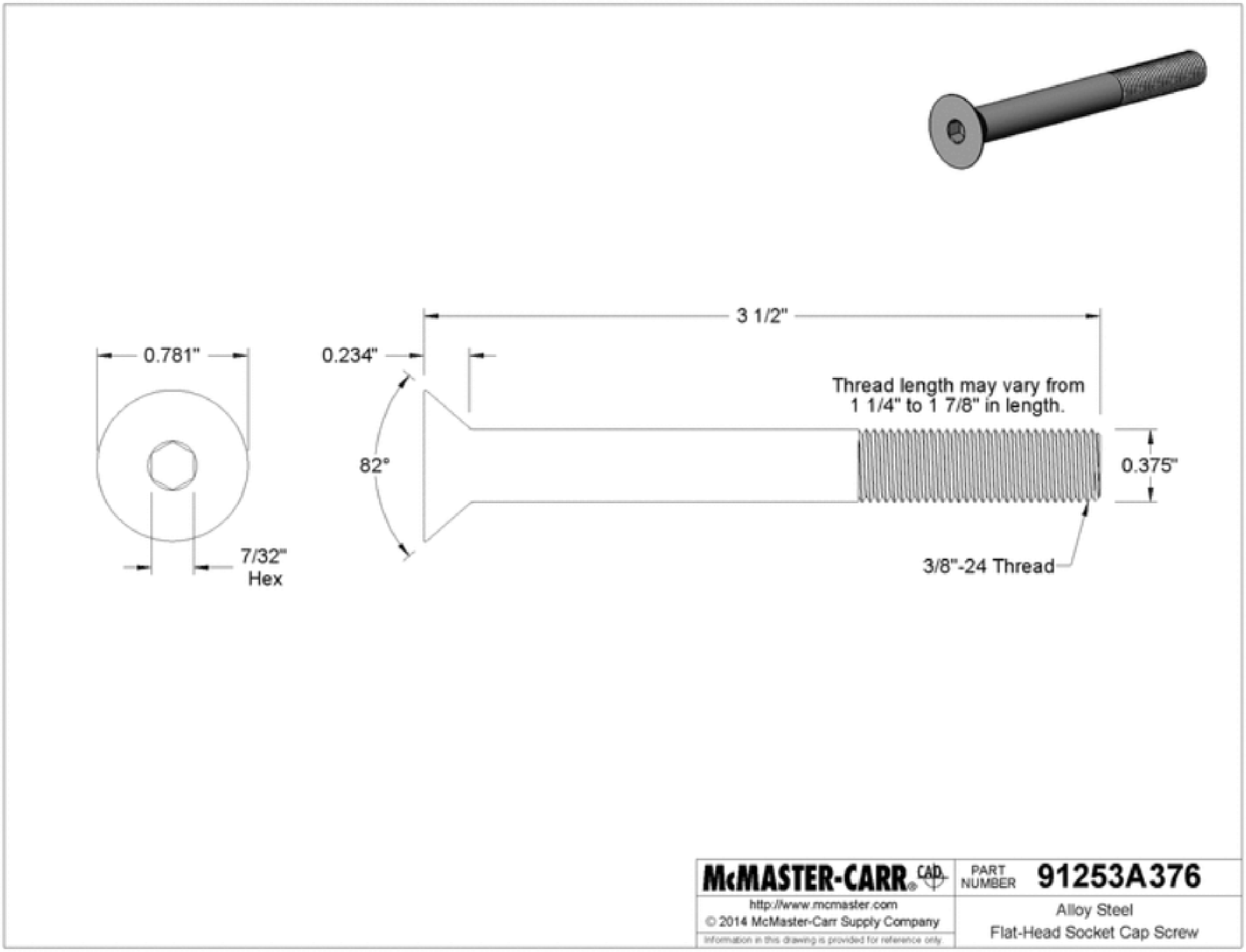
NEXT ASSY | USED ON
APPLICATION

2 | 1

Steel Pipe

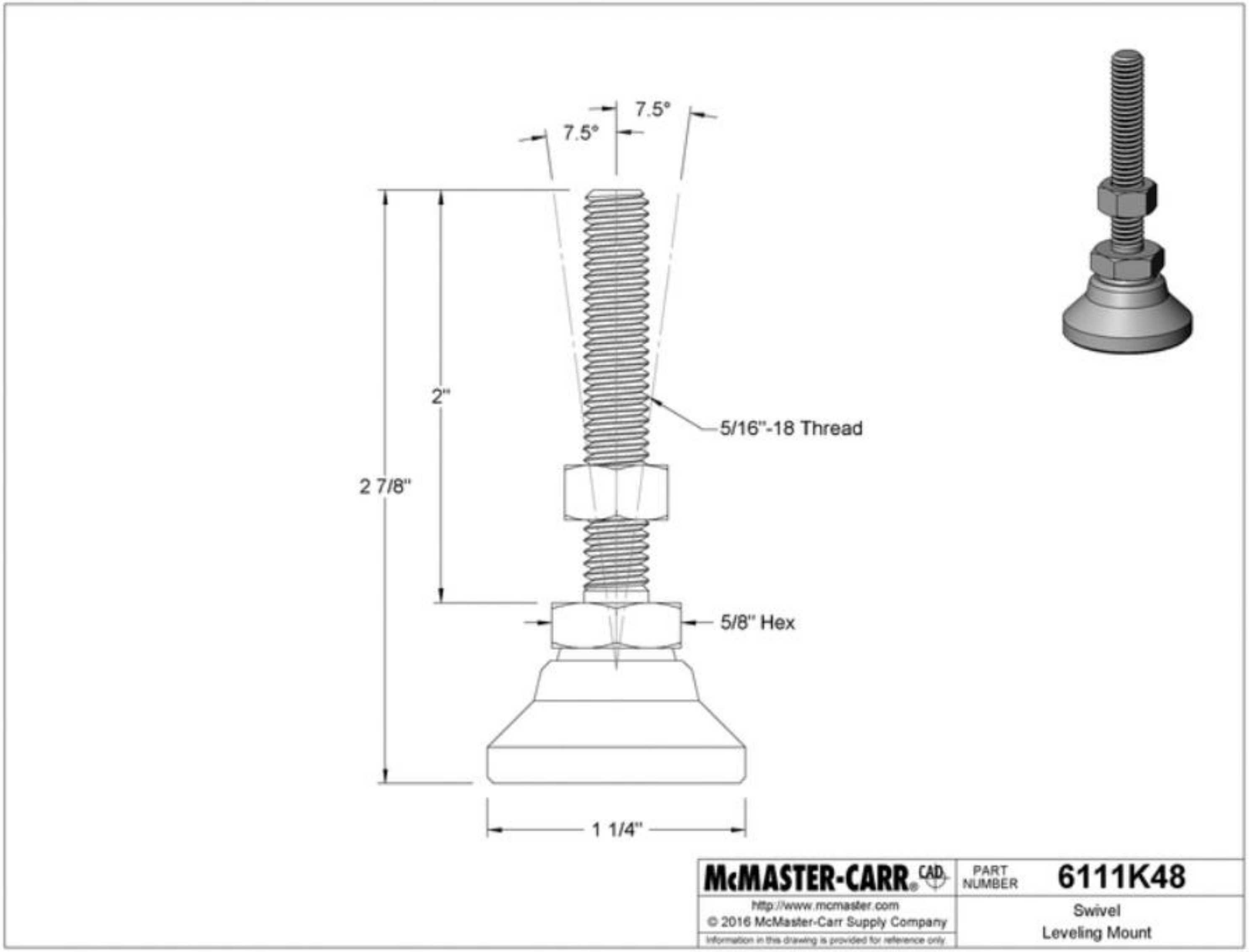

2X ∅ .40 THRU ALL
∅ 1.00 X 100°
10.50
0.75
3.00
2X ∅ .26 THRU ALL
5/16-18 UNC THRU ALL
0.75
24.00
PART NOTES:
- MATERIAL : 1.5" ID X .125" STEEL ROUND TUBE
- TOLERANCES:
X.XX = ±.01
X.XXX = ±.001
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN L.S 2/10
CHECKED A.M 2/10
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
RAIL PIPE
SIZE A
DWG. NO. 1420
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
SOLIDWORKS Educational Product. For Instructional Use Only.

Rail Bolts



3 1/2"
0.781"
0.234"
Thread length may vary from
1 1/4" to 1 7/8" in length.
82°
0.375"
7/32"
Hex
3/8"-24 Thread
McMASTER-CARR
CAD
PART
NUMBER
91253A376
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Alloy Steel
Flat-Head Socket Cap Screw

Threaded Leveling Mount



Appendix O: User Manual

Tensile Testing Environmental Chamber User Manual Part 1 – Structures

Project Goal:

The purpose of the project is to develop an environmental chamber to fit into the current tensile test machine that allows for testing materials at controlled temperatures within the range of 32-410 degrees Fahrenheit. The product should cost less to create than the environmental chambers currently on the market, which are too expensive for the school to purchase. The chamber should also be at a reasonable weight, so that it can be installed and taken off the machine easily in between tests.

Safety and PPE

The Tensile Testing Environmental Chamber is designed to be operated at high temperatures while also straining various materials to failure. PPE is necessary to install, operate, and uninstall the chamber safely.

- Insulating Gloves
  - Protect hands from burns while interacting with chamber and LD50 elements that may be hot during and soon after testing.
  - Protect hands from splinters created by samples that have failed during testing
- Latex Gloves
  - Protect hands from insulation if repairing or replacing insulation sections
- Safety Glasses
  - Protect eyes from splintering created by samples that have failed during testing
  - Protect eyes from insulation if repairing or replacing insulation sections
- Face Mask
  - Protect mouth and lungs from insulation if repairing or replacing insulation sections

Parts List

The following section outlines the parts of the environmental chamber along with materials and tools that may be required in installation and operation. These parts and tools are located in the Composites Lab in Building 192 on Cal Poly campus.

- Rails Parts:
  - 18-8 Stainless Steel Hex Drive Flat Head Screw, M6 x 1.0 mm thread, 75 mm long (x2)
  - 1” diameter aluminum tube, 15” long (x2)
  - Swivel leveling mount, ¼-20 threaded stud (x4)
- Outer Chamber Parts:
  - Main composite structure
  - Back panel

- ¼-20 wing nuts (x12)
- Insulation material
- Slot piece (x2)
- High temperature rubber seal, surface mount, hollow, 5/8" wide
- 500-degree RTV high heat silicon sealant
- Magnobond 56 Epoxy – Magnolia Plastics

- Inner Chamber Parts:
  - Aluminum structure, 5052 0.1" thick sheet
  - 1/8" aluminum rivets
  - Pyrogel XTE insulation
- Door Parts
  - Composite door structure
  - Aluminum plate, 5052 0.1" thick sheet
  - Glass, 3/8" thick ceramic glass, 8"x 22"
  - Tight-Hold Draw Latches, 2-¾" long x 1-3/16" wide
- Installation and Assembly Tools
  - Allen hex socket 4mm
  - 7/16" hex wrench
  - Flathead screwdriver
  - Bubble level

Rail Assembly

1. Begin rail assembly by removing the rubber mat from the base of the LD50. The mat should come off without much force. Be sure to carefully remove around the machine tower arms.
2. Set out both rails and the two necessary flat head hex screws along with the four swivel leveling mounts.
3. Screw the swivel leveling mounts onto both ends of each rail. Make sure to screw it into the end hole farthest from the end of the rod.
   a. Note: mounts will be fully tightened and adjusted to level the rail in a later step

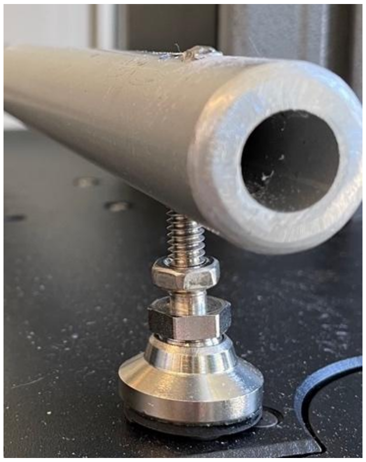


Figure 1: Shows the swivel level mount integration to the rails.

4. Stand rails up one each side of the LD50 near the bolt holes by the tower arms. Screw the flat head hex screws into the back counterbored rail hole and the back LD50 bolt hole. Use the 4mm Allen hex wrench to tighten the screw.
    a. Note: both rails are roughly the same length and can be used on either side.
    b. Note: Counterbored holes will work to affix the rails, but as the back of the chamber is heaviest, we recommend using the back holes.

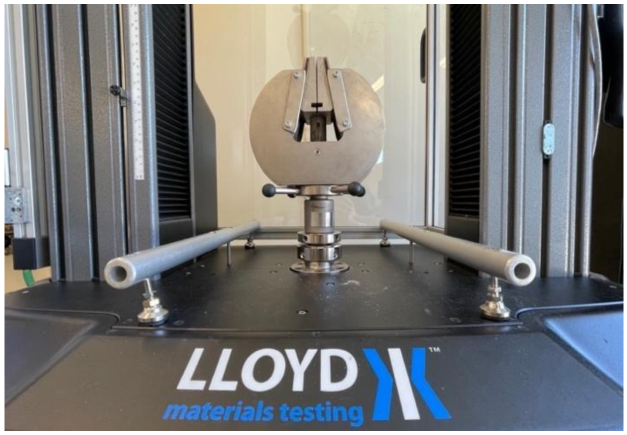


Figure 2: Shows the rails completely set up before leveling with center bolts and leveling mounts in place.

5. Adjust swivel leveling mount heights until rails are level by using a bubble level. Once the leveling mounts are at the right height, tighten the leveling mount nut to the rail.
    a. Note: after leveling each rail individually, place level across the gap so it rests on both rails and make sure they're level from front to back. Rails must be level at the same height for the chamber to sit properly.

Figure 3: Shows an individual rail being checked if it's level.

<u>Chamber Assembly</u>

Back Panel attachment

1. The main composite chamber features backside edges which are lined with bolts. Using the bolts as guides, grab and slot the backside panel with accompanying holes onto the

chamber. (There is some flex to the panel and chamber so if they do not align on first attempt some force is acceptable to achieve perfect alignment.)

Figure 4: Shows the epoxied bolt locations when the back panel is off.

2. Once all bolts are slotted into their accompanying holes on the back panel piece use the ¼" wing nuts to tighten and affix the back panel piece to the chamber. Be aware of over tightening as this can cause damage to the epoxied bolt anchoring.

Figure 5: Shows the back panel fully bolted onto the chamber (top 4 middle bolts were later removed and deemed unnecessary along with bolts next to the ducts).

<u>Attaching to the LD50</u>

Setting up the vise arms

1. If any fixtures are on the machine besides the large claw clamps, take them off by gently removing the pin and placing fixture in a safe place.
2. For the upper arm, an extender needs to be pinned into the system to allow for greater clearance in the Environmental Chamber. The images below show the tool needed to tighten/loosen the top vise to get the extender on.

    a. Note: For the extender arm pin to match, the bottom ring must be loosened to the point where it is touching the other ring or the pin will not fit.

Figure 6: Shows how to add the extender arm to the LD50.

3. For the bottom vise, the pin must be changed to a flush pin otherwise it will interfere with the chamber and the slots will not be able to be added. The flush pin and collar (used to keep the pin from coming out) are located in the LD50 drawer.

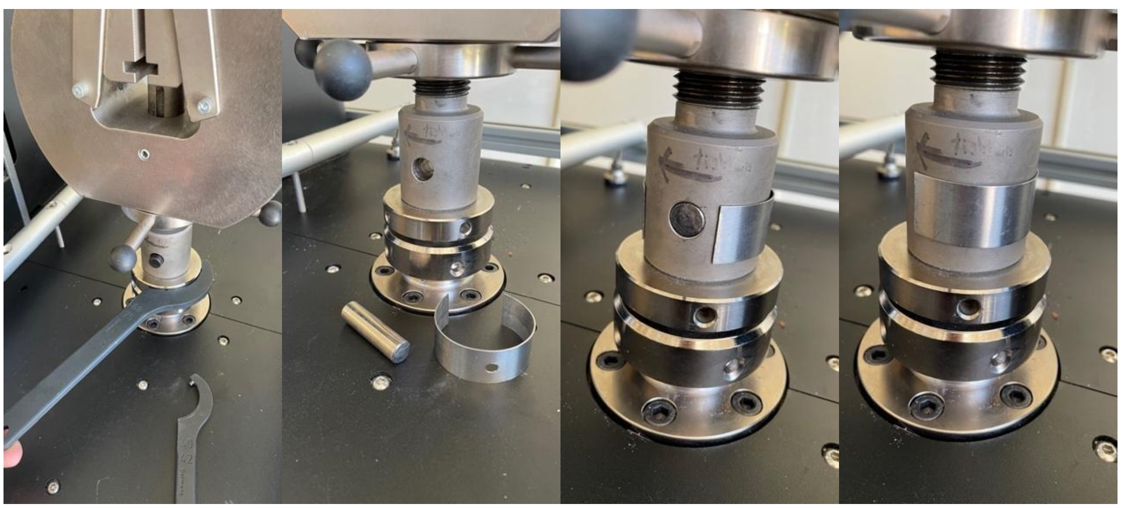


Figure 7: Shows how to install the flush pin to the bottom vise.

Sliding the chamber into place

1. Open both the front and back LD50 blast shield doors to provide full access to the machine testing area.
2. Lift the chamber assembly and rest on the back end of the rails.
    a. Note: lift from the bottom of the chamber instead of the sides or from the top U-channel to ensure internal chamber components do not come out of alignment or are damaged.

Figure 8: Shows one person lifting the chamber while another ensures it is lined up properly.

3. From the front, slide the chamber forward until the chamber top and bottom U-channels meet with the testing clamps’ mount piece and extension arm.
    a. Note: while this procedure can be followed by one user, a second user may be helpful to support the chamber from the back while it is slid into position from the front end.

Figure 9: Shows the chamber on the rails and slid into place against the LD50 arms.

Closing the chamber

1. Insert top and bottom slot blocks between the walls of the internal and external chambers at both the top and bottom. Ensure that the block gasket end is in contact with the testing clamps’ mount piece and extension arm.

   a. Note: When inserting slot blocks, the top and bottom outer chamber walls may flex slightly. This is by design; the deformation is minor and elastic, ensuring a tight fit with no convective heat transfer during testing.

Figure 10: Shows the slots inserted on the top and bottom of the chamber.

2. Lift the door right side up and align it with the front face of the chamber assembly. Make sure that the aluminum side of the door is facing the inside of the chamber.
   a. Note: the heat warning sticker is placed at the bottom of the door. If this is on the top, the door is upside down and needs to be flipped.

Figure 11: Shows the door being held up into position to attach to the chamber.

3. While holding the door securely, attach each of the four latches connecting the door to the main chamber.

Figure 12: Shows the door latches being fastened to the chamber.

a. Note: To remove the door, perform the previous steps in reverse order. Be careful to support the weight of the door completely before beginning to undo any of the latches. A partner may be helpful in this step.
   i. Always set door on a clean surface free of anything that could damage the glass. We recommend laying a piece of cotton underneath the door to ensure the glass will not be damaged.
b. **Warning:** Do not attempt to attach or detach the door while the LD50 machine is in motion or is performing a test. Following a test, do not touch the aluminum surface of the door upon removing it from the chamber as it may be extremely hot.

Running the Machine

1. Once the door is secured, close the blast shield and the machine is ready to be run!

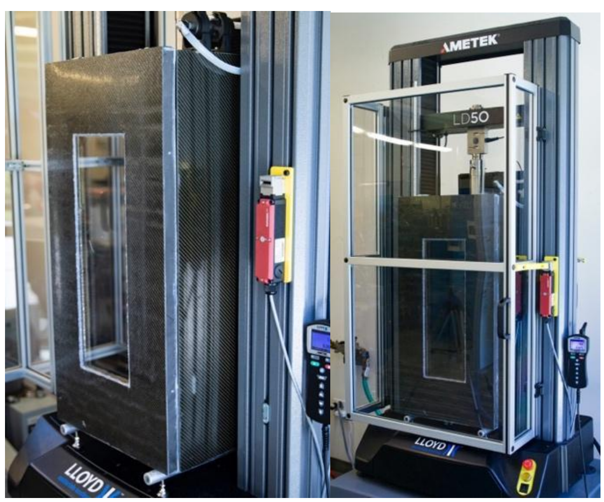


Figure 13: Shows the chamber ready to use before and after the blast shield is closed.

<u>Maintenance and Repair</u>

Sustained use of the environmental chamber may present the need for fixes and maintenance. The following sections outlines recommended methods of repair as well as procedure steps.

Instances of completely broken parts require replacement. Ensure appropriate safety procedures when handling damaged or broken parts.

Any wear or misalignment on the outer chamber, inner chamber, and door structure that produces gaps up to ¼" inch should be filled with RTV high heat silicon sealant. The sealant application procedure is as follows:

1. Clean area of application with acetone or another appropriate cleaner
2. Set up RTV sealant in the applicator according to instructions provided by RTV product.
3. Apply sealant to fill all gaps.
4. Let area sit for 20 minutes before attempting to reposition any parts. Do not perform tests for 24 hours following sealant application as the product has not fully cured.

Note: If excessive or in the wrong area, RTV silicon can be removed using acetone and paper towels in the first 20 minutes of application. After 20 minutes, hardened RTV can be stripped using a small blade or X-Acto knife.

Gaps or holes on composite structure that are greater than ¼" should be repaired using appropriately sized flat composite piece and Magnobond Epoxy adhesive. Similarly, any previously bonded composite parts, such as the corner L brackets, that may have de-attached should be attached using this same adhesive. The procedure is as follows:

1. Ensure the use of proper PPE, including disposable latex gloves.
2. Prepare both surfaces for bonding using sandpaper on the area of contact. Clean both surfaces completely using acetone.
3. Using a disposable cup, disposable mixing stick, and a scale, measure the desired amount of Magnobond 56 epoxy. The weight ratio is 100:77-part A to part B.
4. Mix the two parts together.
5. Using the disposable mixing stick, apply a thin layer onto one of the surfaces to be bonded.
6. Adhere the parts together, applying pressure to ensure complete contact. If needed, apply weights or clamps to maintain pressure throughout the cure.
7. Allow the repaired area to sit for at least 5 hours in 70° F temperature.

If any replaceable parts such as bolts, screws, or rivets are damaged, see the parts list at the top of the user manual for exact part information to replace them. Do not continue to use damaged part and replace them before running the machine again. Most parts can be easily acquired by a local hardware store or through McMaster-Carr's website with included one day shipping.

Hazards

- During testing the glass may reach temperatures around 60 degrees Celsius and will be rather dangerous for prolonged contact, more than 5 seconds. Additionally, wait for 20 minutes after testing to allow for proper cooling.
- Allow 5 minutes of cooling, after testing, before removing the door or tampering with the insides of the chamber to allow sufficient cooling to take place.
- When moving the chamber, it is recommended that at least two people carry it to prevent dropping.

Appendix P: Tensile Testing Raw Data

Dry Sample 3:

Time (s)	Load (N)	Machine Extension (mm)	Stress (MPa)	Extension from Preload (mm)	Strain	Percentage Strain	Gauge Length (mm)
0							
0.374343	-0.04073	1.8448E-07	-0.0013447	-0.0083285	-0.000047591	-0.0047591	174.99
0.748687	304	0.080807	10.036	0.072479	0.00041416	0.041416	175.07
1.12303	555.53	0.17438	18.34	0.16605	0.00094889	0.094889	175.17
1.49737	697.74	0.26796	23.035	0.25963	0.0014836	0.14836	175.26
1.87172	803.13	0.36154	26.515	0.35321	0.0020184	0.20184	175.35
2.24606	888.49	0.45512	29.333	0.44679	0.0025531	0.25531	175.45
2.6204	968.54	0.5487	31.976	0.54037	0.0030878	0.30878	175.54
2.99475	1040.1	0.64228	34.339	0.63395	0.0036226	0.36226	175.63
3.36909	1109.8	0.73586	36.639	0.72753	0.0041573	0.41573	175.73
3.74343	1179.3	0.82944	38.932	0.82112	0.0046921	0.46921	175.82
4.11778	1226.5	0.923	40.492	0.91467	0.0052267	0.52267	175.91
4.49212	1261.5	1.0166	41.648	1.0083	0.0057614	0.57614	176.01
4.86646	1287.8	1.1102	42.515	1.1018	0.0062962	0.62962	176.1
5.24081	1315	1.2037	43.414	1.1954	0.006831	0.6831	176.2
5.61515	1347.1	1.2973	44.474	1.289	0.0073656	0.73656	176.29
5.98949	1379.9	1.3909	45.556	1.3826	0.0079004	0.79004	176.38
6.36384	1413.8	1.4845	46.676	1.4761	0.0084351	0.84351	176.48
6.73818	1428.8	1.578	47.171	1.5697	0.0089697	0.89697	176.57
7.11253	1445.5	1.6716	47.721	1.6633	0.0095046	0.95046	176.66
7.48687	1458.4	1.7652	48.149	1.7569	0.010039	1.0039	176.76
7.86121	1471.4	1.8588	48.578	1.8505	0.010574	1.0574	176.85
8.23556	1485.2	1.9524	49.034	1.944	0.011109	1.1109	176.94
8.6099	1510.9	2.046	49.881	2.0376	0.011644	1.1644	177.04
8.98424	1538.6	2.1395	50.795	2.1312	0.012178	1.2178	177.13
9.35859	1554.3	2.2331	51.313	2.2248	0.012713	1.2713	177.22
9.73293	1569.9	2.3267	51.83	2.3184	0.013248	1.3248	177.32

10.1073	1578.9	2.4203	52.125	2.4119	0.013782	1.3782	177.41
10.4816	1550.4	2.5138	51.186	2.5055	0.014317	1.4317	177.51
10.856	1470.2	2.6074	48.538	2.5991	0.014852	1.4852	177.6
11.2303	1382	2.701	45.626	2.6927	0.015387	1.5387	177.69
11.6046	1362.6	2.7946	44.984	2.7862	0.015921	1.5921	177.79
11.979	1398	2.8882	46.155	2.8798	0.016456	1.6456	177.88
12.3533	1442.8	2.9817	47.633	2.9734	0.016991	1.6991	177.97
12.7277	1502	3.0753	49.588	3.067	0.017526	1.7526	178.07
13.102	1584.7	3.1689	52.317	3.1606	0.01806	1.806	178.16
13.4764	1669.6	3.2625	55.12	3.2542	0.018595	1.8595	178.25
13.8507	1775	3.3561	58.599	3.3477	0.01913	1.913	178.35
14.2251	1885.3	3.4497	62.242	3.4413	0.019665	1.9665	178.44
14.5994	1995.2	3.5432	65.871	3.5349	0.020199	2.0199	178.53
14.9737	2104.2	3.6368	69.469	3.6285	0.020734	2.0734	178.63
15.3481	2213.2	3.7304	73.068	3.7221	0.021269	2.1269	178.72
15.7224	2324.3	3.824	76.734	3.8156	0.021804	2.1804	178.82
16.0968	2435.7	3.9175	80.413	3.9092	0.022338	2.2338	178.91
16.4711	2547.2	4.0111	84.092	4.0028	0.022873	2.2873	179
16.8455	2667.9	4.1047	88.08	4.0963	0.023408	2.3408	179.1
17.2198	2789.2	4.1982	92.083	4.1899	0.023942	2.3942	179.19
17.5941	2910.5	4.2918	96.087	4.2835	0.024477	2.4477	179.28
17.9685	3035.5	4.3854	100.22	4.3771	0.025012	2.5012	179.38
18.3428	3173.7	4.479	104.78	4.4707	0.025547	2.5547	179.47
18.7172	3308.4	4.5726	109.23	4.5642	0.026081	2.6081	179.56
19.0915	3449.9	4.6661	113.9	4.6578	0.026616	2.6616	179.66
19.4659	3591.4	4.7597	118.57	4.7514	0.027151	2.7151	179.75
19.8402	3742.3	4.8533	123.55	4.845	0.027686	2.7686	179.84
20.2145	3893.9	4.9469	128.55	4.9386	0.02822	2.822	179.94
20.5889	4045.4	5.0405	133.56	5.0321	0.028755	2.8755	180.03
20.9632	4196.3	5.134	138.54	5.1257	0.02929	2.929	180.13
21.3376	4347.3	5.2276	143.52	5.2193	0.029824	2.9824	180.22
21.7119	4499.7	5.3212	148.55	5.3129	0.030359	3.0359	180.31
22.0863	4661.8	5.4148	153.9	5.4065	0.030894	3.0894	180.41

22.4606	4823.6	5.5084	159.25	5.5	0.031429	3.1429	180.5
22.8349	4984.2	5.6019	164.55	5.5936	0.031963	3.1963	180.59
23.2093	5144.9	5.6955	169.85	5.6872	0.032498	3.2498	180.69
23.5836	5305.5	5.7891	175.16	5.7808	0.033033	3.3033	180.78
23.958	5470.6	5.8827	180.61	5.8743	0.033568	3.3568	180.87
24.3323	5636.9	5.9763	186.1	5.9679	0.034102	3.4102	180.97
24.7067	5804	6.0698	191.62	6.0615	0.034637	3.4637	181.06
25.081	5971.7	6.1634	197.15	6.1551	0.035172	3.5172	181.16
25.4554	6148.6	6.257	202.99	6.2487	0.035707	3.5707	181.25
25.8297	6324.9	6.3506	208.81	6.3422	0.036241	3.6241	181.34
26.204	6501.2	6.4442	214.63	6.4358	0.036776	3.6776	181.44
26.5784	6677.4	6.5377	220.45	6.5294	0.037311	3.7311	181.53
26.9527	6853.7	6.6313	226.27	6.6229	0.037845	3.7845	181.62
27.3271	7033.3	6.7248	232.2	6.7165	0.03838	3.838	181.72
27.7014	7214.9	6.8184	238.19	6.8101	0.038915	3.8915	181.81
28.0758	7396.4	6.912	244.19	6.9037	0.03945	3.945	181.9
28.4501	7579.1	7.0056	250.22	6.9973	0.039984	3.9984	182
28.8244	7767.3	7.0992	256.43	7.0909	0.040519	4.0519	182.09
29.1988	7955.5	7.1928	262.64	7.1845	0.041054	4.1054	182.18
29.5731	8143.7	7.2863	268.86	7.278	0.041589	4.1589	182.28
29.9475	8331.9	7.3799	275.07	7.3716	0.042123	4.2123	182.37
30.3218	8521.9	7.4735	281.34	7.4652	0.042658	4.2658	182.47
30.6962	8720.4	7.5671	287.9	7.5587	0.043193	4.3193	182.56
31.0705	8915	7.6606	294.32	7.6523	0.043727	4.3727	182.65
31.4448	9109.6	7.7542	300.75	7.7459	0.044262	4.4262	182.75
31.8192	9304.2	7.8478	307.17	7.8395	0.044797	4.4797	182.84
32.1935	9498.9	7.9414	313.6	7.933	0.045332	4.5332	182.93
32.5679	9693.5	8.0349	320.02	8.0266	0.045866	4.5866	183.03
32.9422	9883.9	8.1285	326.31	8.1202	0.046401	4.6401	183.12
33.3166	10005	8.2221	330.31	8.2138	0.046936	4.6936	183.21
33.6909	9986.7	8.3157	329.7	8.3074	0.047471	4.7471	183.31
34.0653	10255	8.4093	338.55	8.4009	0.048005	4.8005	183.4
34.4396	10452	8.5028	345.07	8.4945	0.04854	4.854	183.49

34.8139	10644	8.5964	351.4	8.5881	0.049075	4.9075	183.59
35.1883	10682	8.69	352.67	8.6817	0.04961	4.961	183.68
35.5626	10898	8.7836	359.79	8.7753	0.050144	5.0144	183.78
35.937	11065	8.8772	365.31	8.8688	0.050679	5.0679	183.87
36.3113	11227	8.9707	370.64	8.9624	0.051214	5.1214	183.96
36.6857	11358	9.0643	374.98	9.056	0.051748	5.1748	184.06
37.06	7775	9.1579	256.69	9.1496	0.052284	5.2284	184.15

Dry Sample 2:

Time (s)	Load (N)	Machine Extension (mm)	Stress (MPa)	Extension from Preload (mm)	Strain	Percentage Strain	Gauge Length (mm)
0							
0.930303	-5.1046	0.16316	-0.18657	0.15009	0.00087261	0.087261	172.15
1.86061	-1.0156	0.39573	-0.037121	0.38265	0.0022247	0.22247	172.38
2.79091	674.31	0.6283	24.646	0.61522	0.0035769	0.35769	172.62
3.72121	1219.6	0.86083	44.577	0.84776	0.0049288	0.49288	172.85
4.65152	1429.7	1.0934	52.254	1.0803	0.0062809	0.62809	173.08
5.58182	1514.2	1.326	55.343	1.3129	0.007633	0.7633	173.31
6.51212	1545.5	1.5585	56.486	1.5454	0.0089851	0.89851	173.55
7.44242	1613.1	1.7911	58.958	1.778	0.010337	1.0337	173.78
8.37273	1714.7	2.0236	62.67	2.0106	0.011689	1.1689	174.01
9.30303	1851.4	2.2562	67.667	2.2431	0.013041	1.3041	174.24
10.2333	1952.1	2.4887	71.347	2.4757	0.014393	1.4393	174.48
11.1636	2029.4	2.7213	74.174	2.7082	0.015746	1.5746	174.71
12.0939	2067.6	2.9539	75.57	2.9408	0.017098	1.7098	174.94
13.0242	2091.6	3.1864	76.446	3.1734	0.01845	1.845	175.17
13.9545	2122	3.419	77.559	3.4059	0.019802	1.9802	175.41
14.8848	2130.2	3.6515	77.859	3.6385	0.021154	2.1154	175.64
15.8152	2050	3.8841	74.927	3.871	0.022506	2.2506	175.87
16.7455	1892.7	4.1167	69.178	4.1036	0.023858	2.3858	176.1
17.6758	1898.3	4.3492	69.382	4.3362	0.02521	2.521	176.34
18.6061	1884.3	4.5818	68.869	4.5687	0.026562	2.6562	176.57
19.5364	1831.1	4.8143	66.926	4.8012	0.027914	2.7914	176.8
20.4667	1787.8	5.0469	65.342	5.0338	0.029266	2.9266	177.03
21.397	1757.5	5.2795	64.234	5.2664	0.030618	3.0618	177.27
22.3273	1680.5	5.512	61.422	5.4989	0.031971	3.1971	177.5
23.2576	1600.2	5.7445	58.487	5.7315	0.033322	3.3322	177.73
24.1879	1622.8	5.9771	59.313	5.964	0.034675	3.4675	177.96
25.1182	1728.3	6.2097	63.17	6.1966	0.036027	3.6027	178.2

26.0485	1843.8	6.4422	67.391	6.4292	0.037379	3.7379	178.43
26.9788	2027.4	6.6748	74.099	6.6617	0.038731	3.8731	178.66
27.9091	2234.2	6.9074	81.659	6.8943	0.040083	4.0083	178.89
28.8394	2397.5	7.1399	87.629	7.1269	0.041435	4.1435	179.13
29.7697	2571.7	7.3725	93.997	7.3594	0.042787	4.2787	179.36
30.7	2752.3	7.605	100.6	7.592	0.044139	4.4139	179.59
31.6303	2927.4	7.8376	107	7.8245	0.045491	4.5491	179.82
32.5606	3086	8.0702	112.79	8.0571	0.046843	4.6843	180.06
33.4909	3271.4	8.3027	119.57	8.2896	0.048196	4.8196	180.29
34.4212	3504.2	8.5353	128.08	8.5222	0.049548	4.9548	180.52
35.3515	3775.7	8.7678	138	8.7548	0.0509	5.09	180.75
36.2818	4066	9.0004	148.61	8.9873	0.052252	5.2252	180.99
37.2121	4376.5	9.2329	159.96	9.2198	0.053604	5.3604	181.22
38.1424	4706.1	9.4655	172.01	9.4524	0.054956	5.4956	181.45
39.0727	5047.1	9.698	184.47	9.685	0.056308	5.6308	181.68
40.003	5405.6	9.9306	197.57	9.9175	0.05766	5.766	181.92
40.9333	5778.2	10.163	211.19	10.15	0.059012	5.9012	182.15
41.8636	6156.8	10.396	225.03	10.383	0.060364	6.0364	182.38
42.7939	6550.3	10.628	239.41	10.615	0.061716	6.1716	182.62
43.7242	6965.7	10.861	254.59	10.848	0.063068	6.3068	182.85
44.6545	7384.5	11.093	269.9	11.08	0.06442	6.442	183.08
45.5848	7807.4	11.326	285.36	11.313	0.065772	6.5772	183.31
46.5152	8238.7	11.558	301.12	11.545	0.067124	6.7124	183.55
47.4455	8673.7	11.791	317.02	11.778	0.068477	6.8477	183.78
48.3758	9116.8	12.024	333.22	12.011	0.069829	6.9829	184.01
49.3061	9556.5	12.256	349.29	12.243	0.071181	7.1181	184.24
50.2364	9998	12.489	365.42	12.476	0.072533	7.2533	184.48
51.1667	10446	12.721	381.81	12.708	0.073885	7.3885	184.71
52.097	10894	12.954	398.19	12.941	0.075237	7.5237	184.94
53.0273	11296	13.186	412.87	13.173	0.076589	7.6589	185.17
53.9576	11742	13.419	429.15	13.406	0.077941	7.7941	185.41
54.8879	8407.4	13.652	307.29	13.638	0.079293	7.9293	185.64
55.8182	8986	13.884	328.44	13.871	0.080645	8.0645	185.87
56.7485	9498.9	14.117	347.18	14.104	0.081997	8.1997	186.1
57.6788	9956.4	14.349	363.9	14.336	0.083349	8.3349	186.34
58.6091	10449	14.582	381.91	14.569	0.084701	8.4701	186.57
59.5394	10914	14.814	398.91	14.801	0.086054	8.6054	186.8
60.4697	11345	15.047	414.65	15.034	0.087406	8.7406	187.03
61.4	11642	15.279	425.5	15.266	0.088758	8.8758	187.27
62.3303	11963	15.512	437.25	15.499	0.09011	9.011	187.5
63.2606	12211	15.745	446.31	15.731	0.091462	9.1462	187.73

64.1909	12546	15.977	458.57	15.964	0.092814	9.2814	187.96
65.1212	12844	16.21	469.44	16.197	0.094166	9.4166	188.2
66.0515	13169	16.442	481.33	16.429	0.095518	9.5518	188.43
66.9818	13495	16.675	493.24	16.662	0.09687	9.687	188.66
67.9121	13822	16.907	505.19	16.894	0.098222	9.8222	188.89
68.8424	14149	17.14	517.16	17.127	0.099574	9.9574	189.13
69.7727	14478	17.372	529.15	17.359	0.10093	10.093	189.36
70.703	14795	17.605	540.74	17.592	0.10228	10.228	189.59
71.6333	15109	17.838	552.25	17.824	0.10363	10.363	189.82
72.5636	15373	18.07	561.89	18.057	0.10498	10.498	190.06
73.4939	15689	18.303	573.41	18.29	0.10633	10.633	190.29
74.4242	16001	18.535	584.84	18.522	0.10769	10.769	190.52
75.3545	16312	18.768	596.21	18.755	0.10904	10.904	190.75
76.2848	16623	19	607.57	18.987	0.11039	11.039	190.99
77.2152	16924	19.233	618.56	19.22	0.11174	11.174	191.22
78.1455	17236	19.465	629.96	19.452	0.1131	11.31	191.45
79.0758	17545	19.698	641.27	19.685	0.11445	11.445	191.68
80.0061	17854	19.931	652.57	19.917	0.1158	11.58	191.92
80.9364	18145	20.163	663.21	20.15	0.11715	11.715	192.15
81.8667	18445	20.396	674.14	20.383	0.1185	11.85	192.38
82.797	18742	20.628	685	20.615	0.11986	11.986	192.62
83.7273	19039	20.861	695.87	20.848	0.12121	12.121	192.85
84.6576	19333	21.093	706.62	21.08	0.12256	12.256	193.08
85.5879	19603	21.326	716.48	21.313	0.12391	12.391	193.31
86.5182	19887	21.558	726.88	21.545	0.12526	12.526	193.55
87.4485	20188	21.791	737.86	21.778	0.12662	12.662	193.78
88.3788	20432	22.024	746.79	22.01	0.12797	12.797	194.01
89.3091	20722	22.256	757.37	22.243	0.12932	12.932	194.24
90.2394	20993	22.489	767.3	22.476	0.13067	13.067	194.48
91.1697	21235	22.721	776.14	22.708	0.13202	13.202	194.71
92.1	-156.14	22.954	-5.707	22.941	0.13338	13.338	194.94

Dry Sample 1:

Time (s)	Load (N)	Machine Extension (mm)	Stress (MPa)	Extension from Preload (mm)	Strain	Percentage Strain	Gauge Length (mm)
0							
0.043013	-1.5946		-0.054035				
0.086026	-1.5053		-0.051009				
0.129039	-1.416		-0.047983				
0.172052	-1.3267		-0.044957				
0.215065	-1.2374		-0.041932				

0.258078	-1.1481		-0.038906				
0.301091	-1.0588		-0.03588				
0.344104	-0.96953		-0.032854				
0.387117	-0.88024		-0.029829				
0.43013	-0.79095		-0.026803				
0.473143	-0.70166	1.3699E-06	-0.023777	-0.011232	-0.000067257	-0.0067257	166.99
0.516156	-0.61237	1.2912E-06	-0.020751	-0.011232	-0.000067258	-0.0067258	166.99
0.559169	-0.52308	1.2125E-06	-0.017726	-0.011232	-0.000067258	-0.0067258	166.99
0.602182	-0.43379	1.1338E-06	-0.0147	-0.011232	-0.000067259	-0.0067259	166.99
0.645195	-0.3445	1.0551E-06	-0.011674	-0.011232	-0.000067259	-0.0067259	166.99
0.688208	-0.25521	9.7646E-07	-0.0086484	-0.011232	-0.00006726	-0.006726	166.99
0.731221	-0.16592	8.9778E-07	-0.0056227	-0.011232	-0.00006726	-0.006726	166.99
0.774234	-0.076635	8.191E-07	-0.0025969	-0.011233	-0.000067261	-0.0067261	166.99
0.817247	0.012655	7.4041E-07	0.00042883	-0.011233	-0.000067261	-0.0067261	166.99
0.86026	0.10194	0.013825	0.0034546	0.0025914	0.000015517	0.0015517	167
0.903273	0.19123	0.024583	0.0064803	0.01335	0.000079941	0.0079941	167.01
0.946286	0.28052	0.035332	0.0095061	0.024098	0.0001443	0.01443	167.02
0.989299	0.36981	0.046081	0.012532	0.034848	0.00020867	0.020867	167.03
1.03231	0.4591	0.056816	0.015558	0.045583	0.00027295	0.027295	167.05
1.07533	0.54839	0.067566	0.018583	0.056332	0.00033732	0.033732	167.06
1.11834	0.63768	0.078315	0.021609	0.067082	0.00040169	0.040169	167.07
1.16135	0.72697	0.089064	0.024635	0.077831	0.00046605	0.046605	167.08
1.20436	0.81626	0.099814	0.027661	0.088581	0.00053042	0.053042	167.09

1.24738	0.90555	0.11056	0.030686	0.09933	0.000 59479	0.059479	167.1
1.29039	0.99484	0.12131	0.033712	0.11008	0.000 65916	0.065916	167.11
1.3334	1.0841	0.13206	0.036738	0.12083	0.000 72353	0.072353	167.12
1.37642	1.1734	0.14281	0.039764	0.13158	0.000 78789	0.078789	167.13
1.41943	1.2627	0.15357	0.042789	0.14234	0.000 85234	0.085234	167.14
1.46244	1.352	0.16434	0.045815	0.15311	0.000 91683	0.091683	167.15
1.50546	1.4413	0.1751	0.048841	0.16387	0.000 98126	0.098126	167.16
1.54847	1.5306	0.18586	0.051867	0.17462	0.001 0456	0.10456	167.17
1.59148	1.6199	0.19661	0.054892	0.18538	0.001 11	0.111	167.19
1.63449	1.7092	0.20736	0.057918	0.19613	0.001 1744	0.11744	167.2
1.67751	1.7985	0.21812	0.060944	0.20688	0.001 2388	0.12388	167.21
1.72052	1.8877	0.22887	0.06397	0.21764	0.001 3032	0.13032	167.22
1.76353	1.977	0.23962	0.066995	0.22839	0.001 3676	0.13676	167.23
1.80655	2.0663	0.25038	0.070021	0.23914	0.001 432	0.1432	167.24
1.84956	2.1556	0.26113	0.073047	0.2499	0.001 4964	0.14964	167.25
1.89257	2.2449	0.27188	0.076073	0.26065	0.001 5608	0.15608	167.26
1.93559	2.3342	0.28264	0.079098	0.2714	0.001 6252	0.16252	167.27
1.9786	2.4235	0.29339	0.082124	0.28216	0.001 6896	0.16896	167.28
2.02161	2.5128	0.30414	0.08515	0.29291	0.001 7539	0.17539	167.29
2.06462	2.6021	0.3149	0.088175	0.30366	0.001 8183	0.18183	167.3
2.10764	2.6913	0.32565	0.091201	0.31442	0.001 8827	0.18827	167.31
2.15065	2.7806	0.3364	0.094227	0.32517	0.001 9471	0.19471	167.33
2.19366	2.8699	0.34716	0.097253	0.33592	0.002 0115	0.20115	167.34
2.23668	2.9592	0.35791	0.10028	0.34668	0.002 0759	0.20759	167.35
2.27969	3.0485	0.36866	0.1033	0.35743	0.002 1403	0.21403	167.36
2.3227	4.8221	0.37941	0.1634	0.36818	0.002 2046	0.22046	167.37
2.36572	7.1266	0.39015	0.2415	0.37892	0.002 269	0.2269	167.38
2.40873	9.4312	0.4009	0.31959	0.38967	0.002 3333	0.23333	167.39
2.45174	13.065	0.41165	0.44275	0.40042	0.002 3977	0.23977	167.4
2.49475	48.207	0.4224	1.6336	0.41117	0.002 4621	0.24621	167.41
2.53777	83.349	0.43316	2.8244	0.42192	0.002 5265	0.25265	167.42
2.58078	118.49	0.44391	4.0153	0.43268	0.002 5909	0.25909	167.43

2.62379	153.63	0.45466	5.2061	0.44343	0.0026553	0.26553	167.44
2.66681	188.77	0.46542	6.3969	0.45418	0.0027197	0.27197	167.45
2.70982	223.91	0.47617	7.5878	0.46494	0.002784	0.2784	167.46
2.75283	259.06	0.48692	8.7786	0.47569	0.0028484	0.28484	167.48
2.79585	294.2	0.49767	9.9694	0.48644	0.0029128	0.29128	167.49
2.83886	329.34	0.50843	11.16	0.49719	0.0029772	0.29772	167.5
2.88187	364.48	0.51918	12.351	0.50795	0.0030416	0.30416	167.51
2.92488	399.62	0.52993	13.542	0.5187	0.003106	0.3106	167.52
2.9679	434.76	0.54069	14.733	0.52945	0.0031704	0.31704	167.53
3.01091	469.91	0.55144	15.924	0.54021	0.0032348	0.32348	167.54
3.05392	505.05	0.56219	17.114	0.55096	0.0032992	0.32992	167.55
3.09694	540.19	0.57295	18.305	0.56171	0.0033636	0.33636	167.56
3.13995	575.33	0.5837	19.496	0.57247	0.0034279	0.34279	167.57
3.18296	610.47	0.59445	20.687	0.58322	0.0034923	0.34923	167.58
3.22598	645.61	0.60521	21.878	0.59397	0.0035567	0.35567	167.59
3.26899	678.76	0.61596	23.001	0.60473	0.0036211	0.36211	167.6
3.312	709.39	0.62671	24.039	0.61548	0.0036855	0.36855	167.62
3.35502	740.01	0.63747	25.077	0.62623	0.0037499	0.37499	167.63
3.39803	770.64	0.64822	26.114	0.63699	0.0038143	0.38143	167.64
3.44104	801.26	0.65897	27.152	0.64774	0.0038787	0.38787	167.65
3.48405	831.89	0.66972	28.19	0.65849	0.0039431	0.39431	167.66
3.52707	862.52	0.68048	29.228	0.66924	0.0040075	0.40075	167.67
3.57008	893.14	0.69123	30.266	0.68	0.0040718	0.40718	167.68
3.61309	920.97	0.70197	31.209	0.69074	0.0041362	0.41362	167.69
3.65611	946.38	0.7127	32.07	0.70147	0.0042004	0.42004	167.7
3.69912	971.79	0.72346	32.931	0.71222	0.0042648	0.42648	167.71
3.74213	997.2	0.73421	33.792	0.72298	0.0043292	0.43292	167.72
3.78515	1022.6	0.74496	34.653	0.73373	0.0043936	0.43936	167.73
3.82816	1048	0.75571	35.514	0.74448	0.004458	0.4458	167.74
3.87117	1073.4	0.76647	36.375	0.75523	0.0045224	0.45224	167.76
3.91418	1092.8	0.77722	37.03	0.76599	0.0045867	0.45867	167.77
3.9572	1110.5	0.78797	37.631	0.77674	0.0046511	0.46511	167.78

4.00021	1128.2	0.79873	38.233	0.78749	0.0047155	0.47155	167.79
4.04322	1146	0.80948	38.834	0.79825	0.0047799	0.47799	167.8
4.08624	1163.7	0.82023	39.435	0.809	0.0048443	0.48443	167.81
4.12925	1181.5	0.83098	40.036	0.81975	0.0049087	0.49087	167.82
4.17226	1199.2	0.84174	40.637	0.8305	0.0049731	0.49731	167.83

Boeing Sample 3:

Time (s)	Load (N)	Machine Extension (mm)	Stress (MPa)	Extension from Preload (mm)	Strain	Percentage Strain	Gauge Length (mm)
0							
0.406465	169.91	0.038067	4.6374	0.019132	0.0001105	0.01105	173.02
0.812929	598.72	0.13966	16.341	0.12073	0.00069776	0.069776	173.12
1.21939	1010.7	0.24128	27.584	0.22235	0.0012851	0.12851	173.22
1.62586	1375.1	0.3429	37.53	0.32396	0.0018725	0.18725	173.32
2.03232	1670.6	0.44448	45.596	0.42554	0.0024597	0.24597	173.43
2.43879	1865.3	0.54609	50.909	0.52716	0.0030471	0.30471	173.53
2.84525	1990.1	0.64771	54.315	0.62877	0.0036344	0.36344	173.63
3.25172	2093.7	0.74933	57.142	0.7304	0.0042219	0.42219	173.73
3.65818	2193.4	0.85094	59.864	0.832	0.0048092	0.48092	173.83
4.06465	2291.8	0.95254	62.55	0.93361	0.0053965	0.53965	173.93
4.47111	2376.2	1.0541	64.853	1.0352	0.0059838	0.59838	174.04
4.87758	2447.8	1.1557	66.808	1.1368	0.0065711	0.65711	174.14
5.28404	2515.6	1.2573	68.657	1.2384	0.0071584	0.71584	174.24
5.69051	2571.8	1.3589	70.192	1.34	0.0077456	0.77456	174.34
6.09697	2620.9	1.4606	71.53	1.4416	0.008333	0.8333	174.44
6.50343	2674.2	1.5622	72.985	1.5432	0.0089204	0.89204	174.54
6.9099	2731.6	1.6638	74.552	1.6448	0.0095076	0.95076	174.64
7.31636	2785.4	1.7654	76.022	1.7464	0.010095	1.0095	174.75
7.72283	2830.2	1.867	77.243	1.848	0.010682	1.0682	174.85
8.12929	2886.4	1.9686	78.778	1.9497	0.01127	1.127	174.95
8.53576	2956	2.0702	80.678	2.0513	0.011857	1.1857	175.05
8.94222	3040.8	2.1718	82.991	2.1529	0.012444	1.2444	175.15
9.34869	3125.5	2.2734	85.304	2.2545	0.013032	1.3032	175.25
9.75515	3210.3	2.375	87.616	2.3561	0.013619	1.3619	175.36

10.1616	3296.5	2.4767	89.969	2.4577	0.014206	1.4206	175.46
10.5681	3383.4	2.5783	92.343	2.5593	0.014794	1.4794	175.56
10.9745	3476.2	2.6798	94.874	2.6609	0.015381	1.5381	175.66
11.381	3570.1	2.7815	97.438	2.7625	0.015968	1.5968	175.76
11.7875	3664.1	2.8831	100	2.8641	0.016556	1.6556	175.86
12.1939	3753.9	2.9847	102.45	2.9658	0.017143	1.7143	175.97
12.6004	3842.4	3.0863	104.87	3.0674	0.01773	1.773	176.07
13.0069	3930.8	3.1879	107.28	3.169	0.018318	1.8318	176.17
13.4133	3981.9	3.2895	108.68	3.2706	0.018905	1.8905	176.27
13.8198	4016.5	3.3911	109.62	3.3722	0.019492	1.9492	176.37
14.2263	4068.2	3.4927	111.03	3.4738	0.020079	2.0079	176.47
14.6327	4127.6	3.5943	112.65	3.5754	0.020667	2.0667	176.58
15.0392	4226.1	3.6959	115.34	3.677	0.021254	2.1254	176.68
15.4457	4343.3	3.7975	118.54	3.7786	0.021842	2.1842	176.78
15.8521	4462.1	3.8992	121.78	3.8802	0.022429	2.2429	176.88
16.2586	4581.7	4.0008	125.05	3.9818	0.023016	2.3016	176.98
16.6651	4712.7	4.1024	128.62	4.0834	0.023604	2.3604	177.08
17.0715	4849.7	4.204	132.36	4.185	0.024191	2.4191	177.19
17.478	5007	4.3056	136.65	4.2867	0.024778	2.4778	177.29
17.8844	5164.4	4.4072	140.95	4.3883	0.025366	2.5366	177.39
18.2909	5328.4	4.5088	145.43	4.4899	0.025953	2.5953	177.49
18.6974	5495	4.6104	149.97	4.5915	0.02654	2.654	177.59
19.1038	5665.6	4.712	154.63	4.6931	0.027128	2.7128	177.69
19.5103	5836.2	4.8136	159.28	4.7947	0.027715	2.7715	177.79
19.9168	6006.9	4.9152	163.94	4.8963	0.028302	2.8302	177.9
20.3232	6178	5.0168	168.61	4.9979	0.028889	2.8889	178
20.7297	6349.1	5.1184	173.28	5.0995	0.029477	2.9477	178.1
21.1362	6529.3	5.2201	178.2	5.2011	0.030064	3.0064	178.2
21.5426	6711.3	5.3216	183.17	5.3027	0.030651	3.0651	178.3
21.9491	6893.4	5.4233	188.14	5.4043	0.031239	3.1239	178.4
22.3556	7077.8	5.5249	193.17	5.5059	0.031826	3.1826	178.51
22.762	7283	5.6264	198.77	5.6075	0.032413	3.2413	178.61

23.1685	7481.8	5.7281	204.2	5.7091	0.033001	3.3001	178.71
23.5749	7681.3	5.8297	209.64	5.8107	0.033588	3.3588	178.81
23.9814	7881	5.9313	215.09	5.9123	0.034175	3.4175	178.91
24.3879	8080.7	6.0329	220.54	6.014	0.034763	3.4763	179.01
24.7943	8283.7	6.1345	226.08	6.1156	0.03535	3.535	179.12
25.2008	8491.2	6.2361	231.75	6.2172	0.035937	3.5937	179.22
25.6073	8698.7	6.3377	237.41	6.3188	0.036525	3.6525	179.32
26.0137	8906.2	6.4393	243.07	6.4204	0.037112	3.7112	179.42
26.4202	9113.6	6.5409	248.73	6.522	0.037699	3.7699	179.52
26.8267	9322.2	6.6425	254.43	6.6236	0.038287	3.8287	179.62
27.2331	9541.1	6.7441	260.4	6.7252	0.038874	3.8874	179.73
27.6396	9768.7	6.8458	266.61	6.8268	0.039461	3.9461	179.83
28.0461	9987.5	6.9474	272.58	6.9284	0.040049	4.0049	179.93
28.4525	10213	7.049	278.75	7.03	0.040636	4.0636	180.03
28.859	10439	7.1506	284.91	7.1316	0.041223	4.1223	180.13
29.2655	10653	7.2522	290.76	7.2333	0.041811	4.1811	180.23
29.6719	10878	7.3538	296.88	7.3349	0.042398	4.2398	180.33
30.0784	11106	7.4554	303.12	7.4365	0.042985	4.2985	180.44
30.4848	11340	7.557	309.49	7.5381	0.043573	4.3573	180.54
30.8913	11579	7.6586	316.02	7.6397	0.04416	4.416	180.64
31.2978	11827	7.7603	322.78	7.7413	0.044747	4.4747	180.74
31.7042	12073	7.8619	329.5	7.8429	0.045335	4.5335	180.84
32.1107	12250	7.9635	334.33	7.9445	0.045922	4.5922	180.94
32.5172	12508	8.0651	341.38	8.0461	0.046509	4.6509	181.05
32.9236	12715	8.1667	347.04	8.1477	0.047097	4.7097	181.15
33.3301	12960	8.2683	353.72	8.2493	0.047684	4.7684	181.25
33.7366	13155	8.3699	359.02	8.351	0.048271	4.8271	181.35
34.143	13377	8.4715	365.09	8.4526	0.048859	4.8859	181.45
34.5495	13442	8.5731	366.88	8.5541	0.049446	4.9446	181.55
34.956	13693	8.6747	373.71	8.6558	0.050033	5.0033	181.66
35.3624	13943	8.7763	380.54	8.7574	0.050621	5.0621	181.76
35.7689	14193	8.8779	387.36	8.859	0.051208	5.1208	181.86

36.1754	14443	8.9795	394.19	8.9606	0.051795	5.1795	181.96
36.5818	14693	9.0811	401	9.0622	0.052382	5.2382	182.06
36.9883	14941	9.1827	407.77	9.1638	0.05297	5.297	182.16
37.3947	15181	9.2843	414.32	9.2654	0.053557	5.3557	182.27
37.8012	15414	9.3859	420.7	9.367	0.054144	5.4144	182.37
38.2077	15560	9.4876	424.68	9.4686	0.054732	5.4732	182.47
38.6141	15800	9.5892	431.21	9.5702	0.055319	5.5319	182.57
39.0206	16033	9.6908	437.6	9.6718	0.055906	5.5906	182.67
39.4271	16255	9.7924	443.63	9.7734	0.056494	5.6494	182.77
39.8335	16352	9.894	446.29	9.875	0.057081	5.7081	182.88
40.24	7870.1	9.9956	214.8	9.9767	0.057669	5.7669	182.98

Boeing Sample 2:

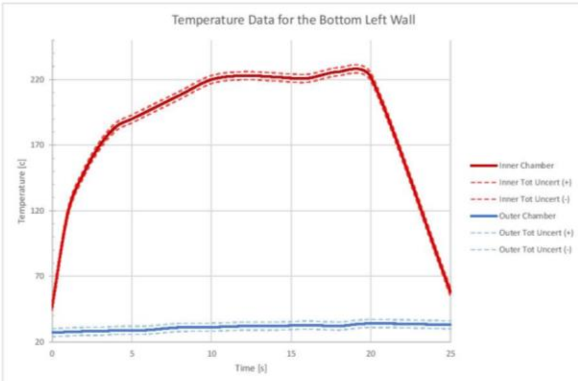
Time (s)	Load (N)	Machine Extension (mm)	Stress (MPa)	Extension from Preload (mm)	Strain	Percentage Strain	Gauge Length (mm)
0							
0.365657	72.395	0.026272	1.9673	0.01388	0.000077	0.0077	180.01
0.731313	135.46	0.11769	3.6809	0.1053	0.00058488	0.058488	180.11
1.09697	135.97	0.2091	3.6949	0.1967	0.0010927	0.10927	180.2
1.46263	136.48	0.3005	3.7088	0.28811	0.0016005	0.16005	180.29
1.82828	136.99	0.3919	3.7227	0.37951	0.0021083	0.21083	180.38
2.19394	137.51	0.48331	3.7366	0.47092	0.0026161	0.26161	180.47
2.5596	395.2	0.57471	10.739	0.56232	0.0031239	0.31239	180.56
2.92525	519.04	0.66611	14.104	0.65372	0.0036316	0.36316	180.65
3.29091	586.27	0.75751	15.931	0.74511	0.0041394	0.41394	180.75
3.65657	621.88	0.84892	16.899	0.83653	0.0046473	0.46473	180.84
4.02222	657.49	0.94032	17.867	0.92793	0.0051551	0.51551	180.93
4.38788	685.48	1.0317	18.627	1.0193	0.0056628	0.56628	181.02
4.75354	713.04	1.1231	19.376	1.1107	0.0061707	0.61707	181.11
5.11919	754.34	1.2146	20.498	1.2022	0.0066786	0.66786	181.2
5.48485	797.06	1.3059	21.659	1.2935	0.0071861	0.71861	181.29
5.85051	840.24	1.3973	22.832	1.3849	0.007694	0.7694	181.38
6.21616	875.16	1.4888	23.781	1.4764	0.0082019	0.82019	181.48
6.58182	912.61	1.5802	24.799	1.5678	0.0087098	0.87098	181.57

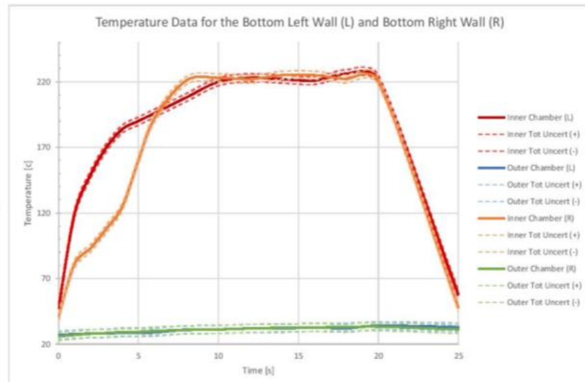
6.94747	969.8	1.6716	26.353	1.6592	0.0092177	0.92177	181.66
7.31313	1027	1.763	27.907	1.7506	0.0097255	0.97255	181.75
7.67879	1081.9	1.8544	29.399	1.842	0.010233	1.0233	181.84
8.04444	1109.8	1.9458	30.159	1.9334	0.010741	1.0741	181.93
8.4101	1140.3	2.0372	30.987	2.0248	0.011249	1.1249	182.02
8.77576	1199	2.1286	32.583	2.1162	0.011757	1.1757	182.12
9.14141	1306.8	2.22	35.51	2.2076	0.012265	1.2265	182.21
9.50707	1437.5	2.3115	39.063	2.2991	0.012772	1.2772	182.3
9.87273	1588.9	2.4028	43.177	2.3905	0.01328	1.328	182.39
10.2384	1766.3	2.4943	47.997	2.4819	0.013788	1.3788	182.48
10.604	1944	2.5857	52.827	2.5733	0.014296	1.4296	182.57
10.9697	2121.8	2.6771	57.659	2.6647	0.014804	1.4804	182.66
11.3354	2299.7	2.7685	62.492	2.7561	0.015312	1.5312	182.76
11.701	2468.3	2.8599	67.073	2.8475	0.015819	1.5819	182.85
12.0667	2634.8	2.9513	71.599	2.9389	0.016327	1.6327	182.94
12.4323	2796.7	3.0427	75.997	3.0303	0.016835	1.6835	183.03
12.798	2955.9	3.1341	80.322	3.1217	0.017343	1.7343	183.12
13.1636	3106.7	3.2255	84.42	3.2131	0.017851	1.7851	183.21
13.5293	3259.6	3.3169	88.577	3.3045	0.018358	1.8358	183.3
13.8949	3407.6	3.4083	92.597	3.3959	0.018866	1.8866	183.4
14.2606	3535.8	3.4997	96.082	3.4873	0.019374	1.9374	183.49
14.6263	3659.2	3.5911	99.436	3.5787	0.019882	1.9882	183.58
14.9919	3769.5	3.6825	102.43	3.6701	0.02039	2.039	183.67
15.3576	3871.7	3.7739	105.21	3.7615	0.020897	2.0897	183.76
15.7232	3973.9	3.8653	107.99	3.853	0.021405	2.1405	183.85
16.0889	4076.9	3.9567	110.78	3.9443	0.021913	2.1913	183.94
16.4545	4189.4	4.0481	113.84	4.0358	0.022421	2.2421	184.04
16.8202	4301.9	4.1396	116.9	4.1272	0.022929	2.2929	184.13
17.1859	4420.2	4.231	120.12	4.2186	0.023436	2.3436	184.22
17.5515	4544.1	4.3223	123.48	4.31	0.023944	2.3944	184.31
17.9172	4669.2	4.4138	126.88	4.4014	0.024452	2.4452	184.4
18.2828	4804.5	4.5052	130.56	4.4928	0.02496	2.496	184.49
18.6485	4941.7	4.5966	134.28	4.5842	0.025468	2.5468	184.58

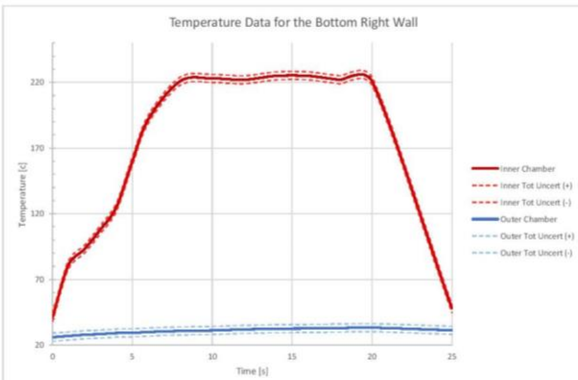
19.0141	5091.2	4.688	138.35	4.6756	0.025975	2.5975	184.68
19.3798	5233.6	4.7794	142.22	4.767	0.026483	2.6483	184.77
19.7455	5376	4.8708	146.09	4.8584	0.026991	2.6991	184.86
20.1111	5531.5	4.9622	150.31	4.9498	0.027499	2.7499	184.95
20.4768	5690.2	5.0536	154.63	5.0412	0.028007	2.8007	185.04
20.8424	5854.7	5.145	159.1	5.1326	0.028515	2.8515	185.13
21.2081	6023.4	5.2364	163.68	5.224	0.029022	2.9022	185.22
21.5737	6192.1	5.3278	168.26	5.3154	0.02953	2.953	185.32
21.9394	6367.6	5.4192	173.03	5.4068	0.030038	3.0038	185.41
22.3051	6547.2	5.5107	177.91	5.4983	0.030546	3.0546	185.5
22.6707	6726.8	5.6021	182.79	5.5897	0.031054	3.1054	185.59
23.0364	6907.5	5.6935	187.7	5.6811	0.031562	3.1562	185.68
23.402	7093.1	5.7849	192.75	5.7725	0.032069	3.2069	185.77
23.7677	7278.6	5.8763	197.79	5.8639	0.032577	3.2577	185.86
24.1333	7464.9	5.9677	202.85	5.9553	0.033085	3.3085	185.96
24.499	7667.3	6.0591	208.35	6.0467	0.033593	3.3593	186.05
24.8646	7863.8	6.1505	213.69	6.1381	0.0341	3.41	186.14
25.2303	8064.2	6.2419	219.13	6.2295	0.034608	3.4608	186.23
25.596	8264.5	6.3333	224.58	6.3209	0.035116	3.5116	186.32
25.9616	8467.8	6.4247	230.1	6.4123	0.035624	3.5624	186.41
26.3273	8674.3	6.5161	235.71	6.5037	0.036132	3.6132	186.5
26.6929	8880.7	6.6076	241.32	6.5952	0.03664	3.664	186.6
27.0586	9087.1	6.6989	246.93	6.6866	0.037147	3.7147	186.69
27.4242	9303.4	6.7904	252.81	6.778	0.037655	3.7655	186.78
27.7899	9517.2	6.8818	258.62	6.8694	0.038163	3.8163	186.87
28.1556	9731	6.9732	264.43	6.9608	0.038671	3.8671	186.96
28.5212	9944.8	7.0646	270.24	7.0522	0.039179	3.9179	187.05
28.8869	10159	7.156	276.06	7.1436	0.039686	3.9686	187.14
29.2525	10378	7.2473	282.01	7.235	0.040194	4.0194	187.23
29.6182	10597	7.3388	287.96	7.3264	0.040702	4.0702	187.33
29.9838	10817	7.4302	293.95	7.4178	0.04121	4.121	187.42
30.3495	11049	7.5216	300.24	7.5092	0.041718	4.1718	187.51
30.7152	11272	7.613	306.3	7.6006	0.042225	4.2225	187.6

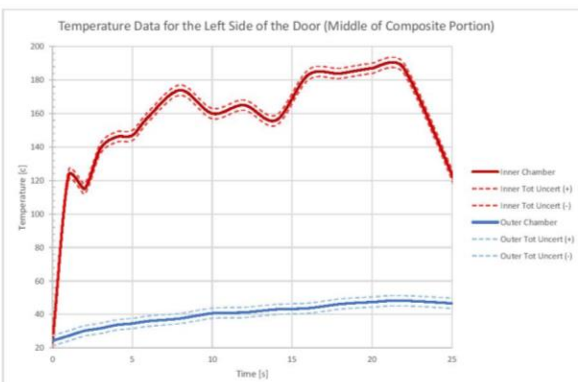
31.0808	11495	7.7044	312.36	7.692	0.042733	4.2733	187.69
31.4465	11718	7.7958	318.41	7.7834	0.043241	4.3241	187.78
31.8121	11942	7.8872	324.52	7.8748	0.043749	4.3749	187.87
32.1778	12169	7.9786	330.67	7.9662	0.044256	4.4256	187.97
32.5434	12395	8.07	336.81	8.0576	0.044764	4.4764	188.06
32.9091	12621	8.1614	342.96	8.149	0.045272	4.5272	188.15
33.2747	12850	8.2528	349.18	8.2404	0.04578	4.578	188.24
33.6404	13080	8.3442	355.42	8.3318	0.046288	4.6288	188.33
34.0061	13309	8.4356	361.66	8.4232	0.046796	4.6796	188.42
34.3717	13539	8.527	367.91	8.5147	0.047304	4.7304	188.51
34.7374	13774	8.6184	374.3	8.6061	0.047811	4.7811	188.61
35.103	14009	8.7099	380.68	8.6975	0.048319	4.8319	188.7
35.4687	14245	8.8013	387.09	8.7889	0.048827	4.8827	188.79
35.8343	14481	8.8927	393.5	8.8803	0.049335	4.9335	188.88
36.2	4533.9	8.9841	123.2	8.9717	0.049843	4.9843	188.97

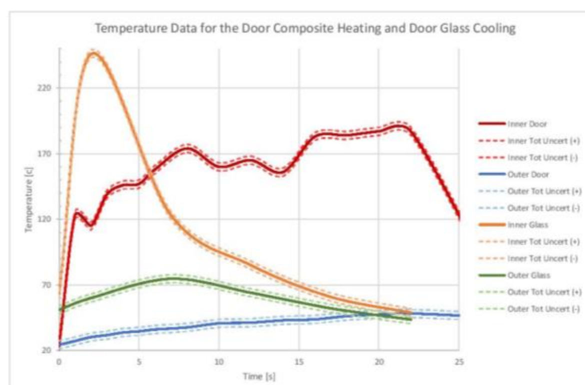
Appendix Q: Heat Bleed Testing

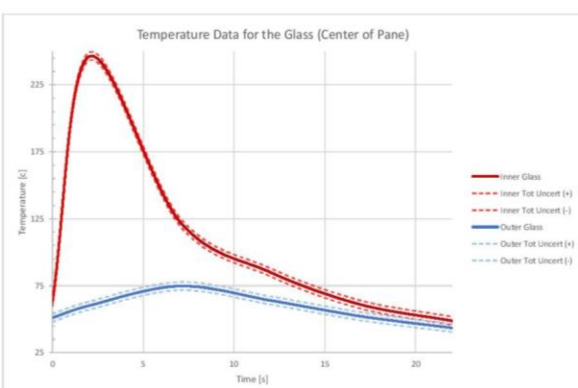












			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty							
Time	Location	Innerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	outerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	delta T		location - facing the door side			
0		47	47.05	46.95	50	44	50.05	43.95	27	27.05	26.95	30	24	30.05	23.95	20					
1		119	119.05	118.95	122	116	122.05	115.95	27.6	27.65	27.55	30.6	24.6	30.65	24.55	91.4		Notes			
2		149	149.05	148.95	152	146	152.05	145.95	28	28.05	27.95	31	25	31.05	24.95	121		inside jumps around 5 degrees celcius			
3		170	170.05	169.95	173	167	173.05	166.95	28.1	28.15	28.05	31.1	25.1	31.15	25.05	141.9					
4		184	184.05	183.95	187	181	187.05	180.95	28.7	28.75	28.65	31.7	25.7	31.75	25.65	155.3					
5		190	190.05	189.95	193	187	193.05	186.95	28.8	28.85	28.75	31.8	25.8	31.85	25.75	161.2					
6	bottom left	196	196.05	195.95	199	193	199.05	192.95	29	29.05	28.95	32	26	32.05	25.95	167					
8		208	208.05	207.95	211	205	211.05	204.95	31	31.05	30.95	34	28	34.05	27.95	177					
10		220	220.05	219.95	223	217	223.05	216.95	31.2	31.25	31.15	34.2	28.2	34.25	28.15	188.8					
12		223	223.05	222.95	226	220	226.05	219.95	32	32.05	31.95	35	29	35.05	28.95	191					
14		222	222.05	221.95	225	219	225.05	218.95	32	32.05	31.95	35	29	35.05	28.95	190					
16		221	221.05	220.95	224	218	224.05	217.95	32.8	32.85	32.75	35.8	29.8	35.85	29.75	188.2					
18		226	226.05	225.95	229	223	229.05	222.95	32.1	32.15	32.05	35.1	29.1	35.15	29.05	193.9					
20		222	222.05	221.95	225	219	225.05	218.95	34	34.05	33.95	37	31	37.05	30.95	188	<------	Max temp at top of side wall		39 C	
25		58	58.05	57.95	61	55	61.05	54.95	33	33.05	32.95	36	30	36.05	29.95	25		max temp at top of chamber		60 C	
heating device removed at 20 min																					
25		58	58.05	57.95	61	55	61.05	54.95	33	33.05	32.95	36	30	36.05	29.95	25	<------	top of chamber	40 C		

			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty						
Time	Location	Innerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	outerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	delta T				
0		41	41.05	40.95	44	38	44.05	37.95	26	26.05	25.95	29	23	29.05	22.95	15				
1		81	81.05	80.95	84	78	84.05	77.95	27	27.05	26.95	30	24	30.05	23.95	54				
2		93	93.05	92.95	96	90	96.05	89.95	27.9	27.95	27.85	30.9	24.9	30.95	24.85	65.1				
3		108	108.05	107.95	111	105	111.05	104.95	28.4	28.45	28.35	31.4	25.4	31.45	25.35	79.6				
4		125	125.05	124.95	128	122	128.05	121.95	29.2	29.25	29.15	32.2	26.2	32.25	26.15	95.8				
5		160	160.05	159.95	163	157	163.05	156.95	29.3	29.35	29.25	32.3	26.3	32.35	26.25	130.7				
6	bottom right	192	192.05	191.95	195	189	195.05	188.95	30	30.05	29.95	33	27	33.05	26.95	162				
8		221	221.05	220.95	224	218	224.05	217.95	30.8	30.85	30.75	33.8	27.8	33.85	27.75	190.2				
10		223	223.05	222.95	226	220	226.05	219.95	31.2	31.25	31.15	34.2	28.2	34.25	28.15	191.8				
12		222	222.05	221.95	225	219	225.05	218.95	32	32.05	31.95	35	29	35.05	28.95	190				
14		225	225.05	224.95	228	222	228.05	221.95	32.5	32.55	32.45	35.5	29.5	35.55	29.45	192.5				
16		225	225.05	224.95	228	222	228.05	221.95	32.7	32.75	32.65	35.7	29.7	35.75	29.65	192.3				
18		222	222.05	221.95	225	219	225.05	218.95	33	33.05	32.95	36	30	36.05	29.95	189				
20		221	221.05	220.95	224	218	224.05	217.95	33.3	33.35	33.25	36.3	30.3	36.35	30.25	187.7	<------	Max temp at top of side wall		45 C
25		48	48.05	47.95	51	45	51.05	44.95	31.3	31.35	31.25	34.3	28.3	34.35	28.25	16.7		max temp at top of chamber		65 C
heating device removed at 20 min																				
25		48	48.05	47.95	51	45	51.05	44.95	31.3	31.35	31.25	34.3	28.3	34.35	28.25	16.7	<------	top of chamber	44 C	

			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty							
Time	Location	Innerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	outerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	delta T		gun on 5.5			
0		23.4	23.45	23.35	26.4	20.4	26.45	20.35	24.3	24.35	24.25	27.3	21.3	27.35	21.25	-0.9					
1		123	123.05	122.95	126	120	126.05	119.95	27.2	27.25	27.15	30.2	24.2	30.25	24.15	95.8					
2		115	115.05	114.95	118	112	118.05	111.95	30.2	30.25	30.15	33.2	27.2	33.25	27.15	84.8					
3		139	139.05	138.95	142	136	142.05	135.95	31.7	31.75	31.65	34.7	28.7	34.75	28.65	107.3					
4		146	146.05	145.95	149	143	149.05	142.95	33.7	33.75	33.65	36.7	30.7	36.75	30.65	112.3					
5		147	147.05	146.95	150	144	150.05	143.95	34.6	34.65	34.55	37.6	31.6	37.65	31.55	112.4					
6	Door structure	158	158.05	157.95	161	155	161.05	154.95	36	36.05	35.95	39	33	39.05	32.95	122					
8	(left side of	174	174.05	173.95	177	171	177.05	170.95	37.6	37.65	37.55	40.6	34.6	40.65	34.55	136.4					
10	door middle)	160	160.05	159.95	163	157	163.05	156.95	40.7	40.75	40.65	43.7	37.7	43.75	37.65	119.3					
12		165	165.05	164.95	168	162	168.05	161.95	41.2	41.25	41.15	44.2	38.2	44.25	38.15	123.8	<---	turned gun up from 5.5 to 6 after this reading			
14		156	156.05	155.95	159	153	159.05	152.95	43	43.05	42.95	46	40	46.05	39.95	113					
16		183	183.05	182.95	186	180	186.05	179.95	43.7	43.75	43.65	46.7	40.7	46.75	40.65	139.3					
18		184	184.05	183.95	187	181	187.05	180.95	46.2	46.25	46.15	49.2	43.2	49.25	43.15	137.8					
20		187	187.05	186.95	190	184	190.05	183.95	47.4	47.45	47.35	50.4	44.4	50.45	44.35	139.6					
22		187	187.05	186.95	190	184	190.05	183.95	48.2	48.25	48.15	51.2	45.2	51.25	45.15	138.8	<---	Temp at glass near edge		77 C	
27		78	78.05	77.95	81	75	81.05	74.95	45.5	45.55	45.45	48.5	42.5	48.55	42.45	32.5		Temp of glass in middle		58.4 C	
heating device removed at 22 min																		Temp of door siding		120 C	**door sidding has
27		78	78.05	77.95	81	75	81.05	74.95	45.5	45.55	45.45	48.5	42.5	48.55	42.45	32.5					vac bag around
																		Near glass	75.8		trapping heat,
																		middle of glass	58.1		probably innacurate
																		door siding	73		reading

			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty			Resolution Uncertainty		Lazer Uncertainty		Total Uncertainty				
Time	Location	Innerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	outerchamber temp [C]	(+)	(-)	(+)	(-)	(+)	(-)	delta T		
0	Door Window	63	63.05	62.95	66	60	66.05	59.95	51	51.05	50.95	54	48	54.05	47.95	12		
2	(middle)	246	246.05	245.95	249	243	249.05	242.95	60	60.05	59.95	63	57	63.05	56.95	186	<---	used tape
7		123	123.05	122.95	126	120	126.05	119.95	74.7	74.75	74.65	77.7	71.7	77.75	71.65	48.3		
12		85	85.05	84.95	88	82	88.05	81.95	64	64.05	63.95	67	61	67.05	60.95	21		
17		60.8	60.85	60.75	63.8	57.8	63.85	57.75	52.1	52.15	52.05	55.1	49.1	55.15	49.05	8.7		
22		48.8	48.85	48.75	51.8	45.8	51.85	45.75	43.5	43.55	43.45	46.5	40.5	46.55	40.45	5.3		
heating device removed at 2 min																		

Appendix R: Test Procedures

F42 Test Procedure Tensile Test

Test Name: Composite Lay-up Tensile Test
Purpose: Determine whether current composite layering and manufacturing techniques provides lay-up sheets with necessary strength characteristics for the external chamber of the Environmental Chamber
Scope: Determine which combination of composite material will be strong enough for the design loads of the environmental chamber wall materials. Testing Load [N] v. Sample deformation [mm] will be plotted, with maximum load before failure conditions recorded in a separate table.
Equipment: LD50 tensile test machine, calipers, ruler, PC
Hazards:

- Fiberglass shards
- Splintering
- Cut fingers
- Cut hands
- Covid

PPE Requirements:

- Goggles - protect from splintering in eyes
- Gloves - protect from splintering in hands
- Blast shield Encasing Tensile Unit - shield from splintering
- PPE (masks, hand sanitizer and social distancing) - protect from virus

Facility: Cal Poly Composites Lab (192-135)
Procedure:
1) Verify that all group members around test area and handling specimens are equipped with proper PPE
2) Take measurements of each specimen with the calipers, taking width and thickness in millimeters
3) Position specimen within the clamps of the LD50 tensile test machine, ensuring that the part is vertical and there is sufficient area being gripped. Tighten the jaws.
4) Measure the height of the specimen from LD50 bottom jaw to top jaw.
5) Close the blast shield on the LD50, see Figure 1 below, and input measurement data and test details into test software. Press run test and watch the machine to ensure the test runs until part failure.

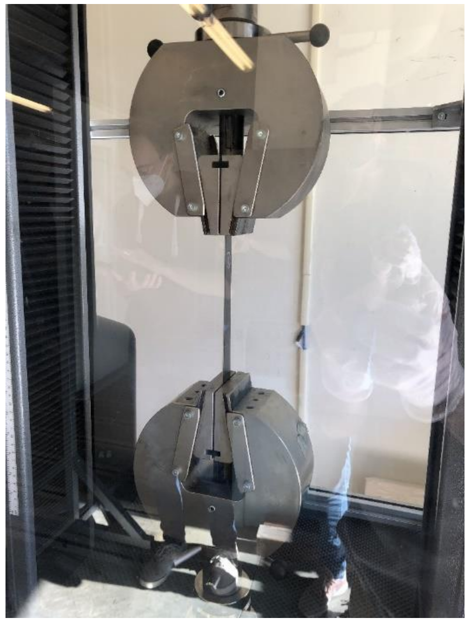


Figure 1: Sample Positioned in clamps with blast shield closed.

6) Take photos of the failure mode, as seen in Figure 2 below. Open the blast shield and remove the specimen from the jaws, taking care to avoid splinters. Group members should be wearing gloves.

Figure 2: Sample post failure still in clamps and behind safety shield.

7) Obtain data from test software to get maximum load and stress/strain curve.

Results: Pass Criteria: 40 lbs applied before failure, without significant delamination between fiberglass and carbon fiber layers.

Number of samples to test: 3 samples of dry carbon layup, 3 samples of Boeing carbon layup

Test Date(s): 02/28/2021

F42 Test Procedure Ease of Installment

Test Name: Ease of Installment Test
Purpose: Determine whether the completed chamber fulfills project requirement of installation by two people.
Scope: Determine whether the environmental chamber is a reasonable weight to be handled by a single person by weighing it on a scale. Determine whether it is possible to install the chamber to the LD50 reasonably easily through installation trials and visual inspection upon completion.
Equipment: LD50 tensile test machine, large scale, completed chamber prototype
Hazards:

- Dropping chamber on feet or hands
- Cut fingers
- Cut hands
- Muscle strain from lifting
- Covid

PPE Requirements:

- Covid PPE (masks, hand sanitizer and social distancing)

Facility: Cal Poly Composites Lab (192-135)
Procedure:
1) Verify that all group members around the area are equipped with proper PPE.
2) Tare the large scale in the composites lab and place the completed environmental chamber so that its full weight is supported by the scale.
3) Record the scale reading and ensure it is a reasonable weight for lifting.
4) Ensure that the rail assembly is installed onto the LD50 and secure.
5) Have a single person carry the environmental chamber over to the LD50 machine and place it on top of the rail assembly, with the chamber door open. This person should then push the chamber into place on the rails and ensure it is secure.
6) Ensure that the chamber door can close, and that the environmental chamber stays secured when operating the door.
7) Close the LD50 blast shield to ensure that the chamber fully fits within the enclosed testing space.
8) Open the blast shield and chamber door and have a single person fully uninstall the environmental chamber.
9) Repeat the previous steps starting from step 5 with a different group member to ensure results are standardized.
Results: Pass Criteria: under 50 lbs, installation by one person in under 20 minutes
Test Date(s): 05/16/2021

Uncertainties: The main uncertainty is in the resolution of the scale.

- Digital scale resolution uncertainty --> ±0.05 lb

Performed By:

- Austin Marshall
- Erik Soldenwagner
- Lauren Schirle
- Michael Ingel

F42 Test Procedure Heat Bleed

Test Name:
Heat bleed and seal test
Purpose:
To verify that that insulation and RTV sealant prevent significant heat transfer to the outer composite chamber.
Scope:
The test is intended to be done after the chamber is finished being constructed with the controls systems and insulation put between the inner and outer chamber. Temperature readings will be read from the outermost surface of the chamber to determine if it meets the criterion set. If the outer surface is less than 37°C or 100°F, the chamber is successful.
Equipment:

1. Heat Guns
2. Infrared Temperature Laser

Hazards:

1. High temperatures
2. Burns
3. Fire risk from heating pad or flammable materials
4. Covid

PPE Requirements:

1. Safety glasses
2. Heat resistant gloves
3. PPE (masks, hand sanitizer and social distancing)
4. Fire extinguisher nearby

Facility:
Bonderson Project Center (197-Highbay) or Cal Poly Composites Lab (192-135)
Procedure:

1. Clear work bench of all unnecessary objects or flammable objects.
2. Place Styrofoam piece under test chamber if on wooden worktable to prevent overheating from the bottom.
3. Begin heating the aluminum side of the chamber to 210°C using the heat gun.
4. Record temperature readings from the infrared laser on the composite side and the aluminum side every 2-5 minutes depending on heating curve.
    a. Continue running for 5-10 minutes to record cooldown time after initial test.
    b. If chamber begins to smoke during the test, immediately turn off.
5. Graph data for each wall to see the heating time and maximum temperatures reached at each temperature gun location.

Results:
Pass Criteria: Outer chamber's maximum temperature remains less than 37°C or 100°F at each temperature gun location.
Fail Criteria: Outer chamber temperature is higher than 60°C or 140°F(lowest temperature skin burns at when touched for some time)
Number of test samples: 1 completed environmental chamber.

Test Date(s): 5/16/21
Test results: See Appendix Q