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Final Project Report: Wine Suitcase

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Executive Summary

The Wine Suitcase Project was proposed by Dr. Becker to address the problem of a lack of safe and secure transportation of wine during worldwide travel. Currently, there are some solutions, like wine bottle diapers (a special bag to put a wine bottle in and catch the liquid if the bottle breaks) and an expensive wine suitcase, but a protective, insulated and cost-effective wine travel suitcase would be of great help to the wine community. This past year, our team has worked to design and produce said suitcase.

The major objectives of this design are that the suitcase has to keep the bottles below the critical temperature of 70°F and safe from breaking during travel and baggage handling. Specifically, the suitcase should be able to pass the International Safe Transit Association's (ISTA) Test Procedure 2A for Packaged-Products 150 pounds or less and keep the wine below a temperature of 70 °F for up to 36 hours [1]. The bottles should be placed in the bag at a maximum of 65 °F initially. In order for the user to know if his/her wine has been above the 70 °F mark, the design should also include a notification system or temperature tracker. Finally, the suitcase should hold up to 12 bottles of 750 mL wine and come in at a total cost of less than $350 to be competitive against current suitcase designs. The suitcase also needs to be able to hold at least one case of wine (12 bottles) of various sizes.

According to these objectives and requirements, a wine suitcase was designed and fabricated using a hard-shell suitcase, foam, insulation and a temperature sensor. Specifically, the hard-shell suitcase and the foam padding satisfied the safety requirement for the bottles and for the temperature stability requirement, the insulation was added as a layer between the foam and suitcase shell. Additionally, in order to communicate to the user what the temperature of the wine is inside the suitcase, the team added a handheld sensor device with Bluetooth capabilities.

After fabrication, 7 tests were performed to evaluate the success of the design against the requirements: bottle physical protection test, bottle quantity test, bottle thermal protection test, weight of suitcase test, size of suitcase test, Thermoplus™ temperature sensor test and a heat transfer simulation test. The team was unable to perform the thermal protection test due to the displacement from San Antonio from COVID-19. Each of the other 6 tests were performed and resulted in a success and satisfied their appropriate requirement. The heat transfer simulation test was added after the displacement from COVID-19 to offset the inability to perform the thermal test in person. The thermal simulation test was run to focus on the most critical 15-minute time-frame of the travel journey where the suitcase may be held in direct sunlight. At all other times, the suitcase will be in the cargo hold or inside the air-conditioned airport. While the simulation is not the same as an in-person test, we can still use it as a good measure of the thermal protection capabilities of our design and were satisfied with the passing results. Overall, once the temperature sensor has been installed, we assert that the Wine Suitcase that was fabricated before displacement will be a fully functioning device that can safely transport wine due to the successes of our testing.

1 Introduction

The Wine Suitcase Project was petitioned by Dr. Becker to develop a suitcase for the transit of wine during large periods of international travel. During these extended periods of travel, the bag may be exposed to aggressive baggage handling and a range of temperatures. Thus, the bag is to be designed to protect the wine from poor handling and high temperatures that will ruin the wine. Specifically, for this project, the suitcase should be able to pass the International Safe Transit Association's (ISTA) Test Procedure 2A for Packaged-Products 150 pounds or less [1]. The suitcase should also be able to keep the wine below a temperature of 70 °F for up to 36 hours. The bottles should be placed in the bag at a maximum of 65 °F initially. In order for the user to know if their wine has been above the 70 °F mark, the design should also include a notification system or temperature tracker of some sort. Finally, the suitcase should hold up to twelve 750-mL bottles of wine and come in at a total cost of less than $350.

With the proposed set of objectives and requirements, the team was able to design a prototype composed of a hard-shell suitcase, foam, insulation and a temperature sensor. The team utilized an existing hard-shell suitcase, purchased from Amazon, and foam padding to satisfy the transit and insulation requirements for the bottles. For additional temperature stability, insulation was added as a layer between the foam and suitcase shell. Additionally, in order to communicate to the user what the temperature of the wine is inside the suitcase, the team added a handheld sensor device. This was originally going to be a passive paper temperature tracker but after further review, the team decided to use an off-the-shelf Bluetooth-enabled digital temperature sensor. Ultimately, with these elements, we have worked to design and produce an apparatus that securely and safely holds wine and will prevent any breakage or cooking of the wine while being transported.

2 Overview of the Final Design

Prior to beginning the prototype design, the team worked on researching current solutions to wine travel and found the Wine Diaper, a special bag to put wine bottles in and catch the liquid if the bottle breaks, and an already existing Wine Suitcase. However, with the Wine Diapers, the user is only able to travel with a few bottles of wine and in both temperature control and physical protection, they do not sufficiently protect the wine. Additionally, the Wine Suitcase currently on the market did not suit the sponsor's desired budget and lacked a proper temperature tracking element.

With these existing products in mind, the team created a design with two main features that work together to accomplish the goal of safe wine travel: bottle protection and passive temperature control.

2.1 Bottle Protection

The bottle protection features must follow and pass the International Safe Transit

Association (ISTA) procedure 2A for packaged products weighing 150 pounds or less. This procedure tests the vibration and drop protection capabilities of the design. Therefore, the bottle protection features consist of both a foam padding and plastic, hard-shell suitcase to protect the bottles. The team discussed other options for suitcase type but decided the hard-shell combined with the use of thick foam padding, would provide the maximum protection for the wine bottles during travel.

2.2 Temperature Control

For the temperature control features, the design must be able to maintain the wine bottles at a temperature below 70 °F for 36 hours given that the maximum initial temperature of the wine bottles will be 65 °F or cooler. Thus, the temperature control consists of the foam insulation as well as the double bubble foil insulation. The team decided that by adding an additional layer of insulation to the design, it would provide the proper thermal protection and set it apart from current designs on the market. In this portion of the design, the product also needs to be able to track the temperature so the user knows if the wine was exposed to temperatures above the desired 70 °F. For this requirement, the design also includes communication to the user via a Bluetooth temperature sensor that will allow the user to see if the wine, at any point in the journey, was exposed to temperatures that may have caused any damage. Originally, the temperature sensor was going to be a passive paper temperature tracker but after further discussion, the team decided to use an off-the-shelf Bluetooth-enabled digital temperature sensor.

Along with these main features of the design, the suitcase had to be capable of holding a case of wine, under a total weight of 50 pounds including the wine and could not exceed a size limit of 62 linear inches, meaning the sum of the length, width and height must equal less than 62 inches. These requirements were all satisfied with the type and size of hard-shell suitcase decided upon by the team.

3 Design Evaluation

3.1 Able to withstand aggressive baggage handling (Testing against ISTA procedure 2A)

3.1.1 Bottle Physical Protection Test

3.1.1.1 Test Overview

This test will verify that the suitcase meets the ISTA 2A procedure shock and vibration tests demonstrating that the design will be able to withstand standard travel baggage handling and any other handling the bag may encounter.

3.1.1.2 Objectives

The objective of this test is to confirm that the wine suitcase will meet the ISTA 2A procedure shock and vibration tests.

3.1.1.3 Features Evaluated

This test will evaluate the suitcase’s ability to protect the wine bottles from physical damage during transit.

3.1.1.4 Test Scope

For this test, the suitcase must be able to maintain the integrity of the sealed, wine-filled bottles after a free fall drop of at least 26 inches. The suitcase must then also be able to maintain the integrity of the wine bottles after experiencing vibration motion. For fixed displacement vibrations, the test will be conducted with vibrations 1 inch peak-to-peak at varying frequencies. While for random vibrations, withstanding an overall Grms level of 1.15.

3.1.1.5 Test Setup and Assumptions

This test will be conducted using a prototype of the wine suitcase that contains the full carrying capacity of 12 wine bottles. The drop portion of the test will be conducted up to 10 times, dropping the suitcase on a corner, followed by 3 unique edges, and finishing with a drop on each of the 6 faces of the suitcase. Then the vibration tests will be conducted by placing the suitcase on the vibration machine, oriented on one of its respective faces and experiencing the vibrations for 10-30 minutes. The test will then be conducted again, on a different face of the suitcase, until each unique face of the suitcase has been tested.

3.1.1.6 Acceptance Criteria

The test must satisfy shock and vibration ISTA 2A requirements and will be successful if all 12 wine bottles do not break or leak after each drop and vibration test.

3.1.2 Test Results

The team was only able to perform a similar version of this test due to the displacement from San Antonio. The team was able to drop the suitcase from about 36 inches and from shoulder height and the suitcase passed with no breakage of the bottles.

3.1.3 Evaluation

Despite being unable to complete the official procedure, the team is still confident that our prototype would have passed and successfully kept the bottles secure. Therefore, this aspect of the design does meet the design requirement for the suitcase in that it is able to withstand aggressive baggage handling.

3.2 Holds up to 12 bottles of varying shape with volumes of 750 mL

3.2.1 Bottle Quantity Test

3.2.1.1 Test Overview

This test will verify that the number of bottles that the suitcase can carry is up to the specifications of a full case (12 bottles)

3.2.1.2 Objectives

The objective of this test is to determine if 12 bottles can fit in the suitcase.

3.2.1.3 Features Evaluated

This test will evaluate the capacity of the suitcase.

3.2.1.4 Test Scope

The quantity test requires that 12 750 mL bottles are used.

3.2.1.5 Test Setup and Assumptions

For this test, we will see if 12 bottle cutouts can be made and all 12 bottles can successfully be placed in the suitcase.

3.2.1.6 Acceptance Criteria

The test will be a success if all 12 bottles can properly fit in the suitcase.

3.2.2 Test Results

The suitcase can hold 12 bottles and they properly fit in the suitcase.

3.2.3 Evaluation

The result of this test was a success. The success accomplishes the requirement that the wine suitcase must hold a case of wine.

3.3 Maintains a temperature below 70°F for up to 36 hours

3.3.1 Bottle Thermal Protection Test

3.3.1.1 Test Overview

This test will verify that the insulation materials of the suitcase will maintain an initial temperature safe enough for the wine not to cook.

3.3.1.2 Objectives

The thermal protection tests aim to determine if the internal temperature of the suitcase remains below 70 °F for 36 hours.

3.3.1.3 Features Evaluated

This test will evaluate the effectiveness of the insulation materials.

3.3.1.4 Test Scope

For this test, the suitcase will be filled with 12 bottles of wine.

3.3.1.5 Test Setup and Assumptions

This test will utilize seven thermocouples to measure the temperature inside the suitcase at various points as well as a previously calibrated sensor to ensure that the temperature and humidity are at the required levels. A thermocouple will be placed at each bottle location on one side of the suitcase and one additional thermocouple at the center of the suitcase. To test that the suitcase can maintain a temperature below 70 °F we will expose the suitcase to the expected temperature profile seen in the Appendix in Table 1. This temperature profile will allow us to see how the suitcase reacts at all expected temperatures and periods of time

3.3.1.6 Acceptance Criteria

This test will be successful if the suitcase maintains the temperature of the bottles below 70 °F after the expected temperature profile.

3.3.2 Test Results

The team was unable to perform this test due to the displacement from San Antonio. The team had plans to perform the test at SwRI during the week of March 16th.

3.3.3 Evaluation

Since this test was unable to be performed, it is advised that the full test plan is followed at a later date to verify the ability of the suitcase to maintain the proper temperature. However, a model of the proposed temperature profile was completed and is outlined in section 3.7.

3.4 Maximum weight of 50 pounds when filled with full wine bottles and the temperature sensor

3.4.1 Weight of Suitcase Test

3.4.1.1 Test Overview

This test will verify that the suitcase will not exceed the weight limit specified in the project requirements so the user does not incur additional travel fees.

3.4.1.2 Objectives

The goal of the weight test is to determine that the fully loaded suitcase does not weigh more than 50 lbs.

3.4.1.3 Features Evaluated

The only feature evaluated will be the complete suitcase including the wine inside.

3.4.1.4 Test Scope

For this test, a prototype of the wine suitcase must be constructed with all the features and materials that are desired for the finished product so that the weight measurement will be accurate and will not change due to the actual suitcase. All 12 bottles of wine must also be placed in the suitcase.

3.4.1.5 Test Setup and Assumptions

This test will require a full prototype of the wine suitcase and a scale. Take the fully constructed wine suitcase prototype and fill it to capacity with 12 bottles of wine. Then take the full wine suitcase, weigh it on a scale and record the weight value.

3.4.1.6 Acceptance Criteria

A successful test will show that the overall weight of the suitcase, while full of wine, is under a value of 50 lbs.

3.4.2 Test Results

The suitcase containing 12 bottles of wine full of liquid weighed in at 44 lbs.

3.4.3 Evaluation

The result of this test was a success and the prototype achieved the weight goal as described in the project requirements.

3.5 Suitcase must not exceed 60 linear inches

3.5.1 Size of Suitcase Test

3.5.1.1 Test Overview

This test will verify the suitcase does not exceed the size limit of 62 linear inches meaning the sum of the length, width and height must equal less than 62 inches.

3.5.1.2 Objectives

The size test will determine that the suitcase does not exceed 62 linear inches.

3.5.1.3 Features Evaluated

The only feature evaluated will be the size of the suitcase.

3.5.1.4 Test Scope

For this test, the suitcase must be filled with wine bottles and zipped closed when being measured.

3.5.1.5 Test Setup and Assumptions

This test consists of measuring and summing the height, width, and length of the suitcase using a measuring tape

3.5.1.6 Acceptance Criteria

The test is a success if the height, width, and length of the suitcase does not exceed 62 inches.

3.5.2 Test Results

After measuring the height, width and length, the suitcase measured in at 61.25 total linear inches (30.25" x 20" x 11").

3.5.3 Evaluation

The total height, width and length of the suitcase did not exceed 62 inches. Therefore, this feature of our design achieved the requirement and is complete.

3.6 Temperature sensor records the thermal history of the suitcase during travel

3.6.1 Thermoplus Temperature Sensor Test

3.6.1.1 Test Overview

To have some idea of the behavior and accuracy of the Thermoplus temperature sensor, the sensor's readings were compared to that of a kitchen thermometer by placing both in a tub of water which was then cooled with ice. This test is in lieu of our previous plan of comparing the Thermoplus readings to the readings found in 3.3 where we would have utilized a calibrated thermocouple thermometer from SwRI. With the displacement, this was the best available comparison.

3.6.1.2 Objectives

The objective of this test is to show some data that supports the sensors accuracy.

3.6.1.3 Features Evaluated

This test will evaluate the sensors ability to accurately report the internal temperature of the suitcase.

3.6.1.4 Test Scope

For this test, the sensor should report a similar readout to that of the kitchen thermometer.

3.6.1.5 Test Setup and Assumptions

Both the kitchen thermometer and Thermoplus sensor will be placed in a pot of water. After 30 minutes, ice will be added to the water. Then after 40 minutes, the sensors will both be removed from ice and placed in a separate, room temperature pot of water for another 80 minutes. Temperature readouts will be taken every 10 minutes, as that is the reading interval that will be in place during travel.

3.6.1.6 Acceptance Criteria

Since the kitchen thermometer is very unlikely to be calibrated, the test will be successful if the Thermoplus sensor and kitchen thermometer give similar readouts to one another that are expected given the conditions they are exposed to.

3.6.2 Test Results

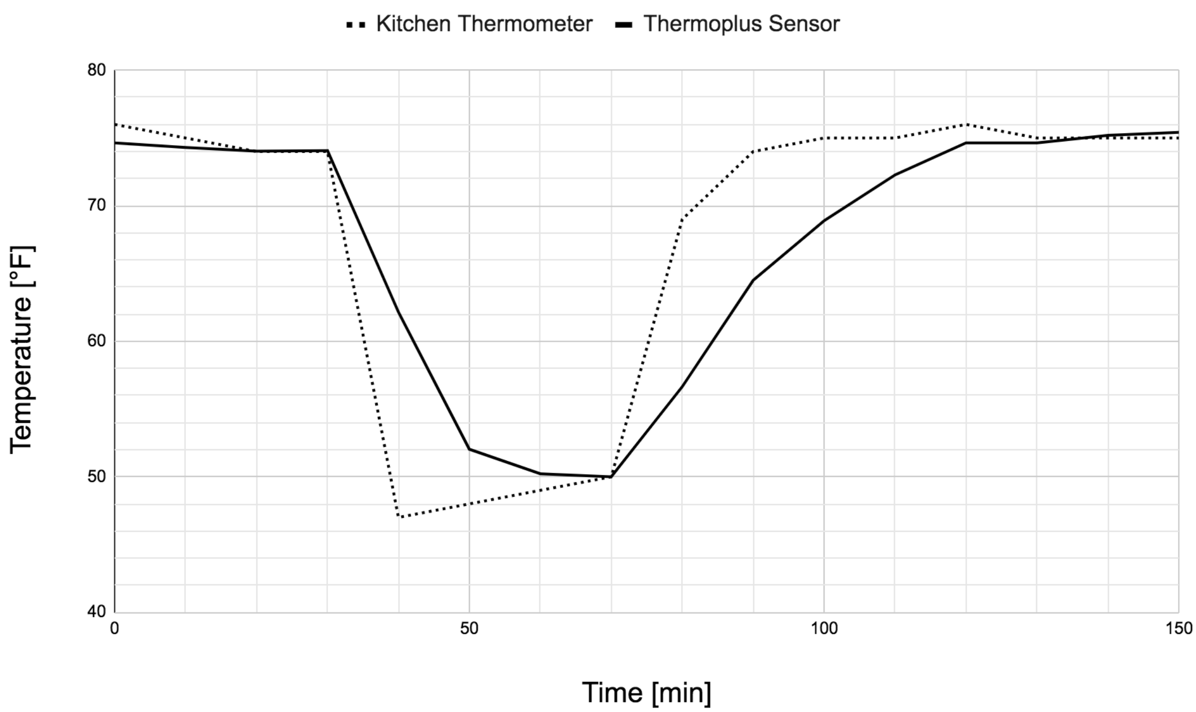

Figure 1. Comparison of Thermoplus temperature sensor and kitchen thermometer

3.6.3 Evaluation

Based on Figure 1, we found that the two sensors agreed at equilibrium, but when the two sensors were exposed to rapid temperature change, the Thermoplus Sensor lagged significantly behind the kitchen thermometer. However, we do not expect this to be an issue in our design. There should be no rapid temperature changes inside the suitcase because of the layers of insulation and, therefore, no issue of the temperature sensor inside the Thermoplus device being at or very near the temperature of the suitcase.

3.7 Maintains a temperature below 70 °F

3.7.1 Heat Transfer Simulation Test

3.7.1.1 Test Overview

This test will consist of a simulation to give verification that our final design will be able to keep the wine bottles below 70 °F in lieu of our physical experiment planned in 3.3.

3.7.1.2 Objectives

This test will verify that the final design keeps the wine sufficiently cool.

3.7.1.3 Features Evaluated

This test will evaluate if the suitcase case can keep the wine bottles cool when exposed to an extreme temperature for a short span of time.

3.7.1.4 Test Scope

The temperature of any wine bottle must not exceed 70 °F.

3.7.1.5 Test Setup and Assumptions

The simulation was written in MatLab using its PDE solver tools. Because it is unreasonable to do a finite element analysis over a time period of 36 hours, the model will simulate the suitcase sitting on the tarmac with an air temperature of 110 °F for 15 minutes, which in extreme cases may occur while traveling. The temperature of the suitcase initially will be 65 °F.

In order to model this situation in MatLab, we had to make several concessions. Because of limitations with MatLab, we are unable to get the exact geometry of the suitcase. Instead of three completely nested prisms representing the layer of suitcase, insulation, and foam, the prisms share two faces, see Figure 2 for an exaggerated representation of the geometry.

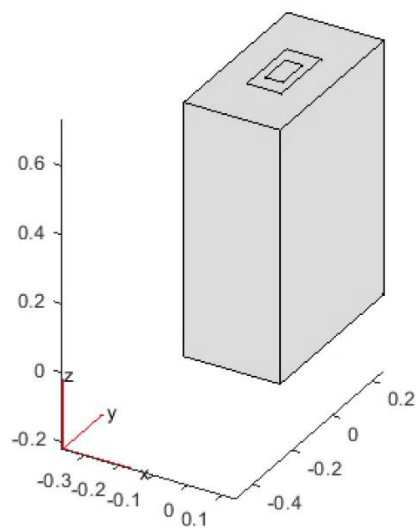

Figure 2. Exaggerated simulation geometry. Inner layer is foam. Middle layer is insulation. Outer layer is suitcase plastic.

To minimize the consequences of this limitation, we chose for the smallest 2 faces for the layers to share. This same issue prevents us from adding blocks of materials to represent the wine bottles. To better approximate the presence of the wine bottles we took a volume weighted average of the foam and wine bottles specific heat and density. Next, we weren't able to get the boundary conditions as we would have wished. We can only program a convection boundary condition or a radiation condition, but not both. We chose convection as we believe it will have a larger role in warming the suitcase. Next, we did not apply the convection boundary condition to the shared faces of the suitcase. Because the top and bottom faces are multilayered faces, the simulation showed strange behavior when attempting to enforce a convection boundary condition on each face. When applied the multilayered faces would, in seconds, become hotter than the ambient air. Finally, we assumed a convective heat transfer coefficient of 50 W/m^{2}K based on [2] and [3].

3.7.1.6 Acceptance Criteria

This test will be a success if at no point during the simulation does the location of a wine bottle exceed 70 °F.

3.7.2 Test Results

In Figure 3, the temperatures of the simulation after 15 minutes are shown. Additionally, the full 15-minute simulation video can be seen in the Appendix in section 5.4.

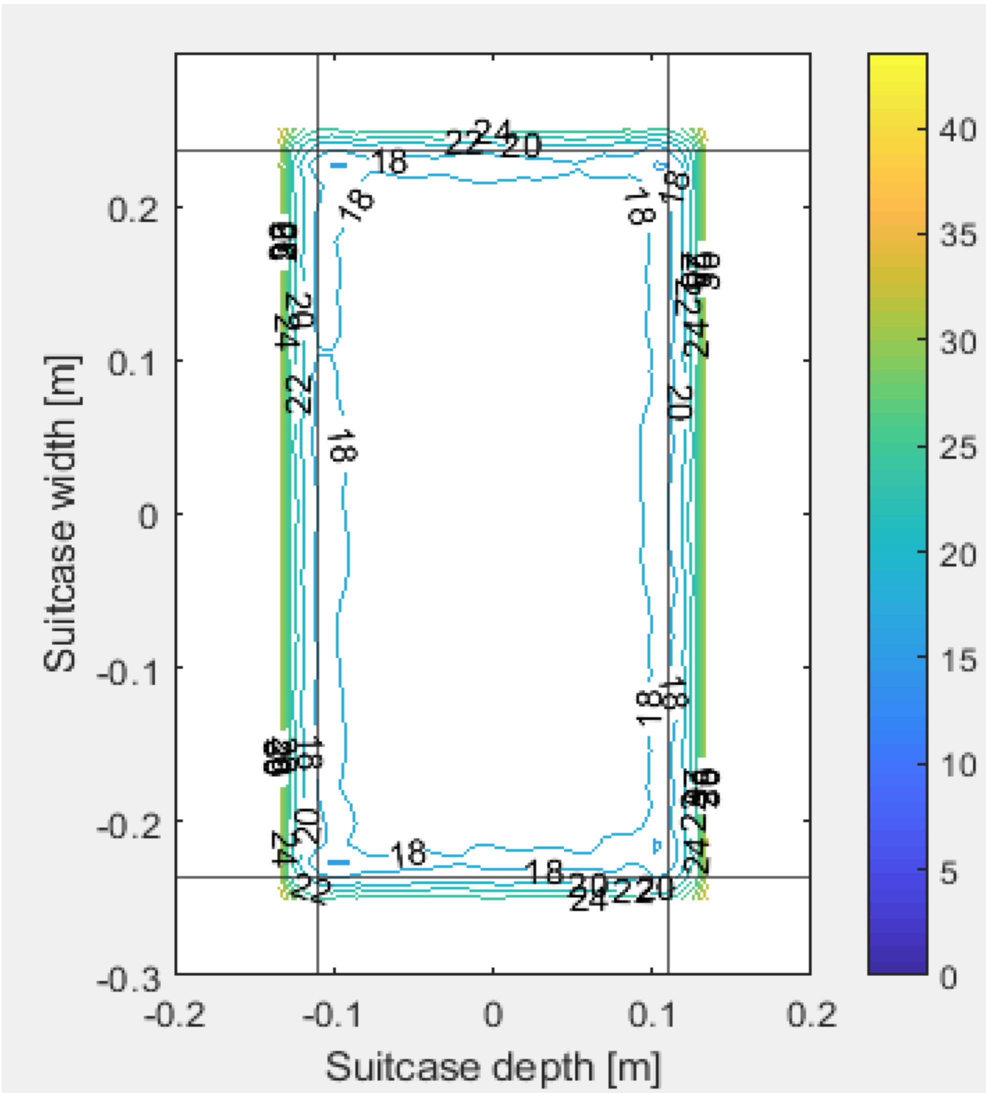

Figure 3. Cross-section of suitcase after 15 minutes (Temperatures in °C). The central boxed region represent where the wine is stored (from about -0.1 to 0.1 on the x-axis and -0.2 to 0.2 on the y-axis).

3.7.3 Evaluation

Based on Fig. 3, at no point where wine is stored does the temperature exceed 70 °F. This passes criteria that all points where wine would be remaining below 70 °F.

However, there are few things to bear in mind with these results. First, the heating of the suitcases is less severe in two ways. There is no convection on the top and bottom of the case and there is no radiation component of the sun shining on the case. Second, this simulation is relatively long and by the limitation of the computational power at our disposal, we could not simulate as many nodes and as small of timesteps as we may have wished. By nature of finite element analysis, this means the longer the simulation the further from reality the results become.

With all this in mind, we believe that the suitcase will perform correctly in real life situation. Originally, we planned to test over a theoretical 36 hours of travel, however the most likely times for failure would be during the 15-minute intervals when the suitcase may be left outside on a hot day. In between those 15-minute interval times, the luggage will be sitting in the luggage hold of a plane at 50 °F or in the chilled air of an airport. Based on these expected conditions and the performance of the case in the simulation, we believe the suitcase will likely fulfill the requirement of keeping the wine below 70 °F over the 36 hours of travel.

4 Conclusions

With each of the tests performed, our prototype performed accordingly and achieved all objectives and requirements with success. For the thermal protection test, the team was unable to perform the test due to the displacement from San Antonio due to COVI-19. However, the heat transfer simulation test was added after the displacement to offset the inability to perform the thermal test in person. While the simulation is not the same as laboratory testing, we can still use it as a good measure of the thermal protection capabilities of our design Ultimately, each of the tests passed appropriately. In light of our displacement from Trinity, we weren’t able to as rigorously test the thermal protection and temperature sensor as we had originally planned, but the results of the tests we did perform give us confidence that the design would have fulfilled all the requirements. Therefore, we assert that once the thermal sensor is installed inside the case, the Wine Suitcase prototype that was fabricated before displacement is a fully functioning device that can be used to safely transport wine according to the requirements and conditions initially proposed to the team.

5 Appendices

5.1 Setup, Operating and Safety Instructions

5.1.1 Setup of Wine Suitcase

1. Purchase all parts as outlined in Table 1 in section 5.2 of the appendix
2. Cut the insulation material to the proper size by placing inside the suitcase and measuring
3. Cut the foam padding for each side of the suitcase as well as a piece for the middle of the suitcase again measuring according to the suitcase size
4. In the two pieces of foam that go inside each side of the suitcase, cut out 6 bottle shaped holes using any form of cutting device; it is easiest to use an average 750 mL size bottle for reference
5. Pick one side of the suitcase and also cut out an area for the temperature sensor to be placed
6. Assemble the suitcase
    a. Place the cut insulation into the suitcase
    b. Insert the foam into the suitcase with the cutouts facing outward
    c. Place the temperature sensor in its respective place but be sure it is off
    d. Place the additional piece of foam in the middle of the suitcase and zip the suitcase for storage until use

5.1.2 Operation of Wine Suitcase

To operate the suitcase, first open the suitcase and ensure that the foam has not shifted and all bottle cutouts are intact. Next, you will place your bottles into the suitcase and secure one side using the straps and the other side using the zippered fabric. Now, turn on the temperature sensor and ensure the additional foam is in place in the middle of the suitcase prior to closing the suitcase for departure. In section 5.3 of the appendix, there is an image that can be used for reference. Note that this image does not have the slot for the temperature sensor nor the middle piece of foam showing, it is solely to demonstrate how all 12 bottles will rest in the suitcase after assembly and beginning of operation.

5.1.3 Safety Instructions for Wine Suitcase

In order to ensure there is no breakage of the wine, the user must be sure to place the middle piece of foam in the suitcase prior to use. Additionally, the user should take caution when rolling and lifting the suitcase as it will be heavy at around 44 lbs. Outside of these two instructions, there are no additional safety instructions.

5.2 Table comprised of the full bill of materials

Table 1. Complete bill of materials including manufacturer, source and part description.

Material	Manufacturer	Source	Description
Double Bubble Foil Insulation	Miami Wholesale	Amazon.com	Two layers of polyethylene industrialized air bubbles bonded between two layers of highly reflective metalized aluminum polyester film. Emissivity: 0.03 Thermal Conductivity: 0.032-0.036 W/m Apparent Density: 54.8 kg/m^3
Coolife Expandable Luggage	Coolife	Amazon.com	The suitcase is mainly made from its ABS+PC hard plastic shell. Dimensions: 20.5 x 11x 29
Charcoal Foam	Foam Factory Inc.	foambymail.com	A polyurethane foam used to protect the wine bottles from breaking and as insulation
Newkiton NK-01B Wireless Thermometer Temperature Sensor	Newkiton	Amazon.com	Bluetooth temperature sensor for measuring the internal temperature of the suitcase

5.3 Image of Suitcase

Figure 4. Image of opened suitcase with 12 750 mL bottles of wine securely fitting inside the constructed initial prototype.

5.4 Thermal Simulation Video

Figure 5. Video of entire 15 minute thermal simulation

6 Bibliography

[1] International Safe Transit Association Testing Procedure 2A

[2] “Convective Heat Transfer,” Engineering ToolBox. [Online]. Available: https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html. [Accessed: 06-May-2020].

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