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Weather Balloon Payload Box

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TABLE OF CONTENTS

I: TABLE OF FIGURES

II: ABSTRACT

Title and Author: Weather Balloon Payload Box by Shellbie Liberty (Engineering Technologies, Safety, and Construction)

Abstract/Artists Statement: A payload box holding a self-rotating camera was constructed to go on a weather balloon that will document the upcoming solar eclipse on August 21, 2017. A group of physics students, and the paper's author, are working under Dr. Darci Snowden on the CWU Near Space Observation Team for research dedicated to the eclipse in Oregon. Various projects, including the payload box, are being designed to go up on a high altitude weather balloon. The payload box was designed and constructed to withstand the impact force of falling from 120,000 ft. This was done so the box could be reusable for future weather balloon projects. To achieve this, the box was made from fiberglass and foam with a thickness of 4 cm to withstand impact. The payload box was also designed to hold an "imaging platform" that will hold and rotate a camera using a servo motor. The motor knows where to rotate the camera based on how much light it senses coming from the windows of the payload box. During the launch in August, the camera should be able to communicate to the "ground station" computer so images can be seen in real time. With an expected terminal velocity of 4.39 m/s (14.40 ft/s), the expected impact force the payload box was designed to withstand (while remaining reusable) is 68.03 N (15.29 lbf).

1: INTRODUCTION

A: Description

One method of conducting astronomical research is launching a weather carrying a payload of scientific instruments used for testing and data collecting up into the atmosphere. Due to the sensitive nature of the scientific instruments used, protection from both the temperature conditions at about 100,000 ft. and the impact with the ground when landing is required if one wants to salvage and reuse their instruments after the balloon flight. Therefore, the purpose of this project is to construct a lightweight, compact, and durable container, or *payload box*, that will house and protect experimental instruments for weather balloon flights.

B: Motivation

This project was motivated by the need to conduct research experiments for astronomical events on a small budget with minimal resources without utilizing an expensive satellite. Weather balloons are a relatively affordable tool to use, but the components are also rather disposable; the balloon and parachute are not reusable, and payload boxes are typically made to throw away after usage. This project involves creating a payload box that can be retrieved and then reused for multiple experiments. The payload box will be used to conduct experiments on a solar eclipse scheduled to be viewable near Culver or Madras, Oregon on August 21, 2017. A Central Washington University (CWU) research group made up mainly of physics students and mentored by Dr. Darci Snowden, called the CWU Near Space Observation Team, will utilize the payload box attached to a weather balloon during the eclipse.

C: Function Statement

The purpose of this project is to create a reusable box that will protect scientific instruments inside it during weather balloon launches.

D: Requirements

The device requirements include being lightweight, compact, and able to withstand atmospheric conditions high up all while protecting the delicate instruments contained inside during and after the balloon launch.

- The box and payload together cannot exceed 1360 g (3 lb.). Also, to meet U.S. Federal Aviation Administration (FAA) regulations (14 CFR §101.1), the box and payload cannot exceed a weight/size ratio of 3 oz. /in^2 (13.18 g/cm^2, 0.1875 psi).
- The dimensions must be 20 x 20 x 20 cm to maintain a miniature cube shape.
- Protrusions from the device must have dampers, contain no sharp edges, and be no more than 6.5 mm on any side.
    - Antenna are an exception to this requirement: they can be 5 ft., but cannot have an impact force that exceeds 50 lb. to break, as per U.S. FAA regulations (14 CFR §101.35).
- The altitude goal is 120,000 ft. (±10,000 ft.) based on the maximum projected height of the weather balloon purchased from High Altitude Science, so the device must withstand atmospheric conditions at that height (temperatures dropping to -51°C, or -60°F).

- Insulation is required to protect alkaline batteries for the instruments and keep the inside temperature above -18°C (0°F) at minimum. The batteries also cannot operate at temperatures above 55°C or 130°F (Energizer Holdings, Inc.).
- The rope connecting the payload box to the balloon cannot have a tensile strength greater than 50 lb., as per U.S. FAA regulations (14 CFR §101.35).
- The attachment of the box to the balloon must remain stabilized during ascent and descent. Rotation must be minimized to alpha 15° in the x, y, and z-axis.
- Instruments inside the box must be protected from an impact force of 20 lb. (88.96 N).
- The box must remain waterproof at 1 m. depth for 30 min. to meet the electronics-rating requirement of IP67 (Resource Supply, LLC).

The budget is $400, and everything must be ready for launch on the August 21, 2017 eclipse.

E: Engineering Merit

The material of the casing must withstand the conditions at 120,000 ft., and have thermal protection for sensitive payload items like batteries inside the box. The material must also withstand descent conditions and have an impact tolerance higher than the estimated impact force with the ground. The velocity of the balloon system as it falls to the ground will need calculating so the impact force with the ground can be estimated, which is dependent on the lift of the parachute during the fall

Both the thermal and impact conditions will require a certain material type and thickness to use that also will ensure a lightweight, compact design for the payload box.

The device must also connect to the weather balloon in a way that stabilizes the box for the duration of the flight. This can be done by hooking the balloon and box with cables in a secure manner using multiple hooks and/or threads to minimize torque from the cable. Kite attachments or fishing equipment could also be added to the sides of the payload box to stabilize the box further. It is impossible to keep the payload box completely still during the flight, but tests can be run on different designs to find the one that provides the best stabilization.

F: Scope of Effort

The device will be created in conjunction with the CWU Near Space Observation team who will be observing the August 21, 2017 eclipse near Madras, Oregon, mentored by Dr. Darci Snowden. The payload box will be provided to the Near Space Observation team, and the physics students on the team will do extra calculations (such as flight predictions and how much helium to add to the balloon) and create instruments to insert inside the payload box. The weather balloon will hold multiple payloads—at least one more besides the payload box being constructed.

As a project benchmark, the protective casing is like the CubeSat project initiated by California Polytechnic State University (Cal Poly) and Stanford University. Therefore, the design of the payload box is limited to a small cube shape. The CWU physics department, and Dr. Snowden herself, have previously created sensing instruments and weather balloons for other astronomical events. Dr. Snowden is also in contact with Montana State University, who is leading the Eclipse Balloon Project for the upcoming eclipse, and has expertise on weather balloon experiments of this caliber.

G: Success Criteria

Project success is dependent on protecting instruments inside the device in the atmosphere when launched up to 120,000 ft. and when the balloon lands back down to the ground. These instruments need protection so the team can collect research data from them during and after the astronomical event. Reusing as many parts from the weather balloon project as possible is also desired, especially the payload box itself.

2: DESIGN AND ANALYSIS

A: Approach

The proposed solution for this project is to create a holding container for scientific instruments launched with a weather balloon to conduct research on a solar eclipse on August 21, 2017. This holding container, or *payload box*, not only needs to store the contents, but protect them from the temperature conditions in the troposphere and stratosphere; and then protect them from impact when the weather balloon payload lands back down on the Earth's surface. There is also a chance that the payload could descend into water after being launched in the outskirts of Madras, Oregon, so the payload box must also be waterproof. The end goal is for the payload box, and the instruments inside, to be reusable for multiple flights and experiments.

Weight is an important aspect to consider when planning a weather balloon launch. To avoid getting a waiver signed by the U.S. Federal Aviation Administration (FAA), the entire payload must not exceed 6 lb., or more than 4 lb. and a weight/size ratio of more than 3 oz. /in^2. Design parameters for this project entail keeping the weight of the payload box and payload (the instruments it carries) no more than 3 lb. Also, the exact weight of all objects the weather balloon will carry needs to be known to properly calculate how much helium to use and how fast the balloon will travel in its flight. The speed is used to predict where the balloon will travel and where it should land.

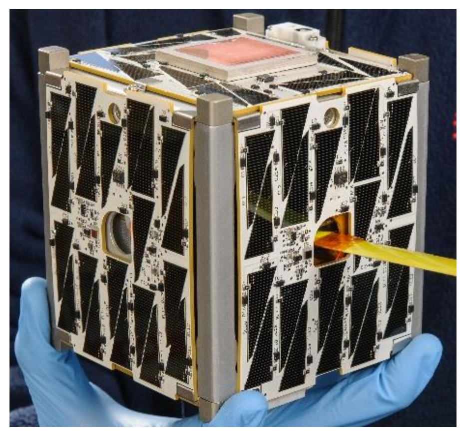

Figure 1: PhoneSat 2.5, a CubeSat developed by NASA's Ames Research Center in Moffett Field, CA.
Source: NASA (2015).

The inspiration for this project came from the CubeSat project developed by California Polytechnic State University (Cal Poly) and Stanford University, in which students created miniature cube satellites (Figure 1). In keeping with the spirit of the CubeSat project, this payload box must keep a cube shape and match similar size limitations. The original design of the payload box was limited to the dimensions of 10 x 10 x 10 cm or 20 x 20 x 20 cm based on the CubeSat project requirements and what instruments were planned to be inside. The final design of the payload box is using dimensions similar to the 20 x 20 x 20 cm limit.

The petite size of the payload box will help keep the weight down, as will the material choice. In making a material selection, impact durability and thermal protection are two other important parameters to consider. The material should be thin (due to weight and size limitations), but still thick enough to provide impact insulation and temperature protection to sensitive instruments like batteries.

Finally, depending on the delicacy of the instruments inside the payload box, the turbulence of the payload will need to be minimized. For the payload box, a design that curtails torque in the rope connecting to the balloon, as well as one that helps balance the box during the flight, will be made and tested for best optimization.

B: Design Description

Most likely, the payload box will carry up a camera with some sort of lens filter to capture images of the eclipse. With this, there are two design options.

Option one is to create an *imaging platform* for one camera to sit on, which would be connected to some type of light sensor that can find which direction the camera should point for the right shot of the sun. (A magnetorque is another sensor that can be used in place of the light sensor.) Because the camera can change viewing angles, there either needs to be an opening going all along the potential camera path, or a see-through material acting as a window in the camera's lens view to keep the box insulated. The second window design could create focusing issues, or other problems that affect the quality of the photography.

Option two for a camera design is to set up multiple cameras at different sides of the cubic payload box to ensure multiple photographing angles. This ensures permanent locations for each camera, so a small opening could be provided for each camera lens that keeps the entire payload box insulated.

Either option keeps the dimensions of the payload box in a cubic shape with the same thickness. Either design will also incorporate a second camera that sits at the bottom of the box and points downward to photograph the terrain and atmosphere below. The first option was chosen for the final box design, using photo sensors to sense which direction light was coming from.

To keep the payload box stable during the lift and fall of the launch, there are also different design options to consider. One option is to apply multiple hooks that help curtail tumbling; an arrangement of 4-5 hooks to attach to the rope from the balloon could help limit movement. Another option is to attach the payload box to a shaft with inner threads. These would dig slightly into the rope or cable attached to the weather balloon, minimizing rotation. Another option is attaching lightweight bars to the sides of the payload box, and then sliding kite material over the bars to help minimize tilt and help with lift and drag. All options may need to be considered if the camera position ends up being critical to the design.

C: Benchmark

There are two benchmarks for this project. The first is the CubeSats made initially by Cal Poly and Stanford University (Figure 1, from previous page). These miniature satellites are launched in conjunction with other miniature satellites in a larger launch vehicle, or deployers of the International Space Station. Due to both the nature of their launch (being crammed in close quarters with many similar devices) and the differences in altitude they hit (low earth orbit; 160 to 2,000 km, or 525,000 to 6,560,000 ft.), they require stricter design parameters than the weather balloon project. However, the design for the payload box will try to stay in the same vein as a CubeSat, just simplified for the parameters of the CWU Near Space Observation team.

Figure 2: Styrofoam cooler modified for weather balloon launch.
Source: Flaig (2013).

The second benchmark for this project is payload containers used for typical weather balloon experiments. Commonly they are made from Styrofoam coolers (Figure 2), but this creates two problems. The first is that the material is disposable and cannot be reused for multiple projects. The second is that the lightweight material causes the payload box to bounce multiple times during landing, which can upset delicate instruments such as the GPS systems inside that alert the experimenters where their payload landed. Bouncing also creates multiple points of impact, causing further deterioration of the container. High Altitude Science, the website that the Near Space Observation team purchased some of their weather balloon supplies from, sells weather balloon kits. They recommend using their Delta Flight Frame product to launch a payload with to ensure stability during the flight (Figure 3, next page). However, the frame is simply made up of flat American basswood (*Tilia americana*) formed into a triangle shape that can have instruments such as a camera sit on top, exposed to the elements. There is no protective covering for any of the instruments, as provided by High Altitude Science, and the wood material makes reusability very unlikely. The Delta Flight Frame limits the way instruments can be packaged to the balloon, and the exposure to the outside air poses further problems.

Figure 3: Delta Flight Frame product from High Altitude Science. *Source:* High Altitude Science (2015).

D: Performance Predictions

Performance of the device depends on the material selected that gives the best impact resistance and the best thermal protection while remaining lightweight. It also depends on how stable the box remains during the flight.

During the descent, the payload box will not be in free fall, instead having a parachute deployed after the weather balloon bursts. The parachute and balloon were both purchased from High Altitude Science, and the type purchased will affect the design of the payload box in regards to impact. The balloon that the group plans to utilize, at 1200 g, has an estimated performance of 110,000 to 120,000 ft. (34 to 37 km), which is the height that the balloon will burst. Then a 1.5 m, 190 g parachute that the group also purchased will be deployed, which needs to be considered when finding the impact velocity of the payload box. This leads into estimating the impact force and the material displacement that will cause to the payload box. The design can then incorporate a certain thickness and material that will protect the instruments inside but remain lightweight. Once a thickness and material are known, the mass and weight of the box can be estimated to make sure it fits both the design requirements and the U.S. FAA regulations (14 CFR §101.31 to 101.39).

The type of balloon and parachute chosen does not affect temperature conditions as much, because the weather balloon and payload box will pass through the troposphere and enter the stratosphere regardless of the type chosen. From 0 to 36,000 ft. (0 to 11 km), the troposphere varies in temperature from 17°C (62°F) to -51°C (-60°F) (Engineering Toolbox, National Weather Service). The stratosphere, ranging from 36,000 to 167,000 ft. (11 to 51 km), increases from the troposphere temperature of -51°C to -15°C (5°F). Therefore, the payload box must keep batteries and other electronics running while at the minimum temperature of -51°C, which is dependent on material selection and design thickness. Essentially, the material will be selected based on temperature data, will be made thick enough to insulate the instruments inside, and will still need to meet the weight limitations from the design requirements, based on the FAA regulations.

E: Description of Analysis

To find which material to select for the payload box, the impact displacement from the descent needed to be analyzed. First, an estimated impact velocity and time were found to be 14.40 ft./sec (4.40 m/s) and about 100 min., respectively (Figure A-1, A-2). This led to finding the impact force of 15.29 lb., or 68.03 N (Figure A-7). Different materials were researched and their maximum displacement was found to compare the data with the impact force (Figure A-3 through A-7). Since the temperature conditions were already known, the impact estimate was the main calculation to find the material and final box design.

Analysis can then go into finding the best design to make the box mostly stabilized during the flight. A calculated mass and weight of the payload box, based on the calculated box thickness, correlates to a calculated length for a kite attachment, or a calculated counter weight to add to the end of a lightweight pole, for example.

F: Scope of Testing and Evaluation

There are four aspects that require testing and evaluation to ensure they meet the design requirements: durability, thermal protection, an operating imaging platform for the camera, and flight stabilization.

Panels, or strips, of material to simulate the payload box walls can be made up to test strain and tensile strength. Smaller versions of the payload box can be made to test the impact before the full-sized box is built. Impact can be tested by either dropping the box from a large height or dropping something from a large height onto the box for both the full size and smaller-scale boxes. Thanks to Dr. Darci Snowden, a high-speed camera can be utilized during these tests to visually document the material displacement during impact. The CWU Near Space Observation team will also conduct multiple weather balloon test flights prior to the August 21, 2017 eclipse, and there is a possibility the payload box could be tested with a weather balloon as well before the official launch.

Testing prior to the flight can also check the payload box material's resistance to low temperature and insulation abilities. Temperatures in the troposphere can drop to as low as -51°C (-60°F). However, current instrument requirements suggest only the batteries will be affected by these low temperatures, and everything else inside will remain functioning throughout the flight. Also, if the batteries are thermally insulated, so too would the other electronics inside the payload box. The thermal insulation can be tested using a freezer and a temperature sensor placed inside the box. The box could also be taken out of the freezer and then immediately tested for tensile strength to check material brittleness.

The imaging platform will be designed together with the CWU Near Space Observation team, as the entire set up requires photo sensors (or similar sensor) to communicate to a stepper motor to turn the table a certain amount of degrees to face the sun. The Near Space Observation team will focus on making the electronics communicate together, while the engineering aspect will focus on creating a table design that can properly attach to the motor and mount the camera while keeping the table balanced. The imaging platform will need to be tested to ensure all the instruments are working prior to the launch, which will involve testing the sensitivity of the photo sensors and making sure the camera can rotate as programmed.

The last design component requiring testing is which design offers the best stabilization of the payload box during the flight. The payload box can be hooked up to an actual weather balloon or a dummy model that simulates the flight conditions, and then a sensor such as an accelerometer can be placed inside to measure the angle of tilt under certain conditions.

G: Analysis

The path the weather balloon will take during the launch needs thorough analysis to ensure that the design does not pose any problems during both ascent and descent. The CWU Near Space Observation physics team members will focus their analysis on the calculations of balloon ascent and descent, eventually using the finished payload box design to finalize the total weight and dimensions of the payload. At that point, all known instruments and payload objects for the launch will be known.

When the descent analysis is complete, a velocity and impact force can be found, which then leads to a material analysis. The material will need to withstand stress and strain from both the impact and the cold temperatures from the troposphere. The material will also need to meet budget and weight requirements.

Once that is finalized, work can be done on stabilizing the box to the weather balloon. Multiple design options will be looked at to see which will have the best stabilizing properties. Both design analysis and testing, using an accelerometer or some other gyro or vibration sensor, will need to be done to ensure the design is a success. Then this attachment apparatus can be connected to the payload box.

H: Device Parts, Shapes, and Conformation

To keep the box design simple, but still make the inside accessible so instruments can be taken in and out and adjusted whenever someone requires it, the lid to the box was designed to simply sit on top of the payload box. Nothing on the box holds the lid down. Therefore, when the payload box is ready for the flight, cables will be tied around the box to ensure the lid cannot slip out. Cables will most likely also need to be tied around the box regardless to implement the balloon stabilization attachment, so the lid should remain very secure during the flight regardless of how turbulent the balloon flight is.

I: Device Assembly, Attachments

The three major components of the design are the box itself, the imaging platform to fit inside the box that the camera will be mounted to, and the outside attachment to the box that will help stabilize everything during the flight.

The box alone is shown in Figure B-1, with B-2 representing the lid. At the request of Dr. Snowden, windows were cut into the four sides of the box so the camera could look through with no interference. The lid simply sits on top of the box for easy access, and will be tied down with cables when attached to the balloon.

A stepper motor will sit inside the payload box and interact with an Arduino and H-bridge—the “brains” of the electronics—and some photo sensors, which will indicate to the motor how much to rotate a 3D-printed table. The table will have a camera mounted to it, and, during the eclipse, the camera will want to aim where there is the most brightness to ensure it can snap footage of the solar eclipse. To implement this, a motor attachment will attach to the motor, as shown in Figure B-4 (without the stepper motor). This will then be glued to an imaging platform, which will have a camera mounted to it (Figure B-5). Both pieces will be made from ABS plastic to remain lightweight and customizable. Since part of the design’s aim is to keep the payload box reusable, the stepper motor attachments will be 3D printed in case future weather balloon launches use different camera set-ups or otherwise require other changes to the design. The low cost of 3D printing designs makes this aspect of the project very flexible both during the process and for future uses. This is also why these parts will not be hard-mounted to the payload box. Instead, the parts and electronic instruments will sit inside the payload box and remain removable, with a material like Styrofoam, felt, or removable tape added in the bottom of the payload box to help keep things stationary during the flight.

The balloon attachment will be added to the payload box by tying the two together with cables. A blind nut, threaded insert, or fishing swivel can be used on the part of the cable attached to the payload box to help isolate the spinning energy during the flight.

J: Tolerances and Ergonomics

Exact tolerancing for the payload box in tight design spots such as the lid, the windows, and any holes that may be cut out of the box for camera lenses to look through, will be difficult to implement with fiber or composite materials. In addition, applying fiber materials to an exact thickness will also be a challenge. This caused some parts of the design to be improved and edited during the construction phase. The thickness of the box will probably remain the same, as a foam material, like Styrofoam, can make up the difference for the fiber material thickness.

The lid and any instruments inside the box must be removable. Therefore, any inserts inside the box that help stabilize electronic instruments (such as a Styrofoam or felt bottom) may not be attached to the box in a permanent fashion (such as using glue).

K: Technical Risk Analysis, Failure Mode Analysis, Safety Factors, Operation Limits

The material selection affects the project budget the most, and makes the box design difficult for other people to replicate in the future. Part of the design involves making as many parts as possible reusable, but in the event parts of the payload box got damaged during the eclipse flight, the design should remain simple enough so future CWU students, or any other interested party, could rebuild the payload box if so desired. There is also a risk in the electronic components failing during the flight. Either the box fails to fully insulate the electronic components, or some other failure in the instruments communicating with one other occurs, such as the stepper motor failing to aim the camera for the proper shot. Some of the electronics that need to communicate to a computer on the ground, such as the GPS system that locates the payload box after landing, could also fail during or after the flight.

The U.S. Federal Aviation Administration (FAA) controls parts of the design for safety reasons. For example, the balloon must be trackable, and its location reported every two hours—in other words, the payload box needs to thermally protect the GPS during the flight so that it can properly function and communicate to the ground computer (14 CFR §101.39). There is also a weight limitation of no more than 4 lb. and a weight/size ratio of no more than 3 oz./in^2, or less than 6 lb. (14 CFR §101.1). The balloon stabilization attachment, as well as the cable or ropes that connect the payload box and stabilization attachment to the weather balloon, must not require an impact force of more than 50 lb. to separate the attachments from the balloon. These requirements are in place so the components of the weather balloon do not cause damage to people or property during landing.

Though the payload box is designed to withstand an impact force with the ground, it still has strength limitations. The box is not designed to hold heavy objects, especially on top of the lid. The box is not guaranteed to protect its insides from water beyond a depth of 1 m. in the original design, and its final design is no longer water proof due to the request to add in windows from Dr. Snowden.

3: METHODS AND CONSTRUCTION

A: Construction

For material analysis, test strips and smaller models of the payload box can be made to test that the material chosen can withstand the estimated impact force while remaining under the weight restrictions. Due to the cost of the material chosen, and how long the construction process will take, the construction of a test box can help check that the material and dimension thickness will succeed. The electronic components will also be set up prior to the construction of the full box to ensure that everything will fit inside. When the box is fully constructed, and the instruments are organized inside, then the balloon stabilization attachment can be constructed and applied to the payload box to test the success of the design.

I: DESCRIPTION

The payload box will be made from foam with fiberglass applied to the surface for added impact strength and thermal protection. The foam will either work as a mold in one piece by purchasing something like a small Styrofoam cooler, or as mold panels for the five sides of the box. The lid will just be a panel mold. By the request of Dr. Darci Snowden, uncovered windows were added to the four sides of the payload box design, which no longer makes the box itself waterproof. However, the electronics could still be protected from water by being covered by plastic inside the box. Due to the fabrication process, which makes meeting tight tolerances very difficult, the lid is designed to simply sit on top of the box, where it will be secured with cables tied around the box when the container is attached to the weather balloon.

The fabrication was done using Style 120 E-Glass, System 2000 epoxy resin, and epoxy hardener, all purchased from Fibre Glast. The first prototype was constructed in late February, and was done using a Styrofoam cooler mold (donated by MET student Seth Rich) and three layers of fiberglass due to the cooler exceeding the calculated dimensions of 2 cm (see Appendix B, Figure B-1 versus the original design in Figure B-7).

An imaging platform was designed and then 3D printed with ABS plastic to hold a camera and allow it to rotate inside the box to get the best photographs of the eclipse. The imaging platform was made up of two pieces: the camera table to hold the camera securely during the balloon flight, and a motor attachment that connects the camera table to a stepper motor. A LinkSprite JPEG Color Camera with TTL Interface, purchased from Spark Fun Electronics (model number LS-Y201, retired product), was chosen for the flight. Photos from the camera will be saved to a microSD card that can be viewed after the flight. The 200 step, 12-volt stepper motor, purchased from Adafruit Industries (model number XY42STH34-0354A), will connect to an Arduino and H-bridge, which will then communicate with four to eight photo sensors. By sensing the amount of light coming through the payload box windows, the motor will know how much to rotate the table to allow the camera to grab a shot. The height of the imaging platform must both consider the height of the stepper motor it attaches to and the height of the window openings in the payload box to ensure that the camera can see outside the box.

To help stabilize the box during the flight, four cables will come from each corner of the box to then secure to the rest of the balloon line. While other payloads will be attached to the balloon line, this payload box will most likely be at the bottom. A foam cylinder will also be attached to the bottom of the payload box to minimize rotation during the flight. Another design option, should the first one fail during testing, is to design kite attachments to two sides of the payload box with carbon fiber poles (or similar lightweight material) to help stabilize the load.

II: Drawing Tree

Below is a representation of how the payload box and imaging platform will be assembled together.

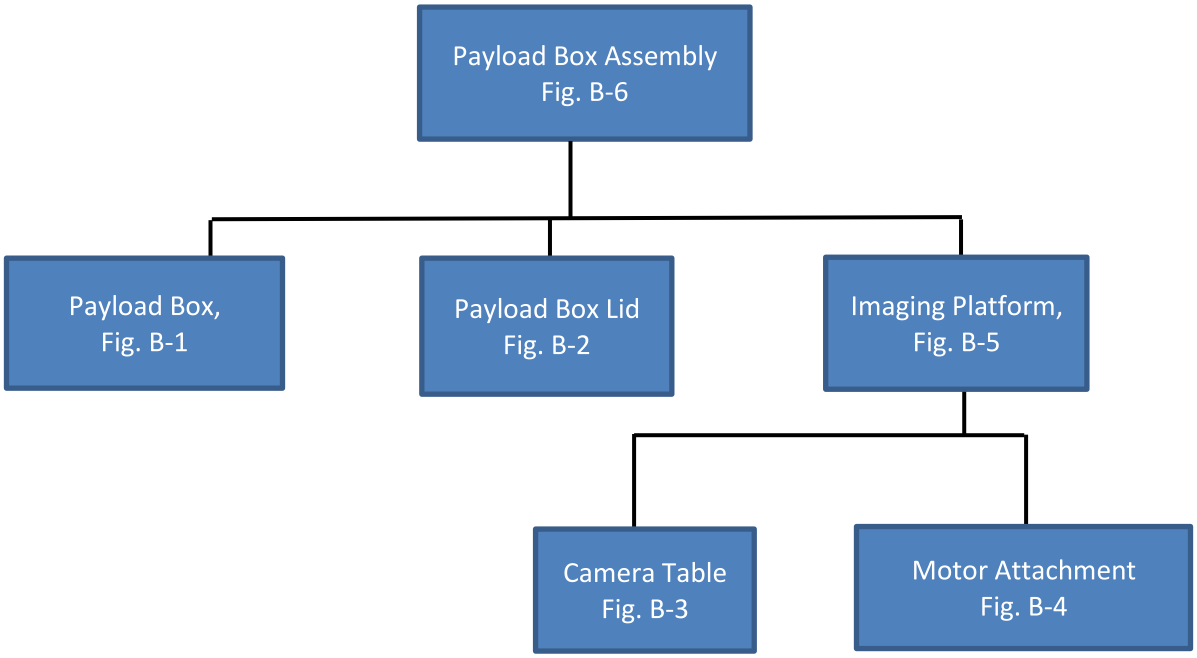

Figure 4: *Drawing tree*

The imaging platform will be designed and built first, since the components can be 3D printed when needed. This will also allow for the final testing of the dimensions and tolerancing before the payload box and lid are then constructed. The fabrication process is expected to take at least a week, maybe longer if scheduling conflicts occur. Electronic components will be added inside the box to finalize the configuration that allows for the most balance. Styrofoam or felt can be added inside to ensure that the instruments stay still and remain safe from the elements during the balloon flight. Once the box is built and finalized, the balloon attachment can be designed and constructed to give the payload box some needed stabilization during the flight, finalizing the assembly process.

III: Parts List and Labels

Most of the parts, such as the electronic components and fasteners, are simple to find and order. The other parts that make up the construction of the payload box, which follows the organization of the drawing tree in Figure 4, are dependent on the type of materials that are available to order while staying within budget. For example, finding foam with the same predicted properties in the right thickness necessary may prove challenging, though a good potential candidate was found in Polystyrene foam panels by Uline. The fiberglass, epoxy, and foam are the most expensive products needed for the project, and are needed for multiple parts that make up the entire payload box construction. They must be specially ordered if donations are not available from the school.

A full list of parts is available under Appendix C, while Appendix D details all the components required to set up the material construction.

All labor will be done at Central Washington University by the student, so no labor or outsourcing costs are necessary.

IV: Manufacturing Issues

The most complicated aspect of manufacturing is the box itself due to the fabrication process. Styrofoam coolers were donated by fellow MET student Seth Rich, which were only slightly above the original design dimensions. The original intent was to take one of the donated coolers and cut it into panels that would be easier to use as a fabrication mold. However, the amount of time it would take to cut the foam was not properly considered in the schedule: the process was both time consuming and too difficult to match the proper tolerancing and straightness required. Therefore, the entire cooler was instead used as a fabrication mold. Due to the round corners and the size of the box, it was difficult to prevent air bubbles from forming after layup and during the dry. Testing will show whether the air bubbles are enough of a problem to limit impact resistance or not, and a new payload box may need to be constructed after the testing in time for the August eclipse.

The 3D printing, while not as complicated, still had unique issues. For the first 3D printing job, CWU physics technician Addison Wenger forgot to account for material shrinkage, so the dimensions for the stepper motor hole and the camera holder were out of tolerance. A second print job was completed, except this time the material did not solidify properly during the print. Both these problems are due to the physics Science II building having a brand-new 3D printer. Faculty are still getting used to using and understanding the printer. Due to these issues, the 3D printer in Hogue was utilized for future prints while the Science II printer is still being figured out.

V: Discussion of Assembly, Sub-Assemblies, Parts, Drawings

The camera set-up needs to be discussed and figured out with the CWU Near Space Observation team so that all the drawing designs and dimensions are finalized, since the camera table set-up has different requirements than the three-camera set up originally designed for the inside of the payload box. Once the dimensions and weight are known, and the camera model is chosen, then the box dimensions can be finalized. The size of the box can be expanded to a cube shape of 25 x 25 x 25 cm if necessary, but keeping to the requirement of 20 x 20 x 20 cm is ideal. The window can be dimensioned on the box (whether it is a long Plexiglas window for the imaging platform, or holes for three camera lenses to peek through) so that the design is ready for manufacturing (see the window design under Appendix B, Figure B-8). This allows extra time to acquire fiber composites, or find a cheaper solution to the material requirements. A foam prototype could be built of the box dimensions to make sure all instruments will fit inside before the fabrication is done.

The dimensions of the box can further be changed if a foam mold proves easier than acquiring foam panels. This change will also affect how the lid is implemented in the design. The lid could either slide into the box, lock on top, or simply lay on top with cables connecting the lid to the box.

Once the box is finalized, the last step is to create an attachment for the weather balloon, using the carbon fiber poles, kite fabric, and cables to tie everything together. A simpler design can also be utilized using foam cylinders or cut outs, if this design proves more successful during testing. Multiple attachments will probably need to be tested to ensure the payload box is as secure and stable as possible during the flight.

4: TESTING METHOD

A: Introduction

To ensure the device will operate properly during the August eclipse, the payload box will need to be tested for impact resistance, cold temperatures, and stabilization.

Impact resistance testing needs to match the descent rate predicted for the payload as best as possible to ensure success. Testing material of a certain weight (such as metal spheres) dropped at a certain height can mimic the impact conditions the box may experience in the field.

In the troposphere, temperatures can go down to -51°C (-60°F), so brittleness is a concern for materials, as well as failure of the instruments if certain devices are not thermally protected (such as batteries). Therefore, both material strength and equipment sensitivity will need testing prior to the launch.

The payload box also needs to be stabilized during the ascent and descent (not too much rotation or jerking movements), so testing how stable the payload box remains is also important for overall device success.

B: Method & Approach

To test impact, the box had a force applied to it that matched the predicted calculated descent velocity and force. Smooth metal spheres were used to represent the impact force the box would have with the ground. Using the known velocity and force, as well as the weight of the spheres, the height in which to drop the spheres to match the same impact energy was calculated. Then the material displacement was measured using calipers or gages—both the diameter of the dent and the depth. Any other, more severe damage would also be recorded using appropriate parameters.

To test the payload box stabilization during the flight, different balloon attachments should be tested. The box was attached in different configurations. When the box was disturbed while on the line, a video camera recorded its movements and how long it took to settle back down. After the test, the video footage was analyzed to measure the angle the box tilted in the x- and y-axis. These tests can form a baseline in which to further design a better stabilizing method for the box during the flight. Other tests can use an accelerometer inside the box to get better data on movements in the x, y, and z-axes.

Temperature is a harder variable to test for given the extreme cold involved. Generally, testing for temperature involves heat, not cold. However, a regular freezer will at least get below freezing, with -51°C being the maximum range of coldness the payload box could be exposed to during the launch. Since batteries are the main thermal concern and are relatively inexpensive, a battery could be placed in the box to check that the box is thermally protected enough for the trip. A temperature sensor that records the thermal changes in the box will be placed inside as well. Once the box has been there for the duration of the time the payload box would be in the troposphere (20-30 minutes), it can be taken out so material brittleness can be tested as well, using similar parameters as the impact testing.

ANSI has reference sources for testing and measuring impact and displacement. Their protocols can be referred to during testing time. The same source can be used for the stabilization of the device during flight. Temperature can follow both ANSI and MIL-STD-810G instruction.

Dr. Darci Snowden has done multiple weather balloon launches and has instructions from conferences and resources from Montana State University. Using her as a resource, as well as the other members of the Near Space Observation team, ascent and descent prediction calculations and data can be verified, as can the payload box stabilization during flight.

C: Test Procedure

I: Impact test

Summary

To test the repeatable durability of the payload box, the box underwent impact that replicated the repeated impact force it will endure when it hits the ground during the eclipse. Metal spheres were dropped two stories onto the bottom of the box, with the weight and height being very specific to match the predicted impact energy the box will undergo during real use.

Time and Location

The test was done on Monday, April 10, 2017 at Hogue Hall's FLUKE lab with fellow MET student Daniel Phan's assistance.

Required Resources

The resources needed for the test are smooth testing sphere(s), a tape measure, safety glasses, a caliper, a depth micrometer, padding to protect the floor or ground from impact, and safety cones or caution tape to block off the area from passersby. The test should be done with at least two people: one person to drop the testing spheres, and another person to stand by and make sure people in the surrounding area are safe. Two people were used to conduct the test due to the testing height being around two stories tall. However, the test could be edited so the drop height was not so extreme. If the weight of the sphere is unknown, then a scale is also required to measure the weight.

Steps

1. If unknown, find the mass of the sphere with a scale. Then calculate the height in which it should be dropped to replicate the impact force using kinematics:

$$\tfrac{1}{2}\, m_1\, v^2 = m_2\, g\, h$$

$$h = \frac{\tfrac{1}{2}\, m_1\, v^2}{m_2\, g}$$

m_1 = mass of the payload box

m_2 = weight of the sphere

2. Measure and mark the height the sphere should be dropped from. This depends on how much height is required from the calculation; a normal tape measure may be sufficient, or longer surveyor tape may be needed. Mark the spot with a pencil mark to the tenths place.
3. Place the box underneath where the sphere will be dropped. Within that area, place protective boards and mats on the floor to prevent damage from impact and debris, and make sure the area is closed off from any passersby. Add a camera in a location that can film the impact without damaging the equipment, if desired.
4. Apply safety glasses, and then drop the sphere from the marked height. Aim for one of the corners of the box.
5. If the box experiences deflection, measure how much deflection took place with a caliper, depth micrometer, or any other appropriate measuring device.

Risk, Safety, and Evaluation Readiness

One major risk is the box could break apart, both into large pieces and small pieces that can scatter. Safety glasses are a must. Since the payload box was made of fiberglass and epoxy, a blast shield may be needed if the box experiences too much degradation during the test. Also, depending on the drop height, the test may need to be done in a large space and/or outside, so care should be taken to make sure the landing area is blocked off from any people. Also, a variety of measuring tools are necessary to measure the height and deflection of material.

Discussion

The impact force was estimated to be 15.29 lbf (68.03 N). The sphere chosen was a 1 in. diameter plain steel ball that weighed 66.2 g. Therefore, using three spheres of the same size and weight would mean the drop height should be 21.3 ft. (6.54 m). The three spheres were kept together in a pouch so that their combined weight impacted the box at the same time.

II: STABILIZATION TEST

Summary

Due to the lack of detailed documentation on high-altitude balloon attachment stabilizing, and the uncertainty of just how the payload box will be affected up in the atmosphere, designing a way to attach the box to the weather balloon hookup proved to be a challenge. Because of this, it was decided that one of the tests for the project would involve trying different attachment designs to get an idea on which design had more potential. In this test, the box was attached to a paracord in different configurations to see which one would make it tilt the least and recover from disturbance the fastest. A video camera recorded the box while it was disturbed in some fashion. The footage was then analyzed to measure the angle of tilt and how long it took to recover from simulated turbulence. The requirements from the proposal state the angle of tilt should be no more than 15° in the x, y, and z axes.

Time and Location

The test was done on Monday, April 24, 2017 in room 211 in Hogue Hall with fellow MET student Roxy Roque's assistance.

Required Resources

The test requires a paracord, a lightweight rod that should not exceed the length of the payload box by more than an inch on both sides, a video camera, and a straight line behind the box that is lined up with the view of the camera. The line should be as straight as possible; use a ruler and leveler to assist in this. A tripod should be used to make sure the camera is level with the line and box while sitting straight. The paracord will need to hang so that the bottom of the payload box is not touching any surface. The payload box cannot bounce off the walls or any obstacles from the sides. Wind, vibrations, and other environmental elements should also be avoided so that the simulated turbulence and disturbances can be 100% controlled by the user. The test is easier to do with two people: one to simulate the turbulence, and another to operate the camera to make sure the straight line and the box are in perfect alignment with the camera lens. After the test, computer software to analyze the angle of tilt in the video images is required.

Both Windows and Mac computers have software that allows the user to measure or calculate the tilt angle.

Steps

1. Plan different balloon attachment configurations. Make sure the necessary supplies are available for the test: cord, rods, or any attachment hardware that your designs demand.
2. Mark a straight line on a wall behind where the box will hang. Use a ruler and/or leveler to help the straightness.
3. Set up a video camera so that it is level with the straight line. Keep the height of the camera the same throughout all tests.
4. Hook up the payload box in one of the designed configurations. Adjust the height of the box so that the bottom will line up with the drawn line from the point of the view of the camera. In other words, both the line and the bottom of the box should be visible in the camera.
5. Simulate several disturbances while the camera films the box. Make sure the box has settled down and returned to a static equilibrium before simulating another turbulence.
6. Once about three or five simulations have occurred, take down the box and set up a different designed configuration. Then repeat steps 4 and 5 for each of the designs you have.
7. After testing, transfer the video files to a computer. Time how long it takes for the box to return to static equilibrium after each disturbance. Also, measure the maximum angle of tilt the box experiences in each simulation. To do this, take a screenshot of the moment the box experiences its maximum angle of tilt, and measure the angle of tilt with a ruler using software tools. If the software to do this is not available, another method is to take the screenshot and draw a triangle of the box and the straight line. If the lengths of the two sides are known, an angle can be calculated instead of measured.

Risk, Safety, and Evaluation Readiness

Safety glasses are not needed for this test, but it is possible for the box to damage people if dropped or swung with enough force. When hanging the box up and simulating turbulence, keep this in mind so that no one is whacked in the head with the box. A camera that can record video footage is also necessary for the test. A photography camera is not sufficient because it is too difficult to snap a photo of the box during simulation to capture its maximum angle of tilt.

Discussion

The required angle of tilt meant the box was not allowed to exceed a tilt of more than 15° in the x, y, and z axes. Two different design configurations were tested: one that had the paracord connecting from the four corners of the box to a single point; and one that had the paracord connecting from the four corners of the box to two points on a rod, with the rod then connecting from one point to the rest of the paracord line. In testing, design one was designated “To Point,” and design two was labeled “Rod.”

D: Deliverables

For the impact test, three tests with three trials each were conducted using either one sphere, two spheres, or three spheres, all with the same drop height of 21.3 ft. Using three spheres dropped at once, which had a combined weight of 201 g, the predicted impression they would make on the box would have a width of 0.300 in. and a depth of 0.100 in. In actuality, very minimal damaged was experienced with all three tests. The largest amount of damage occurred with three balls at a combined weight of 201 g. The dent had a width of 0.627 in and a depth of 0.066 in. Weight vs width and weight vs depth were both plotted to demonstrate the damage measured during the test, as seen under Appendix H.

The predicted angle of tilt for the stabilizing test was about 20° in the x, y, and z axes, and was predicted to take a minute to return to static equilibrium. After analyzing the video for both tests, it appears that the "To Point" design had slightly better recover time and less angle of tilt than the "Rod" design. The average angle for the first test was 13.1° and a recovery of 28 seconds, while the second test had an average angle of 14.2° and a recovery time of 36 seconds. Time vs angle were plotted for both the knot "To Point" and "Rod" designs, which are under Appendix H.

5: BUDGET, SCHEDULE, AND PROJECT MANAGEMENT

A: Proposed Budget

I: Part Suppliers & Substantive Costs

The most expensive part of the project was the material requirements. Most of the instruments and other electronic components was be purchased and provided by other members of the CWU Near Space Observation team, allowing the budget for this project to focus mainly on the payload box construction. Also, many of these supplies can be purchased using grant money Dr. Snowden had received from NASA to fund the high-altitude balloon project.

The fiberglass and epoxy supplies for the fabrication were purchased for around $78 from Fibre Glast. The foam was donated by MET student Seth Rich, and the miscellaneous other supplies required to do the fabrication were either on hand in the Science II physics building on campus, or rather inexpensive to purchase from a local ACE Hardware store.

Some electronic components were purchased for this project, particularly those involving the design of the imaging platform. This part of the project was the second most expensive aspect, though most components were found for under $20 or available to use on campus. The camera, for example, was already purchased by Dr. Snowden prior to the high-altitude balloon project, and will be utilized inside the payload box. The electronics were mainly purchased on Adafruit or Spark Fun Electronics online.

These and other parts and supplies are summarized under Appendix C and D.

II: Labor

Labor was be done on campus by the principle-engineering student, with assistance provided by faculty and staff from both the Science II building and Hogue Hall. Technicians Addison Wenger and Peter Zencak were a big help during the construction stage of the project, which took place in the Science II building on CWU campus. Dr. Snowden also provided much assistance and advice when designing and planning the electronic components of the project.

III: Estimated Total Project Costs

The entire project was estimated to cost $351, with solely the parts of the payload box costing $270. After construction was completed for the payload box prototype in winter quarter, the project cost totaled to $325, which is less than the estimated cost. This is below the budget limit of $400.

IV: Funding Sources

Dr. Darci Snowden has recently received a grant from NASA to help fund astronomical research for the Eclipse Balloon Project (organized by Montana State University), and part of the grant went towards this high-altitude balloon project. Therefore, many aspects of the project, such as the 3D printing required to build the imaging platform parts, and the materials necessary to construct the box, were funded with her grant money. Any other aspects of the project that cannot be paid for with Dr. Snowden’s grant money were paid for by the principle engineer.

B: Proposed Schedule

The payload box construction and testing is confined to the time allotted by the MET 495 course at Central Washington University, which gives a deadline for the last week of the third quarter (the week of June 4 through 10, 2017). The Near Space Observation team advised under Dr. Snowden has a separate deadline, before August 21, 2017, so that everything involved with the weather balloon project is completed by the summer eclipse. For the eclipse, all experimental equipment must be ready to attach to the balloon, weather balloon tests must be finalized, and the dish satellite used to track the balloon and electronics during the flight must be calibrated and working before the deadline. These aspects, however, are beyond the scope of the project attached to the MET 495 class, which requires that only the payload box and its balloon attachment are completed and functional by the last week of the third quarter.

The MET 495 class further divides the project into three components: proposal, construction, and testing. The proposal involves all the planning and analysis for the project; calculations, drawings, and modelling; construction and testing preparation; budgeting and scheduling drafted; and a report summarizing these components. The analysis is all due by the last week of the first quarter, which is the week of December 4 through 10, 2016. The second quarter allows time for the entire payload box, and any attachments to the balloon, to be purchased and/or constructed, with a deadline of the last week of the second quarter (March 5 through 11, 2017). The imaging platform for the camera will also be constructed then, and everything in the payload box will need to be balanced (based on the center of mass). Then, with testing planned in the first and second quarter, testing can now be implemented during the third quarter. This helps finalize the design of the project, which is due in its entirety on the last week of the third quarter (June 4 through 10, 2017).

The schedule for all three quarters is summarized in a Gantt chart in Appendix E, which gives an estimated total project time of 684 hours. Note that the long hours are due to adding in an estimate time for fabricated materials to dry and 3D printed parts to be printed.

C: Project Management

Part of what adds to the total project time is the actual box construction, as the different material layers will require hours of time to dry before a new layer can be applied. Due to both the expense and the lengthy time required to apply the materials, extra care must be taken to apply everything right the first time, so test strips will probably be constructed first both as practice and for testing purposes. Care must also be taken in not inhaling any fumes involved in the material construction, like from the epoxies, and following ASME safety standards.

Material acquisition will also be challenging, to both afford and order the products on time and to make sure the material properties are ideal for the application. However, some parts can be donated, and Dr. Snowden’s grant money will help with the large ticket items.

Test equipment will be made available by Matt Burvee, Dr. Craig Johnson, Prof. Charles Pringle, Prof. Greg Lyman, and Dr. Darci Snowden, and then utilized by the principle engineer, whose resume is show in Appendix J. Testing equipment consists of using the impact testers in Hogue Hall, a high-speed camera from the physics department in Science II, and electronic sensors such as an accelerometer from either Prof. Lyman or Dr. Snowden that will record data during testing.

6: DISCUSSION

A: Design Evolution and Performance Creep

The design of the payload box was influenced by the many testing options the CWU Near Space Observation team had to their disposal. Did they want to test atmospheric conditions during the weather balloon launch, photograph the eclipse during the flight, or analyze the magnetic field? When the decision landed on photography, the group then had to decide what specifically they wanted. Did they want to add filtration to the lenses, use a specialized camera, and/or utilize more than one camera on each side of the box? It was decided that there should be a rotating table inside the payload box that would shift the camera depending on the angle of the sun at that moment of the flight, and then afterwards a camera model was decided. The camera model influenced how big the opening in the box needed to be to ensure the lens could see through it.

It was difficult to pinpoint how the box material would deflect based on the impact it would have with the ground when the box landed after the flight. This influenced the design in several ways beyond simply how thick the box should be. Should only one material be utilized, or should different layers of material be used to help protect the box's contents from impact? Should spring bracing be added to the outside, or a circular shape made of carbon poles to help cushion the box during the fall? Finally, it was decided, because of the rotating camera sitting inside the box, that the design should be simplified to merely the box with differing layers of fiberglass and foam material making up the panels to insulate during impact. More analysis was done during the testing stage to ensure that this material selection can withstand the impact forces involved in the fall, and if more insulation is necessary for the box to remain reusable.

B: Project Risk Analysis

The most important design requirement is that the payload box should be reusable for multiple flights. To ensure the box can, indeed, be reusable, more analysis will occur during the construction and testing stages in the second and third quarter. This involves purchasing or acquiring extra material to create test strips and smaller box models to see if the panels can withstand the impact force as estimated in the calculations. Testing will also need to be applied to the actual payload box once it is constructed to ensure the box retains the same structural strength as estimated. A separate apparatus may need to be built (to perhaps attach to the balloon stability attachment) to further protect the box if tests turn up negative results, or more foam padding may need to be added to the outside.

C: Successful

The success of the project is dependent on the payload box being fully assembled and ready for the weather balloon launch by June 2017, though the actual launch will not occur until August 21, 2017. The payload box must meet all design requirements, including being below the weight limitations, able to withstand impact during the fall, remain reusable, and thermally protected so the scientific instruments remain functioning throughout and after the flight. Even after the official project due date, more work can be done to improve the reusability of the payload box, including making it lighter and cheaper to construct, and simplifying the process for others to reproduce for other weather balloon experiments if they so choose.

D: Project Documentation

Project documentation is organized in this report as well as on a website created and edited during the entire design, construction, and testing process (URL: http://libertyss.wixsite.com/metseniorproject). The weather balloon project, with an emphasis on the physics involved, will further be documented by Griffin Running and Berlie Walker, and presented at SOURCE during spring quarter at Central Washington University. The Near Space Observation team also has their own website to document progress and challenges faced along the way for the weather balloon project (URL: https://sites.google.com/view/cwunearspaceteam/home).

E: Next Phase

The next phase of the project involves going down to the outskirts of Madras, Oregon to launch the payload box attached to the weather balloon under real-life conditions for the August 21, 2017 solar eclipse. The project will be a huge success if everything inside the box remains protected during the launch and after it lands. If reusable, the box will remain with the physics department for future experiments, and the design can be further improved upon based on feedback for the engineering project and after the weather balloon launch.

7: CONCLUSION

To aid in a weather balloon project, advised by Dr. Darci Snowden, a payload box was analyzed and designed to meet the design requirements of a more typical payload container for weather balloon experiments. This meant that the box could hold and protect scientific instruments inside during the flight and when it lands on the ground. Then further engineering was added to the project to make the payload box reusable, as most payload containers are good for only one flight before being discarded. The box still needed to remain cheap and lightweight while having good impact resistance and thermal protection from the cold. Based on analysis of different materials, it was found that making the box 2 cm thick with fiberglass material would ensure it could withstand the impact force of 15.29 lb. with the ground while remaining under the weight limit of 3 lb.

All the parts and materials necessary to construct the payload box have been researched, sourced, summarized in the Appendices, and budgeted per the funds available for the project. Costs can be further reduced if using donated resources available at Hogue Hall and Science II. How the project will be constructed, as well as tested and analyzed afterwards, has also been organized and planned, and is doable with the resources available from Hogue Hall and Science II.

8: ACKNOWLEDGEMENTS

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10: APPENDIX A – ANALYSIS

Figure A-1: Descent velocity and time, 1 of 2 (GS1)

GS1 | Shellbie Liberty | Senior Project | 10/25/16 | 1/2

GIVEN: Payload + box mass = 1360g
Parachute mass = 190g
$\varnothing$ = 1.5m] high altitude science.com
Parachute Cd = .75 ("The Mathematics of Flat Parachutes")

FIND: Descent rate + time

SOL'N: Max. predicted balloon burst height for 1200g balloon (highaltitudescience.com product info) = 120,008ft = 36576m

Air Density, ρ (engineeringtoolbox.com)

@ sea level: $g = 9.708\frac{m}{s^2}$ $\rho = 1.225\frac{kg}{m^3} = 1225\frac{g}{m^3}$

@ 36576m: 40,000m $g = 9.684\frac{m}{s^2}$ $\rho = .003996\frac{kg}{m^3} = 3.996\frac{g}{m^3}$

30,000m $g = 9.715\frac{m}{s^2}$ $\rho = .01841\frac{kg}{m^3} = 18.41\frac{g}{m^3}$

$$g = 9.684 + (36576 - 30,000)\left(\frac{9.715 - 9.684}{40,000 - 30,000}\right) = 9.704\frac{m}{s^2}$$

$$\rho = 3.996 + (36576 - 30,000)\left(\frac{18.41 - 3.996}{40,000 - 30,000}\right) = 13.475\frac{g}{m^3}$$

@ 60,000 ft = 18,288m: 20,000m $g = 9.745\frac{m}{s^2}$ $\rho = .08891\frac{kg}{m^3} = 88.91\frac{g}{m^3}$

15,000m $g = 9.761\frac{m}{s^2}$ $\rho = .1948\frac{kg}{m^3} = 194.8\frac{g}{m^3}$

$$g = 9.745 + (18,288 - 15000)\left(\frac{9.761 - 9.745}{20,000 - 15,000}\right) = 9.756\frac{m}{s^2}$$

$$\rho = 88.91 + (18288 - 15000)\left(\frac{194.8 - 88.91}{20,000 - 15,000}\right) = 158.5\frac{g}{m^3}$$

$$D_p = \frac{2gm}{\rho C_d v^2} \Rightarrow v = \sqrt{\frac{2gm}{\rho C_d D_p}}$$ ("The Mathematics of Flat Parachutes")

$$D_p = \frac{\pi D^2}{4} = \frac{\pi (1.5m)^2}{4} = 1.767m^2$$

Total mass = 1360g + 190g = 1550g

Velocity @ 120,000ft

$$v = \sqrt{\frac{2\left(9.704\frac{m}{s^2}\right)(1550g)}{13.475\frac{g}{m^3}(.75)(1.767m^2)}}$$

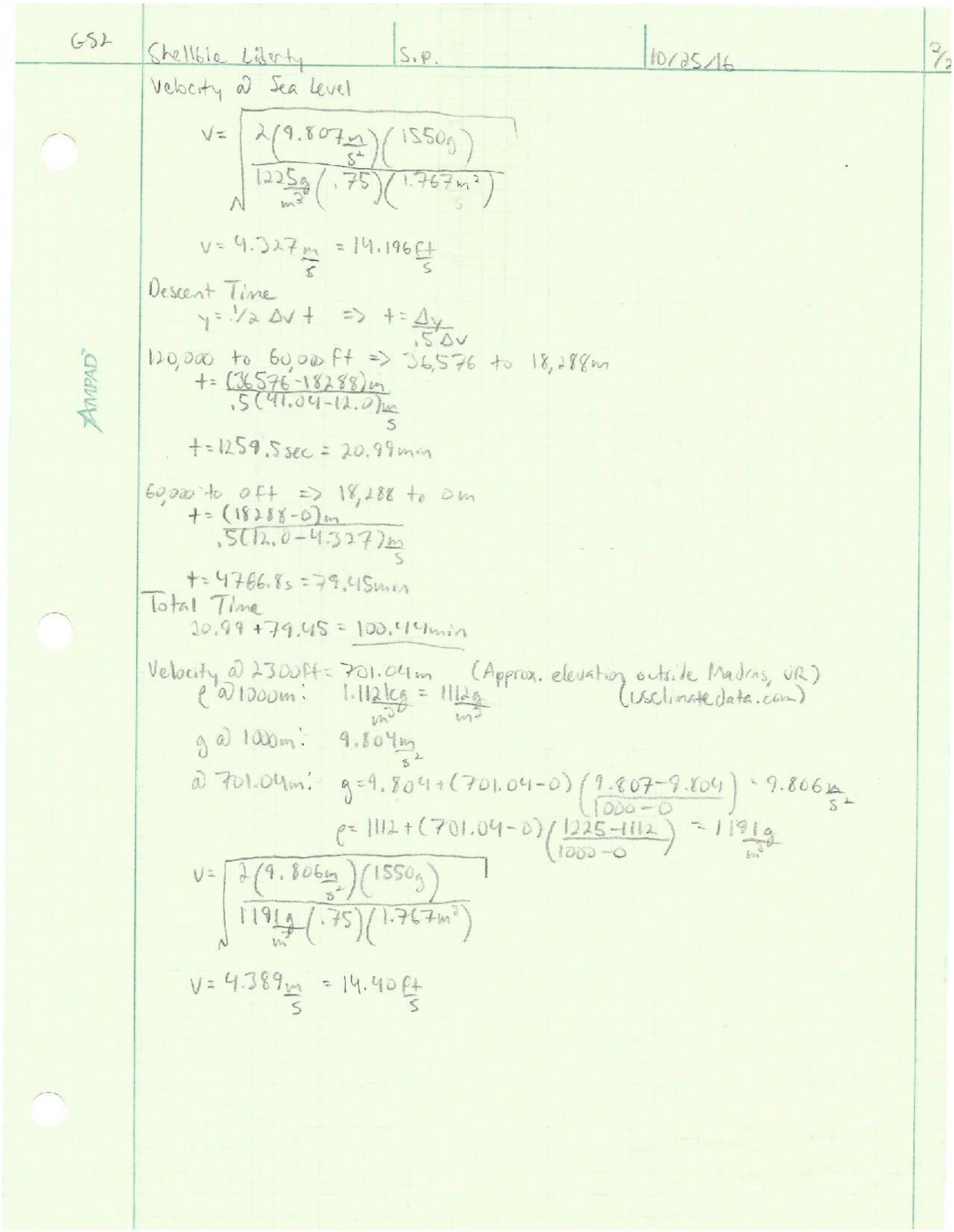
$$v = 41.04\frac{m}{s} = 134.65\frac{ft}{s}$$

Velocity @ 60,000ft

$$v = \sqrt{\frac{2\left(9.756\frac{m}{s^2}\right)(1550g)}{158.5\frac{g}{m^3}(.75)(1.767m^2)}}$$

$$v = 12.0m/s = 39.368ft/s$$

Figure A-2: Descent velocity and time, 2 of 2 (GS2)



GS2 | Shellbie Liberty | S.P. | 10/25/16 | 2/2

Velocity @ Sea Level

$$V = \sqrt{\frac{2\left(9.807\frac{m}{s^2}\right)(1550g)}{1225\frac{g}{m^3}(.75)\left(1.767m^2\right)}}$$

$V = 4.327\frac{m}{s} = 14.196\frac{ft}{s}$

Descent Time

$y = \frac{1}{2}\Delta v t \Rightarrow t = \frac{\Delta y}{.5\Delta v}$

120,000 to 60,000 ft => 36,576 to 18,288m

$$t = \frac{(36576 - 18288)m}{.5(41.04 - 12.0)\frac{m}{s}}$$

$t = 1259.5\,sec = 20.99\,min$

60,000 to 0 ft => 18,288 to 0 m

$$t = \frac{(18288 - 0)m}{.5(12.0 - 4.327)\frac{m}{s}}$$

$t = 4766.8s = 79.45\,min$

Total Time

$20.99 + 79.45 = 100.44\,min$

Velocity @ 2300ft = 701.04m (Approx. elevation outside Madras, OR)

ρ @ 1000m: $1.112\frac{kg}{m^3} = 1112\frac{g}{m^3}$ (usclimatedata.com)

g @ 1000m: $9.804\frac{m}{s^2}$

@ 701.04m: $g = 9.804 + (701.04 - 0)\left(\frac{9.807 - 9.804}{1000 - 0}\right) = 9.806\frac{m}{s^2}$

$\rho = 1112 + (701.04 - 0)\left(\frac{1225 - 1112}{1000 - 0}\right) = 1191\frac{g}{m^3}$

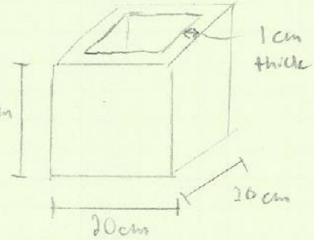
$$V = \sqrt{\frac{2\left(9.806\frac{m}{s^2}\right)(1550g)}{1191\frac{g}{m^3}(.75)\left(1.767m^2\right)}}$$

$V = 4.389\frac{m}{s} = 14.40\frac{ft}{s}$

Figure A-3: Maximum material displacement, 1 of 4 (GS3)

GS3 | Shelbie Liberty | Senior Project | 11/24/16 | 1/4

GIVEN: Payload box weight = 1360g (estimate)
Parachute weight = 190g
(highaltitudescience.com)
Balloon burst height estimate
= 120,000 ft = 1,440,000 in



FIND: Displacement
Material Selection

SOLN: Impact Loading, Mechanics of Materials (9th ed) by Hibbeler, p.737-744

$U_e = U_i$

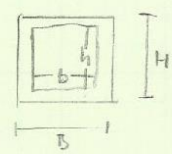
$\frac{1}{2} W \Delta_{st} = \frac{W^2 L}{2AE}$

$\Delta_{st} = \frac{WL}{AE}$ = static displacement

$\Delta_{max} = \Delta_{st}\left[1+\sqrt{1+2\left(\frac{h}{\Delta_{st}}\right)}\right]$ = max displacement

$L = 20cm = 7.874in$

$A = BH - bh$ hollow rectangle



$B = H = 20cm = 7.874in$

$b = h = 18cm = 7.0866in$

$A = (7.874in)^2 - (7.0866in)^2$

$A = 11.78 in^2$

$W = (1360 + 190)g = 1.550kg = 3.41716$

E = Modulus of Elasticity

1. Use E-Glass Fabric, Generic (like Fibre Glast "Style 120 E-Glass")
From matweb.com
$E = 72.4 GPa = 10500 ksi$

$\Delta_{st} = \frac{3.41716(7.874in)}{11.78in^2(10500 \times 10^3 psi)} = 218 \times 10^{-9} in$

$\Delta_{MAX} = 218\times10^{-9} in\left[1+\sqrt{1+2\left(\frac{1440000in}{218\times10^{-9}in}\right)}\right] = .7915in = 2.0104cm$

2. Use Kevlar 49 (like Fibre Glast "KEVLAR Plain Weave Fabric")
From Michigan Tech Dr. John Pilling's homepage
$E = 154 GPa = 22,335.812 ksi$

$\Delta_{st} = \frac{3.41716(7.874in)}{11.78in^2(22335812 psi)} = 102.257\times10^{-9} in$

$\Delta_{max} = 102.257\times10^{-9} in\left[1+\sqrt{1+2\left(\frac{1440000in}{102.257\times10^{-9}in}\right)}\right] = .5427in = 1.378cm$

3. Use Polystyrene, Impact Modified (Styrofoam)
From matweb.com
E = 160 to 812 ksi Use 160ksi

$\Delta_{st} = \frac{3.41716(7.874in)}{11.78in^2(160\times10^3 psi)} = 14.275\times10^{-6} in$

$\Delta_{MAX} = 14.275\times10^{-6} in\left[1+\sqrt{1+2\left(\frac{1440000in}{14.275\times10^{-6}in}\right)}\right] = 6.412in = 16.286cm$

→

Figure A-4: Maximum material displacement, 2 of 4 (GS4)

GS4 | Shellbie Liberty | Senior Project | 11/24/16 | 2/4

4. Use ABS Impact Grade Molded Plastic

From matweb.com

E = 203 to 406 ksi   Use 203 ksi

$$\Delta_{st} = \frac{3.41716(7.874 in)}{11.78 in^2 (203 \times 10^3 psi)} = 11.25 \times 10^{-6} in$$

$$\Delta_{MAX} = 11.25 \times 10^{-6} in \left[1 + \sqrt{1 + 2\left(\frac{1440000 in}{11.25 \times 10^{-6} in}\right)}\right] = 5.692 in = 14.458 cm$$

5. Use Epoxy Carbon Fiber Composite

From matweb.com

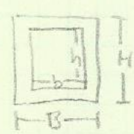
E = 84.8 GPa = 12299,200 ksi   (Average, Grade Cant 19)

$$\Delta_{st} = \frac{3.41716(7.874 in)}{11.78 in^2 (12299200 psi)} = 185.7 \times 10^{-9} in$$

$$\Delta_{MAX} = 185.7 \times 10^{-9} in \left[1 + \sqrt{1 + 2\left(\frac{1440000 in}{185.7 \times 10^{-9} in}\right)}\right] = .7313 in = 1.8575 cm$$

Conclusion: Using materials 1, 2, + 5 preferable.
Alter design to have 2 to 2.25 cm thickness.

2 cm thickness:



B = H = 20 cm = 7.874 in

b = h = 16 cm = 6.299 in

$A = BH - bh = (7.874 in)^2 - (6.299 in)^2$

$A = 22.32 in^2$

Material 1: E-Glass Fabric, Generic

$$\Delta_{st} = \frac{3.41716(7.874 in)}{22.32 in^2 (10500 \times 10^3 psi)} = 114.8 \times 10^{-9} in$$

$$\Delta_{MAX} = 114.8 \times 10^{-9} in \left[1 + \sqrt{1 + 2\left(\frac{1440000 in}{114.8 \times 10^{-9} in}\right)}\right] = .575 in = 1.46 cm$$

Material 2: Kevlar 49

$$\Delta_{st} = \frac{3.41716(7.874 in)}{22.32 in^2 (22335812 psi)} = 53.969 \times 10^{-9} in$$

$$\Delta_{MAX} = 53.969 \times 10^{-9} in \left[1 + \sqrt{1 + 2\left(\frac{1440000 in}{53.969 \times 10^{-9} in}\right)}\right] = .3942 in = 1.001 cm$$

Material 5: Epoxy Carbon Fiber Composite

$$\Delta_{st} = \frac{3.41716(7.874 in)}{22.32 in^2 (12299200 psi)} = 98.0098 \times 10^{-9} in$$

$$\Delta_{MAX} = 98.0098 \times 10^{-9} in \left[1 + \sqrt{1 + 2\left(\frac{1440000 in}{98.0098 \times 10^{-9} in}\right)}\right] = .5313 in = 1.349 cm$$

Conclusion: With any of the 3 materials, 2 cm thickness is okay for design.

→

Figure A-5: Maximum material displacement, 3 of 4 (GS5)

GS5 | Shellbie Liberty | Senior Project | 11/26/16 | 3/4

Looking at Transparent Materials

1. Plexiglas G

From plexiglas.com

$E = 450{,}000\ psi$

$\Delta_{st} = \dfrac{3.41716\,(7.874\,in)}{22.32\,in^2\,(450{,}000\,psi)} = 2.679\times10^{-6}\ in$

$\Delta_{max} = 2.679\times10^{-6}\,in\left[1+\sqrt{1+2\left(\dfrac{1440000\,in}{2.679\times10^{-6}\,in}\right)}\right] = 2.778\ in = 7.056\ cm$

2. Polycarbonate, Optical Grade, Lexan 13

From matweb.com

$E = 2.41\ GPa = 349540.95\ psi$

$\Delta_{st} = \dfrac{3.41716\,(7.874\,in)}{22.32\,in^2\,(349540.95\,psi)} = 3.4486\times10^{-6}\ in$

$\Delta_{max} = 3.4486\times10^{-6}\,in\left[1+\sqrt{1+2\left(\dfrac{1440000\,in}{3.4486\times10^{-6}\,in}\right)}\right] = 3.1515\ in = 8.0048\ cm$

3. Polyimide, Grade Lexan 98

From matweb.com

$E = 6.68\ GPa = 968852.088\ psi$

$\Delta_{st} = \dfrac{3.41716\,(7.874\,in)}{22.32\,in^2\,(968852.088\,psi)} = 1.244\times10^{-6}\ in$

$\Delta_{max} = 1.244\times10^{-6}\,in\left[1+\sqrt{1+2\left(\dfrac{1440000\,in}{1.244\times10^{-6}\,in}\right)}\right] = 1.8927\ in = 4.807\ cm$

4. Polyethylene Terephthalate, Glass/Mineral Reinforced

From matweb.com

$E = 1600$ to $2200\ ksi$ Use $1800\ ksi$

$\Delta_{st} = \dfrac{3.41716\,(7.874\,in)}{22.32\,in^2\,(1800\times10^3\,psi)} = 669.69\times10^{-9}\ in$

$\Delta_{max} = 669.69\times10^{-9}\,in\left[1+\sqrt{1+2\left(\dfrac{1440000\,in}{669.69\times10^{-9}\,in}\right)}\right] = 1.3888\ in = 3.527\ cm$

5. Acrylic, Impact Modified, Molded

From matweb.com

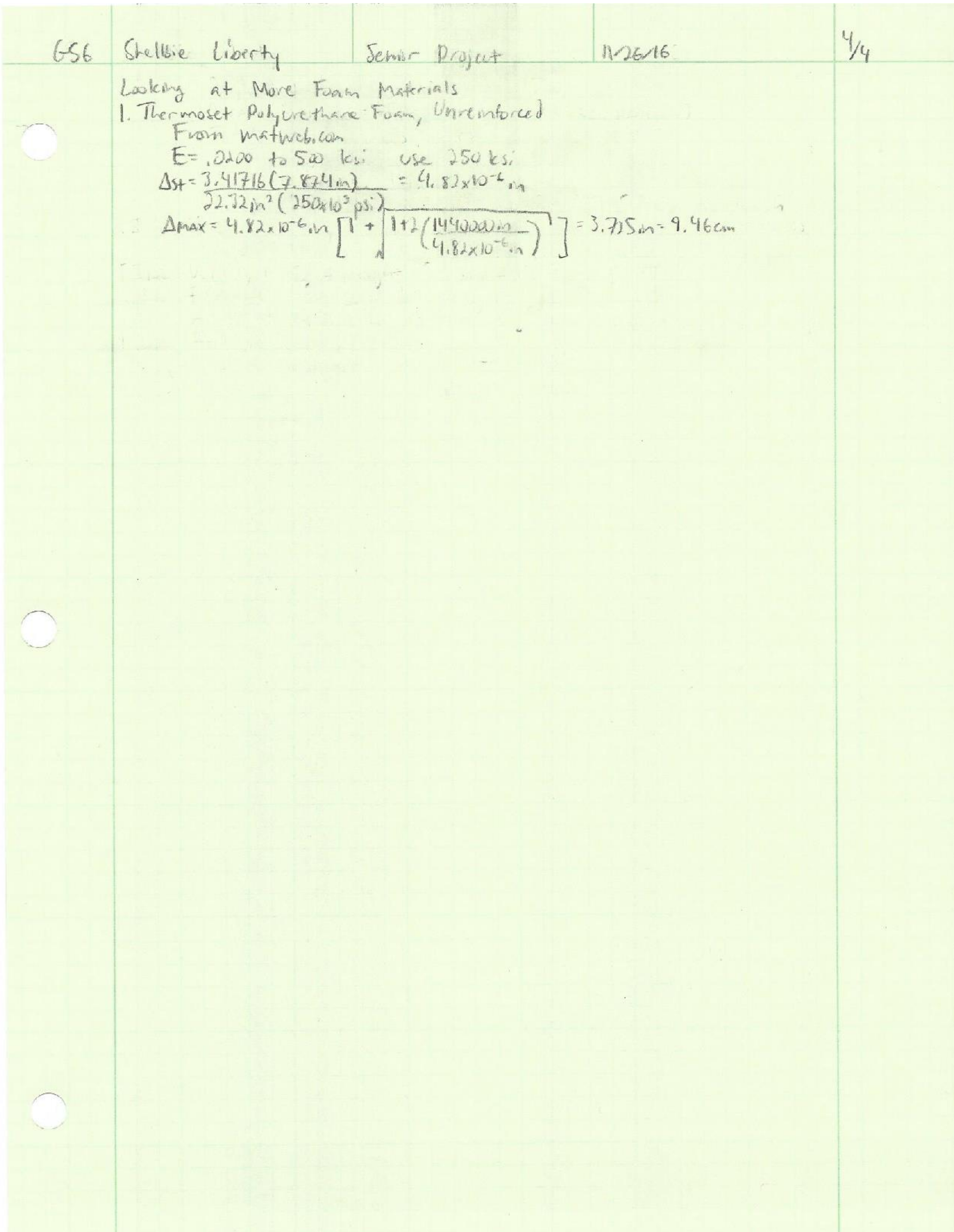
$E = 200 - 510\ ksi$ Use $355\ ksi$

$\Delta_{st} = \dfrac{3.41716\,(7.874\,in)}{22.32\,in^2\,(355\times10^3\,psi)} = 3.396\times10^{-6}\ in$

$\Delta_{max} = 3.396\times10^{-6}\,in\left[1+\sqrt{1+2\left(\dfrac{1440000\,in}{3.396\times10^{-6}\,in}\right)}\right] = 3.127\ in = 7.943\ cm$

Conclusion: Materials 3+4 have the least deflection

Figure A-6: Maximum material displacement, 4 of 4 (GS6)



GS6 | Shellbie Liberty | Senior Project | 11/26/16 | 4/4

Looking at More Foam Materials

1. Thermoset Polyurethane Foam, Unreinforced

From matweb.com

$E = .0200$ to 500 ksi use 250 ksi

$$\Delta_{st} = \frac{3.41716(7.874\,in)}{22.32\,in^2(250 \times 10^3\,psi)} = 4.82 \times 10^{-6}\,in$$

$$\Delta_{max} = 4.82 \times 10^{-6}\,in \left[1 + \sqrt{1 + 2\left(\frac{144000\,in}{4.82 \times 10^{-6}\,in}\right)}\right] = 3.725\,in = 9.46\,cm$$

Figure A-7: Impact force and displacement, 1 of 1 (GS7)

GS7 | Shelbie Liberty | Senior Project | 11/29/16 | 1/1

GIVEN: Payload box weight (estimate) = 1360g

Parachute weight = 190g (highaltitudescience.com)

Launch location around Madras, OR

Elevation ≈ 2300ft = 701.04m (usclimatedata.com)

(Estimate based on elevation average; precise location unknown.)

Impact velocity = $4.389\frac{m}{s} = 14.40\frac{ft}{s}$

FIND: Use best material picks (see GS4)

Impact force

Material displacement

SOLN: Impact Force

$F_{NET} = \frac{\Delta p}{\Delta t} = \frac{mv}{\Delta t}$

Δt = duration of impact; use 0.1sec

$F_{NET} = \frac{(1360+190)g\,(4.389m/s)}{0.1\,sec}$

$F_{NET} = 68.03N = 15.29lbf$

Displacement

$\delta = \frac{PL}{AE}$

Use $A = 22.32 in^2$ (see GS4)

1. Use E-Glass Fabric, Generic

$E = 10500ksi$

$\delta = \frac{15.29\,lbf\,(7.874in)}{22.32in^2\,(10500\times10^3 psi)} = 513.71\times10^{-9}in = 1.305\times10^{-6}cm$

2. Use Kevlar 49

$E = 22335812psi$

$\delta = \frac{15.29lbf\,(7.874in)}{22.32in^2\,(22335812psi)} = 241.49\times10^{-9}in = 613.40\times10^{-9}cm$

3. Use Epoxy Carbon Fiber Composite

$E = 12299200psi$

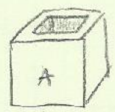
$\delta = \frac{15.29lbf\,(7.874in)}{22.32in^2\,(12299200psi)} = 438.56\times10^{-9}in = 1.114\times10^{-6}cm$

Conclusion: All 3 "best" materials will survive impact w/ design thickness of 2cm.

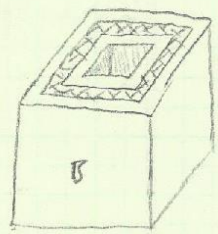
Figure A-8: Payload box mass and weight, 1 of 3 (GS8)

GS8	Shellbie Liberty	Senior Project	11/30/16	1/3

GIVEN: Target mass of payload + box = 1360g
Total box thickness = 2 cm
Shortened thickness to account for material requirements = 1cm
Box dimensions (simplified) = 20 x 20 x 20 cm
Lid dimensions = 20 x 18 x 2 cm
Shortened lid thickness to account for material requirements =
Box volume (t = 2 cm) = 3392000 mm^3 = 3392 cm^3
Box volume (t = 1 cm) = 1,844,000 mm^3 = 1844 cm^3
Lid volume (t = 2cm) = 720,000 mm^3 = 720 cm^3
Lid volume (t = 1 cm) = 360,000 mm^3 = 360 cm^3
(Volume #s from SolidWorks)



2 cm thickness, normal design OR



Layered box for fiber materials; .5cm thick fiber material outside + inside, + some foam material 1cm thick in the middle.

FIND: Total mass + weight of payload box
Estimate using solid box design (Drawing B-8)
Adjust thickness for material requirements, as necessary

SOLN: $m = \frac{\rho}{V}$ $\quad W = mg$

1. Use E-Glass Fabric, Generic (B)
$\rho = 2.54$ to $2.60 \frac{g}{cm^3}$ Use $2.57 \frac{g}{cm^3}$ From MatWeb.com
Use Polystyrene, Impact Modified for middle material
$\rho = .884$ to $2.12 \frac{g}{cm^3}$ Use $1.502 \frac{g}{cm^3}$ From MatWeb.com

$$m = \frac{(2.57 + 1.502)\frac{g}{cm^3}}{(1844 + 360)\,cm^3} = .00185g$$ okay

$$W = .00185g\left(9.81 \frac{m}{s^2}\right) = .0181N$$

2. Use E-Glass Fabric, Generic w/ Thermoset Polyurethane Foam, Unreinforced for middle material
$\rho = .025$ to $1.39 \frac{g}{cm^3}$ Use $.7075 \frac{g}{cm^3}$ From matweb.com

$$m = \frac{(2.57 + .7075)\frac{g}{cm^3}}{(1844 + 360)\,cm^3} = .00149g$$ okay

$$W = .00149g\left(9.81 \frac{m}{s^2}\right) = .0146N$$

Figure A-9: Payload box mass and weight, 2 of 3 (GS9)

GS9	Shellbie Liberty	Senior Project	11/30/16	2/3

3. Use Kevlar 49 (B)
   $\rho = 1.44 \frac{g}{cm^3}$ From Fibre Glast
   Use Polystyrene for middle material
   $m = \frac{(1.44 + 1.502)\frac{g}{cm^3}}{(1844 + 360)cm^3} = .00133g$ okay
   $w = .00133g \left(9.81\frac{m}{s^2}\right) = .0131N$

4. Use Kevlar 49 w/Thermoset Polyurethane Foam, Unreinforced for middle material
   $m = \frac{(1.44 + .7075)\frac{g}{cm^3}}{(1844 + 360)cm^3} = .000974g$ okay
   $w = .000974g \left(9.81\frac{m}{s^2}\right) = .00956N$

5. Use Epoxy/Carbon Fiber Composite (B)
   $\rho = 1.15$ to $2.25 \frac{g}{cm^3}$ Use $1.70 \frac{g}{cm^3}$
   Use Polystyrene for middle material
   $m = \frac{(1.70 + 1.502)\frac{g}{cm^3}}{(1844 + 360)cm^3} = .00145g$ okay
   $w = .00145g \left(9.81\frac{m}{s^2}\right) = .0143N$

6. Use Epoxy/carbon Fiber Composite w/Thermoset Polyurethane Foam for middle material
   $m = \frac{(1.70 + .7075)\frac{g}{cm^3}}{(1844 + 360)cm^3} = .00109g$ okay
   $w = .00109g \left(9.81\frac{m}{s^2}\right) = .0107N$

Conclusion: All materials fit within weight/mass target

Add in window material; simplify window dimensions to 18.5x1.5x.5cm
∴ volume = 13.88 cm^3

1. Polyimide, Grade Cant 98
   $\rho = .00545$ to $1.88 \frac{g}{cm^3}$ Use $.943 \frac{g}{cm^3}$ From matweb.com
   $m = \frac{.943 \frac{g}{cm^3}}{13.88 cm^3} = .0679g$ okay
   $w = .0679g \left(9.81\frac{m}{s^2}\right) = .666N$

Figure A-10: Payload box mass and weight, 3 of 3 (GS10)

GS10 | Shelbie Liberty | Senior Project | 11/30/16 | 3/3

2. Use Polyethylene Terephthalate, Glass/Mineral Reinforced

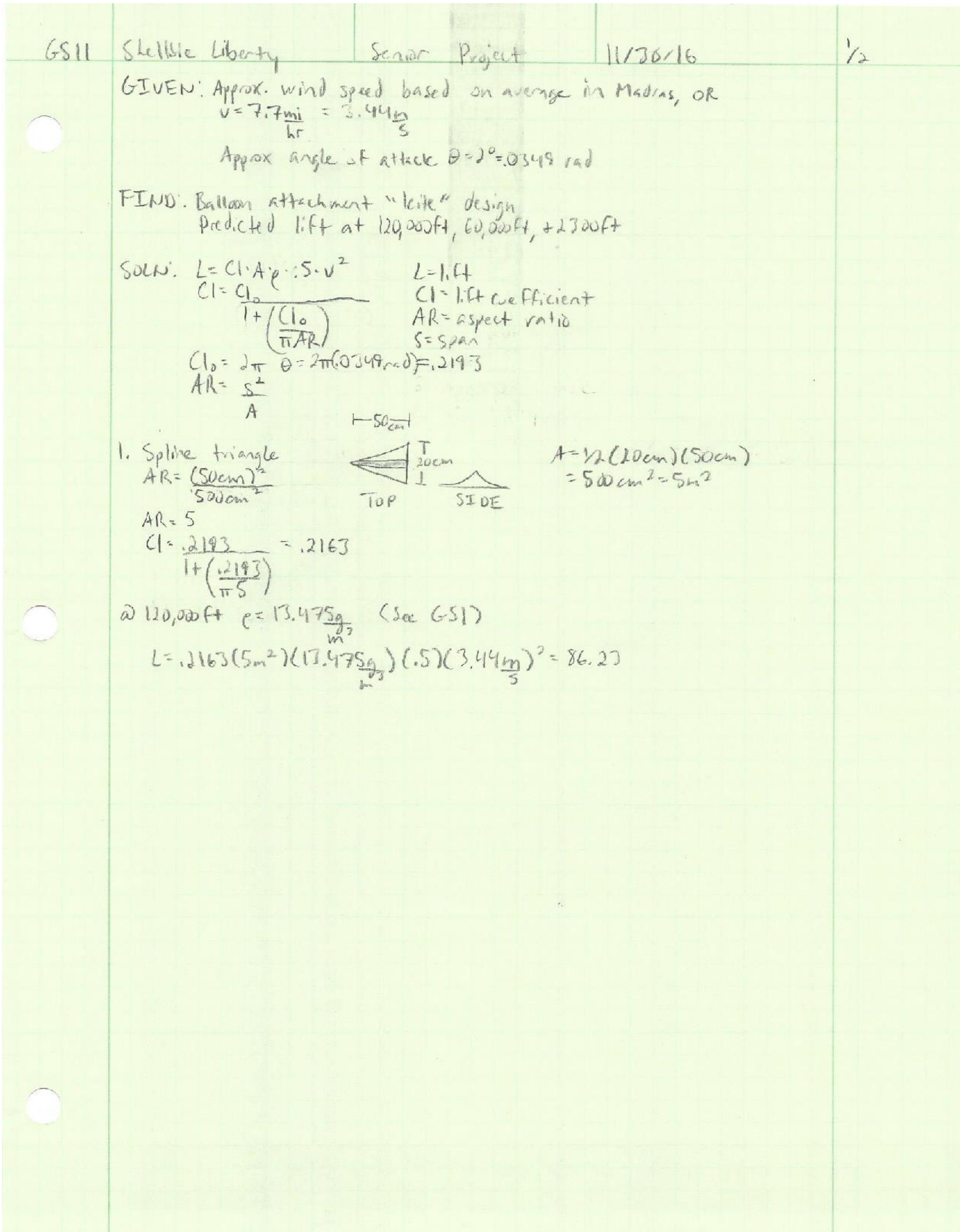
$\rho = 1.42$ to $1.83\frac{g}{cm^3}$ Use $1.625\frac{g}{cm^3}$ From matweb.com

$$m = \frac{1.625\frac{g}{cm^3}}{17.88\,cm^3} = .1171g$$

$$w = .1171g\left(9.81\frac{m}{s^2}\right) = 1.149g$$

Conclusion: Adding window material to existing 6 previously analyzed material combinations still does not exceed target mass/weight.

Figure A-11: Balloon stabilization attachment design, 1 of 2 (GS11)



GS11 | Stellible Liberty | Senior Project | 11/30/16 | 1/2

GIVEN: Approx. wind speed based on average in Madras, OR

$v = 7.7 \frac{mi}{hr} = 3.44 \frac{m}{s}$

Approx angle of attack $\theta = 2° = .0349$ rad

FIND: Balloon attachment "kite" design

Predicted lift at 120,000ft, 60,000ft, +2300ft

SOLN: $L = Cl \cdot A \cdot \rho \cdot .5 \cdot v^2$ L = lift

$Cl = \frac{Cl_o}{1 + \left(\frac{Cl_o}{\pi AR}\right)}$ Cl = lift coefficient

AR = aspect ratio

S = span

$Cl_o = 2\pi\theta = 2\pi(.0349 rad) = .2193$

$AR = \frac{S^2}{A}$

1. Spline triangle

50cm

20cm

TOP SIDE

$A = ½(20cm)(50cm) = 500 cm^2 = 5m^2$

$AR = \frac{(50cm)^2}{500cm^2}$

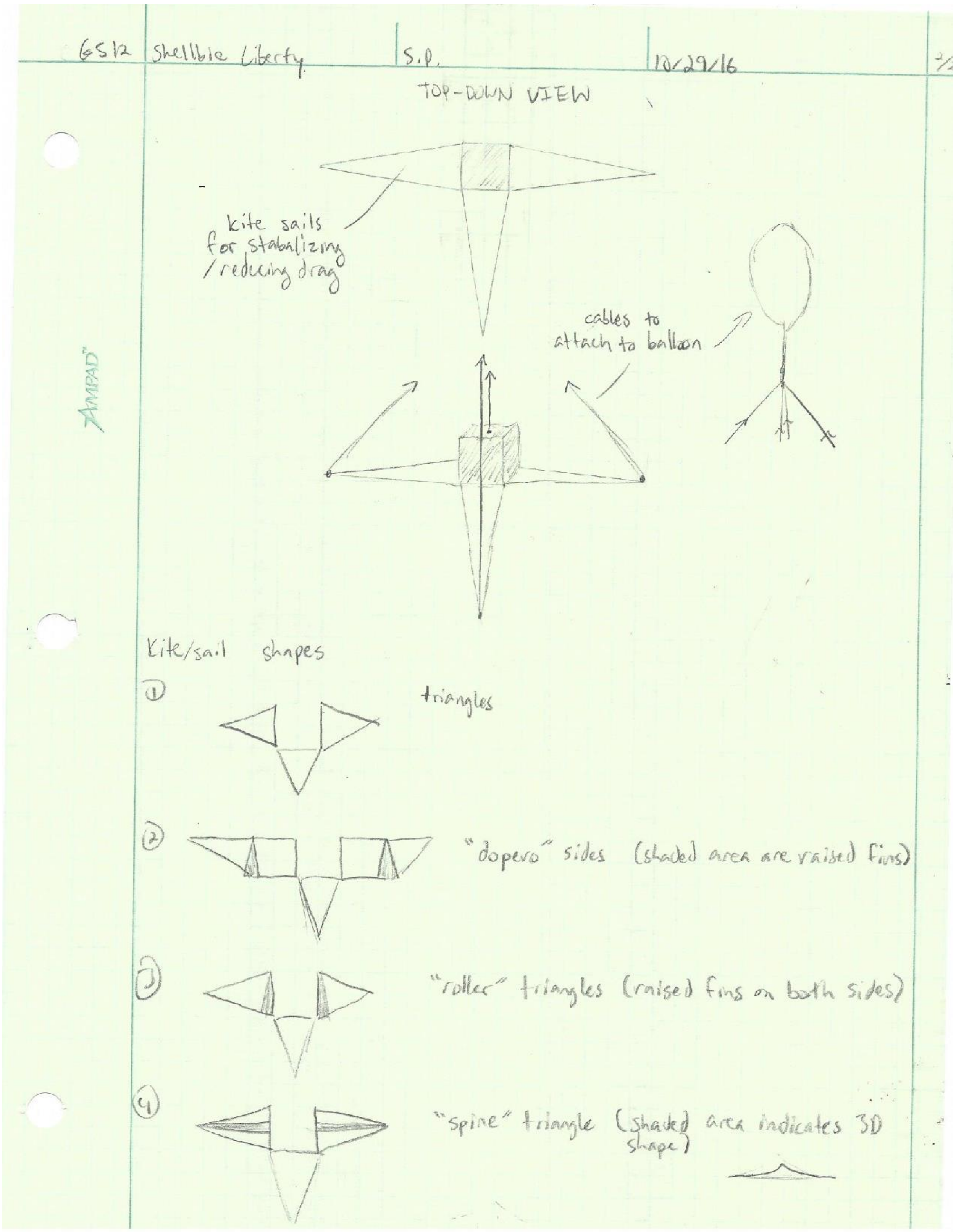
AR = 5

$Cl = \frac{.2193}{1 + \left(\frac{.2193}{\pi 5}\right)} = .2163$

@ 120,000ft $\rho = 13.475 \frac{g}{m^3}$ (See GS1)

$L = .2163(5m^2)(13.475 \frac{g}{m^3})(.5)(3.44 \frac{m}{s})^2 = 86.23$

Figure A-12: Balloon stabilization attachment design, 2 of 2 (GS12)



11: APPENDIX B – DRAWINGS

Figure B-1: Payload box

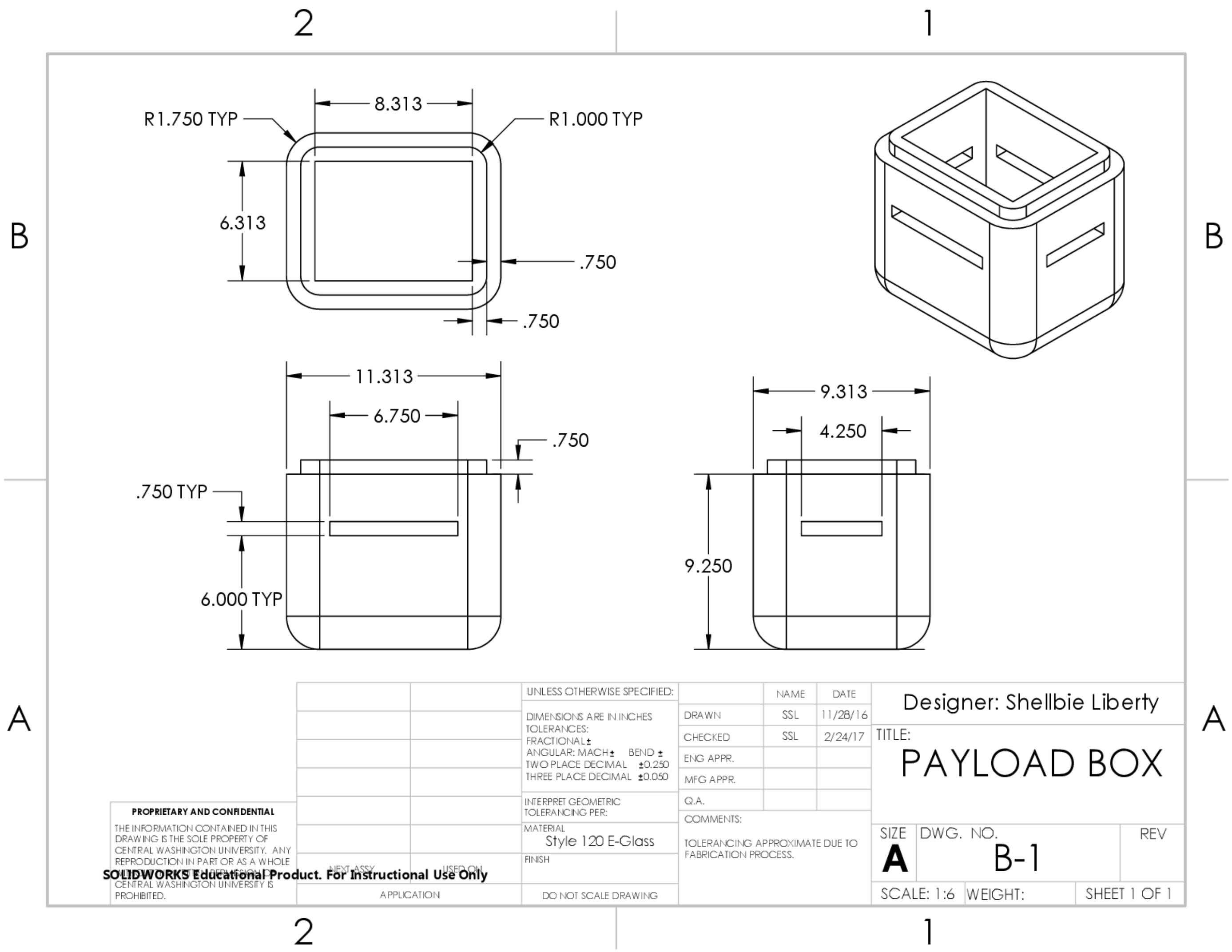


Figure B-2: Payload box lid

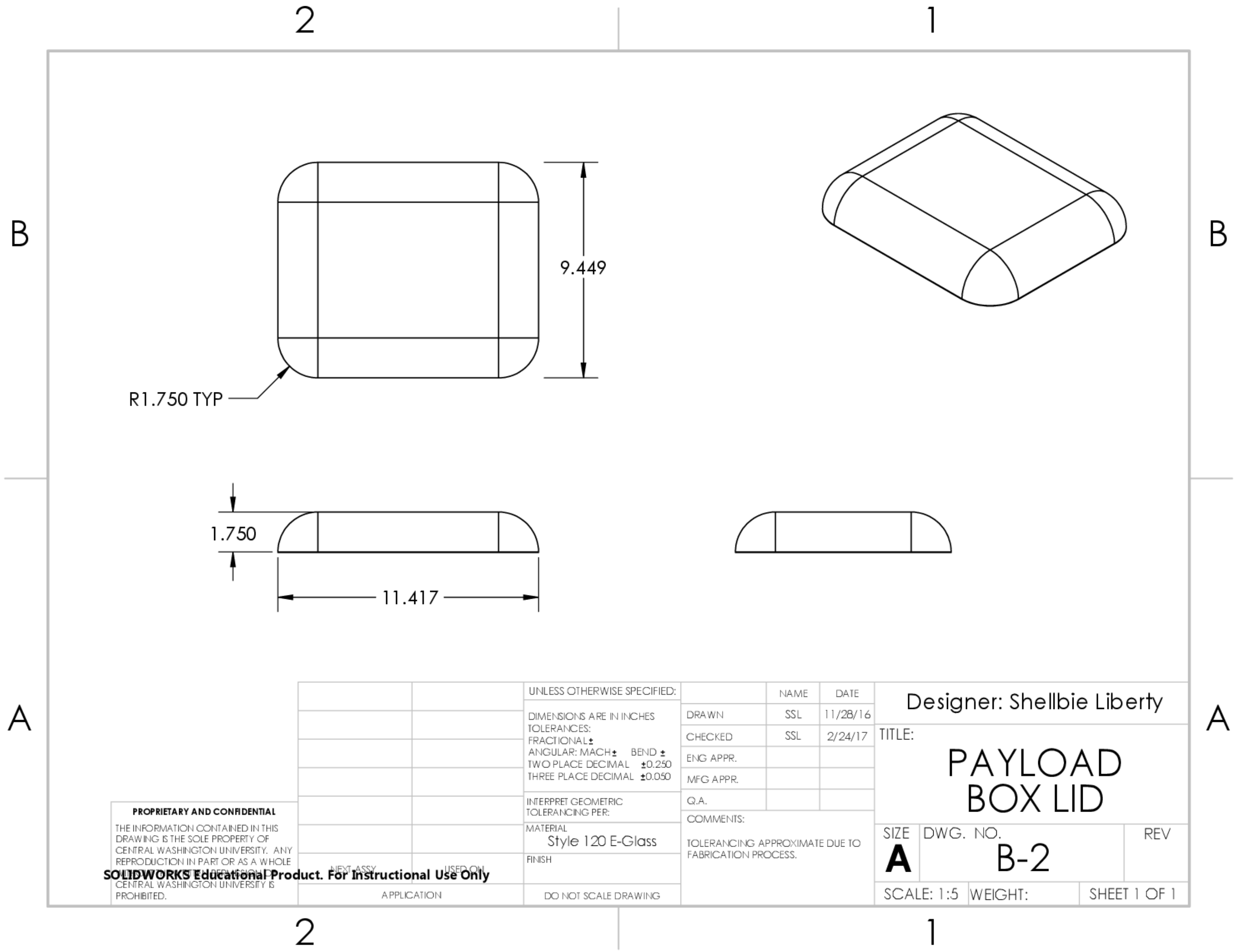


Figure B-3: Camera table

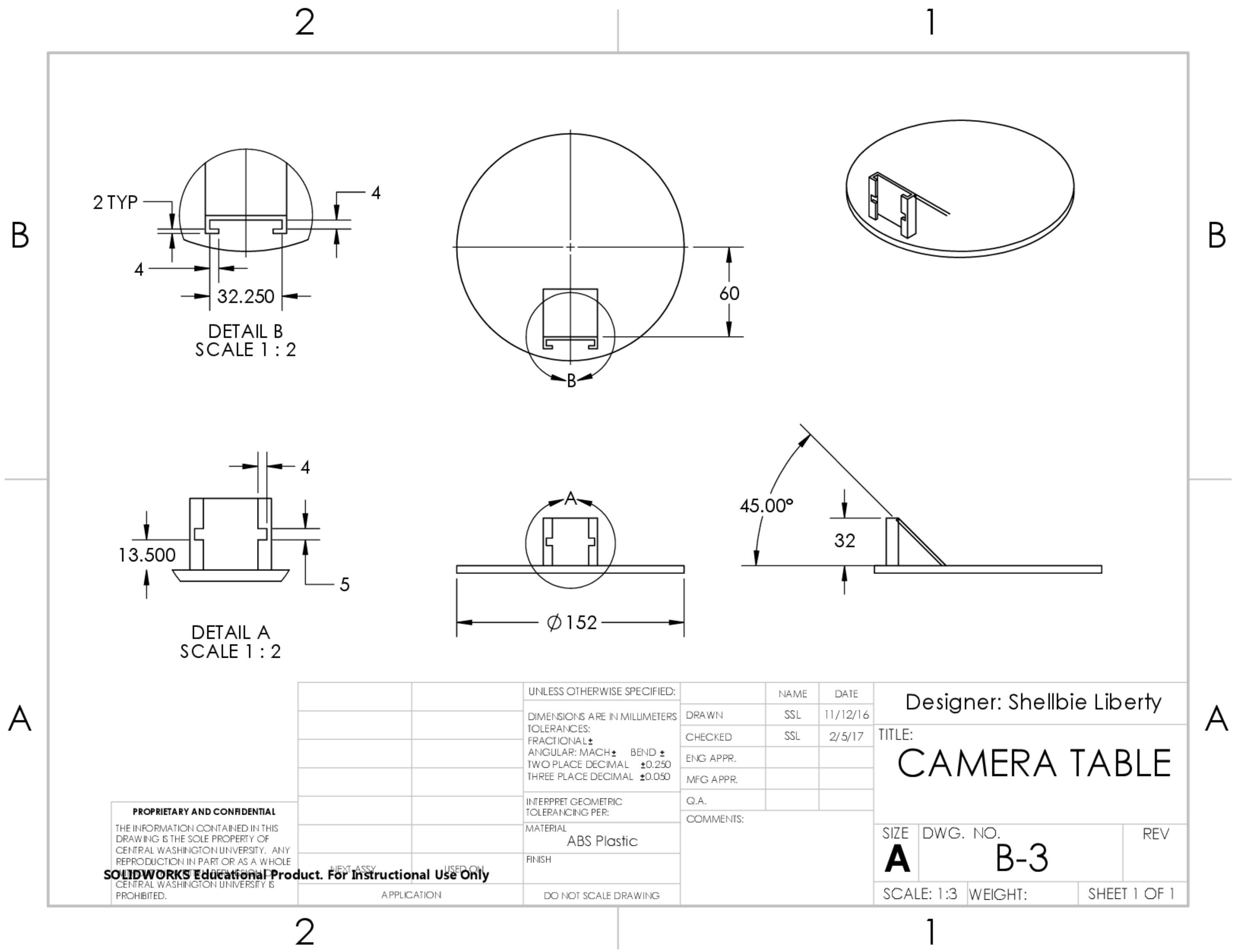


Figure B-4: Motor attachment

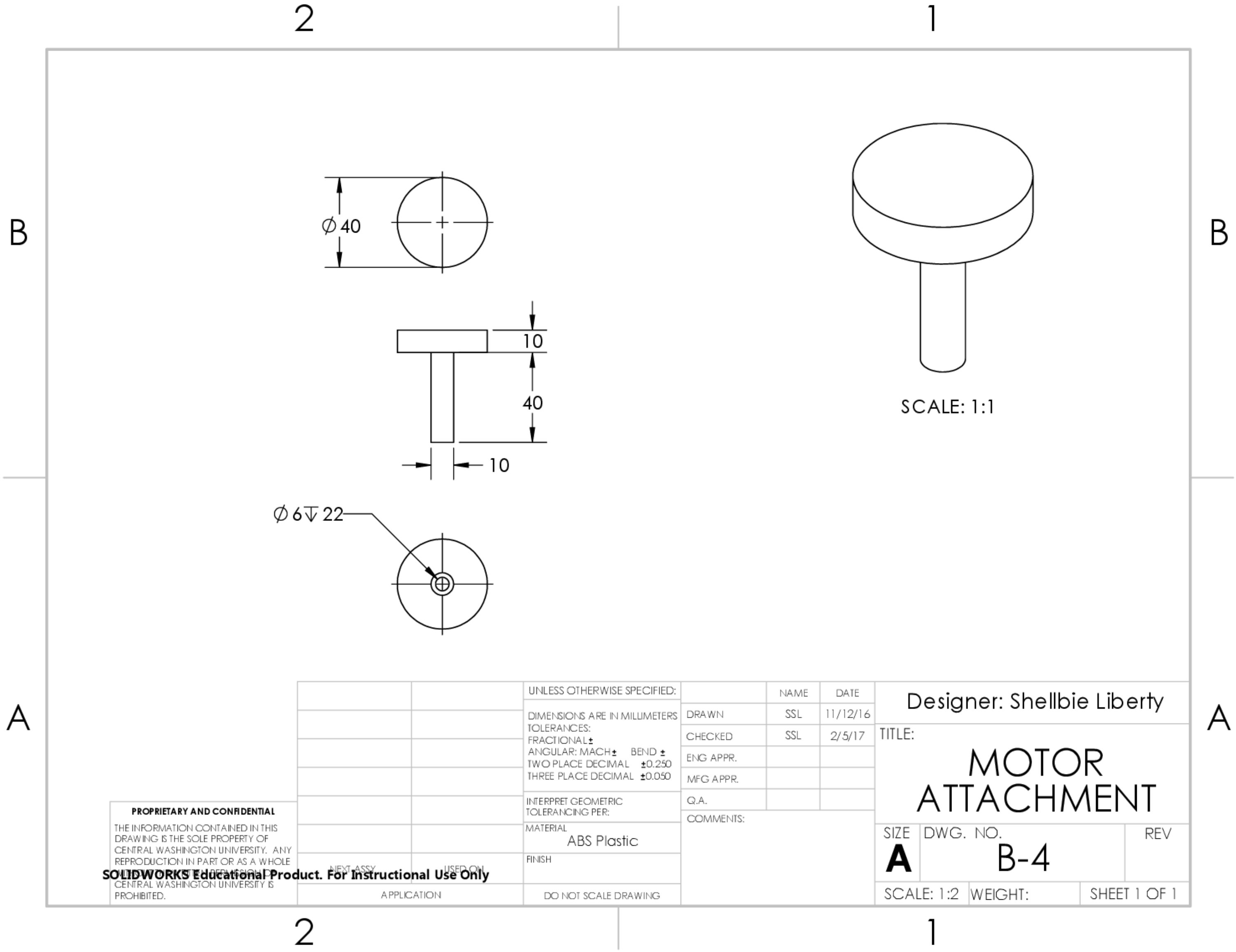


Figure B-5: Imaging platform

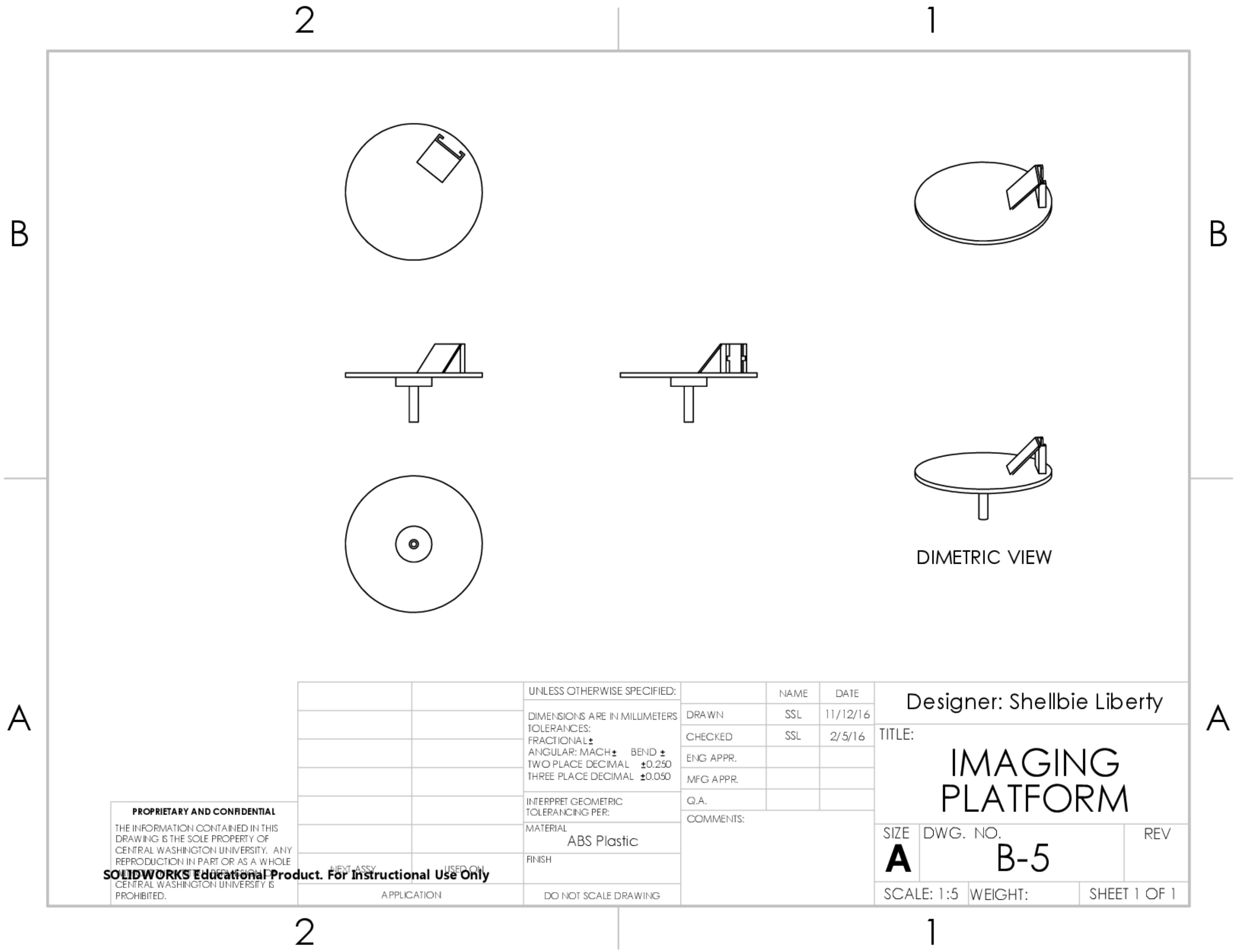


Figure B-6: Payload box assembly

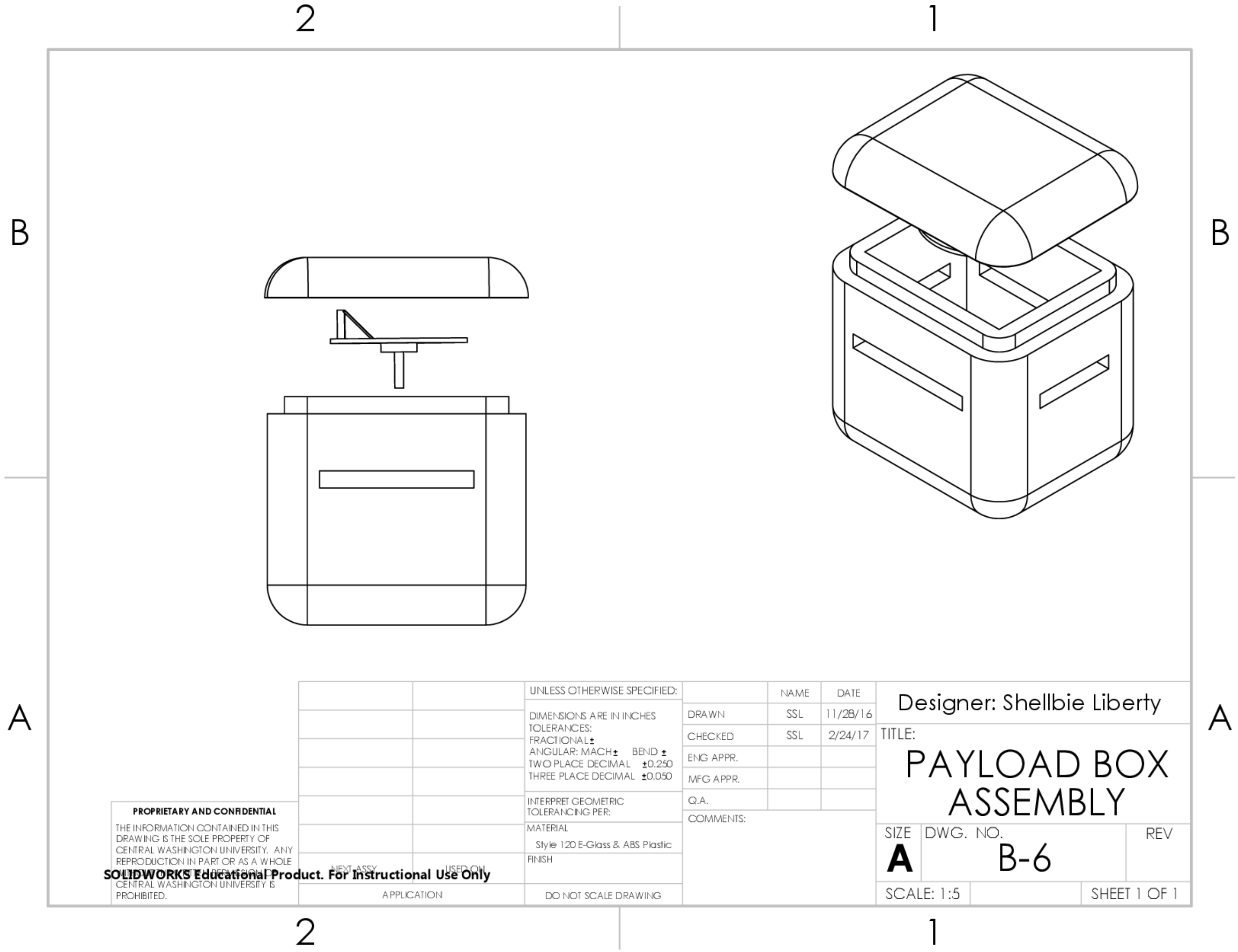


Figure B-7: Payload box, Design 1

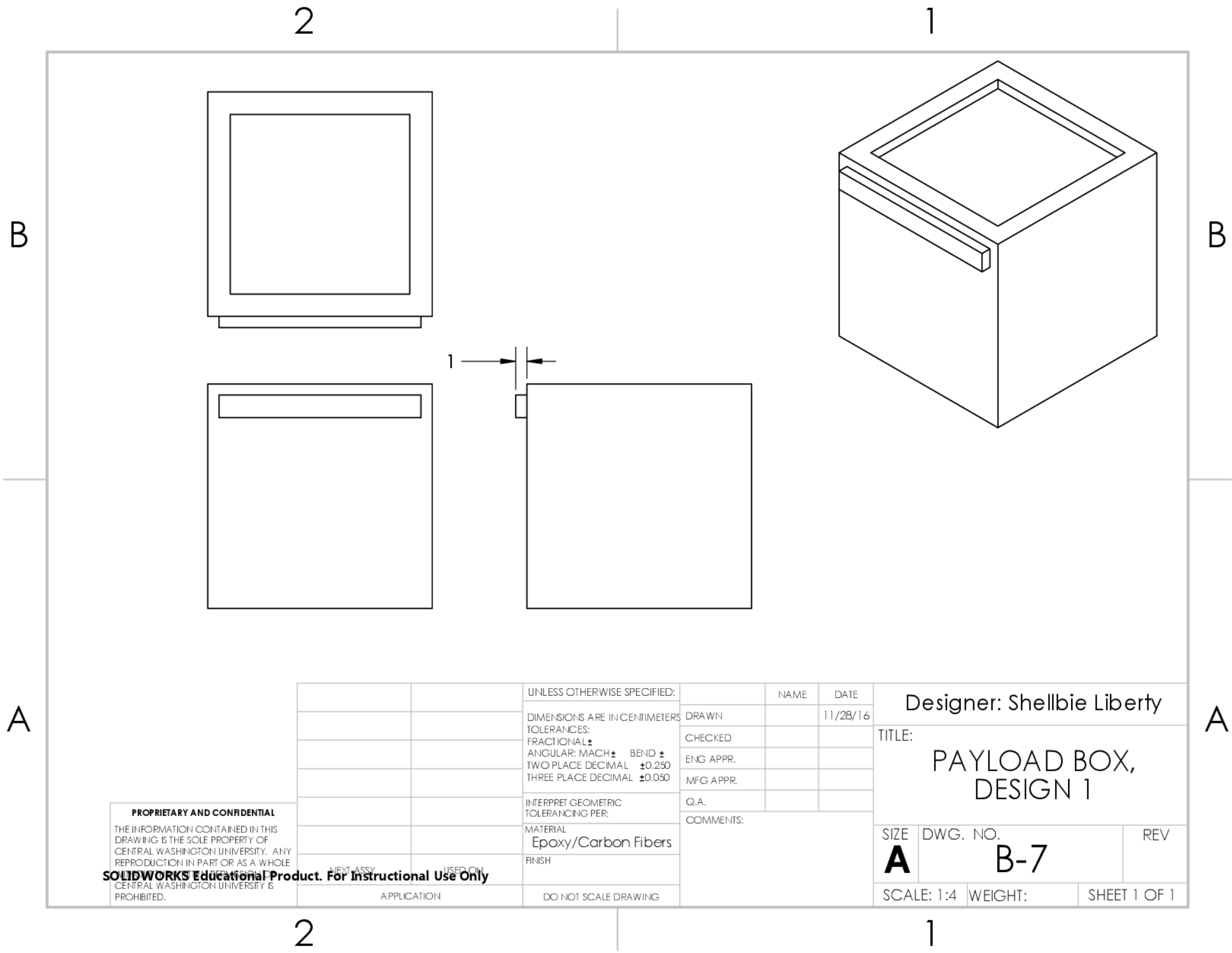
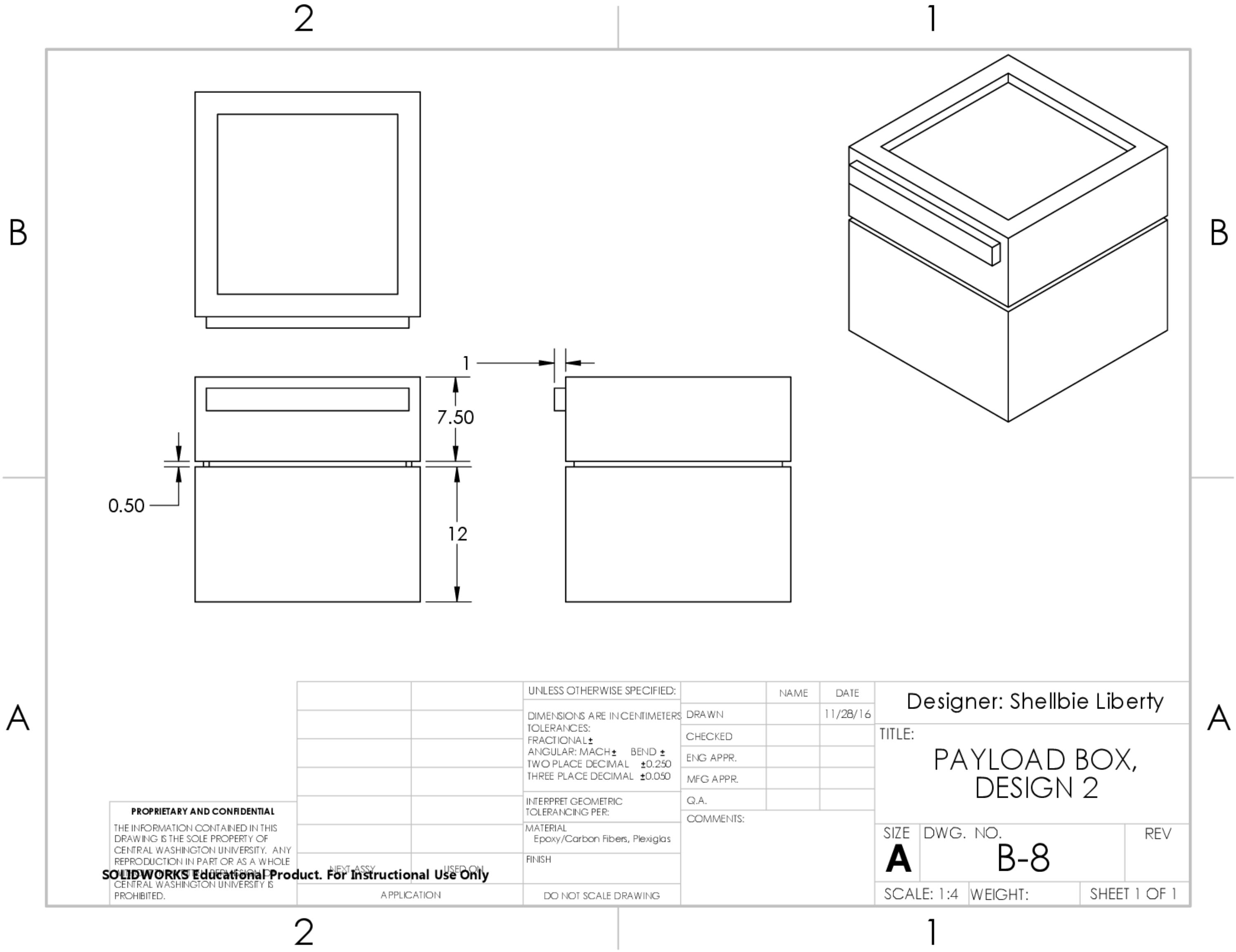


Figure B-8: Payload box, Design 2



12: APPENDIX C – PARTS LIST

Part Ident	Part Description	Source	Cost	Disposition
Arduino	Model Mini R5	Spark fun Electronics	$34	On Hand (CWU)
Camera table	3D printed, ABS Plastic	CWU	$5	Order/Printed
Felt liner	Cut to size, applied with tape	Michael's	$10.00	Order
Foam containers x3	Styrofoam, 7.5 x 9.5 x 7 in	Seth Rich	$24.00	Donation
Foam cylinder	Foam pool floater, x3	Target	$5.97	Order
H-bridge breakout board	Adafruit TB6612 1.2A DC/Stepper motor driver	Adafruit	$4.96	Order
LinkSprite JPEG Color Camera x2	w/TTL Interface, Model LS-Y201 Ver. 1.1	Spark fun Electronics	$49.95	Order
Motor attachment	3D printed, ABS Plastic	CWU	$5	Order/Printed
Paracord	Black paracord	Fred Meyer's	$6.99	Order
Payload box	Built with mold	CWU	$83.09	Order/Built
Payload box lid	Built panel	CWU	$27.70	Order/Built
Stepper motor	Model XY42STH34-0354A	Adafruit	$14	Order
		Total Cost:	$271	

13: APPENDIX D – BUDGET

Part Ident	Part Description	Source	Cost	Disposition
Arduino	Model Mini R5	Spark fun Electronics	$34	On hand
Battery	Energizer AA Alkaline battery	Wal-Mart	$6.00	Order
Camera table	3D printed, ABS Plastic	CWU	$5	Order/Printed
Dust mask	Sanding and fiberglass valved respirator	Hardware Store	$9.00	On hand
E-Duck Tape	Decorative duct tape	Fred Meyer's	$3.99	Order
Epoxy hardener	#2060 1/2 Pint	Fibre Glast	$21.95	Order
Epoxy resin	#2000 Quart	Fibre Glast	$44.95	Order
Felt liner	Cut to size, applied with tape	Michael's	$10.00	Order
Fiberglass fabric	Style 120 E-Glass, 38" wide roll	Fibre Glast	$11.45	Order
Foam cylinder	Foam pool floater, x3	Target	$5.97	Order
H-bridge breakout board	Adafruit TB6612 1.2A DC/Stepper motor driver	Adafruit	$4.96	Order
LinkSprite JPEG Color Camera	w/TTL Interface, Model LS-Y201 Ver. 1.1	Spark fun Electronics	$49.95	Order
Mixing container	Solo clear cup, pack of 28	Fred Meyer's	$3.49	Order
Motor attachment	3D printed, ABS Plastic	CWU	$5	Order/Printed
Multi-mix container	Quart size	Ace Hardware	$1.59	Order
Nitrile gloves	Package of disposable gloves, small/medium	CWU	$9.79	On hand
Packing tape	54.6 yard, clear	Ace Hardware	$5.99	Order
Paint brush	Disposable brush x6	Ace Hardware	$7.04	Order
Paracord	Black paracord	Fred Meyer's	$6.99	Order
Release film	#1580 low temperature, perforated, 60" wide	Fibre Glast	$5.75	Order
Stepper motor	Model XY42STH34-0354A	Adafruit	$14	Order
Styrofoam cooler x3	Mold and middle panel material	Seth Rich	$24.00	Donation
Styrofoam cooler, large	Styrofoam, 10 in deep	Seth Rich	$30.00	Donation
Tape	Black duct tape	Fred Meyer's	$4.59	Order
		Total Cost:	$325	

14: APPENDIX E – SCHEDULE

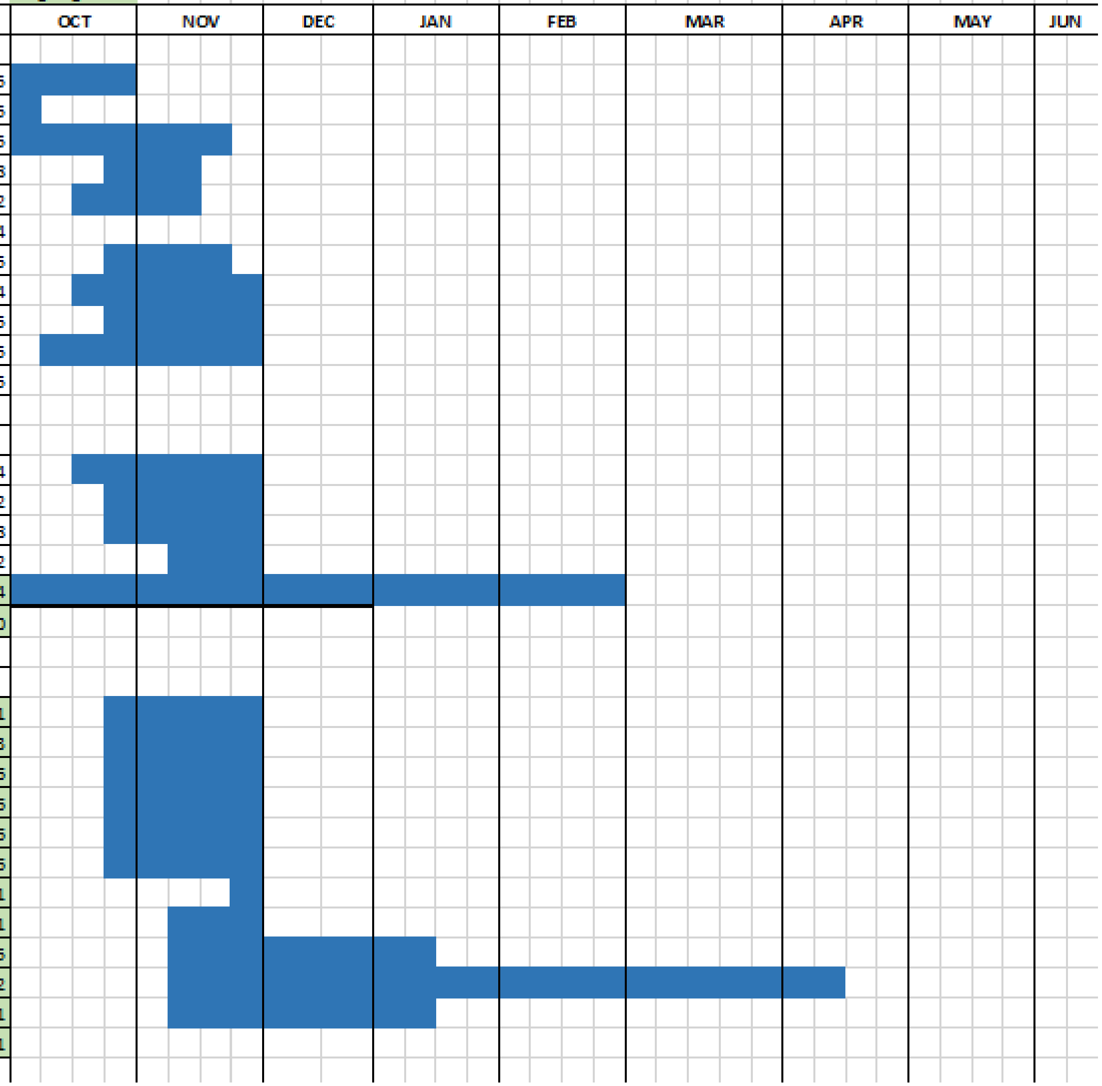
Project Title: Payload Box

Eng. Tech.: Shellbie Liberty

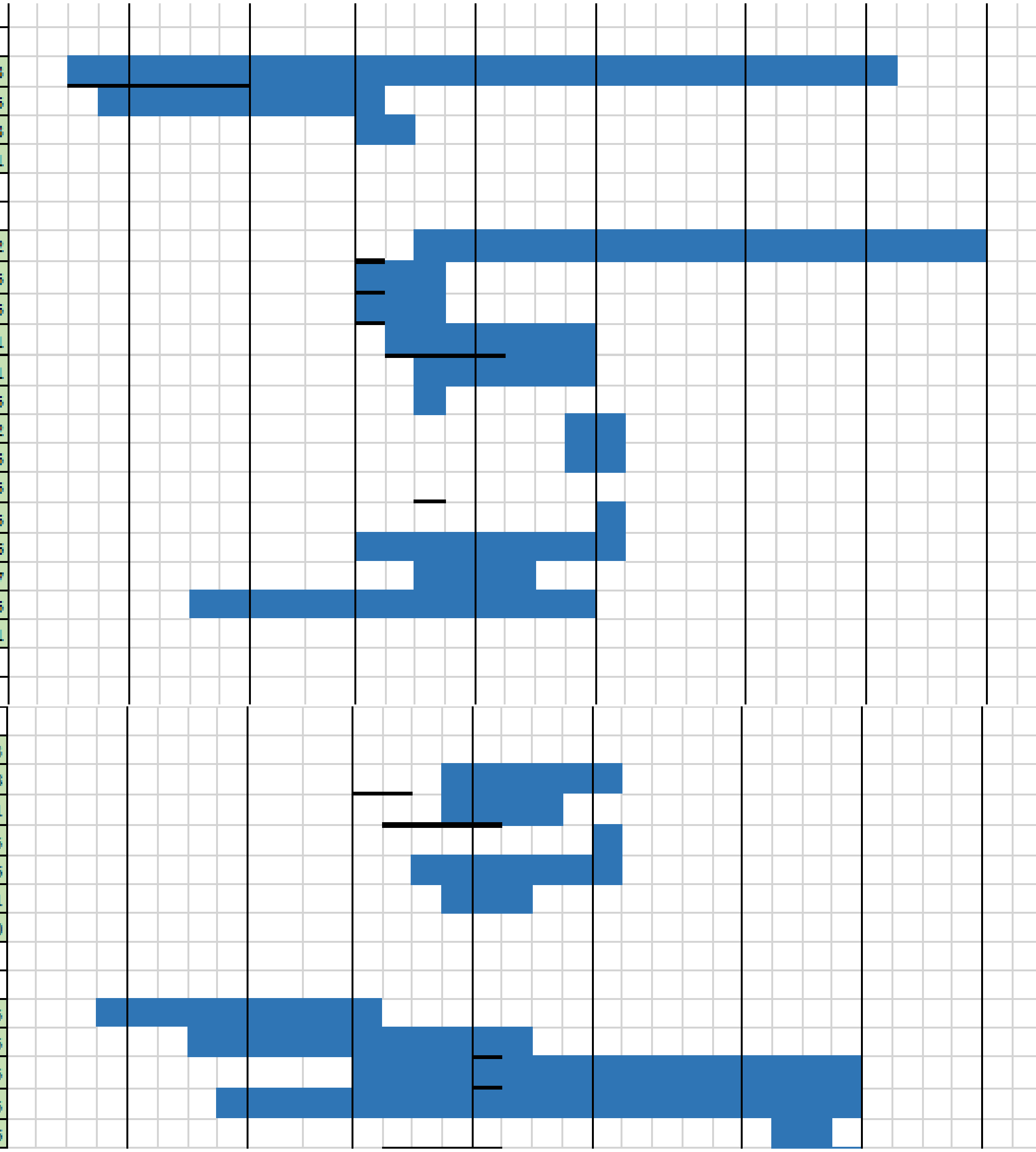
Scale: 1 square/unit = 1 week

Ongoing

Task ID	Description	Time (hrs.) Est.	Act.
1	Proposal	25	25
1a	Outline	2	1.5
1b	Intro	4	5
1c	Methods	5	8
1d	Analysis	6	12
1e	Discussion	4	4
1f	Parts & Budget	2	15
1g	Drawings	5	24
1h	Schedule	2	5
1i	Summary & Appx	5	5
	subtotal:	60	105
2	Analysis		
2a	Descent velocity and time	2	4
2b	Max material displacement	2	2
2c	Impact force & displacement	2	8
2d	Payload box mass & weight	2	2
2e	Balloon stabil. attachment	2	14
	subtotal:	10	30
3	Documentation		
3a	Payload box "default" design	0.5	1
3b	Payload box lid	0.5	0.83
3c	Payload box window, bottom	0.5	1.16
3d	Payload box window, top	0.5	1.16
3e	Payload box window, large	0.5	0.66
3f	Payload box window, small	0.5	0.66
3g	Payload box w/window ass.	0.5	1
3h	Payload box "default" ass.	0.5	1
3i	Servo motor hook up	0.5	1.25
3j	Servo table	0.5	1.42
3k	Servo assembly	0.5	1
	subtotal:	5.5	11.1



4	Proposal Mods		
4a	Project Schedule	1	4.33
4b	Project Part Inv.	2	2.75
4c	Critical Design Review	2	3
	subtotal:	5	10.1
5	Part Construction		
5a	Make servo motor 3D parts	4	6.22
5b	Buy Stepper Motor	0.5	0.5
5c	Buy Arduino	0.5	0.5
5d	Make instruments w/group	4	11.1
5e	Buy fiber materials	0.5	1
5f	Buy/acquire foam	0.5	0.25
5g	Make box top, bottom, lid	168	4.62
5h	Make payload box	2	1.5
5i	Order foam poles	0.5	0.25
5j	Make balloon attachment	4	0.5
5k	Photo Documentation	1	0.6
5l	Update Website	4	5.37
5m	Manufacture Plan	4	2.75
	subtotal:	194	35.1
6	Device Construct		
6	Device Construct		
6a	Assemble Box	170	13
6b	Assemble Imaging Platform	4	8
6c	Assemble Instruments	4	1
6d	Assemble Balloon Attach	4	0.5
6e	Photo Documentation	1	116
6f	Update Website	4	1
	subtotal:	187	140
7	Device Evaluation		
7a	List Parameters	3	0.5
7b	Design Test & Scope	3	0.5
7c	Obtain Resources	4	0.5
7d	Make Test Sheets	4	0.5
7e	Plan Analysis	3	0.66



7f	Instrument Device	2	1.25
7g	Test Plan	2	0.83
7h	Perform Evaluation	8	2.33
7i	Test Photo Documentation	3	0.08
7j	Update Website	5	7.17
	subtotal:	37	14.3
8	495 Deliverables		
8a	Get Report Guide	0.5	0.5
8b	Make Rep Outline	0.5	0.5
8c	Write Report	12	11.6
8d	Make Slide Outline	1	0.5
8e	Create Presentation	3	2.33
8f	Make CD Deliv. List	2	0.1
8g	Write 495 CD Parts	8	0.5
8h	Update Website	12	3.7
8i	Project CD	2	0.5
	subtotal:	41	20.2
9	Eclipse Project		
9a	MATLAB Training/Program	25	
9b	Setting up dish	10	3.33
9c	Planning payload	3	3
9d	Weather balloon tests	5	6.5
9f	Electronics troubleshoot	40	18.2
	subtotal:	83	31.1
	Total hours:	684	396

15: APPENDIX F – EXPERTISE AND RESOURCES

Dr. Darci Snowden is an assistant professor of atmospheric physics and geophysics for Central Washington University (CWU), has previously done weather balloon experiments, and has been to multiple conferences instructing how to properly launch, track, and analyze weather balloon data. She is also well versed in MATLAB, Python, and coding for Arduinos (C/C++), which are the programming languages the physics group will use for the electronic instruments to communicate to each other and the ground computer during the launch.

Two of the teammates in the CWU Near Space Observation team are Griffin Running and Berlie Walker, undergraduate physics students at CWU. The principle engineer is an undergraduate mechanical engineering technology student.

Peter Zencak is a technician in the physics department, with many years dedicated to the subject and in assisting staff and students on physics assignments and projects. Addison Wenger, another technician, is a physics student who has knowledge on much of the equipment in the Science II building, as well as experience in tutoring students at CWU in physics.

Prof. Greg Lyman is an assistant professor for electronics engineering technology. His experience with electronic equipment will be of great use during the testing stage of the project. Between Prof. Lyman and Dr. Snowden, all the scientific instruments for the payload box should be in working order, which will help finalize the payload box construction.

Dr. Craig Johnson is a mechanical engineering technology professor with a background in material science, while Matt Burvee is an engineering technician with knowledge and experience with all the engineering testing equipment in Hogue Hall. Prof. Charles Pringple and Prof. Roger Beardsley are both assistant professors for mechanical engineering technology. All together they have and will continue to be resource on material construction, analysis, and testing for the later quarters.

16: APPENDIX G – EVALUATION SHEET

A: Estimated Impact Force

mass = 1.550 kg
velocity = 4.389 m/s

Time (sec)	Force (N)	Force (lbf)
0.025	272.118	61.175
0.05	136.059	30.587
0.075	90.706	20.392
0.1	68.030	15.294
0.125	54.424	12.235
0.15	45.353	10.196
0.175	38.874	8.739
0.2	34.015	7.647
0.225	30.235	6.797
0.25	27.212	6.117
0.275	24.738	5.561
0.3	22.677	5.098
0.325	20.932	4.706
0.35	19.437	4.370
0.375	18.141	4.078
0.4	17.007	3.823
0.425	16.007	3.599
0.45	15.118	3.399
0.475	14.322	3.220
0.5	13.606	3.059
0.525	12.958	2.913
0.55	12.369	2.781
0.575	11.831	2.660
0.6	11.338	2.549
0.625	10.885	2.447
0.65	10.466	2.353
0.675	10.078	2.266
0.7	9.719	2.185
0.725	9.383	2.109
0.75	9.071	2.039
0.775	8.778	1.973
0.8	8.504	1.912
0.825	8.246	1.854
0.85	8.003	1.799
0.875	7.775	1.748
0.9	7.559	1.699
0.925	7.355	1.653
0.95	7.161	1.610
0.975	6.977	1.569

1	6.803	1.529
1.025	6.637	1.492
1.05	6.479	1.457
1.075	6.328	1.423
1.1	6.185	1.390
1.125	6.047	1.359
1.15	5.916	1.330
1.175	5.790	1.302
1.2	5.669	1.274
1.225	5.553	1.248
1.25	5.442	1.223
1.275	5.336	1.200
1.3	5.233	1.176
1.325	5.134	1.154
1.35	5.039	1.133
1.375	4.948	1.112
1.4	4.859	1.092
1.425	4.774	1.073
1.45	4.692	1.055
1.475	4.612	1.037
1.5	4.535	1.020
1.525	4.461	1.003
1.55	4.389	0.987
1.575	4.319	0.971
1.6	4.252	0.956
1.625	4.186	0.941
1.65	4.123	0.927
1.675	4.061	0.913
1.7	4.002	0.900
1.725	3.944	0.887
1.75	3.887	0.874
1.775	3.833	0.862
1.8	3.779	0.850
1.825	3.728	0.838
1.85	3.677	0.827
1.875	3.628	0.816
1.9	3.581	0.805
1.925	3.534	0.794
1.95	3.489	0.784
1.975	3.445	0.774
2	3.401	0.765

B: Displacement Estimate and Data

Length (in)	7.874
Area (in^2)	22.32

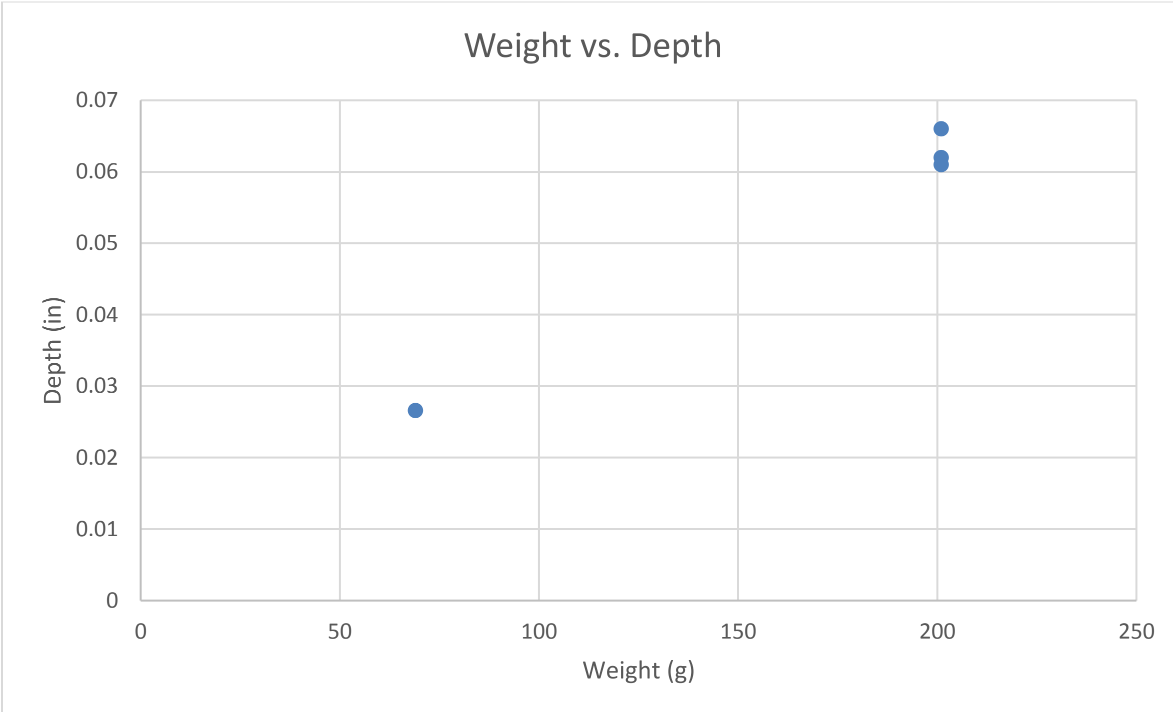
Force (lbf)	Material / Piece	Young's Modulus (psi)	Displacement (in)	Displacement (cm)
15.29	E-Glass Fabric, Generic	10500000	5.137E-07	1.305E-06
15.29	Kevlar 49	22335812	2.415E-07	6.134E-07
15.29	Epoxy/Carbon Fiber Composite	12299200	4.386E-07	1.114E-06

17: APPENDIX H – TESTING DATA

A: Impact Drop Test

Drop height = 6.54 m (21.3 ft.)
Weight: 1 ball = 69 g (0.152 lbs.)
2 balls = 134 g (0.295 lbs.)
3 balls = 201 g (0.443 lbs.)
Payload box w/lid = 1160 g (2.557 lbs.)
Payload box = 828 g (1.825 lbs.)
Lid = 329 g (0.725 lbs.)

Trial	Drop weight	Height	Damage?
1	69 g	21.3 ft	No
2	69 g	21.3 ft	No
3	69 g	21.3 ft	Yes: 0.142 in width, 0.0266 in depth
4	134 g	21.3 ft	No
5	134 g	21.3 ft	Minimal
6	134 g	21.3 ft	Minimal
7	201 g	21.3 ft	Yes: 0.627 in width, 0.066 in depth
8	201 g	21.3 ft	Yes: 0.281 in width, 0.061 in depth
9	201 g	21.3 ft	Yes: 0.381 in width, 0.062 in depth


Weight vs. Depth
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Depth (in)
0
50
100
150
200
250
Weight (g)

Shellie Liberty | Senior Project | 4/5/17 | 1/1

GIVEN: Payload box mass = 1.360 kg
Terminal Velocity = 4.327 m/s
mass of steel ball = 69 g
Impact force = 68.03 N

FIND: Height to drop ball to mimick impact conditions

SOLN: $\frac{1}{2} m_{BOX} v_{BOX}^2 = m_{BALL}\, g\, h$

$\frac{1}{2}(1.360 kg)(4.327 m/s)^2 = .069 kg\,(9.81 m/s^2)\, h$

$h = 18.8 m$

Try using more than one ball

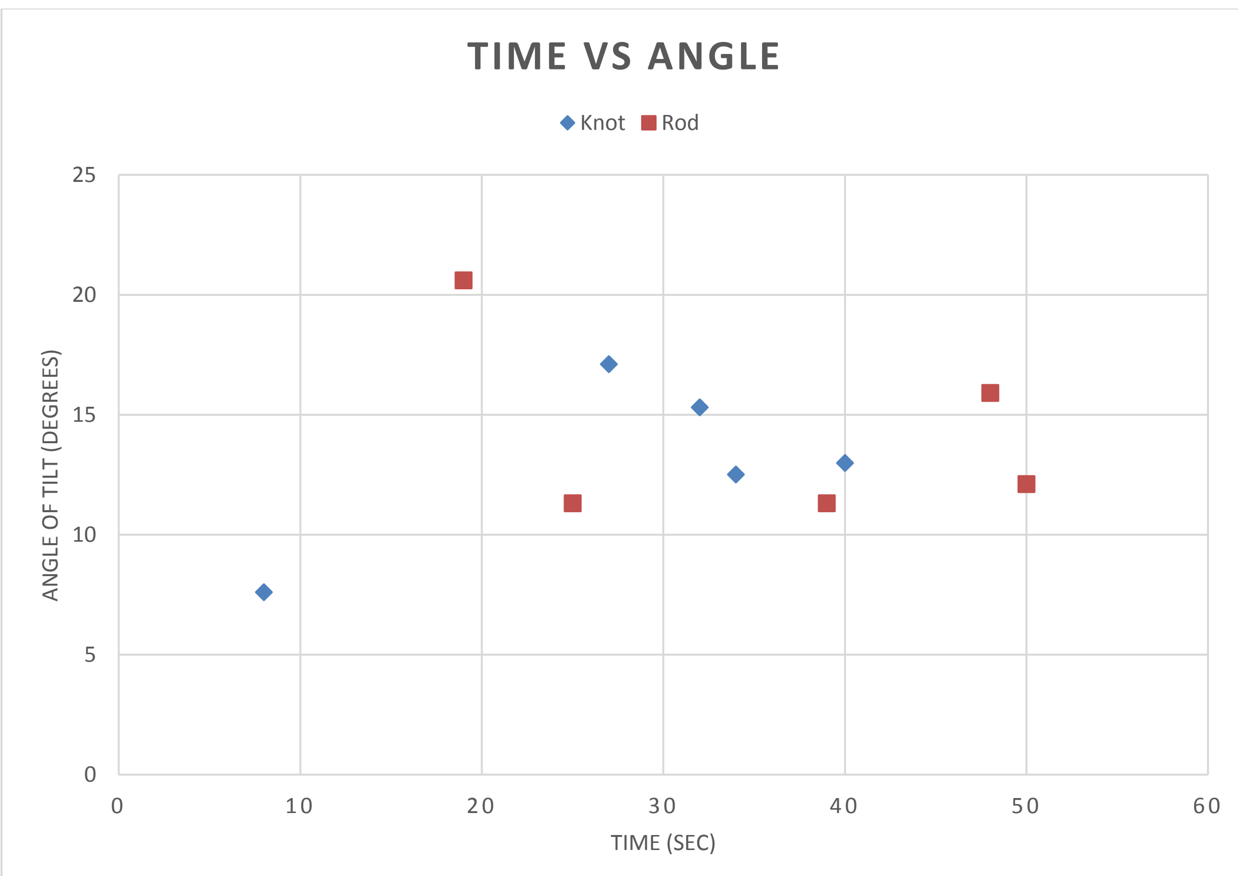
Three balls: $h = \frac{\frac{1}{2}(1.360 kg)(4.327 m/s)^2}{3(.069 kg)(9.81 m/s^2)}$

$h = 6.27 m = 20.57 ft$

Height doable at two stories (approximately)

B: Stabilization Test

To Point		
Test	**Time (sec)**	**Angle (Degrees)**
1	32	15.3
2	40	13.0
3	8	7.6
4	34	12.5
5	27	17.1
Rod		
Test	**Time (sec)**	**Angle (Degrees)**
1	19	20.6
2	48	15.9
3	39	11.3
4	25	11.3
5	50	12.1



18: APPENDIX I – RESUME

SHELLBIE LIBERTY

16822 80th Ave NW • Stanwood, WA 98292 • (425) 293 3228 • Shellbie.Liberty@cwu.edu

June 2017 graduate of ABET-accredited BSMET program seeking an entry level mechanical engineering position.

Key Skills and Knowledge:

- Solid command of the tools and practices of AutoCAD and SolidWorks to design mechanical equipment, utilizing GD&T, and some CNC programming.
- Developing instrumentation and sensor skills using LabVIEW.

TECHNICAL SKILLS

Programs:

- Adobe Photoshop
- AutoCAD
- LabVIEW
- MS Excel
- MS Word
- SolidWorks (like CATIA)

Machining:

- band/table saws
- belt sanders
- CNC metal/wood
- drill presses
- jointer
- lathes
- mills
- pin router
- plasma cutter

EDUCATION

Central Washington University – Ellensburg, WA

Bachelor of Science in Mechanical Engineering Technology (BSMET), Ongoing, 6/2017

Completed Courses in Major:

- 3D Modelling, Application in Strength & Materials, Applied Thermodynamics, Basic Electricity, Casting Processes, Ceramics & Composites, CAD/CAM (Design & Drafting), Engineering Project Cost Analysis, Fluid Mechanics, Instrumentation, Lean Manufacturing, Machining, Mechanical Design, Metallurgy, Statics, Strength of Materials, and Technical Dynamics.

Senior Design Project (9/2016 to 6/2017):

- Ongoing project to design a payload box for electronics sent on a high-altitude weather balloon.
- Collaborating with students from the Physics department on design requirements to ensure proper instrument safety during and after balloon launch.

Volunteer:

- Astronomy Club: Managed rooftop telescopes, 2016 to 2017
- Created and managed a website for a college-sponsored event: https://asmecwu.wixsite.com/conference

Everett Community College – Everett, WA

Associate in Arts & Sciences, GPA: 3.9, 6/2013

Study Focus:

- One year Japanese study, Mathematics, and Russian.

Volunteer:

- Disabilities: Note taker for students with disability, 2010 to 2012
- Russian Club: Treasurer and event planner, 2010 to 2012

WORK EXPERIENCE

Helper Clerk, Safeway – Smokey Point, WA

Shelf stocker and organizer, 10/2013 to 11/2014

- Extra holiday assistance and training, helped customers with inquiries in person and over the phone.

Volunteer, Marysville Public Library – Marysville, WA

- Organized books and media, assisted the public, 9/2013 to 12/2014