Purdue University
Project Grissom

107 MacArthur Drive
Room #150
West Lafayette, Indiana 47906

September 4, 2017

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1. Summary of CDR Report

1.1. Team Summary

1.1.1. Team Name and Mailing Address

Purdue University Students for the Exploration and Development of Space
107 MacArthur Drive, Room 150 West Lafayette, Indiana 47906

1.1.2. Mentor Contact Information and TRA/NAR Certifications

Victor Barlow, NAR 88988 L3CC, TRA 6839 TAP, Level 3 Certified

vmbarlow@purdue.edu 765-414-2848 (Cell)

1.2. Launch Vehicle Summary

1.2.1. Size and Mass

Our launch vehicle will be 122” tall when assembled and weigh an estimated 30 pounds when not loaded with propellant or motor hardware. The rocket will have a nominal outer diameter of 5.15” and be constructed fully out of filament wound composite fiberglass.

1.2.2. Final Motor Choice

We are using an Aerotech Rocketry L1520 Blue Thunder as our means for propulsion. It is a 75mm diameter, 3 grain motor that produces a total impulse of 3,715 newton seconds over the course of a 2.4 second burn time.

1.2.3. Recovery System

The rocket will utilize standard dual deployment recovery methods, including redundant electronics and ejection charges using a Telemetrum and RRC3+ Sport. A 24” drogue parachute will deploy at apogee, followed by a 100” main parachute at an altitude of 700’ above the ground. The shock cord will consist of 1/2” tubular Kevlar with a 7,200 pound rating.

1.2.4. Rail Size

Our vehicle will utilize a 1.5” rail guide that is 12’ tall and supplied at the launch field.

1.2.5. Milestone Review Flysheet

See attached flysheet.

1.3. Payload Summary

1.3.1. Payload Title

The experimental payload that will be flown in this launch vehicle is a “Target Detection System”

1.3.2. Experiment Overview

Adjacent to the launch site will be three 40ft x 40ft differently colored tarps. The payload flown will be permanently fixed to the launch vehicle. It will record video of the ground and targets during powered flight. This video will be processed by an onboard computer. The onboard computer will serve to identify the tarps and to distinguish them by their respective colors.

2. Changes Made Since PDR

2.1. Changes Made To Vehicle Criteria

There have been no changes the criteria the launch vehicle is required to meet, and follows all requirements set forth by the 2018 NASA SL handbook.

2.2. Changes Made To Payload Criteria

The following is a list of criteria that will be used to ensure the success of the payload. The list is comprehensive including original criteria proposed in the Preliminary Design Review and newly proposed or changed criteria:

- The payload bay must be located in a section independent from the recovery bay
- The payload must fit within a tube that is 12 inches in length and 4.815 inches in diameter
- The payload must have a power supply independent from the one used in recovery
- The payload must weigh less than or equal to 2 pounds
- The drag produced by the video recording device must be minimized
- The payload must be operable for at least 2 hours
- Two externally mounted LED's are to be used to indicate the cameras are actively recording
- Two externally mounted LED's are to be used to indicate the batteries are actively supplying power
- An externally mounted switch is to be used to activate/deactivate both battery supplies
- Both onboard computers must be remotely accessible via WiFi to initiate/terminate the recording programs

2.3. Changes Made To Project Plan

With our educational engagement requirements met, our focus on our project plan has shifted to fundraising through as many different sources and mediums as possible. The funding plan has been approved by the Purdue SEDS board of executives, our faculty mentor, and the office of the bursar.

3. Vehicle Criteria

3.1. Design and Verification Of Launch Vehicle

3.1.1. Unique Mission Statement and Mission Success Criteria

It is the goal of the Purdue University SL team to design, build, test, and fly a student launch vehicle to an altitude of one statute mile while carrying a camera system capable of detecting and differentiating tarps of three distinct color values. A successful mission will include the following aspects:

- The vehicle flight is stable during ascent
- The vehicle reaches an altitude of one statute mile

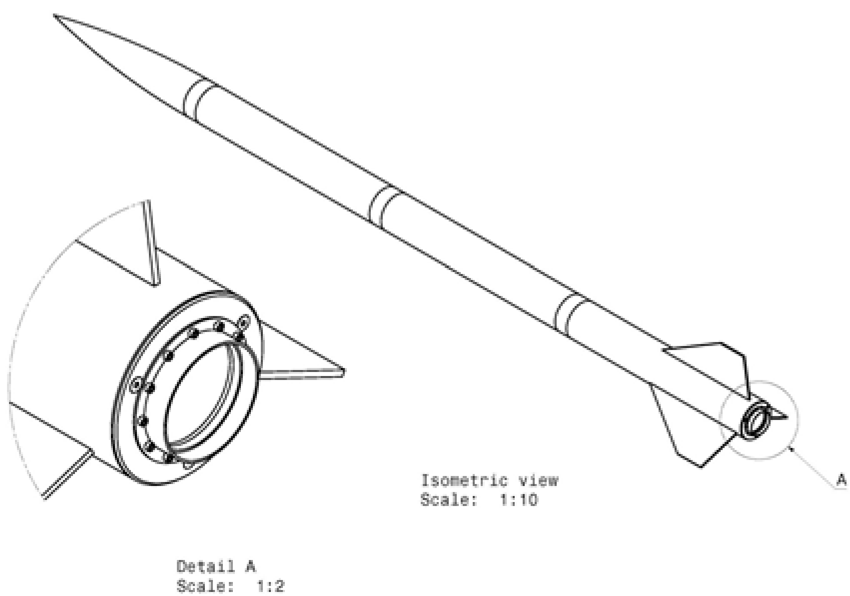
- All recovery gear is successfully deployed at the appropriate altitudes
- The vehicle lands safely within the recovery zone boundaries
- The vehicle can be flown again without need for repairs or alterations
- The onboard payload system identifies and differentiates the three targets

3.1.2. Chosen Design Alternatives From PDR

All of the design alternatives chosen during PDR have remained unchanged except for the interior construction of the nosecone. Our team has chosen to omit the housing tube and coupler that would carry KATE, and opt simply for a coupler with a switch band, two bulkheads, and the associated metal hardware. The shape of the nosecone and nosecone bay, upper airframe, avionics bay, mid airframe, payload bay, and lower airframe are all the same as presented during PDR.

3.1.3. Dimensional Drawings Using CATIA

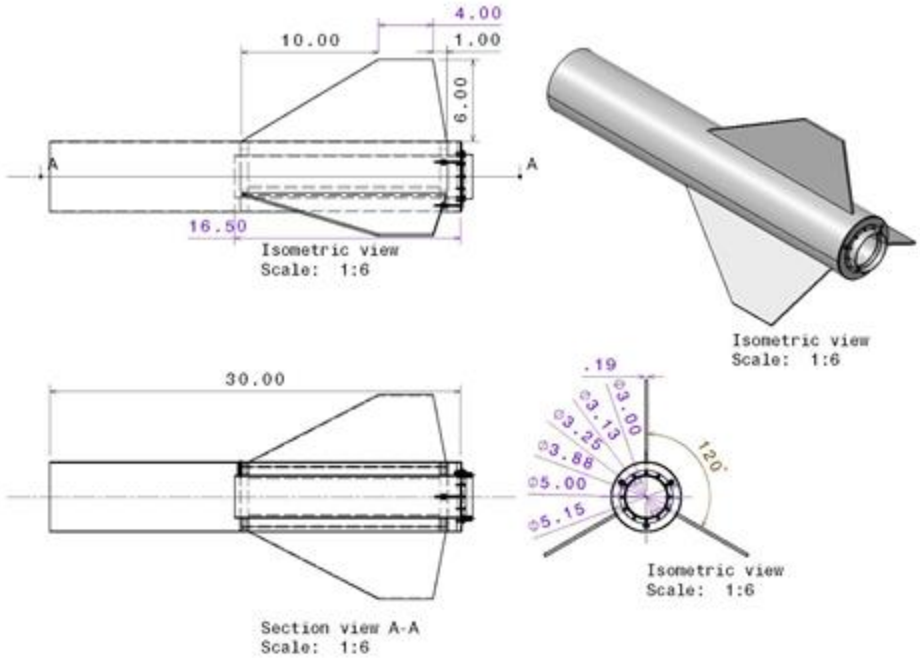
3.1.3.1. Assembled launch Vehicle



The image above and all following drawings were created in CATIA V5.

The assembled launch vehicle, as shown above, includes all metal hardware and fiberglass structural components that make up the body of the rocket and its subsystems, but does not include the recovery gear such as parachutes, fireproofing, tethers, or linkage. The motor casing is also not shown, but the motor retainer, thrust plate, and all appropriate fasteners are modeled in the drawing. The detailed view of the rear end of the rocket shows how the motor retainer will be mounted to the thrust plate, as well as how the thrust plate will be secured to the rocket. These components will be discussed and shown in more detail in the next section.

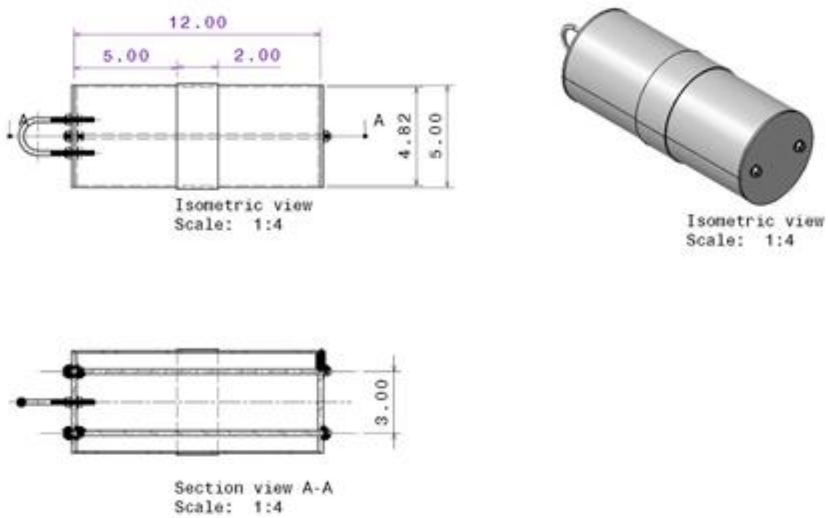
3.1.3.2. Lower Airframe Subsystem and Components



Our lower airframe section will have a 5.15” outer diameter, 5.00” inner diameter, be 30.00” long, and have a fin span of 6.00”. The top 5.00” of the tube will interface with the payload coupler. The tube itself will be slotted to allow for through the wall mounted fins, that will glue to both the motor tube and the airframe. The fin tabs will run the full length of the fins, and be notched to interface with wooden centering rings. These notches will serve to both align the fins perpendicular to the body and provide a lateral clamping force to distribute loads. Each wooden centering ring will be mated to a fiberglass ring as well, in order to increase strength of the plywood and increase the bond area used for gluing.

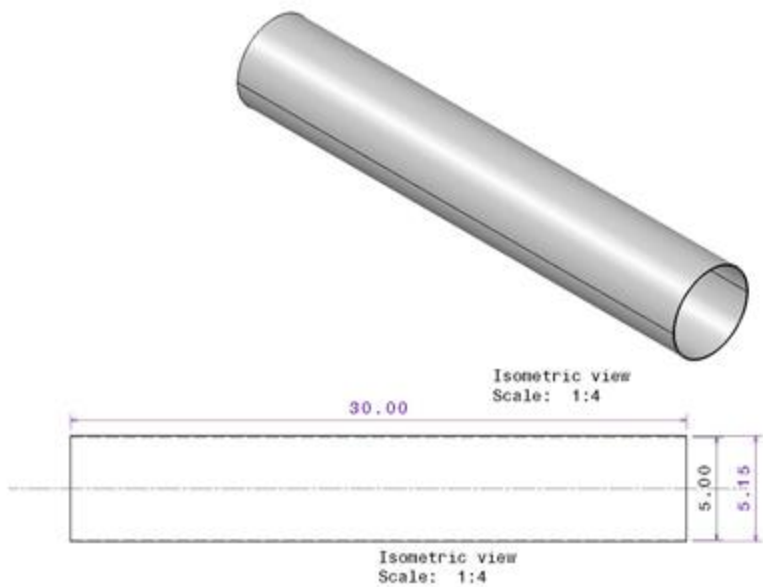
The bottom centering rings will be tapped and threaded to accept inserts, into which bolts will be screwed that hold on the thrust plate and motor retainer. The thrust plate itself will be 0.375” thick stepped aluminum that will align with the airframe concentrically and transfer thrust loads to the airframe, not the motor mount, fins, and glue joints. The thrust plate will also be tapped and threaded to accept bolts that secure the motor retainer into place, providing positive motor retention. The entire lower airframe and motor mount assembly will be bolted to the payload bay assembly of the rocket using removable metal rivets in order to prevent separation during flight.

3.1.3.3. Payload Bay Subsystem and Components



Our team decided to use a coupler with one caliber of tube interfacing with an airframe on either side. Furthermore, we determined that despite the added complexity, the camera band would make mounting and removal of the cameras easy and worth the effort. As a result, our payload bay is 12.00” long: 5.00” on either end and a 2.00” long camera band. Threaded rods will run through the bulkheads and be secured with nuts and washers, clamping the bulkheads over the ends of the tube and sealing the payload inside from any hot gasses produced during ejection charges. Both ends of the payload bay coupler will be secured into place using metal rivets to prevent separation during flight. The tether for the drogue recovery gear will be secured to the bulkhead using the stainless steel u-bolt.

3.1.3.4. Mid Airframe Subsystem and Components

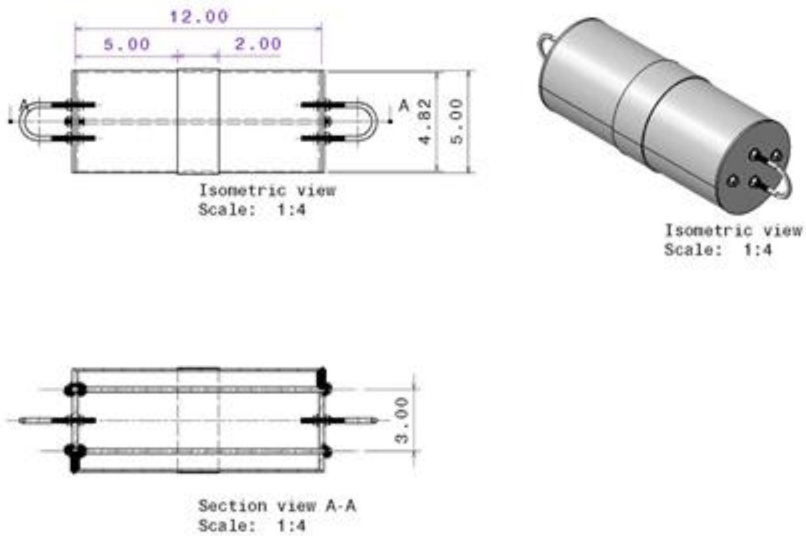


The mid airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for drogue recovery gear.

The team elected to use a standard 30” length of tubing. As a result, we do not need to pay an extra fee to have the tube recut to a custom length and the center of gravity remains as far from the aft of the rocket as possible. This also provides us with ample room to pack our drogue recovery gear in, allowing us to use more of the space for coupler shoulders and to allow for longer couplers in the future if needed.

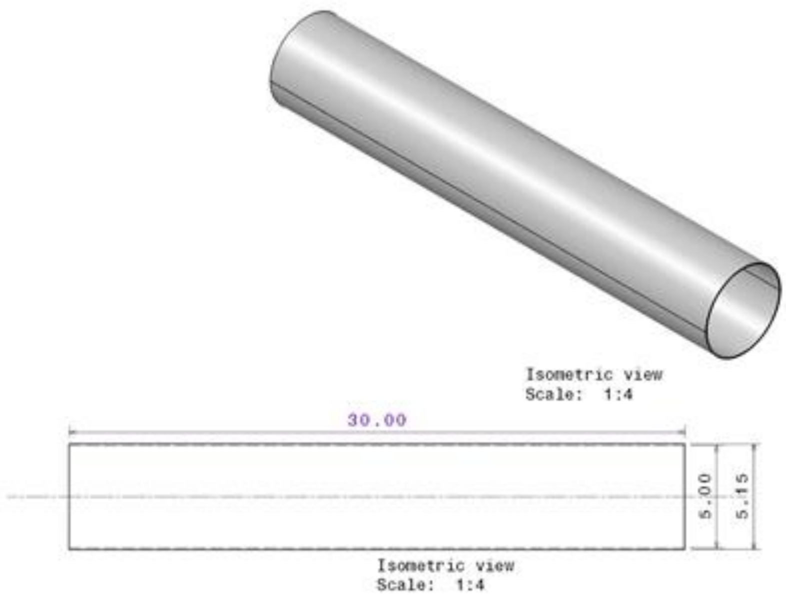
This tube will mate with the avionics bay coupler one one end, and the payload bay coupler one the other end. The mid airframe will be secured to the payload bay coupler using multiple removable metal rivets to hold the lower sections of the rocket together during flight. The avionics bay and upper sections of the rocket will be shear pinned into place to eliminate the possibility of drag separation during ascent, and remain secured until the drogue parachute is deployed.

3.1.3.5. Avionics Bay Subsystem and Components



Our team decided to use a coupler with one caliber of tube interfacing with an airframe on either side. Furthermore, we determined that despite the added complexity, the switch band would make mounting and removal of the electronics easy and worth the effort. As a result, our payload bay is 12.00” long: 5.00” on either end and a 2.00” long camera band. Threaded rods will run through the bulkheads and be secured with nuts and washers, clamping the bulkheads over the ends of the tube and sealing the payload inside from any hot gases produced during ejection charges. One end of the avionics bay coupler will be secured into place to the mid airframe using shear pins to prevent drag separation during flight until the drogue recovery gear is deployed. The other end of the avionics bay coupler will be secured to the upper airframe using removable metal rivets to prevent separation during flight. The tethers for both drogue and main recovery gear will be secured to the bulkheads using the stainless steel u-bolts.

3.1.3.6. Upper Airframe Subsystem and Components

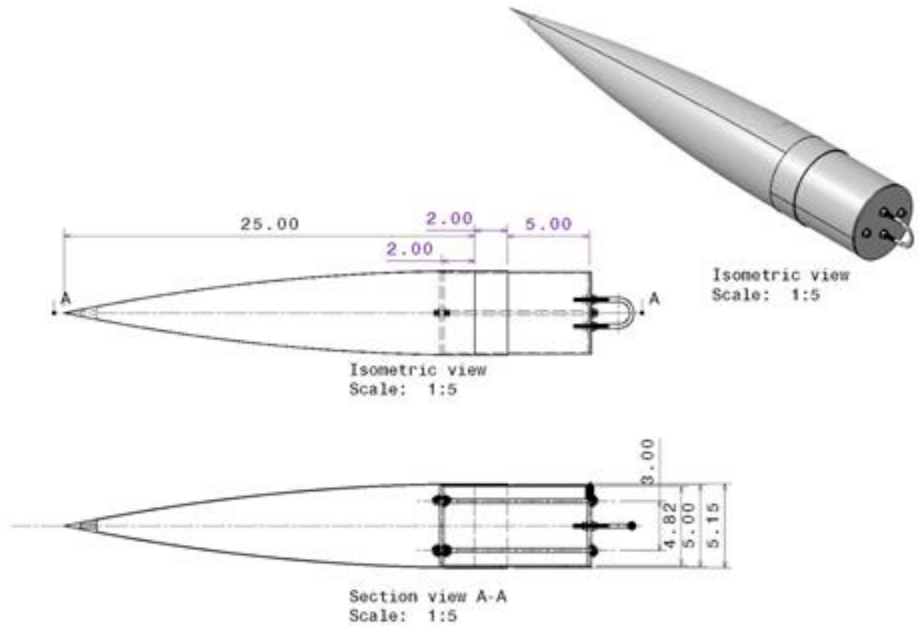


The upper airframe will have an outer diameter of 5.15”, and inner diameter of 5.00”, and will be 30” long. 5.00” of both ends of the tube will be used to interface with coupler tubes, leaving 20.00” of usable room for main recovery gear.

The team elected to use a standard 30” length of tubing. As a result, we do not need to pay an extra fee to have the tube recut to a custom length and the center of gravity remains as far from the aft of the rocket as possible. This also provides us with ample room to pack our main recovery gear in, allowing us to use more of the space for coupler shoulders and to allow for longer couplers in the future if needed.

This tube will mate with the nosecone bay coupler one one end, and the avionics bay coupler one the other end. The upper airframe will be secured to the avionics bay coupler using multiple removable metal rivets to hold the sections of the rocket together during flight. The nosecone bay of the rocket will be shear pinned into place to eliminate the possibility of drag separation during ascent, and remain secure until the main parachute is deployed.

3.1.3.7. Nosecone Subsystem and Components



The nosecone section will be a total of 32.00” long and have a maximum outer diameter of 5.15” at the base of the cone and switch band, and a 5.00” outer diameter at the coupler tube. The nosecone alone is 25” long, and the bottom 2.00” will interface with the nose cone coupler. The switch band is 2.00” long and will be located 2.00” from the top of the coupler tube, leaving 5.00” of coupling exposed to interface with the upper airframe.

Our team decided to use a nose cone with a 5:1 length to diameter ratio with an ogive shape and metal tip. This nose cone reduces drag over those with a lower aspect ratio, and increases the amount of internal space that can be used for mounting additional payloads, electronics, or tracking devices in the future. The metal tip will be secured using a standard bolt and washer, while the coupler will be riveted into place in the base. The coupler will be compressed between two bulkheads held in place by two sections of threaded rod.

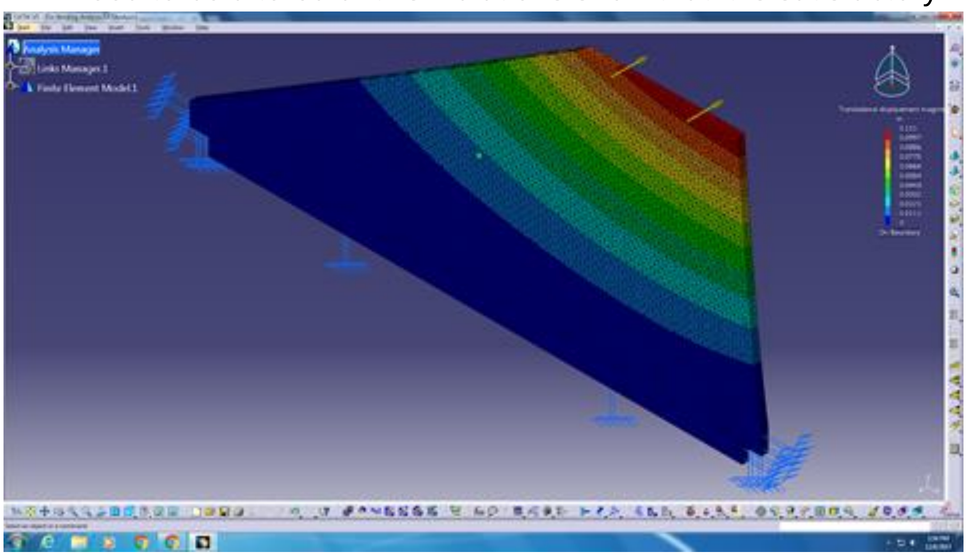
3.1.4. Completeness and Manufacturability

The majority of the parts used for the flight vehicle are commercially bought and will need little to no modification, with the exception of drilling holes to accept fasteners, switches, or vents. Parts such as the fins and plywood centering rings with indexing tabs will need to be custom fabricated and supplied by a third party contractor. All supplies needed for construction, such as sandpaper, adhesives, and solvents will be purchased with the materials or supplied by Purdue SEDS. Overall, there is very little manufacturing that the team needs to perform in house outside of 3D printing.

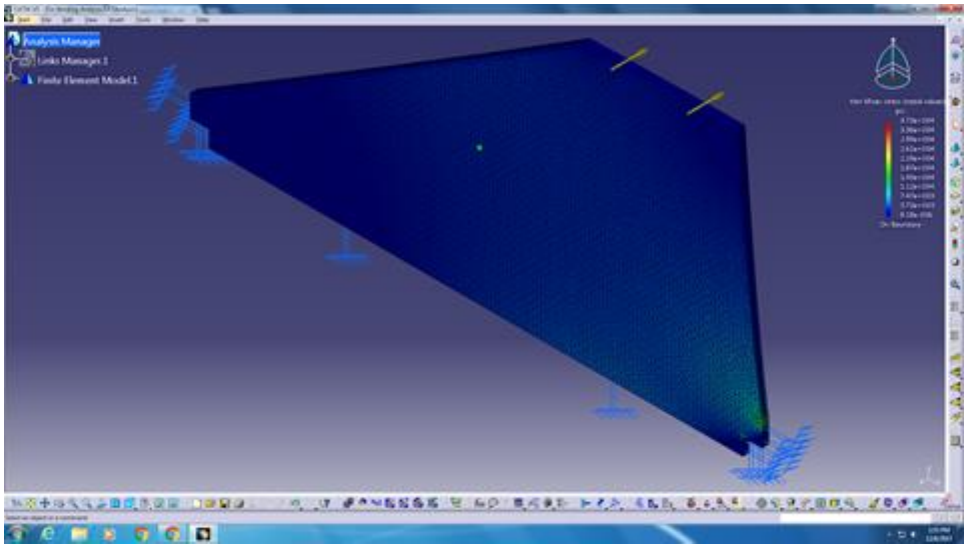
3.1.5. Design Integrity

3.1.5.1. Material Use For Fins, Bulkheads, and Structural Members

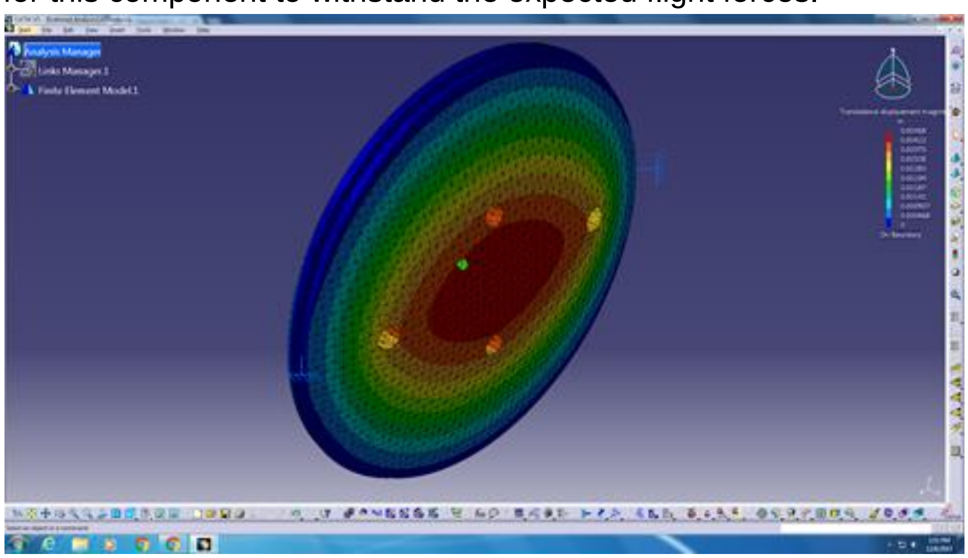
The validation of the shape and materials used for fins, bulkheads, and structural members of the rocket was completed using finite element analysis within CATIA. Each part was designed and given the appropriate material properties, such as young's modulus, yield strength, and poisson ratio. The program then created a mesh around the part, and every part was given a mesh size of 0.1” and mesh sag of 0.01”. Afterwards, each structural member was clamped in the appropriate location to mimic their location and position within the rocket. Once the clamps were applied, loads and distributed forces were also applied to the part to best approximate the displacement and stress the parts would endure. Lastly, each part was simulated under the conditions applied to it and captured as an image. If a simulated part exceeded the materials yield strength, that part will not be considered adequate to withstand the expected flight forces and will need to be altered until simulations show that it is satisfactory.



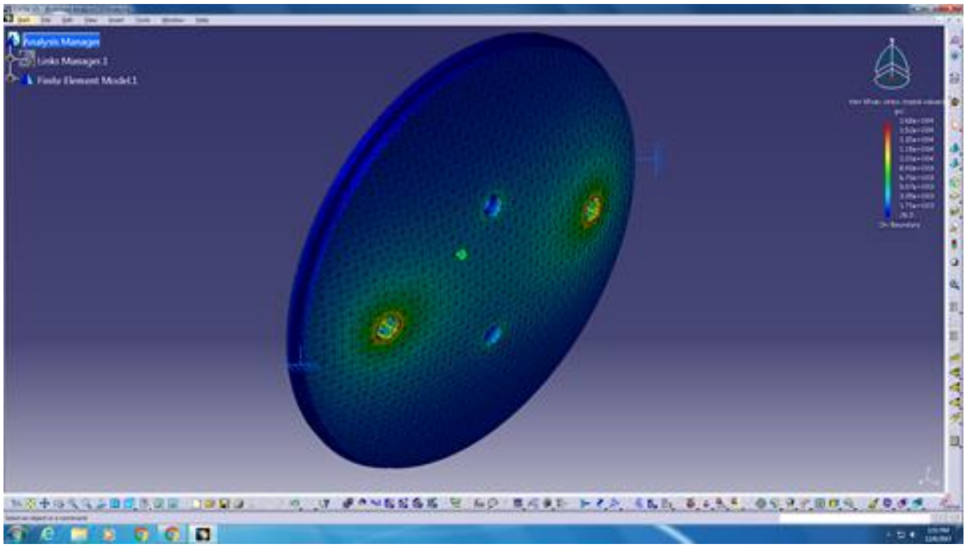
The figure above is a screen capture of the translational displacement of the rocket fin. On all of the root edges of the fin is a blue figure, representing a clamp on the part. This mimics how the fin tab will be glued to the motor tube inside of the rocket, rendering it unable to move. At the top of the fin is a lateral distributed force of fifty foot pounds, which is greater than the landing energy the lower section of the rocket is expected to withstand during landing. The distributed force was placed at the tip of the fin, maximizing the distance between the clamp and the force, and thus maximizing the moment. With these settings, the maximum experienced translational displacement of the tip of the fin is expected to be 0.111”. This is shown by the area of red within the image, according the the color legend shown on the right.



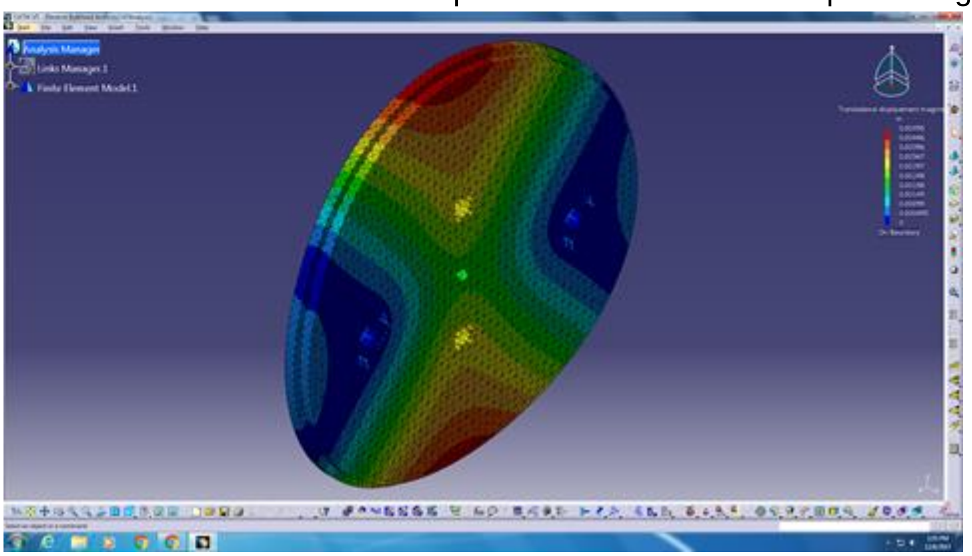
The image above is a screen capture of the Von Mises forces experienced by the vehicle's fin when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 3.73e+4 pounds per square inch, located on the back edge of the fin above the root where it would meet the airframe. This is below the yield strength of the material, meaning that the fin will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.



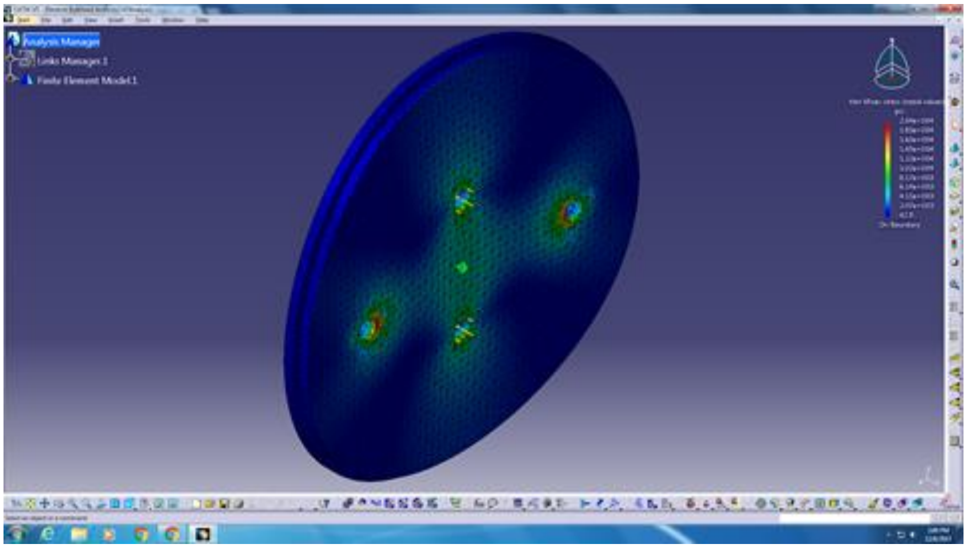
The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled against the coupling tube by the threaded rods that hold it in place within the rocket. On the perimeter of the bulkhead is a blue figure, representing a clamp on the part. A distributed force of five hundred pounds was then applied to the holes that would accept the threaded rod, mimicking the rods pulling on the bulkhead against the coupling tube. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.00468”. This is shown by the area of red within the image, according the the color legend shown on the right.



The image above is a screen capture of the Von Mises forces experienced by the vehicle’s bulkhead when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 1.68e+4 pounds per square inch, located around the holes that accept the threaded rods to hold the bulkhead in place. This is below the yield strength of the material, meaning that the bulkhead will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.

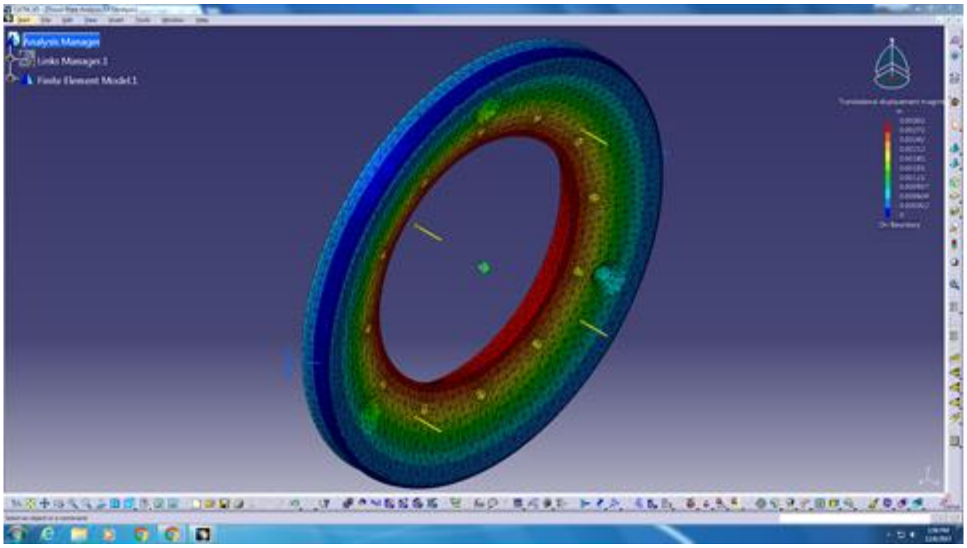


The figure above is a screen capture of the translational displacement of the rocket bulkhead when pulled on by the u-bolts that connect to the recovery harness. Within the holes that would accept threaded rods to hold the bulkhead in place is a blue figure, representing a clamp on the part. A distributed force of five hundred pounds was then applied to the holes that would accept the u-bolts, mimicking the force pulling on the bulkhead against the threaded rods. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.00495”. This is shown by the area of red within the image, according the the color legend shown on the right.

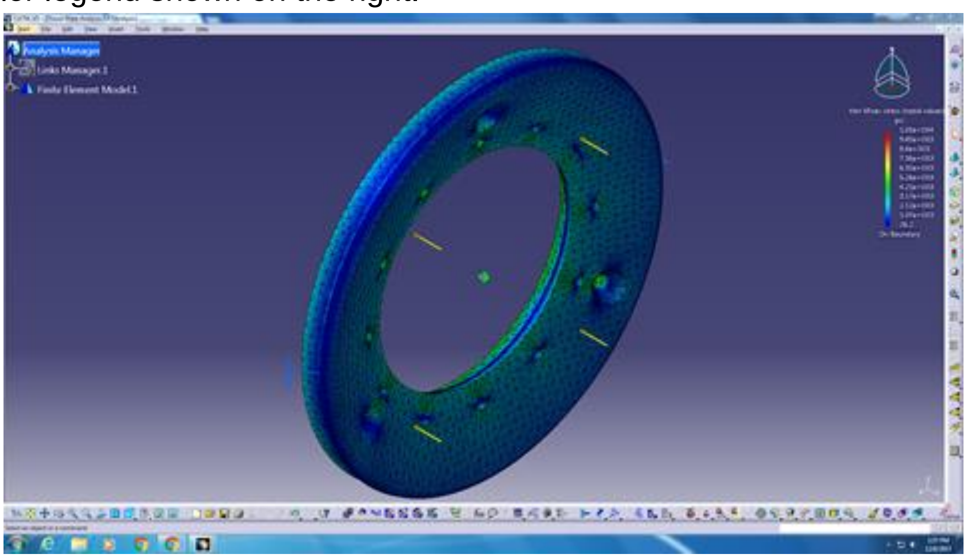


The image above is a screen capture of the Von Mises forces experienced by the vehicle’s bulkhead when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 2.04e+4 pounds per square inch, located around the holes that accept the threaded rods to hold the bulkhead in place. This is below the yield strength of the material, meaning that the bulkhead will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.

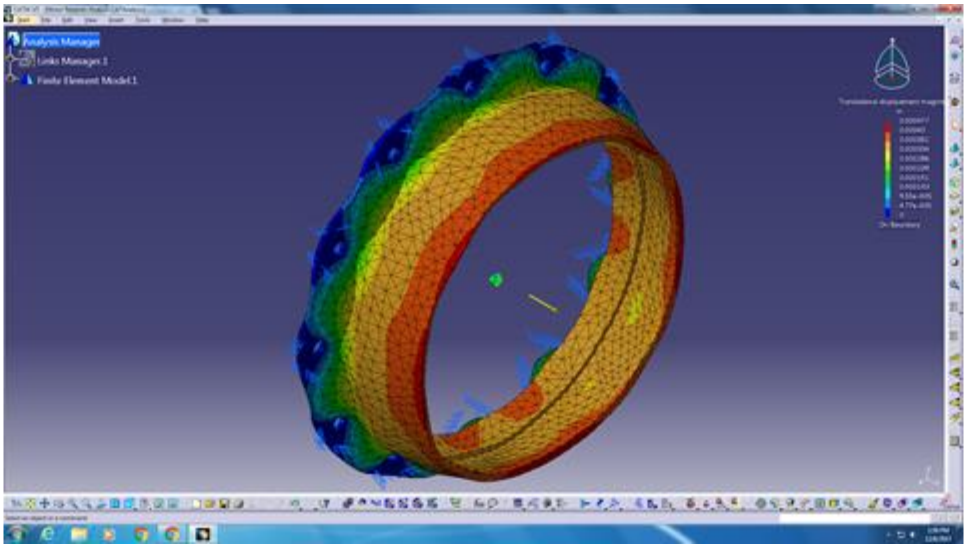
3.1.5.2. Motor Mounting and Retention



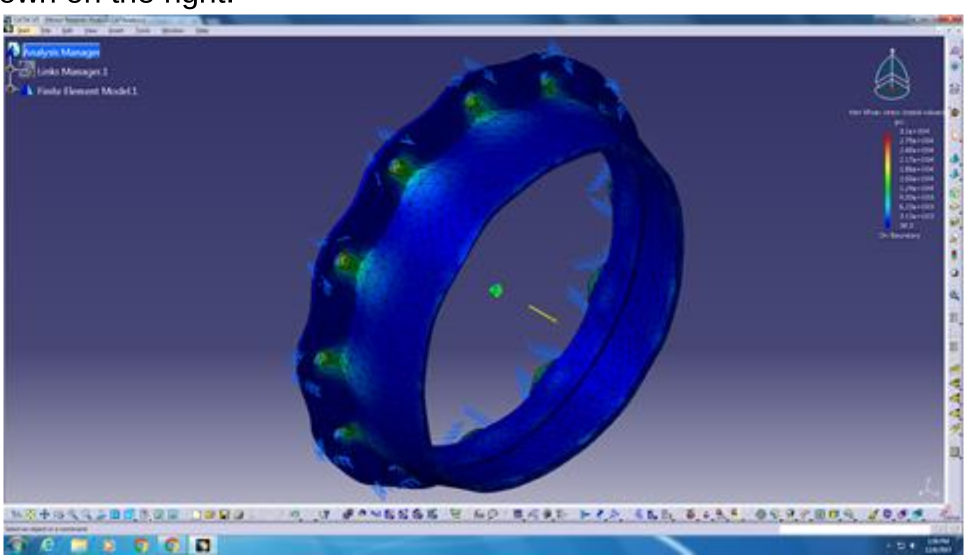
The figure above is a screen capture of the translational displacement of the rocket thrust plate when pushed against the airframe by the thrust of the motor that propels the rocket and held in place by three screws. On the perimeter of the thrust place is a blue figure, representing a clamp on the part. A distributed force of one thousand pounds was then applied to the face that would accept the motor retainer. With these settings, the maximum experienced translational displacement of the center of the plate is expected to be 0.00302”. This is shown by the area of red within the image, according the the color legend shown on the right.



The image above is a screen capture of the Von Mises forces experienced by the vehicle’s thrust plate when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 1.05e+4 pounds per square inch, located on the inner face of the plate and around the holes that accept studs to hold the motor retainer in place. This is below the yield strength of the material, meaning that the plate will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.



The figure above is a screen capture of the translational displacement of the rocket motor retainer when pulled on by the motor casing attempting to be removed from the motor tube by the force caused by parachute deployment. Within the holes that would accept studs to hold the retainer in place on the thrust plate is a blue figure, representing a clamp on the part. A distributed force of one thousand hundred pounds was then applied to the inner face that would contain the motor casing, mimicking the force pulling on the retainer against the studs. With these settings, the maximum experienced translational displacement of the center of the bulkhead is expected to be 0.000477”. This is shown by the area of red within the image, according the the color legend shown on the right.



The image above is a screen capture of the Von Mises forces experienced by the vehicle’s motor retainer when exposed to the same clamping and displacement force as mentioned above. With these variables in place, the maximum expected stress within the component is simulated to be 3.10e+4 pounds per square inch, located on the inside of the holes that accept the studs to hold the retainer in place. This is below the yield strength of the material, meaning that the plate will not experience any deformation past the elastic range. This demonstrates that the team has chosen the proper material and thickness for this component to withstand the expected flight forces.

3.1.5.3. Final Mass of Launch Vehicle and Subsystems

The final mass of the launch vehicle and subsystems, including the recovery gear, metal components, and structural members is expected to be approximately 30.0 pounds sans motor. The final flight ready mass of the launch vehicle, including ejection charges and the motor and motor hardware, is expected to be approximately 38.0 pounds. During descent, after all of the motor propellant has been expelled and ejection charges have been fired, the final descent mass of the launch vehicle is expected to be 34.1 pounds.

3.2. Subscale Flight Results

3.2.1. Recorded Flight Data

3.2.2. Scaling Factors

3.2.2.1. Constant Factors

3.2.2.2. Variable Factors

3.2.3. Launch Day Conditions and Simulation

3.2.4. Flight Analysis

3.2.4.1. Predicted Vs. Recorded Flight Data

3.2.4.2. Errors and Discontinuities

3.2.4.3. Estimated Full Scale Drag Coefficient

3.3. Recovery Subsystem

3.3.1. Chosen Design Alternatives From PDR

There were only minor changes that needed to be made from PDR. The first change made was two completely redundant systems (2 external key switches, 2 altimeters, 2 batteries for each altimeter, and 2 sets of e-matches). The second change made from PDR was to increase the amount of 4Fg black powder in the redundant charge well by approximately 10-20%. The parachute, harnesses, bulkheads, and attachment hardware are all the same as presented during PDR.

3.3.2. Parachute, Harnesses, Fireproofing, Bulkheads,and Attachment Hardware

Our team decided to use the Skyangle Cert 3 Drogue Parachute as a means of drogue recovery. Although it weighs more than some alternatives, occupies more volume, and has a lower drag coefficient, we chose it because it is cheaper and more robust. This choice of parachute is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four shroud lines attach at the bottom to a 1,500 pound rated heavy duty, nickel plated swivel. Each shroud line is made of ⅝” military spec tubular nylon with a tensile strength of 2,250 pounds. The parachute has a tested drag coefficient of 1.26 and a surface area of 6.3 square feet. It will be attached to the tether via a ¼" stainless steel quick link that connects through the swivel and a loop in the shock cord. The estimated mass of the drogue parachute, not including the mass of quick links that attach the parachute to the shock cord or fireproofing, is 0.375 pounds.

The team will be using the Skyangle Cert 3 XL Parachute as a means of main recovery. Although it weighs more than some alternatives and occupies more volume, we chose it because it has a high drag coefficient, is cheaper and more robust than the Fruity Chute alternative from PDR. It is still sized to provide a slow enough landing so that that no section of the rocket touches down with more than 75 foot pounds of energy, as listed in the requirements. Furthermore, it adds more weight above the center of gravity than the Fruity Chute, increasing our margin of stability. The option our team chose is constructed of zero porosity, 1.9 ounce per square yard, silicone coated balloon cloth. Four shroud lines attach at the bottom to a 1,500 pound rated heavy duty, nickel plated swivel. Each shroud line is made of ⅝" military spec tubular nylon with a tensile strength of 2,250 pounds. The parachute has a tested drag coefficient of 2.59 and a surface area of 89.0 square feet. It will be attached to the tether via a ¼" stainless steel quick link that connects through the swivel and a loop in the shock cord. The estimated mass of the main parachute, not including the mass of quick links that attach the parachute to the shock cord or fireproofing, is 3.81 pounds.

For the shock cords in our rocket our team has decided to use a 40' long section of ½" tubular kevlar. They are lightweight, fire resistant, volumetrically efficient, and have a high tensile strength. The tethers are rated for 7,200 pounds lifting force, which will be more than adequate for the purpose of this project, based on the weight of our rocket. Each end will have a loop sewn into the fabric through which we can pass a quick link for easy attachment to the rocket. In addition, each individual tether, drogue and main, will have a loop sewn ⅓ of the length from the top. This will provide an attachment point for the parachute we will be using for recovery. The estimated mass of the tether, not including the mass of quick links that attach the shock cord to the rocket and parachute, is 0.5 pounds.

Our team decided to use the Nomex blankets as a means of fireproofing the parachutes from the ejection charge gases. They are relatively inexpensive and lightweight, but the main advantage is that it can be passed over the shock cord and attached directly to the parachute. As a result, we can tightly wrap the parachute inside of the material, as opposed to simply packing insulation around it, risking a gap in the fireproofing. Both the drogue and main parachute will be protected using this method, and both Nomex blankets will be 18"x18" squares. We estimate that the total mass of both the drogue and main Nomex blankets is approximately 0.25 pounds.

The bulkheads we will be using for the rocket will be constructed from 0.25" thick 6061 T-6 aluminum stock, and contain four 0.25" holes. Two of these holes will be spaced 3.0" apart from center to center and will accept threaded rods that secure the bulkheads to the coupler tube. The other two holes will be 1.625" from center to center and will mate with the u-bolt that attaches the rocket to the recovery tether. These bulkheads will accept the shock of deployment and carry the weight of the rocket during descent, so it is imperative that they be exceptionally strong. Each bulkhead is estimated to weigh 0.45 pounds, for a total of 2.7 pounds with all six bulkheads.

All attachment hardware, including nuts, bolts, washers, u-bolts, and quick links will be constructed from high strength stainless steel, either type 316 or 18-8 depending on availability and sourcing. These alloys were chosen for their exceptional strength, corrosion resistance, and general robustness. They will not oxidize in the presence of residue from the black powder ejection charges, and will maintain their properties for many flights. The estimated weight of the attachment hardware is approximately one pound, and will be verified as the team procures components.

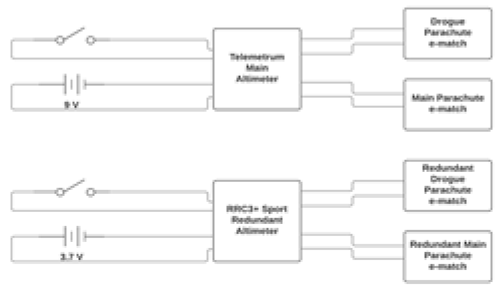
3.3.3. Avionics Components and Redundancy:

The avionics team decided on using the Telemetrum as our primary altimeter and GPS and the RRC3+ Sport as our secondary altimeter. To ensure the most redundant system, the two different altimeters operate using separate batteries. Telemetrum uses a 3.7V LiPo battery, while the RRC3+ Sport uses a 9V battery. To facilitate the separation of the launch vehicle in order to deploy the drogue and main parachutes, we decided on using black powder charges. The backup charge contains 15% more black powder than the primary charge.

3.3.4. Electrical Schematics

The two electrical schematics below show the testing electrical circuits (First image) and the final electrical circuits. They show the wiring layout showing how the altimeter is connected to the battery, the external key switch, and the 2 e-matches.

AVIONICS CIRCUIT DIAGRAM V1 billing4 | November 12, 2017

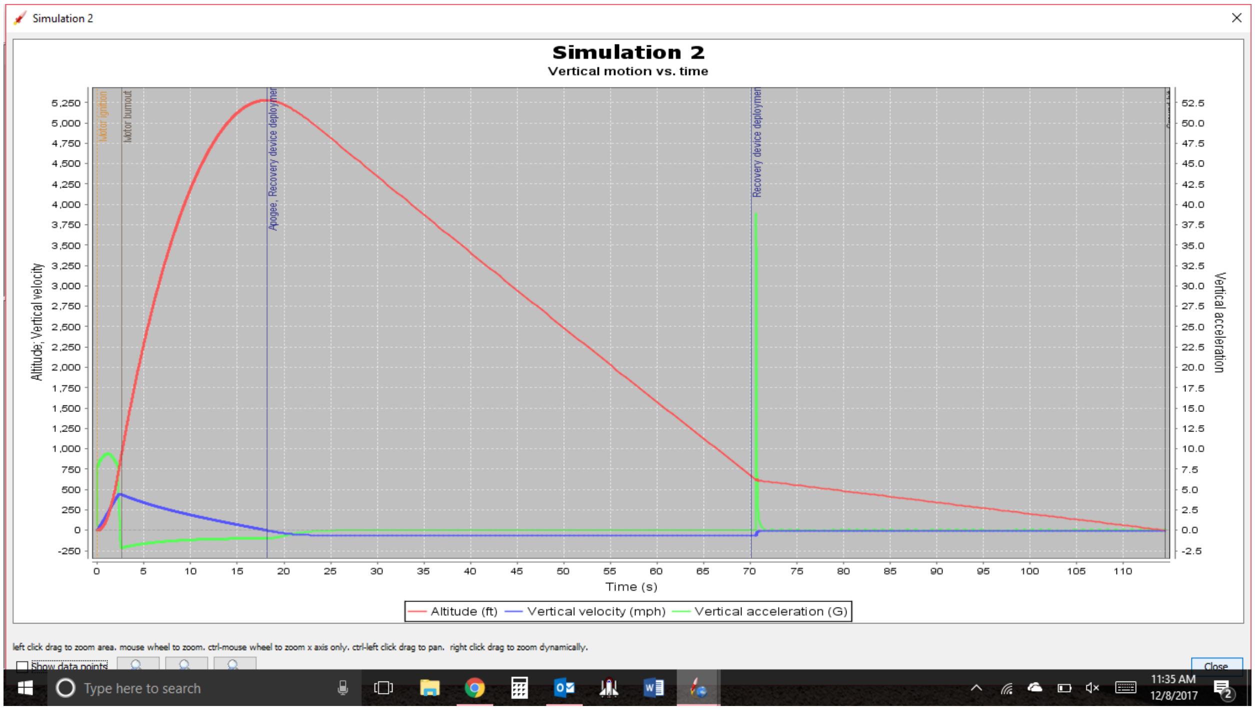


3.3.5. Locating Tracker Operating Frequency

The Telemetrum can be configured to communicate GPS data over a wide range of frequencies. It will be set to use the 434.550 MHz channel which is the frequency that is recommended on the Altus Metrum website. We are using the TeleBT in combination with the Arrow II Model 440-3 3 Element Yagi Beam antenna to communicate with the Telemetrum in flight.

3.4. Mission Performance Predictions

3.4.1. Altitude Predictions With Simulated Vehicle Data

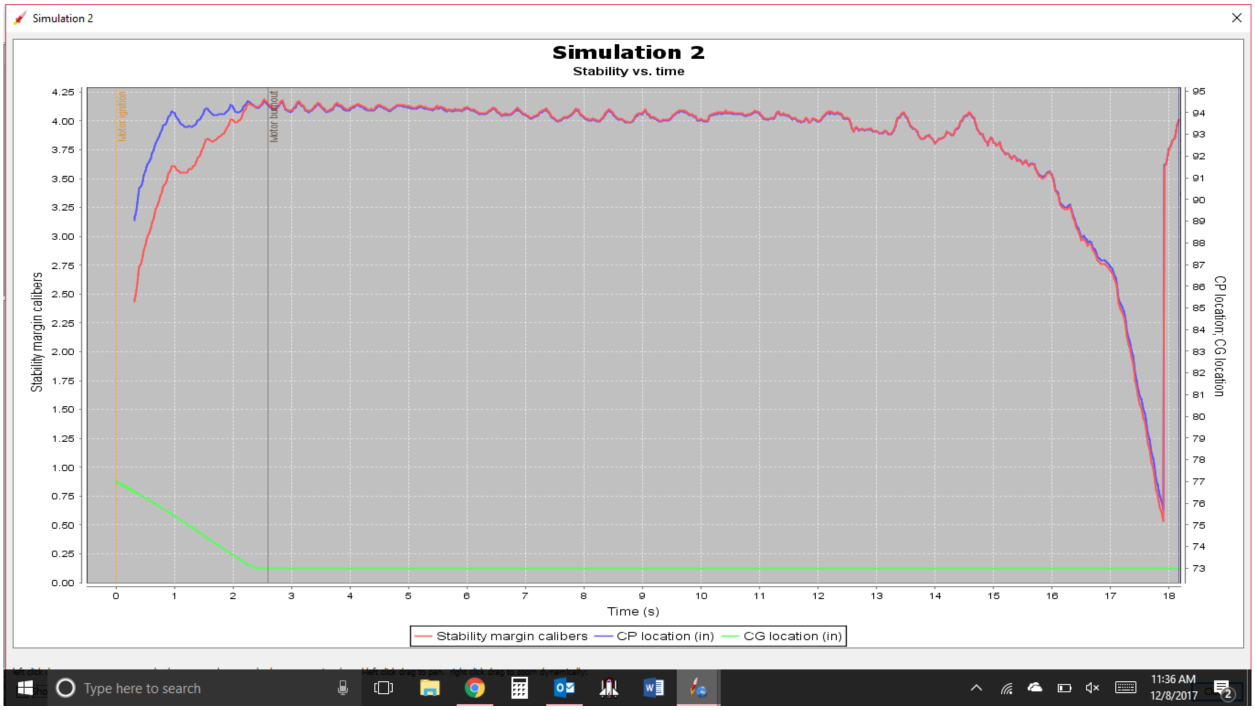


As can be seen from the graph above, our rocket is simulated to reach a maximum altitude of 5,281’ above ground level. This is nearly exactly our target altitude of 5,280’ above ground level. The team is currently deliberately incorporating a ballast of approximately one pound in order to manipulate our apogee to approach our target altitude as closely as possible.Once our group has constructed our flight vehicle, we will have a more accurate weight measurement for the rocket that can then be entered into the simulation program and we can adjust the ballast accordingly. Because the rocket is anticipated to weigh more than the simulation shows, as weight is added into the computer model our ballast will decrease.

Other factors, such as surface finish and the cross sectional airfoil of the fins, are variables that we do not have implicit control over. Our team cannot accurately measure surface smoothness to compare the real and digital models, which will account for some difference in our actual and expected altitudes. In addition, the only choices presented to us when varying the fin’s cross section are “square, rounded, or airfoiled”. There is no direct input for edge thickness or taper length, further limiting our simulations.

All altitude simulations from which the graph above is derived were accomplished using OpenRocket 15.03 using the extended barrowman calculation method and a six degree of freedom runge kutta 4 simulation method. Geodedic calculations were evaluated using spherical approximation, and a 0.02 second time step for simulation calculations was used. Further altitude calculations will be done in RASAero II using similar parameters, and will be discussed later.

3.4.2. Stability Margins With CP/CG Relationships and Locations



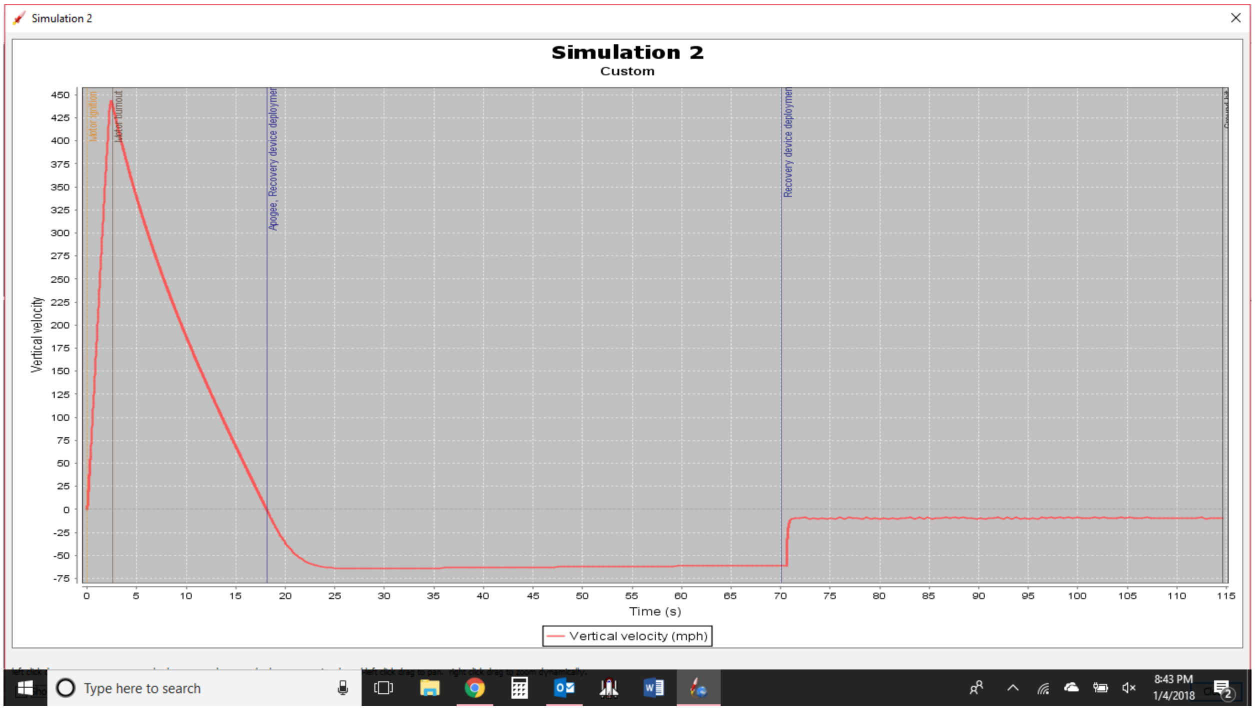
As seen from the graph above, the rocket exits the 144” long, 1.5” launch rail with a minimum stability margin of approximately 2.25 calibers, meeting the minimum requirement of 2 calibers. During the ascent phase, the rocket does not experience a significant drop in stability until it reaches a low enough velocity that the fins cannot maintain aerodynamic stability. At this point, the rocket begins slowing down significantly due to drag and gravity and starts arcing over as it approaches apogee. Despite this, the rocket maintains roughly 4 calibers for nearly all of the boost and coast phase.

The center of pressure, a node where the total sum of all pressures acts on the vehicle, starts at a distance of nearly 88.5” from the datum, which is deemed to be the tip of the nose cone. During the entire flight profile, the location of center of pressure closely follows the stability margin calibers when graphed and does not move more than 5” aft of its original location until the rocket has slowed enough to begin arcing. This movement is in itself only one caliber, as the maximum shift is equal to the diameter of the rocket airframe.

The center of gravity, a node where all moments about an axis of rotation equally oppose each other, begins at a distance of approximately 77” from the datum of the rocket, placing it roughly 11” ahead of the center of pressure. During the burn time of the motor, the center of pressure moves forward at a constant rate due to the constant burn rate of the solid propellant. The total shift is nearly 4”, or almost a full caliber.

3.4.3. Kinetic Energy At Landing

3.4.3.1. Graph Of Velocity Vs. Time



The figure above illustrates the vertical velocity of the rocket over time. The rocket accelerates quickly during boost and begins decelerate before reaching apogee, where it then deploys a drogue parachute and descends rapidly at an estimated 60 miles per hour. At an altitude of seven hundred feet above ground level, the main parachute will deploy to slow the vehicle considerably before touching down at a speed of approximately 9.2 miles per hour. The total landing energy, assuming a burnout mass of 34.1 pounds and impact speed of 9.2 miles per hour, will be approximately 95.3 foot pounds.

3.4.3.2. Lower Section Kinetic Energy At Landing

The bottom section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 19.3 pounds at touchdown. This will consist of the lower airframe and motor assembly, payload bay, middle airframe, and drogue recovery gear. Assuming the landing velocity is still eight and a half miles per hour, the landing energy for this section will be roughly 54.6 foot pounds.

3.4.3.3. Mid Section Kinetic Energy At Landing

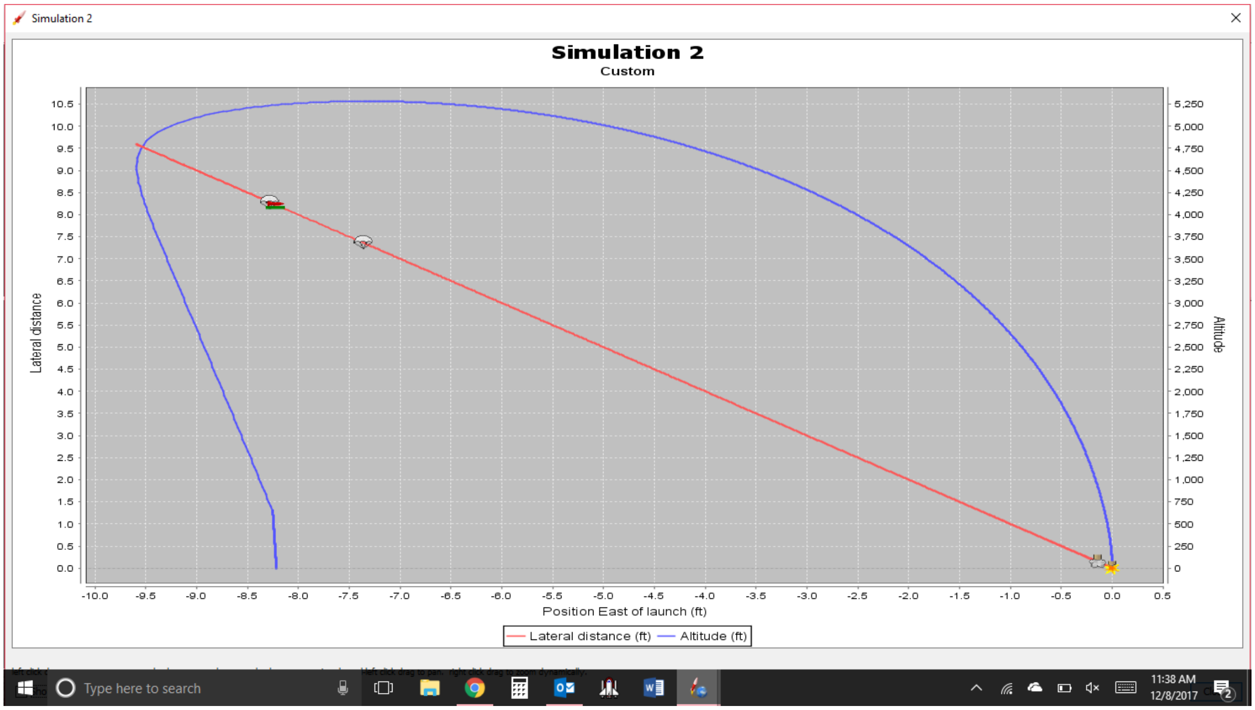
The middle section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 9.71 pounds at touchdown. This will consist of the avionics bay, upper airframe, and main recovery gear. Assuming the landing velocity is still eight and a half miles per hour, the landing energy for this section will be approximately 27.5 foot pounds.

3.4.3.4. Nosecone Kinetic Energy At Landing

The nose section of the rocket that will be falling independently while remaining tethered to the remainder of the vehicle is expected to weigh 4.68 pounds at touchdown. This will consist of the nosecone, Multitronix Telemetry Pro, and nose coupler. Assuming the landing velocity is still eight and a half miles per hour, the landing energy for this section will be roughly 13.2 foot pounds.

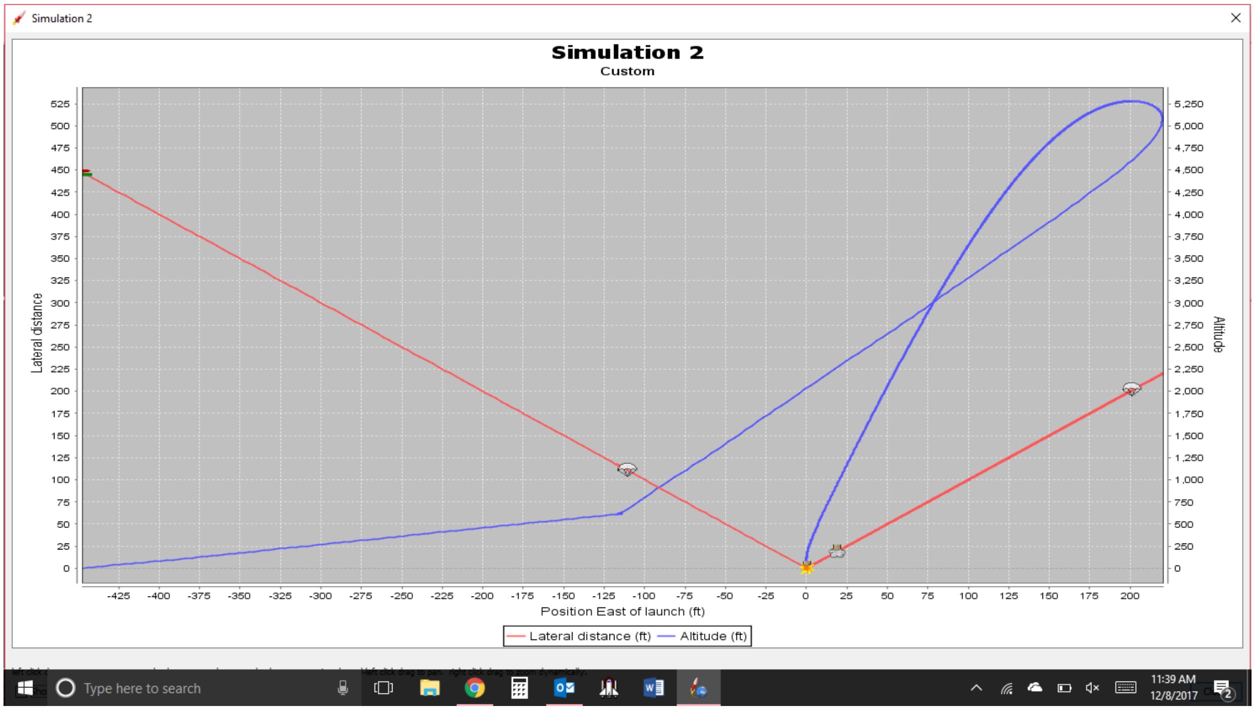
3.4.4. Drift Distance Calculations

3.4.4.1. 0 MPH Drift Distance Calculations



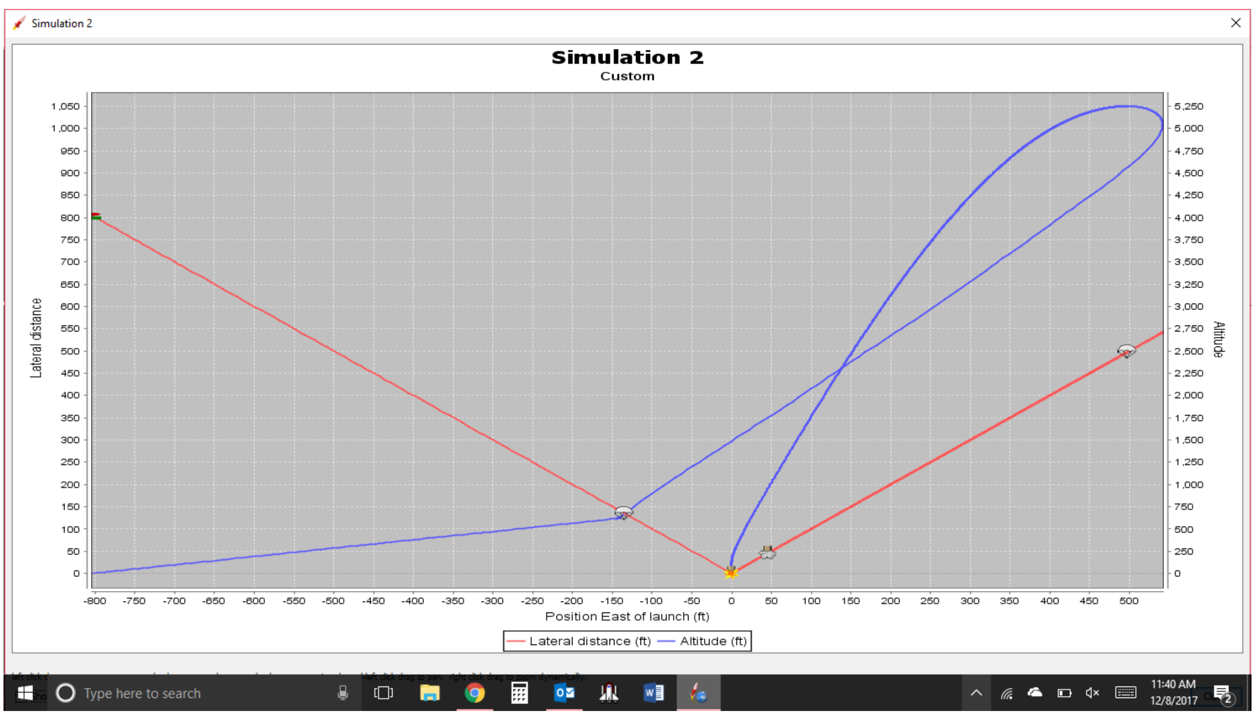
With an average wind speed of zero miles per hour with zero standard deviation and zero percent turbulence intensity, our simulated maximum drift distance during flight is roughly ten feet.

3.4.4.2. 5 MPH Drift Distance Calculations



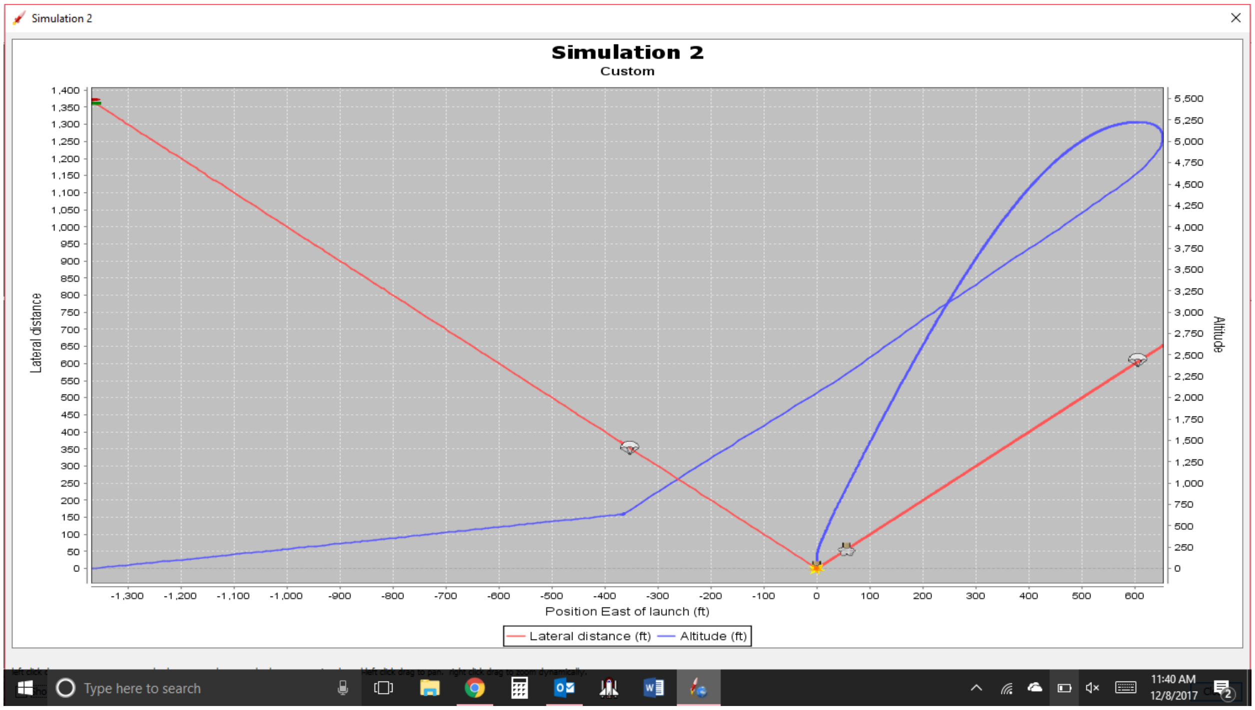
With an average wind speed of five miles per hour with 0.5 miles per hour standard deviation and ten percent turbulence intensity, our simulated maximum drift distance during flight is roughly 450'. The rocket travels nearly 225' east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 450' west of the launch position.

3.4.4.3. 10 MPH Drift Distance Calculations



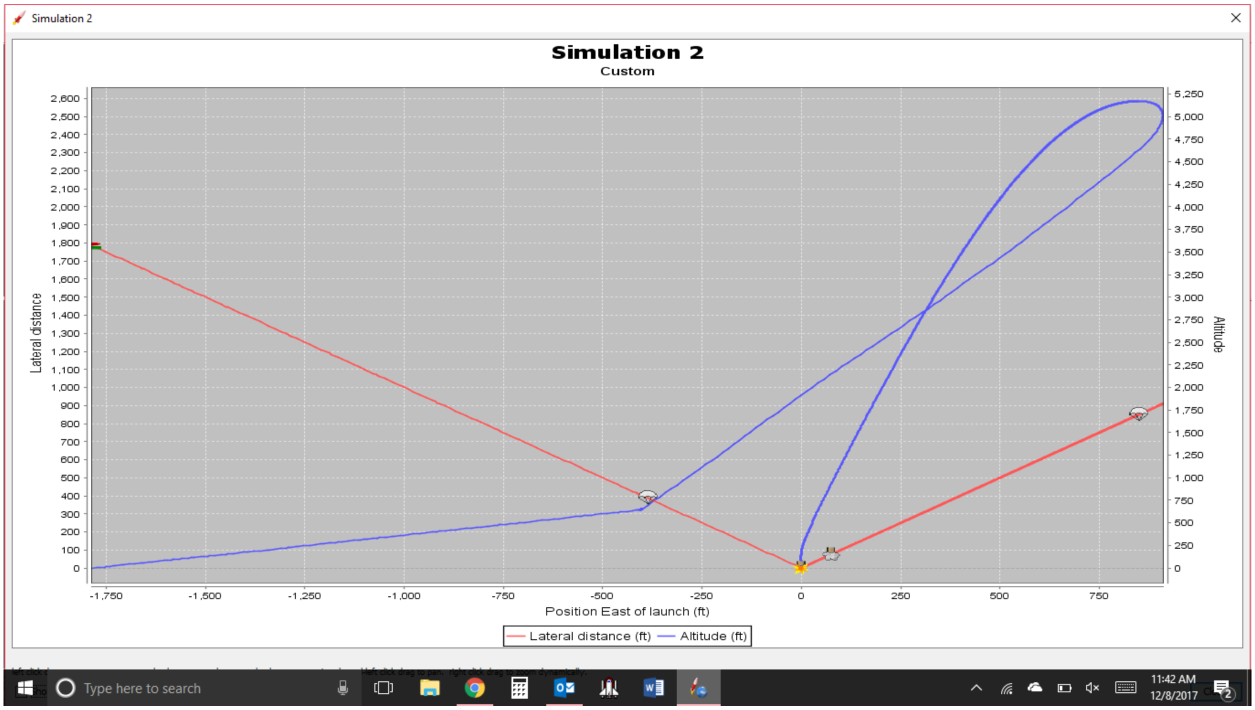
With an average wind speed of ten miles per hour with one mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 800’. The rocket travels nearly 550’ east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 800’ west of the launch position.

3.4.4.4. 15 MPH Drift Distance Calculations



With an average wind speed of fifteen miles per hour with 1.5 mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1,300’. The rocket travels nearly 650’ east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 1,300’ west of the launch position.

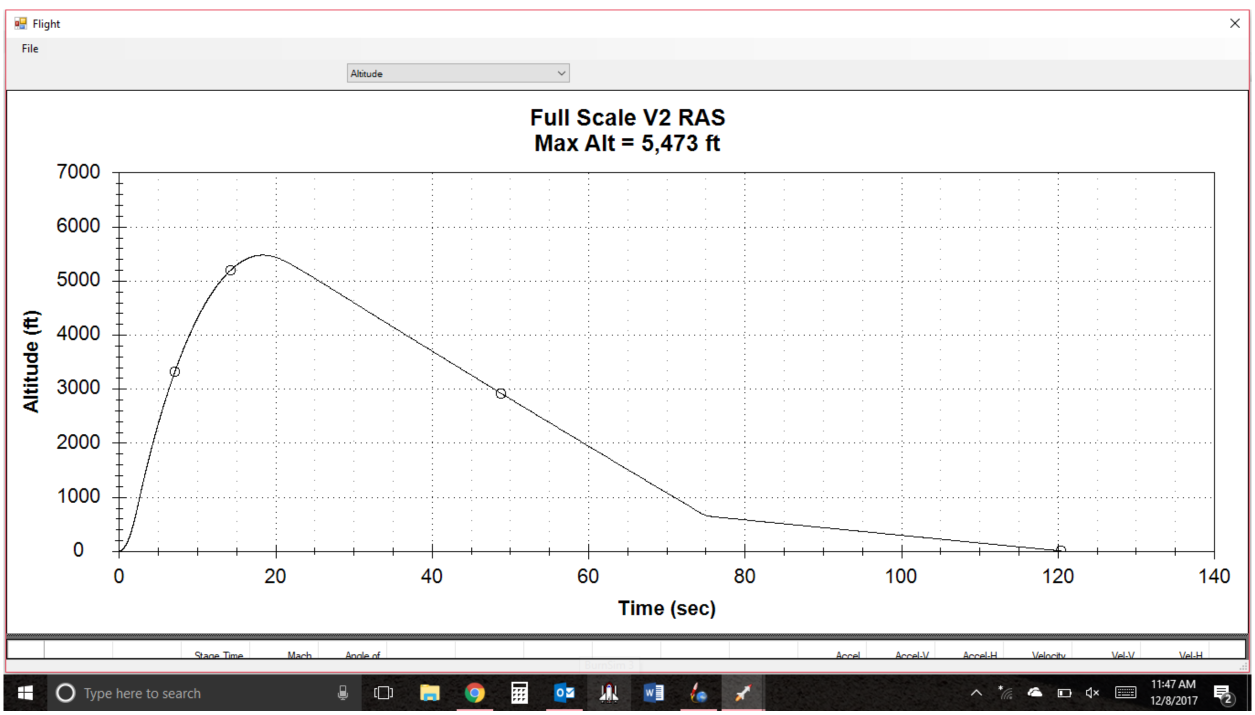
3.4.4.5. 20 MPH Drift Distance Calculations



With an average wind speed of twenty miles per hour with 2 mile per hour standard deviation and 10 percent turbulence intensity, our simulated maximum drift distance during flight is roughly 1,800'. The rocket travels nearly 900' east of the launch site as it tilts into the wind, then drifts back over the launch site during recovery and continues heading west until touchdown 1,800' west of the launch position.

3.4.5. RASAero Calculations

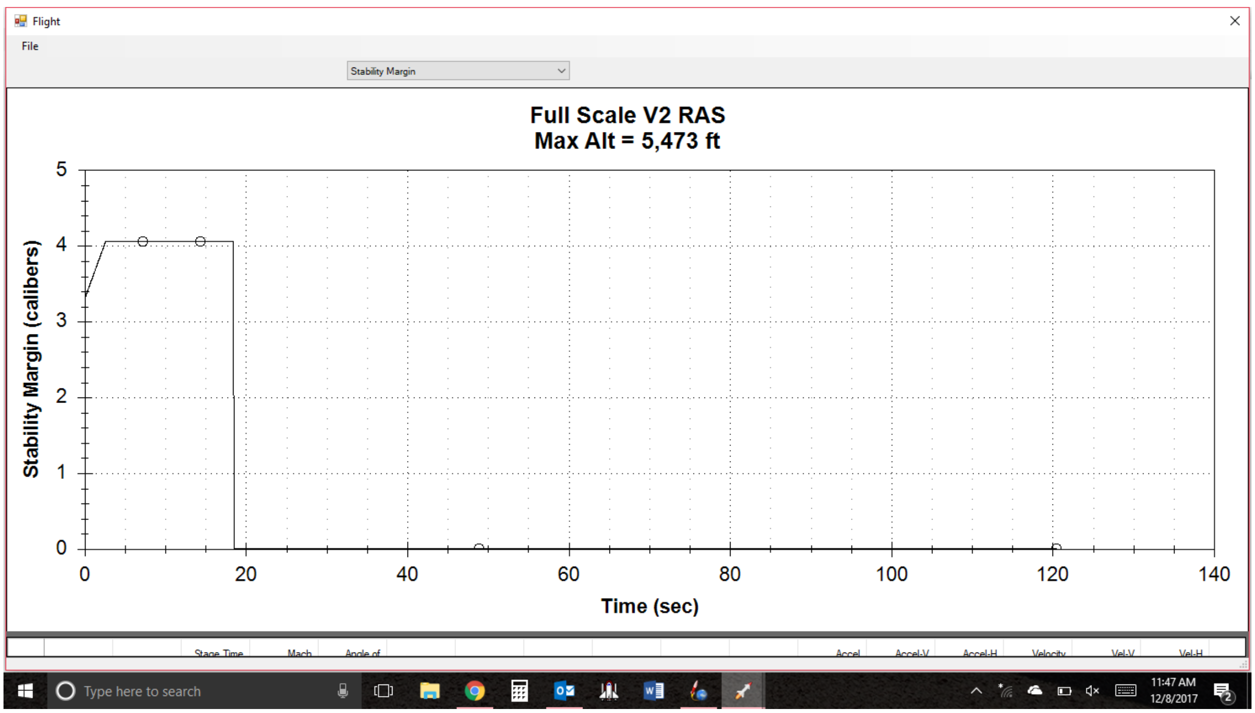
3.4.5.1. Altitude Predictions With Simulated Vehicle Data

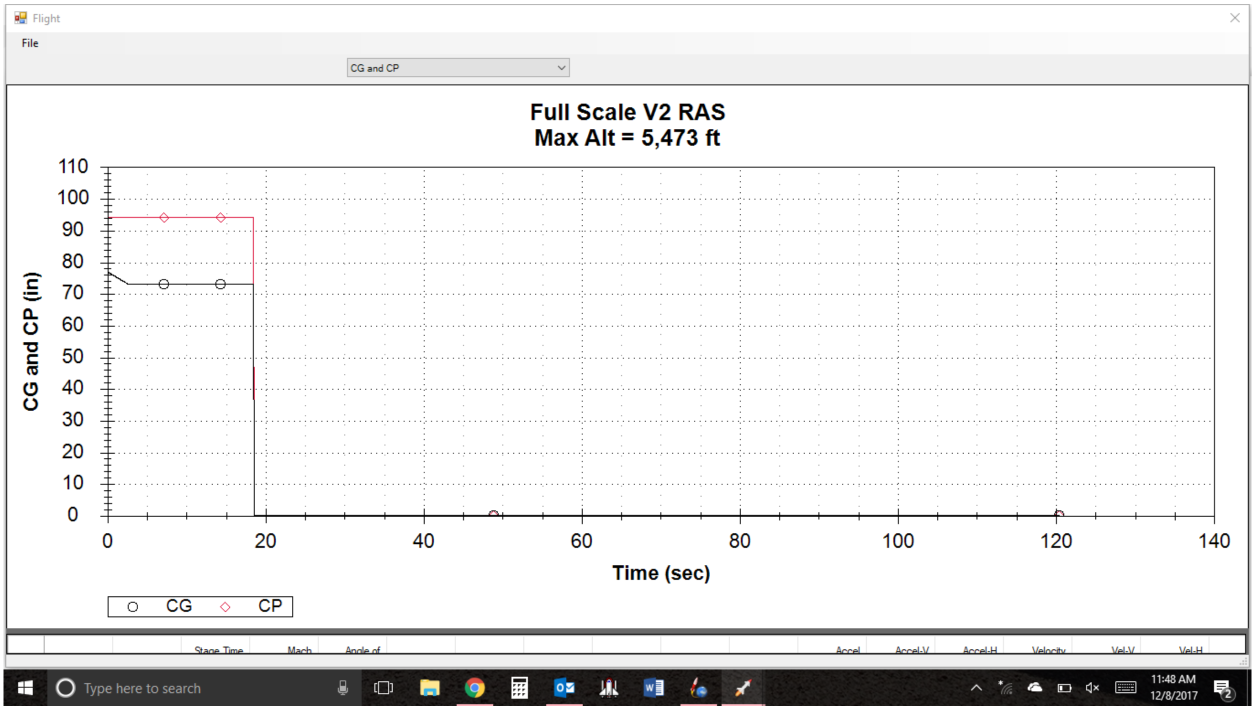


The graph above, which was produced using RAS Aero II, is a result of running an identical simulation as the team performed with OpenRocket 15.03. All simulation settings were the same, and the vehicle dimensions and metrics were input manually. As a result, the same rocket flying on the same motor is predicted to achieve a maximum altitude of 5,473 feet above ground level. This is an increase of 192' over the OpenRocket simulations, and a total of 193' over the target altitude of one mile.

Originally, RAS Aero II had a 242' difference than our OpenRocket 15.03 model. We believe that this was due to a missetting of the surface finish. After adjusting the smoothness of the vehicle, the models began approaching each other once again. We will continue to iterate the design in both programs as changes are made and weights are updated. In time, our group expects the difference in the models to decrease and approach the desired altitude of 5,280 feet.

3.4.5.2. Stability Margins With CP/CG Relationships and Locations

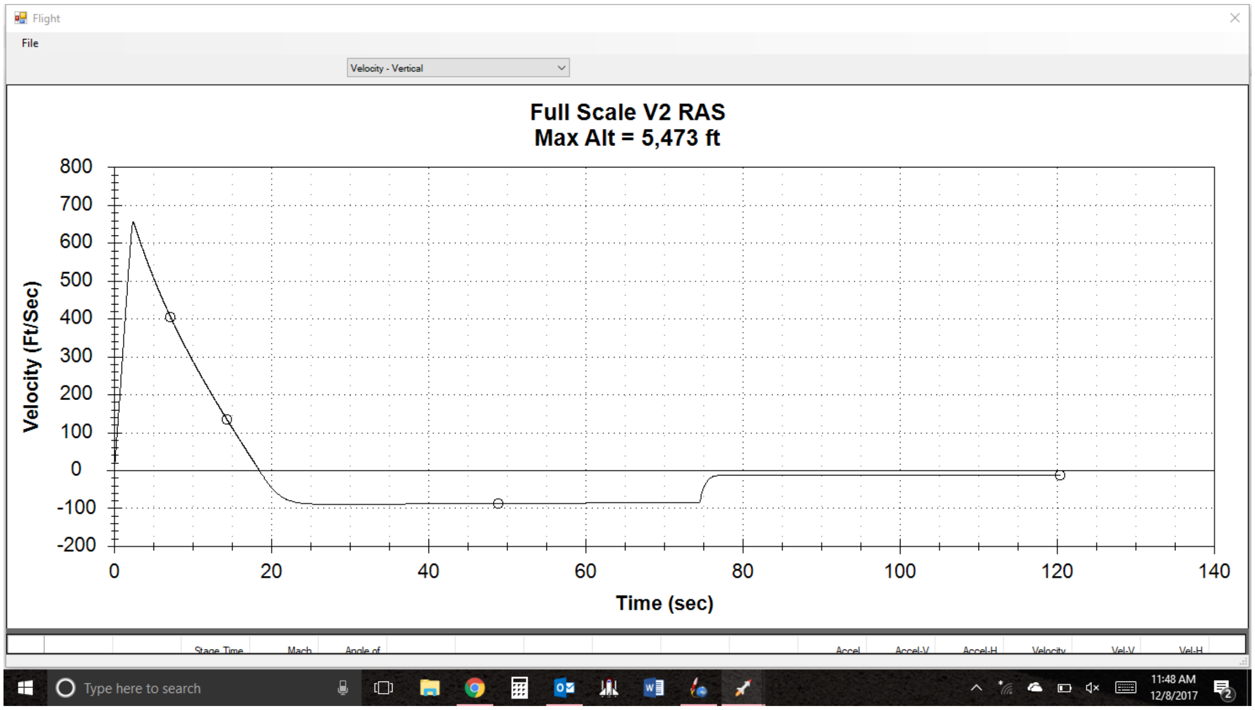




The stability margin graph shown above, produced using RASAero II, shows similar results to the stability curve produced in OpenRocket. The static stability is approximately 3.4 calibers, but is higher than the stability at the time of launch rail clearance which is estimated by OpenRocket to be nearly 2.5 calibers. OpenRocket does, however, calculate the static stability to be 3.38 calibers, so these estimates do in fact reinforce each other. Furthermore, RASAero predicts the stability during the coast phase to be approximately 4.1 calibers after expelling all of the propellant mass. This, again, is roughly equal to the stability predicted by OpenRocket.

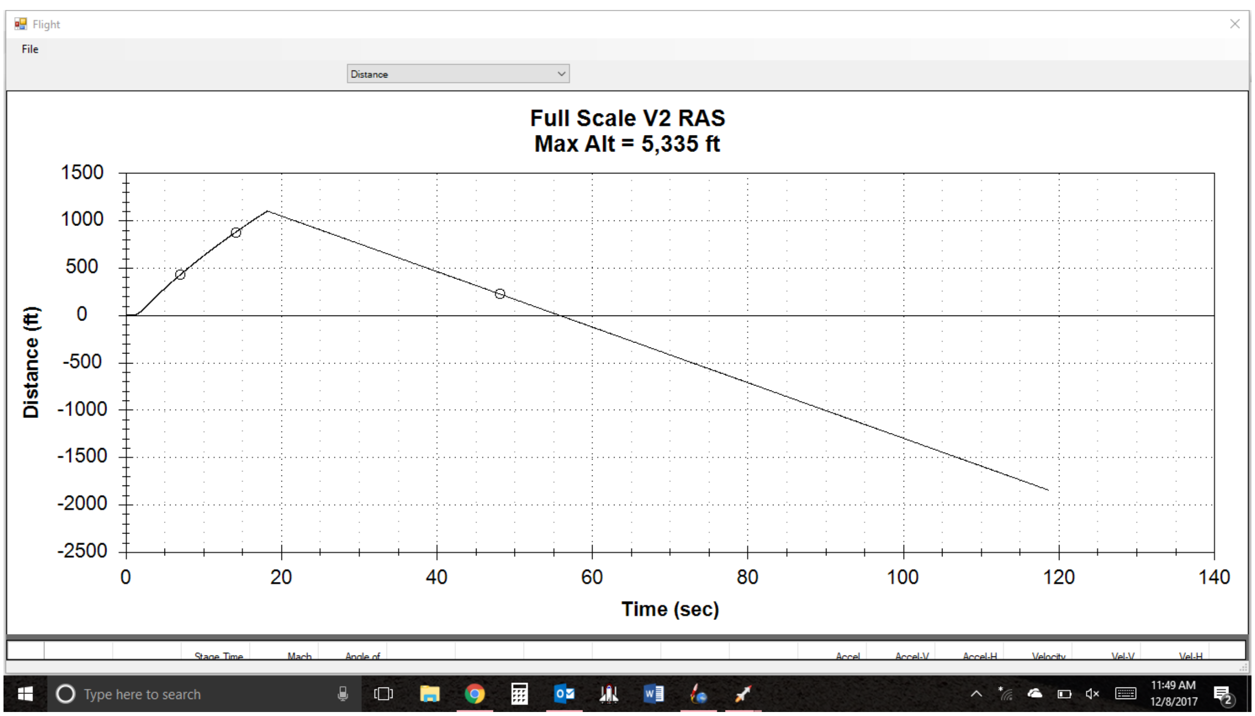
In addition, the location and change in both the center of pressure and center of gravity are approximately equal to those in OpenRocket 15.03. The center of gravity starts at 77” from the datum and moves nearly one full caliber forward. The center of pressure in OpenRocket started at less than 90” from the tip of the nosecone and moved aft to approximately 94”, which is roughly equal to where RAS Aero II places the center of pressure during the flight simulation.

3.4.5.3. Kinetic Energy At Landing



The graph above was created using RASAero II and depicts the vertical velocity of our vehicle during the flight. Just as in OpenRocket, the terminal velocity during drogue descent is roughly one hundred feet per second and terminal velocity during main descent is approximately fifteen feet per second. These figures are nearly identical between the two independent simulation platforms.

3.4.5.4. Drift Distance Calculations



The image above shows the drift of our launch vehicle while flying in twenty mile per hour winds, similar to the drift model created in OpenRocket 15.03. The rocket originally drifts approximately 1,200’ in one direction as it tilts into the wind on ascent. At apogee, the rocket begins drifting back towards the launch site, passing it and continuing to drift a further 1,800’ past the point of origin. The maximum distance of 1,800’ is a close approximation of the model created in the other simulation platform, but RAS Aero II predicts that the rocket will tilt into the wind and travel an additional 300’ than OpenRocket predicted. As a result of this increased tilt, the apogee altitude varies slightly as well. The original RAS model simulated a maximum altitude of 5,473’, but only reaches 5,335’ when factoring wind and tilting.

3.4.6. Differences between Calculations

Generally speaking, the two simulation platforms produce nearly identical numbers for altitude, stability, and descent velocity. The altitude predicted from RASAero, which had the highest variance, was still within a 4 percent margin of error of the OpenRocket estimate. As we mature our computer simulations to match our real world weights and metrics, we predict that the differences between the simulations will decrease. If this is not the case, we will begin simulating the vehicle in a third platform, such as RockSim.

4. Safety

4.1. Launch Concerns and Operation Procedures

4.1.1. Draft Of Final Assembly and Launch Procedures

4.1.1.1. Recovery Preparation

General Information:

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down
- Do not attempt to recover the rocket from atypically dangerous areas to avoid personnel injury from dangerous terrain
- If the rocket becomes entangled with power lines upon its return to the ground, call the power company and stand clear until proper personnel arrive to avoid electrocution hazards
- Leave no trace during retrieval to minimize pollution from team members

Preparation for retrieval:

- Ensure the rocket is being launched in an area which will not complicate retrieval; there should be an extremely minimal chance that the rocket will collide with personnel or onlookers, man-made structures, or wildlife, and the area which the rocket is expected to land in should not feature dangerous terrain or power lines
- Carefully pack each parachute using the “burrito” technique to prevent shroud line tangling. Any team member who packs the parachute or connects the shock

cord must be supervised by at least one other team member who is using the safety checklists
- Completely tighten all quick links, shear pins, screws, and motor retainers prior to flight to reduce the chance of parts falling from the rocket

During retrieval:
- Before approaching the rocket, observe whether or not it seems there is still fuel present within. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution, then ensure the motor is isolated and/or the fuel is safely disposed of; fire protection services may be needed for this task.
- Double-check the area around the rocket before approaching to ensure there are no hazards from nearby terrain or man-made structures such as power lines
- Extinguish any fires present to avoid burn hazards and care for the surrounding environment
- Double-check for sharp edges from damaged parts to avoid cuts or lacerations, especially before making physical contact with the rocket
- Once the above points have been acknowledged appropriately, and all post-flight inspection procedures have also been followed, the rocket may be prepared for transport
- If the rocket was damaged enough during flight for parts to fall off, ensure these parts are also retrieved appropriately so unwary passerby do not get involved with them. Apply the same safety procedures to these parts one would with the rocket as a whole
- Do not forget to also check the launchpad for damage, nor to clean it and take it down to prepare it for travel!

After retrieval:
- Double-check the rocket thoroughly for any damage which may have occurred during flight to avoid possible mishaps during the next use of the rocket
- Replace/charge all batteries prior to or in between flights to ensure they are ready for the next use of the rocket
- Securely attach all batteries to their electronics sled using both zip ties and electrical tape to ensure they are secure and will not be lost
- Securely prepare the rocket and launchpad during transportation to prevent damage during the journey to the next destination

4.1.1.2. Motor Preparation

The motor used in this project will be the Aerotech Rocketry L1520 Blue motor, and instructions regarding its preparation will be supplied with the purchase of the motor. The preparation procedures defined by Aerotech Rocketry must be followed word-for-word by team members when preparing the motor. If the motor is not prepared properly, the following hazards could occur:

- A CATO (catastrophic failure)
- A fire
- Motor ignition failure
- Combustion instability
- The rocket launches at an unpredicted time
- The rocket's flight is unstable
- The motor exits the rocket at ignition or during boosts

Before working with the motor, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

To accompany Aerotech Rocketry's instructions, general guidelines for motor preparation are as follows:

- Double check to ensure the motor is proper for the desired flight profile and certified by NAR, Tripoli, or CAR.
- Ensure the motor is unused, has not been tampered with in any way, and is being used for a purpose recommended by the manufacturer.
- Ensure the motor casing and nozzle are in good condition and have no defects or cracks.
- Check that the motor mount is secure, is in good condition, and will not deflect motor thrust.
- Ensure the use of a blast deflector to prevent the motor's exhaust from hitting the ground.
- Check the stability of the rocket after installing the motor, and ensure the nose cone does not fit too tightly into the body tube as this can cause the motor to be expelled by the ejection charge.

It is important to closely follow proper safety procedures and the manufacturer's instructions when preparing the motor, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the preparation of the motor while filling out the pre-launch checklist.

4.1.1.3. Setup On Launcher

General Information:

- PPE required for all launch setup procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down

- Ensure conditions are proper for launch before beginning setup. Check hazard analysis and contingency plans for all conditions which mean you should not launch, such as lightning or excessive wind speeds
- Have appropriate first aid materials, such as a first aid kit, and fire-fighting materials, such as a fire extinguisher, on hand to deal with a medical emergency or launchpad fire if one arises. Also have a communication device with which to contact emergency personnel in the case of a launchpad fire or serious injury
- Have a backup launching area and backup launch dates in case the planned launch area is unavailable for some reason. Doing this can prevent delays in retrieving launch data

Before setup
- Choose a launch site at which rigid ground is available to prevent personnel from falling and to prevent the launch pad from sinking and causing an unplanned trajectory
- Choose a launch site which is greater than 750 meters from any water sources
- Choose a launch site with high visibility and minimal threats from passerby, weather, wildlife, man-made structures, or dangerous terrain

During setup
- Ensure the ground is stable before placing the launch pad. If there are minor worries about unstable ground, place a rigid system which can be used for support underneath the launch pad, such as wooden planks. If there are serious worries about unstable ground, find a better launch site
- At least one personnel member must be watching the launch pad at all times after placing it to ensure it does not change from its intended position and no wildlife or weather tampers with its condition
- Ensure launch rails are not bent or twisted to prevent an unplanned or ballistic trajectory
    - Check for additional abrasions or other damage as well to ensure the rocket starts in a vertical trajectory.
    - Unfold launcher legs and place the launchpad on firm ground.
    - Make sure said ‘firm ground’ is dry and has minimal amounts of dust to ensure a clean ignition.
    - Clear all obstructions and keep any flammable objects (barring the rocket itself) 100 feet away from the launcher.
- Ensure launchpad support struts are not bent, cracked, rusted, or showing other signs of damage to prevent an unplanned or ballistic trajectory
- Ensure the launch rail is properly lubricated, if necessary, so all planned ejections occur and the rocket achieves the planned height and follows the planned trajectory

- Clean launchpad of any dust, pebbles, or anything that can turn into a projectile due to jetblast to prevent injury to onlookers
- Double-check to ensure that the launch pad has not sunk from its intended position due to unstable ground
- After observing the above safety precautions, carefully transport the launch vehicle to the launchpad without damaging it. Then, slide the launch vehicle onto the rail, ensuring it is firmly secured and all rail buttons are well-aligned and are properly attaching the rocket to the launchpad
- Once the rocket is firmly attached to the launch rail, check it over at least two times for damage or leakages
- Double-check that all batteries in the rocket are firmly secured and are at a desirable charge level to prevent payload or avionics bay failure, which can result in failure of the mission goals or failure to eject parachutes at the desired time
- Make the necessary adjustments to the payload and the avionics bay to prime everything for performance during the launch. Double-check that all connections have been properly made in the avionics bay and to the payload, that both the avionics bay and payload have not been damaged, and that the avionics bay and payload are thermally insulated, as any of these issues could cause payload or avionics bay failure
- Check to make sure the igniters have not been damaged in any way, are functional, and have been obtained from a reliable source and then attach the igniters to the rocket. This process must be done under the supervision of at least one other team member who is using the safety checklists
- Double-check to make sure all components of the rocket are securely attached and fastened
- If no damage is found on the rocket or launch pad, the rocket is securely attached to the launch pad and control systems, and the launch pad and control systems are in good condition, retreat to a safe distance and proceed with ignition procedures

4.1.1.4. Igniter Installation

The igniters used in this project will be supplied with the purchase of the Aerotech Rocketry L1520 Blue motor. The installation procedures for the igniters will be defined by the accompanying instructions from Aerotech Rocketry. These instructions must be followed word-for-word by team members. If the igniters are not installed properly, the rocket may misfire or launch too early.

Before working with the igniters, all team members must secure loose hair and clothing, wear closed-toe shoes, and remove jewelry. Team members must also wear ANSI 787.1-certified safety glasses with a side shield and heat-resistant leather or canvas gloves for protection in the case of an accident.

To accompany Aerotech Rocketry's instructions, general guidelines for igniter installation are as follows:

- Before approaching the rocket with the igniters, inspect the launch control mechanism to ensure it is disabled and not communicating with the rocket. For example, ensure any safety keys being used are removed before connecting the wires of the igniters to their clips.
- Inspect the igniter wires before installation to ensure they are not touching each other.
- Inspect the igniter clips before installation to ensure they are clean.
- Use an igniter plug/holder to keep the igniter in place once it is installed.

It is important to closely follow proper safety procedures and the manufacturer's instructions when installing the igniters, as doing so greatly reduces the chances of an accident. To ensure proper procedures are followed, two team members must supervise the installation of the igniters while filling out the pre-launch checklist.

4.1.1.5. Troubleshooting

Construction

- Machine failure: Consult online information, the machine manual, or any staff members who may work with the machine about how to fix the problem. Attempt to find a planned machine to use as a backup while the machine is being fixed
- Damage to, loss of, or failure to receive parts: Attempt to order new parts and have them sent through expedited shipping. Extra parts should be kept in storage in case an issue like this arises
- Loss or unavailability of work area: If not done previously, select another work area and obtain permission to work in that area. Preferably, a secondary work area should be chosen and prepared prior to the occurrence of any emergency

Vehicle Components

- Rust or component expansion: Attempt to find suitable non-metal replacements for metal parts, store the rocket indoors, be aware that humidity might be the cause of the expansion
- Part failure, loss, or damage: Run simulations of the rocket's flight as well as stability and load-bearing tests and examine the affected area to determine how to improve the design of the rocket. Use spare parts to replace any lost parts or order new ones with expedited shipping if no spare parts are available
- Poorly aligned motor tube: Realign the motor using a level, and do not rush the process. Double-check the alignment of the motor before all flights

Ignition and Launch

- Rocket does not launch when the electrical launch system is used: Remove the launcher's safety interlock or disconnect its battery and wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket
- Ignition failure: Ensure a physical connection exists between the ignition controller's power source and the ignitor. Check for dust or damage on the alligator clips. Ensure all pyrotechnic compound used is dry, has no dust on it, and is unburnt and undamaged. Make sure the fuel grain has no dust or moisture on or in it and is undamaged. Ensure proper motor packing procedures were followed
- Loss or unavailability of launch area: If not done previously, select another launch area and obtain an FAA waiver for that area. Preferably, a secondary launch area should be chosen and prepared prior to the occurrence of any emergency
- Rocket disconnects or is unstable on the launch rail: Ensure the launch rail buttons are properly aligned and working as planned, double check that the rocket was attached to the launch rail buttons using proper procedures, ensure the rail itself was set up using instructions which came with the product

Aerodynamics

- Adverse effects from drag: Ensure the appropriate amount of shear pins, fasteners, and vent holes are being used
- Unpredictable trajectory: High wind speeds, mid-air collisions, or damage to rocket components may have caused this. Wait for wind speeds to lessen, ensure there are no obstacles in the flight path, and check all components of the rocket for damage
- Instability: Measure the physical center of gravity and compare it to the calculated center of pressure. Run simulated stability tests. Make changes as necessary to increase the stability margin by adding ballast or changing fin size

Avionics and Payload

- Altimeter failure or loss of continuity: Between rounds, check and secure motor connections with alligator clips and masking tape. Double check altimeter settings. Check batteries and electronic connections to ensure they are working as planned
- Loss of signal from GPS: Postpone flight and check the GPS unit, signal continuity, and batteries between flight
- Arming system failure: Consult the manufacturer's instruction manual, ensure the system is undamaged and communicating properly with the team before initiating the next flight

- Overheating of avionics or payload: Ensure the avionics bay and payload are properly thermally insulated. If they are not, take efforts to insulate them with putty. Ensure the avionics bay and payload are not overloaded with wiring, as this can cause overheating and even fire hazards
- Inappropriate or no ejection: Check altimeters for damage and ensure they are being run with proper settings. If everything is in working condition, check remaining ejection charges for damage and ensure they are being properly packed
- Payload camera fails or takes poor quality pictures: Test the payload camera on the ground, double-check batteries and connections related to the camera, check the performance of the payload computer used by checking its batteries and connections, and double check that the rocket followed its planned flight path and was stable
- Poor overall electronic performance: Test the reliability of the wiring and batteries. If doing so yields no results, overly wet atmospheric conditions may have caused this. Try launching on a different date or at a different location

Recovery

- Parachute deployment failure: Ensure proper parachute and ejection charge packing procedures are being followed, check that there was no damage to the parachute beforehand, ensure spacing between the ejection charges and parachutes is proper, check for altimeter failure, and ensure there is no excessive velocity when the parachute system is being deployed. The recovery system mount for the parachute should also be examined to see if it is working as planned and is undamaged
- Stage separation failure: Ensure faulty ejection charges are not being used, ensure ejection charges are being packed properly, double check the design of the rocket to ensure the strength of the bonds holding the stages together is not excessive, and check for altimeter failure
- Shock cord issues: Ensure the shock cord is of the proper size and is being packed properly, ensure the shock cord has been bought from a reliable source and is not damaged, and ensure any parachute which the shock cord may have been tangled in is the correct size for the rocket
- Excessive or insufficient landing speed: Check parachutes for damage and ensure they are properly sized, packed, and protected from harm

Personnel

- Low amounts of communication: Encourage members to talk to each other about the project, have an organized group of subteams within the project and obtain updates from subteam leaders weekly

- Inactivity: Train all members to work in all areas necessary, track and encourage meeting attendance, encourage members to bring friends to meetings, improve communication
- Low availability of personnel: Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they can work around them, attempt to help team members prevent their semester schedules from being too strenuous by giving them quality advice
- Conflicts of important academic or personal events with team events: Talk to the parties concerned well in advance of the conflicting event to try and work out a change of date
- Hypothermia: Call medical personnel immediately if hypothermia is suspected. Warm the person slowly, focusing on warming the chest area first as warming the limbs before the core may cause shock. Dry the person and remove wet clothing, if needed. Do not immerse the person in warm water and do not directly apply heat sources such as water bottles or heat packs to the person without first wrapping them in cloth. Give the person CPR if necessary and, if they are responsive, give them a warm drink which does not have alcohol or caffeine in it. As body temperature rises, warm the person's head and neck as well
- Heatstroke or heat exhaustion: Call 911 if the situation is serious, i.e. the affected person is being extremely unresponsive. Attempt to lower the body temperature of the affected person using cold water, ice, or cooling blankets. Get the affected person to a shaded or air-conditioned place, and give them water to hydrate
- Physical injury: Call medical personnel immediately if the injury is serious. Attempt to slow any bleeding using cloth or a similar substance - if safety procedures have been followed, a first aid kit should be nearby. Treat the affected person for shock if the wound is of moderate severity or greater; however, be cautious of moving the affected person if it is believed that doing so could cause them more harm. If that is the case, the situation is best left to medical personnel and you should not attempt to move the affected person
- Electrocution: Call medical personnel immediately. Separate the person from the electric source by turning its power off or standing on a non-conductive object and using another non-conductive object to remove the person from the source. Do not try to separate the person from current with a high-voltage source if you feel a tingling sensation in your legs and lower body. Hop on one foot to a safe place where you can wait for a power company or emergency personnel to disconnect the source. After removing the affected person, do CPR if necessary and check for other injuries while waiting for medical personnel to arrive
- Chemical contact: Shower the chemical off the affected area with water; if the chemical got in the eyes, apply water to the eyes, preferably with the use of an

eyewash station. If a chemical was swallowed, call the poison hotline immediately at (800) 222-1222. If a dangerous situation persists after washing the area with water, call 911

4.1.1.6. Post Flight Inspection

General information

- PPE required for all recovery and post-flight inspection procedures: ANSI Z87.1 safety glasses, leather or canvas gloves, closed-toe shoes or boots, and clothing which covers all exposed skin from the neck down
- Before beginning inspection, it may be necessary for competition officials to verify the results of the launch. Be aware of this
- Components of the rocket which have been damaged during flight may be dangerous to touch. Take extra care to observe the rocket closely before making physical contact with it, especially in the area which will be touched
- Components of the rocket may also be hot to the touch for a small span of time after the fuel stops burning. Be aware of this and be sure to wear appropriate PPE before making physical contact with the rocket

Exterior rocket inspection

- Before approaching the rocket, observe whether or not it seems there is still fuel present within. If unburned fuel is present, wait for the fuel to safely burn away. If the fuel is not burning away, clear the surrounding area of fire hazards while exercising extreme caution, then ensure the motor is isolated and/or the fuel is safely disposed of; fire protection services may be needed for this task.
- After handling unburned fuel check the rocket for any missing parts. If there are missing parts, enforce the team's best efforts to locate them in order to minimize pollution to the environment and to recover as much of the rocket as possible
- Make sure all fasteners, joints, and shear pins are undamaged and secured in place
- Check the nose cone for damage such as cracks, holes, or warping
- Check the body tube for damage. Look for any bending or twisting of the body tube and make sure there are no holes other than the ones necessary for the payload. Dry off the body tube of any water accumulated during flight, either from vapor or upon landing
- Check the fins and any other aerodynamic surfaces for twisting or cracking

Interior rocket inspection

- Ensure that all ejection charges were successfully and safely deployed. If ejection charges remain unfired in the rocket even though they should have gone off, exhibit extreme care when removing and disposing of them, ensuring that proper PPE is worn and no flammable objects are nearby. Remove and dispose of the rest of the ejection charges safely and with care as well

- Verify that the recovery system was fully and successfully deployed and that it suffered no damage throughout the rocket's flight. Check to make sure there are no tears in the parachute, the shock cord and parachute shroud lines are in good condition, and the recovery system mount on the rocket is firmly secured and free of signs of stress such as cracks or torsion. Also check the recovery system for signs of heat damage, as that means the packing methods being used are poor or the spacing between the recovery system and the ejection charges is incorrect
- Check the motor for damage such as cracks or nozzle bending and check the centering rings and motor mount for signs of strain such as cracks or bending. Ensure the motor tube is still angled correctly and is tightly secured if the rocket is to be used again in the future
- Check bulkheads for damage such as cracks or bending
- Check the avionics bay and the payload for internal damage and failures. In the event of a hazardous material leak, such as that from damaged lithium ion batteries, notify fire personnel and clear the immediate area
- Recover any data and footage from the flight; only after retrieving the data should the avionics and payload be disarmed. After disarming the avionics bay and payload, disarm the launch controller

Pad inspection

- Ensure the launch rails show no signs of damage, such as deformation or bending
- Ensure the launchpad's support legs and struts show no signs of damage, such as cracks or deformities
- Clean the pad of dust left by the rocket exhaust or any other dirt which it has accumulated. Ensure this waste is disposed of safely
- Once the launch pad has been checked for damage and cleaned properly, it may be taken down and prepared for safe transportation

4.2. Safety and Environment (Vehicle and Payload)

The seriousness of the risks discussed in this section will be evaluated by two criteria: the likelihood of an event to occur and the impact of the event should it happen or fail to be prevented. Categories of likelihoods and impacts are discussed below:

Likelihood Of Event

Category	**Value**	**Gauge**
Remote	1	Less than 1% chance of occurrence.
Unlikely	2	Less than 20% chance of occurrence.

Possible	3	Less than 50% chance of occurrence.
Likely	4	Less than 85% chance of occurrence.
Very Likely	5	Greater than 85% chance of occurrence.

Impact of Event

Category	**Value**	**Gauge**
Negligible	1	Minimal injury, damage to equipment or facility, or environmental effects. Flight continues as normal.
Minor	2	Minor injuries, major reversible damage to equipment or facility, and minor environmental impact. Flight proceeds with caution.
Moderate	3	Moderate injuries, reversible failure, and reversible environmental impact. Flight is put on hold until effects are reversed.
Major	4	Potentially serious injuries, partial failure, and serious, reversible environmental effects. Flight is scrubbed or put on hold until system is removed.
Disastrous	5	Potentially life threatening injury, total failure, and serious, irreversible environmental damage. Flight is scrubbed or completely destroyed.

By cross examining the likelihood of an event with the impact it would have if it occurred, a total risk can be calculated which is detailed in the table below. The color code displayed is as follows:

- Green: Minimal risk
- Yellow: Low risk
- Orange: Medium risk
- Light red: High risk
- Dark red: Very high risk

Category	**Negligible**	**Minor**	**Moderate**	**Major**	**Disastrous**
Remote	1	2	3	4	5
Unlikely	2	4	6	8	10
Possible	3	6	9	12	15
Likely	4	8	12	16	20
Very Likely	5	10	15	20	25

4.2.1. Project Risks

The following hazards threaten the progress or completion of the project as a whole:

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**
Improper Funding	3 (Lack of revenue)	5 (Inability to purchase parts)	15, High	Create and execute a detailed funding plan properly, minimize excessive spending by having multiple members check the necessity of purchases
Failure To Receive Parts	2 (Shipping delays, out of stock orders)	5 (Cannot construct and fly vehicle)	10, Medium	Order parts while in stock well in advance of needed date
Damage to or Loss of Parts	2 (Failure during testing, improper part care during construction, transportation, or launch)	5 (Cannot construct or fly vehicle without spare parts)	10, Medium	Have extra parts on hand in case parts need to be replaced, follow all safety procedures for transportation, launch, and construction
Rushed Work	2 (Rapidly approaching deadlines, unreasonable schedule expectations)	4 (Threats of failure during testing or the final launch due to a lower quality of construction and less attenktion paid to test data)	8, Medium	Set deadlines which both keep the project moving at a reasonable pace and leave room for unforeseen circumstances
Major Testing Failure	2 (Improper construction of the rocket, insufficient data used before	5 (Damage to vehicle parts, possible disqualificatio n from the	10, Medium	Only include reliable elements in the design which have been confirmed to work

	creating the rocket's design)	project due to a lack of subscale flight data, an increase in budget for buying new materials, delay in project completion)		through prior designs or extensive mathematical and physical analysis
Unavailable Test Launch Area	2 (Failure to locate a proper area to launch subscale rockets for testing, failure to receive an FAA waiver for the test launch)	5 (Disqualification from the project due to a lack of subscale flight data)	10, Medium	Secure a reliable test launch area and FAA waiver well in advance of the dates on which test launch data is required
Loss or Unavailability of Work Area	1 (Construction, building hazards, loss of lab privilege)	4 (Temporary inability to construct vehicle)	4, Low	Follow work area regulations and have secondary spaces available
Failure in Construction Equipment	1 (Improper long-term maintenance of construction equipment, improper use or storage of equipment)	3 (Possible long-term delay in construction)	3, Low	Ensure proper maintenance and use of construction equipment and have backup equipment which can be used in case of an equipment breakdown
Insufficient Transportation	1 (Insufficient funding or space available to bring all project members to launch sites or workplace)	3 (Loss of labor force, team members lose knowledge of what is happening	3, Low	Organize and budget for transportation early and keep track of dates on which large amount of transportation are needed

		with the project, low attendance to the final launch)		
Design Flaw	2 (Program logic error, improper data entry, oversight)	5 (Inability to complete objectives or construct vehicle)	10, Medium	Collaborate and share design files for peer evaluation
Lack of Communication	3 (Members fail to keep other members updated on their personal progress and pertinent information they are aware of)	3 (Possible oversight of important deadlines or project aspects, possible delays to the project from a design which does not mesh well)	9, Medium	Encourage members to talk to each other about the project, have an organized group of subteams within the project and obtain updates from subteam leaders weekly
Inactivity	2 (Members are unable or unwilling to work)	5 (Low attendance, loss of team members, labor shortages, inability to construct vehicle)	10, Medium	Train all members to work in all areas necessary
Low Availability of Personnel	2 (Classes become extremely involved, other extracurriculars have events which cannot be skipped)	2 (Labor shortages, low attendance, specific responsibilitie s of absent team members are overlooked)	4, Low	Determine who has time to complete tasks and declare those members responsible, ensure the schedule and deadlines are known by all team members so they can work around them, have team

				members prevent their semester schedules from being too strenuous
Personal Injury	2 (Members are unable to work)	3 (Temporary loss of team member and labor force)	6, Low	Keep first aid kit on hand at all times and train all members to follow procedures
Damage By Non-Team Members	1 (Accidental damage caused by other workspace users)	4 (Extensive repairs necessary, delay in construction)	4, Low	Separate all components from other areas of the workspace as necessary
Improper Transit Availability for Rocket	1 (No safe way to transport the subscale rockets or final rocket to the launch site)	5 (Failure to launch)	5, Low	Organize rocket transportation well in advance
Damage During Transit	2 (Mishandling)	5 (Inability to fly rocket)	10, Medium	Protect all rocket components during transit
Calendar Conflicts	3 (Overlap with classes)	4 (Inability of team members to travel)	12, Medium	Inform professors and concerned persons about overlap ahead of time
Failure to Plan for Breaks and Holidays	1 (Unreasonable expectations of team members)	1 (Slight delay in project progress)	1, Minimal	Do not expect a large amount of progress over breaks and holidays, as members will likely be busy and/or distanced from the designated workplace
Weather Delays	3 (Poor weather conditions	5 (Possible disqualificatio	15, High	Have multiple dates available on which

	during test launches, such as high wind speeds, ice and frost, or storms)	n from the project due to a lack of subscale flight data)		test launches can be conducted in case of adverse weather conditions

4.2.2. Personnel Hazard Analysis

The following hazards are threats to team members and bystanders presented by the project:

Stage of Project	**Hazard**	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**
Construction	Power Tool Cuts or Lacerations	3 (Careless construction procedures)	4 (Possible hospitalization)	12, Medium	Secure loose hair, clothing, and jewelry; wear appropriate PPE; brief personnel on proper construction procedures
Construction	Entanglement with Construction Machines	3 (Loose hair, clothing, or jewelry)	5 (Severe injury, death)	15, High	Secure loose hair, clothing, and jewelry; wear appropriate PPE
Construction	Electrocution	3 (Improper use of equipment, static build-up)	4 (Possible explosion, destruction of electrical tools or components, possible severe harm to personnel)	12, Medium	Give labels to all high voltage equipment warning of their danger; ground oneself when working with high-voltage equipment
Construction	Physical Contact With Heat Sources	3 (Contact with rocket parts which were recently worked with, improper use of soldering	3 (Moderate to severe burns)	9, Medium	Wear appropriate PPE, turn off all construction tools when not in use, be aware of the safety

		iron or other construction tools)			hazard that parts which were recently worked with present)
Construction	Falling Hazards	3 (Improper use of ladders, attempting to climb unstable objects)	4 (Bruising, abrasions, possible severe harm if falling into construction equipment)	12, Medium	Do not climb objects which are not ladders, when using ladders have another person present to stabilize the ladder
Construction	Tripping Hazards	3 (Materials which were not returned to a safe location after use, loose cords on or above the ground during construction processes)	4 (Bruising, abrasions, possible severe harm if tripping into construction equipment)	12, Medium	Brief personnel on proper clean-up procedures, tape loose cords or wires to the ground if they must cross a path which is used by personnel
Construction	Physical Contact with Falling Construction Tools or Materials	3 (Materials which were not returned to a safe location after use)	5 (Bruising, cuts, lacerations, possible severe physical injury)	15, High	Brief personnel on proper clean-up procedures, wear shoes that cover the toes
Construction	Dust or Chemical Inhalation	3 (Airborne particulate debris)	3 (Short to long-term respiratory damage)	9, Medium	Wear appropriate PPE or respirator, work in well ventilated area
Construction	Eye Irritation	3 (Airborne particulate debris)	2 (Temporary eye irritation)	6, Low	Wear appropriate PPE or protective eyewear, wash with water

Construction	Contact with Airborne Chemical Debris	3 (Airborne particulate debris)	2 (Minor burns, abrasions)	6, Low	Wear appropriate PPE such as gloves or lab coats, wash with water
Construction	Direct Contact with Hazardous Chemicals	3 (Chemical spills, improper use of chemicals)	3 (Moderate burns, abrasions)	9, Medium	Wear appropriate PPE such as gloves or lab coats, wash with water
Construction	Workplace Fire	2 (Unplanned ignition of flammable substance, through an overheated workplace, improper use or supervision of heating elements, or improper wiring)	5 (Severe burns, loss of workspace, irreversible damage to project)	10, Medium	Have fire suppression systems nearby, prohibit open flames, and store energetic devices in Type 4 magazines
Construction	Unintended Black Powder Ignition	3 (Accidental exposure to flame or sufficient electric charge)	5 (Possible severe hearing damage or other personal injury)	15, High	Label containers storing black powder, one may only handle the black powder if he/she possesses a low-explosives user permit
Construction	Hearing Damage	2 (Close proximity to loud noises)	4 (Long term hearing loss)	8, Medium	Wear appropriate PPE such as ear muffs when using power tools

Launch	Heatstroke	3 (High temperatures on launch day)	3 (Exhaustion and possible hospitalization)	9, Medium	Wear clothing appropriate to the weather, ensure all members have access to water at launch
Launch	Hypothermia	3 (Low temperatures on launch day)	3 (Sickness and possible hospitalization)	9, Medium	Wear clothing appropriate to the weather, ensure all members have access to a warm area to rest at launch
Launch	Dehydration	3 (Failure to drink adequate amounts of water)	3 (Exhaustion and possible hospitalization)	9, Medium	Ensure all members have access to water at launch
Launch	Burns From Motor Exhaust	1 (Proximity to launch pad)	3 (Mild to moderate burns)	3, Low	Maintain minimum safe launch distances
Launch	Electrocution	2 (Improper use or construction of the control system)	4 (Potential serious injury to personnel)	8, Medium	Brief personnel on how to handle the control system, only use control systems which have been reliably tested and approved for use
Launch	Injury from Projectiles Caused by Jetblast	1 (Failure to properly clean launchpad, failure to wear proper PPE, failure to stand an	3 (Moderate injury to personnel)	3, Low	Clean the launchpad before use, ensure all members are wearing proper PPE for launch, ensure all team

		appropriate distance from the rocket during launch)			members are an appropriate distance from the rocket when launching
Launch	Injury from Ballistic Trajectory	3 (Recovery system failure)	5 (Severe injury, death)	15, High	Keep all eyes on the rocket and call “heads up” if needed
Launch	Injury from Falling Components	3 (Failure to keep all components securely attached to the rocket; result of improper staging constraints, part failure, or excessive vibration)	5 (Severe injury, death)	15, High	Keep eyes on the rocket at all times; make sure all team members who cannot watch the rocket have spotters nearby; alert others if the rocket enters a ballistic trajectory.
Launch	Premature Ignition	2 (Short circuit)	2 (Mild burns)	4, Low	Prepare energetic devices only immediately prior to flight
Launch	Premature Ignition Charge Detonation	2 (Exposure to heat, premature altimeter deployment)	2 (Mild burns)	4, Low	Only prepare igniters and ejection charges immediately prior to flight; only arm altimeters immediately prior to flight.
Launch	Launch Pad Fire	2 (Dry launch area)	3 (Moderate burns)	6, Low	Have fire suppression systems nearby and use a protective ground tarp

Recovery	Injury from Navigating Difficult Terrain	2 (Uneven ground, poisonous plants, fast-moving water)	4 (Broken bones, infections, drowning, etc.)	8, Medium	Do not attempt to recover the rocket from atypically dangerous areas
Recovery	Power Lines	2 (Rocket becomes entangled In lines)	5 (Severe electrocution hazards)	10, Medium	Call the power company and stand clear until proper personnel arrive
Recovery	Burn Hazards	3 (Rocket has not fully cooled, failure to take appropriate care around unburned fuel, failure to extinguish nearby fires before retrieving the rocket)	5 (Severe burn hazards)	15, High	Extinguish any fires present before recovering, wait for motors to fully burn before recovering, wear appropriate PPE when recovering
Recovery	Kinetic Damage to Personnel	1 (Failure to take appropriate care around unburned fuel, post-landing rocket explosion)	5 (Possible severe kinetic damage to personnel)	5, Low	Extinguish any fires before recovering, wait for motors to burn fully before recovering, wear appropriate PPE when recovering
Recovery	Cuts or Lacerations from Damaged Rocket Components	2 (Sharp edges from damaged parts)	3 (Moderate cuts or lacerations to personnel retrieving the rocket)	6, Low	Check the rocket for sharp edges before recovering, wear appropriate PPE when recovering

4.2.3. Failure Modes and Effects Analysis

The following hazards are threats to the vehicle used in the project and its successful completion of the mission:

Area of Interest	**Hazard**	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**
Vehicle Components and Construction	Instability	1 (Stability margin of less than 1.00)	5 (Potentially dangerous flight path and loss of vehicle)	5, Low	Measure physical center of gravity and compare to calculated center of pressure
Vehicle Components and Construction	Airframe Failure	1 (Buckling or shearing on the airframe from poor construction or use of improper materials, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical analyses of the body tube, bulkheads, fasteners and shear pins, make use of reliable building techniques, confirm analyses with test launches
Vehicle Components and Construction	Fin Loss or Damage	1 (Poor construction or improper materials used, faulty aerodynamic modeling, damage after landing from previous flights)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive mathematical and physical flight analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches, check to make

					sure the fins are still in good condition before launches - especially if launching the same rocket twice
Vehicle Components and Construction	Fastener Failure	1 (Excessive force, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use fasteners with a breaking strength safety factor of 2
Vehicle Components and Construction	Joint Failure	1 (Excessive force, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate joint design according to extensive mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches
Vehicle Components and Construction	Centering Ring Failure	1 (Excessive force from motor, poor construction)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate centering rings according to extensive mathematical and physical flight analyses, make use of reliable building techniques, confirm analyses with test launches
Vehicle Components	Motor Mount Failure	1 (Faulty motor or motor mount	5 (Partial or total	5, Low	Use mathematical

and Construction		preparation, poor construction, damage to motor mount)	destruction of vehicle, ballistic trajectory)		and physical analyses to ensure the motor mount works as planned, test the motor mount with subscale flights, check the motor mount for damage before flight, team members who prepare the motor must be supervised by at least one other team member
Vehicle Components and Construction	Destruction of Bulkheads	1 (Poor construction or improper bulkheads chosen which cannot withstand launch forces, faulty stress modeling)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to extensive high-stress mathematical and physical analyses, make use of reliable building techniques, run stability tests, confirm analyses with test launches
Vehicle Components and Construction	Destruction of Nose Cone	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, possible deviations from flight path)	3, Low	Check the nose cone for damage before and after each launch, choose a nose cone which is strong enough to withstand

					launch forces according to mathematical and physical flight simulations, confirm choice of nose cone with subscale launches
Vehicle Components and Construction	Motor Tube Angled Incorrectly	1 (Poor construction, damage from previous flights, poor storage, or transportation)	3 (Lower rocket stability, rocket does not follow desired flight path well)	3, Low	Ensure proper measurements and alignments are made during construction, ensure there is no rush to attach the motor tube, double-check the alignment of the motor before each flight, test that the desired motor alignment is correct with subscale flights
Vehicle Components and Construction	Motor Tube Comes Loose	1 (Poor construction, damage from previous flights, poor storage, or transportation, faulty motor preparation)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Check the motor and motor tube for damage before each launch, run mathematical and physical flight simulations to ensure the tube performs as planned, confirm

					simulations with subscale launches
Vehicle Components and Construction	Component Destruction Due To Drag Forces	1 (Poor construction or improper materials used)	5 (Partial or total destruction of vehicle, ballistic trajectory)	5, Low	Use appropriate materials according to mathematical and physical analyses, make use of reliable building techniques
Vehicle Components and Construction	Premature Stage Separation	1 (Premature ejection, poor choice of shear pins or fasteners)	5 (Possible recovery failure and damage to or loss of vehicle, ballistic trajectory)	5, Low	Check altimeter settings prior to flight, use appropriate vent holes, and run thorough analyses to determine which types of shear pins and fasteners should be used
Vehicle Components and Construction	Forgotten or Lost Components	3 (Carelessness with rocket components, failure to take note of inventory before attempting to launch)	4 (Rocket does not launch at the desired launch time)	12, Medium	Have spares for components which are small and easy to lose, have an inventory of all rocket parts to be checked before moving the rocket to a launch site
Vehicle Components and Construction	Poorly placed center of gravity	2 (Carelessness with rocket design, weight which was not considered in mathematical	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, adding

		or physical analyses)			and leaving room to add extra ballast as needed
Vehicle Components and Construction	Poorly placed center of pressure	2 (Carelessness with rocket design, design aspects which were not considered in mathematical or physical analyses)	3 (Lower rocket stability)	6, Low	Extensive, up-to-date, and detailed simulations and models of the rocket and its flight, changing design aspects such as fin size as needed
Launch, Propulsion, and Ejection	Premature Ejection	1 (Altimeter programming, poor venting)	5 (Zippering, possible recovery failure and damage to or loss of vehicle)	5, Low	Check altimeter settings prior to flight and use appropriate vent holes
Launch, Propulsion, and Ejection	Ejection Charge Failure	4 (Not enough power, electrical failure)	5 (Ballistic trajectory, destruction of vehicle)	20, High	Ground test charge sizes at least once before flight
Launch, Propulsion, and Ejection	Rocket Disconnects from the Launch Rail	2 (High wind speeds, failure to properly use the rail buttons, faulty rail buttons)	5 (Partial or total destruction of vehicle, ballistic trajectory which endangers personnel, onlookers, and property on the ground)	10, Medium	Use mathematical and physical analyses to ensure the rail buttons are properly aligned and working as planned, double check the rail buttons are properly attaching the rocket to the launch pad before launch, test rail buttons

					with subscale flights)
Launch, Propulsion, and Ejection	Flightpath Interference	2 (Wildlife in the air, unforeseen obstacles such as a loose balloon)	4 (Minor to severe change in the vehicle's flightpath, possible ballistic trajectory)	8, Medium	Ensure there are clear skies above before launching, ensure an FAA waiver has been obtained for the designated launch area
Launch, Propulsion, and Ejection	Unplanned Amounts of Friction Between Rocket and Launch Rail	2 (Faulty setup of launch rail, faulty installation of rocket on launch rail, failure to properly lubricate launch rail as needed, weather conditions cause excess friction)	2 (Rocket does not follow the designated flight path well, lower maximum height)	4, Low	Set up the rail using instructions which come with the product, use lubrication on the rail as needed according to weather and rail type, ensure the rocket is properly installed on the launch rail
Launch, Propulsion, and Ejection	Failure to Ignite Propellant	1 (Faulty motor preparation, poor quality of propellant, faulty igniter, faulty igniter power source, damage to motor)	5 (Rocket does not immediately launch and is a considerable hazard until it is confirmed that it will not launch, changes to igniters or rocket required)	5, Low	Purchase propellant and motors only from reliable sources, team members who prepare the motor and igniters must be supervised by at least one other team member, determine if the igniters chosen

					work well during subscale testing
Launch, Propulsion, and Ejection	Propellant Fails to Burn for Desired Duration	1 (Faulty motor preparation, poor quality of propellant, damage to motor)	3 (Rocket does not follow the designated flight path well, lower maximum height, if drastic change in maximum height the ejection charges for recovery may not deploy)	3, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member
Launch, Propulsion, and Ejection	Propellant Burns Through Rocket Components	1 (Faulty motor preparation, poor quality of propellant, poor construction, damage to motor, damage to propellant casing)	5 (Ballistic trajectory, catastrophic destruction of vehicle)	5, Low	Purchase propellant and motors only from reliable sources, check the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member, test propellant casing in subscale flights
Launch, Propulsion, and Ejection	Propellant Explosion	1 (Faulty motor preparation, poor quality of propellant, damage to	5 (Ballistic trajectory, catastrophic destruction of vehicle,	5, Low	Purchase propellant and motors only from reliable sources, check

		motor)	possible harm to bystanders)		the motor for damage prior to launching, team members who prepare the motor must be supervised by at least one other team member
Avionics and Payload	Payload Camera Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	4 (Disqualified, objectives not met)	12, Medium	Test payload prior to flight, check batteries and connections before flight
Avionics and Payload	Poor Quality of Payload Pictures	3 (Payload camera failure, programming error, ballistic trajectory, unstable/shaky flight)	3 (Lower score, objectives possibly not met if payload camera completely misses its targets)	9, Medium	Test payload prior to flight, check batteries and connections before flight, ensure the rocket follows its planned flight path and is stable through test flights
Avionics and Payload	Payload Computer Failure	3 (Electrical failure, program error, poor setup of wiring causes a connection to come undone, forgotten connection, battery failure)	5 (Disqualified, objectives not met, loss of electronic control)	15, High	Test payload prior to flight, check batteries and connections before flight

Avionics and Payload	Altimeter Failure	3 (Loss of connection, improper programming, altimeter comes dislodged, forgotten connection, battery failure)	5 (Ballistic trajectory, destruction of vehicle, improper timing for ejection of parachutes and stages)	15, High	Secure all components to their mounts and check settings, check batteries and connections before flight
Avionics and Payload	GPS Lock Failure	2 (Interference or dead battery)	5 (Loss of vehicle)	10, Medium	Ensure proper GPS lock and battery charge before flight
Avionics and Payload	Power Loss to Avionics Bay and/or Payload	3 (Faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Test the reliability of the wiring and batteries through subscale flights, check batteries and connections before flight
Avionics and Payload	Improper Avionics and Payload Insulation	1 (Poor construction, damage to rocket body, avionics bay, or payload)	4 (Avionics bay and payload do not perform as planned, possible failure to trigger ejection charges at correct time, possible failure to meet mission objectives, possible recovery failure, possible	4, Low	Take efforts to properly seal avionics and payload such as the use of putty, follow proper construction procedures, check the avionics bay, payload, and rocket body for damage before launch, check insulation of avionics bay and payload through test

			ballistic trajectory)		launches
Avionics and Payload	Avionics Bay Fire	3 (Faulty wiring, battery failure, poor setup of wiring, adverse weather)	5 (May be disqualified if objectives are not met, possible failure to trigger ejection charges, damage to internal rocket components)	15, High	Thermal protection of avionics bay, do not overload avionics bay with wiring, only purchase avionics and payload equipment from reliable sources, check avionics bay and payload performance with test launches
Avionics and Payload	Human Error When Arming Avionics and Payload	3 (Forgotten connection, forgetting to activate avionics bay components or payload prior to launch)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Leave reminders in multiple places to check that the avionics bay and payload are armed and ready before launch, follow launch checklists closely
Avionics and Payload	Arming System Failure	3 (Faulty arming system, faulty wiring, battery failure, poor setup of wiring causes a connection to come undone, forgotten connection)	5 (Disqualified, objectives not met, failure to correctly trigger ejection charges)	15, High	Ensure the avionics bay is successfully communicating with the team prior to flight, test arming system through test launches

Recovery	Poor Spacing Between the Ejection Charge and the Parachute	2 (Failure to properly consider the requirements of the recovery system, poor budgeting of space in rocket, failure to read instructions that come with parachute and/or ejection charges)	5 (Partial or total damage to the parachute, parachute does not launch from the rocket, possible recovery failure)	10, Medium	Read all instructions which come with the parachute and ejection charges, establish clear requirements of the recovery system early in the design process, run mathematical and physical analyses on the design of the rocket, ensure the parachute is spaced properly with subscale test flights
Recovery	Airframe Zipper	2 (Excessive velocity when recovery system is deployed)	5 (Partial yet severe destruction of vehicle)	10, Medium	Properly time ejection charges and use an appropriately long tether
Recovery	Stage Fails to Separate	2 (Faulty ejection charge, excessive strength is used to hold stages together, altimeter failure)	4 (Rocket does not follow desired flight path, possible ballistic trajectory, lower maximum height, damage to the rocket)	8, Medium	Any team member who loads the ejection charges must be supervised by at least one other team member, examine ejection charges for damage before launch, ensure proper functionality of

					the altimeters, ejection charges, and interstage joints and fasteners through test flights and mathematical and physical analyses, have a secondary ejection charge for each stage separation
Recovery	Main Parachute Fails to Deploy	2 (Poor design of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	5 (Main parachute does not slow down the rocket, recovery failure, ballistic trajectory)	10, Medium	Any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency
Recovery	Drogue	2 (Poor design	5 (Drogue	10,	Any team

	Parachute Fails to Deploy	of where parachute is in rocket, poor sealing of parachute chamber, poor loading of parachute, faulty parachute or ejection charge, altimeter failure)	parachute does not slow down the rocket, recovery failure, ballistic trajectory)	Medium	member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachute and ejection charges for damage before launch, run mathematical and physical analyses as well as subscale tests to ensure parachute is in the right position in the rocket, have a secondary ejection charge in case of emergency
Recovery	Parachute Canopy Breaks or Tears	1 (Poor canopy materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the

					recovery system for damage before launch
Recovery	Parachute Shroud Lines Break	1 (Poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	4 (Possible recovery failure, ballistic trajectory)	4, Low	Only buy parachutes from reliable sources, remove threats to parachute integrity from the parachute housing, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch
Recovery	Shock Cord Break or Disconnect	1 (Faulty shock cord, damage to shock cord, poor connection to the rocket)	5 (Parachute disconnect from the rocket, recovery failure, ballistic trajectory)	5, Low	Any team member who connects the shock cord to the rocket must be supervised by at least one other team member, check the shock cord for damage before and after flight, only buy shock cords from reliable sources, analyze the shock cord with test flights

Recovery	Tangled Parachute or Shock Cord	1 (Faulty or damaged shock cord or parachute, poor packing of shock cord and/or parachutes, poor sizing of parachutes or shock cord, unstable or ballistic flight)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Only buy parachutes and shock cords from reliable sources, any team member who seals or packs the parachute chamber must be supervised by at least one other team member, examine parachutes and shock cord for damage before launch, check performance of parachutes and shock cord in test flights, appropriately follow recommended sizings for shock cord and parachutes
Recovery	Parachute Comes Loose from Rocket	1 (Failure of recovery system mount on the rocket body, poor shroud line materials, improper ejection of recovery system, damage from previous flights or transportation)	5 (Recovery failure, ballistic trajectory)	5, Low	Only buy parachutes from reliable sources, test the recovery system through mathematical and physical analyses as well as subscale flights, check the recovery system for damage before launch, double

					check that the recovery system is properly mounted before launch
Recovery	Heat Damage to Parachute or Shock Cord	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	4 (Shock cord or parachutes may not fully achieve their goal, possible ballistic trajectory, possible failed recovery)	4, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and packing methods of ejection charges and parachutes with test flights
Recovery	Parachute or Shock Cord Catch Fire	1 (Not enough space given between ejection charge and parachute, poor insulation of parachute, poor parachute packing, faulty or poorly chosen ejection charge)	5 (Shock cord or parachutes do not fully achieve their goal, possible ballistic trajectory, possible failed recovery, damage to internal rocket components)	5, Low	Any team member who packs the parachute or ejection charges must be supervised by at least one other team member, use recommended sizing methods for ejection charges, confirm proper placement and

					packing methods of ejection charges and parachutes with test flights
Recovery	Excessive Landing Speed	3 (Parachute damage or entanglement, improper load, lower coefficient of drag for the parachutes than needed, lower surface area of the parachutes than needed)	5 (Partial or total destruction of vehicle)	15, High	Properly size, pack, and protect parachute, check the parachute for damage before and after launch, use subscale flights to determine if the subscale parachutes were accurately sized
Recovery	Insufficient Landing Speed	3 (Improper load, higher coefficient of drag for the parachutes than needed, higher surface area of the parachutes than needed)	2 (Unexpected changes in flightpath and landing area, increased potential for drift)	6, Low	Use subscale flights to determine if the subscale parachutes were accurately sized, use recommended and proven-to-workparachute sizing techniques

4.2.4. Environmental Hazard Analysis

The following hazards are either threats to the project from the environment or threats to the environment from the project:

Hazard	**Likelihood (Cause)**	**Severity (Effect)**	**Risk**	**Mitigation**
High Air Pressure	2 (Poor air pressure forecast)	4 (Premature drag separation)	8, Medium	Use appropriate amount of shear pins and vent holes

Crowded Landscape	3 (Trees, brush, water, power lines)	5 (Inability to recover the rocket, obstacles that may be dangerous to personnel during recovery)	15, High	Angle rocket into wind as necessary to reduce drift
Collisions with Man-made Structures or with Humans	2 (Failure to properly predict trajectory, failure to choose an appropriate launch area)	5 (Damage to public property or private property not owned by the team, damage to team equipment, serious damage to team personnel or passerby)	10, Medium	Do not launch under adverse conditions which may affect the course of the rocket, run a large number of tests which analyze the rocket’s trajectory mathematically and physically, choose a launch area which is not close to civilization, follow launch procedures closely
Unstable Ground	2 (Poor choice of launch site, inclement weather creating mud or softening the ground)	3 (Personnel may slip or fall and damage equipment or themselves, launch pad may sink into the ground and cause an unexpected trajectory)	6, Low	A rigid system which can be used to support the launch pad, such as wooden planks (if needed to reduce their flammability, they may be wetted directly underneath the rocket), choice of a launch site which has rigid ground, observation of launch pad condition shortly before launch
Wildlife Contact with Rocket	1 (Failure to accurately predict trajectory, unexpected appearance of	4 (Damage to vehicle components, damage to wildlife,	4, Low	Launch in an open area with high visibility, be aware of the surroundings when choosing a launch

	wildlife, poor choice of launch area)	unexpected trajectory close to the ground)		area and launching
Wildlife Contact with Launch Pad	1 (Failure to monitor the launch pad, poor choice of launch area)	4 (Possible inability to launch the rocket, unpredictable launch behavior or trajectory)	4, Low	Have at least one team member monitoring the launch pad at all times, launch in an open area with high visibility, be aware of the surroundings when choosing a launch area and launching, if animals tamper with the launchpad do not launch
High Humidity	3 (Climate, poor forecast)	1 (Rust on metallic components, expansion of rocket components and difficulty assembling the rocket because of this)	3, Low	Use as little metal as possible, apply rust prevention techniques, store the rocket indoors, choose a launch site with a desirable climate, choose not to launch if heat expansion makes assembly necessitate drastic adaptation
Wet Conditions	3 (Climate, poor forecast)	3 (Threats to electronic performance, possible short circuit)	9, Medium	Choose a launch site with a desirable climate, read accompanying instructions for any electronics with regard to wet conditions, do not launch during rainfall which is more than a light sprinkle
Dry Conditions	2 (Climate, poor long-term forecast)	3 (Increased chance of launch pad fire if there is dry brush	6, Low	Clear all dry brush away from the launch pad area before launch, choose a launch area with a

		present near to the launch pad)		climate that is not often dry, do not launch if there is an unavoidable fire hazard present due to dry conditions
Lightning	3 (Poor forecast)	4 (Threats to electronics and team personnel)	12, Medium	Do not launch during storms or attempt to launch if there is a storm approaching, check the forecast for the day in advance
High Wind Speeds	3 (Poor forecast)	4 (Inability to launch, excessive drift, unpredictable trajectory, destruction of parachute or damage to rocket parts, loose equipment blown away)	12, Medium	Angle into wind as necessary and abort if wind exceeds 20 mph
High Temperatures	3 (Poor forecast)	3 (Heat-related personnel injuries, failure in rocket structure, launchpad fires from overheated components or dry brush, excessive friction on the launch rail [especially if the heat is from sun	9, Medium	Ensure team is protected from the sun through shade and sunscreen and stays hydrated, choose a launch location with small amounts of brush, store the rocket in an area with regulated temperature

		exposure])		
Low Temperatures	3 (Poor forecast)	3 (Cold-related personnel injuries, Frost on ground, ice on vehicle, clogging of vehicle ventilation, change in rocket rigidity and mass, higher drag force on rocket)	9, Medium	Ensure team is wearing appropriate clothing for extended periods of time in cold environments, keep the rocket at room temperature or bundled in materials which hold in heat, if ice appears anywhere on the rocket do not launch and return it to a warm location
Pollution from Exhaust	5 (Combustion of APCP motors)	1 (Small amounts of greenhouse gases emitted)	5, Low	Carpool to events to reduce pollution from exhaust in another way
Chemical Pollution to Water Sources	2 (Fuel leakages, battery fluid leakages, launch too close to a water source)	4 (Danger of sickness to wildlife or humans which rely on the water sources)	8, Medium	Do not launch if the launching area is within 750 meters of a water source, check the rocket for leakages before launch
Pollution from Team Members	2 (Failed disposal of litter, improper cleanup procedures, members walk through important plantlife, farming fields, sod, etc.)	4 (Litter may degrade extremely slowly, wildlife may consume harmful litter)	8, Medium	Brief team members on proper cleanup procedures, foster a mindset of leaving no trace at launch sites, only the minimum number of required team members should retrieve the rocket
Pollution from Vehicle	2 (Loss of components from vehicle, debris scattering from a	4 (Materials degrade extremely slowly,	8, Medium	Properly fasten all components

	crash or mid-flight explosion)	wildlife may consume the materials)		

5. Payload Criteria

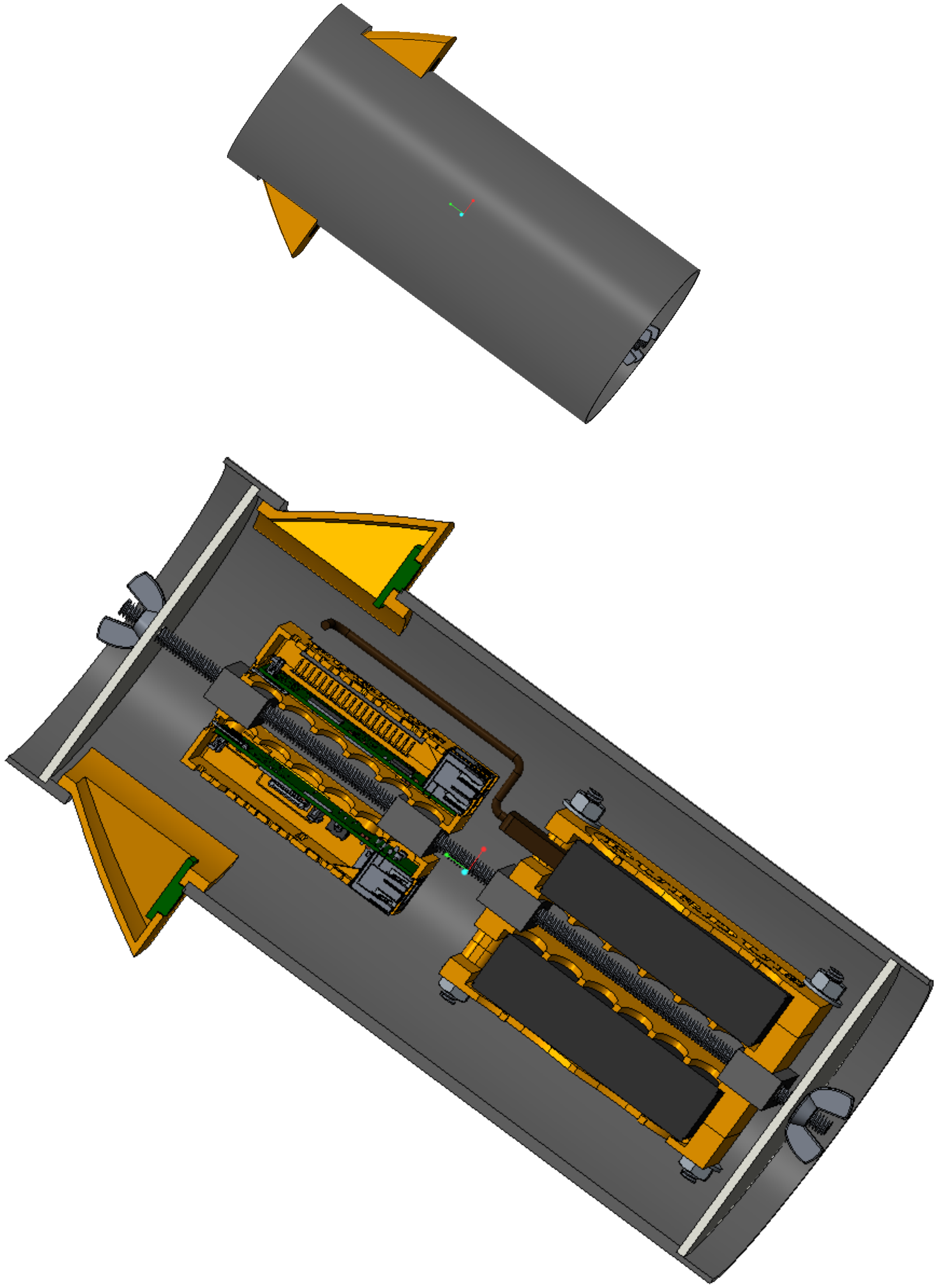
5.1. Design Of Payload Equipment

Given the three options for payload missions, this team will launch a payload containing a target detection system. The system will identify three 40’ x 40’ colored targets on the ground in real time on board the rocket during flight. The design will consist of a recording device protruding from the side of the rocket aimed at the ground. This footage will then be processed by an onboard computer. The computer will identify the three tarps and distinguish between the tarps based on color. This computer will be powered by a commercially available rechargeable battery supply.

To ensure success, this payload will be comprised of a full redundancy system. There will be two cameras, two batteries, and two on board computers operating completely independently. The rationality behind this design sacrifices extra weight in return of an insurance plan. It was decided that this payload will remain fixed to the launch vehicle and not be deployed at apogee to minimize the complexity of the system.

5.1.1. Chosen Design Alternatives From PDR

The changes in the payload design since PDR have mostly been at the software level. The python script design has been updated to feature a more optimized target detection algorithm that features an improved detection ability and a decrease in the amount of false positives detected. The code has been further optimized to run more efficiently as well. More specific details can be found in section 5.1.2.4. The physical mounting and payload bay design has remained unchanged and are illustrated below:

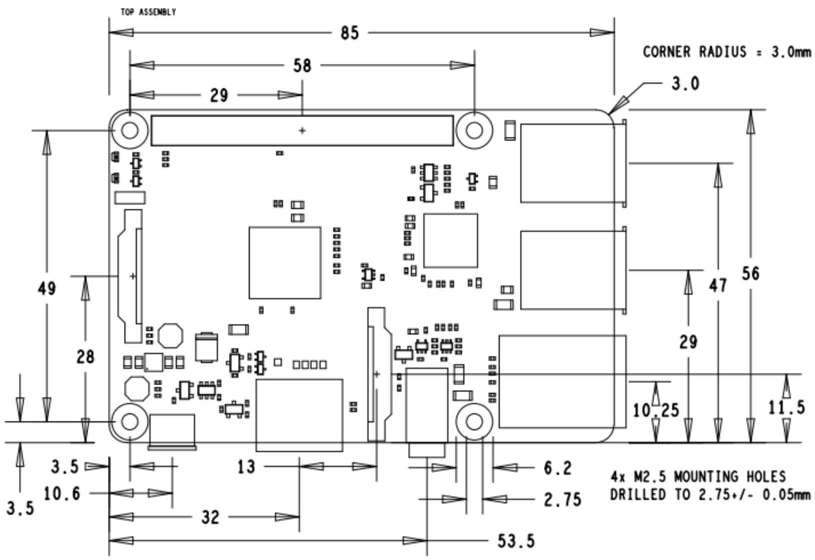


5.1.2. System Level Design Analysis

5.1.2.1. Computer Subsystem

The Raspberry Pi Model 3 B is the chosen system for the computing purposes of our payload. The Pi was chosen because of its small size, low cost, relatively high performance, and easy programmability. The Pi features 1 gigabyte of SDRAM, a Quad

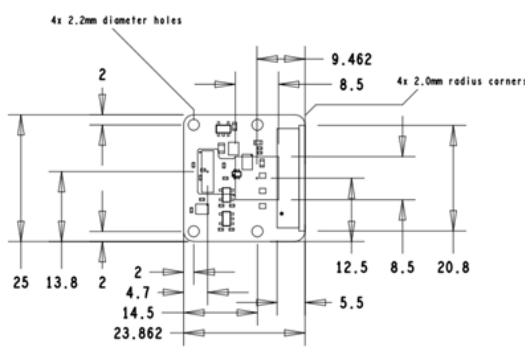
Cortex A52 processor clocked at 1.2 GHz, has wifi capability built in, and costs $35 USD. The dimensional drawing of the Pi can be found below.



The team has decided that two of the same model Raspberry Pi will be included in the payload. The target tracking system will be completely redundant with two Pi's and 2 Pi Cameras. The computers will be running the same team-written python scripts. This system will be purely for the purposes of backup in case one system goes down.

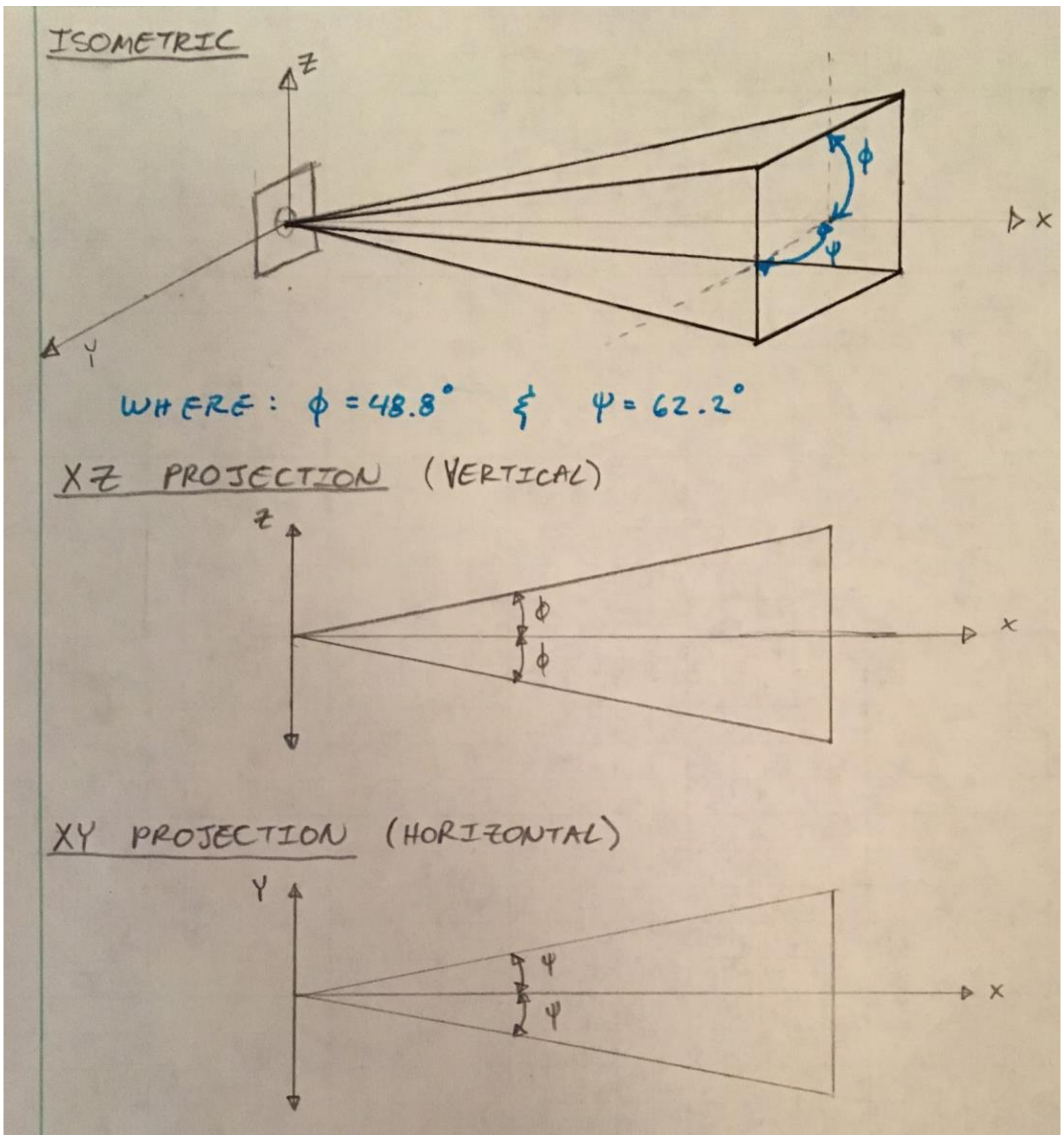
5.1.2.2. Camera Subsystem

The Raspberry Pi Camera V2 was selected to be used for the payloads recording device. As discussed in the PDR it was chosen for its low cost at $25.99, high resolution of 8 MP, availability, and compatibility with the onboard computer. It also features fast frame rates of 30 fps and 60 fps at 1080p and 720p, respectively. It is illustrated below:



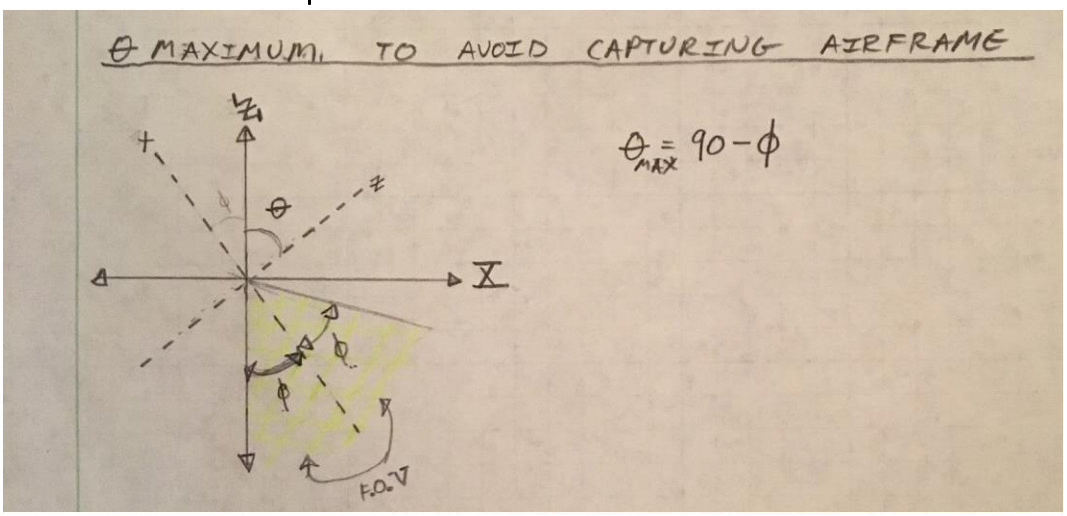
A critical design factor of the camera subsystem is determining the angle at which the camera protrudes from the rocket airframe. Due to geometry limitations of the camera itself, it is apparent that the more perpendicular the camera protrudes from the airframe, the more aerodynamic drag will become a flight inhibiting factor. Conversely, by angling the camera towards the airframe, drag will be reduced; however, as will the field of vision. Limiting the field of vision is an issue of utmost concern when the ultimate goal is target detection. Therefore, the design of the camera shroud and angle was an optimization challenge between minimizing drag and maximizing field of view.

The design process began by studying what the camera's default field of view is. As defined by the manufacturer, the Raspberry V2 camera detects images within a 48.8 degree radius in the vertical direction and 62.2 degree radius in the horizontal direction. This is illustrated in the schematic below:



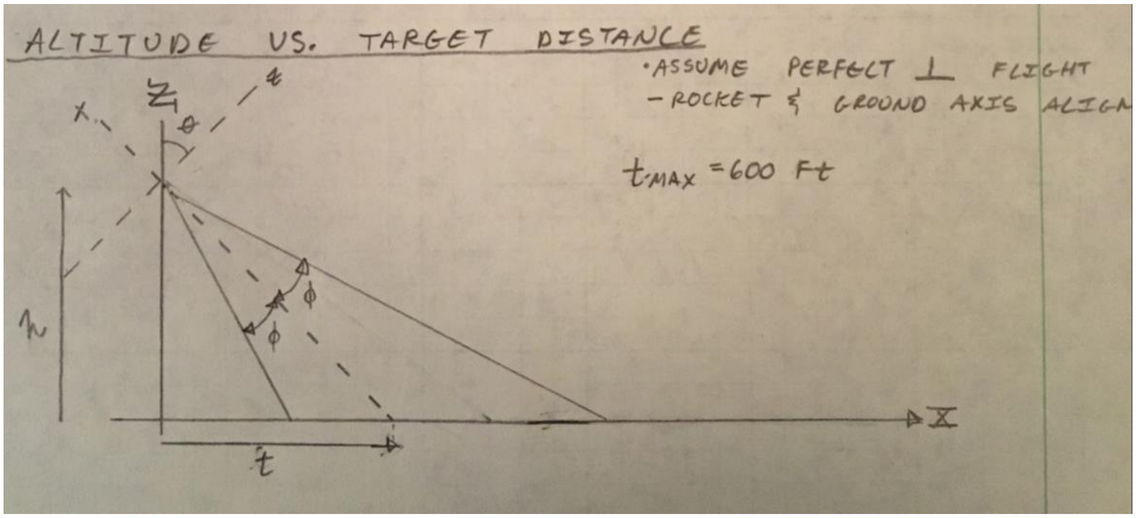
Having analyzed the camera's field of view, it was then necessary to determine how it should be mounted relative to the airframe of the rocket. For notation purposes "X,Y, and Z" correspond to an absolute frame of reference corresponding to the airframe, whereas, "x, y, and z" correspond to a frame of reference relative to the camera. For calculation purposes it was assumed that the Y and y axises would remain parallel throughout the design process.In other words, the camera would not rotate relative to the rocket in the vertical direction. The variable theta was used to describe the angle between the camera and airframe (aka the angle between Z and z).

To begin designing the angle at which the camera should be oriented, the upper limit of theta was determined. The upper limit of theta represents the maximum tilt of the camera before the airframe begins to intersect the video footage. This theta_max = 41.2 degrees and was calculated by subtracting the camera's vertical field of view from 90. A geometric schematic of this problem is illustrated below:



It was determined for a compromise between field of view, simplicity, and fabrication ease, that theta be set to 90 degrees. While some airframe will be captured in the footage, the camera has such a wide field of vision that this obtrusion of vision would be negligible. In fact, since rotation of the rocket is a concern, the increase in theta yields the added benefit of being able to capture footage from "behind" the rocket's air frame.

Having determined theta, calculations were then performed to approximate how well the camera could pick up on the targets knowing the maximum distances the targets would be located away from the launch rail. It was assumed that the rocket would have a perfectly vertical flight meaning that the Z axis and vertical plane relative to the launch site would be coincident. The variable h represents the height of the rocket and the variable t represents the distance of the targets relative to the launch pad. It is known that t_max is equal to 600ft. This is illustrated in an XZ projection shown below:



Mounting the camera with a theta set to 90 degrees yields that when the rocket approached its target height of 5280 feet, the camera would capture footage of the ground within a 6031 foot radius of the launch rail. It was also calculated that at this angle, the targets located at a maximum distance of 600 feet from the launch rail would begin to enter the camera's field of vision once the rocket hits an altitude of 525 feet. This was a desirable result because it indicates that the targets can be identified for about 90% of the rocket's accent. If the targets are located closer than 600 feet away, they will be accounted for in an even larger percentage of the rocket's flight.

5.1.2.3. Battery Subsystem

5.1.2.3.1. Design Alternatives With Pros And Cons

There are many power supply categories available, and there are hundreds of options within each category. In order to narrow down the possibilities between the variety of options available to the team, a list of basic requirements was created. Although the list was not lengthy, it narrowed down the field of possibilities quite a bit. The requirements on this list are as follows:

1. The battery must be less than $30 per battery
2. The battery must be less than one pound
3. The battery must be less than four inches wide in order to fit into the payload bay (4.815 inch diameter)

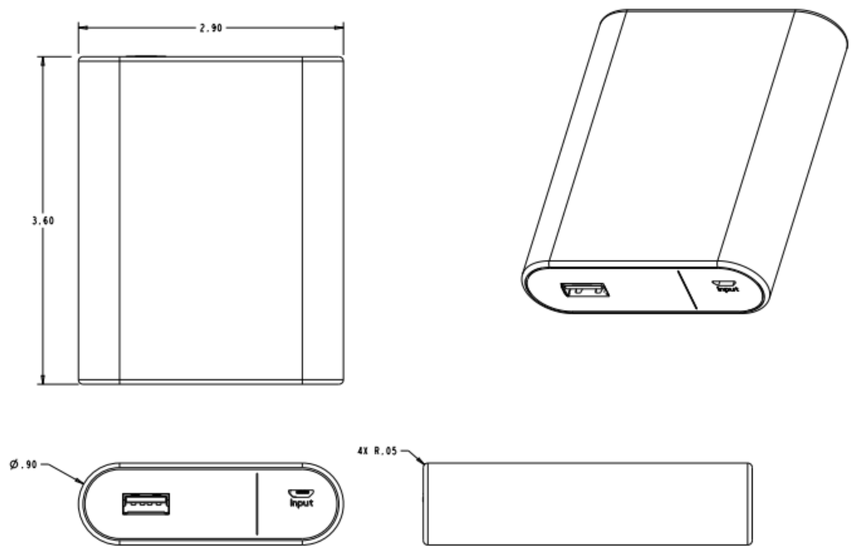
Based on these requirements, the top five options were chosen and listed along with defining options in a spreadsheet which can be seen below.

1	Battery (Supplier/Link)	mAh	L (in)	W (in)	T(in)	m(lb)	Price ($)	Amps (A)	Volts (V)
2	RAVPower Portable Charger with 2 ports (Amazon)	20100	6.81	3.19	0.87	0.84	49.99	2.4 per	5
3	RAVPower Portable Charger with 1 port (Amazon)	6700	3.54	1.57	0.98	0.26	13.99	2.4	N/A
4	Anker PowerCore Charger with 1 port (Amazon)	10000	3.6	2.3	0.9	0.4	25.99	2.4	5
5	Anker PowerCore 2-in-1 Portable/Wall Charger (Amazon)	5000	3.6	2.8	1.2	0.42	25.99	2.1	5
6	ROMOSS USB for Raspberry Pi (Adafruit)	10000	5.4	2.4	0.8	0.64	39.95	2	5 each

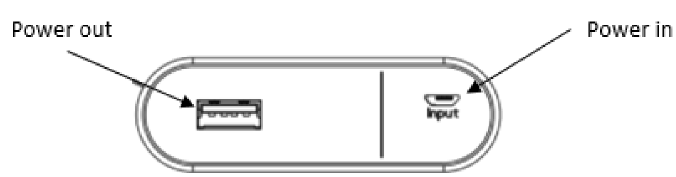
5.1.2.3.2. Leading Choice

The leading choice for the power supply is two Anker PowerCore Chargers with 10,000 mAh per unit. This options allows for a perfect weight distribution on either side of the mounting sled in the payload bay along with complete redundancy for the payload. This battery fits the cost requirement along with the dimension requirement set by the team.

5.1.2.3.3. Dimensional Drawing



5.1.2.3.4. Wiring Diagram



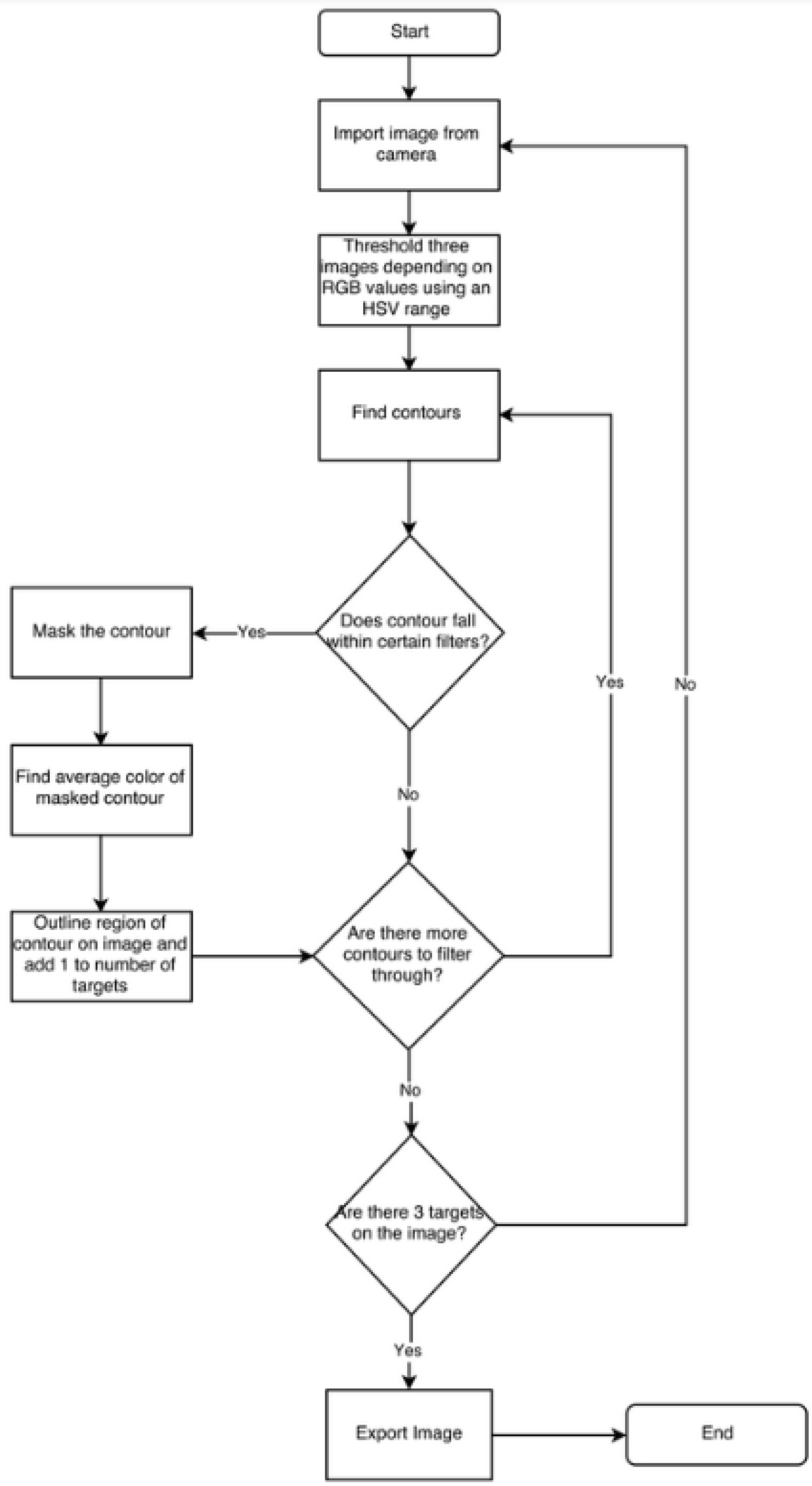
5.1.2.3.5. Estimated Mass

The estimated mass of the power supply is approximately 0.4 lbs.

5.1.2.4. Software Subsystem

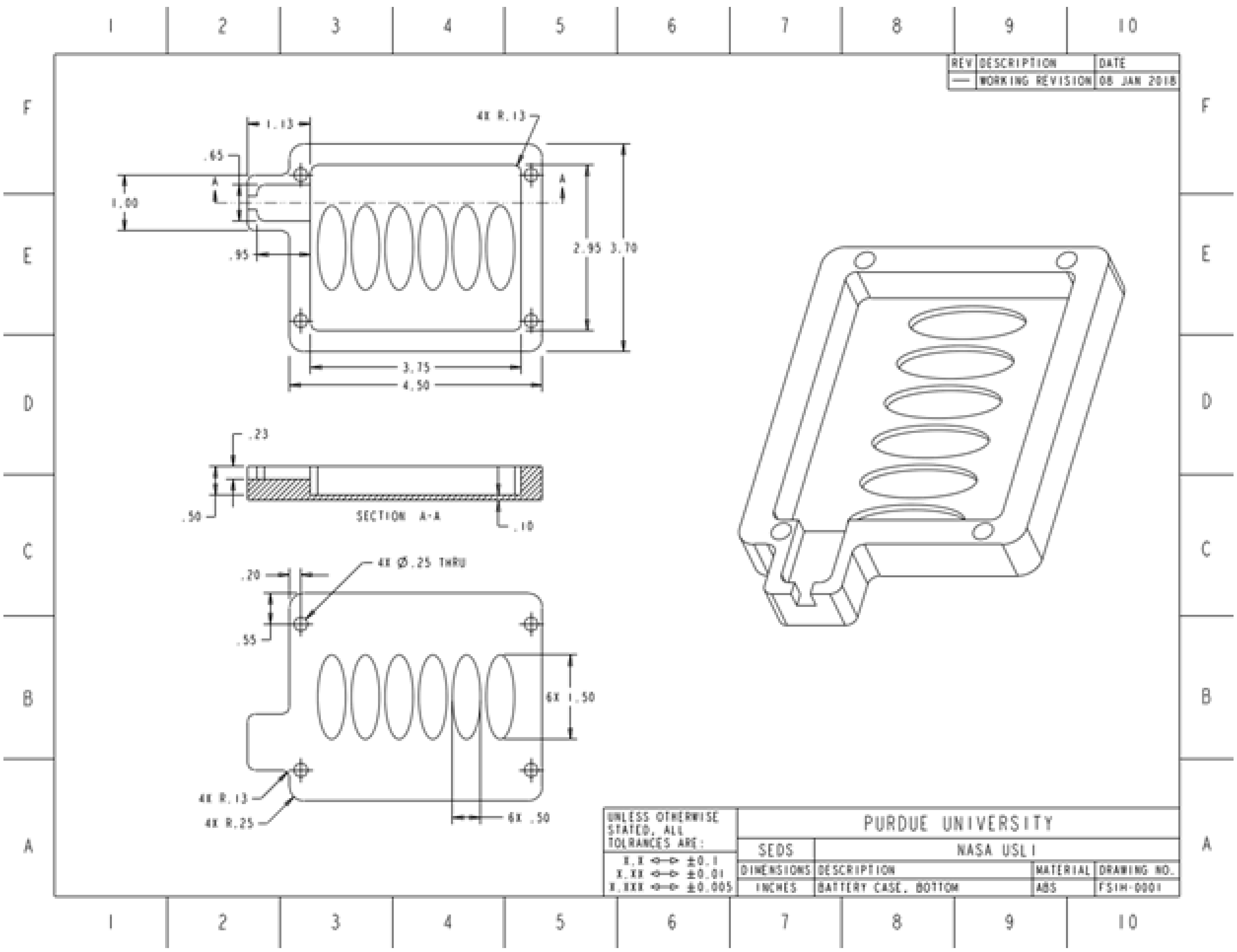
The backbone of the software subsystem is the Raspbian operating system running on the raspberry pi. We are using the latest version of the operating system. It was chosen because it interfaces easily with the pi hardware and pi peripherals that we will be using such as the pi camera. Within the operating system, we have installed Python libraries and dependencies as the target detection program is being written in Python 3.0.

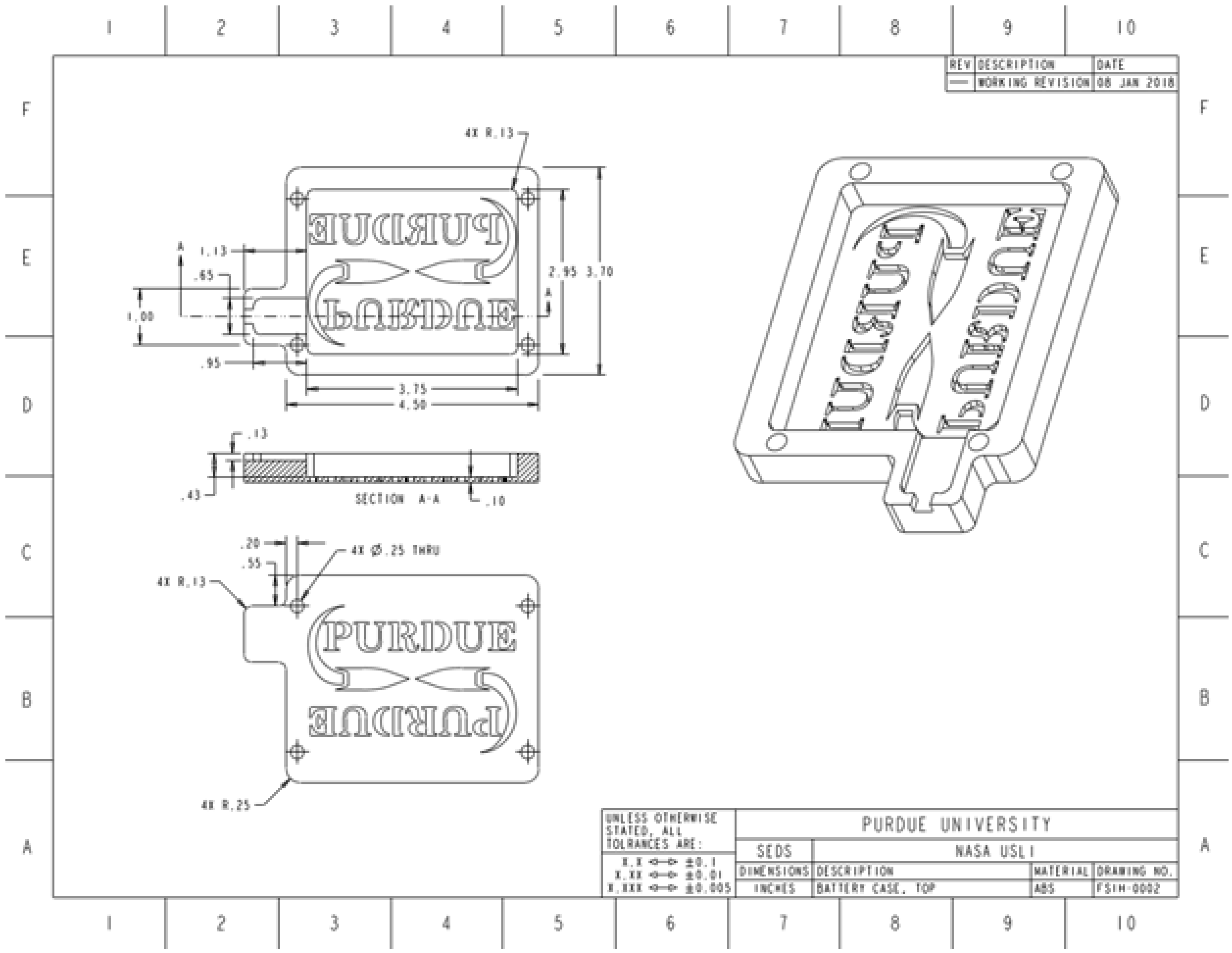
The target detection program is being written to best balance performance on the hardware and detection rate of the targets. The basic algorithm for the detection software is as follows. The first step is importing an image from the pi camera. The second step is initializing two arrays for each tarp color that will hold the the hue, saturation, and value of the color. The first array is for the minimum, and the second array is for the maximum. This is repeated for each of the three tarps. The HSV values are determined by converting the given RGB values to HSV and then opening up the ranges to what we believe is best based on experimental evidence. The third step in the program is finding contours on the image. This is approached by treating the captured image as an array of pixels, and the program will search through each pixel and determine of the two adjacent pixels have a threshold different value from one another. If a threshold is detected, then it is checked whether or not it falls within the range of the given threshold HSV values for any of the tarps. If yes, the image outside the contour threshold is masked with a black value for those pixels. When a closed contour (the tarp) is found, a rectangle is drawn around the tarp signalling that it has been found. This process repeats until three contours are found. If three tarps have been detected and labelled, the Python script saves an image of the camera capture with the overlay drawn on to the local directory. The name of the image file is incremented so that an image can be saved for every frame that all three tarps are detected. This program runs in real time, capturing each frame as quickly as the hardware can process it. The following flow chart can more simply explain the workings of the program.



5.1.2.5. Hardware/connectors (dimensional drawings, CAD)

The payload bay has been designed to be a mix of commercial off the shelf (COTS) parts, and parts that 3D printed parts that can be easily fabricated by the team. The onboard computer and battery supply will be mounted to a custom fabricated sled. The sled will ride along two parallel threaded rods. The rationality behind this design configuration is that the threaded rods serve the dual purpose of holding the bulkheads located at opposite ends of the payload tube together in addition to providing a mounting anchor within the payload tube. A full drawing package of the payload sled can be seen below.

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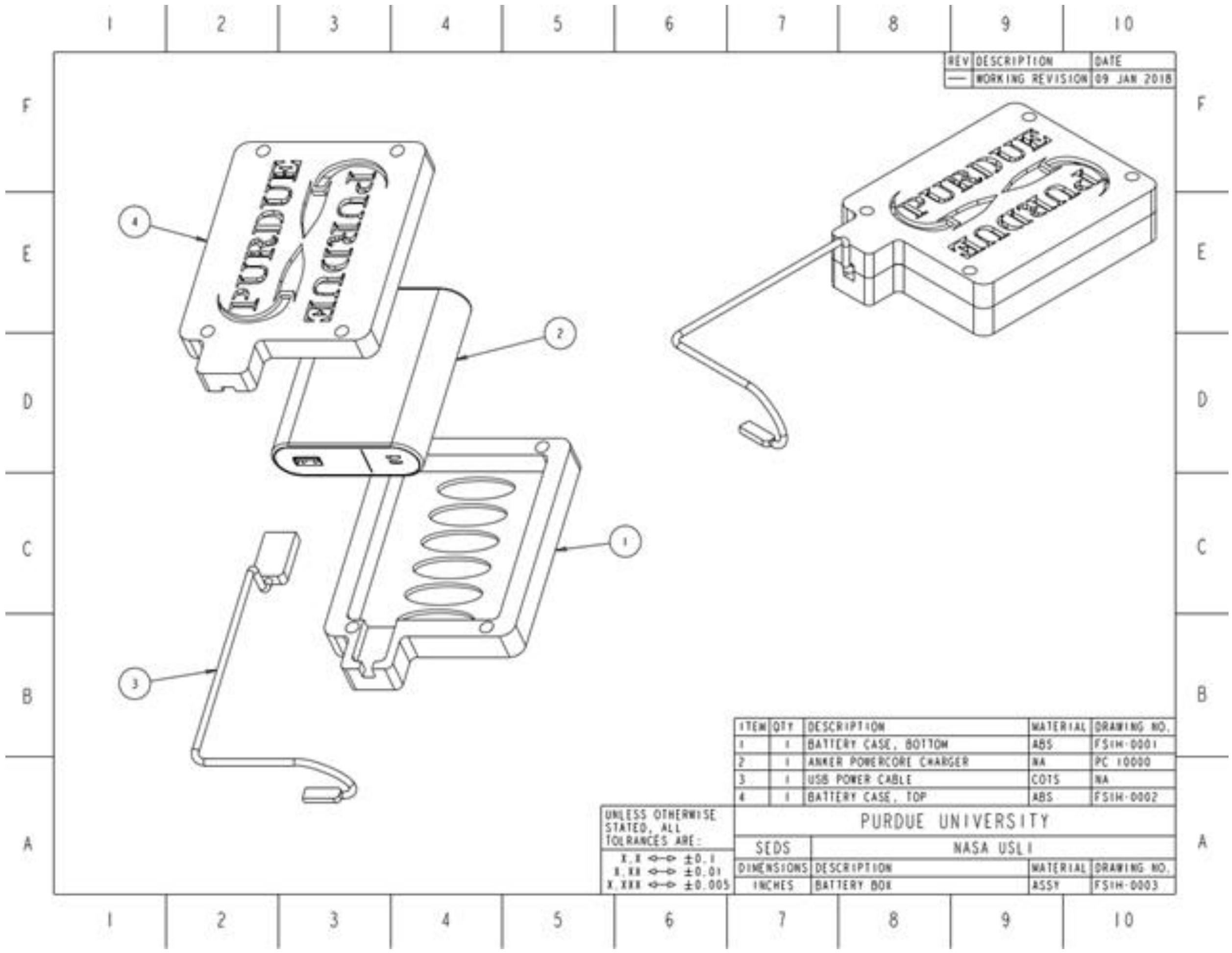

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— WORKING REVISION 09 JAN 2018
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3 1 USB POWER CABLE COTS NA
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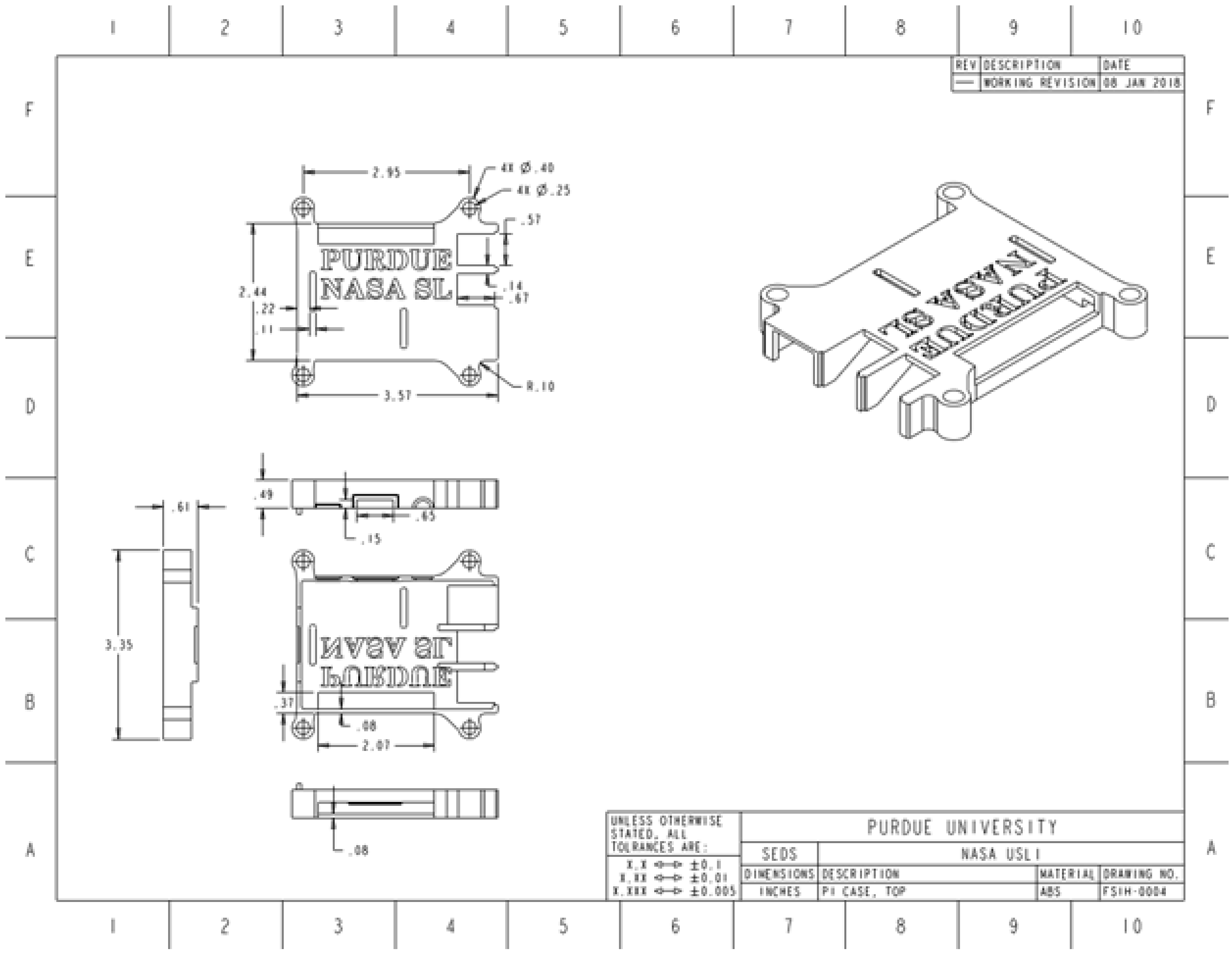
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UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
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X.XXX ±0.005
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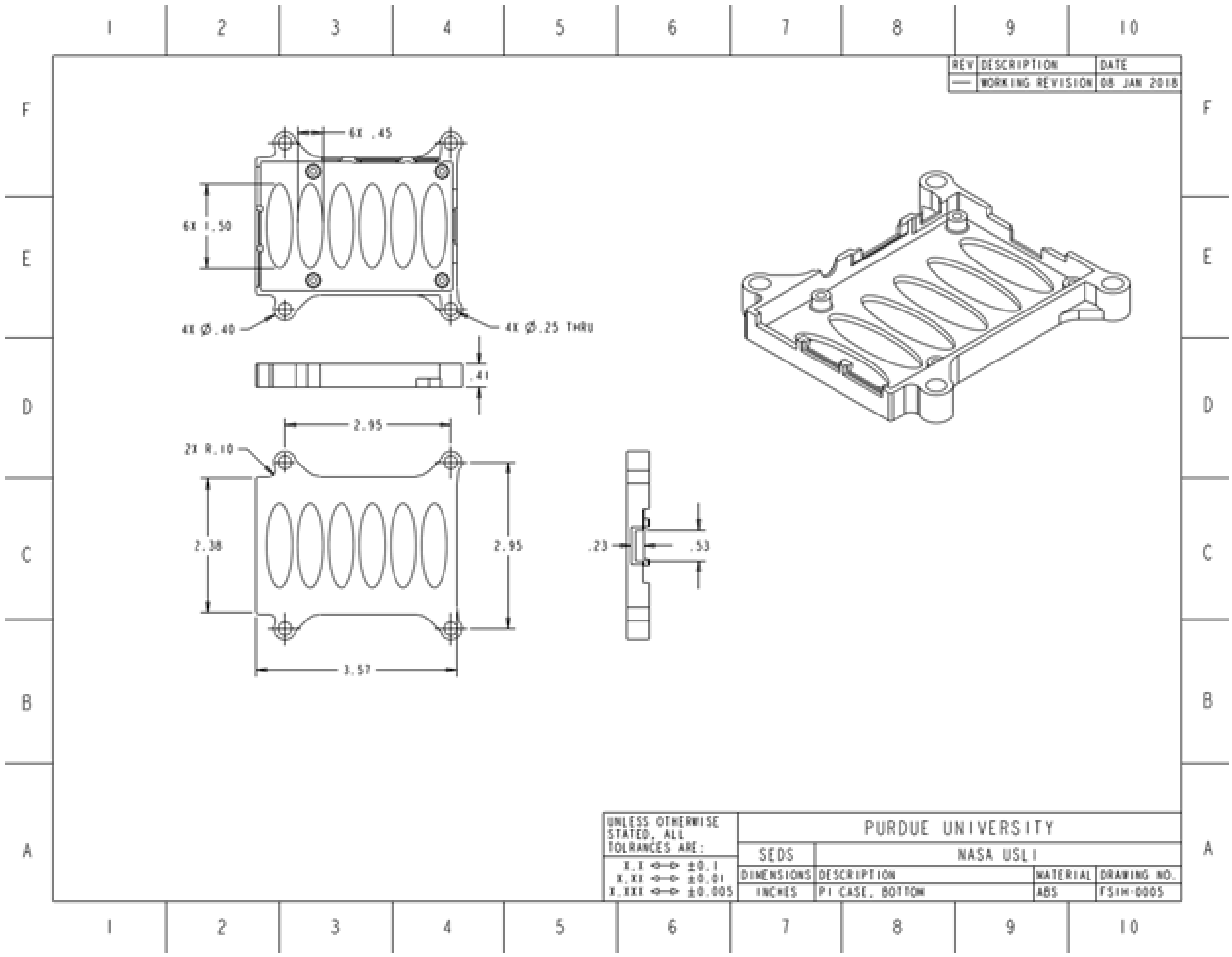
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UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
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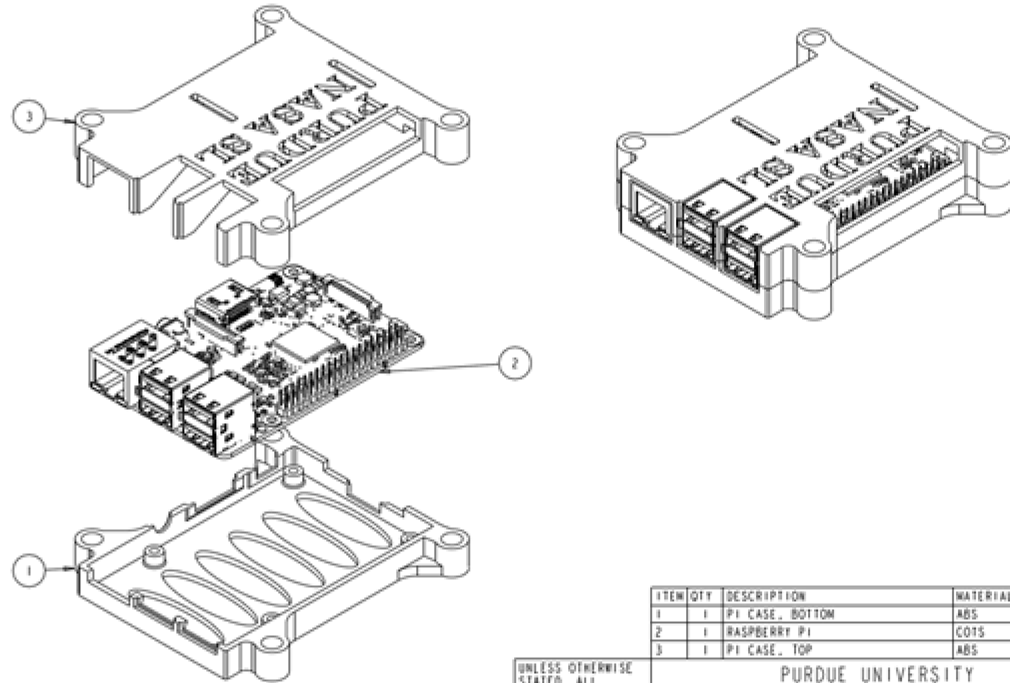
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS DESCRIPTION MATERIAL DRAWING NO.
INCHES PI CASE, BOTTOM ABS FSIH-0005

REV	DESCRIPTION	DATE
—	WORKING REVISION	09 JAN 2018



ITEM	QTY	DESCRIPTION	MATERIAL	DRAWING NO.
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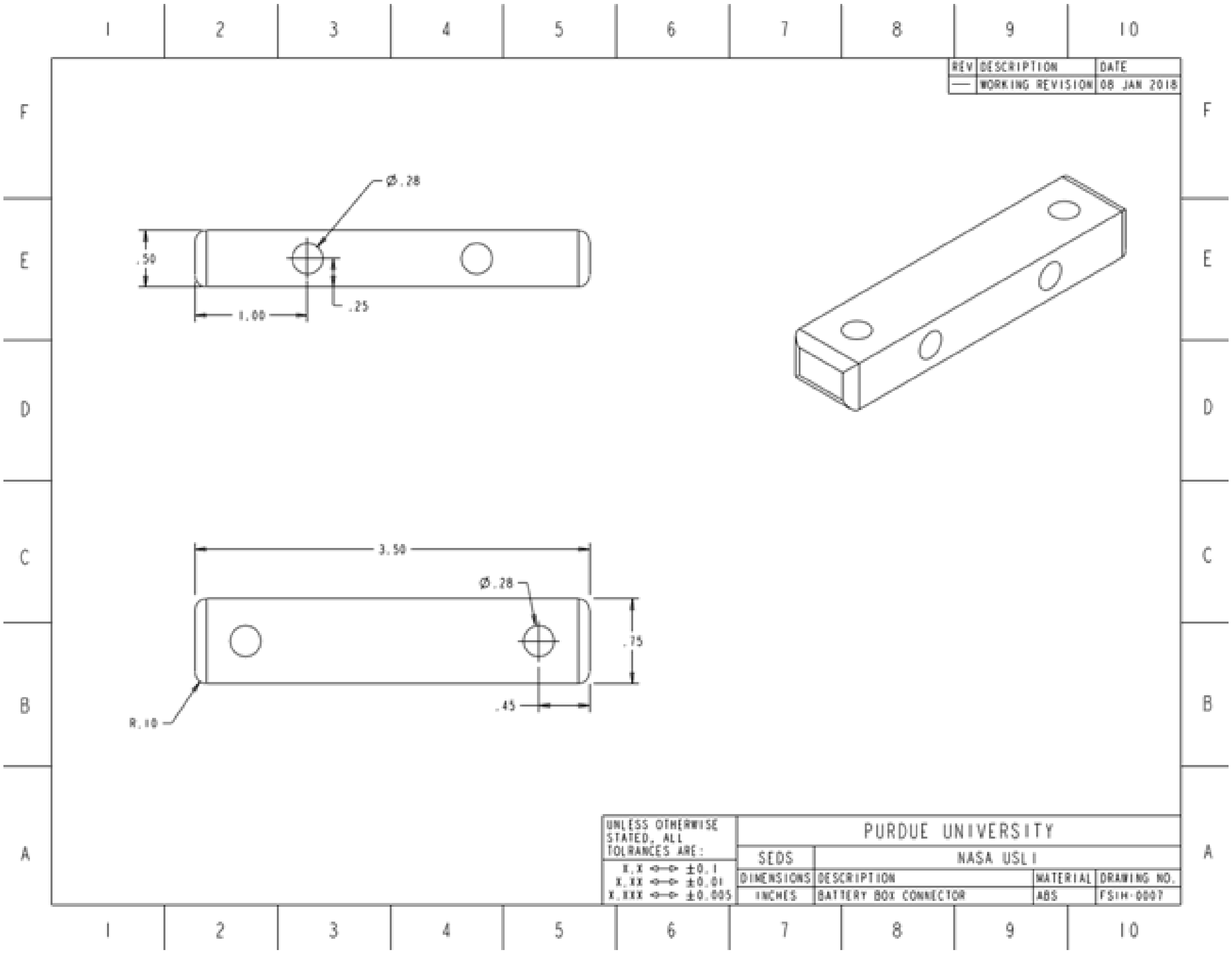
2	1	RASPBERRY PI	COTS	3B
3	1	PI CASE, TOP	ABS	FSIH-0004

UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:

X.X ⟷ ±0.1
X.XX ⟷ ±0.01
X.XXX ⟷ ±0.005

PURDUE UNIVERSITY			
SEDS	NASA USLI		
DIMENSIONS	DESCRIPTION	MATERIAL	DRAWING NO.
INCHES	RASPBERRY PI BOX	NA	FSIH-0006



REV DESCRIPTION DATE
— WORKING REVISION 08 JAN 2018
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R.10
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
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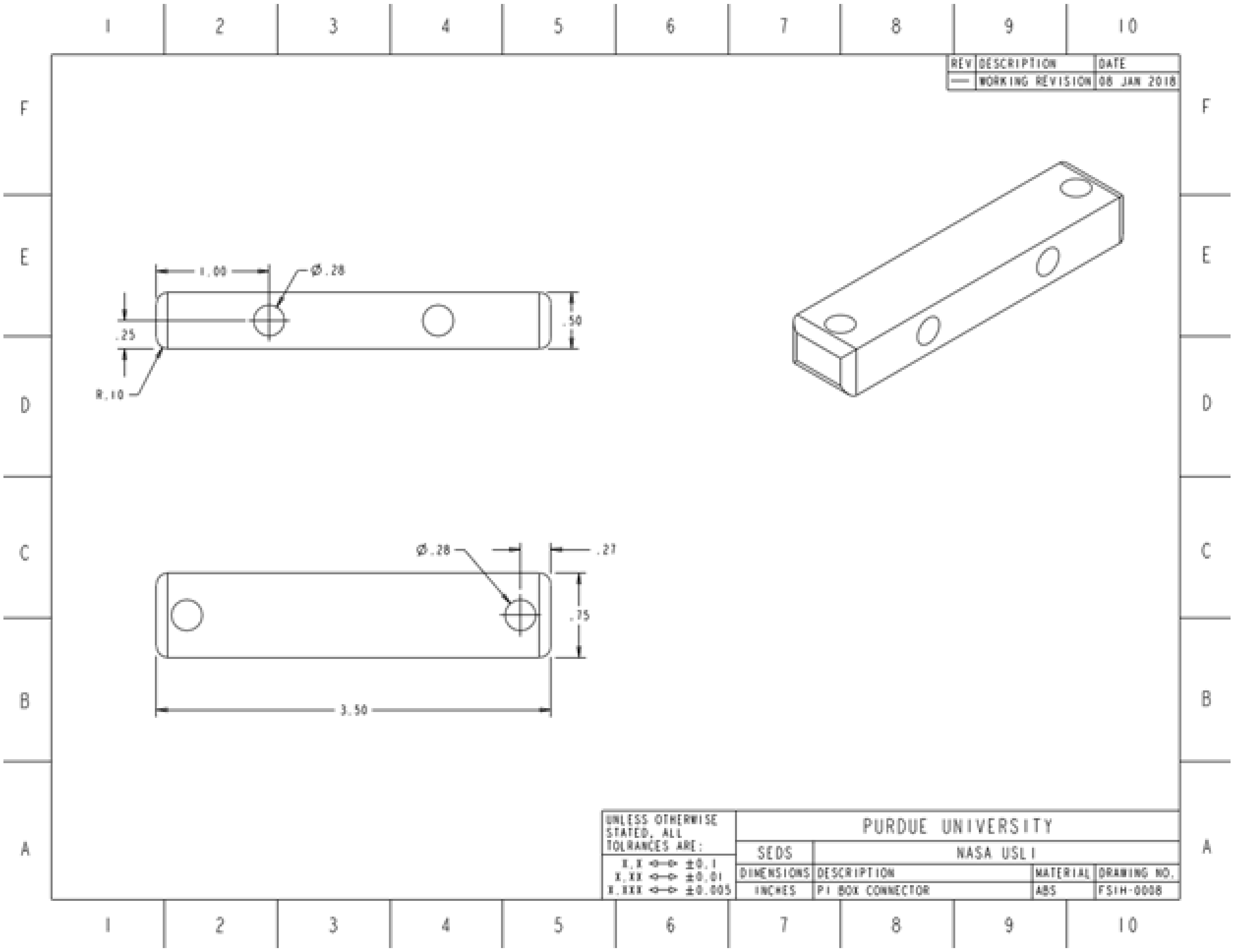
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS INCHES
DESCRIPTION BATTERY BOX CONNECTOR
MATERIAL ABS
DRAWING NO. FSIH-0007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WORKING REVISION 08 JAN 2018
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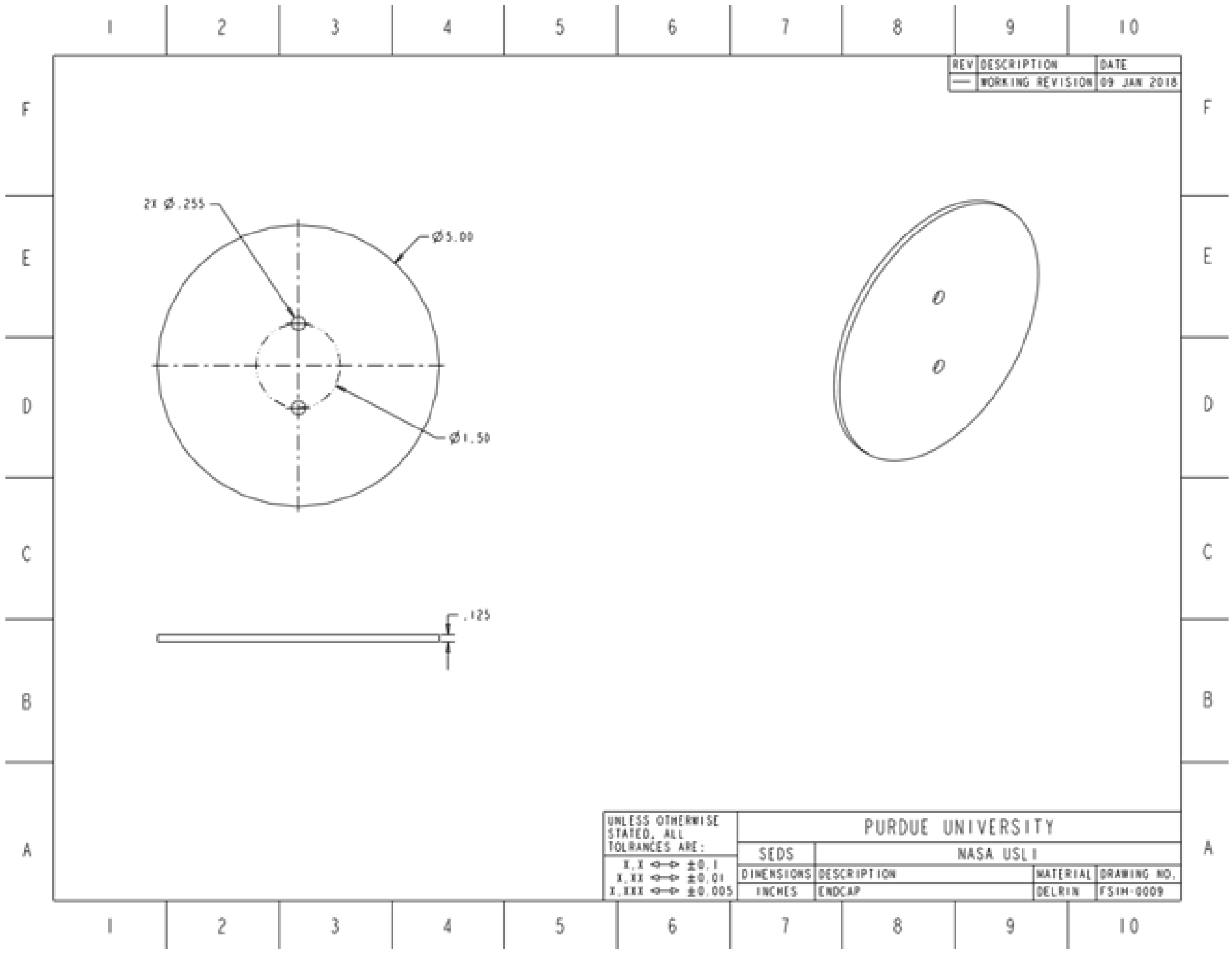
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS
INCHES
DESCRIPTION
PI BOX CONNECTOR
MATERIAL
ABS
DRAWING NO.
FSIH-0008



REV DESCRIPTION DATE
WORKING REVISION 09 JAN 2018
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Ø5.00
Ø1.50
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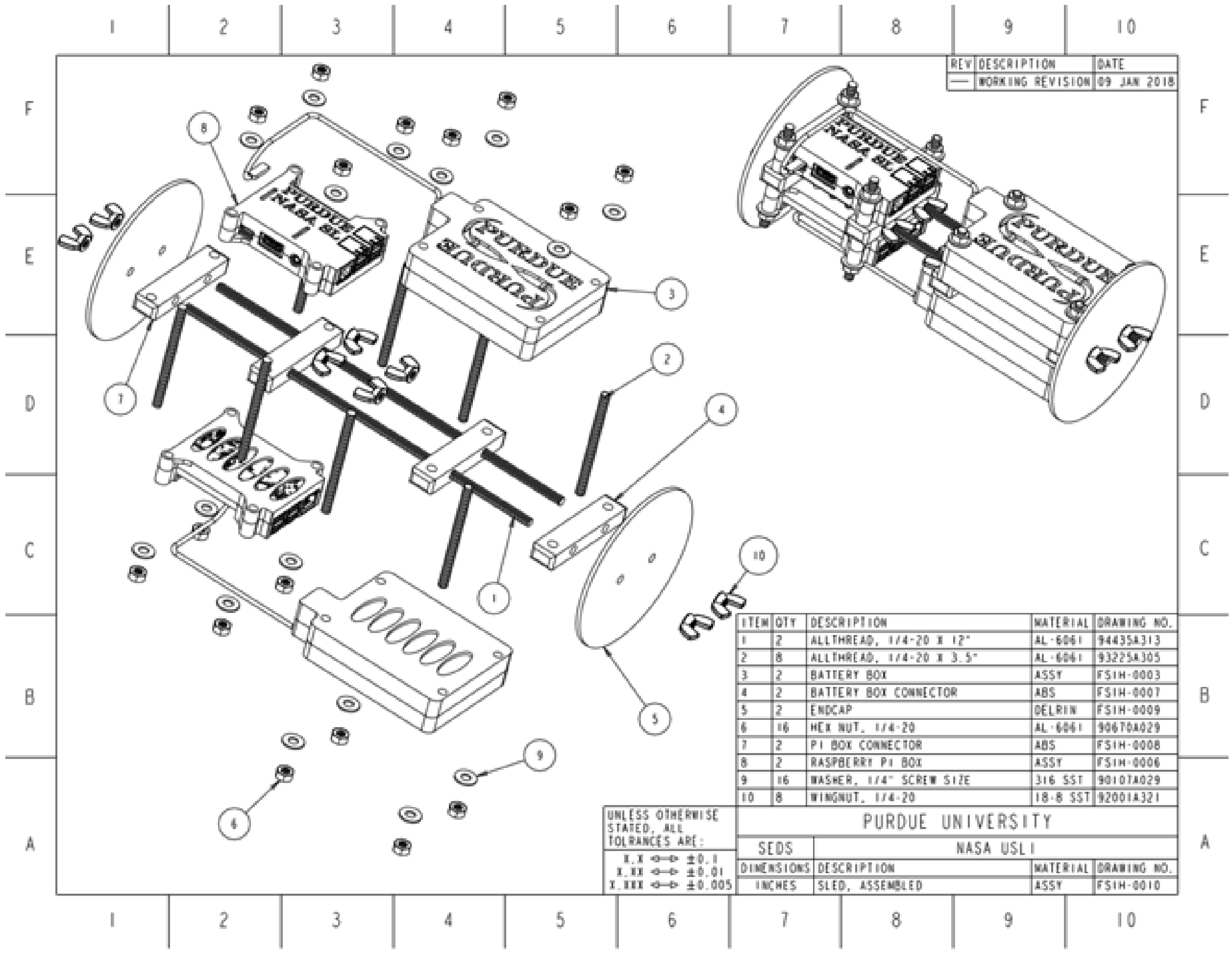
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS
INCHES
DESCRIPTION
ENDCAP
MATERIAL
DELRIN
DRAWING NO.
FSIH-0009



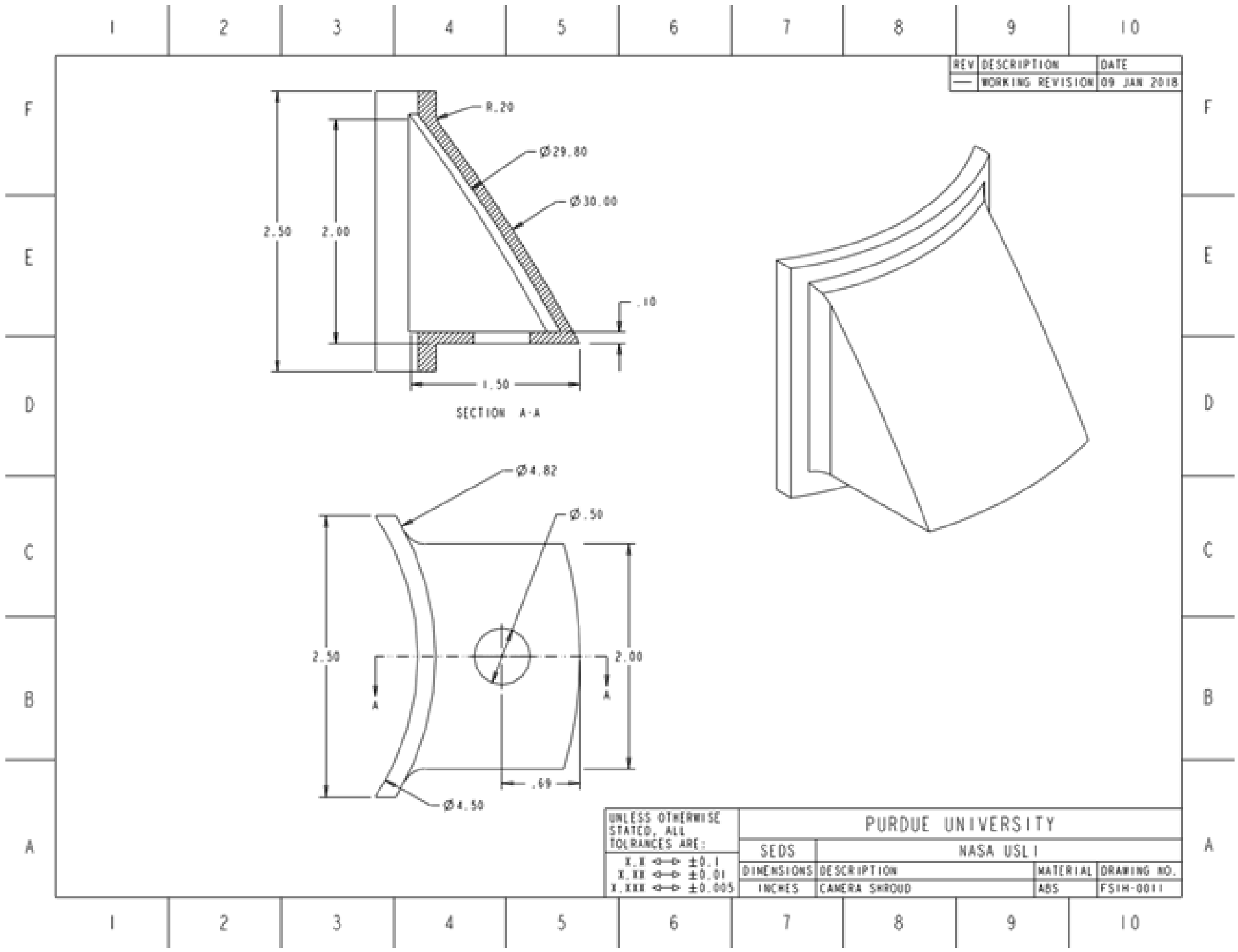
REV	DESCRIPTION	DATE
—	WORKING REVISION	09 JAN 2018

ITEM	QTY	DESCRIPTION	MATERIAL	DRAWING NO.
1	2	ALLTHREAD, 1/4-20 X 12"	AL-6061	94435A313
2	8	ALLTHREAD, 1/4-20 X 3.5"	AL-6061	93225A305
3	2	BATTERY BOX	ASSY	FSIH-0003
4	2	BATTERY BOX CONNECTOR	ABS	FSIH-0007
5	2	ENDCAP	DELRIN	FSIH-0009
6	16	HEX NUT, 1/4-20	AL-6061	90670A029
7	2	PI BOX CONNECTOR	ABS	FSIH-0008
8	2	RASPBERRY PI BOX	ASSY	FSIH-0006
9	16	WASHER, 1/4" SCREW SIZE	316 SST	90107A029
10	8	WINGNUT, 1/4-20	18-8 SST	92001A321

UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:

X.X ↔ ±0.1
X.XX ↔ ±0.01
X.XXX ↔ ±0.005

PURDUE UNIVERSITY			
SEDS	NASA USLI		
DIMENSIONS	DESCRIPTION	MATERIAL	DRAWING NO.
INCHES	SLED, ASSEMBLED	ASSY	FSIH-0010


REV DESCRIPTION DATE
— WORKING REVISION 09 JAN 2018
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Ø30.00
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1.50
SECTION A-A
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2.50
2.00
A
A
.69
Ø4.50
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
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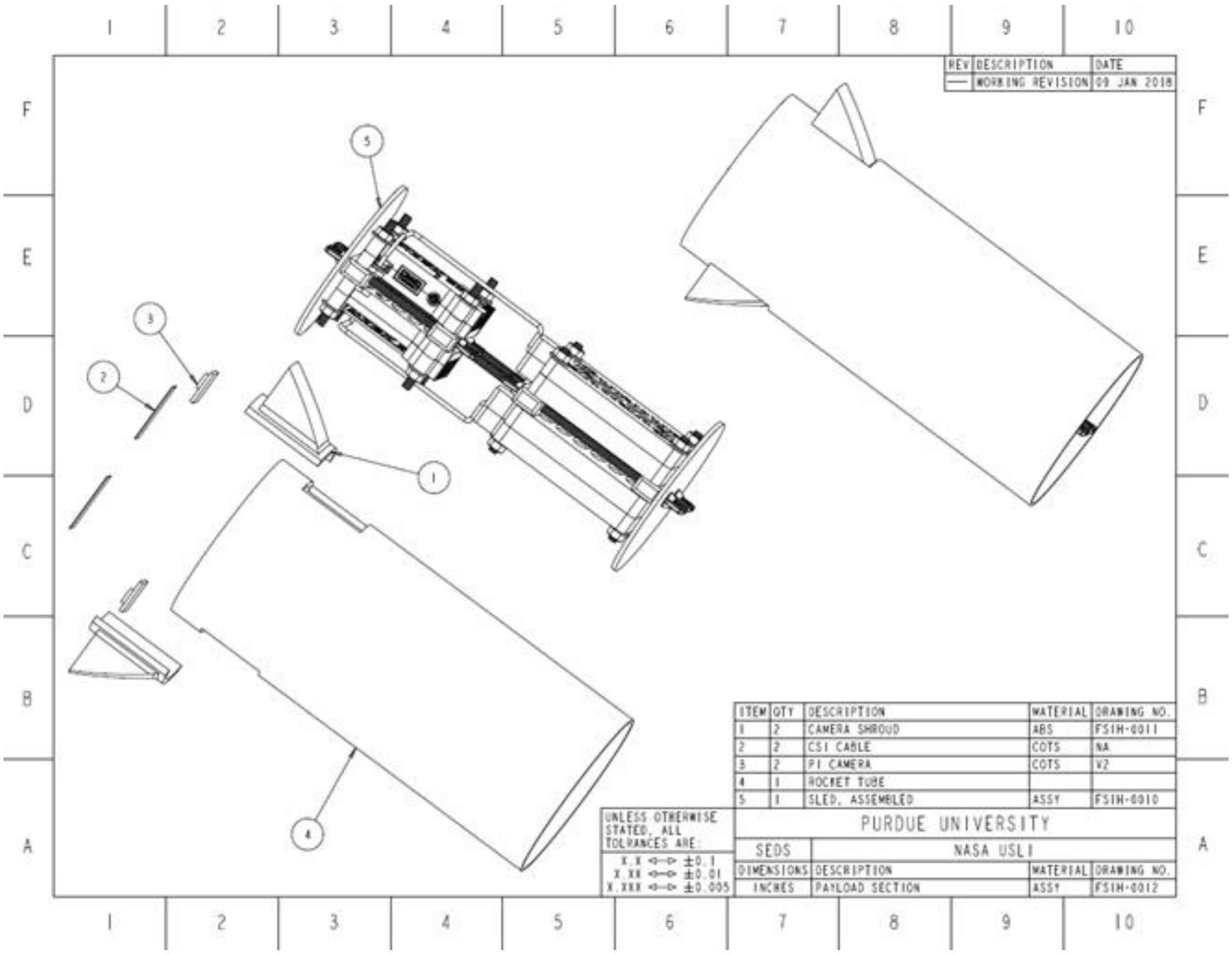
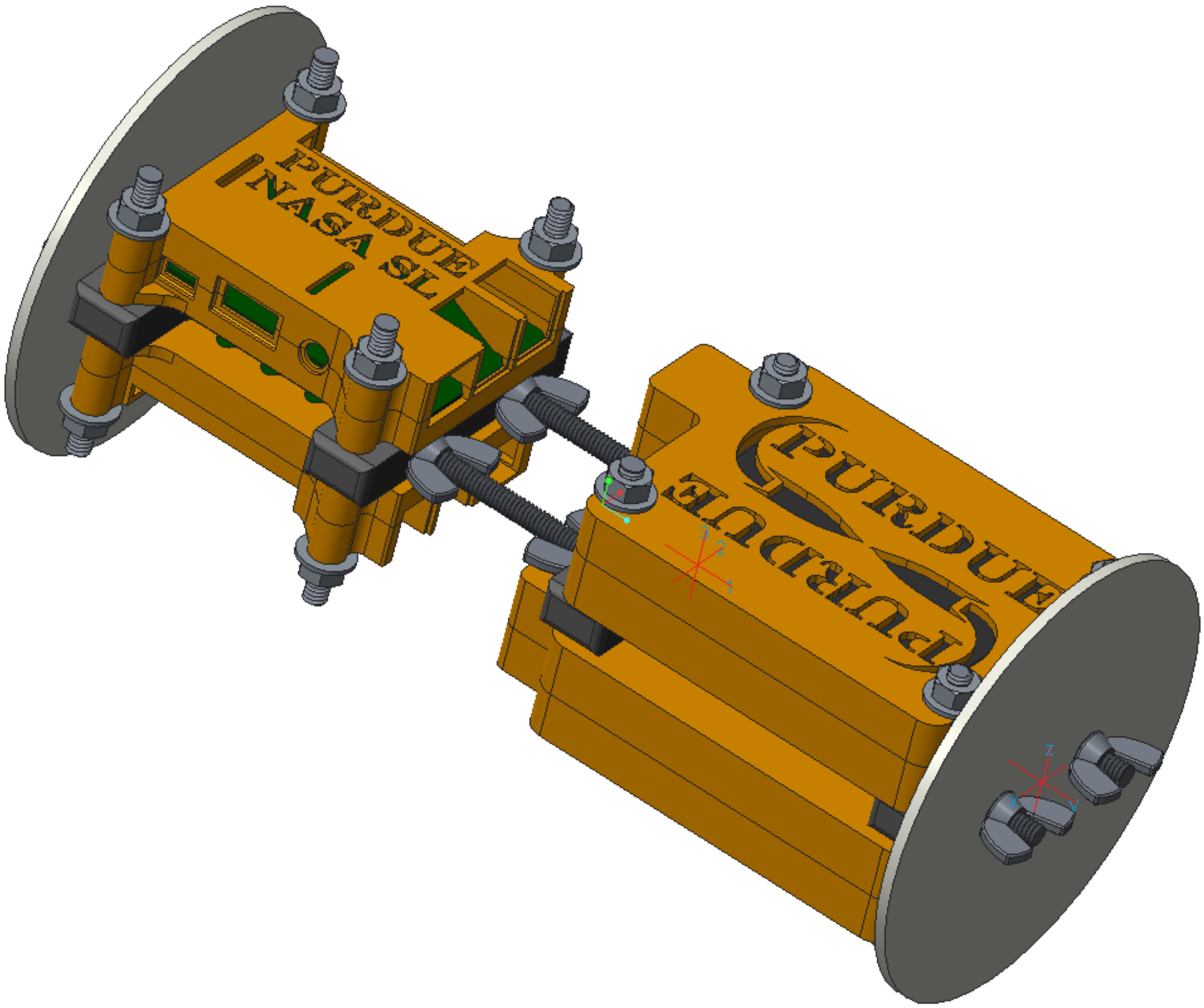
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS DESCRIPTION MATERIAL DRAWING NO.
INCHES CAMERA SHROUD ABS FSIH-0011



5.1.3. Payload and Vehicle Integration (CG, drag, etc)

The payload sled’s center of gravity is located close to the centerline axis the of the rocket tube, weighted towards the battery boxes. By using two redundant systems, it was fairly simple to maintain a balance of weight along the axis, and by placing the side with the batteries towards the forward end (with the raspberry pis and cameras towards the aft end of the rocket), the payload section can help shift the CG of the whole system up, towards the nose. This is especially important for the payload section, since it is located closest to the bottom end of the rocket, just above the motor. A view of the approximate CG can be seen in the picture below.



Note that the two red axes in the picture above mark the location from which the CG is calculated (X, Y, Z) and where the CG is located (1, 2, 3). The CG with respect to the XYZ axis is approximately (0”, -4.3”, 0”), or, more specifically, calculated as the following -1.2850381e-03 -4.3060032e+00 0.0000000e+00 INCH.

The redundancy of the two systems in the payload bay also allows for two, mirrored shrouds 180 degrees from each on the aft side of the rocket tube. This symmetry, coupled with a minimal profile on the shrouds, ensures that drag is minimized and any drag that is induced will not lead to a spin on the rocket’s trajectory.

5.1.4. Justification Of Materials, Dimensions, and Placement

Our rocket heavily relies on 3D printed parts, designed and printed by members of our team. As there are many different types of print materials, it was necessary to make a smart decision regarding which material we would use. The main materials we had to choose between were ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid). While each has its own unique benefits, ultimately we made the decision to use ABS for its ability to withstand higher temperatures and pressures. Since the parts will be undergoing a lot of stress, they must not break down or otherwise fail during flight. Since the goal of the parts is not to look incredible, but rather to withstand the force of launch, it was an easy decision to use ABS.

Another choice we needed to make was the material used to hold the payload in place. The chart below shows the stress/strain plot for the specific steel we chose. For something as fairly trivial as this, there are many choices that could work. The major issue here is the maximum tensile strength the material can withstand. Since our rocket will never reach or exceed this value, it is safe to use this material to hold the payload in

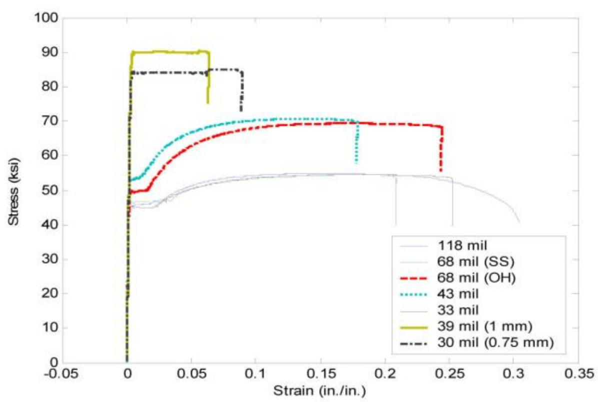


Figure 4.1 Stress-strain curves for tested materials.

The ASTM A307 Grade A and A 325 Bolts properties are listed in Table 4.2.

Table 4.2 ASTM A307 Grade A and A 325 Bolt Properties

Sizes	ASTM A307 Grade A 1/2 in. (13 threads/in.) 1/4 in. (20 threads/in.)	ASTM A325 Type 1 1/2 in. (13 threads/in.)
Tensile, ksi	60	120
Yield, ksi	--	92
Elong. %,	18	14
Chemical properties		
Carbon	0.33	0.55
Manganese	1.25	0.57
Phosphorus	0.041	0.048
Sulfur	0.15	0.058
Silicon	--	0.32

place.

Figure from: https://digital.library.unt.edu/ark:/67531/metadc10983/m1/46/high_res/

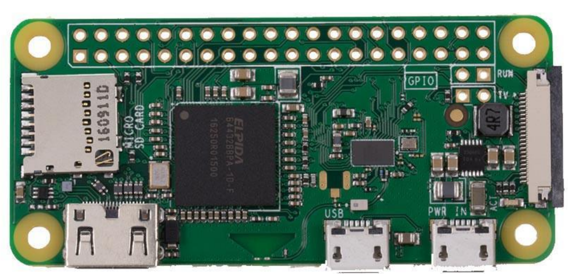
A final note to make regards the placement of the rocket components for rocket stability, specifically the placement of the battery and computer. In order to maintain stability, it is a requirement to have the center of pressure be located behind the center of gravity. This is taken into account on our rocket. According to NAR.org, in an ideal case, the center of gravity will be no closer than 1.5 times the diameter of the body tube to the center of pressure. In order to achieve this, the battery must be kept forward of the computer. This balances the center of gravity beyond the center of pressure in such a way that stability is maintained. It should be noted that the center of gravity on our rocket is located approximately 9 inches or more than two body diameters ahead of the center of pressure, following the NAR recommendation.

5.2. Subscale Design

5.2.1. System Level Design Analysis

5.2.1.1. Computer Subsystem

The team has decided to use the Raspberry Pi Zero W for use with the subscale rocket. The objective of the subscale launch is to obtain a video of flight, so not as much processing power is needed as the full scale launch. The Pi Zero W is used solely for capturing the video. It features a single core ARM1176JZF-S processor, 512 MB of RAM, and built in WIFI. It features a smaller Camera CSI port that can be connected to the Pi Camera with the use of an adapter.



The Pi Zero W was picked for several main reasons. The first reason is that the size of the Zero fits the subscale rocket, being only 65 mm x 30 mm x 5 mm. The second reason is that it is very inexpensive, being only $10 USD. The Zero W was picked over the Zero because it has built in wifi, simplifying connecting it with other devices after the test video has been taken.

5.2.1.2. Camera Subsystem

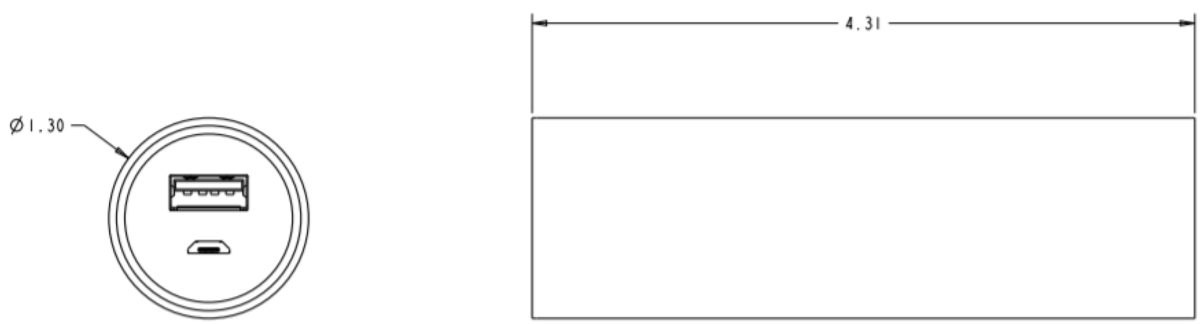
The camera used in the subscale design is the same as that for the full scale flight. In order to ensure design parity and develop confidence in the payload, it is desirable to maintain as much similarity between the two flights as possible. The camera has a minimal footprint and works with both different computer systems, so it was simple to use the same component and design constraints for the subscale flight. Thus, the same design choices and mounting scheme developed in section 5.1.2.2, above, and so will not be repeated in this section.

5.2.1.3. Battery Subsystem

A list of requirements was created in order to narrow down the many possibilities available. The requirements are as follows:

1. The battery must be less than $20
2. The battery must be less than one half of a pound
3. The battery must be less than two inches by two inches in order to fit into the subscale (three inch inner diameter)

Based on these requirements, the Anker PowerCore 5000 was chosen. This battery was chosen because it meets all of the requirements and also satisfies the max power draw of the Raspberry Pi Zero, which we will be using in our subscale rocket (350 mA / 1.75 W). Along with meeting the requirements listed and those of the Pi Zero, the battery is made by the same company and will therefore perform in a similar fashion to the battery in use for the full scale. Shown below is a dimensional drawing of the subscale battery.

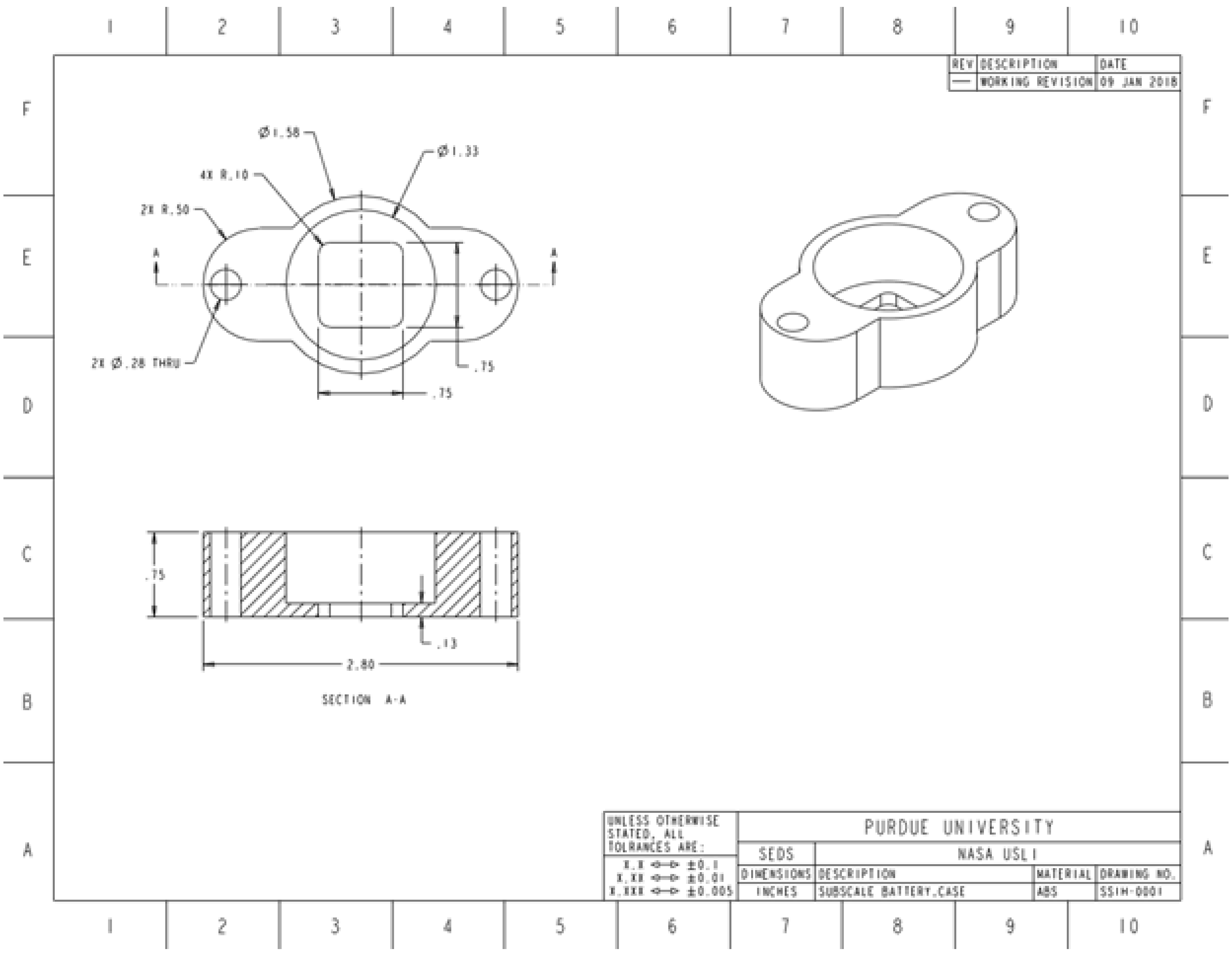


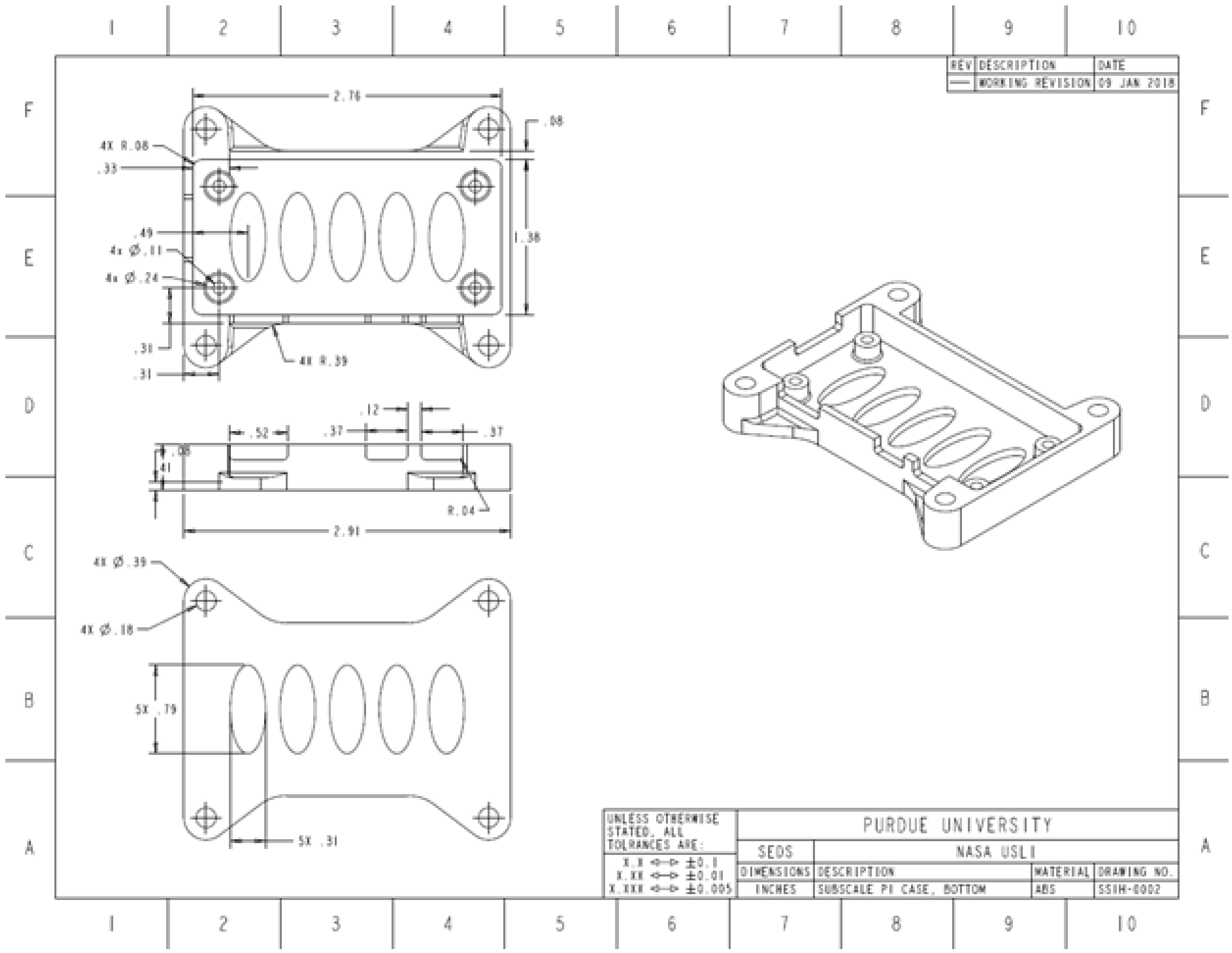
5.2.1.4. Software Subsystem

The software being used for the subscale payload is very basic compared to the full scale payload. This was decided to be a requirement based on the specifications of the computer being used in the subscale rocket, the Raspberry Pi Zero W. It does not have the same processing capability of the full scale Raspberry Pi and therefore would not be able to run the same software. The Raspberry Pi Zero W is running the latest version of the Raspbian operating system. Within the operating system, the terminal is being used to run the following command: raspivid -o video.h264 -t xxxxxx, where xxxxxx is the length of time needed to record the video. This command accesses the connected picamera to record a video in h264 format of the specified file name with the specified length of time. The video that is recorded will be plugged into the software subsystem being used in the full scale payload for further testing.

5.2.1.5. Hardware/connectors (dimensional drawings, CAD)

A set of subscale hardware was developed to facilitate the required subscale flight. This hardware is similar to the full scale hardware, but scaled down significantly to both fit in the smaller diameter rocket tube and to accommodate the smaller hardware used for this flight (the computer, and battery are both smaller, as detailed in the previous sections). A full drawing package of the subscale payload sled hardware components is shown below.

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— WORKING REVISION 09 JAN 2018
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.33
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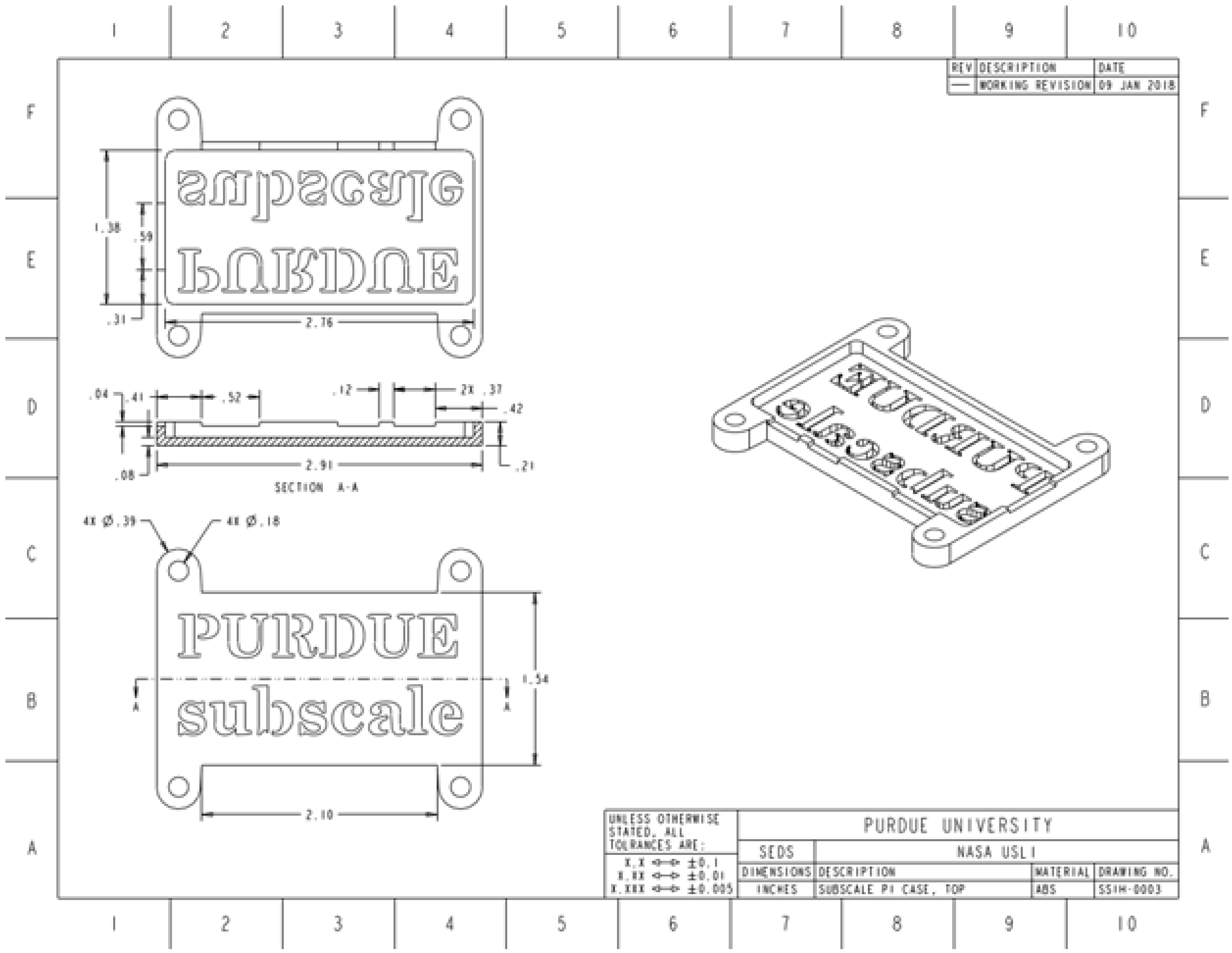
4x Ø.11
4x Ø.24
1.38
.31
.31
4X R.39
.12
.52
.37
.37
.08
.41
R.04
2.91
4X Ø.39
4X Ø.18
5X .79
5X .31
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
X.X ±0.1
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS INCHES
DESCRIPTION SUBSCALE PI CASE, BOTTOM
MATERIAL ABS
DRAWING NO. SSIH-0002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— WORKING REVISION 09 JAN 2018
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.21
SECTION A-A
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4X Ø.18
PURDUE
subscale
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A
A
2.10
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
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X.XX ±0.01
X.XXX ±0.005
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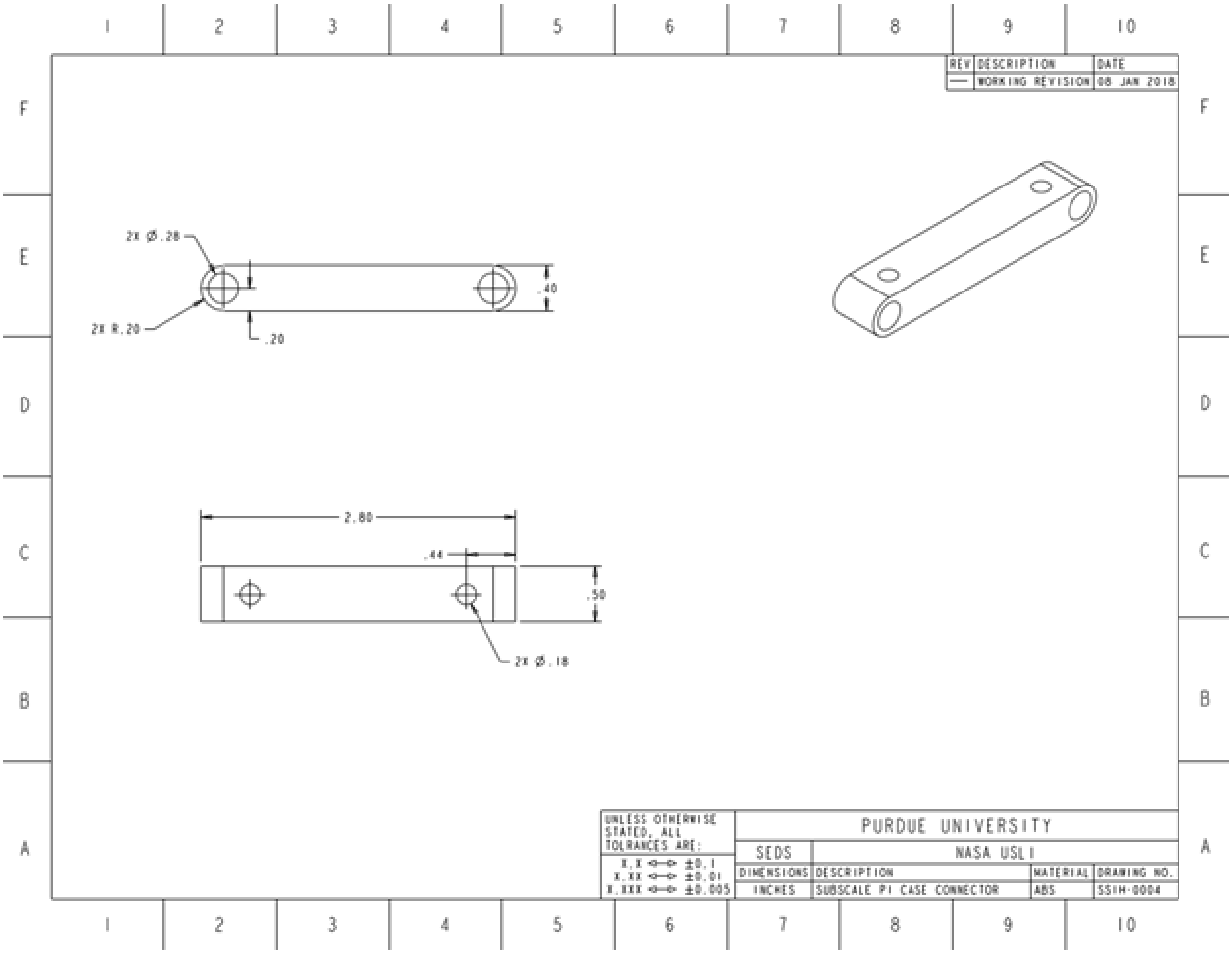
SEDS
NASA USLI
DIMENSIONS INCHES
DESCRIPTION SUBSCALE PI CASE, TOP
MATERIAL ABS
DRAWING NO. SSIH-0003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— WORKING REVISION 08 JAN 2018
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2X Ø.18
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X.X ±0.1
X.XX ±0.01
X.XXX ±0.005
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SEDS
NASA USLI
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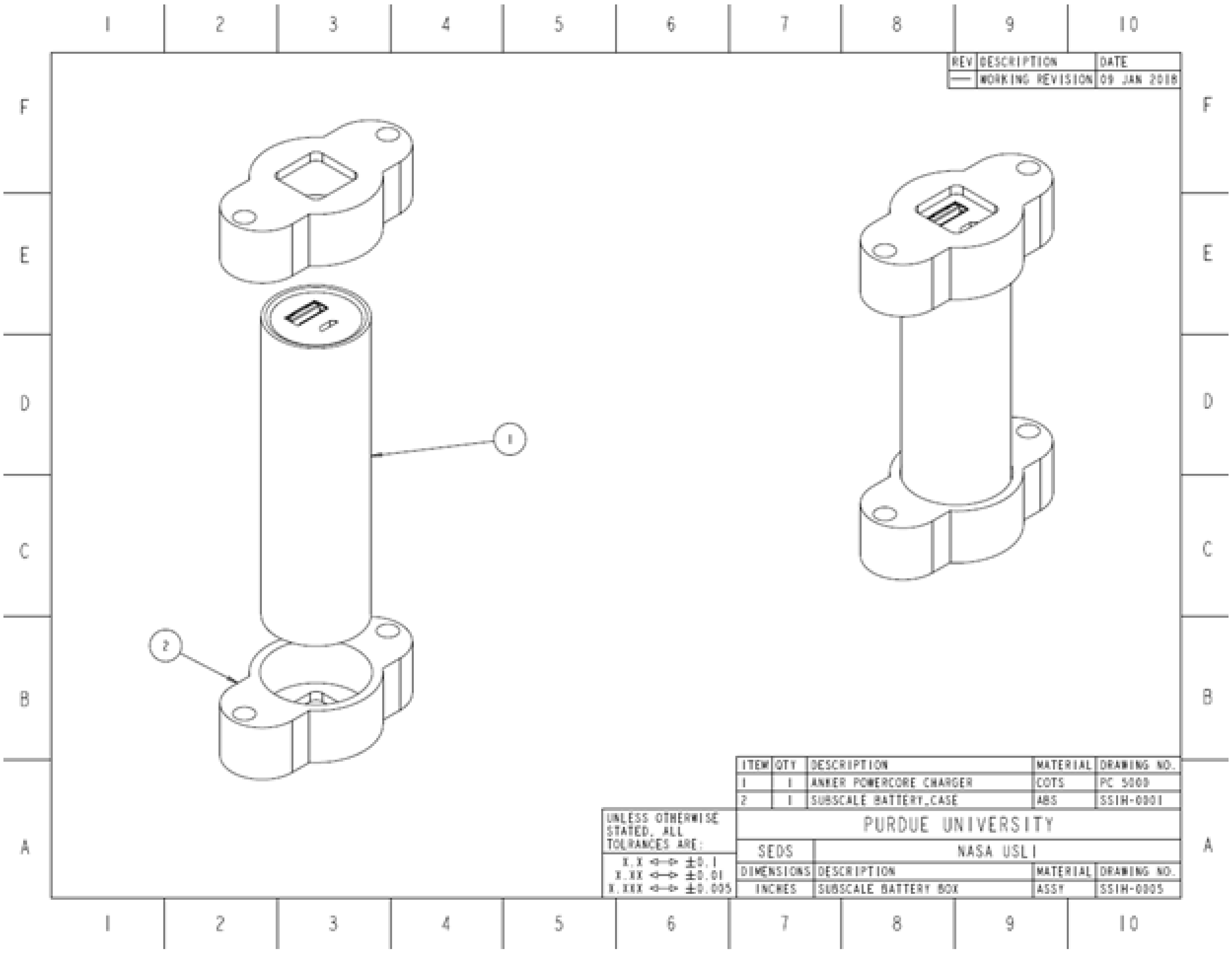
INCHES SUBSCALE PI CASE CONNECTOR ABS SSIH-0004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— WORKING REVISION 09 JAN 2018
1
2
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2 1 SUBSCALE BATTERY,CASE ABS SSIH-0001
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
X.X ±0.1
X.XX ±0.01
X.XXX ±0.005
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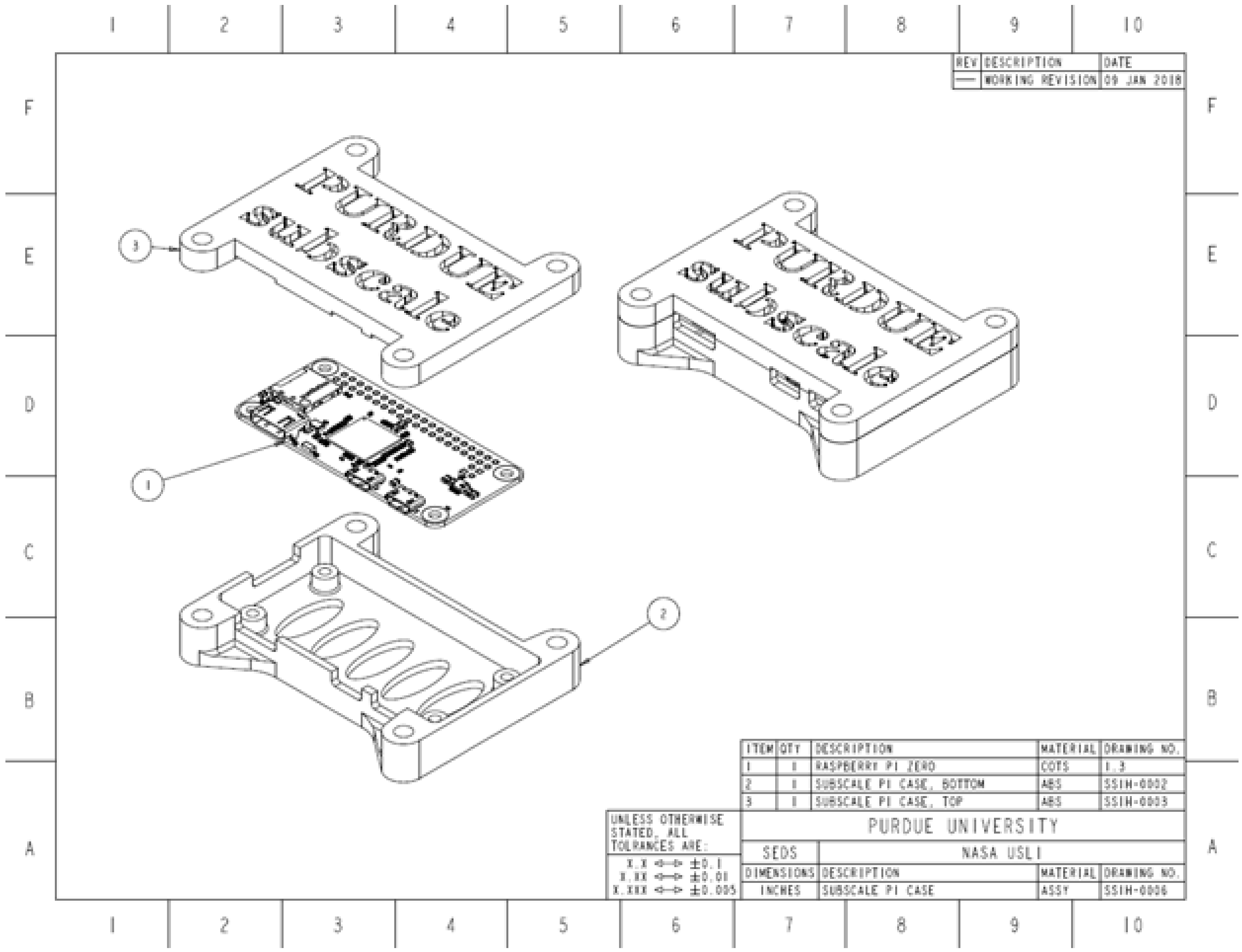
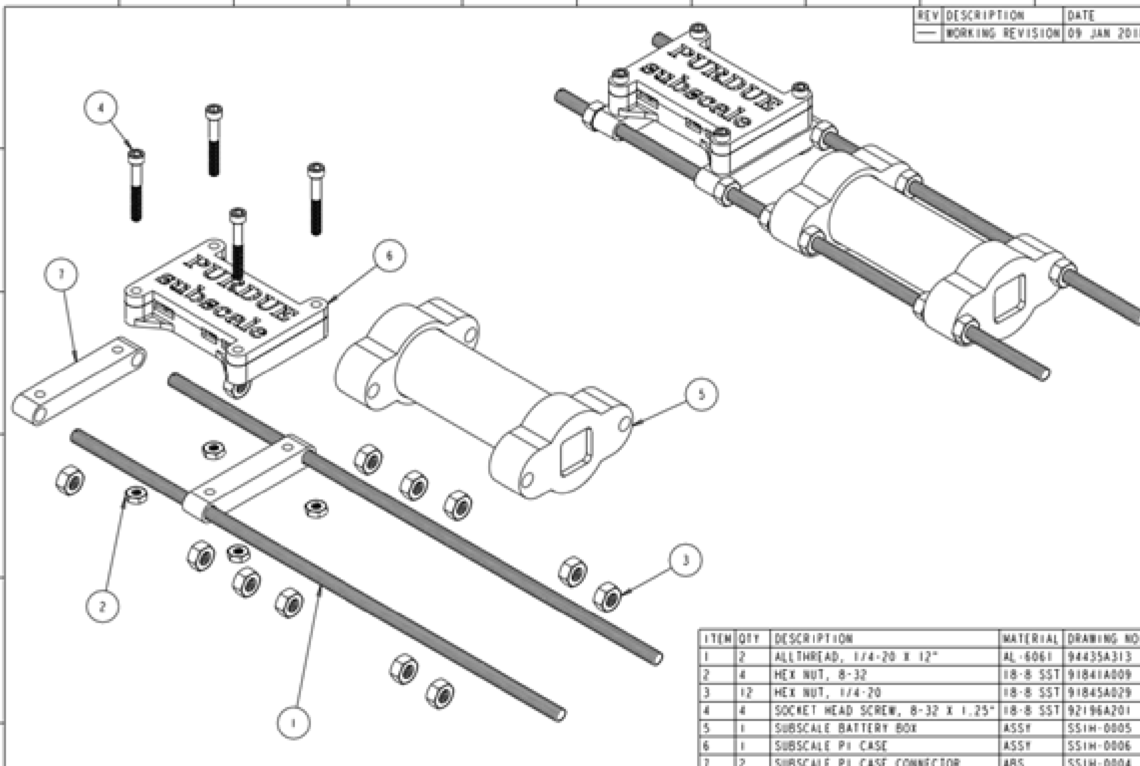
SEDS
NASA USLI
DIMENSIONS DESCRIPTION MATERIAL DRAWING NO.
INCHES SUBSCALE BATTERY BOX ASSY SSIH-0005



REV DESCRIPTION DATE
— WORKING REVISION 09 JAN 2018
PURDUE subscale
PURDUE subscale
3
1
2
ITEM QTY DESCRIPTION MATERIAL DRAWING NO.
1 1 RASPBERRY PI ZERO COTS 1.3
2 1 SUBSCALE PI CASE, BOTTOM ABS SSIH-0002
3 1 SUBSCALE PI CASE, TOP ABS SSIH-0003
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
X.X ±0.1
X.XX ±0.01
X.XXX ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS DESCRIPTION MATERIAL DRAWING NO.
INCHES SUBSCALE PI CASE ASSY SSIH-0006



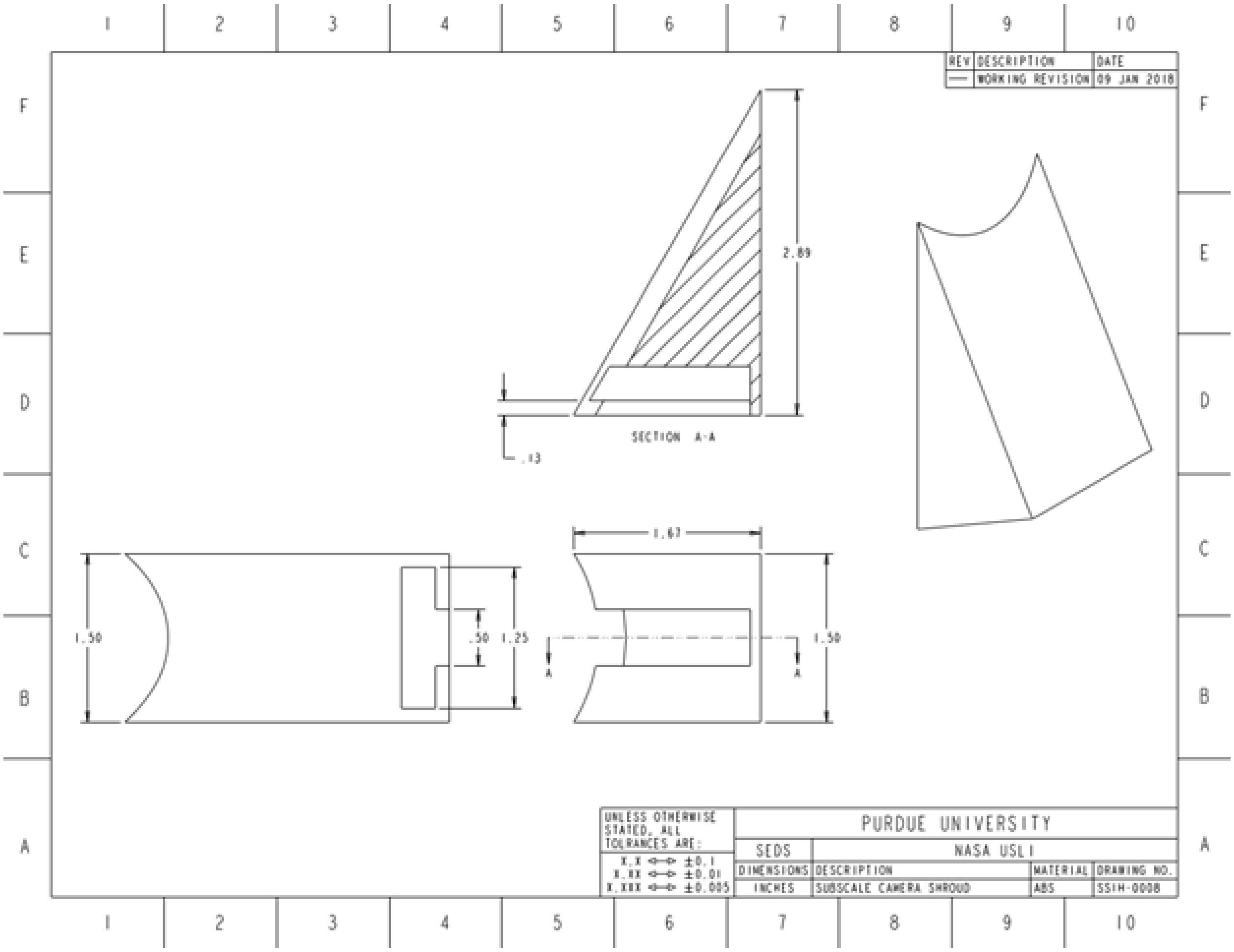
REV	DESCRIPTION	DATE
—	WORKING REVISION	09 JAN 2018

ITEM	QTY	DESCRIPTION	MATERIAL	DRAWING NO.
1	2	ALLTHREAD, 1/4-20 X 12"	AL-6061	94435A313
2	4	HEX NUT, 8-32	18-8 SST	91841A009
3	12	HEX NUT, 1/4-20	18-8 SST	91845A029
4	4	SOCKET HEAD SCREW, 8-32 X 1.25"	18-8 SST	92196A201
5	1	SUBSCALE BATTERY BOX	ASSY	SSIH-0005
6	1	SUBSCALE PI CASE	ASSY	SSIH-0006
7	2	SUBSCALE PI CASE CONNECTOR	ABS	SSIH-0004

UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
X.X ⇔ ±0.1
X.XX ⇔ ±0.01
X.XXX ⇔ ±0.005

PURDUE UNIVERSITY

SEDS	NASA USLI		
DIMENSIONS	DESCRIPTION	MATERIAL	DRAWING NO.
INCHES	SUBSCALE SLED, ASSEMBLED	ASSY	SSIH-0007



REV DESCRIPTION DATE
— WORKING REVISION 09 JAN 2018
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.13
SECTION A-A
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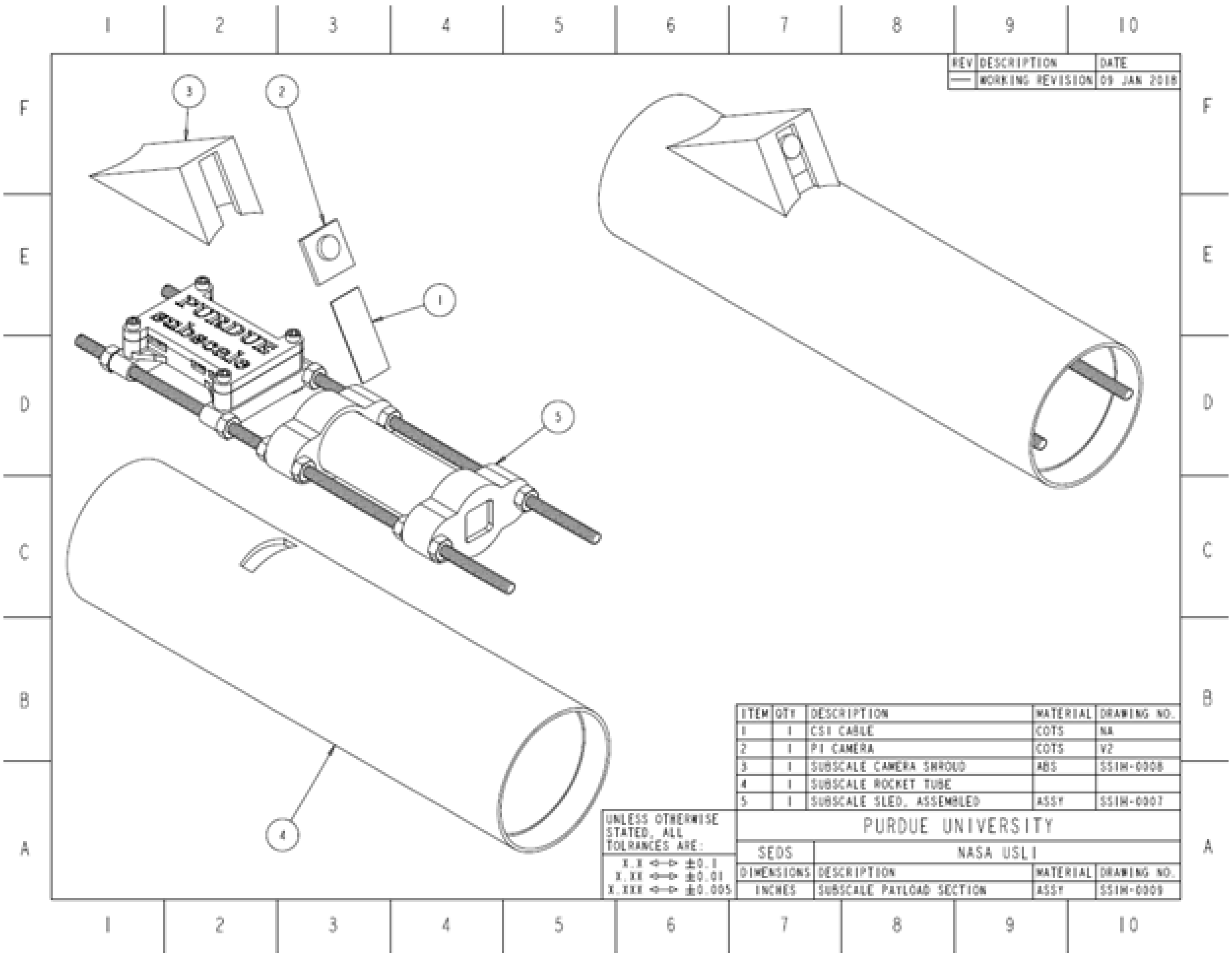
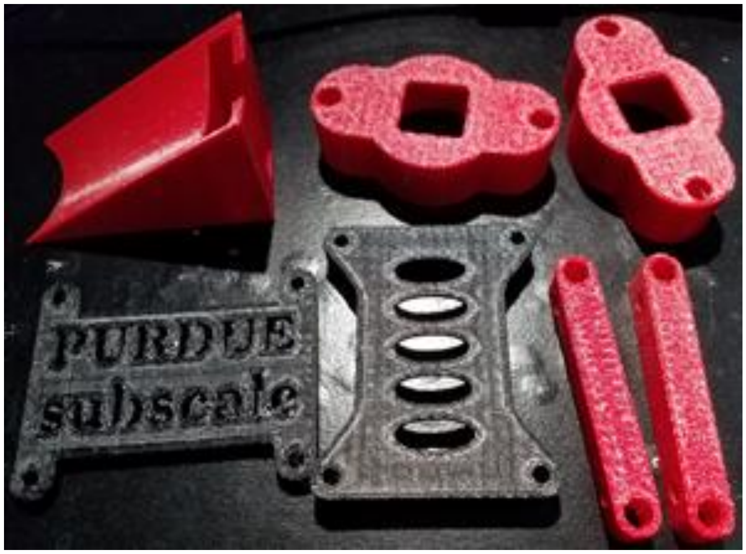
.50
1.25
1.50
A
A
UNLESS OTHERWISE STATED, ALL TOLRANCES ARE:
X.X ⇔ ±0.1
X.XX ⇔ ±0.01
X.XXX ⇔ ±0.005
PURDUE UNIVERSITY
SEDS
NASA USLI
DIMENSIONS DESCRIPTION MATERIAL DRAWING NO.
INCHES SUBSCALE CAMERA SHROUD ABS SSIH-0008

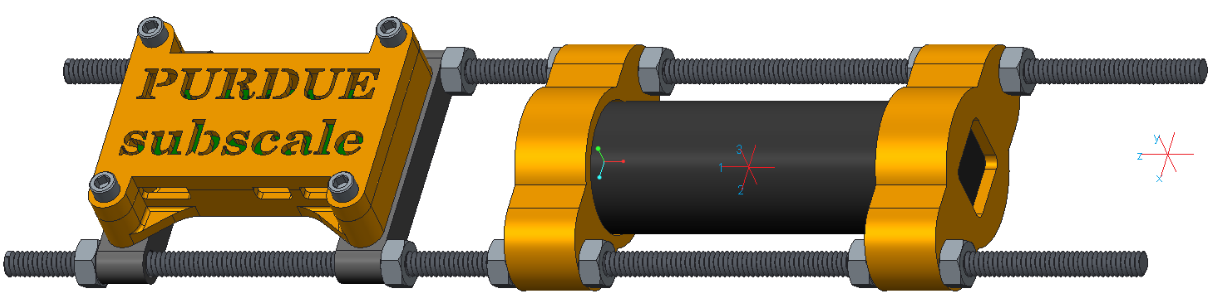


The subscale parts were printed (see below) at an on-campus makerspace and needed no post processing, except for the shroud which required 2 mounting holes drilled into it. Note that the subscale shroud is mounted externally, whereas the full scale shroud is designed to be mounted internally. This is to make the mounting simpler for the subscale flight, while the full scale mounting scheme is designed to be more robust. However, pending the outcome of the subscale flight, the full scale shroud may be redesigned to match the subscale configuration.



5.2.2. Payload and Vehicle Integration (CG, drag, etc)

The subscale payload sled's center of gravity is located close to the centerline axis the of the rocket tube, weighted towards the battery, similar to that of the full scale. Although the subscale payload bay does not use redundant systems, it is still possible to keep the CG along the centerline. By placing the heavier components (namely, the battery), directly along the axis, it was fairly simple to maintain a balance of weight along the axis, and by placing the side with the batteries towards the forward end (with the raspberry pis zero and camera towards the aft end of the rocket), the payload section can help shift the CG of the whole system up, towards the nose. This is especially important for the payload section, since it is located closest to the bottom end of the rocket, just above the motor. A view of the approximate CG can be seen in the picture below.



Note that the two red axes in the picture above mark the location from which the CG is calculated (X, Y, Z) and where the CG is located (1, 2, 3). The CG with respect to the XYZ axis is approximately (0", -0.2", 4.5"), or, more specifically, calculated as the following 4.4500212e-03 -1.9089251e-01 4.4906669e+00 INCH. Note that the names of each of these axes is different than those for the full scale CG calculations.

The subscale rocket uses only a single camera and external camera shroud, but the minimal profile design on the shroud, should ensure that induced drag is minor and will not significantly affect the rocket's trajectory.

6. Project Plan

6.1. Testing

6.1.1. Tests Required To Prove Design Integrity

6.1.1.1. Avionics Continuity Testing

Upon testing we wired together the 9v battery, the switch, and 2 e-matches all to the RRC3+ Sport. We first wanted to make sure the altimeter worked so we powered it up and it was successful analyzing the air pressure and continuity. Again for continuity, the RRC3+ Sport from Missile Works indicated that both the main and drogue e-matches were successfully connected to the altimeter. We knew that the e-matches had successful continuity due to the correct number of beeps given to us by the altimeter audibly.

6.1.1.2. Avionics Battery Power Drain Testing

For the avionics battery power drain testing we connected the battery, altimeter, and switch together. Then made sure the altimeter was receiving power when it was turned on by checking for audible and visual response. For the full scale launch in Huntsville, Alabama we need the altimeters to run for at least 1 hour on the launch pad and for the duration of the flight. Due to total time needed for the altimeters to be running as well as the power needed to ignite the e-matches we estimated that about 50 mAh were needed to power the entire system. For the subscale launch we have more than enough to power the RRC3+ Sport and e-matches, for the full scale launch, we will add a redundant 9v battery for the RRC3+ Sport and a redundant 3.7v LiPo battery for the Telemetrum.

Power Requirements

· 3.5 VDC to 10.0 VDC / Optimized for 9V battery power

· 6ma @ 9V quiesecent / 35ma @ 9V during piezo and LED operation

Bridgewire Resistance	Maximum No-Fire Current	Minimum All-Fire Current	Recommended Minimum Firing Current	Recommended Nominal Firing Current	Maximum Test Current
1 ohm ± .2 ohms	.30 amp. (300milliamp.)	.60 amp (600 milliamp.)	.75 amp	1.00 amp	.04 amp (40 milliamp.)

6.1.1.3. Payload Battery Power Drain Testing

Testing the performance of the payload battery will ensure that all electrical components of the payload will receive its respective power requirements for the full duration of its operation. The criteria for a successful payload battery are as follows. The battery must be able to supply a constant 5 volts, the battery must be capable of providing 2 amps at anytime, must be capable of providing at least a constant 1 amp, and the battery must fulfill all prior criteria for the duration of at least two hours.

In order to test the payload battery, a digital usb multimeter will be connected in between the payload battery and the Raspberry Pi, and various stress tests using a system benchmarking tool will be performed with the Raspberry Pi to see if the battery is capable of following all the predefined criteria. If the Raspberry Pi does not receive a constant voltage of around 5 volts, the Raspberry Pi could face under-voltage problems. If the Raspberry Pi were to receive voltages of 4.65 volts or less, the Raspberry Pi will resort to reducing the clock speeds of the CPU, GPU, and DRAM which will significantly reduce the on board software speed. Reaching voltages below 4.65 volts may also result in the shut off of the Raspberry Pi and termination of the payload software. If the Raspberry Pi were to receive amperage lower than 1 amp, the Raspberry Pi as well as the peripherals that the Raspberry Pi is powering may not get receive enough current and can suffer in performance.

6.1.1.4. Camera Testing

Testing performed on the camera will be used to ensure that the hardware is capable of meeting the requirements of the payload. The testing will ensure that the camera is capable of capturing the targets, and will be used to determine the ranges of values that are expected to be captured for the hue, saturation, and value of each tarp based on the given RGB values.

The main testing plan for the camera is laid out as follows. The three tarp samples that were provided to us will be used for testing purposes of the camera. It will be assumed that the RGB values of the samples are the same as the RGB values of the tarps that will be set up at the final launch, within a reasonable margin of error. These three samples will be placed in as many different environments with different lighting conditions as determined could be reasonable to expect for the final launch. Images will be taken both indoors and outdoors, with varying natural and artificial lighting. All images will be captured with the pi camera being powered by the raspberry pi so as to keep the testing conditions as close to the completed subsystem as possible. Once all the images are taken, sampling techniques will be employed to determine the HSV value for each tarp sample in each image. The maximum number for each H, S, and V value and the minimum number for each H, S, and V value will be used for each tarp in the software subsystem.

6.1.1.5. Software Testing

Testing the performance of the software used on the Raspberry Pi will ensure that the payload will be able to capture and analyze images all throughout flight time. The criteria for successful payload software are as follows. The software must be able to continually run using adequate error handling, must be able to correctly identify a target if it appears in an image, must be able to process at least 10 frames per second.

In order to test that the software is capable of continuously running, the software will have to pass through multiple simulations with pre-recorded or simulated media. So far, programs can be tested using a google earth video with the tarps and their approximate RGB values as well as the launch location, or using prototype test flight videos with a similar launch environment. Testing the software in multiple different environments will ensure that the software does not only work in specific cases and won't run into any foreseeable runtime errors that will cause the program to crash. If a program is not able to continually run on the Raspberry pi without crashing, error handling should be integrated into the code or new approaches and algorithms towards object detection should be pursued.

Testing that the software is capable of detecting objects will also use media similar to above including both simulated and test flight video and images. In all of the provided testing media, the software should be able to detect the presented tarps with each test having parameters that match the tarps presented. In depth analysis of all processes and image transformations will also be analyzed to ensure that the tarp detection algorithm is working for the right reasons. In order to clearly visualize all steps that take place within the program, a simple GUI application will be developed that will present the initial image, the initial image's transformations, and lastly the final image with all tarps detected. A simple GUI application can be made in python using PyQt4 that will be able to display all the relevant transformations present in the currently proposed real-time tarp detection algorithm. Being able to view all of the image transformations will allow for easier and quicker troubleshooting for inadequate tarp detection algorithms. If the current real-time tarp detection algorithm proves to be inadequate in detecting tarps, parameters and program flow may be modified, or a new approach for tarp detection should be pursued.

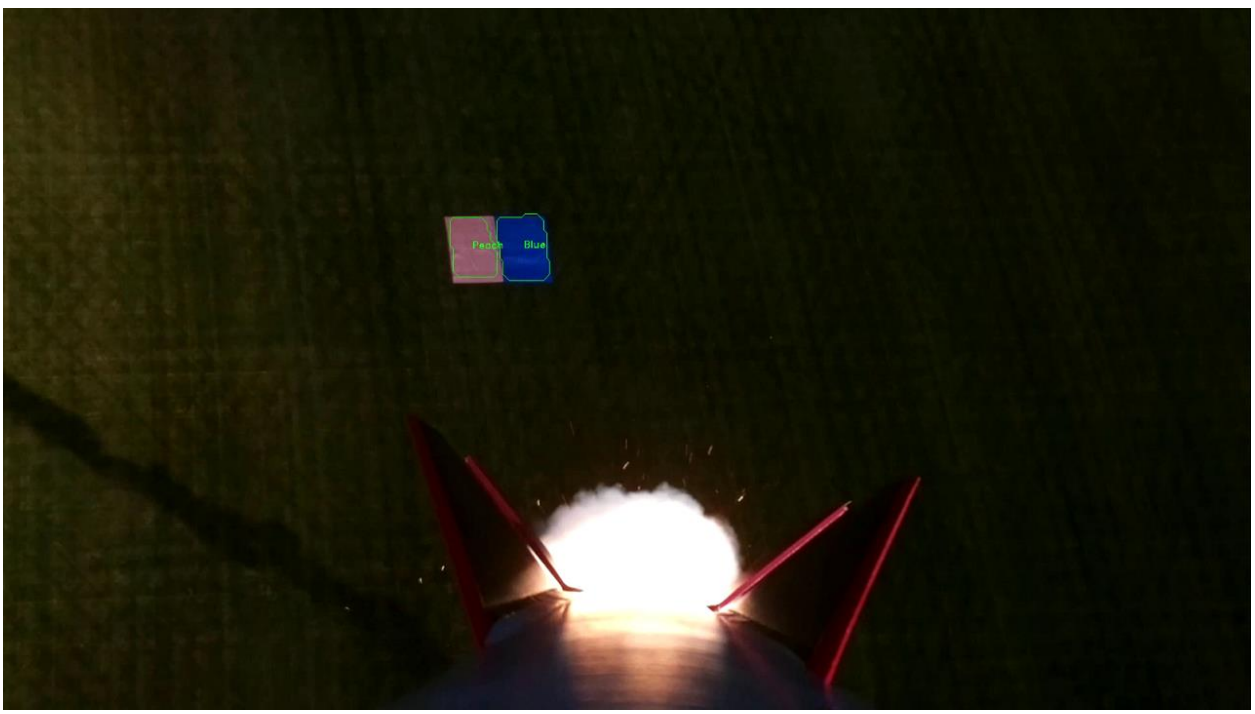
Testing that software performance would simply involve running the software on the Raspberry Pi and creating a benchmarking tool within the software. The software present on the Raspberry Pi should be able to analyze at least 10 images per second to ensure final video quality. Analysis speed can be found by creating a class that records the time every time an image is analyzed that will later be able to find the FPS over the course of running. This benchmarking class will also be used to find the time taken for each image transformation to discover the most computationally expensive transformations. If a step in the software is too computationally expensive, alternative algorithms or steps will be considered.

6.1.2. Completed Tests and Results

6.1.2.1. Prototype Flight

The prototype was a subscale rocket built personally by one of the team members. The team decided that the flight could be used as a test case for the payload. The computer and camera system was the same system that is used in the payload criteria for the full scale rocket, consisting of the Raspberry Pi 3 B and the Pi Camera. The objective of the flight with regards to this project was to test that the payload system could be used aboard a functional rocket and to obtain a video that could be processed by our team-written software after the flight. At the launch site, two tarps of size sixteen x twenty-four feet and two different known colors were placed approximately one hundred feet from the launch site. The camera was set to record 30 frames per second at a resolution of 1920 x 1080.

The flight and results obtained was largely a success. The team was able to capture a video that was saved locally to the computer and accessible to be processed. The video was trimmed through a video editor so that it only consisted of frames that included the flight. The resulting video file was input as a parameter into the target detection software written by the team. Below is a picture of the tarps from the rocket mid-flight, with the overlay drawn on from the program correctly identifying the tarps.



The range of RGB values for the blue tarp were determined to be [60 - 134, 100 - 255, 56 - 135] for minimum and maximum R, G, and B respectively. The range of RGB values for the peach tarp were determined to be [152 - 190, 40 - 101, 128 - 173] for minimum and maximum R, G, and B respectively. These values were converted to to HSV format by running them through a simple python script. The HSV values for the blue tarp were then calculated as [110 - 111, 189 - 231, 117 - 211] for H, S, and V respectively. The HSV values for the peach tarp were then calculated as [166 - 172, 45 - 91, 131 - 212] for H, S, and V respectively.

When the video was run through the program, it was confirmed that using the HSV color scale yielded a higher target detection rate with a smaller amount of false positives. Using this scale, we were able to fine tune the H value and open up the other values to achieve the best results. This flight video gave us a much better idea as to the values that will be implemented in our final program, after the camera testing has been performed and RGB values of the three tarp samples have been determined.

The subscale flight had the camera placed at an angle that was perpendicular to the body of the rocket. This was different from the angle that was determined to be used for the subscale and full scale flight. The prototype flight was useful in helping the team to determine what angle the camera will be placed at for the final launch. It was decided that placing the camera perpendicular to the body yielded good results in terms of field of view of the camera. In the future, this result will be compared to the result from the subscale flight and the decision will then be made about the best camera angle for the final launch.

6.1.2.2. Google Earth Flight Simulation

As one way of testing the target detection software written for the payload, a video was produced by the team in Google Earth that acted as a flight simulation to be processed by the software. Three squares of size forty feet x forty feet were drawn adjacent to one another at a location near Huntsville, AL. The color of each square was set to the exact RGB values specified by NASA. The option to simulate atmosphere was checked in the Google Earth settings. Screenshots were saved at different simulated altitudes ranging from ground level to one mile. A video was recorded with the camera starting at ground level facing the squares, and slowly zoomed out to one mile in altitude while slowly spinning. This was to simulate the flight of the rocket camera subsystem looking down at the tarps. The picture belows shows a screen capture of the Google Earth test at one mile in altitude approximately with the simulated atmosphere.

This video and images were then run through the target detection program written by the team members. The video was processed several times on the Raspberry Pi computer subsystem, with every iteration using a different set of HSV maximum and minimum values for each square set until the squares could be detected throughout the entire simulation flight. This test was useful in determining the HSV values as well as testing how robust the program would be in handling moving frames. This test also provided information as to how many frames per second could be processed by the computer subsystem. The image below shows successful detection of the targets in one frame of the video.

6.2. Requirements Compliance

6.2.1. General Requirements and Verification Plan

The general requirements for the team as a whole, as agreed on unanimously by the team members are as follows:

1. Create and maintain a functioning website and social media profile with regular project updates, documents, and milestones that highlight our progress as it relates to the scope of the project.
2. Not spend any money out of pocket using personal funds without a means of being fully reimbursed through Purdue SEDS or some other school related organization.
3. Have a successful sub scale flight and recovery on a sub scale motor while carrying a functional payload system.
4. Have a successful full scale test flight and recovery on a full scale motor while carrying a functional redundant payload system.
5. Successfully design, build, and test a working on board payload capable of meeting the requirements derived by the team and presented to us by NASA within the 2018 USLI College and University Handbook.
6. Fulfill and exceed all educational engagement requirements presented to us by NASA within the 2018 USLI College and University Handbook.
7. Have a functioning and attractive rocket booth that highlights the work done by our team, including a functional payload on display for viewers to see and a full scale rocket for spectators to interact with.
8. No disqualification by any means whatsoever.
9. Successful finish of the competition in Huntsville, Alabama.

General requirements will be met by ensuring that each subteam operating within the scope of the project are aware of their respective tasks, plans, and procedures. In addition, all team members will become familiar with tasks, plans, and procedures of other subteams in order to understand how each team is interconnected and affects the project as a whole. Furthermore, members will be able to work in multiple disciplines and participate in subteams that they are not directly assigned to in order to make them a more rounded individual and gain a broader understanding of everything taking place within the group. Lastly, everyone will gain firsthand experience in design, construction, and launching of high powered rockets prior to the completion of the competition in Huntsville, Alabama. By ensuring the transparency and fluidity of group work, team members will cooperate in a manner that mitigates any risks to the general requirements.

6.2.2. Vehicle Requirements and Verification Plan

The vehicle will be tested to operate within the requirements provided in the 2018 USLI College and University Handbook:

1. The vehicle will deliver the payload to an apogee altitude of 5,280 feet above ground level (AGL).
2. The vehicle will carry one commercially available, barometric altimeter for recording the official altitude used in determining the altitude award winner. Teams will receive the maximum number of altitude points (5,280) if the official scoring altimeter reads a value of exactly 5280 feet AGL. The team will lose one point for every foot above or below the required altitude.
3. Each altimeter will be armed by a dedicated arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
4. Each altimeter will have a dedicated power supply.
5. Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).
6. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.
7. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.
8. The launch vehicle will be limited to a single stage.
9. The launch vehicle will be capable of being prepared for flight at the launch site within 3 hours of the time the Federal Aviation Administration flight waiver opens.

10. The launch vehicle will be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board components.
11. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated Range Services Provider.
12. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).
13. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).
    a. Final motor choices must be made by the Critical Design Review (CDR).
    b. Any motor changes after CDR must be approved by the NASA Range Safety Officer (RSO), and will only be approved if the change is for the sole purpose of increasing the safety margin.
14. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria:
    a. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews.
    b. Each pressure vessel will include a pressure relief valve that sees the full pressure of the valve that is capable of withstanding the maximum pressure and flow rate of the tank.
    c. Full pedigree of the tank will be described, including the application for which the tank was designed, and the history of the tank, including the number of pressure cycles put on the tank, by whom, and when.
15. The total impulse provided by a College and/or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).
16. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail button loses contact with the rail.
17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.
18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. Subscales are not required to be high power rockets.
    a. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale will not be used as the subscale model.

b. The subscale model will carry an altimeter capable of reporting the model's apogee altitude.

19. All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. The purpose of the full-scale demonstration flight is to demonstrate the launch vehicle's stability, structural integrity, recovery systems, and the team's ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at a lower altitude, functioning tracking devices, etc.). The following criteria must be met during the full-scale demonstration flight:
    a. The vehicle and recovery system will have functioned as designed.
    b. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:
        i. If the payload is not flown, mass simulators will be used to simulate the
        payload mass.
        ii. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.
    c. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale demonstration flight.
    d. The full-scale motor does not have to be flown during the full-scale test flight. However, it is recommended that the full-scale motor be used to demonstrate full flight readiness and altitude verification. If the full-scale motor is not flown during the full-scale flight, it is desired that the motor simulates, as closely as possible, the predicted maximum velocity and maximum acceleration of the launch day flight.
    e. The vehicle must be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the launch day flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.
    f. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).
    g. Full scale flights must be completed by the start of FRRs (March 6th, 2018). If the Student Launch office determines that a re-flight is necessary, then an extension to March 28th, 2018 will be granted. This extension is only valid for re-flights; not first-time flights.

20. Any structural protuberance on the rocket will be located aft of the burnout center of gravity.
21. Vehicle Prohibitions
    a. The launch vehicle will not utilize forward canards.
    b. The launch vehicle will not utilize forward firing motors.
    c. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.).
    d. The launch vehicle will not utilize hybrid motors.
    e. The launch vehicle will not utilize a cluster of motors.
    f. The launch vehicle will not utilize friction fitting for motors.
    g. The launch vehicle will not exceed Mach 1 at any point during flight.
    h. Vehicle ballast will not exceed 10% of the total weight of the rocket.

The plan to verify vehicle requirements is to conduct a series of ground tests and electronics tests followed by at least one subscale test flight and one full scale test flight. Ground testing will be done to ensure that ejection charges are appropriately sized and supply enough pressure to successfully deploy the drogue and main recovery gear. Electronics testing will be done to ensure that our circuits are operating properly without any indication of a short or open in the system. In place of energetics, we will use light bulbs as an indication that the circuit is complete and the bulbs illuminate, signaling an ejection charge. A minimum of one subscale flight will be performed to ensure that our vehicle is stable, our electronics operate as intended, and our recovery devices deploy as expected. It will also give us an opportunity to test our experiment, which will be discussed later in further detail. Lastly, a full scale flight test will be performed to further validate the vehicle’s stability, systems, and recovery. It will give us an additional chance to properly size our ejection charges, become familiar with the launch procedures and checklists, and give the team practice using GPS and telemetry receivers for vehicle tracking.

6.2.3. Recovery Requirements and Verification Plan

The recovery system will be tested to operate within the requirements provided in the 2018 USLI College and University Handbook:

1. The launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the RSO.
2. Each team must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full-scale launches.

3. At landing, each independent sections of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf.
4. The recovery system electrical circuits will be completely independent of any payload electrical circuits.
5. All recovery electronics will be powered by commercially available batteries.
6. The recovery system will contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.
7. Motor ejection is not a permissible form of primary or secondary deployment.
8. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.
9. Recovery area will be limited to a 2500 ft. radius from the launch pads.
10. An electronic tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.
    a. Any rocket section, or payload component, which lands untethered to the launch vehicle, will also carry an active electronic tracking device.
    b. The electronic tracking device will be fully functional during the official flight on launch day.
11. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).
    a. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.
    b. The recovery system electronics will be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.
    c. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.
    d. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

The recovery system will be tested on the ground as well as in at least one full scale flight. The avionics will remain the same for all flights, and we will ground test with them to ensure that they work as designed, ignite the ejection charges, properly pressurize the airframe sections enough to break the shear pins, and fully deploy the recovery gear. The gear will also be tested in flight, as we will be using the same recovery gear on the full scale test flight as in the competition flight. Furthermore, each parachute will be subjected to a drop test in order to determine inflation time and altitude loss from the time it was deployed to the time it fully inflated.

6.2.4. Experiment Requirements and Verification Plan

The experimental payload of the rocket has a number of specified requirements that need to be met for the ultimate success of the mission. The primary objective of the experiment, is to design and implement an on-board camera system on the rocket capable of identifying objects on the ground. More specifically, the system needs to be able to identify and differentiate between three 40’x40’ adjacent tarps of different colors near the launch site. This payload must employ a custom-designed software package capable of doing the aforementioned processing in real time. Additionally, such processing must be done in flight, as it is required that the rocket not land on any of the three tarps.

The primary means of verifying the payload design is derived from video data captured during test launches of the payload. Such test launches not only allow for verification of hardware related design choices and procedures, it more importantly yields imaging data that can be run through software that is still being developed. For example, the first test launch of the payload used a very primitive version of the final payload’s software package, doing no in-flight processing of the video data it was capturing. This was not critical to the success of the test because the data could later be used to aid software development.

In later test flights, further developments in the payload’s design will be tested. For example, the full scale test flight will test the experiment’s ability to process imaging data in real-time aboard the rocket. The full scale test flight will act as a dress rehearsal for the payload system, as final payload hardware will also be tested as the team looks for any potential weaknesses in the implementation of the payload system.

6.2.5. Safety Requirements and Verification Plan

The safety team prioritizes the wellbeing of all involved with the launch when making its requirements. The requirements of the safety team are verified by how well the people involved with the launch follow and are aware of safe procedures and how safe the launch is overall. In order to ensure all personnel members working on this project understand the safe practices which are relevant to it, all team members will sign a team safety statement. This statement is an affirmation by team members that they will comply with all relevant laws and regulations, along with the NAR High Power Rocketry Safety Code. It also affirms that they will obey all instructions given by the Safety Officer and Range Safety Officer, whether verbally or through team safety documents. It also affirms that members are aware that safety breaches are dangers which can completely halt the launch of the rocket. Documents created by the safety team for this project and relevant safety resources (such as materials safety data sheets) will be discussed by the safety officer in front of the entire project team to keep them aware of proper project procedures and any dangers associated with high-power rocketry they may not have been aware of.

The safety team has four derived requirements for the rocket considering the scope of
the NASA guidelines and the mission of the payload. They are as follows (in no particular order):

1. Achieve full compliance with local, state, and federal laws and maintain a positive reputation as a team which prioritizes lawful and safe rocketry.
2. Provide each team member with the knowledge required to work safely with high-power rockets and any hazardous materials associated with these rockets.
3. Create and utilize fully-functional hazard analysis and contingency plans to both prevent and react optimally to any emergency situations.
4. Have an organized set of procedures which can be followed at all times to enforce safe construction and launch practices and to be fully prepared for any emergency. This includes adhering to the team safety statement and following established safety checklists for pre-launch, launch, and post-launch.

If these four requirements are met fully by all project personnel, the safety team has efficiently served its purpose.

6.3. Budgeting and Timeline

6.3.1. Line Item Budget

6.3.1.1. Full Scale Budget

Rocket Parts	Unit Cost	Quantity	Total
5:1 5" Von Karman FWFG Nosecone	108.95	1	108.95
5" G10 FG Avionics bay lid	16	6	96
5" FWFG Airframe, 30" long	85	3	255
Custom Airframe Slotting, 3/16" wide, 15" long	6	3	18
5" FWFG Switch Band, 2" long	7	2	14
5" FWFG Coupler, 12" long	53	2	106
3" FWFG Motor Tube, 30" long	50	1	50
1/8" G10 FG Centering Ring	9	2	18
1/2" Plywood Centering	5	2	10
3/16" G10 FG Fins	20	3	60
Skyangle Cert 3 XL Parachute	189	1	189
Skyangle Cert 3 Drogue Parachute	27.5	1	27.5
18" x 18" Nomex Parachute Protector	10.95	2	21.9

40' Long Double Looped Kevlar Tether	61	2	122
Large Rivet Package	4.5	2	9
1515 Series Rail Button Package of 4	7.95	1	7.95
75mm AeroPac Flanged Motor Retainer	50	1	50
5"/75mm SC Precision Thrust Plate	55.59	1	55.59
Aerotech 75mm 3G Hardware Set	450	1	450
Aerotech 75mm 3G L1520-T Reload	199	2	398
			2066.89

6.3.1.2. Sub Scale Budget

Item	**Unit Cost**	**Quantity**	**Total**
5:1 3" Ogive Standard Wall FWFG Nosecone	58.95	1	58.95
3" G10 FG Avionics Bay lid	10	6	60
3" FWFG Standard Wall Airframe, 60" long	100	1	100
Custom Airframe Slotting, 3/32" wide, 9" long	5	4	20
3" FWFG Switch Band, 1" long	4	3	12
3" FWFG Coupler, 6" long	15	2	30
38mm FWFG Standard Wall Motor Tube, 30" long	32	1	32
1/8" G10 FG Centering Ring	6	2	12
1/4" Plywood Centering	3.55	2	7.1
3/32" G10 FG Fins	10	3	30
Top Flite 50" Main Parachute	26.95	1	26.95
Top Flite 15" Drogue Parachute	6.95	1	6.95
9" x 9" Nomex Parachute Protector	6.95	2	13.9
20' Long Double Looped 5/16" Kevlar Tether	26.99	2	53.98
Medium Rivet Package	3.5	2	7
1010 Series Rail Button Package of 4	6.95	1	6.95
38mm AeroPac Motor Retainer	25	1	25
CTI 38mm 4G Casing	50.6	1	50.6
CTI 38mm 4G I470 WT Reload	55	1	55
			608.38

6.3.1.3. Avionics Budget

Item	Unit Cost	Quantity	Total

TeleMetrum - Altus Metrum	$300.00	1	$300.00
TeleDongle - Altus Metrum	$100.00	1	$100.00
RRC3+ Sport - Missile Works	$70.00	1	$70.00
Electronic Match	$1.00	25	$25.00
ALTIMETER MOUNTING POSTS	$3.68	2	$7.36
6g Charge well	$8.50	2	$17.00
Missle Works USB Interface Module	$32.95	1	$32.95
Pair Programming / Debug Cable	$5.00	1	$5.00
9V Battery Clip	1	1	1
9V Battery - Duracell	$6.00	4	$24.00
9V Battery Holder	$2.50	1	$2.50
Dual Altimeter Wiring Kit - Binder Design	$20.00	1	$20.00
3/4" Panel-Mount Key Switch - McMaster-Carr	$14.10	2	$28.20
National Hardware 1 Count 1/4-in to 20 x 2.5-in Stainless Steel Plain Eye Bolt with Hex Nut	$1.00	4	$4.00
Hillman 0.375-in x 36-in Standard (SAE) Threaded Rod	$2.90	2	$5.80
#10-32 Stainless-Steel Wing Nut (6-Pack)	$7.80	1	$7.80
Screws, bolts, nuts	~$10.00	1	$10.00
Sled - 3D Printed	~$5.00	2	$10.00
Masking Tape	$7.08	1	$7.08
FFFFg Black Powder	$26.00	1	$26.00
Arrow 3-element Yagi	$49.00	1	$49.00

			$752.69

6.3.1.4. Payload Budget

FULL SCALE			
Item	Unit Cost	Quantity	Total
Raspberry Pi Model 3B	35.1	2	70.2
10,000 mAh battery, 5V 2.4A output	25.99	2	51.98
Raspberry Pi V2 camera	23.99	2	47.98
Raspbery Pi power recorder			TBD
3D print material			TBD
Threaded barstock			TBD
nuts / wingnuts			TBD
			170.16
Subscale			
Item	Unit Cost	Quantity	Total
Raspberry Pi Zero W	24.99	1	24.99
10,000 mAh battery, 5V 2.4A output	17.99	1	17.99
Raspberry Pi V2 camera	22.99	2	45.98
Camera cable	9.39	1	9.39
32G micro SD card	9.99	1	9.99
Ribbon cable for LEDS	10.01	1	10.01
50 cnt LED multicolor pack	6.99	1	6.99
3D print material			TBD
Threaded barstock			TBD
nuts / wingnuts			TBD
			125.34

6.3.1.5. Branding Budget

Item	Unit Cost	Quantity	Total
T-Shirts	15	32	480
Polos	15	32	480
			960

6.3.1.6. Travel Budget

Item	Unit Cost	Quantity	Total
Hotel Room	200	24	4800

Gas	40	32	1280
			6080

6.3.2. Funding Plan

6.3.2.1. Sources Of Funding

Assuming that the team requires around $11000, there will be five primary ways funds will be made to support the NASA USLI project:

1. Skip-a-meals and Campus Fundraisers: Skip-a-meals are social events where individuals can mention the name of our organization at a designated food establishment and a percentage (usually half) of money they spend at the establishment will be given to the team. These events usually last for a whole afternoon.

2. INSGC Grant: We are in the process of receiving a grant for $5000 from the Indiana Space Grant Consortium, which results in grants paying more than we had previously anticipated. We are still applying to grants in the event that we are unable to receive a company sponsorship.

3. Company Sponsorship: We have been unsuccessful as of so far in finding any company willing to provide a portion of our funds, but we are still making inquiries.

4. Crowdfunding: Our crowdfunding campaign will begin in the week of January 15th, and will continue with the anticipation of receiving roughly $3500 assuming adequate advertising and campaiging.

5. SEDS Treasury: Our parent organization is providing $700 towards funding the project.

Below is an updated chart with the anticipated funds from each of our sources.

Fund Source	**Funds Generated**
SEDS Treasury	$700
Restaurant Socials (4 throughout year)	$800 ($200 each)
INSGC Grant	$5000
Crowdfunding Campaign	$3500
Company Sponsorship	$1000
TOTAL:	$11000 (~$500 margin)

6.3.2.2. Allocation Of Funds

Allocation of funds has changed slightly since preliminary design review. Below is a Gantt change identifying when funds will be generated from each of the methods above. Colored spaces indicate inbound funds. Notably, funds from the INSGC Grants has specifically been allocated towards travel costs, which is a requirement by INSGC.

Both restaurant fundraisers and the crowdfunding campaign, as funding sources that will result in us receiving funds sooner, will be used to reimburse costs for the subscale rocket, and to pay for the full scale rocket. Funds from the INSGC grants will be used to pay for largely travel costs, but may also be allocated nominally to purchasing materials for the full scale rocket. Below is an ideal date to receive a company sponsorship, but no true date has been confirmed.

Week of:	Jan. 15th	Jan. 22nd	Jan. 29th	Feb. 5th	Feb. 12th	Feb. 19th	Feb. 26th	Mar. 5th	Mar. 9th	Mar. 16th
Restaurant Fundraisers							Last Fundraiser Ends			
INSGC Grant						Funds in Pocket				
Crowdfunding Campaign							Campaign Ends			
Company Sponship							Ideal Date			

6.3.2.3. Material Acquisition

Materials for the subscale rocket were purchased by individuals on the team. Individuals will be reimbursed using funds from the SEDS Treasury, crowdfunding campaign, and restaurant fundraisers. The full scale rocket will be purchased also using funds from the crowdfunding campaign and restaurant fundraisers. All materials for the payload, avionics, and subscale have already been purchased. Materials for the full scale will be procured from various retailers mentioned in the budget section.

6.3.3. Educational Engagement

6.3.3.1. Documentation of Outreach

The following pages contain filled educational engagement activity report forms from all of the events members from the team have participated in and interacted with students at.

Educational Engagement Activity Report

Please complete and submit this form each time you host an educational engagement event.
(Return within 2 weeks of the event end date)

School/Organization name: Purdue USLI Team / Purdue SEDS

Date(s) of event: October 22nd, 2017

Location of event: West Lafayette, Purdue Campus

Instructions for participant count

Education/Direct Interactions: A count of participants in instructional, hands-on activities where participants engage in learning a STEM topic by actively participating in an activity. This includes instructor- led facilitation around an activity regardless of media (e.g. DLN, face-to-face, downlink.etc.). Example: Students learn about Newton's Laws through building and flying a rocket. ***This type of interaction will count towards your requirement for the project.***

Education/Indirect Interactions: A count of participants engaged in learning a STEM topic through instructor-led facilitation or presentation. Example: Students learn about Newton's Laws through a PowerPoint presentation.

Outreach/Direct Interaction: A count of participants who do not necessarily learn a STEM topic, but are able to get a hands-on look at STEM hardware. For example, team does a presentation to students about their Student Launch project, brings their rocket and components to the event, and flies a rocket at the end of the presentation.

Outreach/Indirect Interaction: A count of participants that interact with the team. For example: The team sets up a display at the local museum during Science Night. Students come by and talk to the team about their project.

Grade level and number of participants: *(If you are able to break down the participants into grade levels: PreK-4, 5-9, 10-12, and 12+, this will be helpful.)*

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4	53			
5-9				
10-12				
12+				
Educators (5-9)				
Educators (other)				

Are the participants with a special group/organization (i.e. Girl Scouts, 4-H, school)? Y N

If yes, what group/organization?

Linnwood Elementary School

Briefly describe your activities with this group:

We gave the children a variety of supplies like card board, discorded plastics, and other recycla bles. with these they attatched their own designs to stomp rockets and then tested them, attempting to make them better each time.

Did you conduct an evaluation? If so, what were the results?

N/A, not enough time, Students had to return to their school

Describe the comprehensive feedback received.

We were told by the teachers that more launching stations and materials would make for less clashing of the students and would make the process of launching/testing the rockets much easier.

Educational Engagement Activity Report

Please complete and submit this form each time you host an educational engagement event.
(Return within 2 weeks of the event end date)

School/Organization name: Purdue SEDS/USLI

Date(s) of event: 10/21/17

Location of event: Purdue Campus, West Lafayette

Instructions for participant count

Education/Direct Interactions: A count of participants in instructional, hands-on activities where participants engage in learning a STEM topic by actively participating in an activity. This includes instructor- led facilitation around an activity regardless of media (e.g. DLN, face-to-face, downlink.etc.). Example: Students learn about Newton's Laws through building and flying a rocket. ***This type of interaction will count towards your requirement for the project.***

Education/Indirect Interactions: A count of participants engaged in learning a STEM topic through instructor-led facilitation or presentation. Example: Students learn about Newton's Laws through a PowerPoint presentation.

Outreach/Direct Interaction: A count of participants who do not necessarily learn a STEM topic, but are able to get a hands-on look at STEM hardware. For example, team does a presentation to students about their Student Launch project, brings their rocket and components to the event, and flies a rocket at the end of the presentation.

Outreach/Indirect Interaction: A count of participants that interact with the team. For example: The team sets up a display at the local museum during Science Night. Students come by and talk to the team about their project.

Grade level and number of participants: *(If you are able to break down the participants into grade levels: PreK-4, 5-9, 10-12, and 12+, this will be helpful.)*

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4				
5-9	75			
10-12				
12+				
Educators (5-9)				
Educators (other)				

Are the participants with a special group/organization (i.e. Girl Scouts, 4-H, school)? Y N

If yes, what group/organization?

Briefly describe your activities with this group:

walked 3 groups of 25 students through the process of splitting into teams and planning a trip to mars. Had them select a role (scientist, mechanic, leader, etc.) select STEM tools for the problem (Imager, lander, rover, altimeter) and plan a flight path and landing spots.

Did you conduct an evaluation? If so, what were the results?

Yes, children enjoyed the activity and while some were upset in the beginning by clashing teams, by the end all of the groups learned to work together.

Describe the comprehensive feedback received.

N/A, activity was recieved with positivity and enthusiasm.

Educational Engagement Activity Report

Please complete and submit this form each time you host an educational engagement event.
(Return within 2 weeks of the event end date)

School/Organization name: Purdue Space Day 2017

Date(s) of event: 10/21/2017

Location of event: Purdue University - West Lafayette, IN

Instructions for participant count

Education/Direct Interactions: A count of participants in instructional, hands-on activities where participants engage in learning a STEM topic by actively participating in an activity. This includes instructor- led facilitation around an activity regardless of media (e.g. DLN, face-to-face, downlink.etc.). Example: Students learn about Newton's Laws through building and flying a rocket. ***This type of interaction will count towards your requirement for the project.***

Education/Indirect Interactions: A count of participants engaged in learning a STEM topic through instructor-led facilitation or presentation. Example: Students learn about Newton's Laws through a PowerPoint presentation.

Outreach/Direct Interaction: A count of participants who do not necessarily learn a STEM topic, but are able to get a hands-on look at STEM hardware. For example, team does a presentation to students about their Student Launch project, brings their rocket and components to the event, and flies a rocket at the end of the presentation.

Outreach/Indirect Interaction: A count of participants that interact with the team. For example: The team sets up a display at the local museum during Science Night. Students come by and talk to the team about their project.

Grade level and number of participants: *(If you are able to break down the participants into grade levels: PreK-4, 5-9, 10-12, and 12+, this will be helpful.)*

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4	35	15		
5-9				
10-12				
12+				
Educators (5-9)				
Educators (other)				

Are the participants with a special group/organization (i.e. Girl Scouts, 4-H, school)? Y N

If yes, what group/organization?

Briefly describe your activities with this group:

1. Made small rockets and launched them
2. Made space suits with kids
3. Made a capsule to protect an egg w/kids
4. Lead kids around campus
5. Talked with kids about rockets and space

Did you conduct an evaluation? If so, what were the results?

Yes, all the students seemed to enjoy them. Also all of the parents said we did great and that they were all excited for next year.

Describe the comprehensive feedback received.

Overall good job, most are looking forward to next year.

Educational Engagement Activity Report

Please complete and submit this form each time you host an educational engagement event.
(Return within 2 weeks of the event end date)

School/Organization name: Purdue USLI team / Purdue SEDS

Date(s) of event: October 14th, 2017

Location of event: Market Square, Lafayette, Carnahan hall

Instructions for participant count

Education/Direct Interactions: A count of participants in instructional, hands-on activities where participants engage in learning a STEM topic by actively participating in an activity. This includes instructor- led facilitation around an activity regardless of media (e.g. DLN, face-to-face, downlink.etc.). Example: Students learn about Newton's Laws through building and flying a rocket. ***This type of interaction will count towards your requirement for the project.***

Education/Indirect Interactions: A count of participants engaged in learning a STEM topic through instructor-led facilitation or presentation. Example: Students learn about Newton's Laws through a PowerPoint presentation.

Outreach/Direct Interaction: A count of participants who do not necessarily learn a STEM topic, but are able to get a hands-on look at STEM hardware. For example, team does a presentation to students about their Student Launch project, brings their rocket and components to the event, and flies a rocket at the end of the presentation.

Outreach/Indirect Interaction: A count of participants that interact with the team. For example: The team sets up a display at the local museum during Science Night. Students come by and talk to the team about their project.

Grade level and number of participants: *(If you are able to break down the participants into grade levels: PreK-4, 5-9, 10-12, and 12+, this will be helpful.)*

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4	22			
5-9	27			
10-12				
12+				
Educators (5-9)				
Educators (other)				

Are the participants with a special group/organization (i.e. Girl Scouts, 4-H, school)? Y N

If yes, what group/organization?

6.3.3.2 Outcome of Outreach

Depicted Above: Purdue SEDS and Purdue USLI Members host 700 children from the Lafayette area for Space Day, an annual event for the education and engagement of elementary and middle school students. At this event Astronaut Mark Polansky interacted with the kids and gave a presentation on the benefits of STEM involvement and the excitement of space exploration. At this event the children were broken up into groups of 35 - 50 and participated in a variety of STEM related activities which varied by age range.

Depicted Above: Children attend Mini-Makers Faire in Lafayette, staffed by volunteer Purdue USLI Members. Children ages 8 through 15 got a chance to use Tynker to explore the uses and basic skills of coding and animation through coding.

6.3.3.3 Plans for Future Outreach

Through establishing relationships with Purdue University, outreach organizations like Mini-Maker Faire in the Lafayette area, and student organizations like AIAA and SEDS, Purdue's USLI team plans on continuing their education and engagement of youth in the Lafayette and West Lafayette area.

6.3.4. Timeline

01/11/2018	Final day for subscale launch
01/11/2018	Final motor choice made for launch
01/12/2018	CDR reports, slides, and flysheet posted online by 8AM CDT
01/13/2018	Purdue SL general meeting
01/14/2017	Indiana Rocketry Launch
01/16/2018	CDR video teleconferences start
01/20/2018	Purdue SL general meeting

01/27/2018	Purdue SL general meeting
01/31/2018	CDR video teleconferences end
02/03/2018	Purdue SL general meeting
02/07/2018	FRR Q&A
02/10/2018	Purdue SL general meeting
02/11/2018	Indiana Rocketry Launch
02/17/2018	Purdue SL general meeting
02/24/2018	Purdue SL general meeting
03/03/2018	Purdue SL general meeting
03/04/2018	Final day for full scale launch
03/05/2018	FRR reports, slides, and flysheet posted online by 8AM CDT
03/06/2018	FRR video teleconferences start
03/10/2018	Purdue SL general meeting
03/11/2018	Indiana Rocketry Launch
03/17/2018	Purdue SL general meeting
03/22/2018	FRR video teleconferences end
03/24/2018	Purdue SL general meeting
03/31/2018	Purdue SL general meeting
04/04/2018	Travel to Huntsville, Alabama
04/04/2018	LRR
04/05/2018	Launch week kickoff and activities
04/06/2018	Launch week activities
04/07/2018	Launch day

7. Appendix A

7.1. NAR High Power Rocket Safety Code

1. Certification. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.
2. Materials. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
3. Motors. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

4. Ignition System. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the “off” position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.
5. Misfires. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher’s safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.
6. Launch Safety. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.
7. Launcher. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor’s exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.
8. Size. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. Flight Safety. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations

when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. Launch Site. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).
11. Launcher Location. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.
12. Recovery System. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.
13. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

7.2 NAR Minimum Distance Table

Installed Total Impulse (Newton-Seconds)	Equivalent High Power Motor Type	Minimum Diameter of Cleared Area (ft.)	Minimum Personnel Distance (ft.)	Minimum Personnel Distance (Complex Rocket) (ft.)
0 — 320.00	H or smaller	50	100	200
320.01 — 640.00	I	50	100	200
640.01 — 1,280.00	J	50	100	200

1,280.01 — 2,560.00	K	75	200	300
2,560.01 — 5,120.00	L	100	300	500
5,120.01 — 10,240.00	M	125	500	1000
10,240.01 — 20,480.00	N	125	1000	1500
20,480.01 — 40,960.00	O	125	1500	2000

Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors