NASA Student Launch

2013-2014 FRR

April 18, 2014

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SUMMARY OF FRR REPORT

TEAM SUMMARY

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LAUNCH VEHICLE SUMMARY

The launch vehicle is comprised of two separate stages: a booster stage and a sustainer stage. The two stage rocket is constructed out of fiberglass, balsa wood, aluminum, and acrylic. It is estimated to weigh in at 79.6 pounds. To deliver the rocket to its predetermined altitudes the rocket will be powered by a Cesaroni M3100-WT motor in its booster stage that will be succeeded by a Cesaroni L1720-WT motor in the launch vehicle's sustainer stage. Four separate recovery systems will be implemented in insure all sections of the rocket land within the kinetic energy guidelines. Altimeter bays have been modeled for the booster, lower sustainer, upper sustainer, and fairing airframe sections.

PAYLOAD SUMMARY

The main payload will be a hazard detection payload onboard a rover. The rover will be deployed from a fairing so that the terrain can be processed during descent. The brain of the rover will be a BeagleBone Black microprocessor. An off-the-shelve PCB will transmit data from the rover via SMS to a custom cell-phone app. A custom PCB will contain any sensors and circuits necessary for the rover to operate. The rover will use power screws for movement to test out how good they are on several terrains.

CHANGES MADE SINCE CDR

CHANGES MADE TO VEHICLE CRITERIA

Since the CDR, the launch vehicle has undergone 2 primary changes.

1. The pyro cap used to operate the opening of the fairing has been redesigned. The overall size and well size for black powder was determined to be too large. To cut down on unnecessary weight the size of the pyro cap was dramatically decreased. Furthermore, the material used was changed from aluminum to 3D printed ABS plastic. More details on the change in design can be found in Payload Integration.
2. Due to the events of the first full scale test launch, the booster's airframe had to be cut in half. The booster landed forward section first. Due to the AV bay not separating to deploy the booster recovery, the AV bay was forced back into the booster airframe. To attempt a removal of the coupler airframe, the team had to cut the booster's airframe just below the location of the AV bay coupler tubing. A 12 ton press was used to force the stuck coupler tubing up the airframe just enough so that a new piece of coupler tubing could be epoxied between the two halves of the cut booster frame to join them back together. To ensure a strong joint, four 6-32 machine screws were also inserted into either side of the cut section of the booster airframe and into the new coupler section.
3. To ensure the safety of the rover during flight, a two piece shock absorbing plate has been designed and constructed to sit just below the rover so that the rover rests on it during flight. The piece is constructed of a soft foam insulation material that has a piece of acrylic attached atop of it. The rover will rest on top of the acrylic piece. More information can be found in Payload Integration.
4. The foam that will be used to house the rover has been changed again. After an issue arose with acquiring material for our first full scale launch, the team had to use their backup material choice. The new foam material is extruded polystyrene insulation. This material still allows virtually no moisture absorption, and proved its success by safely housing the rover during the full scale test launch. More information can be found in Payload Integration.
5. The number of black powder ejection charges has been increased to add redundancy.

CHANGES MADE TO PAYLOAD CRITERIA

Since the CDR, the payload has seen two primary changes.

1. The hazard detection payload has had the parachute cam redesigned since CDR. The thickness of the walls has been increased to prevent the part from breaking due to the impact stress from the parachute opening.

2. A BMP180 pressure sensor and an ADXL345 accelerometer have been added to the custom PCB to have better precision in detecting launch events such as launch, apogee, and landing.

Changes Made to Project Plan

Feedback Given from CDR

CDR Discussion items	Team response
The ignition system for the sustainer on the full scale rocket is housed in the sustainer, correct?	The ignition system is located in an avionics bay that is located between the lower and middle sustainer section of airframe. This is located below the fairing, and the ignitor wires run down through holes in the centering rings into the motor.
What is the coast time?	
What controls the ignition of the sustainer? Timer?	Two featherweight Raven altimeters control the motor ignition of the sustainer.
Is the algorithm of the Tiltometer closed loop or is it a 1-time open loop system?	It is an open loop system.
Be careful using 1 W or more when transmitting data. The RF interference can be detrimental to other components.	Altimeters have an aluminum shielding from the components transmitting data.
The waiver constraint at the alt launch site is 10,000 ft. If the target is 10,000 ft, and the team overshoots the waiver will be busted. How confident is the team that if anything, it will undershoot 10,000 ft? Is there a backup motor planned to ensure that 10,000 ft will no be broken at the alternate launch site?	The team is confident in not exceeding the 10,000 ft waiver. The nose cone's altimeter bay has the ability of adding a weighted balast system in it if it is deemed necessary.
We appreciate the detail in how the parachute will be constructed.	Thank you.

The drift constraint is 5,000 ft at either launch site. An email was sent with that requirement in early February.	The initial email was missed, all emails are being forwarded to multiple people on the team so it does not happen again.
The team will need to demonstrate that the total drift from the pad will not exceed 5,000 ft.	The drift has been calculated to be within 5000 feet.
The team did not include a section that addressed each line item in the PDR feedback.	The FRR has the feedback from the CDR.
What caused the staging issue during the first subscale test flight?	The stage coupling was too tight. Since the subscale used motor seperation for staging, the motor was not able to immediately separate the stages. The stages finally separated after immense pressure buildup. The violent ejection of the booster caused failer in booster recovery, while the second stage motor was wicked out.
What is the spring force of the spring that opens the payload fairing?	6.43 lb/in
What is the ejection charge doing when the payload fairing deploys?	The ejection charge is separating the pyro cap from the pyro shells. With the cap removed from the fairing, the fairing is allowed to open and deploy the payload.
If the team lists different likelihoods for a certain compnent or subsystem, use the most likely scenario for the analysis as the worst case scenario.	If multiple scenarios existed, worst case scenario was assumed in determining the risk level.
In the verification, be sure to make the verification as objective as possible. Refer to specific procedures, results from tests, results from analysis, etc.	Mentioned various tests for systems in the description of each hazard analysis table.

Clarify whether or not the team is using an ejection charge to separate the stages in the full scale.	We are using ejection charges to separate the stages in the full scale.

Vehicle Criteria

Design and Construction of Vehicle

Nose Cone Design

The current design for the nose cone was researched and designed to provide the optimal degree of lift versus drag to meet our target speed and to accomplish the tasks set forth by the competition. There are several designs from which we could have chosen, including the tangent ogive, the secant ogive, the parabolic, and the Von Karman designs.

The initial type of cone that we selected was the tangent ogive, as was used in the previous year's design. The tangent ogive melds smoothly with the rest of the body, provided that the equation is utilized properly.

Through our research, we determined that the Von Karman design would be the best suited to our goal (reaching a speed of about 0.8 Mach). Figure 3 below shows degrees of effectiveness for various nose cone designs with respect to varying Mach numbers.

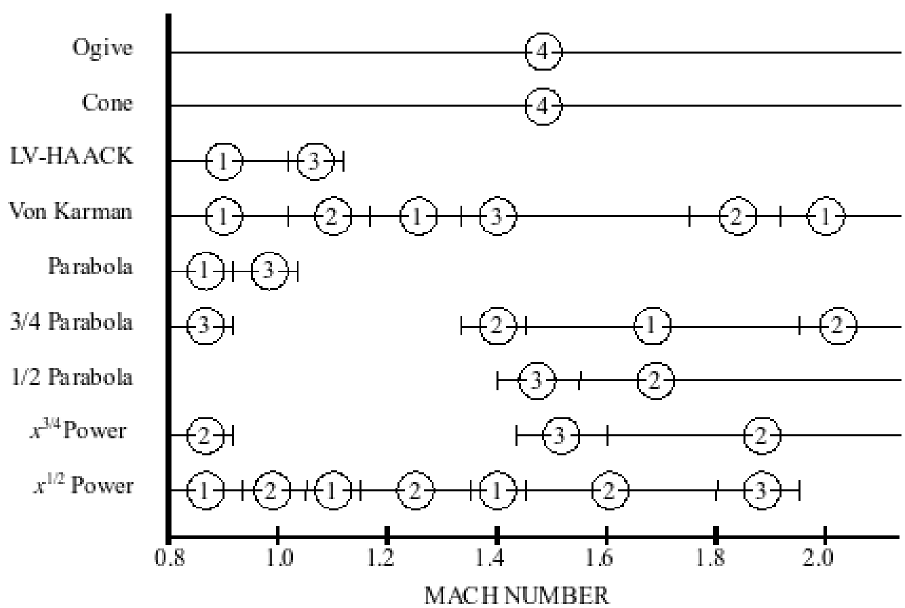

Figure 1: Nose Cone Effectiveness Comparison

As seen from the graph, the Von Karman is ranked “1” for the desired Mach range in which the rocket will fly. In addition, it also has a relatively wide range ranked “1” which gives us a bit of leeway in case our speed varies.

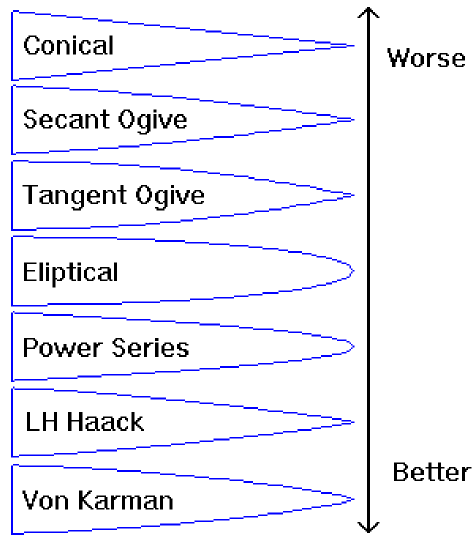

Figure 2: Nose Cone Effectiveness Comparison #2

Figure 3.2 relates a generalized version of the first, indicating that the LH Haack and the Von Karman are the two most effective designs for the flight.

The equations used to generate the Von Karman (LD-Haack) type cone in our SolidWorks renderings are shown by Equations 18 and 19.

$$y = \frac{R}{\sqrt{\pi}}\sqrt{\theta - \frac{\sin(2\theta)}{2} + Csin^3\theta} \tag{18}$$

$$C = 0\ for\ LD - Haack \tag{19}$$

The components chosen are shown in the exploded view of the nose cone bay below. The cone itself is of the Von Karman design, while the specialized parts (washers, bolts, and U-bolt) will be supplied by a hardware manufacturer. Additionally, the nose cone will house a GPS sled to track the section upon separation from the main vehicle. The recovery portion of the nose cone and fairing section will be described later.

Figure 3: Von Karman Nose Cone.

As mentioned before, we chose to use the Von Karman design because we discovered that it provided the optimal ratio of lift versus drag for our intended speed. The tip of the cone, made out of machined aluminum, ensures a perfect point and more rigid surface for decreased deformation during landing. At the rear of the cone is an elongated shoulder which will allow us to ensure a snug fit with the rest of the rocket's body.

This particular piece will be purchased through Rocketry Warehouse and will be according to the specifications specified. It will be a six inch diameter filament wound fiberglass nose cone with a caliber ratio of 5:1.

The nose cone system, being the leading edge of the rocket, is integral to the overall performance of the rocket. Due to the varying materials in the tip, the rocket will be able to cut more smoothly through the air than if it were made of the material composing the rest of the shell. Without the bulkhead residing in the base of the shell, nose cone and fairing system would lack a recovery device and would therefore lack another essential stabilization. The rocket nose cone, being a static component of the overall system, is a foundation piece. It can change, but the factors that would initiate a change are few and are relatively isolated to the mechanical aspects of the overall design.

Name of Part	**Design / Type**	**Size/Ratio**	**Materials**
Nose Cone (x1)	Von Karman	6in. diameter / 5:1	Filament-wound

			Fiberglass + ABS Plastic tip
Centering Ring (x1)	N/A.	6in. outer diameter 5in. inner diameter 0.5in. thick	Balsa Wood
Wooden Bulkhead (x1)	N/A.	5in. diameter 0.5in. thick	Balsa Wood
Bulkhead (x1)	N/A.	6in. diameter 0.14in. thick	G10 Fiberglass
Threaded Rod (x2)	N/A.	0.25in. diameter 3in. long	Aluminum 6061-T6
Threaded Rod (x2)	N/A.	0.25in. diameter 10in. long	Aluminum 6061-T6
U-Bolt (x1)	Extended Length U-Bolt	3/8" – 16 Thread 2 7/16" Width (Inside Edges)	Stainless Steel
Washers (x4)	General Purpose Washer	3/8" Screw Size	Stainless Steel
Nuts (x4)	Standard Hex Nut	3/8" – 16	Stainless Steel

Table 1: Material specifications for nose cone design

Sustainer Stage Ignition Bay

The sustainer stage ignition bay will serve three purposes:

1. Connect the booster stage to sustainer stage during booster burn phase
2. House black powder charges for booster stage separation
3. House and protect the ignition system for the sustainer stage

The bay will be composed of a 6.0" fiberglass body tube measuring 6.0" in length. The read centering ring will be placed 3.5" from the rear of the sustainer. This will allow the forward coupler of the booster stage to seamlessly couple with the sustainer stage, as seen in the figure below.

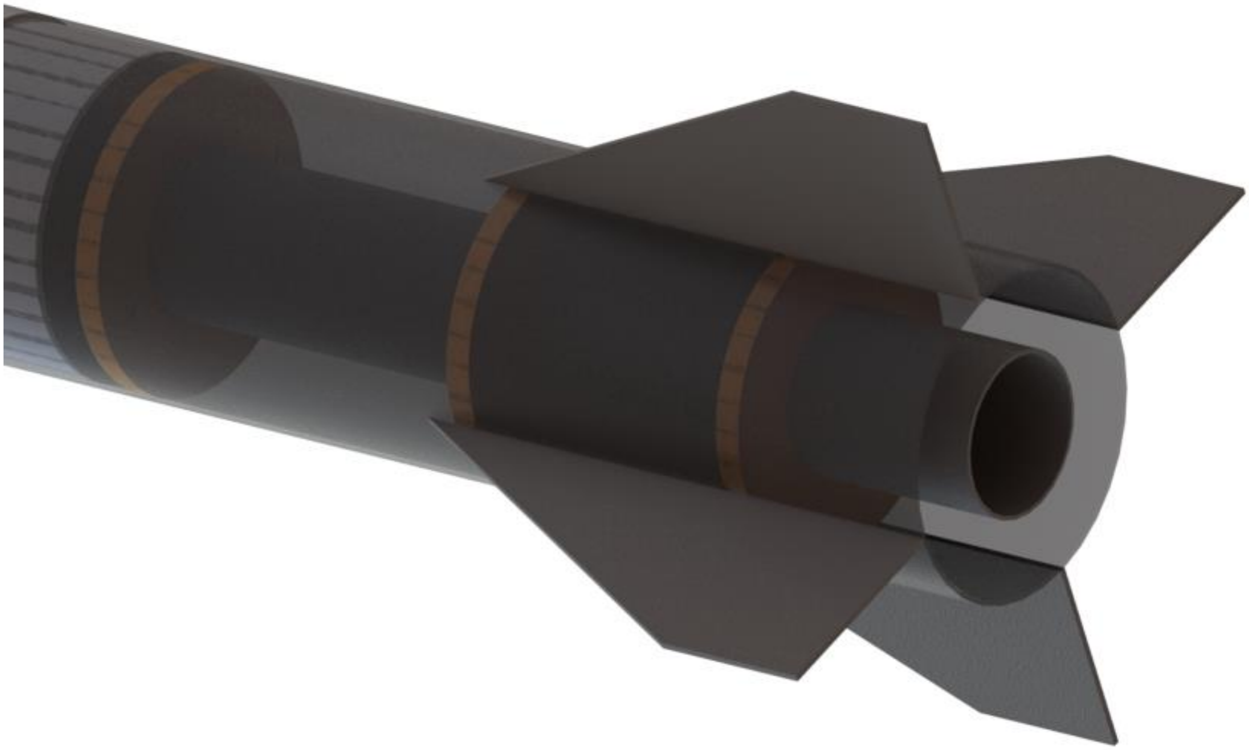

Figure 4: Sustainer stage propulsion bay connection.

Located inside of the first centering ring of the sustainer stage propulsion bay will be the ignition control system for the sustainer stage. This system will be run using a Featherweight Raven altimeter. The system will have two outputs, the first being for the ignition of the black powder for sustainer stage separation. The second output will be for the ignition of the booster stage following the burn out and separation of the booster stage.

The two outputs will be programmed using the Featherweight interface. The planned programming is given in the next section.

To promote safety, calculations have been done to find the range of altitudes the rocket must reach for the ignition of the sustainer stage to take place. This range takes into account a maximum offset of 10 degrees from vertical. Additionally, a mechanical rolling switch will be positioned inside of the sustainer stage ignition bay to detect stage separation. If stage separation does not occur and/or the altitude conditions are not met, sustainer stage ignition will be aborted and the vehicle will continue through the rest of the programmed mission.

Booster Stage

The booster stage will serve a single purpose:

1. Boost the sustainer to an altitude of 3,699 feet where the sustainer's motor will then ignite to propel the second stage to the target altitude of 10,000 feet.

The booster stage is comprised of a 6.0 inch diameter outer tube comprised of G-12 fiberglass. At the top of the stage, near the coupler and the sustainer ignition bay, the RRC3 altimeter pair that governs the actions of the booster stage reside on a sled suspended between two threaded aluminum rods placed at 180 degrees from each other. The logic for these two altimeters is listed in Figure 6 below.

Booster Recovery

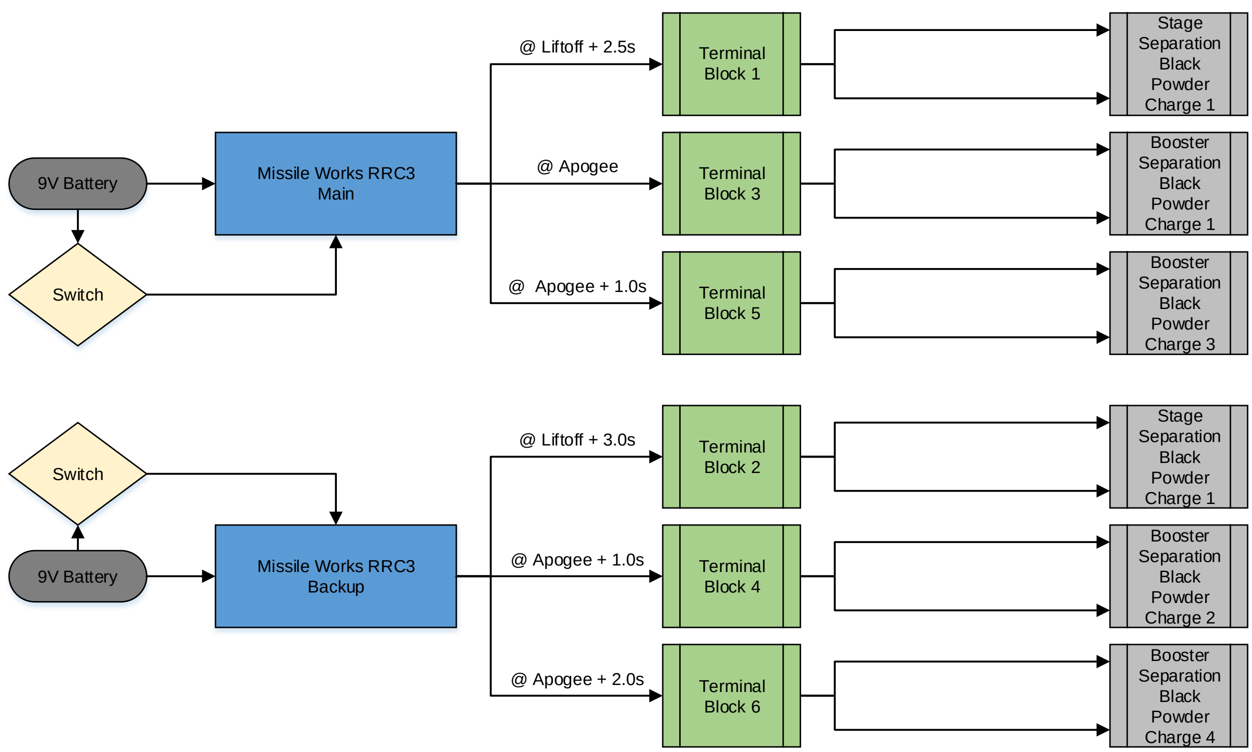

Figure *5*: **Booster recovery logic.**

The booster will be the first section to be recovered, at motor burnout two MissleWorks RRC3's will be used to separate the booster from the sustainer. These altimeters were chosen for being both able to separate the booster and provide redundant recovery events at apogee at half of the price of the Raven. There are two black powder charges at apogee + 1.0 seconds, this is due to the combination of one altimeter being in backup mode and the other being in apogee only mode.

2nd Stage Motor Ignition

Using OpenRocket and taking an iterative approach with the new larger vehicle it was determined that to achieve the highest altitude that the 2nd stage motor will have to provide thrust 3.0 seconds after burnout. In the following flowchart it shows the ejection charge as being 3.0 and 3.5 seconds, those values are placeholders until we are able to statically test the motor. The motor will be tested on a static thrust stand and the time taken from sending the ignition signal until the motor produces thrust will be documented and then subtracted from the 3.0 second delay. Two igniters will be used with one from each Raven for redundancy.

Tiltometer

The goal of the tiltometer is to detect the inclination of the rocket with respect to the Earth's surface in order to prevent the rocket from firing its second stage motor at an unsafe angle. The entire system has been custom designed and assembled by the electronics team since the commercial versions, such as the RocketTiltometer, were all unavailable or very expensive. The custom PCB attaches onto an Arduino UNO due to the simplicity of using this microcontroller. Figure 6 shows the final assembled tiltometer PCB.

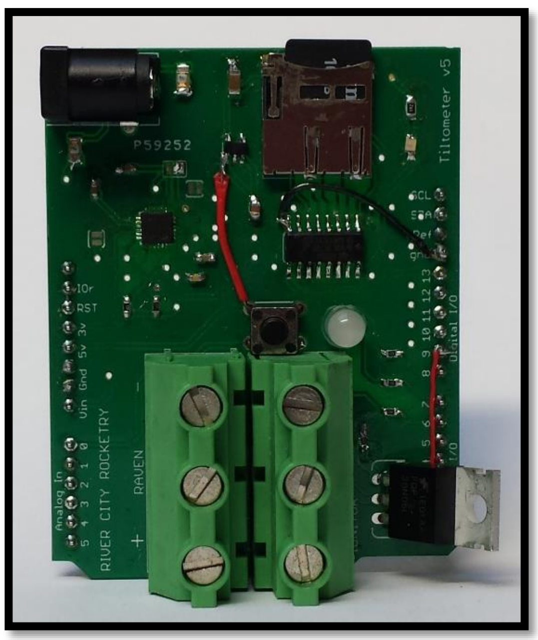

Figure 6. Tiltometer PCB

Construction of the tiltometer is complete, and the device properly detects when the device has been rotated an arbitrary angle away from the axis perpendicular to the ground. The team also has the tiltometer recording data onto an SD card. The device logs its current orientation every three seconds to the SD card. With this data, the team can re-construct the device's orientation over time, and determine if the tiltometer would allow the rocket's second stage motors to fire. The tiltometer will be tested in the air at the team's next launch. For the first launch, the device will only log its orientation before, during, and after the rocket ascends. From there, the team will analyze the orientation data, and make any needed tweaks before allowing the device to operate during a full launch.

The tiltometer has been tested on the ground via an externally-connected LED that indicates when it rotates more than a certain threshold angle (40 degrees) from the vertical axis. The device was carefully rotated away from the vertical axis to make sure the indication LED turned on, which it did. The tiltometer was also shaken violently by hand, to simulate vibrations seen during rocket ascent. After shaking the device, the team verified that the tiltometer's angle estimate did not drift from its previous angle estimate.

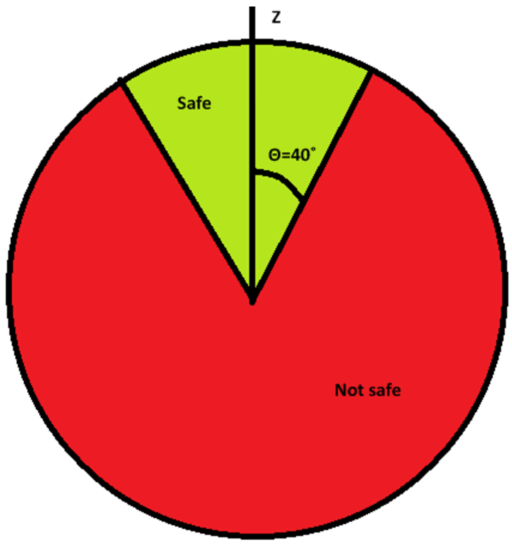

Figure 7. Tiltometer firing ranges. Red=safe to fire. Yellow=not safe to fire. Z is perpendicular to Earth's surface.

To get accurate angle readings, the team has to calibrate the tiltometer. When the device is first turned on, readings from the onboard IMU will drift for roughly 1 minute before stabilizing at a single set of values. To calibrate the device, the program waits slightly more than this period of time, and sets the angle estimate offsets of the device. After doing this, the device reads out a flat <0, 0, 0> [+/- ~0.01 in each component] angle estimate. At this point, the tiltometer is armed and ready to operate. It is important during this process that the tiltometer is oriented in the same angle it is oriented at inside the rocket, so that the tiltometer's vertical axis is aligned with the axis perpendicular to the ground. The calibration process has been tested extensively on the ground, and reliably results in a reading of <0, 0, 0> for the rocket after completion.

The tiltometer was tested for angle reading drift on March 8, 2014. To test for drift, the tiltometer was placed on a flat surface, and continuously read data for 10 minutes.

During this period, the device experienced a maximum of 3.16 degrees of drift for the x-axis readings. Y-axis readings peaked at 0.28 degrees of drift, and z-axis readings at 0.08 degrees of drift. Drift readings are graphed below.

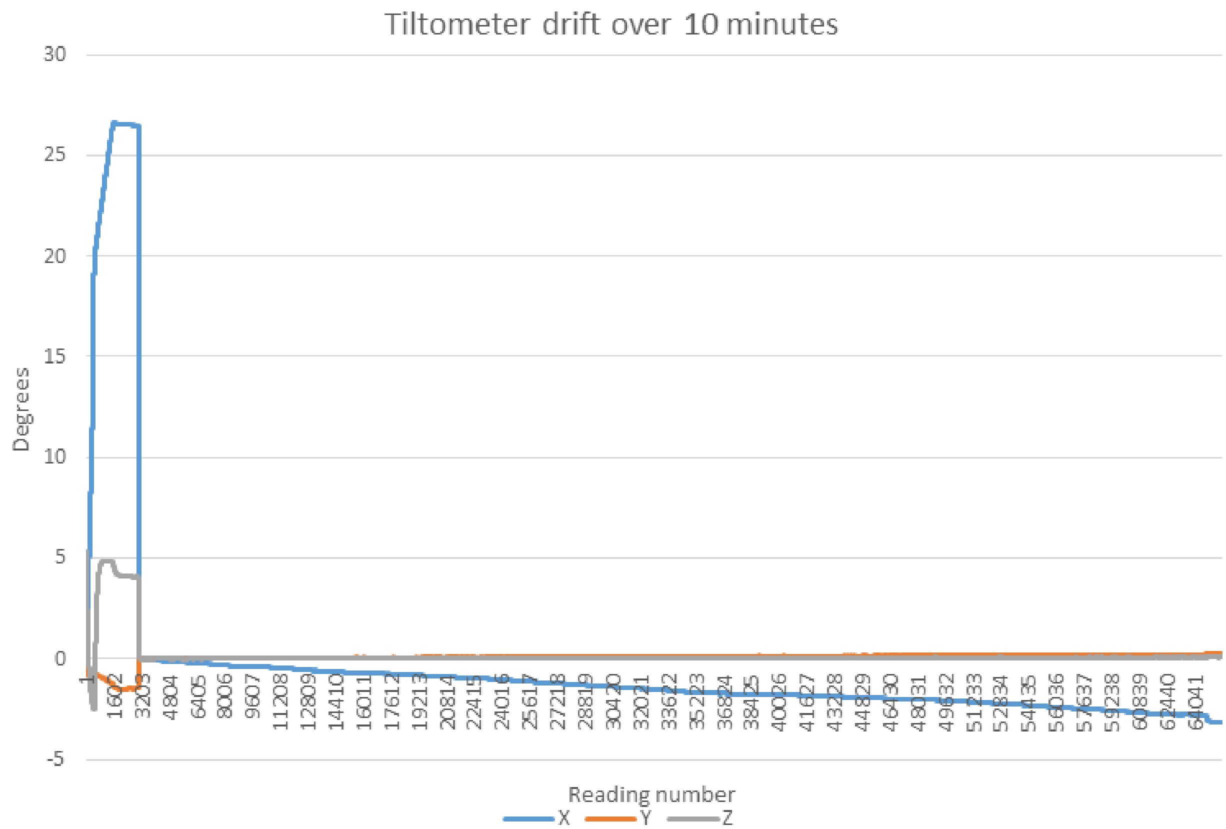

Figure 8. Tiltometer drift testing. Readings around 3203 mark the end of the calibration phase.

The data readings up until ~reading 3203 are the values read by the tiltometer before the device is calibrated. Once the device gets calibrated, the readings stabilize around 0 degrees, except for x-angle readings. These results were recorded before the tiltometer PCB was manufactured, and do not taken into account later coding changes. There is still one error the team needs to fix in getting the tiltometer not to trigger incorrectly (twisting the device around the vertical axis can trigger exceeding of the angle threshold), but this error will be simple to correct.

Electrical System

The tiltometer's basic function will be to read angle values from an accelerometer and gyroscope, and based on the angle it will allow current to flow from a Raven altimeter to the motor igniter or block it. An MPU6050 IC will be used to read angles since it contains a 3-axis accelerometer and gyroscope in one package which simplifies the circuitry. The electrical schematic of the final tiltometer revision is shown in Figure 9.

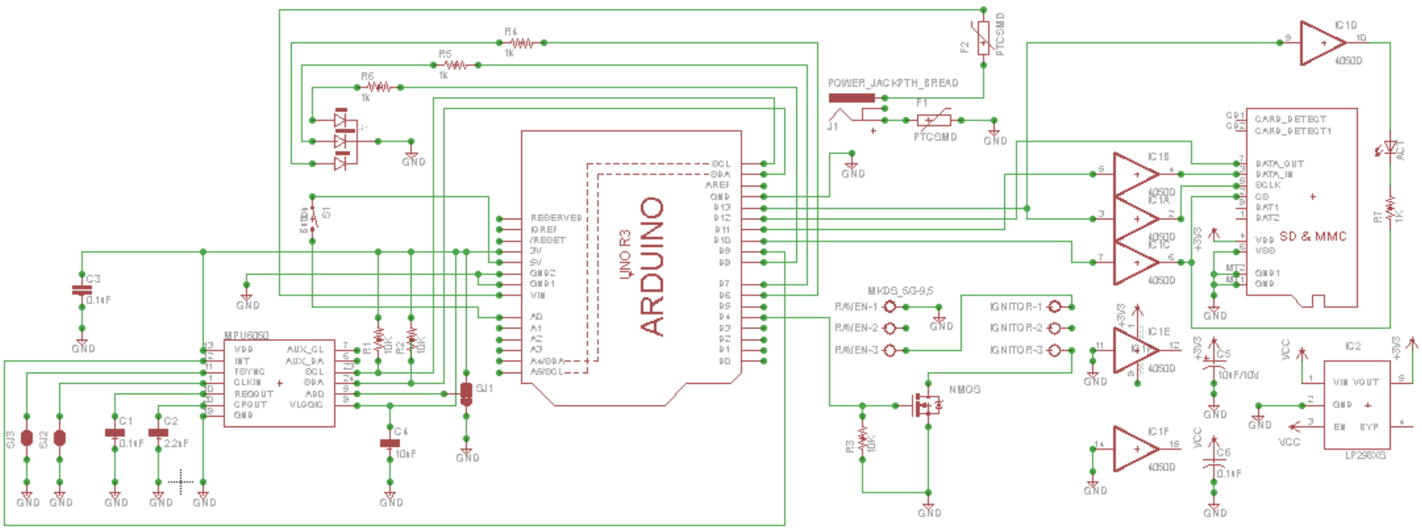

Figure 9. Electrical Schematic of Tiltometer PCB.

The MPU6050 IC uses I2C communication protocol which reduces the amount of pins needed on the Arduino compared to UART or SPI communication. This chip operates from 2.375-3.46V which is why it is tied to the Arduino's 3.3V power bus. Some of the technical specifications of the accelerometer and gyroscope are shown in Table 2.

Parameter		Accelerometer	Gyroscope
Range		±2g, ±4g, ±8g, ±16g	±250 °/s, ±500 °/s, ±1000 °/s, ±2000°/s
Sensitivity	X-axis	±50mg	0.1 °/s/g
	Y-axis	±50mg	0.1 °/s/g
	Z-axis	±80mg	0.1 °/s/g
Frequency	X-axis	1000Hz	33kHz
	Y-axis	1000Hz	30kHz
	Z-axis	1000Hz	27kHz

Table 2. Specifications for Accelerometer and Gyroscope on the MPU6050 IC.

The method this circuit works is that the Raven's output will be connected to the input terminal block on the Tiltometer's PCB, and the motor's igniter will be connected to the output terminal block. An N-channel mosfet will act as a switch to allow the current from the Raven to flow to the igniter as long as the Arduino keeps a high signal output on the mosfet's gate. An FQP30N06L Mosfet is being used as it is rated for 60V and 30A which is more than what the Raven will output.

If the MPU6050 IC detects the angle is greater than 40 degrees, the Arduino will pull the signal low on the mosfet's gate. This will cause the mosfet to switch off and no current will flow to the igniter. If the angle is less than 40 degrees, the mosfet will stay on. The mosfet circuit has been tested to work on its own and it has also been tested on board of the PCB.

The 30A current should not be seen by the Arduino, but in case the current does flow to the Arduino, two fuses are at the negative and positive terminals of the power source for the Arduino. The fuses will blow if the current going to the Arduino exceeds 7A, therefore protecting it from being fried.

The circuit also includes a reset button and an RGB led to indicate the status of the Tiltometer. A 9V battery powers the Arduino and the attached Tiltometer PCB. The current layout of this PCB is shown in

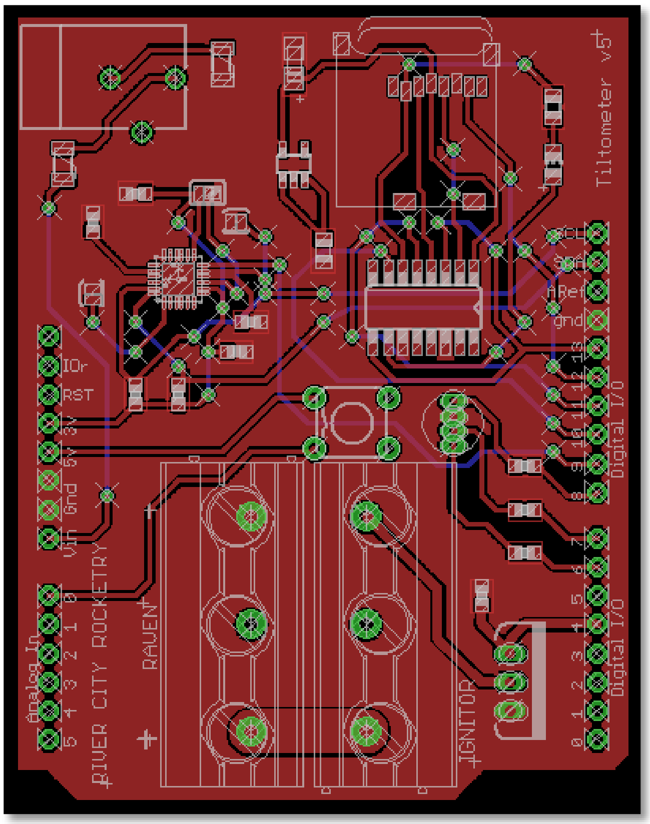

Figure 10. Layout of Tiltometer PCB

As can be seen, the circuit for the MPU6050 is as far from the terminal blocks connecting the igniter and Raven. The reason for this is to prevent any parasitic effects on the MPU6050. Both of the terminal blocks are rated for 600V, 30A so they should be able to withstand the power required to light the igniter. The terminal blocks are also large enough to allow several altimeter outputs to be wired to it.The Tiltometer PCB is able to contain all the components on a board the same size as the Arduino UNO. Therefore, the Tiltometer measures 2.7”x2.1” and it will be oriented vertically in the rocket.

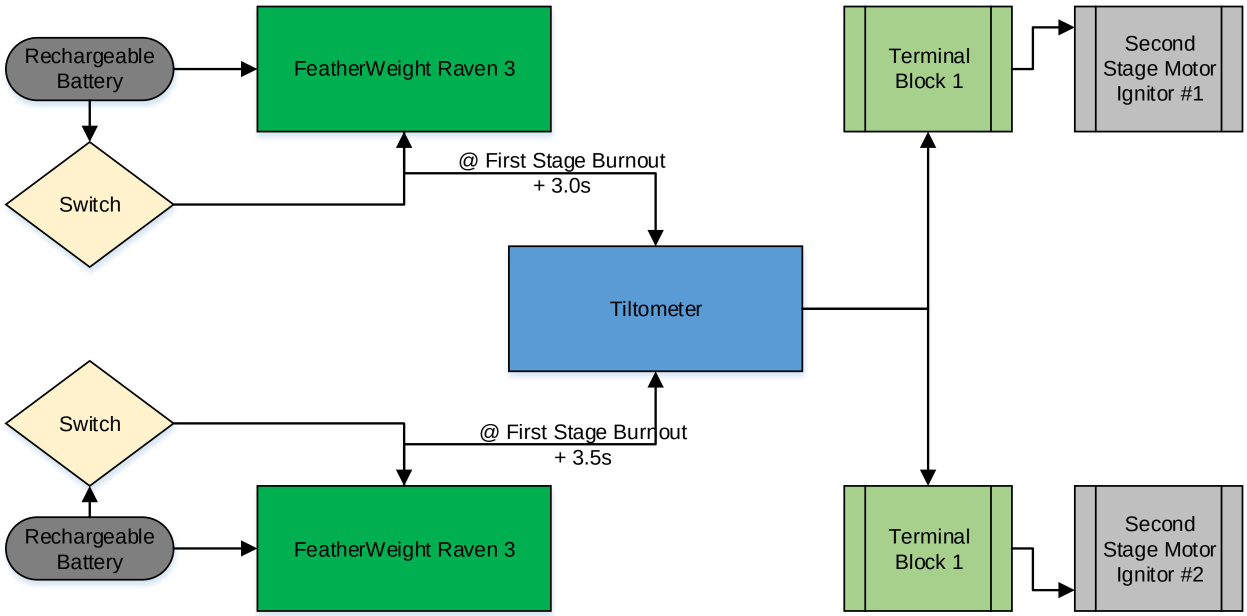

Figure 11: 2nd Stage ignition logic.

Apogee Event

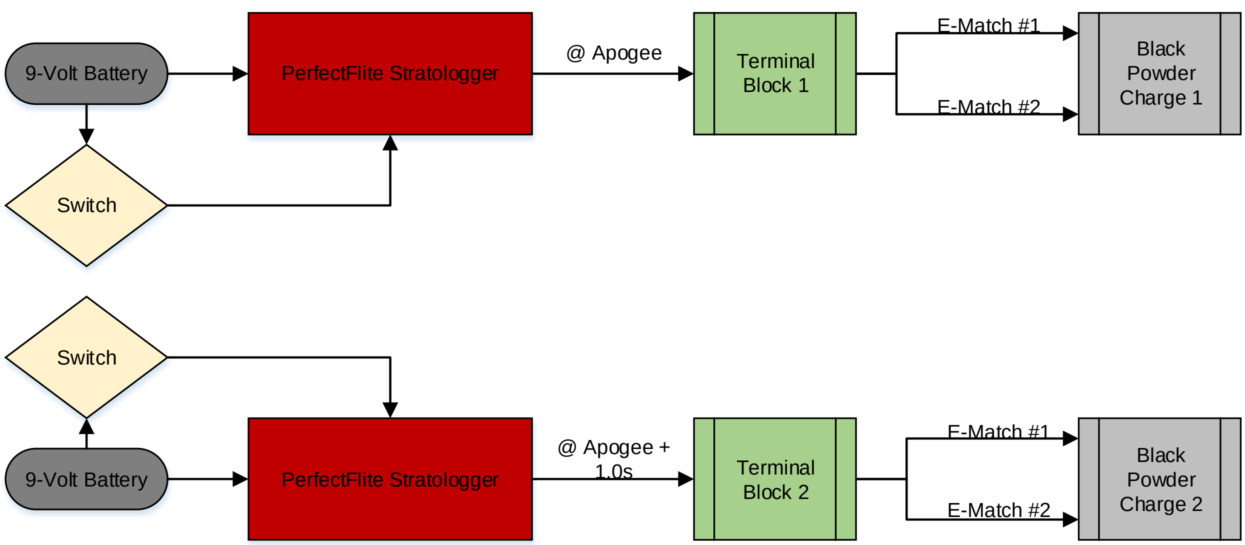

Figure 12: Apogee recovery logic.

The apogee event uses two StratoLogger's that deploy at apogee and apogee + 1.0 seconds. This is a standard dual deployment for high powered rocketry.

Lower Sustainer Ejection

The lower sustainer will be ejected at 7500 ft. and will be under parachute when ejected. The same Ravens that powered the motor ignition will power the black powder charges to separate the lower sustainer from the fairing payload.

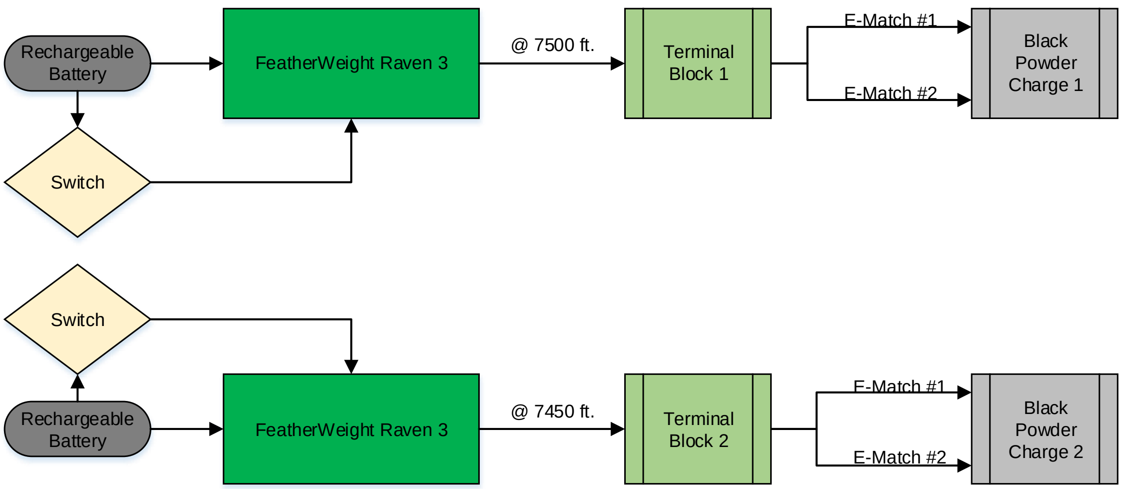

Figure 13: Lower sustainer recovery logic.

Fins

The fins used on the rocket's booster and sustainer are constructed out of G-10 fiberglass and have the dimensions listed in the table below.

	Booster Fin Set	Sustainer Fin Set
Number of Fins	4	4
Fin Rotation (degrees)	0	0
Fin Cant (degrees)	0	0
Root Chord (in.)	10	11
Tip Chord (in.)	2	3
Height (in.)	4	4

Sweep Length (in.)	8.95	8.94
Sweep Angle (degrees)	63.4	63.43
Thickness (in.)	0.125	0.125

Table 3. Fin dimensions.

G-10 fiberglass is well-known for its use in model rocketry and is renowned for its strength and high factory of safety when under stress. Below is a rendered image of one of the booster fins.

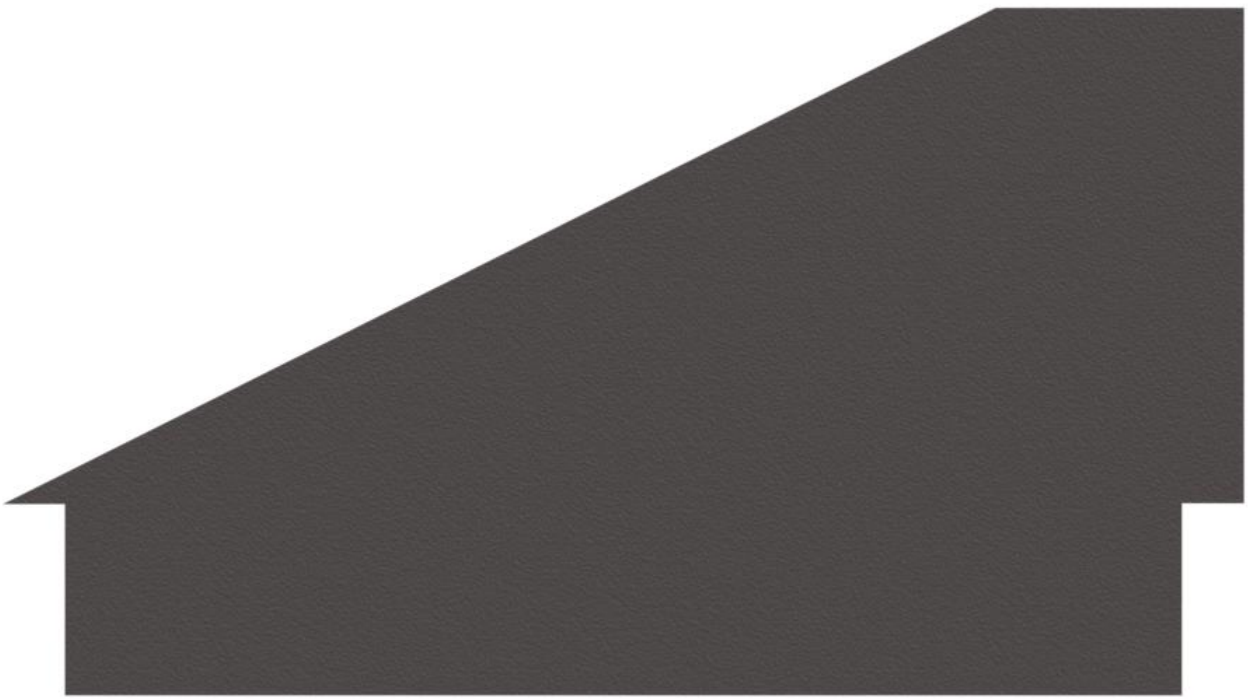

Figure 14. Booster fin.

The fin has a tab that is inserted into the body of each stage, which will be epoxied (using Proline epoxy) to the inner tube, centering rings, and the outer airframe to ensure complete stability and adhesion to the rocket. The overhang on either end of the tab will allow the epoxy to bind to a larger surface area than if the tabs extended all the way along the root chord.

As stated before, the fins used on the rocket's booster and sustainer are constructed out of G-10 fiberglass and have the dimensions listed in the table below.

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There are six wooden bulkheads in areas that bear little to no stress and therefore do not need high strength, heavy-weight materials. Six G10 fiberglass bulkheads supply high strength materials in stress bearing locations and one 6061-T6 aluminum bulkhead provides the strength needed to withstand the stress input in that area.

Several aluminum threaded rods are included in the design. These allow electronics to be mounted between the bulkheads.

Permanent assemblies (ie, fins, inner tubes, centering rings, and bulkheads) are assembled using Proline epoxy and J.B. Weld. This ensures stability and permanent adhesion between parts. The AV bays are riveted together to allow the bays to be removable after flight.

The first and second stages, the booster and sustainer respectively, are attached using two 4-40 shear pins located 180 degrees from each other. These pins will release when the black powder charges ignite, allowing for stage separation and clearance from the booster stage.

The motors will be inserted into a 2.953 inch inner tube, which is epoxied to the centering rings and the fins. The fins and the centering rings are in turn epoxied to the outer airframe, thus ensuring a snug, permanent fit. In order to prevent the loss of the motor during flight, a 75 millimeter Aeropack motor retention ring will be attached to the bottom of the sustainer and booster's motors. The retention ring on the booster will have a flange while the sustainer will not. The 75mm retention ring is shown below.

Figure 15. Aeropack 75mm motor retention ring.

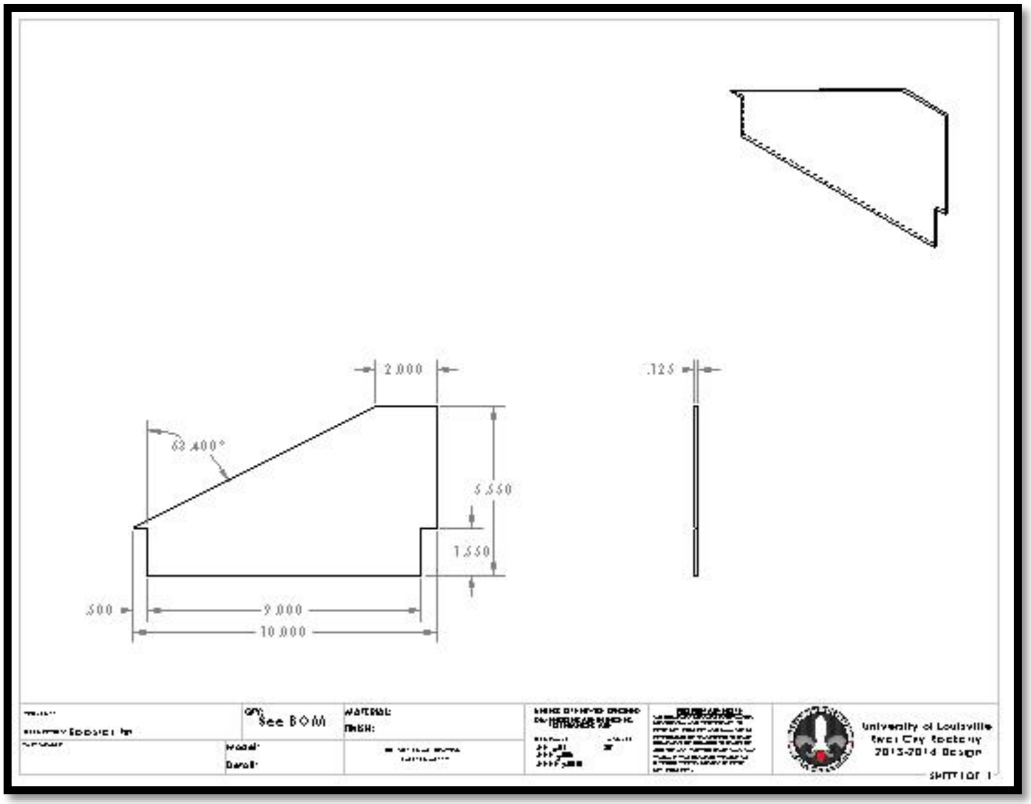


Figure 16. Booster Fin.

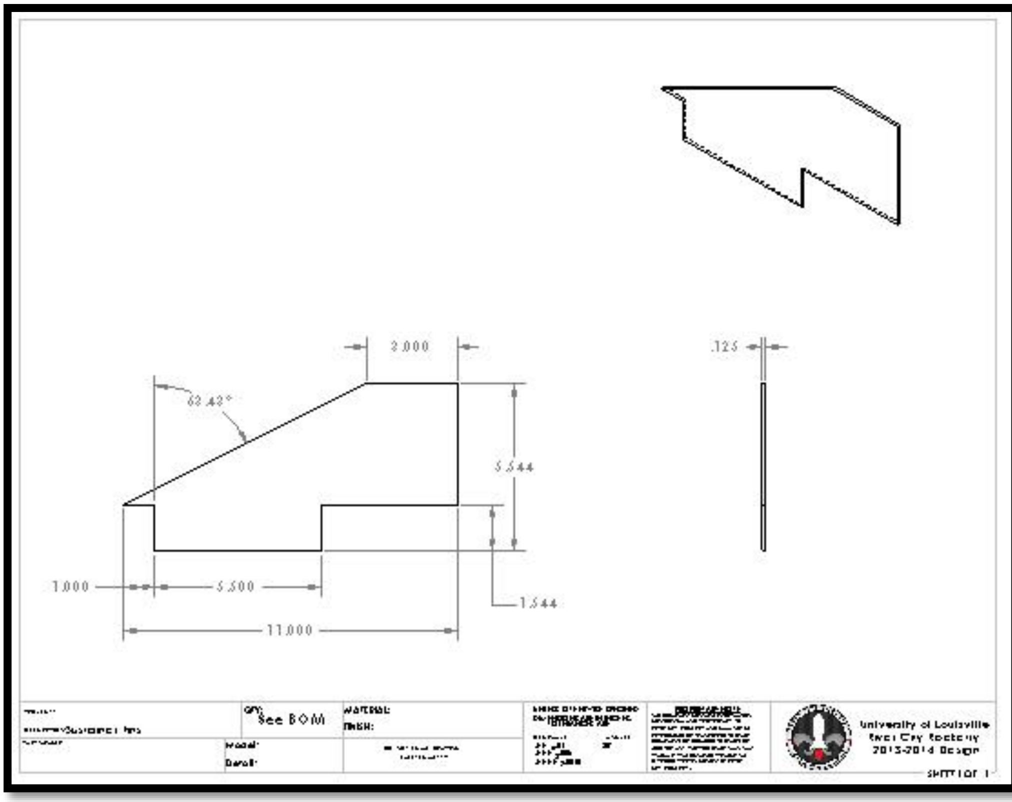


Figure 17. Sustainer Fin.

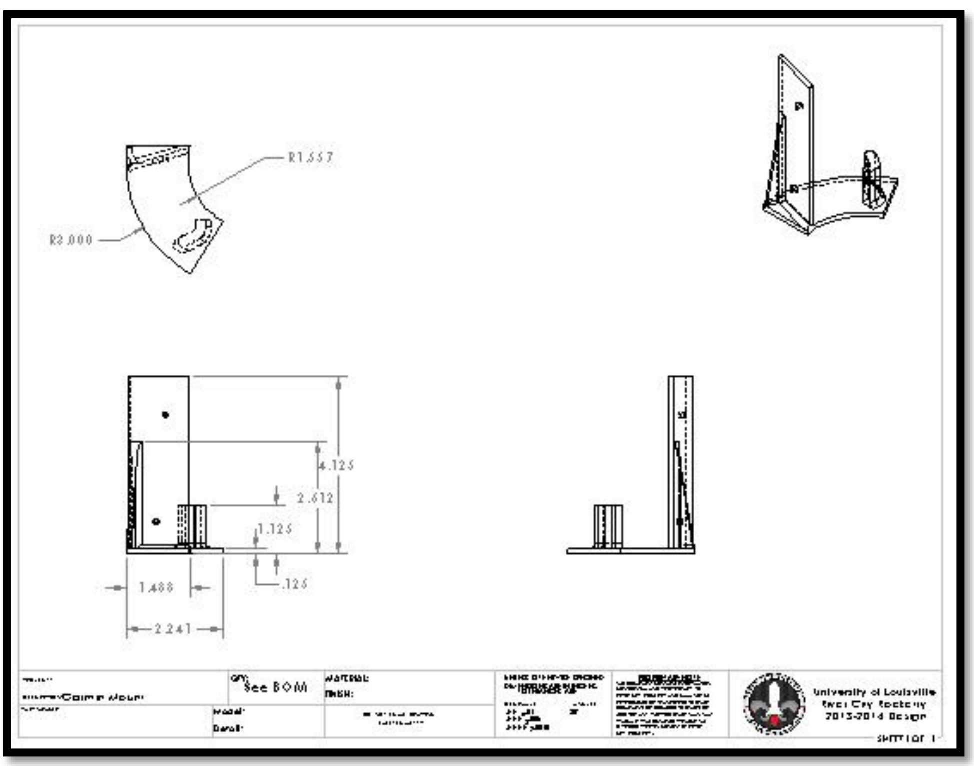


Figure 18. Garmin Mount

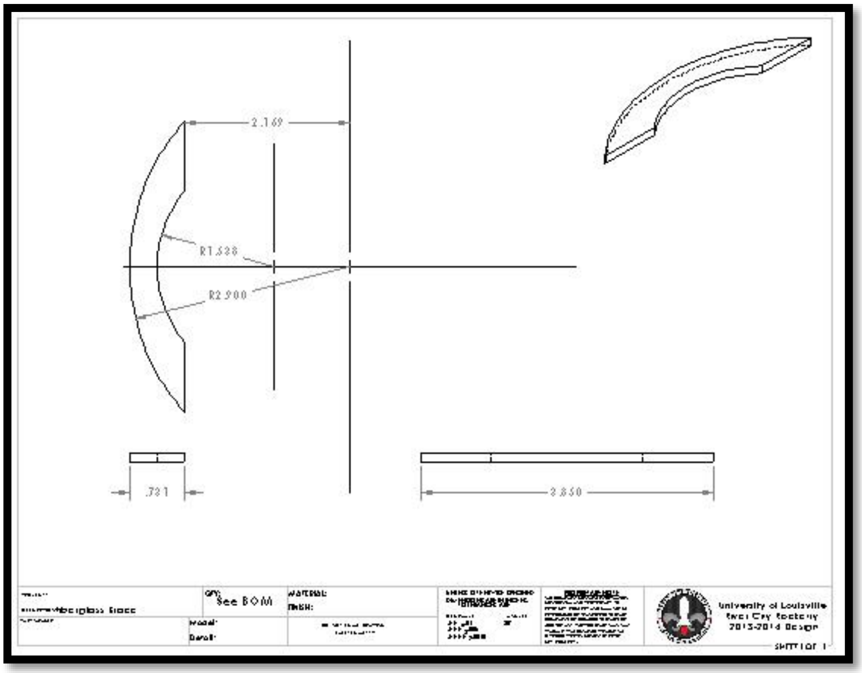


Figure 19. Fiberglass Brace

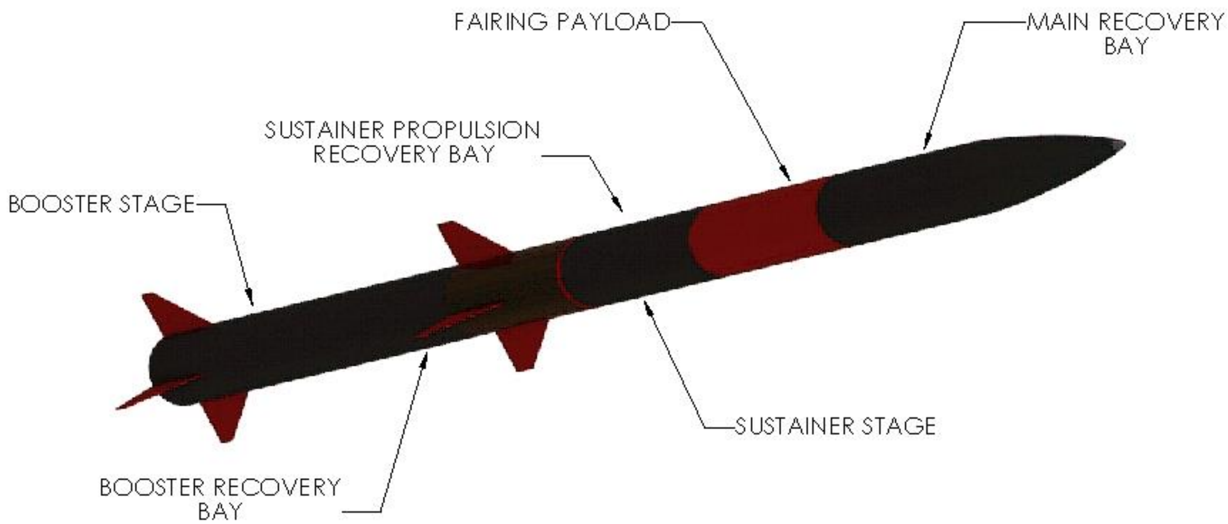


Figure 207. Rocket Assembly Model.

As shown in the model above, the rocket is separated into dual stages; the booster stage, containing the booster motor attaches to the booster recovery bay, which contains the black powder charges for booster separation and parachute deployment. The booster recovery bay is attached to the sustainer propulsion/recovery bay (containing the motor and parachute) via a friction fit. The lack of shear pins will allow for easier separation when the charges detonate. The next section is the fairing/payload section, which separates from the sustainer via black powder charges. The fairing contains the hazard detection payload (see Payload Criteria for more information) and its corresponding parachute. Sitting above the fairing and below the nosecone is the final set of black powder charges, which will separate the nosecone from the fairing, allowing the drogue parachute to deploy which in turn will cause the main parachute (functioning for both the nosecone and the fairing) to deploy.

Flight Reliability

We have successfully completed black powder testing as of the submittal of this document. They system will be using black powder as separation charges for each section. For booster separation, there are two charges at 2 and 3 grams respectively. Following this event, booster apogee occurs, setting off four charges with varying amounts of powder (four, five, six, and seven grams respectively). Next stage is the sustainer separation at apogee, with four charges with five, six, seven, and eight grams of powder respectively. Following this, the lower sustainer ejects using four charges with five, six, seven, and eight grams of powder respectively. Next stage is payload deployment, using two charges with two e-matches each with 0.7 grams of powder each. Final stage is nosecone separation and parachute deployment, using four charges with five, six, seven, and eight grams of powder respectively.

Following the successful testing of the full-scale on April 20th, 2014, more test data will be available and will be attached to the FRR via addendum.

Workmanship

During the construction of the rocket, workmanship must be taken as seriously as the initial design. To ensure maximum precision, the team will be making many components utilizing CNC machining technologies.

Several of the components have been made using standard machining processes. Even without computerization, accuracy within ±0.001 is very feasible.

Through accurate machining, careful assembly, and thorough checks, the team will be able to increase chances of mission success by eliminating potential problems due to poor workmanship.

Full-Scale Test Launch

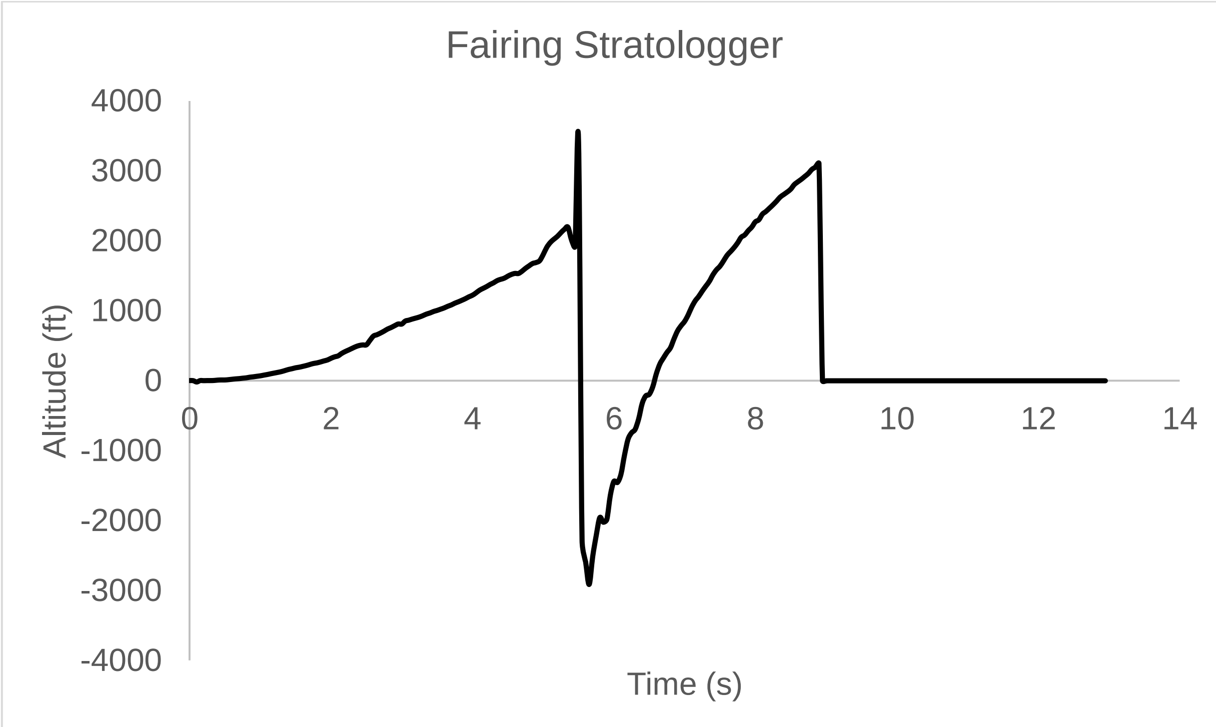


Figure 18. Fairing Stratologger.

At the present time, we are unsure as to what was the exact cause of the incident because, with our present resources, our gathered data is inconclusive. What we do know is that at six seconds after initial ignition, something caused one of the Featherweight Raven Stratologgers to register a sudden drop in altitude into the negative range. This was also recorded on each of the other Stratologgers in the nosecone.

RECOVERY SUBSYSTEM

Overview

The purpose of any vehicle is to deliver a payload so that the payloads mission can be completed successfully. Because this vehicle has multiple payloads the requirements for each payload were factored in to determine the recovery method.

Payload	Requirements the recovery system must satisfy
Hazard Detection	Be able to land and perform surface maneuvers.
Stage Separation	Land independently of the launch vehicle.
Fairing	Be able to eject a payload during descent.

Table 4. Payload specific recovery requirements.

For the hazard detection payload to be able to perform surface maneuvers it must either be able to leave the vehicle after landing or be ejected during descent, the fairing must be able to eject a payload during descent. To reduce complexity it was decided to merge these two requirements and recover each rocket section independently under its own parachute. The sections that will be recovered will be the booster section, the lower sustainer, the hazard detection payload, and the nose cone with the fairing tethered to the nose cone.

Recovery Requirements

The recovery system must meet the following requirements set forth by the Statement of Work (SOW) and those set forth by the team, shown below, to be considered a success.

1. The parachute system(s) shall be designed and manufactured by the team. Commercially available parachute systems shall not be used on the vehicle.
2. At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lb_f,
3. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.
4. The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.
5. Each altimeter shall be armed by a dedicated arming switch which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.
6. Each arming switch shall be capable of being locked in the ON position for launch.
7. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.
8. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.
9. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch till landing).

The recovery system must meet the following requirements which have been set forth by the team.

10. At landing all vehicle sections will have a landing kinetic energy at or less than 60 ft-lb_f.

Requirement 10 overrides requirement 2 which has been put forth by the statement of work.

Structural Elements

Bulkheads

The bulkheads used are 9/16 inch balsa which has been epoxied to 1/8 inch G10 fiberglass by the use of ProLine 4500 high temp epoxy. The balsa and fiberglass bulkheads were purchased through Wildman Rocketry and were the same type used in previous years.

Harness Material

The harness material is 9/16ths tubular nylon with a rated strength of 2300 lbs. To construct the harness eight inches were folded over at the ends and sewn together with enough room for attachment hardware. Three straight stitches run the length of the folded cord and will be stitched in the pattern shown in Figure 21. The final assembled harness is shown in Figure 22

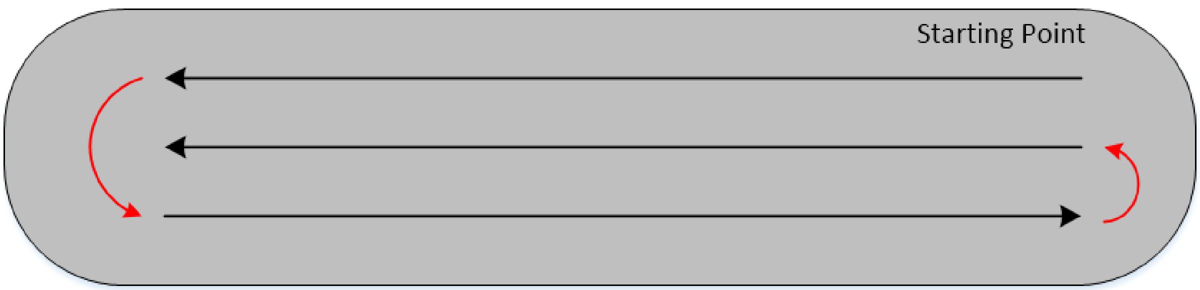


Figure 21: Harness stitch pattern.

Figure 22: Completed harness stitch.

Once the stitches were complete, shrink wrap was tubing was applied to each stitch to protect the stitches and thus protect the strength of the shock cord. The shrink wrapped cord is shown in Figure 23.

Figure 23: Shrink wrapped shock cord attachment point.

<u>Attachment Hardware</u>

The attachment hardware comprises of the permanent hard points of the vehicle and the hardware that is used to attach the shock cable to the hard points and the suspension lines of each parachute.

Hard Points

The hard points are different for each section of the vehicle to be recovered, Table 5 shows each sections hard point and the rated strength.

Attached Section	Type of Harness	Quantity	Rated Load (lbs.)
Booster Motor Tube	3/8th inch forged eye-bolt	1	

Booster avionics bay	3/8th inch black oxide u-bolt	1	
Sustainer avionics bay	3/8th inch black oxide u-bolt	1	0
Hazard Detection Payload	See the parachute cam section		
Fairing		2	
Nose Cone	3/8th inch black oxide u-bolt	1	0

Table 5: Vehicle Hard Points.

Shock Cord Hardware

The shock cord connects to the previously defined hard points, with the hazard detection payload being an exception, via a 9/16th inch aluminum carbineer from McMaster Carr with a rated strength of 2200 lbs. The hazard detection payload does not have shock cord, it instead attaches directly to the suspension lines of the parachute.

Electrical Components

The electrical components used in the recovery of the vehicle are commercially available altimeters for ejection of the parachutes at the correct altitude or time of flight, and tracking electronics so that the position of each non-tethered section of the vehicle can be found after descent.

Altimeters

Multiple different kinds of altimeters are used in the vehicle with each having a specific reason for being chosen. The following section describes a brief overview of each type of altimeter used. After each altimeter has been described, the batteries that power each device and switch will be described.

PerfectFlite Stratologger Altimeter

Figure 24: PerfectFlite Stratologger

The PerfectFlite Stratologger altimeter is a common altimeter used in high powered rocketry. It records its altitude at a rate of 20Hz with a 0.1% accuracy. In previous testing, the altimeter was found to be accurate to ±1 foot. The StratoLogger can be configured to provide a constant serial (UART) stream (9600 baud rate ASCII characters) of the device’s current altitude over ground. The device can be safely powered by a 4V-16V source and requires 1.5 mA typical, 10A maximum (when activating e-matches).

Featherweight Raven Altimeter

Figure 25. Featherweight Raven.

The Featherweight Raven altimeter records its altitude at a rate of 200Hz via accelerometers and at 20Hz using a pressure transducer with a 0.3% accuracy. The Raven will be powered by its own Featherweight Power Perch which also features a magnetic switch which will be used to lock the altimeter in the on position externally. The device is rated at 30+ amps for air – start applications.

MissleWorks RRC3 Altimeter

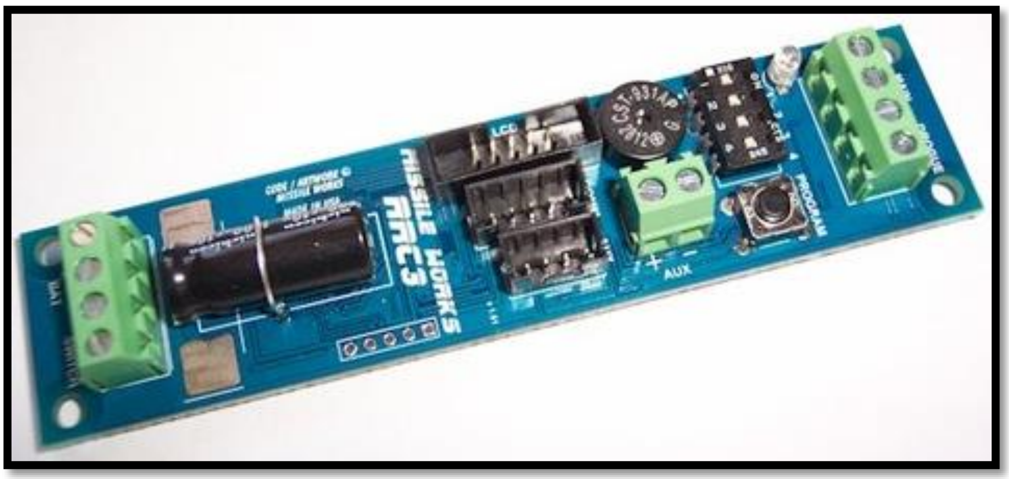


Figure 26: MissleWorks RRC3 Altimeter.

The MissleWorks RRC3 altimeter records data at a rate of 20Hz using a pressure transducer. It will be powered via an external 9-Volt Duracell battery. This altimeter has three outputs, an apogee event, descent altitude event, and an auxiliary event. The auxiliary event is not constrained to altitude, and can be used as a timer after an event has been determined.

Batteries

The Stratologger and RRC3 will be powered by Duracell 9-Volt Alkaline batteries, the batteries will be mounted to the altimeter sled via 3-D printed housings and the use of battery clips will connect the battery to the altimeters. As stated previously, the Raven uses a 3.7 Volt lithium polymer batter that attaches to the Power Perch add-on. All batteries will be checked for full charge the night previous to launch.

Switches

The Raven Power Perch add-on contains a separate magnetic switch, this switch has been used successfully by the team and other groups active in high powered rocketry. The RRC3 and Stratologger will use a Featherweight screw switch, this is the same switch that was used during last year's competition.

Connections

Terminal blocks are used to connect the altimeter to the ejection charge. This is done by permanently epoxying the terminal blocks and wires to the bulkhead, running the wires into the avionics bay via hole in the bulkhead, then using epoxy to close the hole.

<u>Tracking</u>

We will be using a commercially available system to track the nose cone, booster, and lower sustainer assemblies. A cape for the hazard detection payload will be used to track the payload. Both systems utilize GPS technology to provide the information, we viewed this as a more accurate system and less susceptible to interference from other tracking equipment.

Garmin Astro DC 40

Figure 27. Garmin Astro DC 40 GPS Tracker

A Garmin Astro DC 40 will be used to track the booster, lower sustainer, and nose cone rocket sections. The system consists of both a handheld receiver and transmitter unit. The unit will be taken off of the collar and attached to each section. The unit advertises a seven mile range and updates location every five seconds.

GPS/GPRS Cape

Figure 28: GPS/GPRS Cape

More information on the GPS/GPRS Cape can be found in section X.

Redundancy

To maintain redundancy a minimum of two altimeters will be used for each portion of the vehicle they are required. Each altimeter within that section will have a dedicated battery and switch. Table 6 shows each altimeter being used at each ejection event and the total number of altimeter outputs for the event.

Recovery Event	Altimeter Used	Total Number of Outputs
Booster Separation	RRC3	2
Booster Main Deployment	RRC3	4
Nose Cone Deployment	Stratologger	4
Lower Sustainer Separation	Raven	4
Rover Separation	Stratologger	2

Table 6: Recovery Redundancy.

The amount of redundancy in the booster main deployment and the nose cone deployment was achieved using a built in fail-safe of the Stratologger and using the RRC3 in apogee only mode. The apogee only mode automatically deploys the main ejection charge one second after apogee.

The failsafe feature was first noticed during sub-scale testing during the first unsuccessful flight. As described in the CDR the sustainer motor did not fire correctly and as such the apogee altitude was less than the set value of the Stratologger. When the vehicle hit apogee the drogue was deployed followed by the main charge immediately after.

Parachute Selection

Parachute are broken down into the following types: solid textile, slotted, and rotating (Knacke 5-3). With four parachutes being used during descent and all of them being in the air simultaneously the chances of a midair collision are much higher than one active parachute as seen in a dual deployment scheme. By keeping all parachutes the same type the flight path will be more similar than if each was different, for this reason it was deemed that all parachutes will have the same geometry.

Geometry

The parachute geometry was selected to minimize the total mass of all parachutes. To accomplish this the geometry with the highest drag coefficient and minimum area was chosen. Table 7 shows drag coefficient ranges vs. parachute geometry, the drag coefficient is based on total area including the vent hole and all openings (Knacke 5-3).

Parachute Geometry	Drag Coefficient Range	
	Lower	Upper
Annular	0.85	0.95
Triconical	0.8	0.96
Extended Skirt (10% Flat)	0.78	0.9
Flat Circular	0.75	0.8
Conical	0.75	0.9
Extended Skirt (14.3% Flat)	0.75	0.9
Ringsail	0.75	0.85
Biconical	0.7	0.92
Hemishperical	0.62	0.77
Cross	0.6	0.85
Ringslot	0.56	0.65
Disc - Gap - Band	0.52	0.58
Conical Ribbon	0.5	0.55
Flat Ribbon	0.45	0.5
Guide Surface (Ribbless)	0.3	0.34
Ribbon (Hemisflo)	0.3	0.46
Guide Surface (Ribbed)	0.28	0.42

Table 7. Drag coefficient range vs. parachute geometry.

The triconical had the highest upper drag coefficient and the annular had the highest lower drag coefficient. The annular was chosen because the average of the range was the highest in addition to also having the advantage of using less fabric as each individual gore is smaller due to the size of the vent hole.

Sizing

The terminal velocity of each rocket section was calculated by

$$V = \sqrt{\frac{2Eg_c}{m}} \tag{20}$$

where E is the maximum landing energy, this value is lower than what is stated in the statement of work (SOW) due to the hard landing surface., is the total mass of the section to be recovered (lb_m), and g_c is the dimensional constant. The steady state velocity under parachute is calculated by

$$V = \sqrt{\frac{2mg}{\rho C_d A}} \tag{21}$$

where g is acceleration due to gravity, ρ is the density of air, C_d is the drag coefficient of the parachute, and A is the parachute area including vent holes and openings. By combining equations 1 and 2 the area can be calculated by

$$A = \frac{m^2 g}{\rho C_d E g_c} \tag{22}$$

The nominal diameter is then determined by

$$D_0 = \sqrt{\frac{4A}{\pi}} \tag{23}$$

Table 8 shows the estimated mass, total parachute area, nominal diameter, and landing velocity for the launch vehicle sections and hazard detection payload.

Section	**E (ft-lb$_f$)**	**m (lb's)**	**A (ft)**	**D_0 (ft^2)**	**V (ft/s)**
Booster	60	15.9	62.567	8.9254	15.583
Lower Sustainer	60	18	80.185	10.104	14.646
Upper Sustainer	60	14.7	53.479	8.2518	16.206
Hazard Detection Payload	25	5.5	17.967	4.783	17.102

Table 8. Vehicle mass, parachute area, parachute diameter, and landing velocity.

This value of D_0 was used to determine the individual gore dimensions as shown in Figure 29

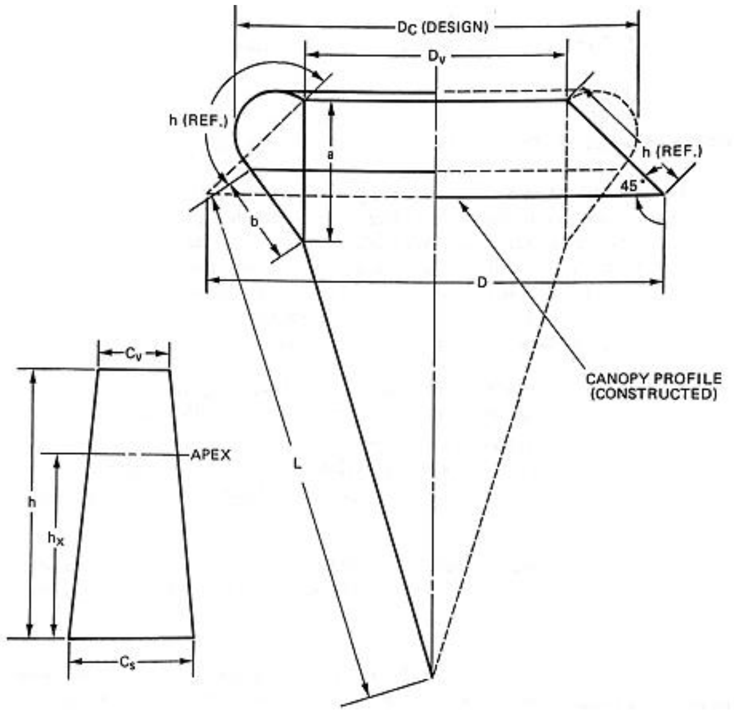


Figure 29. Parachute and gore layout.

The general gore dimensions and parameters are shown in Table 9.(Knacke 6-23).

Dimension	Ratio, D_0
D	1.040
D_C	0.940
D_V	0.611
L	1.250
h	0.304
hx	0.209
a	0.319
b	0.200

Table 9: Parachute gore dimensions.

C_V is then calculated using

$$C_V = \frac{\pi D_V}{N_G} \tag{24}$$

where N_G is the number of gores. C_S is then calculated using

$$C_S = \frac{\pi D}{N_G} \tag{25}$$

Using equations 24, 25, and the ratios shown in Table 9, all relevant gore dimensions are shown in Table 10.

Rocket Section	Ng	C_V (in.)	C_S (in.)	h (in.)	a (in.)	b (in.)
Booster	10	20.56	33.65	32.56	34.17	21.42
Lower Sustainer	10	23.27	38.09	36.86	38.68	24.25
Upper Sustainer	10	19.01	31.11	30.10	31.59	19.80
Hazard Detection Payload	10	11.02	18.03	17.45	18.31	11.48

Table 10: Nominal parachute dimensions.

Descent Velocities and Kinetic Energy

The descent velocities shown earlier were from the estimated mass of the vehicle. After construction of the vehicle the descent velocities were recalculated using the actual mass of the vehicle. Equation 21 was used to determine the landing velocity. The kinetic energy was determined via

$$E = \frac{1}{2} mV^2 \tag{26}$$

The results are shown in

Landing Section	Mass (lb_m)	A (ft^2)	V (ft/s)	E (lb_f-ft)
Booster	19.4	80.185	14.649	64.699
Booster avionics bay	1.5	80.185	14.649	5.0025
Sustainer Assembly	15.7	62.567	14.919	54.305
Nose Cone	10.2	53.489	15.453	37.852
Fairing	14.4	53.489	15.453	53.437
Hazard Detection Payload	6	17.967	17.211	27.619

Table 11: Kinetic Energy of Each Sections.

Avionics Bays

Each section that will be recovered will have its own custom designed altimeter sled and corresponding avionics bay. This section will cover the avionics bays for the booster recovery, apogee event, and lower sustainer ejection, the rover ejection event will be covered in the fairing payload section. All electronics will be attached to the sled via nylon 4-40 screws, this was done so that in a catastrophic failure the screws shear and the altimeters have an increased chance to survive. All sleds will also be 3D printed out of ABS, this was done to reduce the mass of each of the sleds. After being printed the sleds will go through and acetone treatment to strengthen them.

Universal Components

Battery Holster

The battery holster that houses the 9 – volt batteries will be the same on all described avionics bays. The holster consists of two parts, the base and the cover, that screw into each other using two 4-40 nylon screws. Each component of the battery holster will be printed out of Makerbot ABS plastic, this is done to make the design as lightweight as possible and to allow for custom mounting if needed.

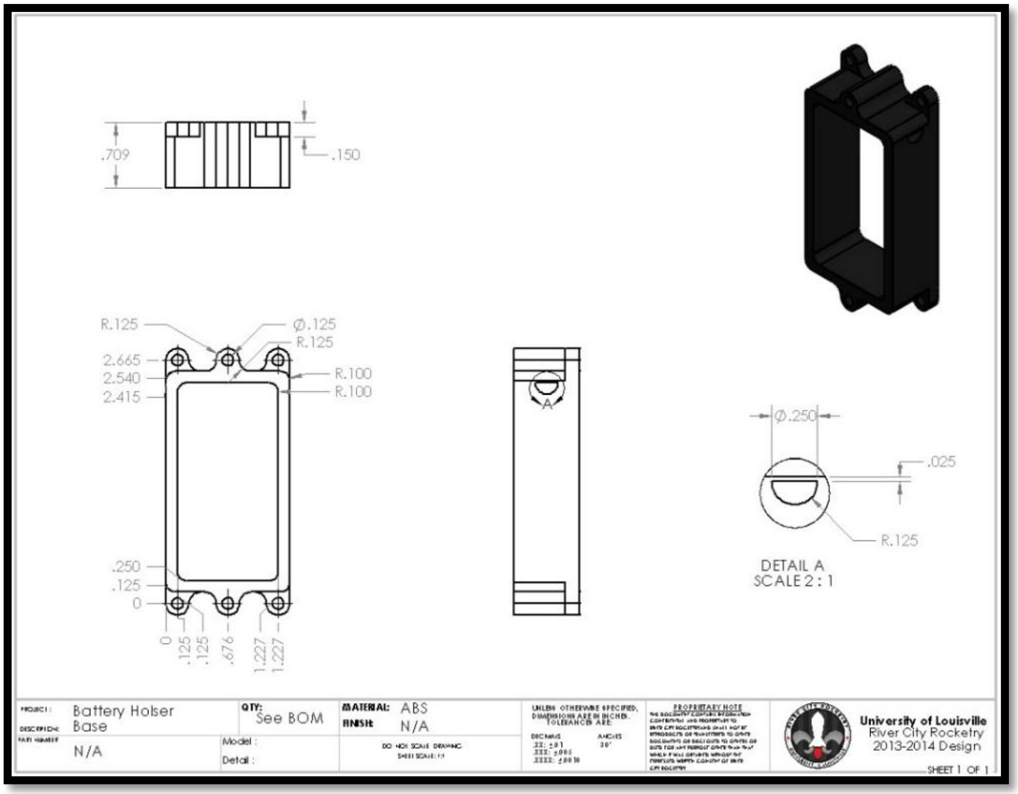


Figure 30: Battery holster base.

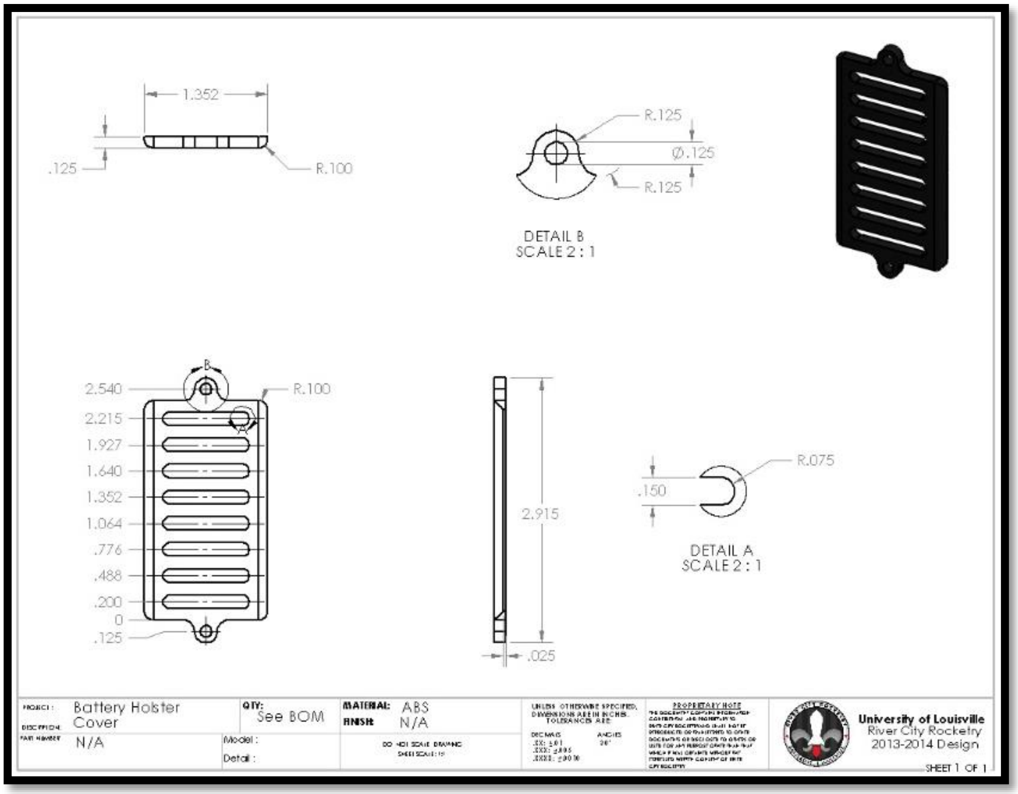


Figure 31: Battery holster cover.

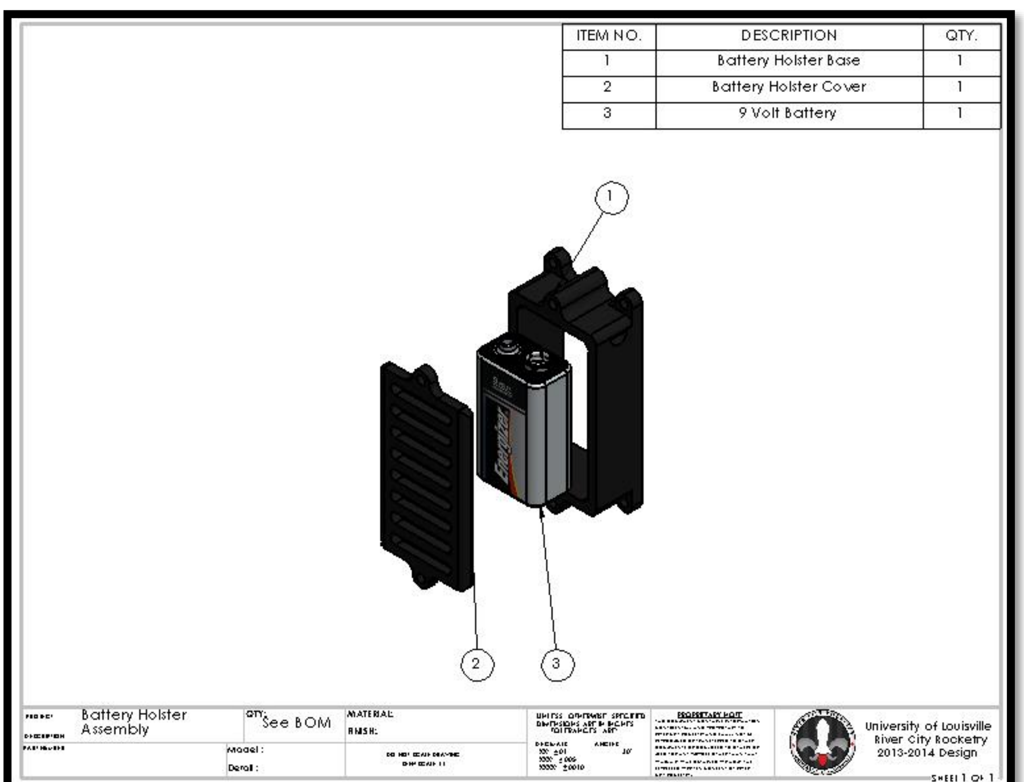


Figure 32: Battery holster assembly.

Booster Avionics Bay

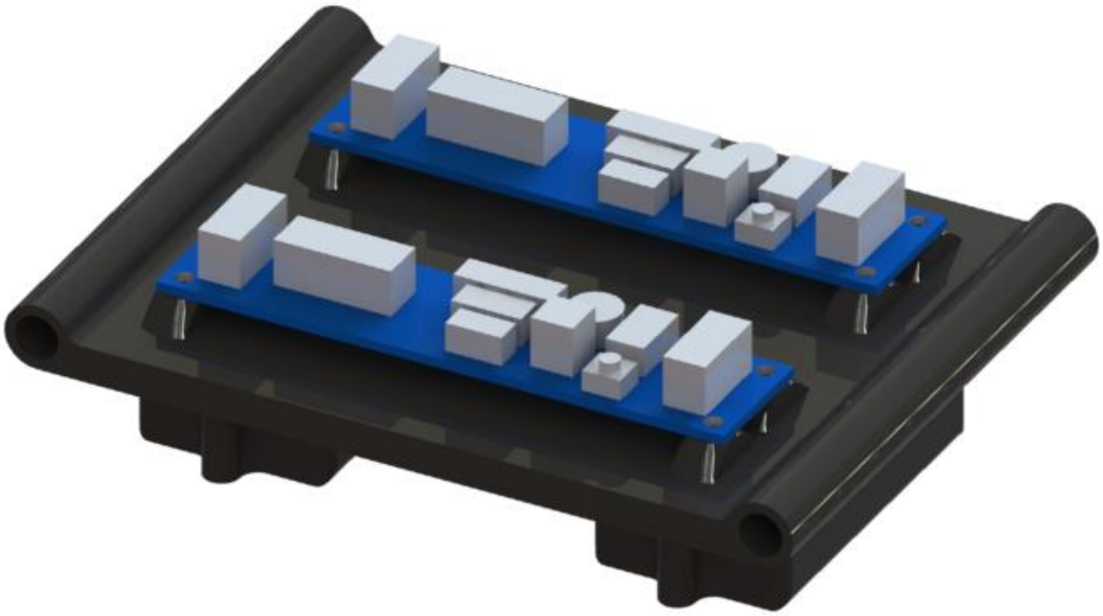


Figure 33: Booster altimeter sled.

The booster avionics bay consist of a sled designated for two battery holsters and two MissleWorks RRC3 altimeters, and the two battery holsters. Standoffs for the altimeters will be built into the sled and be tapped so the altimeters and the battery holsters screw directly into the sled. This reduces the chance that a small piece can be lost or damaged.

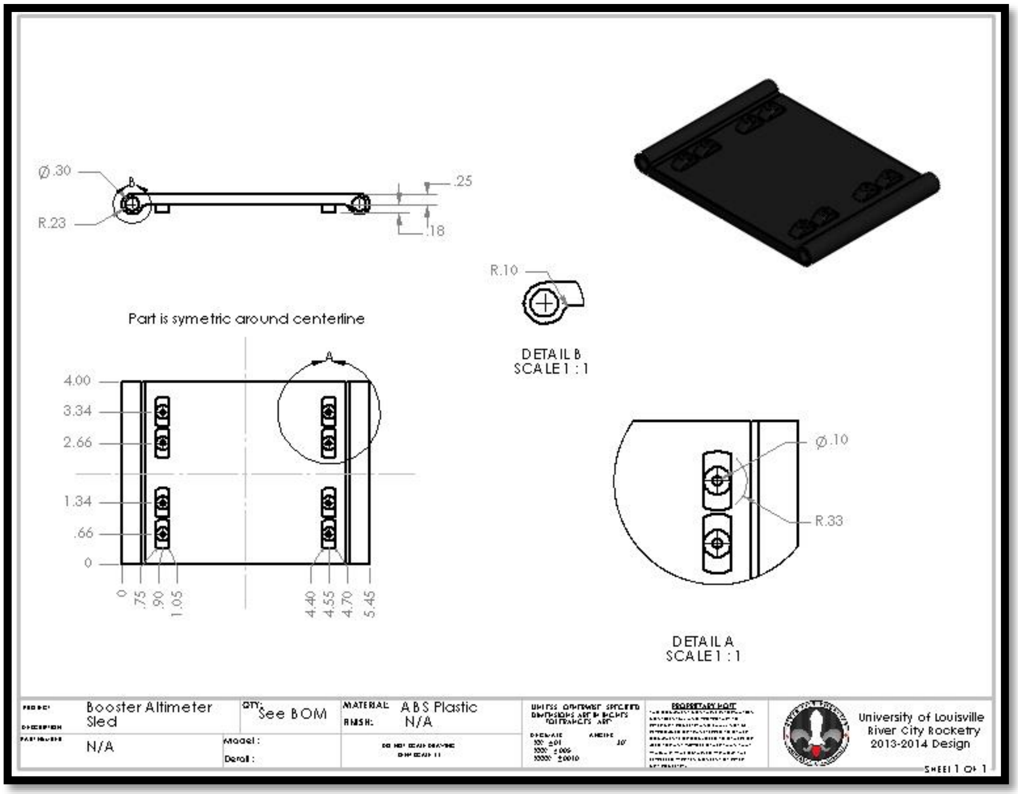


Figure 34: Booster altimeter sled.

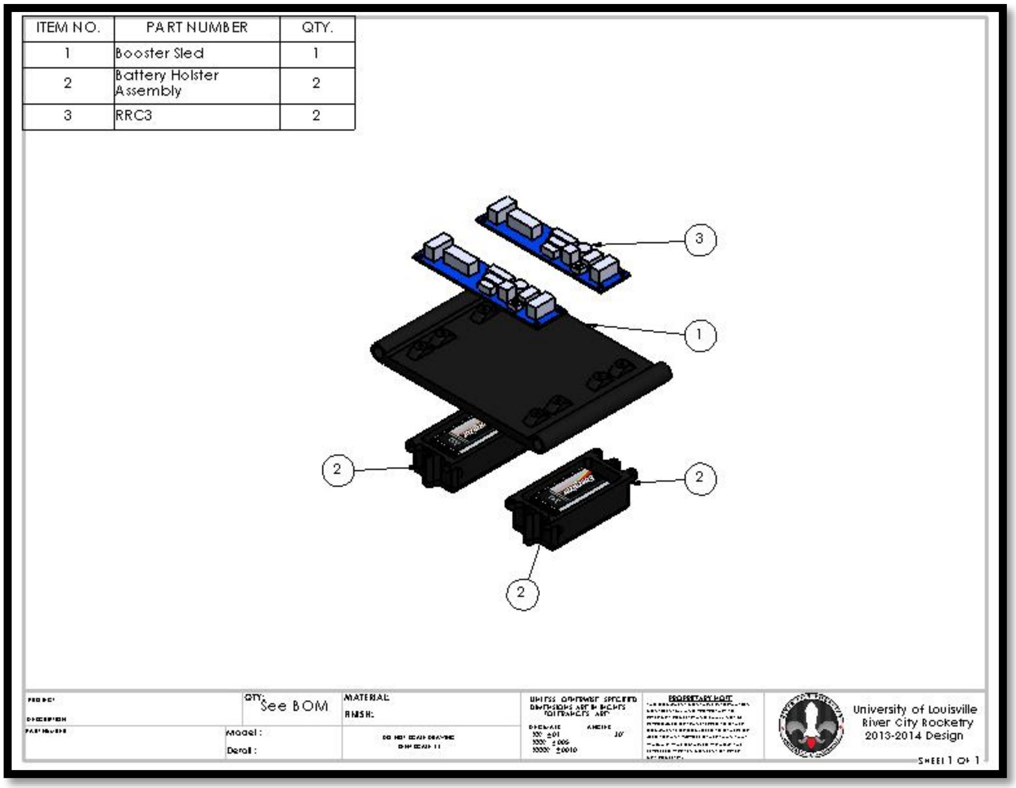


Figure 35: Booster altimeter sled BOM.

The sled will be held in place between two sets of bulkplates via two ¼ inch aluminum threaded rods. The rods had to be placed far enough apart (4.5 inches) to avoid contact with the sustainer motor retainer. To not waste the space between the threaded rods the altimeters will be mounted perpendicular to the vehicles direction of travel, this will not pose a problem as the RRC3 is a barometric altimeter with no orientation dependence.

Lower Sustainer Avionics Bay

Figure 36: Sleds of the lower sustainer avionics bay.

The lower sustainer avionics bay consists of two separate 3D printed ABS sleds, one holds the tiltometer and Raven altimeters, and the other is a mount for a GoPro camera. Both the tiltometer and Raven's will screw in directly to the sled using tapped holes for nylon 4-40 screws. This sled will have to hold two Raven altimeters plus power perches, one Arduino which will function as the tiltometer, and one 9-volt batteries.

The two Raven's will be opposite of the tiltometer and will be activated through the power perch magnetic switch. Last year's team utilized the magnetic switch through the air-frame successfully and during sub-scale testing the magnetic switch was activated through the airframe and thus will not be an issue.

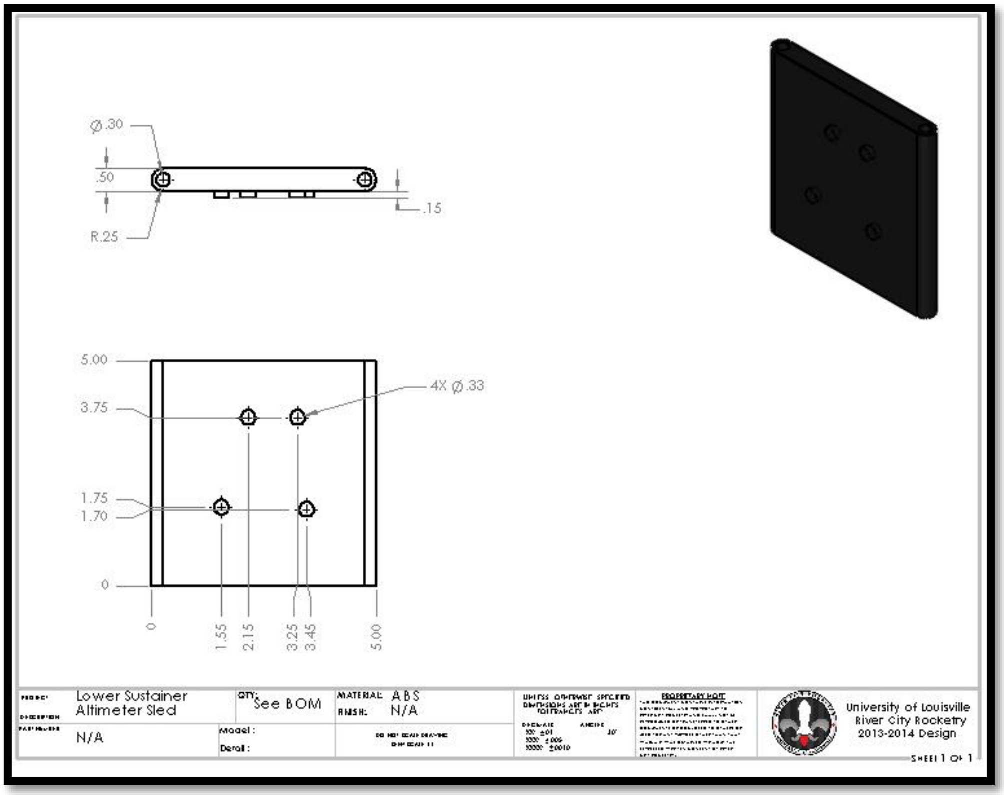


Figure 37: Tiltometer sled.

The GoPro camera mount is beneath a wooden bulkplate that rests underneath of the altimeter sled, the bulkhead will be covered in aluminum tape to shield the altimeters from the GPS unit stationed within the lower sustainer. The GoPro mount consist of one solid piece of 3D printed ABS plastic in which with three additional 3D printed parts that hold the camera into place will be screwed into.

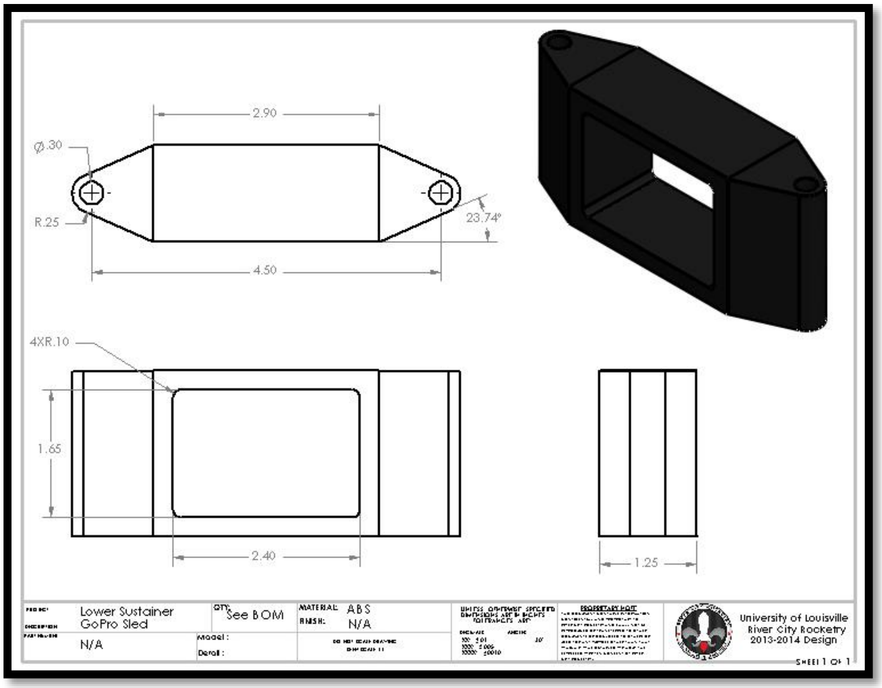


Figure 38: GoPro sled.

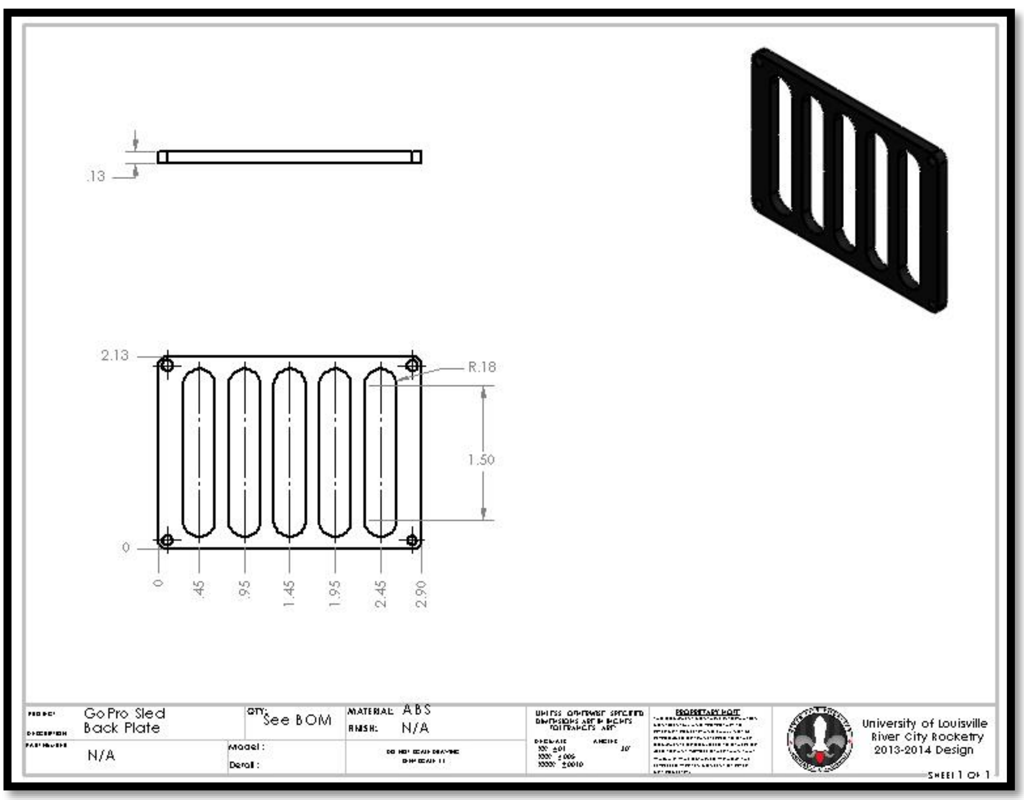


Figure 39: GoPro backplate.

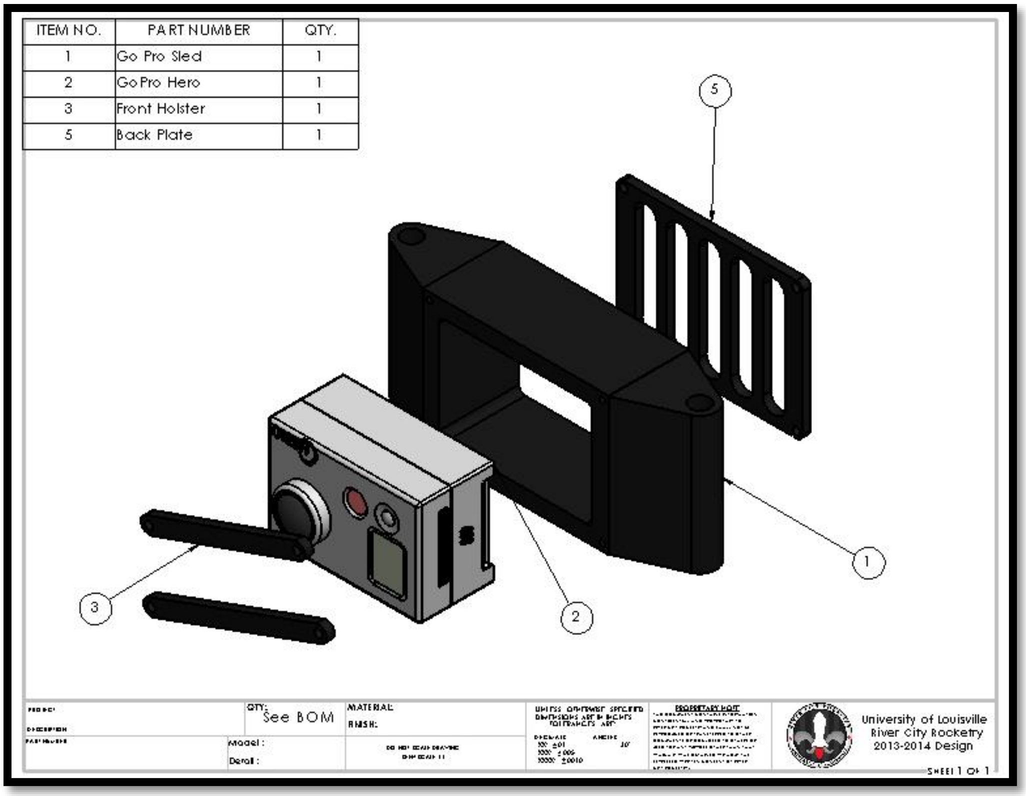


Figure 40: GoPro BOM.

Figure 41: GoPro sled.

Nose Cone Avionics Bay

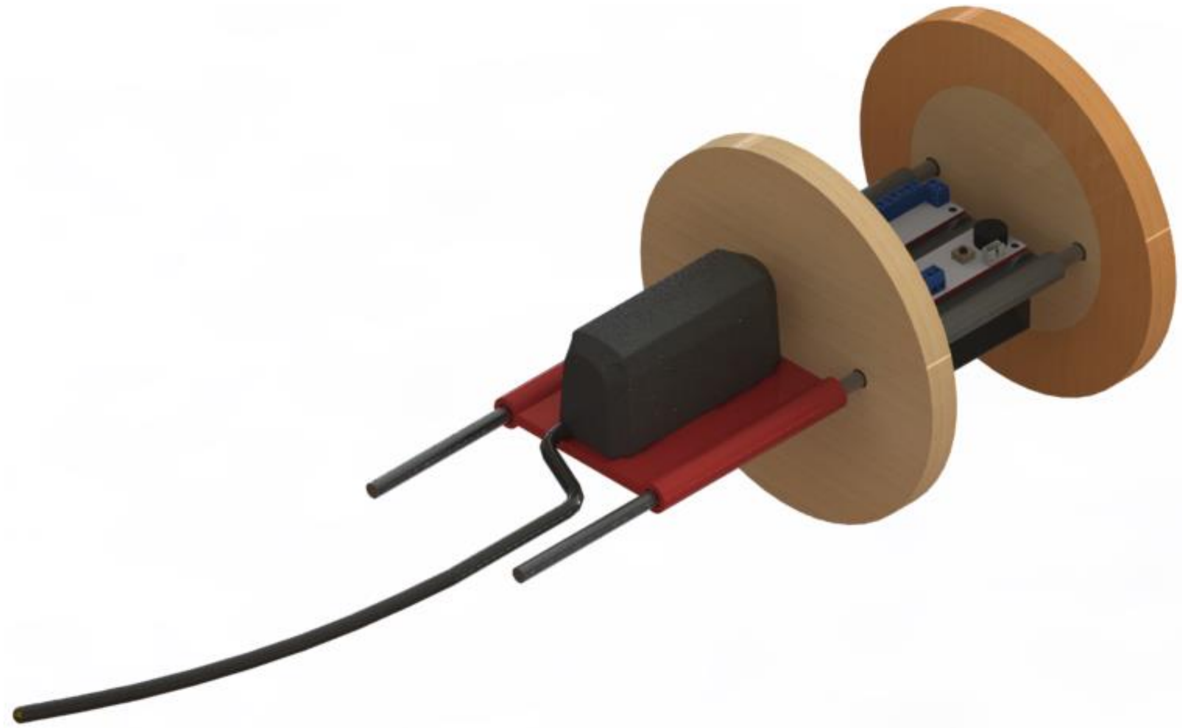


Figure 42: Rendering of nose cone avionics bay.

The nose cone avionics bay consists of two sleds that will both reside in the nose cone. The forward most sled houses a Garmin Astro DC 40 GPS dog collar which will be used to track the vehicle section. This sled will be held in place via aluminum threaded rods similar to all other avionics bays. Beneath the GPS sled will be a wooden bulkplate which will be covered with aluminum tape to shield the altimeters from the GPS signal.

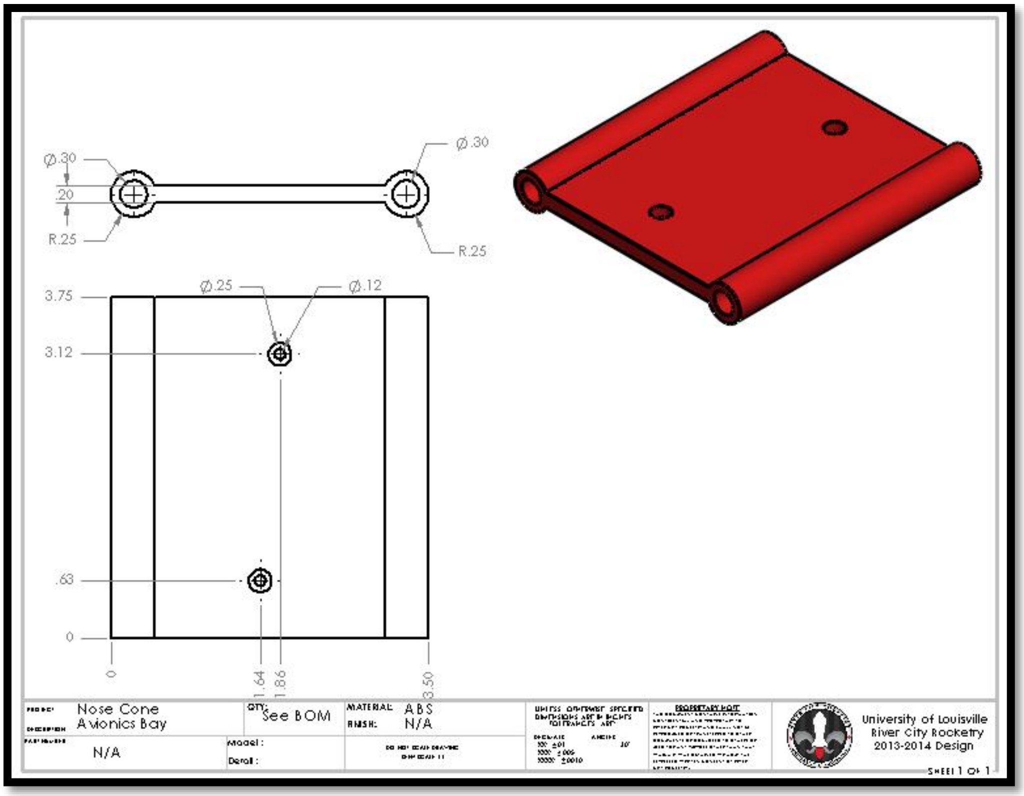


Figure 43: Nose Cone GPS sled.

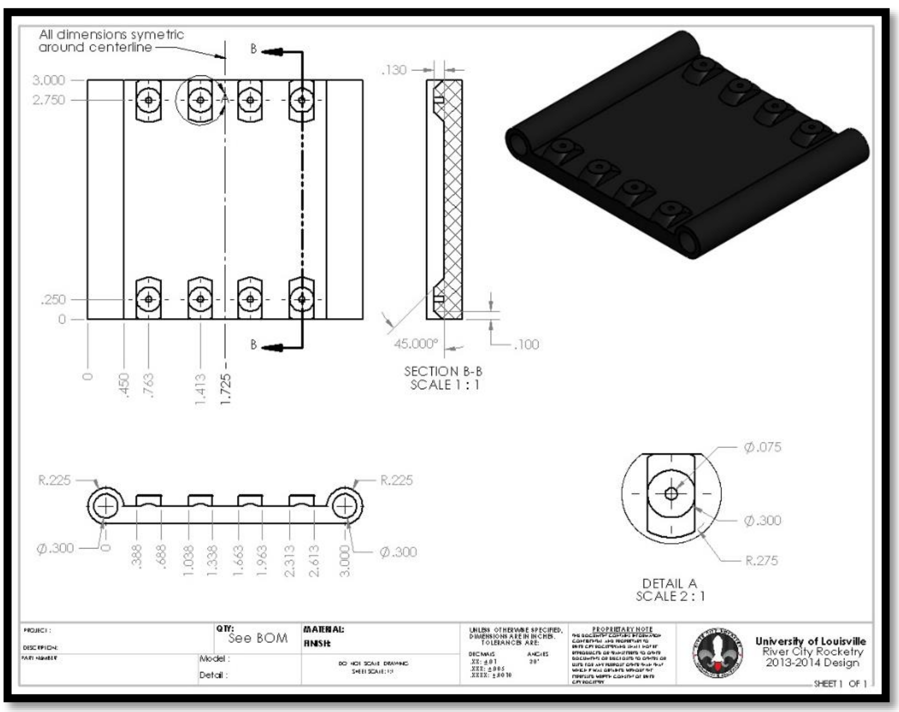


Figure 44: Nose cone Stratologger sled.

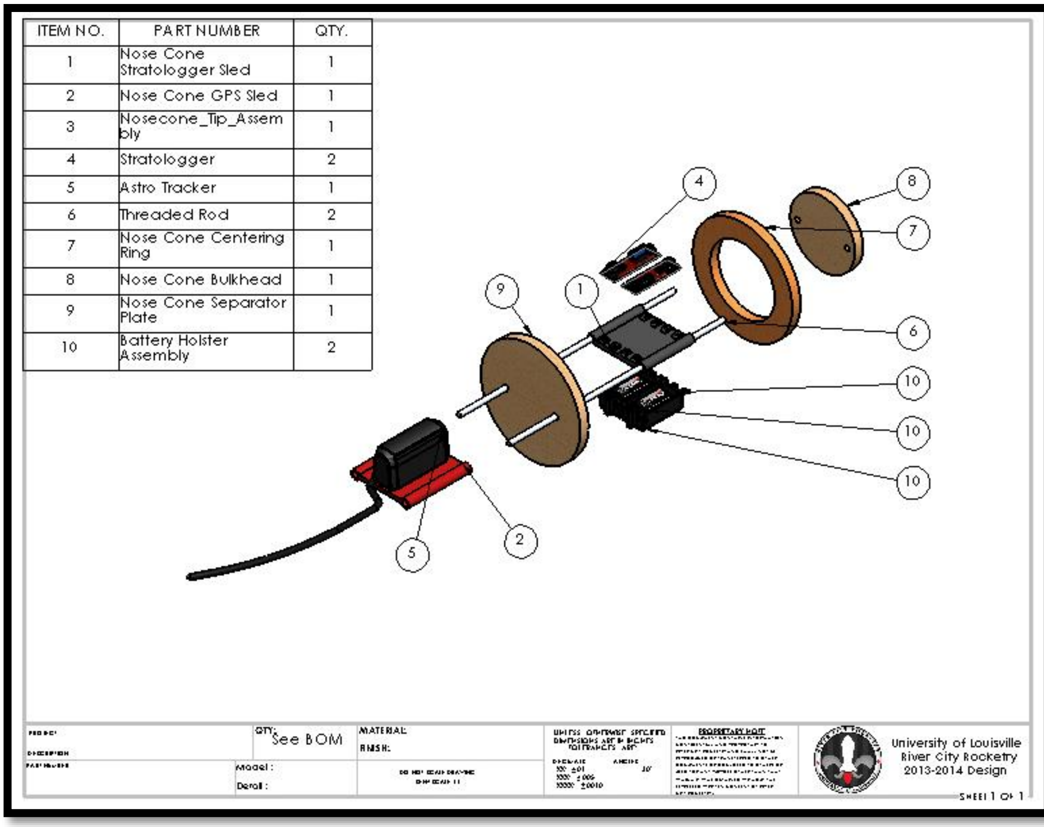


Figure 45: Nose cone altimeter and GPS BOM.

<u>Electronic Schematics</u>

As with the structural portion of the avionics bays each section will have their own wiring schematic. All schematics are shown in the following figures.

Booster Recovery Wiring Schematic

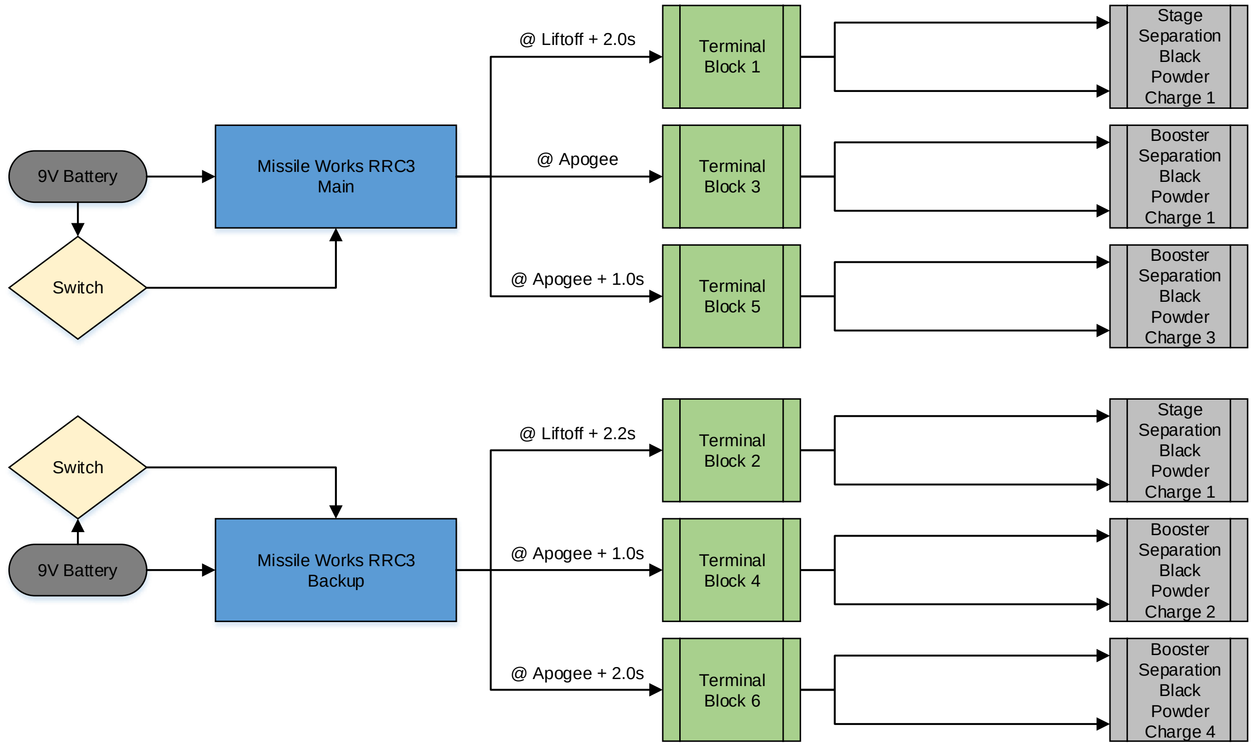


Figure 46: Booster Recovery Schematic and Logic.

Nose Cone Recovery Schematic

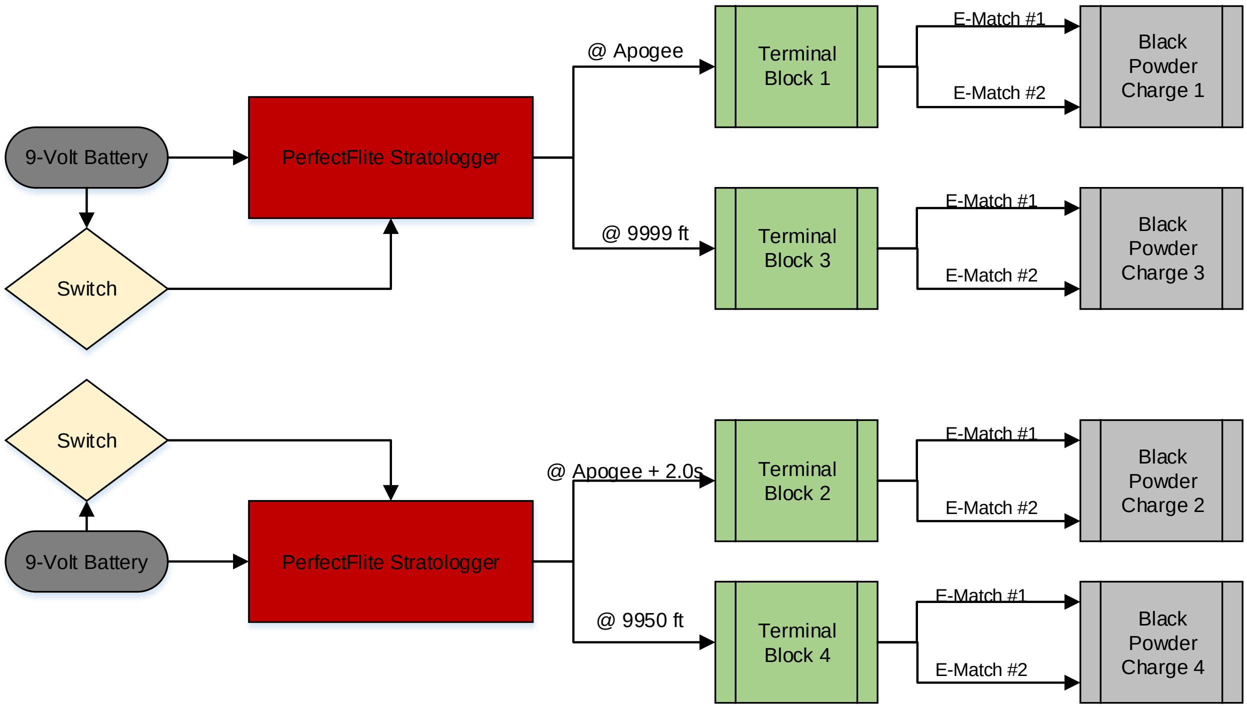


Figure 47: Nose Cone Recovery Schematic and Logic.

Lower Sustainer Recovery Wiring Schematic.

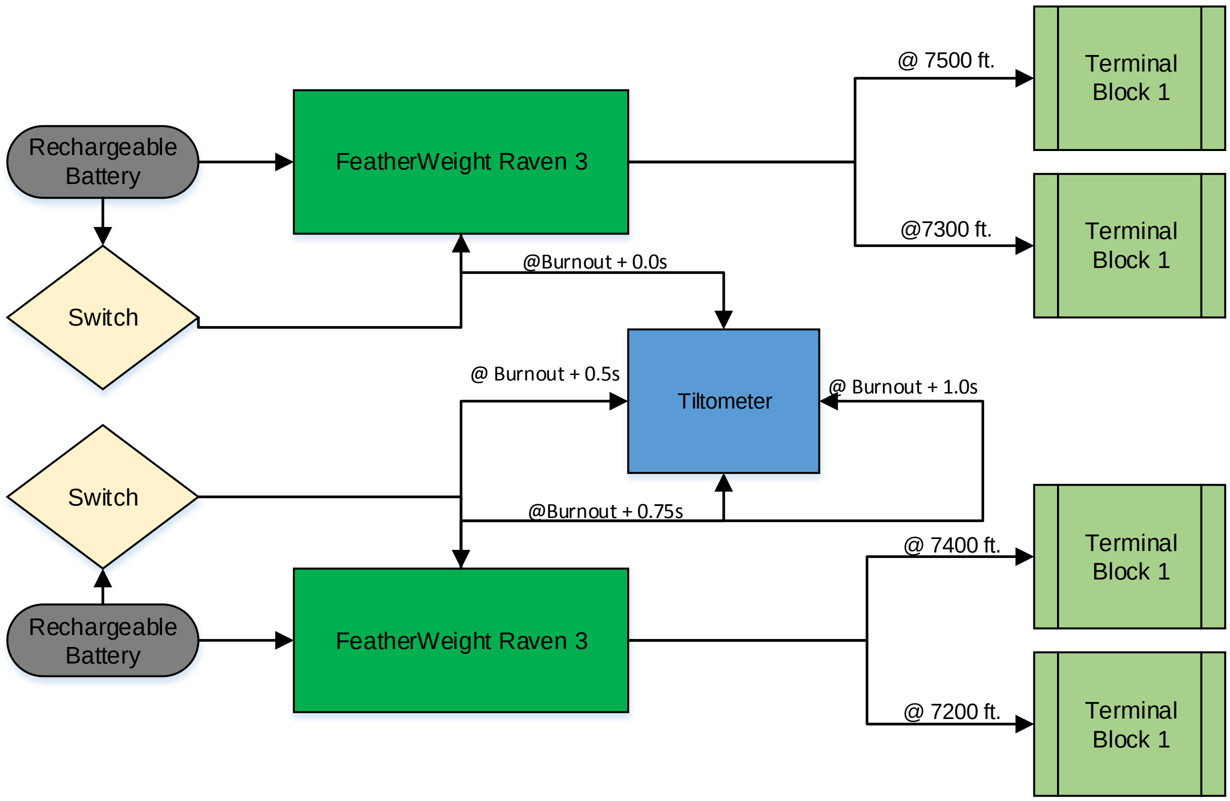


Figure 48: Booster Wiring Schematic and Logic.

Hazard Detection Payload

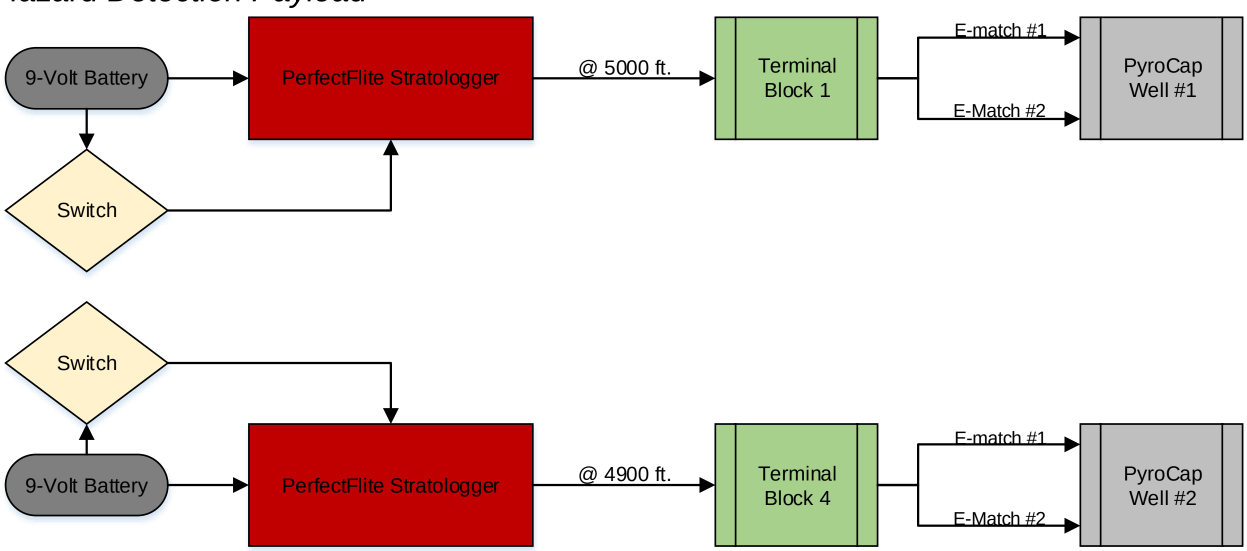


Figure 49: Hazard Detection Wiring Schematic and Logic.

Rocket Locating Transmitters

To meet the requirements set forth by the statement of work each non-tethered section of the vehicle needs to have the ability to be remotely tracked/located. To accomplish this task it was decided to utilize GPS technology, this was decided upon due to a lower chance of interference from opposing teams tracking equipment and that it was used during testing the previous year. The frequency, range, and wattage of the Garmin Astro DC 40 are shown in Table 12.

Transmitter	Range	Wattage	Frequency
Garmin Astro DC 40	7 miles	2 Watts	151.820 MHz

Table 12: Garmin Astro DC 40 Transmission Information

The GPS/GPRS cape uses a cell phone module and thus the power transmission is controlled remotely by the closest cellular base station. The station dynamically assigns a power level with the intent to maintain good signal-to-noise ratio while limiting interference, overloading, and power consumption. The Telit GE-864 GPRS module is rated for different classes which control the power levels it can be assigned by the base stations. The GPS module is also assigned an operating range called a level but this is not controlled by the base stations. The information for each of the modules onboard are shown in Table 13.

Module	Class/Level	Power (W)	Frequency (MHz)
GPRS	1	1	1800/1900
	4	2	850/900
GPS	L1	-	1572.42

Table 13: GPS/GPRS Cape Transmission Information

To prevent these modules from interfering with the on-board electronics a bulkhead will be covered with aluminum tape immediately above and below the GPS transmitter. In addition to the aluminum tape near the GPS the bulkheads immediately surrounding the altimeter bays will be covered in aluminum tape.

Deployment and Harness Assemblies

Booster Separation

The separation of the booster takes place after motor burnout via timer. The RRC3 altimeter is basing a timer after launch detect. At 2.0 seconds a black powder charge is ignited to separate the booster from the sustainer.

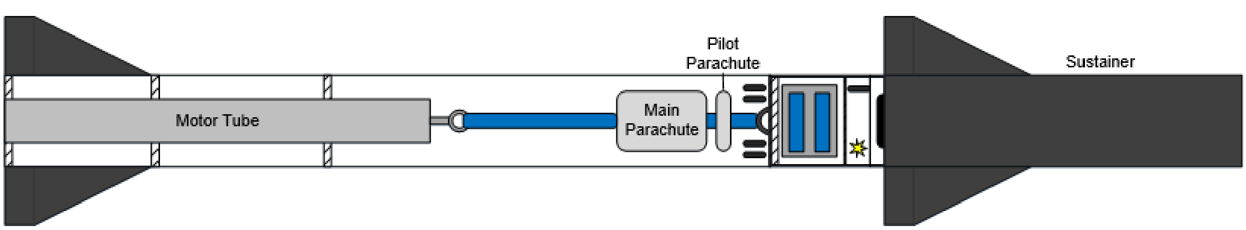


Figure 50: Booster and Sustainer Separation.

Booster Deployment

The booster harness is shown in Figure 51. It consists of two sections of shock cord, one pilot parachute, one 3/8th inch black oxide U-Bolt, and one 3/8th inch forged eye-bolt.

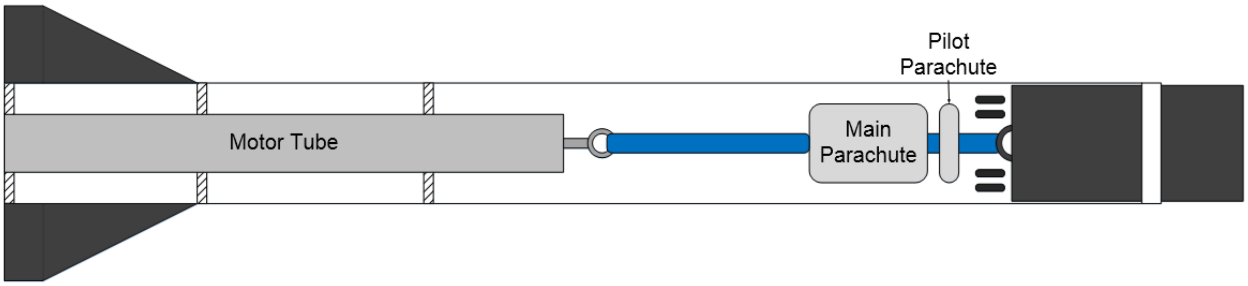


Figure 51: Booster Recovery Harness

At apogee the black powder charges are ignited and push the avionics bay out of the booster, this opens the pilot parachute to air.

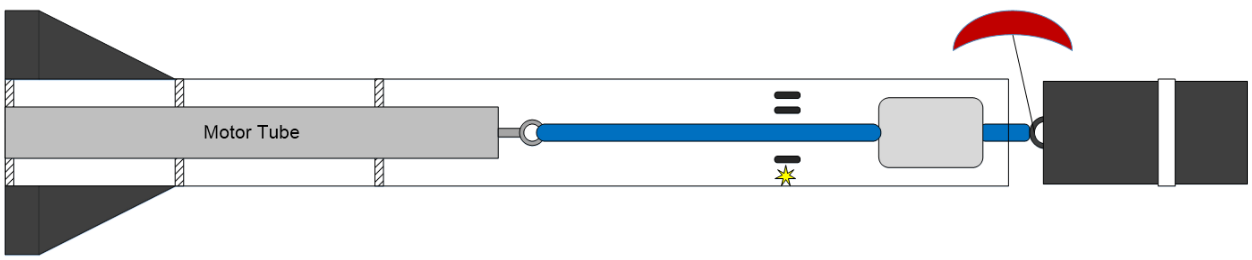


Figure 52: Booster Pilot being open to air.

The pilot parachute is attached to the avionics bay. The main parachute is attached to the avionics bay via 30 feet of shock cord and to the booster motor mount via 6 feet of shock cord. The deployment bag is being pulled from the pilot and the weight of the booster assembly. To maintain control of the bag after the main is fully inflated the bag is tied to the avionics bay.

Nose Cone Ejection

Due to the nose cone also ejecting with airframe attached vs. the more common just nose cone ejection. The pilot parachute is attached to the top of the deployment bag, the top of the deployment bag is attached to the fairing so as not to fly away after the main inflates. Figure 53 shows the harness of the nose cone assembly. It consists of two square u-bolts which are attached to the base of the main parachute, shock cord, and one u-bolt which is permanently mounted to the nose cone avionics bay.

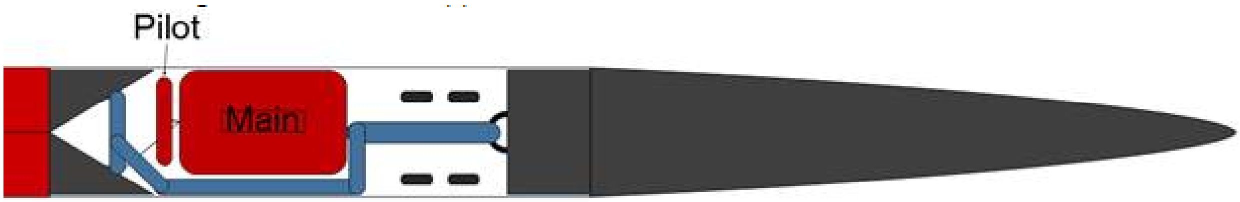


Figure 53: Nose Cone Harness.

At apogee the altimeters fire a black powder charge to separate the body sections and expose the pilot to atmosphere. Once exposed to air the pilot will pull the main parachute out and allow it to inflate as it will be pulled on both ends. One by the pilot and one by the weight of the rocket. The deployment bag is attached to the fairing so that after the main inflates the bag is retained. In addition to the pilot being able to pull the main parachute, the backup deployment charges can push the parachute out of the vehicle.

Figure 54: Nose Cone opening to air.

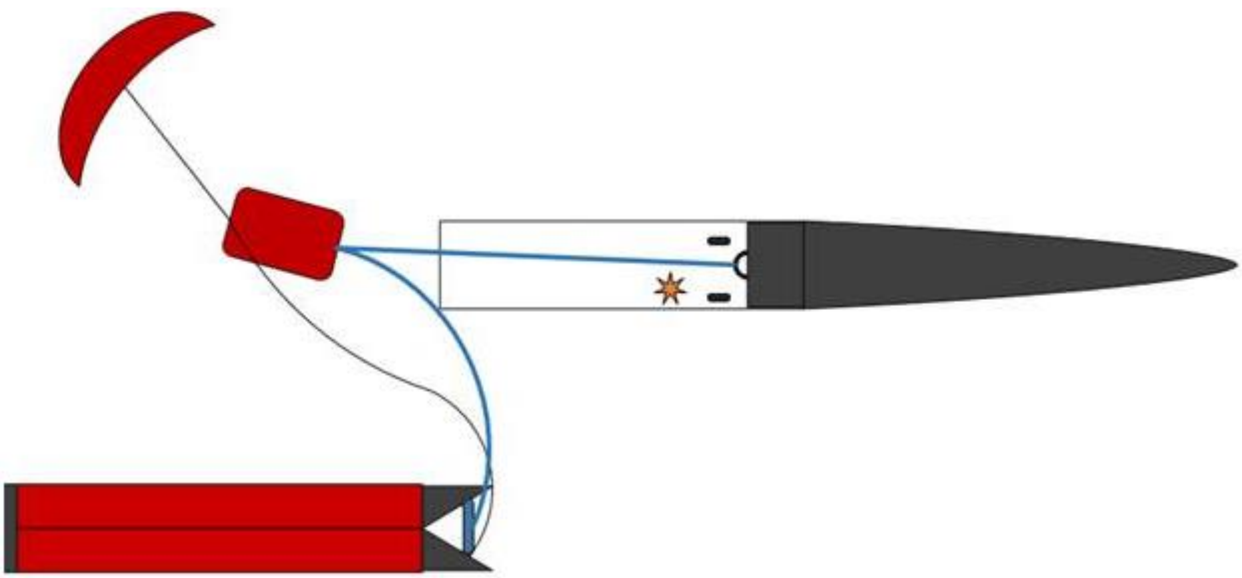


Figure 55: Pilot pulling the main parachute out of the vehicle.

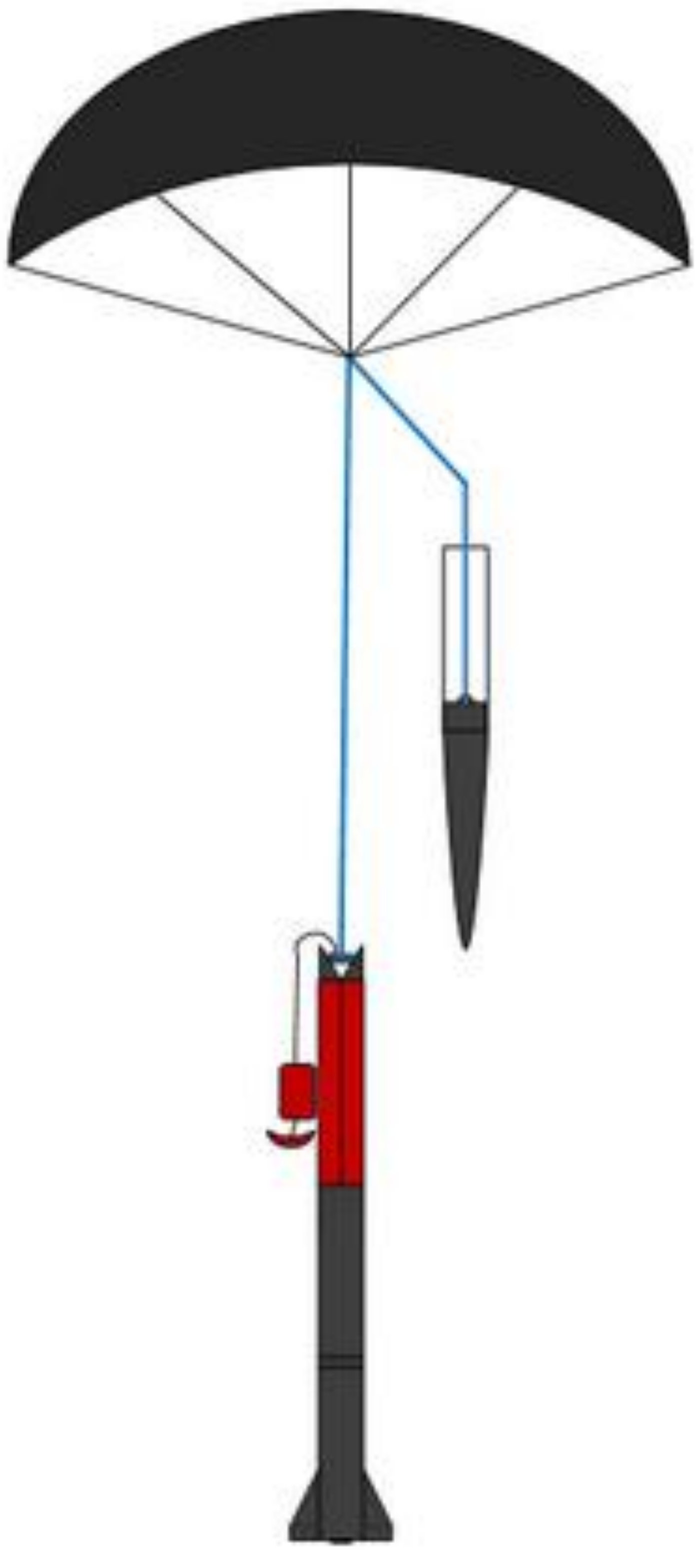


Figure 56: Sustainer under Apogee Parachute.

Lower Sustainer Ejection

The lower sustainer under parachute at the time of its deployment. The top of the parachute deployment bag is attached to the bottom of the fairing, this is to pull the parachute out of the deployment bag.

At 7500 feet the Featherweight Raven's deploy their ejection charges and separate the fairing from the lower sustainer. The deployment bag is attached to the base of the fairing so to keep it attached after main inflation. The weight of the lower sustainer then pulls the main out of the deployment bag.

Fairing Actuation

Fairing actuation is described in section blah blah blah.

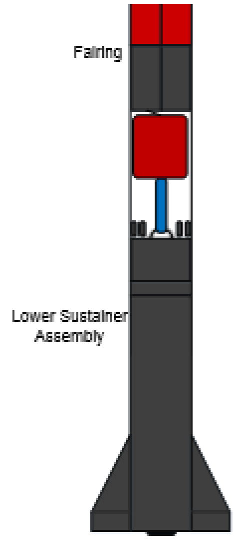


Figure 57: Lower Sustainer Assembly.

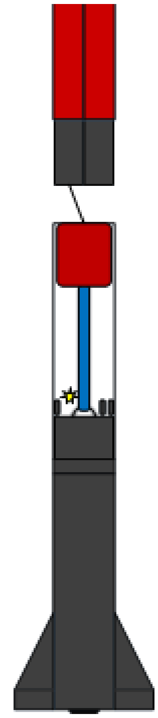


Figure 58: Lower Sustainer Ejection

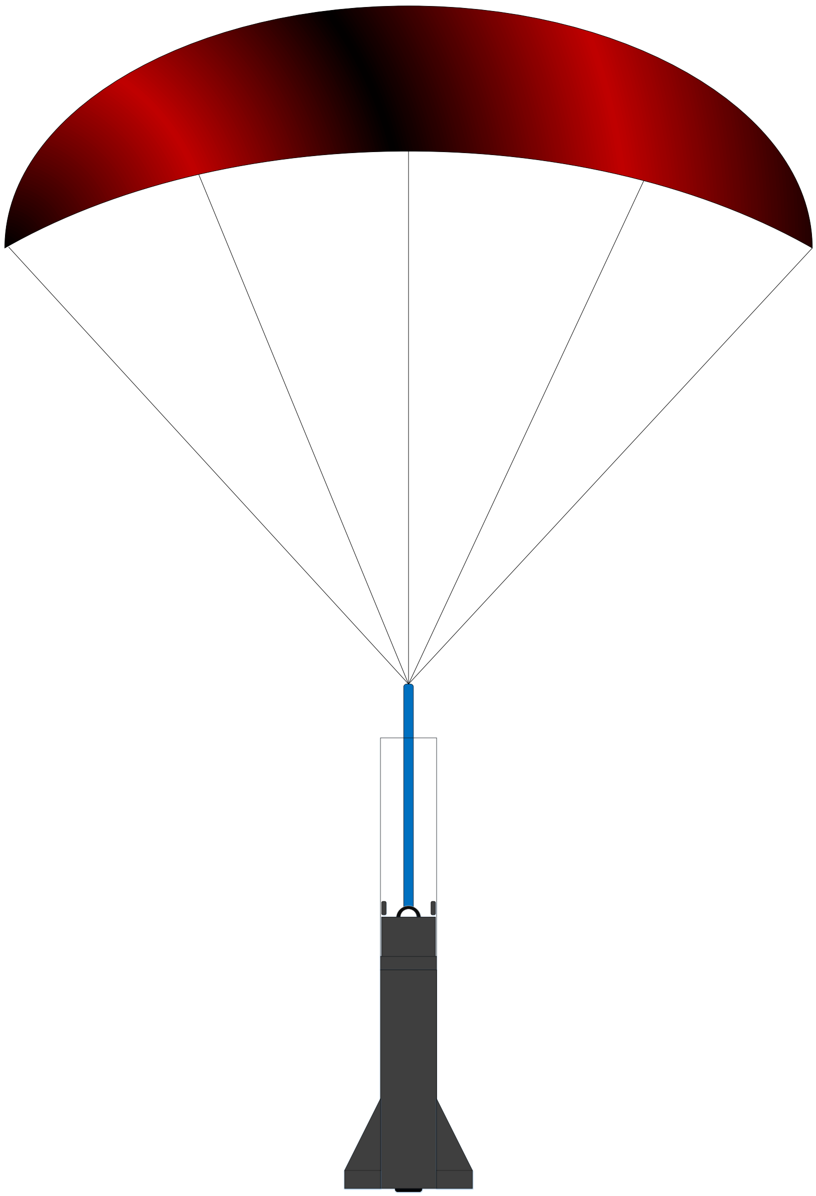


Figure 59: Lower Sustainer under Parachute.

Parachute Construction

The canopy will be made of MIL-C-44378 0.75 oz. rip stop nylon; the reason this material was chosen is because the team had success using it last season. The suspension lines will be made of 1/8th inch nylon para-cord with 400 lb tensile strength. The harness that connects the suspension lines to the launch vehicle will be made of 9/16th inch tubular nylon with a tensile strength of 500 lbs, there will be one harness per parachute. There will be ten suspension lines per parachute as each parachute has ten gores.

To account for the loss of fabric during hemming and sewing the panels together the cut dimensions must be greater than the characteristic dimensions listed previously. Figure

60 shows the hem layout. The shown dimension H will be ½ inches, so a total of two inches will be added to the total height of each gore.

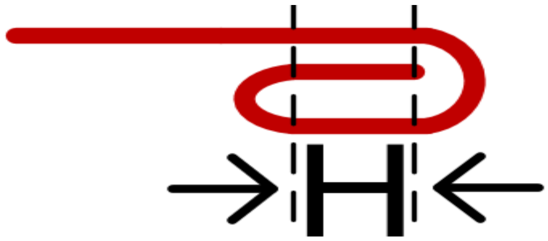


Figure 60: Hem layout.

The individual gores will be sewn together in a French felled seam, also known as a double lap seam, as shown in Figure 61. The shown dimension “S” will be ½ inch so a total of 1.5 inches will be added to both C_s and C_v for each gore.

Figure 61: Added fabric due to stitching

Seam Construction

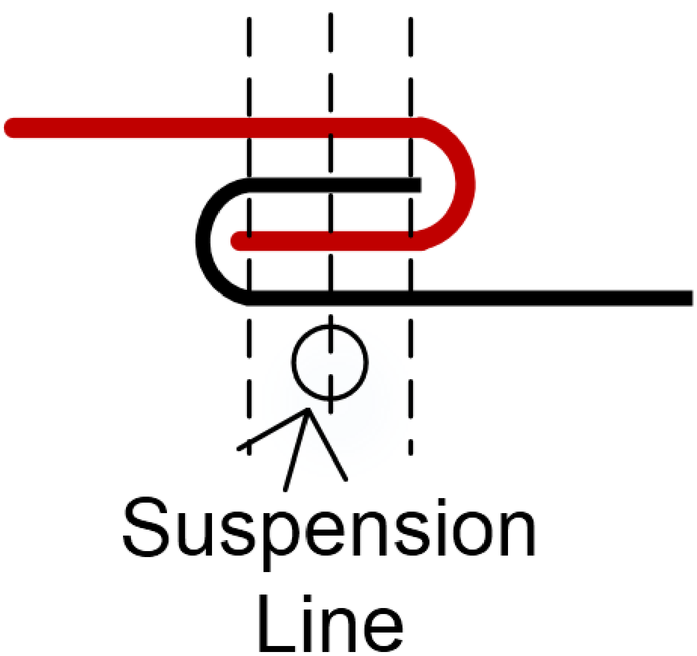


Figure 62: Seam that will connect each gore panel together.

As stated previously the seam that will hold the parachute together will be the French felled seam, it will consist of two straight stitches running along the outer edge of the seam as shown by the two outermost dashed lines in Figure 62. A third stitch will run along the center of the seam that will connect suspension line sleeving to the edges of the parachute and will form permanent attachment points for the suspension lines.

After each gore has been hemmed along the edges that do not connect to another panel a flat panel will be laid out. At the outer edge of the panel a layer of ½ inch double sided seam basting tape will be applied, this is to ensure that the panels are perfectly aligned when sewing.

Figure 63: Applying seam tape to gore panel.

Then the other panel will be aligned next to the edge of the seam tape, once the alignment is finished the original panel will be folded over the added panel to hold them in place. The second panel will be then folded over to complete the seam.

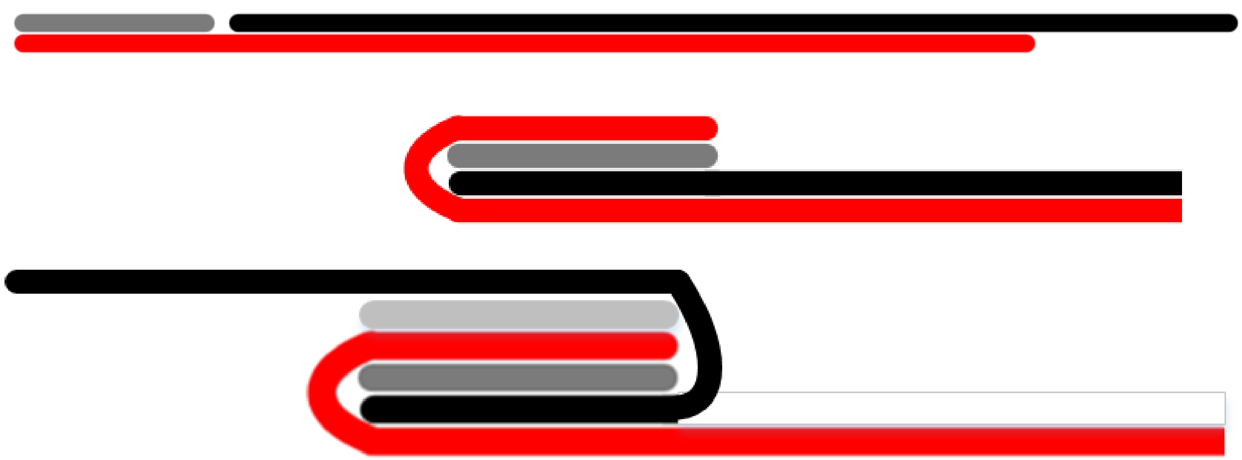


Figure 64: Seam Construction.

The following figures show representatives samples of the completed parachutes.

Figure 65: Testing Parachute Opening with Wind Power.

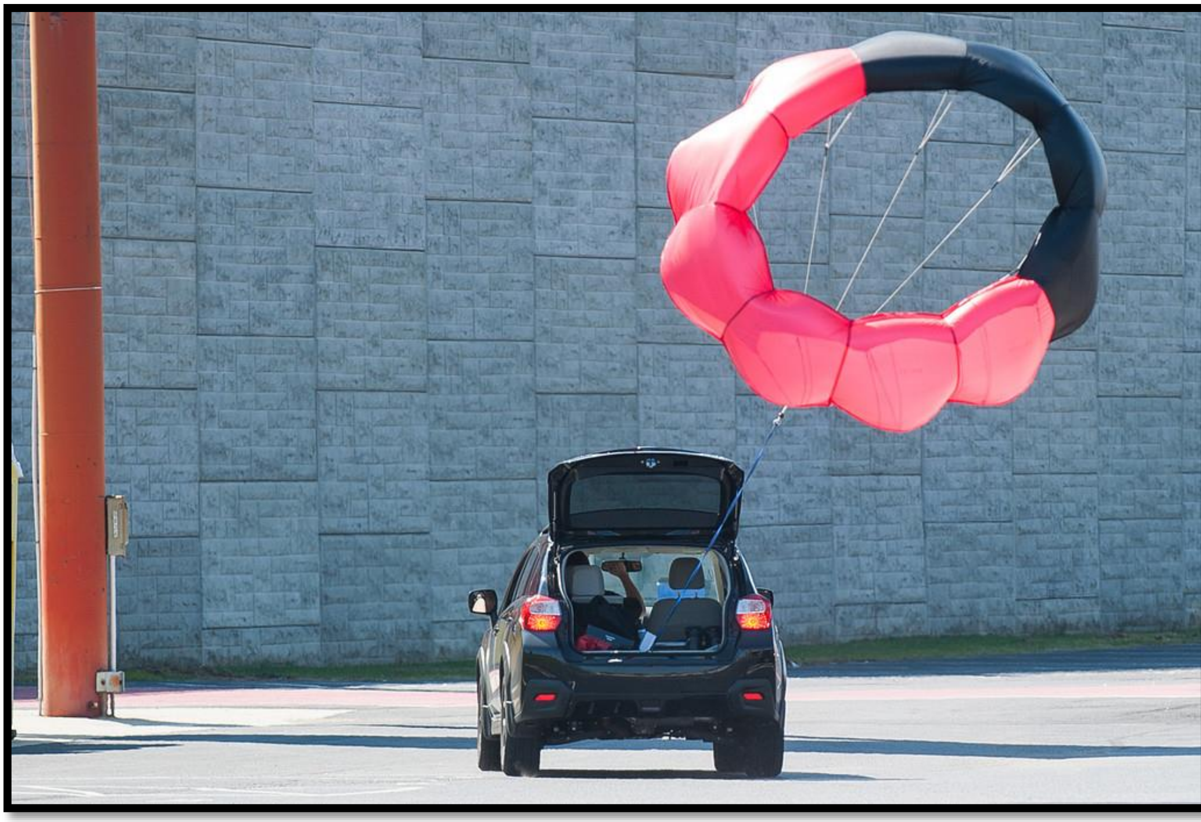


Figure 66: Testing Parachute Opening via Tow Vehicle.

Parachute Folding

Folding the parachute consists of the following steps, images are after for clarity.

1. Lay the canopy out flat with suspension lines taunt
2. Fold each gore in half to where each suspension line is at the same point.

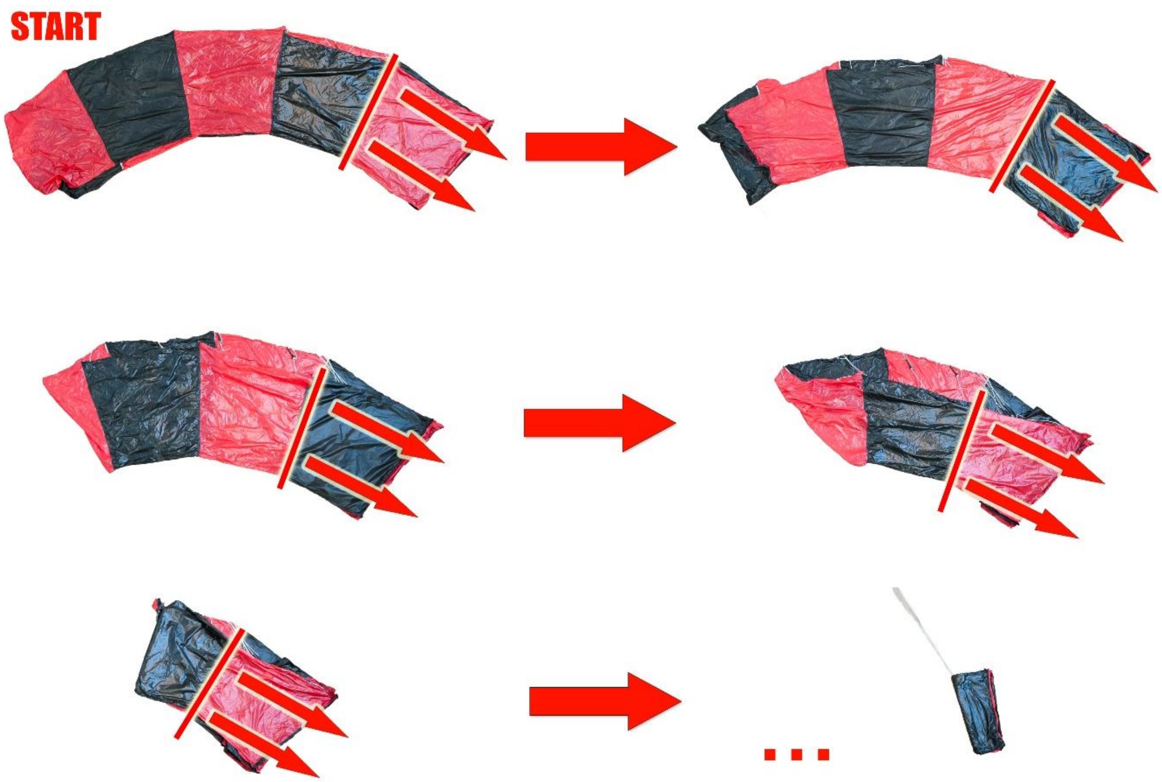


Figure 67: Parachute Folding Part 1

3. Fold the folded gores 90 degrees into the suspension lines
4. Fold into quarters with the suspension lines being folded into the middle first
5. Fold other end to the suspension lines
6. Fold in half
7. Roll towards suspension lines
8. Place in deployment bag with suspension lines at the bottom

Figure 68: Parachute Folding Continued.

Ground Testing

Ground testing consisted of black powder ejection testing, pull force to determine how much force was required to open deployment bags, and opening tests using vehicles.

BP Testing

All ejection events were tested using four grams of BP. Since the tests were performed the vehicle crashed and thus more testing is to be completed and documented in the addendum.

Figure 69: Nose Cone BP Ejection Test.

<u>Deployment Bag Opening Tests</u>

To test the amount of force required to open the deployment bag a fishing scale was used. The scale was hooked to the top of the deployment bag while the suspension lines were pulled. Figures

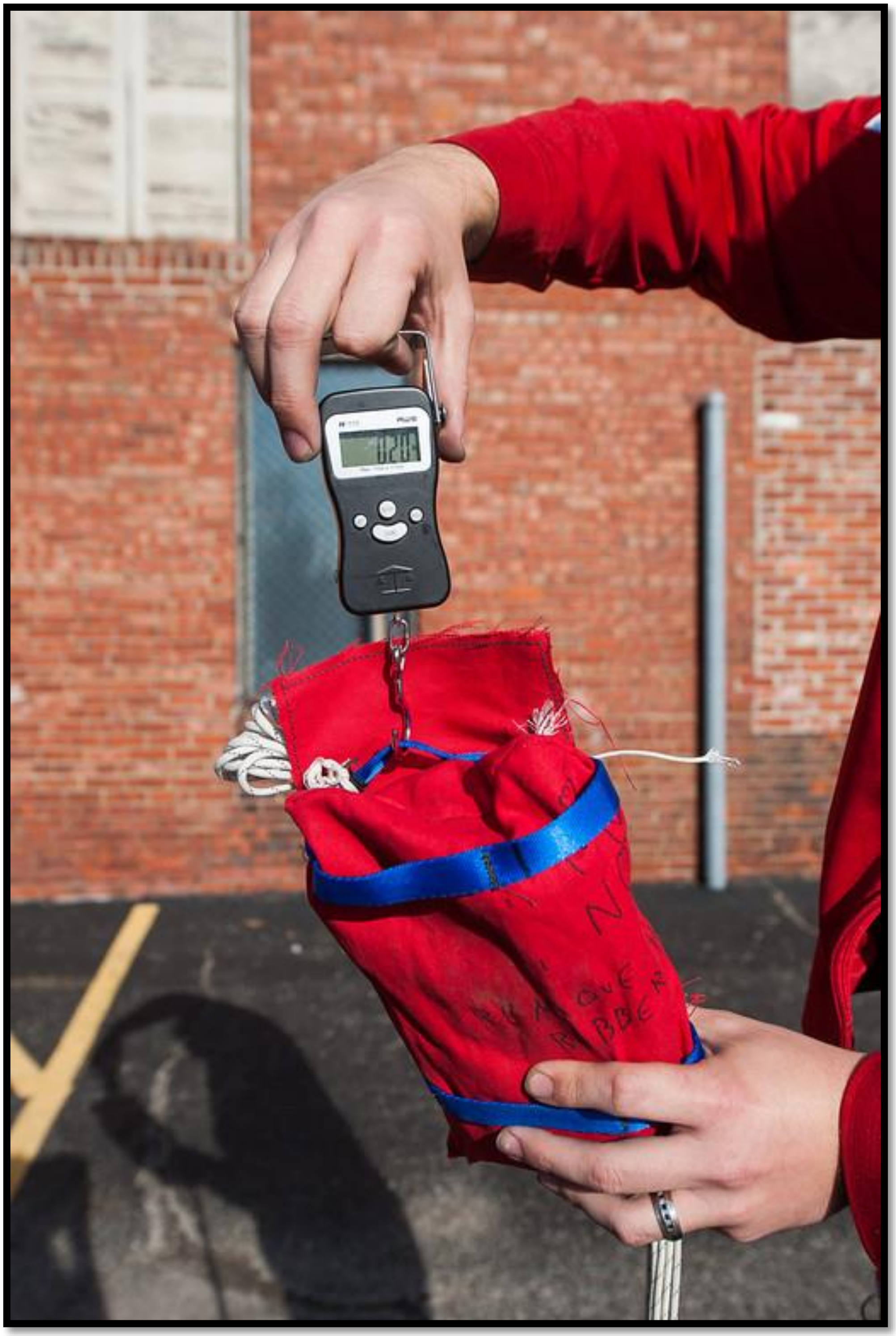


Figure 70: Deployment Bag Test Setup.

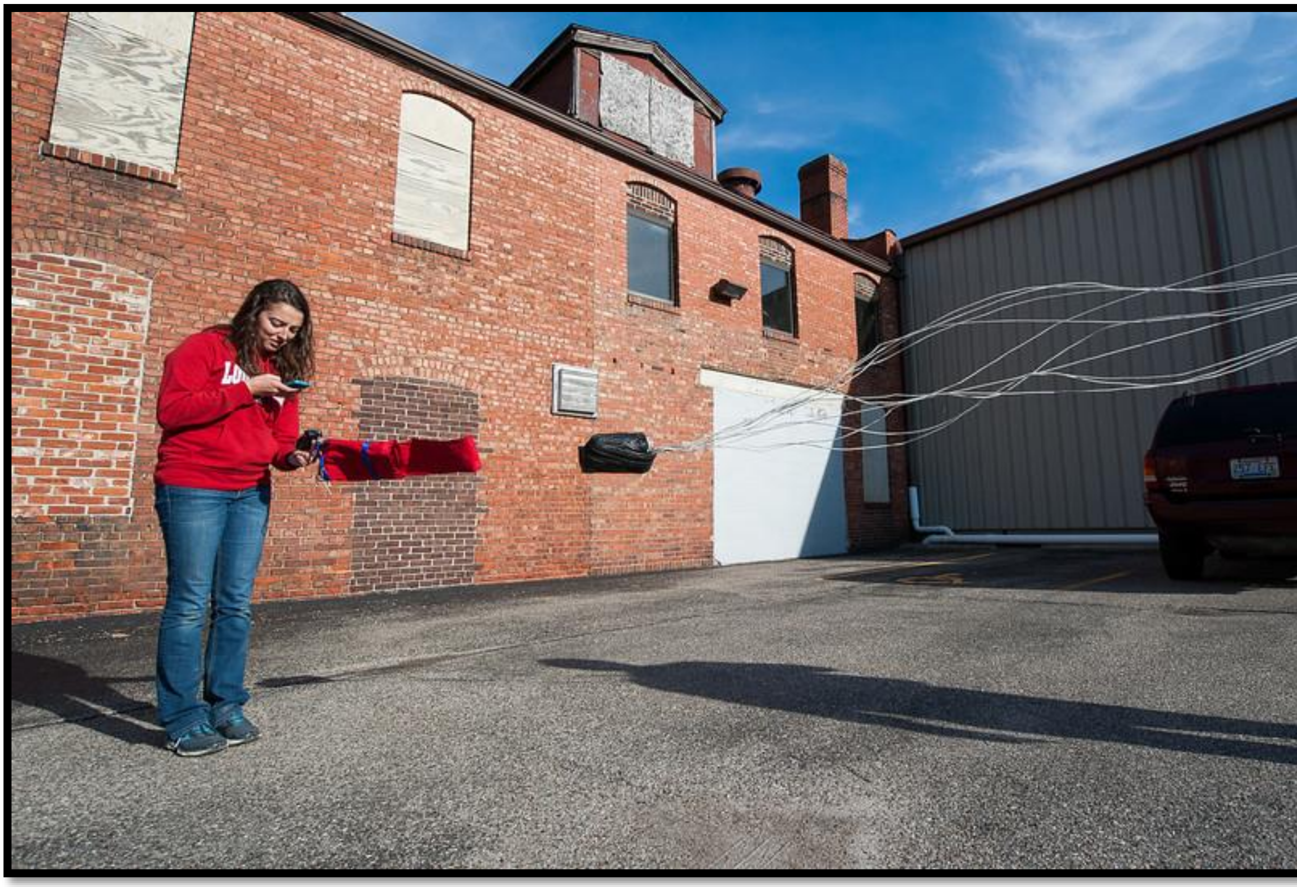


Figure 71: Parachute coming out of Deployment Bag.

The results of the tests are shown in Table 14

Deployment Bag	Opening Force
Booster	1.23
Sustainer	1.78
Nose Cone	1.4
Rover	1.24

Table 14: Deployment Bag Opening Force.

MISSION PERFORMANCE PREDICTIONS

Mission Performance Criteria

The following criteria must be satisfied for the mission to be considered a success.

1. The vehicle and hazard detection payload must be reusable.
2. The apogee altitude be at 10,000 feet or less.
3. A horizontal drift must be less than 1.5 miles if the alternate launch site is to be used.
4. The vehicle must have a stability margin greater than 1.75 while the booster is active and a stability margin greater than 1.10 for the sustainer.
5. Velocity at rail exit (assuming 10 foot rail), is not below 60 ft/s.

Vehicle Characteristics

A combination of OpenRocket, solid modeling, and weighing of component parts allows us to create a simulation of the full scale shown in .Figure 72.

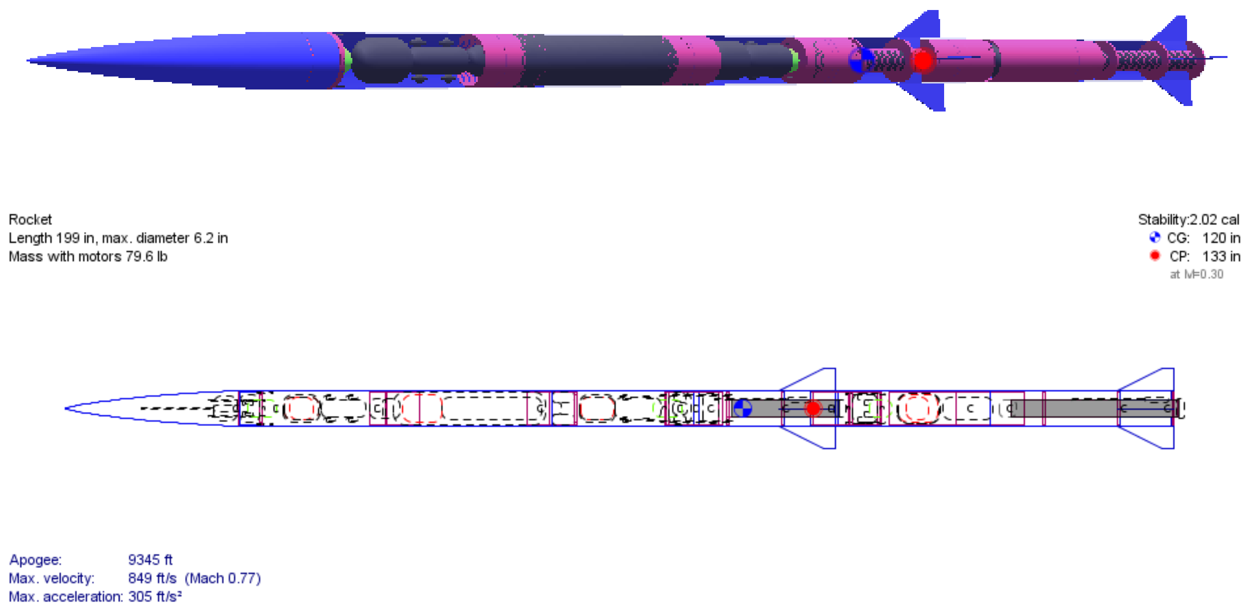


Figure 72: OpenRocket simulation

Overall Length (inches)	199
Overall Mass (lbs)	79.6
Stability Margin Both Stages	2.02
Stability Margin Single Stage	1.11

Figure 73: Vehicle dimensions.

Component	CG / in	Mass / lb	CP / in	$C_{N\alpha}$
Nose cone	21.119	2.97	15.501	2
Upper Sustainer	44	3.33	44	0
Fairing	71.75	3.78	71.75	0
Recovery Tube	99	3.2	99	0
Witness Ring	112	0.128	112	0
Lower Sustainer	125	3.11	125	0
Trapezoidal fin set	133	1.03	132	4.08
Witness ring	137	0.024	137	0
Body tube	151	3.46	151	0
Body tube	180	4.16	180	0
Trapezoidal fin set	193	1.27	192	4.08
Total	**120**	**79.6**	**133**	**10.2**

Figure 74: Critical mass components with their related CG and CP.

Motor Thrust Curves

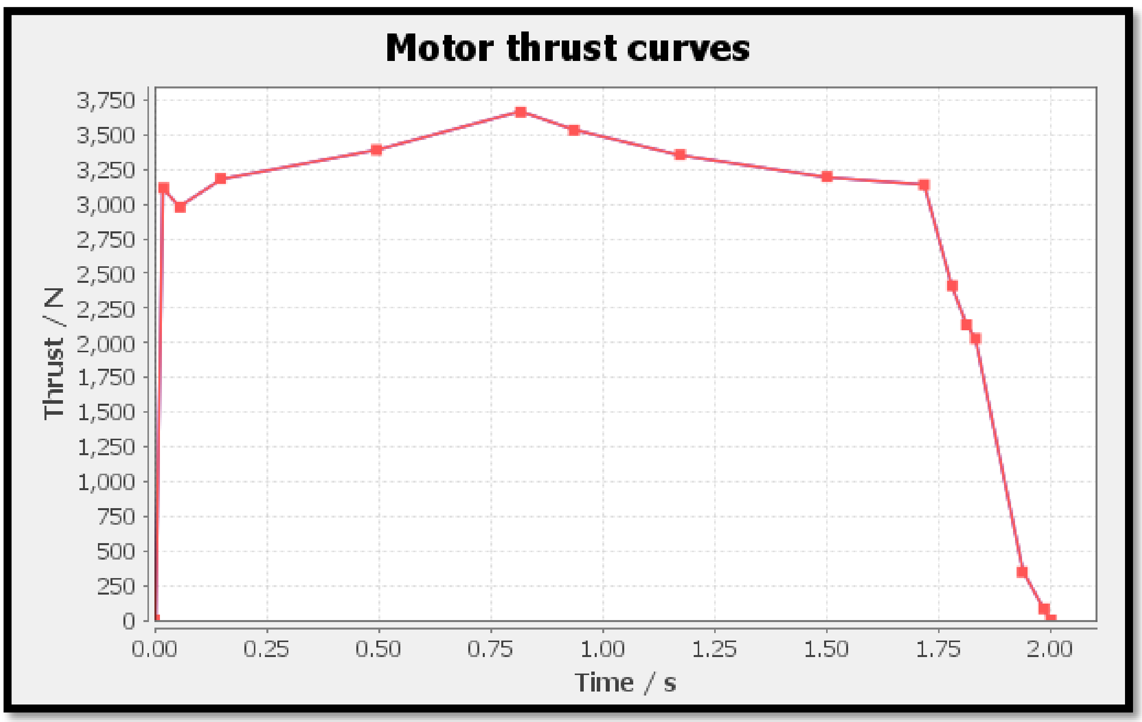


Figure 75: Thrust curve of the M3100 motor to be used in the booster.

Other justification for motor selection:

- Thrust-to-Weight Ratio: 8.8
- Rail Exit Velocity: 74 ft/s
- Projected Altitude: 9,800 ft.
- Max Acceleration: 308 ft/s^2
- Burn Time: 1.97 seconds
- Max Thrust: 3666 N
- Average Thrust: 3118 N

- Total Impulse: 6131 Ns

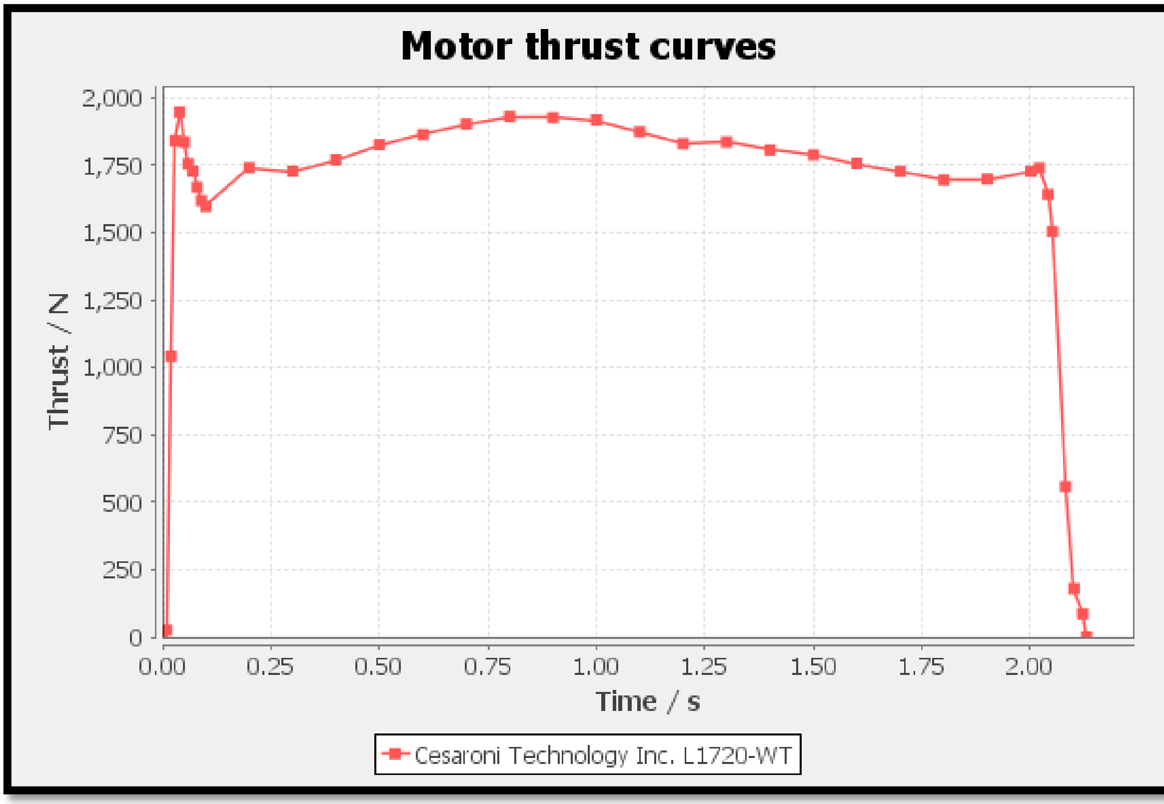


Figure 76: L1720 Thrust Curve

Other justification for motor selection:

- Thrust-to-Weight Ratio: 8.3
- Max Acceleration: 210 ft/s^2
- Burn Time: 2.11 seconds
- Max Thrust: 1947 N
- Average Thrust: 1754 N
- Total Impulse: 3696 Ns

Altitude vs. Distance

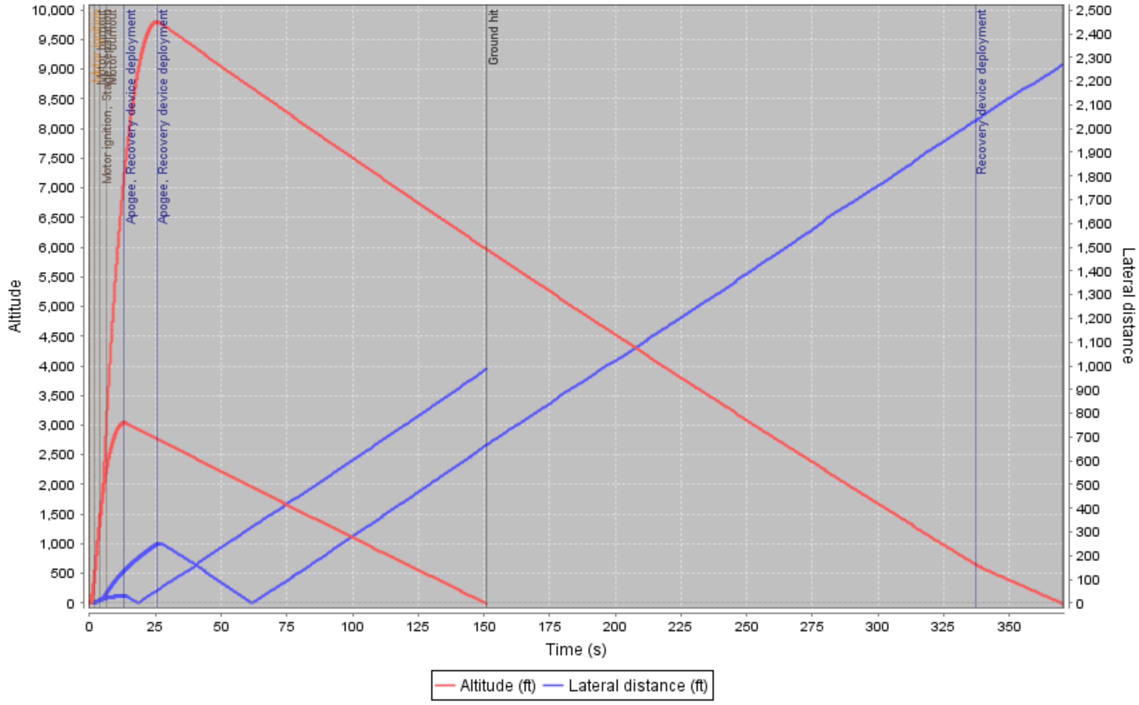


Figure 77: Altitude v. Lateral Distance.

CP and CG Locations

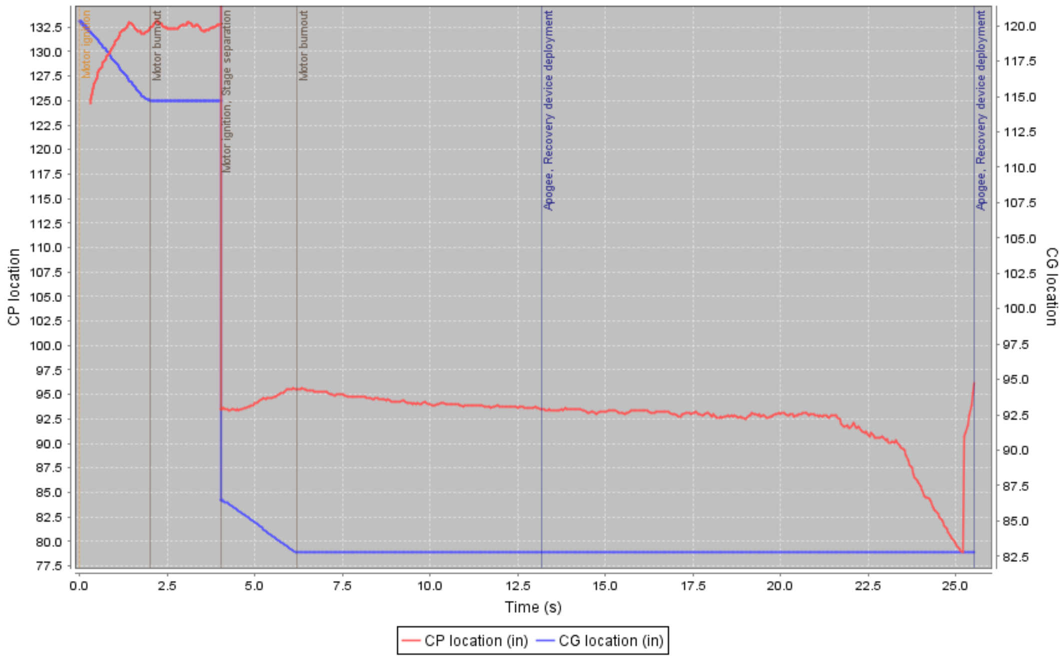


Figure 78: CP and CG versus time

Drag Characteristics

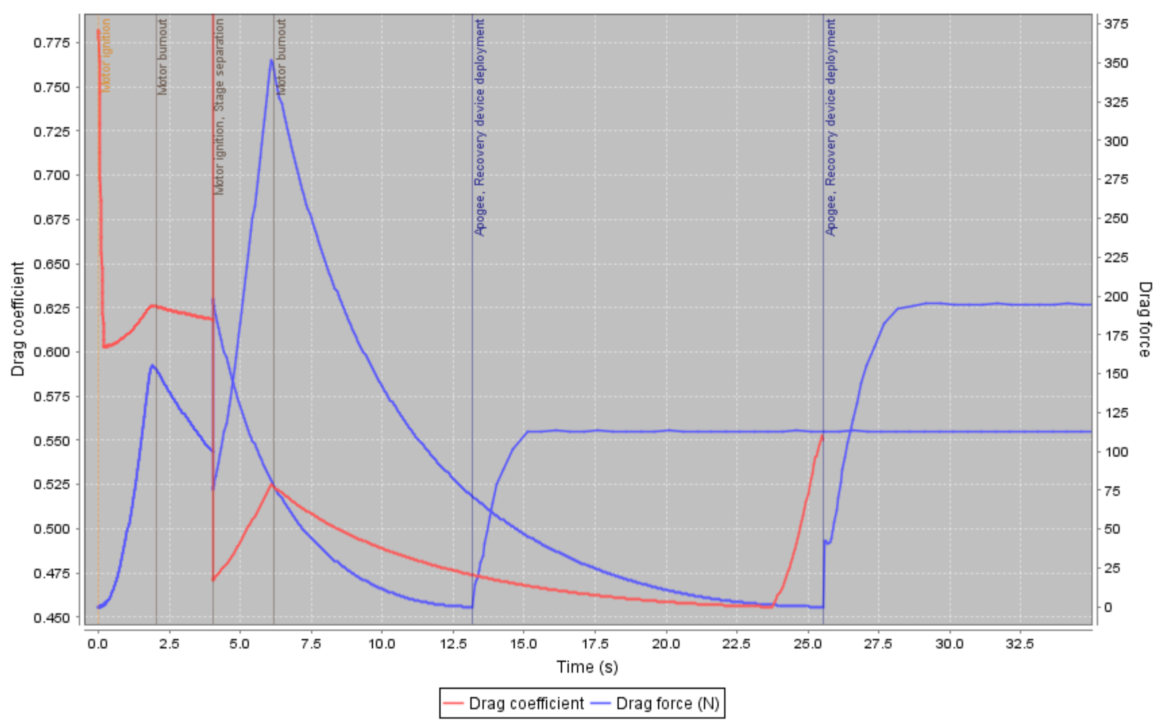


Figure 79: Drag force and drag coefficient

Drag Characteristics

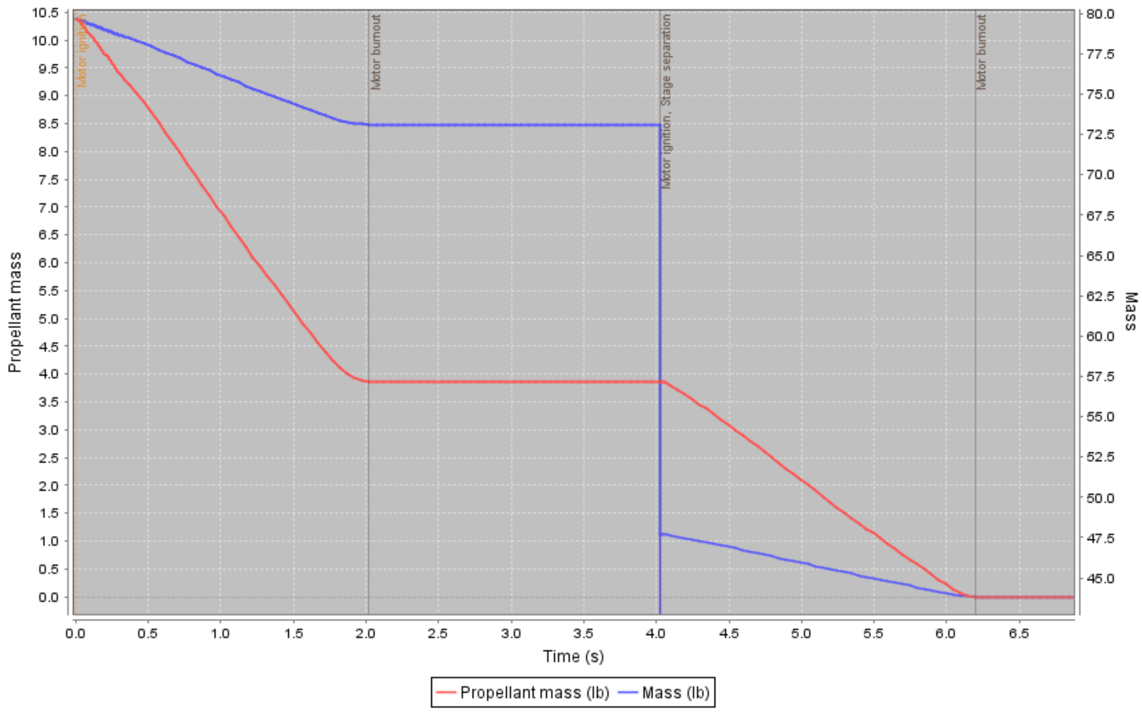


Figure 80: Propellant Mass v. Mass

Stability Margin

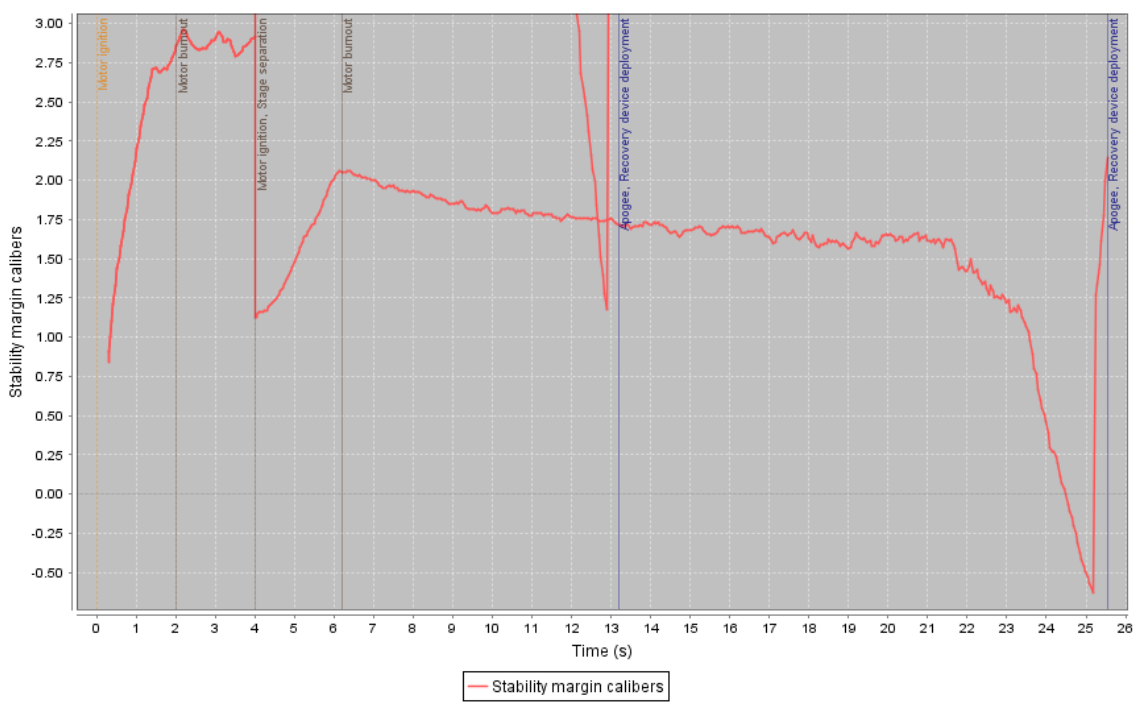


Figure 81: Stability margin.

Drift Calculations

The total drift is calculated using by

$$Drift = D_A + D_D \quad (X)$$

where D_A is the ascent drift and D_D is the descent drift. Ascent drift is determined using the OpenRocket simulation and shown in Table 15, upwind drift is defined to be negative and downwind is defined to be positive.

Wind Speed (mph)	5	10	15	20
Booster Drift (ft.)	-25.255	-37.25	-469.5	-425
Sustainer Drift (ft.)	-250.89	-418.4	-2350	-2500

Table 15: Ascent drift.

Descent drift was calculated using

$$D_D = V_W t \quad (X)$$

where t is the descent time, and V_w is the wind speed. The descent time was calculated using

$$t = \frac{\Delta H}{V_t} \quad (X)$$

where ΔH is the net altitude difference and V_t is the steady state velocity under parachute. The steady state velocity was calculated using

$$V_t = \sqrt{\frac{2mg}{\rho C_d A}} \quad (X)$$

Due to the nature of the recovery scheme the steady state velocity will be different not only for each section but for different altitudes because the values for A and m will be different. To account for this the process was repeated with the different sections over different altitudes to determine the total descent time. The resulting total descent drifts are shown in Table 16.

Wind Speed (mph)	5	10	15	20
Booster Drift (ft.)	707.35	1414.70	2122.04	2829.39
Lower Sustainer Drift (ft.)	1923.857	3847.72	5771.57	7695.43
Upper Sustainer Drift (ft.)	1450.29	2900.58	4350.87	5801.16
Rover Drift (ft.)	1591.40	3182.79	4774.19	6365.59

Table 16: Total descent drift.

The total drift is then calculated using equation (X), the results are shown in Table 17

Wind Speed (mph)	Drift (ft.)			
	Booster	Lower Sustainer	Rover	Upper Sustainer
5	682.10	1672.97	1340.51	1199.4
10	1377.45	3429.32	2764.39	2482.18
15	1652.54	3421.57	2424.19	2000.87
20	2404.39	4895.23	3865.59	3301.16

Table 17: Total vehicle drift.

The highest drift is the lower sustainer at 4895.23 feet which is within the 5000 feet allowable limit.

SAFETY AND ENVIRONMENT (VEHICLE)

Safety Officer Responsibilities

The safety officer for the River City Rocketry team during the 2013-2014 season is Emily. She is responsible for ensuring the overall safety of the team, students, and the public as well as compliance with all laws and regulations. The following are the Safety Officer's specific responsibilities.

- Establish and brief the team on a safety plan for various environments, actions, and materials used.
- Remain active in the design, construction, testing, and flight of the rocket in order to quickly identify any new safety hazards and to ensure the team complies with the team safety plan.
- Identify safety violations and take appropriate action to mitigate the hazard.
- Enforce proper use of Personal Protective Equipment (PPE) during construction, testing and flights of the rocket.
- Make MSDS sheets and operator manuals available and easily accessible to the team at all times.
- Provide plan for proper purchase, storing, transporting, and use of both motors and energetic devices.
- Ensure compliance with all local, state, and federal laws.
- Ensure compliance with all NAR regulations
- Provide a written team safety manual that includes hazards, safety plans and procedures, PPE requirements, MSDS sheets, operator manuals, FAA laws and NAR regulations.

- Confirm that all team members have red and comply with all regulations set forth by the team safety manual.
- Ensure the safety of all participants in educational outreach activities, providing PPE as necessary.

Emily has written a team safety manual that each team member was required to review and sign indicating compliance. The document includes hazards, proper safety plans and procedures, PPE requirements, MSDS sheets, FAA laws, and NAR regulations. The manual will be revised throughout the year as a need arises. Emily has confirmed that each team member has read and acknowledged the safety manual and will continue to enforce all statements in the safety manual. The manual can be found on the team website along with a signed document of compliance from each team member.

Hazard Analysis

Risk Assessment Matrix

By methodically examining each human interaction, environment, rocket system and component, hazards have been identified and will continue to be brought to the team's attention. Each hazard has been assigned a risk level through the use of a risk assessment matrix, found in Table 20, by evaluating the severity of the hazard and the probability that the hazard will occur.

A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, damage to the rocket and/or damage to equipment. This criteria is outlined below in Table 18.

Severity		
Description	**Value**	**Criteria**
Catastrophic	1	Could result in death, significant irreversible environmental effects, complete mission failure, monetary loss of $5k or more.
Critical	2	Could result in severe injuries, significant reversible environmental effects, partial mission failure, monetary loss of $500 or more but less than $5k.
Marginal	3	Could result in minor injuries, moderate environmental effects, complete failure of non-mission critical system, monetary loss of $100 or more but less than $500.
Negligible	4	Could result in insignificant injuries, minor environmental effects, partial failure of non-mission critical system, monetary loss of less than $100.

Table 18: Severity Criteria

A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. The probability value was determined for each hazard based on an estimated percentage chance that the mishap will occur given the following:

- All personnel involved have undergone proper training on the equipment being used or processes being performed.
- All personnel have read and acknowledged that they have a clear understanding of all rules and regulations set forth by the latest version of the safety manual.
- Personal Protective Equipment is used as indicated by the safety lab manual and MSDS.
- All procedures were correctly followed during construction of the rocket, testing, pre-launch preparations, and the launch.
- All components were thoroughly inspected for damage or fatigue prior to any test or launch.

The criteria for the selection of the probability value is outlined below in Table 19.

Probability		
Description	**Value**	**Criteria**
Almost Certain	1	Greater than a 90% chance that the mishap will occur.
Likely	2	Between 50% and 90% chance that the mishap will occur.
Moderate	3	Between 25% and 50% chance that the mishap will occur.
Unlikely	4	Between 1% and 25% chance that the mishap will occur.
Improbable	5	Less than a 1% chance that mishap will occur.

Table 19: Probability Criteria

Through the combination of the severity value and probability value, an appropriate risk level has been assigned using the risk assessment matrix found in Table 20. The matrix identifies each combination of severity and probability values as either a high, moderate, or low risk. The team's goal is to have every hazard to a low risk level by the time of the competition launch. Those that are not currently at a low risk level will be brought down through redesign, new safety regulations, or any other measures seen fit to reduce risk. Risk levels will also be reduced through verification of systems.

Risk Assessment Matrix				
Probability Value	**Severity Value**			
	Catastrophic-(1)	Critical-(2)	Marginal-(3)	Negligible-(4)

Almost Certain- (1)	2-High	3-High	4-Moderate	5-Moderate
Likely-(2)	3-High	4-Moderate	5-Moderate	6-Low
Moderate-(3)	4-Moderate	5-Moderate	6-Low	7-Low
Unlikely-(4)	5-Moderate	6-Low	7-Low	8-Low
Improbable-(5)	6-Low	7-Low	8-Low	9-Low

Table 20: Risk Assessment Matrix

Lab and Machine Shop Risk Assessment

Construction and manufacturing of parts for the rocket will be performed in both on-campus and off-campus labs. The hazards assessed in Table 21 are risks present from working with machinery, tools, and chemicals in the lab.

Launch Pad Risk Assessment

The hazards outlined in Table 22 are risks linked to the launch pad that the team has previously designed and built. Since the launch pad was used throughout the entirety of last season without any problems, we are confident in the safety of its design.

Stability and Propulsion Risk Assessment

The hazards outlined in Table 23 are risks associated with stability and propulsion. There are particular risks involved when staging a rocket. This year is the team's first experience attempting a complex rocket. The risks were initially higher than would be considered acceptable for the competition launch. Sub-scale tests have verified that the team can successfully launch a dual stage rocket successfully.

The team is confident in the full scale version of our rocket's ability to stage successfully. During the first full scale test, the rocket staged without any flaws. All hazards associated with staging have been reduced to levels acceptable for competition.

Recovery Risk Assessment

The hazards outlined in Table 24 are risks associated with the recovery. Since there are four recovery systems onboard, many of the failure modes and results will apply to all of the systems but will be stated only once for conciseness.

Fairing Risk Assessment

The hazards outlined in Table 25 are risks that are related to the fairing. This includes potential risks during assembly, launch, recovery, and operation of the fairing.

Vehicle Assembly Risk Assessment

The hazards outlined in Table 26 are risks that could potentially be encountered throughout the assembly phase and during launch preparation.

Environmental Hazards to Rocket Risk Assessment

The hazards outlined in Table 27 are risks from the environment that could affect the rocket or a component of the rocket. Several of these hazards resulted in a moderate risk level and will remain that way for the remainder of the season. These hazards are the exception for needing to achieve a low risk level. This is because several of these hazards are out of the team's control, such as the weather. The hazards that the team can control will be mitigated to attain a low risk level.

Hazards to Environment Risk Assessment

The hazards outlined in **Table 28** are risks that construction, testing or launching of the rocket can pose to the environment.

Top 5 Risks:

1. Sustainer does not ignite-

Although the team has successfully ignited the sustainer during each launch, this is still a great risk to the vehicle due to the severity of the results. Testing has validated that the method of igniting the sustainer is reliable. However, in the case that the sustainer does not ignite, the recovery is designed so that it will successfully recover all parts of the rocket. Even though the team would suffer a mission failure, the rocket will be recovered, allowing the team to debug the situation during a test.

2. Improperly sized black powder charge.

Calculations were made in order to determine the necessary size of the black powder charges for each section. Significant ground testing has been performed in order to ensure that the black powder charges are properly sized. While the ground testing supports the calculations, ground testing cannot fully simulate the forces that will have to be overcome during a full scale launch. Due to malfunctions during the maiden flight of the full scale, black powder charge sizing was not able to be verified. This will be validated during further full scale testing.

3. Improperly sized vent holes

Calculations were made in order to determine the necessary size and quantity of the ventilation holes needed for each of the avionics bays. Due to malfunctions during the maiden flight, the sizing of the holes were not verified to be appropriately sized. If the vent holes are too small, the barometric based altimeters will not function properly. The validation of the sizing of the vent holes will occur during further full scale testing.

4. Parachutes don't deploy.

Due to the complexity of the rocket, there are six parachutes that must deploy for a successful recovery. If any one of the parachutes fail to deploy, a section of the rocket or the rover will become ballistic, risking mission performance. Due to malfunctions during the maiden flight, the functionality of the parachute deployment system could not be fully tested. Significant ground testing has been performed to ensure that during the next full scale test that the parachutes deploy. Each of the parachutes and deployment bags have been tested for ease of deployment. Also, ground testing has been performed to ensure that the black powder charges will separate the rocket where it needs to in order to allow parachutes to deploy,

5. Tiltometer malfunction

Should the tiltometer malfunction, the sustainer may not ignite. This could result in a mission failure. Ground testing has been performed to ensure the tiltometer is making accurate measurements. The tiltometer has not been flown in full functionality, but just as a data collection device, in order to have an understanding of how the tiltometer reacts without risking a mission failure. Once this is validated, the tiltometer will be flown in full functionality,

Lab and Machine Shop Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Using power tools and hand tools such as blades, saws, drills, etc.	1. Improper training on power tools and other lab equipment.	1a. Mild to severe cuts or burns to personnel. 1b. Damage to rocket or components of the rocket. 1c. Damage to equipment	2	4	Low	1. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them. 1. Safety glasses must be worn at all times. 1. Sweep or vacuum up shavings to avoid cuts from debris.
Sanding or grinding materials.	1. Improper use of PPE. 2. Improper training on the use of a Dremel tool.	1a. Mild to severe rash. 1b. Irritated eyes, nose or throat with the potential to aggravate asthma. 2. Mild to severe cuts or burns from a Dremel tool and sanding wheel.	3	3	Low	1a. Long sleeves should be worn at all times when sanding or grinding materials. 1b. Proper PPE should be utilized such as safety glasses and dust masks with the appropriate filtration required. 2. Individuals must be trained on the tool being used. Those not trained should not attempt to learn on their own and should find a trained individual to instruct them.
Working with chemical components resulting in mild to severe chemical burns on skin or eyes, lung damage due to inhalation of toxic fumes, or chemical spills	1. Chemical splash. 2. Chemical fumes.	1. Mild to severe burns on skin or eyes. 2. Lung damage or asthma aggravation due to inhalation of fumes,	2	4	Low	MSDS documents will be readily available at all times and should be thoroughly reviewed prior to working with any chemical. 1. Nitrile gloves shall be used when handling hazardous materials. 1. Personnel are familiar with locations of safety features such as an eye wash station. 1. Safety goggle are to be worn at

						all times when handling chemicals. 2. When working with chemicals producing fumes, appropriate precautions should be taken such as working in a well-ventilated area, vapor masks, fume hood.
Damage to equipment while soldering	1. Soldering iron is too hot 2. Prolonged contact with heated iron	The equipment could become unusable. If parts of the payload circuit get damaged, they could become inoperable.	3	3	Low	1. The temperature on the soldering iron will be controlled and the team is experienced in soldering. The soldering iron will be set the correct temperature 2. For temperature sensitive components we can use the sockets to solder our ICs to.
Dangerous fumes while soldering	1. Use of leaded solder can produce toxic fumes 2. Leaving soldering iron too long on plastic could cause plastic to melt producing toxic fumes.	Team members could become sick due to inhalation of toxic fumes. Irritation could also occur.	3	3	Low	1. The team will use well ventilated areas while soldering. Fans will be used. 2. The soldering iron will only be on parts for the recommended amount of time.
Potential burns to team members while soldering	Team members do not pay attention while soldering	The team member could suffer minor to severe burns.	4	3	Low	Team members will be encouraged to follow all safety protocols related to soldering.
Overcurrent from	Failure to	Team members	2	4	Low	The circuits will be analyzed

power source while testing	correctly regulate power to circuits during testing	could suffer electrical shocks which could cause burns to heart arrhythmia				before they are powered to insure they don't pull too much power. Power supplies will also be set to the correct levels.

Table 21: Lab and Machine Shop Risk Assessment

Launch Pad Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Unstable launch tower	Un-level ground or improperly staked launch tower.	If the launch pad is unstable while the rocket is leaving the pad, the rocket's path will be unpredictable.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR. Ensure that the launch pad is stable and secure prior to launch.
Unleveled launch pad	Un-level ground or improperly leveled launch tower.	The launch tower could tip over during launch, making the flight of the rocket unpredictable.	1	5	Low	The launch pad should always be placed on a level surface. Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR.
Cracked weld on launch pad	Fatigue and over stressing during transportation.	The launch tower could potentially become unstable.	3	4	Low	The launch tower should be inspected prior to each use for any cracked welds. Launch tower is to be kept clean in order to be able to identify any cracks.
Rocket gets caught in launch tower or experiences high friction forces	Misalignment of launch tower joints	Rocket may not exit the launch tower with a high	2	5	Low	During setup, the launch tower will be inspected for a good fit to the rocket. A spare piece of airframe is taken out and run through the launch pad. If any resistance is noted, the joints of the tower can be moved to improve the alignment of the tower, allowing

						the rocket to freely move through the tower. Also, graphite is applied to each beam in order to reduce any frictional forces on the rocket.
Sharp edges on the launch pad	Manufacturing processes.	Minor cuts or scrapes to personnel working with, around, and transporting the launch tower.	4	3	Low	Sharp edges of the launch pad should be filed down and de-burred.
Brush fire caused by rocket during launch	Dry launching conditions.	Small brush fire.	4	3	Low	Wait until the range safety officer has cleared personnel to approach the launch pad and extinguish any fires that have been started. The launch tower also has a blast deflector to prevent brush fires.

Table 22: Launch Pad Risk Assessment

Stability and Propulsion Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Motor fails to ignite.	1. Faulty motor. 2. Delayed ignition. 3. Faulty e-match. 4. Disconnected e-match.	1,3,4. Rocket will not launch. 2. Rocket fires at an unexpected time.	3	4	Low	Follow NAR safety code and wait a minimum of 60 before approaching the rocket to ensure that the motor is not simply delayed in launching. If there is no activity after 60 seconds, have the safety officer check the ignition system for a lost connection or a bad igniter. If this does not fix the failure mode, be prepared to remove the ignition system from the rocket motor,

						retrieve the motor from the launch pad and replace the motor with a spare. Igniters have been securely installed throughout the season, having a 100% success rate.
Motor explodes on the launch pad.	Faulty motor	Rocket and interior components significantly damaged.	1	5	Low	Confirm that all personnel are at a distance allowed by the Minimum Distance Table as established by NAR in order to ensure that no one is hurt by flying debris. Extinguish any fires that may have been started when it is safe to approach. Collect all debris to eliminate any hazards created due to explosion. The motors the team have selected are from a reliable supplier. The team has had a 100% success rate.
Rocket doesn't reach high enough velocity before leaving the launch pad.	1. Rocket is too heavy. 2. Motor impulse is too low. 3. High friction coefficient between rocket and launch tower.	1,2. Unstable launch.	1	5	Low	Too low of a velocity will result in an unstable launch. Simulations are run to verify the motor selection provides the necessary exit velocity. The launch pad will be coated in graphite prior to each launch in order to minimize friction. Should the failure mode still occur, the issue should be further examined to determine if the cause was due to a faulty motor or in the booster needs to be redesigned.
Booster does not separate from rocket.	1. High angle of flight. 2. Too tight of fit	1. Booster motor will not fire.	3	4	Low	1. A tiltometer will be placed in the rocket to determine the angle of flight. If the angle of flight is too

	between the booster and sustainer.	2. Damage to interior components of the booster section.				high, the sustainer motor will not fire and the rocket will fully recover. 2. The coupling between the booster and sustainer will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight. Ground testing has been performed to ensure separation occurs with ease.
Sustainer ignites early.	False reading from the altimeter.	Significant damage to the booster section, particularly in the case of burns to the booster recovery system. Would also result in loss of overall altitude achieved.	3	4	Low	Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. Should altimeters continue to fail, a redesign would need to be evaluated to ensure proper ignition.
Sustainer does not ignite	1. Altimeter malfunction. 2. Tiltometer malfunction. 3. Faulty igniter or igniter becomes dislodged.	1,2,3. Sustainer motor will not fire and the rocket will achieve an altitude significantly below the goal. Rocket will still fully recover.	1	5	Low	1. Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. 2. The tiltometer will not allow the sustainer to ignite at an angle greater than 40°. Tiltometer will be significantly tested prior to use to ensure it allows the signal to ignite the motor within the allowable

						range. The tiltometer will be zeroed on the launch pad prior to each use. 3. There will be 2 igniters used for redundancy.
Sustainer ignition delayed	1. Altimeter malfunction. 2. Bad connection between ignition control systems.	If the delay allows for the rocket to fall past parallel to the ground, significant damage would be done to the rocket and personnel could be at risk. If it is a short delay, causing the rocket to fall less than 90°, there will be a loss in altitude.	1	5	Low	1. Test altimeters to make sure they are fully operable prior to flight. Altimeters have special bays designed to ensure secure mounting throughout the flight. Raven diagnostic codes will alert personnel if there is an error. 2. All connections are to be inspected prior to flight. This inspection is included as a part of launch day procedures.
Fins shear during flight	Insufficient adhesion during installation resulting in a failure in the epoxy.	Unstable rocket, causing the flight path to become unpredictable.	1	5	Low	Confirm all personnel are alert and at a distance allowed by the Minimum Distance Table as established by NAR. Examine external epoxy beads for cracks prior to launch.
Airframe buckles during flight	Airframe encounters stresses higher than the material can support.	Rocket will become unstable and unsafe during flight.	1	5	Low	Through prediction models, appropriate material selection, and a secure factor of safety, this failure mode can be nearly eliminated.
Internal bulkheads fail during flight	Forces encountered are	1. Internal components	1	5	Low	The bulkheads will be designed to withstand the force from the motor

	greater than the bulkheads can support.	supported by the bulkheads will no longer be secure. 2. Parachutes attached to bulkheads will be left ineffective.				firing with an acceptable factor of safety. 1. Electrical components could be damaged and will not operate as intended during flight. 2. A catastrophic failure is likely. A portion of the rocket or the fairing would become ballistic.

Table 23: Stability and Propulsion Risk Assessment

Recovery Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket does not split to allow for recovery system deployment.	1. Not enough pressurization to break shear pins. 2. Coupling has too tight of fit.	1,2. Rocket follows ballistic path, becoming unsafe.	1	5	Low	1. The separation section of the rocket will be designed to ensure that the black powder charge provides sufficient pressurization, allowing the rocket to separate and deploy its recovery system. 2. The coupling between the sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight. If separation does not occur, the rocket will follow a ballistic path, becoming unsafe. All personnel at the launch field will be notified immediately.
Altimeter or e-match failure	Parachutes will not deploy.	Rocket follows ballistic path, becoming unsafe.	1	5	Low	Multiple altimeters and e-matches are included into systems for redundancy to eliminate this failure mode. Should all altimeters or e-matches fail, the

						recovery system will not deploy and the rocket will become ballistic, becoming unsafe. All personnel at the launch field will be notified immediately.
Parachute does not open	1. Parachute gets stuck in the deployment bag. 2. Parachute lines become tangled.	1,2. Rocket follows ballistic path, becoming unsafe.	1	4	Moderate	Deployment bags will be specially made for the parachutes. This will allow for an organized packing that can reduce the chance of the parachute becoming stuck or the lines becoming tangled. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.
Rocket descends too quickly	Parachute is improperly sized.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Simulations have been performed to validate the design.
Rocket descends too slowly	Parachute is improperly sized.	The rocket will drift farther than intended, potentially facing damaging environmental obstacles.	3	3	Low	The parachutes have each been carefully selected and designed to safely recover its particular section of the rocket. Should this be too large, the parachute will have to be resized.
Parachute has a tear or ripped seam	Parachute is less effective or completely ineffective depending on the severity of the	The rocket falls with a greater kinetic energy than designed for, causing components of	2	5	Low	Through careful inspection prior to packing each parachute, this failure mode should be eliminated.

	damage.	the rocket to be damaged.				
Parachute or chords become burnt	Parachute is less effective or completely ineffective depending on the severity of the damage.	The rocket falls with a greater kinetic energy than designed for, causing components of the rocket to be damaged.	2	5	Low	Through careful packing and the appropriate use of Nomax material, this failure mode is unlikely.
Recovery system separates from the rocket	1. Bulkhead becomes dislodged. 2. Parachute disconnects from the U-bolt.	1,2. Parachute completely separates from the component, causing the rocket to become ballistic.	1	5	Low	The cables and bulkhead connecting the recovery system to each segment of the rocket are designed to withstand expected loads with an acceptable factor of safety. Should the rocket become ballistic, all personnel at the launch field will be notified immediately.

Table 24: Recovery Risk Assessment

Fairing Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Sustainer does not eject from the rocket	1. Nylon shear pins do not fully shear. 2. Friction between sustainer and booster is too high.	Rocket will not achieve goal altitude. Rover will be unable to deploy. Rocket will still completely recover.	1	4	Moderate	1. Black powder charges have been designed to overcome the shear strength of the shear pins, allowing the rocket to separate easily. 2. The coupling between the two sections will be sanded down to have a loose fit, preventing the two sections from getting stuck together during flight.
Fairing gets tangled	Improper packing	Rover will not	2	5	Low	Special foam inserts are designed

in parachute.	of parachute.	perform as intended.				to house both the rover and the parachute in separate compartments. The foam inserts will keep the parachute shielded from the pinch point of the fairing when opened. The parachute is housed above the rover to ensure they do not become entangled during deployment.
Battery in altimeter housing dies.	1. Use past the normal life of the battery. 2. Extremely cold weather	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	2	5	Low	Batteries will be checked for sufficient charge during launch day preparations. If the launch is delayed and the batteries have been left on, batteries should be rechecked for a sufficient charge to power the systems.
E-match fails	1. E-match become dislodged. 2. Faulty e-match.	1,2. Ejection charges will not fire, preventing the rocket from splitting and the rover being deployed.	1	5	Low	1. A pyro cap was specially designed and machined for this system to ensure secure connection of the e-matches to the black powder charges. 2. The designed pyro cap allows for two separate black powder charges and e-matches. It is unlikely that the entire system will fail due to the redundancy.
Springs become dislodged.	Fairing does not completely open.	Rover will not deploy.	2	4	Low	Springs were selected with a high enough tension in mind to remain secure on the fairing.
Springs become fatigued.	Springs do not provide enough force to open fairing.	Rover will not deploy.	2	4	Low	Springs will be monitored for signs of fatigue and replaced as necessary. Springs are to be removed when not launching in order to prevent stretching.
Airframe becomes	Airframe for	Rocket will	1	5	Low	Airframe will have ribbed supports

deformed	fairing has a vertical cut through the entire airframe. Due to the nature of wound fiberglass, this could deform.	become unstable and unsafe during flight.				and internal components, such as bulk plates to support the structure.
Fairing does not separate from the sustainer	Friction between coupling and airframe is too high for pressurization from black power charge to overcome.	Rover will not deploy and will not be able to perform as intended.	1	4	Low	Coupling and airframe will be sanded to provide a smooth surface, allowing the two parts to easily separate. The springs that force the fairing apart were carefully selected to provide enough force to open the fairing upon separation, but not so much force that the rocket cannot separate.

Table 25: Fairing Risk Assessment

Vehicle Assembly Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Rocket drop (INERT)	Mishandling of the rocket during transportation.	Minimal damage and scratches to components of the rocket.	4	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.
Rocket drop (LIVE)	Mishandling of the rocket during transportation.	1. Minimal damage and scratches to components of the rocket if no charges go off. 2. Charges	1	5	Low	The rocket has been designed to be durable in order to survive loads encountered during flight and upon landing. Careful handling should be practiced while transporting the rocket.

		prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.				
Black powder charges go off prematurely	1. Altimeters send a false reading. 2. Open flame sets off charge.	1,2. Charges prematurely go off, resulting in a serious safety threat to personnel in the area and significant damage to the rocket.	1	5	Low	All electronics will be kept in their OFF state for as long as possible during preparation. Open flames and other heat sources will be prohibited in the area.
Seized nut or bolt due to galling or cross threading	Repetitive uninstalling and reinstalling of parts made of materials prone to galling.	Component becomes unusable, potentially ruining expensive, custom machined parts. Amount of rework depends on the location and component that seized.	2	4	Low	Through proper choice in materials, appropriate pre-load, and proper installation, the risk of galling can be eliminated.

Table 26: Vehicle Assembly Risk Assessment

Environmental Hazards to Rocket Risk Assessment

Hazard	Cause/ Mechanism	Outcome	Severity Value	Probability Value	Risk Level	Mitigation
Low cloud cover.	N/A	Unable to test entire system.	1	4	Moderate	When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system.
Rain	N/A	1. Unable to launch. 2. Damage electrical components and systems in the rocket.	1	4	Moderate	1. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. 2. Have a plan to place electrical components in water tight bags. Have a location prepared to store the entire rocket to prevent water damage.
High winds	N/A	1. Have to launch at high angle, reducing altitude achieved. 2. Increased drifting. 3. Unable to launch.	1	4	Moderate	1,2,3. When planning test launches, the forecast should be monitored in order to launch on a day where weather does not prohibit launching or testing the entire system. If high winds are present but allowable for launch, the time of launch should be planned for the time of day with the lowest winds.
Trees	N/A	1. Damage to rocket or parachutes. 2. Irretrievable rocket components.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. Drift calculations have been computed, so we can estimate how far each component of the rocket will drift

						with a particular wind velocity. The rocket should not be launched if trees are within the estimated drift radius.
Swampy ground	N/A	Irretrievable rocket components.	1	4	Moderate	With the potential of the salt flats being extremely soft, as well as local launch sites, the rocket should not be launched if there is swampy ground within the predicted drift radius that would prevent the team from retrieving a component of the rocket.
Ponds, creeks, and other bodies of water.	N/A	1. Loss of rocket components. 2. Damaged electronics.	1	4	Moderate	Launching with high winds should be avoided in order to avoid drifting long distances. The rocket should not be launched if a body of water is within the estimated drift radius. Should the rocket be submerged in water, it should be retrieved immediately and any electrical components salvaged. Electrical components are to be tested for complete functionality prior to reuse.
Extremely cold temperatures.	1. Batteries discharge quicker than normal. 2. Shrinking of fiberglass.	1. Completely discharged batteries will cause electrical failures and fail to set off black powder charges, inducing critical events. 2. Rocket will	1	5	Low	1. Batteries will be checked for charge prior to launch to ensure there is enough charge to power the flight. Should the flight be delayed, batteries will should be rechecked and replaced as necessary. 2. If the temperatures are below normal launch temperature, black powder charges should be tested to ensure that the pressurization

		not separate as easily.				is enough to separate the rocket. If this test is successful, the rocket should be safe to launch.
Humidity	N/A	Motors or black powder charges become moist and don't ignite.	1	5	Low	Motors and black powder should be stored in a location free from moisture to remove
UV exposure	Rocket left exposed to sun for long periods of time.	Possibly weakening materials or adhesives.	4	4	Low	Rocket should not be exposed to sun for long periods of time. If the rocket must be worked on for long periods of time, shelter should be sought.

Table 27: Environmental Hazards to Rocket Risk Assessment

Hazards to Environment Risk Assessment						
Hazard	**Cause/ Mechanism**	**Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Harmful substances permeating into the ground or water.	Improper disposal of batteries or chemicals.	Impure soil and water can have negative effects on the environment that in turn, work their way into humans, causing illness.	4	3	Low	Batteries and other chemicals should be disposed of properly in accordance with the MSDS sheets. Should a spill occur, proper measure are to be followed in accordance with the MSDS sheets and any OSHA standards.
Destruction of salt flats.	Staking of the launch tower in hard ground.	Holes will have to be drilled in the salt flats in order to properly stake the launch tower.	4	1	Moderate	Due to the nature of the location of the competition launch, holes will have to be drilled into the salt flats in order to stake the launch pad. This has been discussed with personnel at the site and they have verified that this is acceptable to do.

Table 28: Hazards to Environment Risk Assessment

NAR/TRA Procedures

NAR Safety Code

The below table describes each component of the NAR High Power Rocket Safety Code, effective August 2012, and how the team will comply with each component.

NAR Code	Compliance
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.	Only Darryl Hankes, Gregg, and Zak are permitted to handle the rocket motors. If during the season, an additional team member achieves the required certification, he/she will be approved to handle the motors after that date.
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.	The Mechanical Engineering team will be responsible for selecting the appropriate materials for construction of the 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.	Motors will be purchased through Wildman Rocketry and will only be handled by certified members of the team who are responsible for understanding how to properly store and handle the 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.	All launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any safety issues.
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 batter and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.	The team will comply with this rule and any additional precautions that the Range Safety Officer makes on launch day.
6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure	The team will comply with this rule and any determination the Range Safety

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.	Officer makes on launch day.
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.	The team will ensure that the launch pad meets these requirements, using any additional tools necessary on launch day to ensure compliance and a safe launch.
8. **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	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

applicable altitude limit in effect at that launch site.	
9. **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).	All team launches will be at NAR/TRA certified events. The Range Safety Officer will have the final say over any rocketry safety issues.
10. **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.	The team will comply with this rule and any determination the Range safety Officer makes on launch day.
11. **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.	The Recovery team will be responsible for designing and constructing a safe recovery system for the rocket. A safety checklist will be used on launch day to ensure that all critical steps in preparing and packing the recovery system and all necessary components into the rocket are completed.
12. **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.	The team will comply with this rule and any determination the Range Safety Officer makes on launch day.

Table 29: NAR Safety Code Compliance

Team Safety

A team safety meeting will be held prior to any construction in order to ensure that every team member is fully aware of all team safety regulations as detailed in the team safety manual which has been included in the appendix. Each team member is required to review and acknowledge the safety manual. As revisions are made and released, team members are responsible for remaining up to date with team safety regulations. The team safety manual covers the following topics:

- Lab Workshop Safety
- Material Safety
- Personal Protective Equipment regulations
- Launch Safety Procedures
- Educational Engagement Safety
- MSDS sheets
- Lab and tool specific rules.

If a violation to the contract occurs, the violator will be revoked of his or her access to the lab until having a meeting with the safety officer to review and reconfirm compliance with the safety rules.

Prior to each launch, a briefing will be held to review potential hazards and accident avoidance strategies. In order to prevent an accident, a thorough safety checklist has been created and will be reviewed on launch day. Throughout preparations, it will be the responsibility of the safety officer to confirm that each of the necessary tasks for a successful launch are completed. Two team members are required to sign off, verifying that each required task has been completed in order to ensure a safe launch.

<u>Local/State/Federal Law Compliance</u>

The team has reviewed and acknowledged regulations regarding unmanned rocket launches and motor handling. Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C, Code of Federal Regulation 27 Part 55: Commerce in Explosives; and fire prevention, and NFPA 1127 "Code for High Power Rocket Motors" documentation will be made available to all members of the team. The previously listed documents are included in the appendix. Due to the length of Regulation 27, Part 55, a URL is given for the document.

<u>Motor Safety</u>

Darryl Hankes, the team mentor, who has obtained his Level 3 TRA certification, will be responsible for acquiring, storing, and handling the teams rocket motors at all times. Team members Gregg and Zak, whom are Level 2 certified, are permitted to assist in this responsibility for the sub-scale flights. The full scale motors require a Level 3 certification, so Darryl is the only person permitted to handle the competition motors. If at any time, another member of the team acquires the appropriate certification, they will be added to the list of people permitted to handle the team's motors. By having obtained at minimum a Level 2 certification, the individual has demonstrated that he or she understands the safety guidelines regarding motors. Any certified member of the team that handles or stores the team's motors is responsible for following the appropriate measures. The motors for both test and competition launches will be transported by car to the launch site.

<u>Safety Compliance Agreement</u>

The University of Louisville USLI team understands and will abide by the following safety regulations declared by NASA. The following rules will be included in the team safety contract that all team members are required to sign in order to participate in any builds or launches with the team.

1. Range safety inspections of each rocket before it is flown. Each team shall comply with the determination of the safety inspection.

2. The Range Safety Officer has the final say on all rocket safety issues. Therefore, the range Safety Officer has the right to deny the launch of any rocket for safety reasons.
3. Any team that does not comply with the safety requirements will not be allowed to launch their rocket.

PAYLOAD INTEGRATION

Overview of Physical Integration

The team's rocket utilizes a unique fairing to house and deploy the rocket's scientific payload. Precision design and engineering applications were used to ensure the structural integrity of the fairing during and after construction. Due to the nature of wound fiberglass, the team had to carefully build the fairing through a developed plan to acquire the proper end result that would allow the fairing to perfectly integrate with the rest of the launch vehicle.

Wound fiberglass is inherently under constant compressive forces. When cutting the fiberglass airframe perpendicular to the axis of the airframe, you do not notice the compression, as you are not specifically deforming the structural integrity of the wound material. However, when cutting the fiberglass down the axis of the airframe, it becomes apparent that the wound material will want to compress inwards onto itself. This permanent deformation to the integrity of the wound fiberglass material will cause the two halves of the airframe, when placed together, to take on a more oblong shape.

Figure 82. Representation of fiberglass deformation.

To counteract this issue, the team came up with a solution to ensure no deformation to the section of airframe of the fairing so that when the two halves were placed together, they formed a perfect circle. It was determined that all of the bulkplates and coupler tubing would be installed prior to the cutting of the airframe. After the epoxy had dried, a jig was built so that a band saw could be used to precisely cut the fairing in half. Having the bulkheads already epoxied in place did not allow the fairing airframe and coupler tubing to deform at all. This allowed for the system to keep its cylindrical shape, thus allowing for proper integration into the launch vehicle.

<u>Design and Verification of Fairing Integration</u>

The fairing can be divided into three main sections: the altimeter housing, payload housing, and fairing retention bay. Each section has its own primary role in ensuring the safe deployment and recovery of the specific payload. The main components that make up the fairing, including airframe and bulk plates, can be visualized as equally divided into separate halves.

Altimeter Housing

In order to save space within the confinements of the fairing, the team wanted to have a standalone altimeter within the fairing. This called for no separate altimeter bay. The team designed an altimeter housing, shown in *Figure **83***, that would be 3D printed from ABS plastic. The enclosure would incorporate a StratoLogger, a 9V battery, an acrylic glass face plate, and a screw switch that would be used to activate the altimeter.

Figure 83. Altimeter housing assembly.

The decision to use 3D printing of this component allowed for a unique design. The outer body of the housing has an outer diameter that matches the inner diameter of the coupler tubing where it sits in the fairing assembly. The housing hosts a body extrusion that will safely house a standard 9V battery. A vented lid was 3D printed separately. The lid is screwed in place and properly constrains the battery in place. Included in the 3D printed design are raised extrusions that will also be properly tapped to allow for the StratoLogger, screw switch, and the acrylic glass front plate to be securely mounted to the altimeter housing.

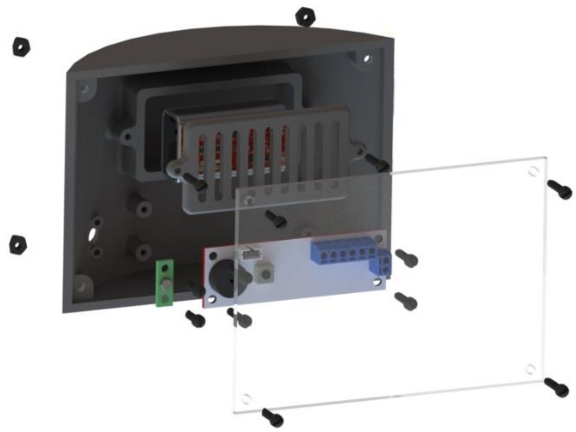


Figure 84. Exploded view of the altimeter housing.

Furthermore, there is a hole in the back of the altimeter housing which can be seen in more detail below in Figure 85. Once assembled, this hole will line up with a hole that will be drilled into the coupler tubing the altimeter housing rests in. This hole will allow access to the screw switch so that the altimeter can be armed on the launchpad.

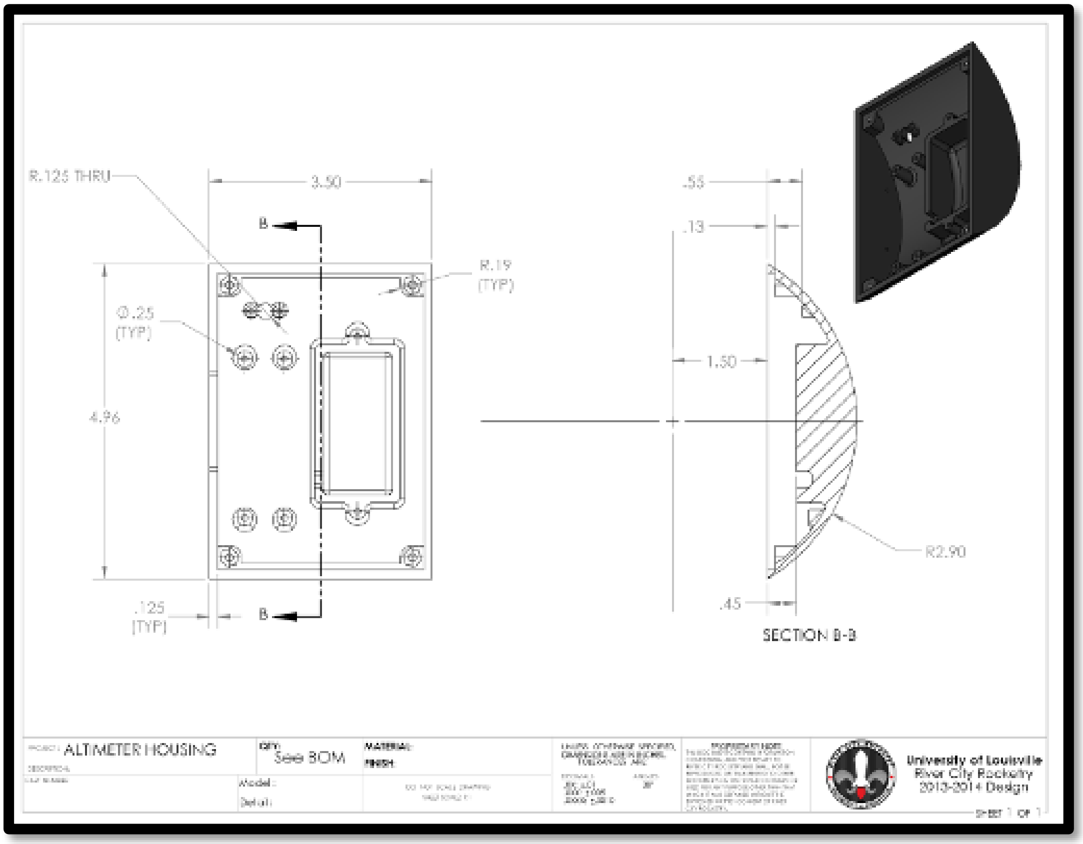


Figure 85. Altimeter housing basic dimensional drawing.

Utilizing information from StratoLogger's website, the port hole size for the altimeter housing was determined. Table 30 shows the information gathered and calculated from StratoLogger's website.

Avionics Bay			
Diameter (inches)	Length (inches)	Volume (in^3)	Single Port Hole Size (in)
1.6	6.0	12.06	0.032
2.1	6.0	20.78	0.048
3.0	8.0	56.55	0.113
3.0	12.0	84.82	0.17
3.9	8.0	95.57	0.202
3.9	12.0	143.35	0.302
5.5	12.0	285.10	N/A
7.5	12.0	530.14	N/A

Table 30. StratoLogger's volume to port hole size comparison.

In order to decide on the appropriate port hole size, the volume of the altimeter housing was calculated. This value was cross referenced against the information in Table 30 and the volume one step higher was chosen as guidance. A safety factor of 1.5 was chosen to influence the size of the final port hole size.

Altimeter Housing	
Volume (in^3)	12.92
Single Port Hole Size (in)	0.17
Safety Factor	1.5
Final Port Hole Size (in)	0.255

Table 31. Altimeter housing port hole analysis.

Table 31 shows the data used to determine the final port hole size for the altimeter housing. With the safety factor applied, it was determined that the ¼ inch hole used for the screw switch was adequate enough to act as a proper port hole for the StratoLogger.

Fairing Pyro Cap

The primary objective of the fairing is to safely deploy a specific payload at a predetermined altitude. The fairing is designed in such a way that the two halves of the fairing want to remain open in its equilibrium state. In order for the fairing to stay closed, thus encapsulating the payload, a 3D printed ABS plastic pyro cap and shell will be used to securely constrain the fairing shut. The shell that secures around the pyro cap is comprised of two sections, “Shell A” and “Shell B”. With the fairing being primarily completely symmetric in shape and split in halves, each bulkplate is a half-moon in shape. Each shell is securely mounted to its own half-moon bulkplate on one half of the fairing.

In the design of the pyro cap system, tolerances were a key item of concern. The shells had to be able to snuggly fit together, but could not be toleranced so tight that they would become stuck together if accidentally closed too tightly. In order to countreract this the radial dimension of the mating flange of Shell B was calculated and designed to a specific tolerance. Table 32 shows the maximum and minimum clearances for the fitment of Shell B into Shell A.

Shell B Clearance	
Maximum (in)	0.013
Minimum (in)	0.003

Table 32. Fitment clearances for Shell B into Shell A.

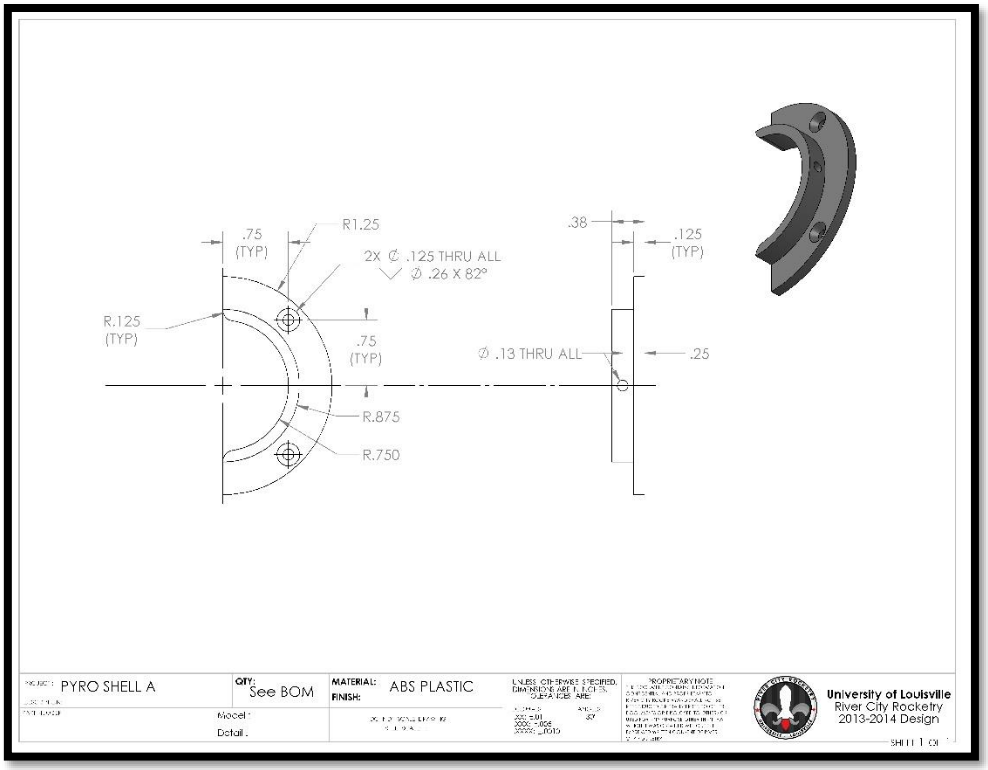


Figure 86. Detailed drawing of Shell A.

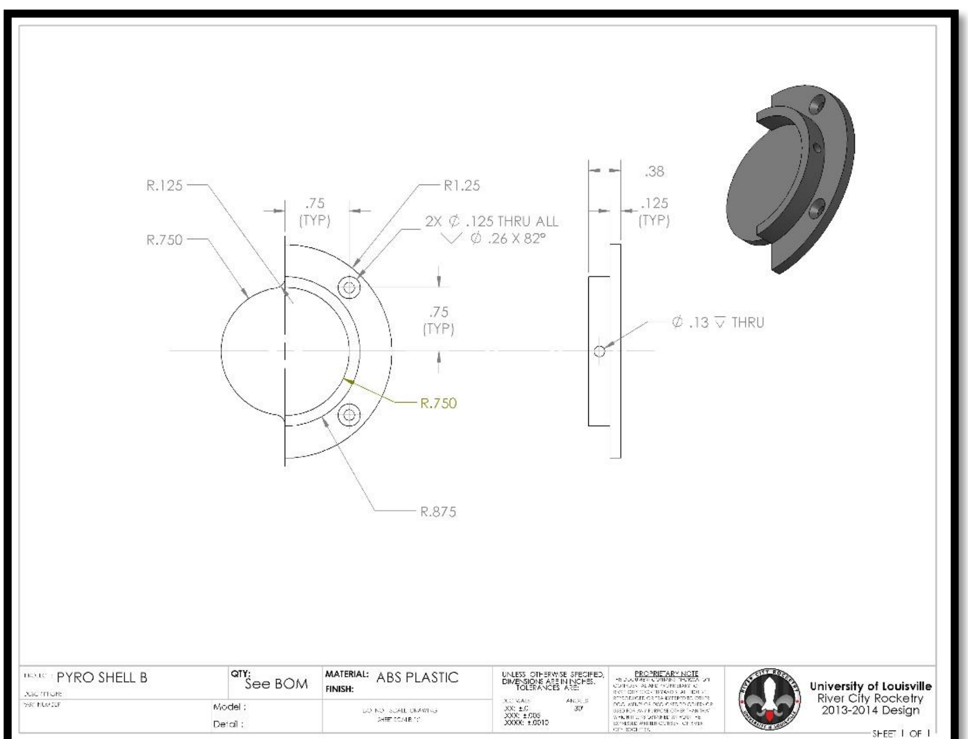


Figure 87. Detailed drawing of Shell B.

Similar to the tolerances going into the design of the two shell halves, the pyro cap went under the same rigorous precise design criteria to ensure a clearance fitment into the shells. Table 33 shows the clearance fitment for the pyro cap into the assembly.

Pyro Cap Clearance	
Maximum (in)	0.026
Minimum (in)	0.006

Table 33. Fitment clearances for the pyro cap into the shell components.

The pyro cap is designed to house two separate chambers for black powder charges. This is to ensure all rocket systems are fully redundant. To save space, the design was modified such that there are two concentric semi-circle black powder wells.

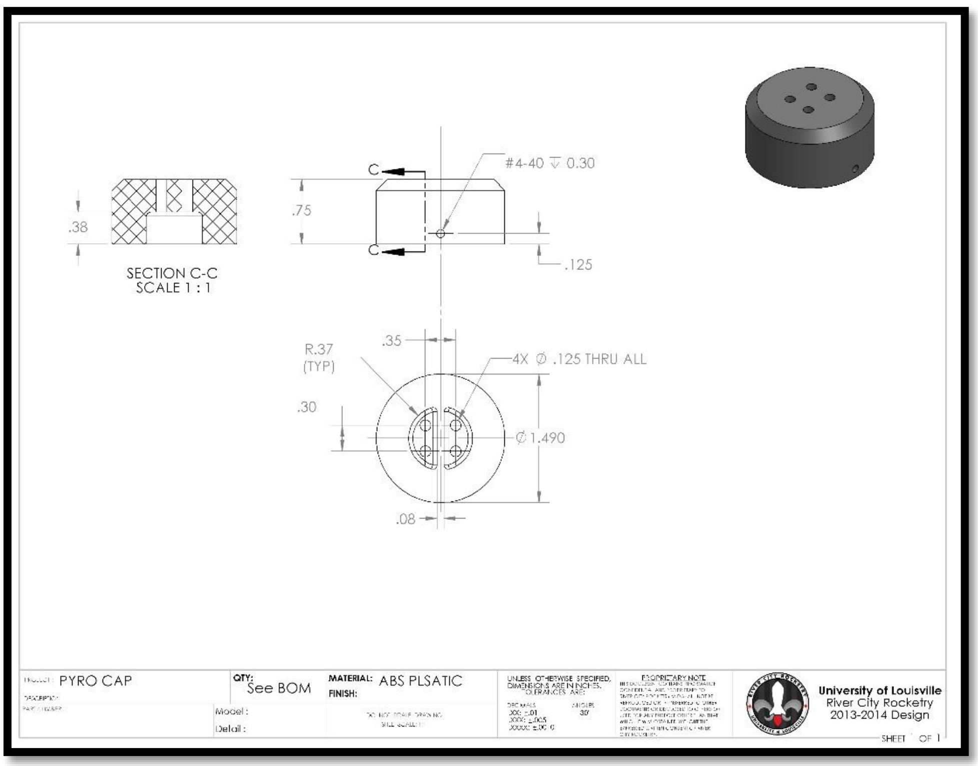


Figure 88. Detailed drawing of the pyro cap.

Pyro Cap Black Powder Well Dimensions			
Diameter	.75 in^3	Black Powder in Wells	
Depth	.38 in	1	2
Volume	.07 in^3	0.7 g	1 g

**Volume is accurate. The well is not an exact half semi-circle as there is a .08 in wall between wells*

Table 34. Black powder compartment dimensions.

Pyro Cap Black Powder Well Dimensions			
Diameter	.75 in3	Black Powder in Wells	
Depth	.38 in	1	2
Volume	.07 in3	0.7 g	1 g
**Volume is accurate. The well is not an exact half semi-circle as there is a .08 in wall between wells*			

Table 34 details the overall dimensions of the black powder chambers. By including two black chamber wells, the system is fully redundant. This is further accomplished by having two access ports for electronic matches in each black powder well. This was to ensure that in the event which the primary chamber's ignition fails to jettison the pyro cap, the secondary well will fire with more overall pressure.

As mentioned in Changes Made to Vehicle Criteria, the pyro cap was changed from its original design. Due to the multiple unknowns in the design and verification of the pyro cap, the original design was overly conservative in structural integrity. Wall thickness were unnecessarily thick, black powder wells were unnecessarily large, and overall the height was unnecessary.

We tested the original pyro cap in a large closed parking lot. The test stand was simple, and consisted of a board, with similar thickness of the bulkplate the pyro cap assembly would be mounted to, secured in place by a cinder block and an empty tool box. The pyro cap assembly was mounted to the board, the weights were placed on top of the board to hold it in place. An electronic launch controller with 30 feet of lead wires was used to safely ignite the black powder in the pyro cap. For the test, only the central chamber was used. The test plan was to test each black powder well at various increments of black powder.

Figure 89. Ejection charge ignition for the pyro cap.

Figure 89. Ejection charge ignition for the pyro cap.Figure 89 shows the ignition of the black powder ejection charge within the pyro cap. The explosion was violent and, as you can see in the figure, the cinder block actually lifts off the test bed. Only 1.3 grams of black powder was used in this test. Only about 10% of the black powder well was filled during this test. Seeing such a violent ejection with such little black powder, the team decided that a re-design was immediately necessary.

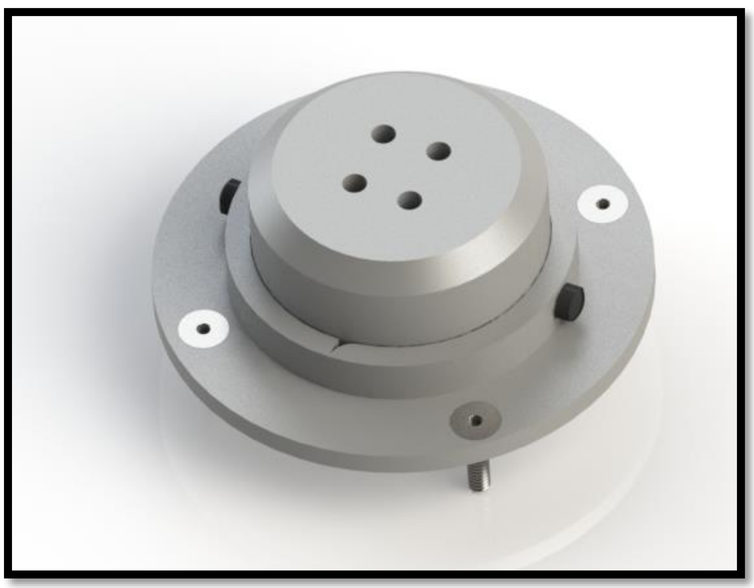


Figure 90. Newly designed pyro cap assembly.

The new black powder charge is roughly 60% smaller than the original design. The black powder wells were also sized more efficiently. After testing the new pyro cap, it was determined that 0.7 grams of black powder was enough to jettison the new pyro cap. The secondary chamber would then be filled with 1.0 grams of black powder. Due to the proper sizing of the new pyro cap black powder charges, the wells were sized such that 1.0 grams of black powder fills up just over 90% of the well. This allows both wells to be filled with their specific amount of black powder, and have enough room for protective wadding.

Prior to testing of the new pyro cap, the material was a point of concern. Due to the known combustion temperature of black powder, the team wasn't sure if the pyro cap would survive a single ignition. Furthermore, having just a .08 inch thick wall separating the two wells, there was uncertainty on whether or not the ignition of the first well wouldn't also blow a hole through the thin wall and immediately ignite the second well as well.

After testing the new pyro cap deployment system, the cap and shells were placed under scrupulous inspection. Neither the shells, nor the cap showed signs of damage. The thin wall between the two black powder wells also stayed intact. Multiple pyro cap assemblies were 3D printed in the event one sees irreparable damage after multiple uses, but it was determined that this new design would satisfy the requirements for a sound integration into the payload ejection system.

The pyro cap is secured into place by two 4-40 nylon screws. A #4-40 threaded eyebolt is to be epoxied into the top of the pyro cap. A section of Kevlar wound nylon cord will be tied from the eyebolt on the pyro cap to the eyebolt mounted to the bulkplate to the side of the pyro cap assembly. This will ensure that when the pyro cap is jettisoned from the fairing that it will not free fall to the round where it could cause damage people or property.

Payload Integration and Recovery Section

The final section of the fairing is self contained. This means that the section is completely seperated from the elements. The payload has to be constrained safely within the fairing. In order to do so the chosen method of constraint will be to have foam, that is specifically designed for aerospace applications, CNC'd to a precise geometric structure to securely house the payload. Utilizing these foam inserts allows for a modular design of the rocket in the sense that any sized payload can be launched as long as its dimensions fit within the airframe of the rocket. Only a new foam piece would have to be machined.

After re-evaluating the budget for the vehicle, it was decided that the previous foam selection was not worth the investment. The team tested Pactiv's 2 in thick polystyrene insulation sheets. Structurally, the foam is rigid, and easy to machine. This proved useful in shaping it to conform to the body of the rover. The material was tested in the first full scale launch of the launch vehicle, and the rover was unharmed. The team then used this information to decide that the use of the polystyrene insulation board was not only acceptable, but vastly more attracive due to it's low cost.

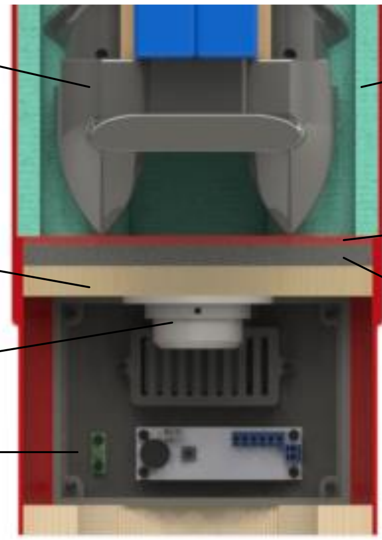


Figure 91. Integration of the payload into the fairing.

Figure 91 lays out the integration of the payload into the fairing. At the base of the fairing sits the altimeter housings. The StratoLoggers control the ejection of the pyro cap assembly which is mounted to the balsa bulkplate. To protect the payload from the acceleration of the launch vehicle, a shock absorbing foam material is located above the balsa bulkplate. To ensure the rover doesn't dig into the shock absorbing foam, a 1/8 in thick acrylic bulkplate is secured to the top of the foam. The rover sits on the acrylic bulkplate. During ascent, the force from the launch vehicle into the rover is evenly distributed across the acrlyic bulkplates and shock absorbing foam. This methodology has proven to safely house the rover during full scale testing.

Due to the nature of high powered rocketry, the design, form, and function of the foam inserts had to be able to stand up to the rigerous requirements called for in this field of rocketry. In order to determine the proper material, analysis was completed to ensure that the maximum pressure the foam inserts would see in it's smallest cross-section would not exceed the structural limits of the selected foam.

Foam Material Selection Analysis				
Max Acceleration (ft/s^2)	Force on Rocket ($ft\text{-}lb/s^2$)	Pressure on Foam (psi)	Safety Factor	Required Compressive Strength (psi)
341	24722.5	49.97	3	149.91

Table 35. Analysis to determine proper foam material.

A safety factor of 3 was used in determining the appropriate foam material. The primary reasoning behind this, was due to the fact that while this material is not necessarily untested, the application for its use is. Table 35 lays out how the minimum required compressive strength was determined. The simulated maximum acceleration of the launch vehicle was used to determine the force on the rocket. From there, the force was applied tested against the smallest cross-sectional area of the foam inserts. This gave the team an estimated pressure on the foam at the weakest point. By applying the safety factor, the required compressive strength was determined.

The two below figures further shows the process of the fairing's systems. The spring loaded payload actuation system has proven itself as a reliable means of payload ejection. With the foam inserts, the acrylic bulkplates, and the spring actuation, the payload can reliably be deployed during flight.

Figure 92. View of spring actuated payload ejection system.

Figure 93. Team member showing the actuation of the fairing.

Creating a launch vehicle with real world applications was the primary objective going into the design of the payload recovery system. A faring was designed to allow a nonspecific payload to be encapsulated inside. The fairing functions by housing an allocated payload within itself. When the payload is ready for deployment, the fairing is opened and releases the payload. This method permits a payload of any size to reside within the faring as long as its dimensions are able to fit within the allowed space of the airframe. A broad spectrum of payload shapes and functions can be used without interfering with the recovery. By this methodology, the team has developed a fairing system that has complete versatility.

PAYLOAD CRITERIA

EXPERIMENTAL CONCEPT

Creativity and Originality

The required hazard detection payload for the competition has been upgraded to include a rover. The rover concept was chosen as a means of incorporating all payload systems into a single package. The rover's mechanical structure is all custom designed and built, as well as the printed circuit board (PCB) that interfaces the microprocessor with all the required sensors and circuits. The rover uses several original systems such as the power screws for movement, which has only been done a few times before. Using power screws is a creative method of obtaining an all-terrain vehicle as it only requires the screws to slightly dig into the ground to begin movement. By having a mobile platform, the detection system is not limited to operation during descent but it may be used on the ground as well by having the rover drive around in many terrains. To insure that the rover's parachute does not get tangled with the screws, an original system was designed to release the parachute from the rover. This system as well as other components on the rover are 3D printed. This allows the team to be as creative as possible since complex parts are easily produced.

On the electronics side of the rover, the team had to be creative in designing the circuits to fit on a PCB the size of the BeagleBone Black microprocessor. One of the highlights of the electronics is the Pulse Width Modulation (PWM) circuit that sends the signal to operate the motors. This system could have been done in software but since image processing was resource intensive, it was decided to create the signal using hardware.

The software team was able to create an original custom Android app to receive data being transmitted by the rover. This allows anyone with an Android phone to enter their phone number into the program and receive data from the rover. Some of the data being sent includes GPS coordinates and the results of the hazard detection program. Since the team is using the OpenCV image processing library, the team is able to be creative as they want to detect any hazards they wish to program.

Uniqueness or Significance

The hazard detection payload is unique as it attempts to integrate several systems onto a rover. The significance of why a rover was chosen is because a hazard detection system would fit well into any rover's sent to other planetary bodies to insure they land safely. This payload is unique as it could be able to drive to the location of the detected hazard pending further work. Image processing onboard the rover is very significant, since object detection/recognition is an important topic that would allow the automation of many tasks. By using a BeagleBone Black, the payload becomes even more unique as this is a fairly new platform which is capable of running several complex tasks.

The rover is very significant since the team attempts to engage the public in space exploration and other activities by bringing attention to the rover's that are on other planetary bodies. Not only does the team hope to attract attention towards space, but since many of the parts are 3D printed, the team will try to educate the public on the use of this new technology. The rover concept is significant as it attempts to draw more attention than just having a hazard detection system. Overall, this payload achieves many complex tasks that could be useful for future planetary missions, and is also able to engage the public due to the unique rover design which is sure to attract attention.

SCIENCE VALUE

Payload Objectives

The success of the recovery mission depends directly on the success of the scientific payload. The camera on the rover determine the success of the mission through visual recognition of hazards. For all intents and purposes, the hazard detection will begin once the payload has been deployed from the fairing. It should be noted that the detection of hazards shall be active during the entire flight, it will only be able to detect once it is released from the fairing.

The purpose of this payload will be to scan the terrain for potential landing hazards, using a custom software package. The data from the hazard camera will be processed onboard by the BeagleBone micro controller and transmitted to a ground station in real-time. The system must meet the following objectives in Table 36 as set forth by the Statement of Work (SOW) to be considered a success. Requirements marked with an asterisk (*) are additional standards that were set by the River City Rocketry Team.

1. The payload shall incorporate a camera system that scans the surface during descent in order to detect potential landing hazards.
2. The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.
3. The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station.
4. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical onboard component.
5. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.
6. The electronic tracking device shall be fully functional during the official flight at the competition launch site.
7. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.
8. *The rover must successfully release its parachute once landed.
9. *The rover must travel at least 20 feet once it has landed.
10. *The system will report any errors preventing full functionality.
11. *The system will wait until the launch phase of operation to perform in-flight activities.
12. *The system will send an acknowledgement of the launch event in real time to an Android device.

Table 36. Payload Objectives

Payload Success Criteria

To determine a successful mission, we expect the payload to meet the following. Objectives of the mission include: detecting apogee, recording local hazards, landing safely, and collecting/transmitting environmental data to a designated device. Explaining further on the mission success, we are testing unconventional locomotion methods on this rover, given a safe landing is achieved.

Once the rover lands on terra firma, the vehicle is pushed along its course by the pontoon-like screws that run the length of the rover. A successful test of this kind of locomotion could lead to a new form of movement that does not experience the same challenges of wheeled translocation. In the event that our payload system meets the criteria listed below, we would classify the final test a success (as per Statement of Work).

1. The GPS coordinates sent to webserver must match the expected the location.
2. Each of the tested hazards must be able to be detected and identified correctly 90% of the time.
3. Data is sent to webserver correctly 90% of the time.
4. Rover is able to detach parachute and drive off safely for at least 20 feet.
5. All electronics must be operational after 1 hour with the same power supply.

Table 37. Payload Success Criteria

Experimental Logic, Approach, and Method of Investigation

Due to the nature of a hazard-detection payload, most of the experiments to be performed by the payload will be evaluated on a pass or fail basis. To verify that our software package is correctly registering and identifying hazards, we will have to visually compare that the object identified in an image is the hazard that we were looking for. The hazard detection of the payload is based on the OpenCV framework. The image processing program will be tested to ensure that it identifies any of the hazards. The procedure for testing visual recognition will first be done on static pictures that will be filtered for hazards. After the static pictures have been filtered, we will move on to filtering dynamic video from the integrated USB camera. The results of the tests will then be communicated from the payload as a pass or fail.

The experimentation of the rover will be testing the ease and predictability of movement. It will test the ability of the vehicle to traverse the encountered landscape of the landing area. Testing with the unconventional transportation of the screws will give us insight on the system's feasibility as a "most-terrain" vehicle. We predict that the screws will offer more stability on a variety of terrain than their wheeled counterparts. As one example, the screws have traction all along the axis of rotation. Conversely, the wheels of a standard rover only have "n" number of contact areas, (where n = number of wheels).

The approach to the experiment be predicting distance travelled and efficiency of travel with the technology being qualified on the rover. Our method of investigation pertaining to the locomotion will be to design the optimal algorithm for traversing the given terrain. One of our options is to alternate which screw of the rover is active (for turning purposes).

We will also verify the optimal speed setting for the active motors. Due to our chosen setup, the motors will have a constant speed when active. Therefore the screws will either be turning or not. Tests have been conducted on farmland, but will continue for several terrains to insure that using power screws is a viable method of locomotion. Similar to the image processing, a pass or fail will be given to the system.

The approach to the experiment will be predicting distance travelled and efficiency of travel with the technology being qualified on the rover. Our method of investigation pertaining to the locomotion will be to design the optimal algorithm for traversing the given terrain. Tests will be conducted on several terrains to insure that using power screws is a viable method of locomotion. Similar to the image processing, a pass or fail will be given to the system.

The experimental logic behind the pressure sensor will be to insure that it can accurately read different pressure values. These values are of significance as it tells the payload what altitude it is at. This is important not only for payload events, such as activating the parachute cam, but it provides a method of analyzing the rover's parachute. This will be good in determining if it was sized correctly. The approach that will be taken is to have several launches with the pressure sensor on a rocket, and then comparing these values to an altimeter. If the values are similar than it will be given a pass.

The experimental logic behind the pressure sensor will be to ensure that it can accurately read different pressure values. These values are of significance as it tells the payload what altitude it is at. This is important not only for payload events, such as activating the parachute cam, but it provides a method of analyzing the rover's parachute. This will be good in determining if it was sized correctly. The approach that will be taken is to have several launches with the pressure sensor on a rocket, and then comparing these values to an altimeter. If the values are similar than it will be given a pass.

Test/Measurement meaningfulness

Pressure sensor tests are extremely important to ensure that the payload works. If launch/landing detection are not working, the rover's parachute will not release, hazard detection results will not be transmitted, and the rover will not driver forward, resulting in failure of a fair portion of the electronics team's additional requirements.

Data on reliability of the hazard detection algorithm will be useful for determining if the algorithm is actually useful for meaningfully scanning for hazards.

Rover drivability measurements will also be very meaningful for the success of the mission, since the drivability of the rover on different terrains is one of the main objectives the team is trying to test.

Variables

Since the rover will be ejected from the fairing in the air, there are many variables that could affect this payload. The main variable that could affect this payload is weather conditions. The reason is that high winds could cause the rover to spin on descent which could blur the images the camera captures. This could cause the software programs to misidentify a hazard. A second variable will be the different shapes and sizes of the hazards that the software will be trying to identify. For example, a hazard we will scan for is a crowd which can be in any shape or color. The next variable that could affect the payload is the data that the BeagleBone is handling. If the BeagleBone captures an image which takes longer to process for hazards, the transmission to the ground station would be delayed. The next variable that this payload will experience is altitude. At higher altitudes, the camera may have a harder time discerning shapes which could cause hazard misidentifications. The final variable that will greatly affect the rover is the terrain, as the power screws might react differently. To fight against these variables, the team will have to design several experiments to test how much the payload is affected and attempt to find a solution.

Controls

To test the functionality of the hazard detection payload, the team has some options it can use as controls. The main control will be at what altitude the rover is deployed from the fairing. The team will attempt to deploy the rover at several altitudes to see when software is able to detect a hazard. After an acceptable altitude has been identified, this will become a control point for the rover. A second control the team has is what hazards the software will be looking for. By narrowing it down to a few hazards, system resources will be freed up, thus increasing performance. A third control the team has is how the data is encrypted when sending it to the ground station. By choosing an encryption method, the latency in data transmission may be decreased. A final control point is the design of the rover. This will allow the camera to be orientated in the best orientation possible so that it can better detect hazards.

Expected data

Data will be gathered when testing the rover on various terrains. As previously mentioned, the data received will be Boolean, pass/fail answers to questions such as "Does the rover drive on the Salt Flats?"

To test the pressure sensor, pressure readings will be taken from the sensor and compared to an external source, such as a website or another sensor. The units of the readings will be in some unit of bars, such as millibars. If the values of the two readings correspond fairly closely, the team will know the pressure sensor is functional.

Data from the hazard detection system will consist of a series of images, along with an indication of which, if any, hazards were detected in these images. The team can pre-screen the images to determine the number and types of hazards in the images. Then, the totals returned from the image processing algorithm can be compared to the pre-screened totals. This will allow the team to determine how close the algorithm gets to detecting the correct numbers of and types of hazards in the images. The data that is collected from the hazard detection payload is very significant as object recognition via images is a topic that is of great importance. By having a successful payload, the team will be able to demonstrate a possibly cheaper method of achieving this. By improving upon the information obtained from the team's payload, this system could be used by others to detect terrain hazards for other rovers sent to other planetary bodies. By doing so the best landing zone could be identified, thus potentially improving the mission's success.

Components	Accuracy Description
Telit GE864 – GPS Receiver	GPS is accurate to less than 2.5 meters when it's between -40C and 80C. Sensitive up to -163dBm on 48 channels.
BMP180 Pressure Sensor	The pressure is accurate from ±0.12hPa and its resolution is 0.01hPa.

Table 38. Component Accuracy Description

<u>Experiment process procedures</u>

To test rover traction, the rover will be placed in various positions on different terrain types. Also, the rover will be given different starting locations on different terrain types. For example, in an area where the rover gets poor traction, the rover will then be placed in a location with good traction to test what will happen when the rover initially has a good "foothold".

To check that the launch/apogee/landing events are detected, the pressure sensor will be connected to an LED. To check for launch detection, the pressure sensor will be rapidly raised in the air. The pressure sensor will be programmed so that if launch is detected, the LED will display. The same method will be used to check landing detection, except the device will be rapidly lowered in the air. To check for apogee, again the same method will be used, but the device will be first raised in the air and then lowered.

PAYLOAD DESIGN

The purpose of the hazard detection payload is to incorporate a system aboard the rocket that is capable of scanning the terrain during descent for any landing hazards. To accomplish this goal, the team has decided to design a rover that will contain all of the required electronics. A webcam will be attached to a BeagleBone Black microprocessor, which will be doing real-time image processing aboard the rover. The hazard data as well as GPS coordinates and flight events will be transmitted via SMS to an Android phone which has a custom made app that will interpret the sent data. The rover will be using power screws for movement that will be activated once the rover detects landing. To prevent tangling with the parachute, a release mechanism called a parachute cam has been designed. This payload will be housed inside a fairing in the rocket which will open up during descent to deploy the rover with its own parachute. The hazard detection payload has been divided up into electrical, software, and mechanical subsystems which are discussed in the following sections.

Rover's Structural Elements

The rover that was designed by the team was inspired by the ZIL-2906 which was a Soviet vehicle to recover cosmonauts in remote places. By using power screws, the vehicle only needs to slightly dig into the ground to obtain traction. A Hot-Wheels RC toy called the Terrain Twister also incorporates the use of power screws for movement. These two vehicles are shown in Figure 94.

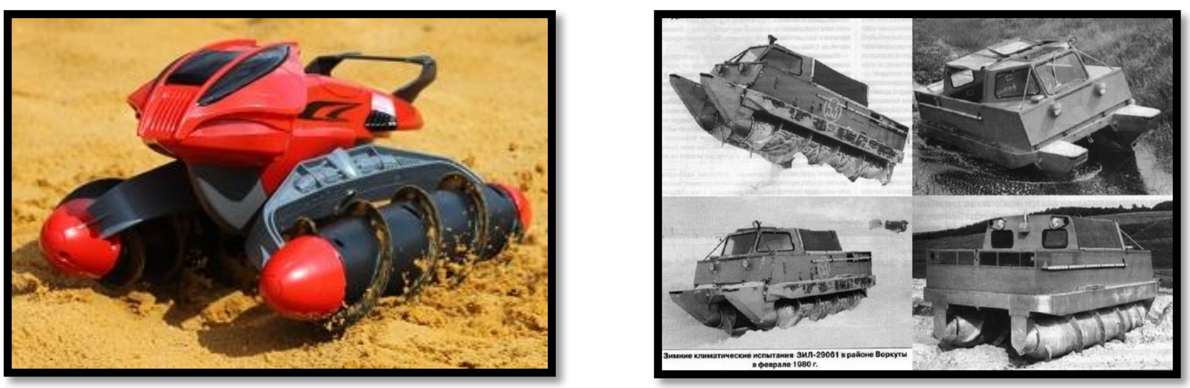


Figure 94. Terrain Twister (Left), ZIL-2906 (Right)

Similar to the previously mentioned vehicles, the rover the team designed uses one power screw on each side of a platform to which they're attached to. The platform is where all the electronic components will be mounted. Figure 95 through Figure 98 shows the rover that was designed without the parachute cam included as a new one is being 3D printed. Figure 99 shows the general dimensions of the rover.

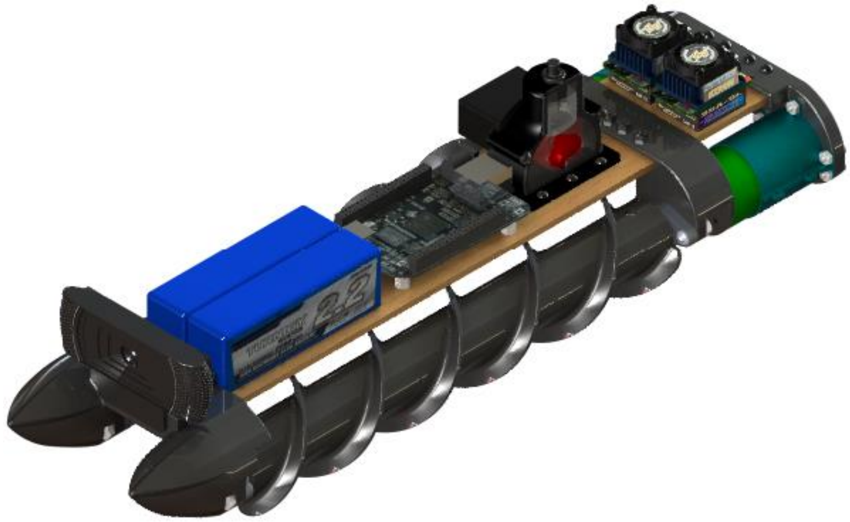


Figure 95. 3D Model of Rover

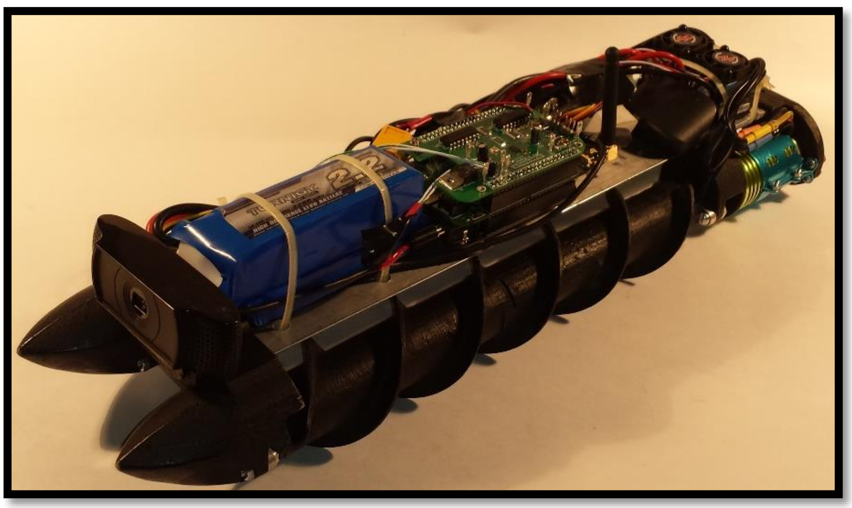


Figure 96. Picture of Assembled Rover without Parachute Cam.

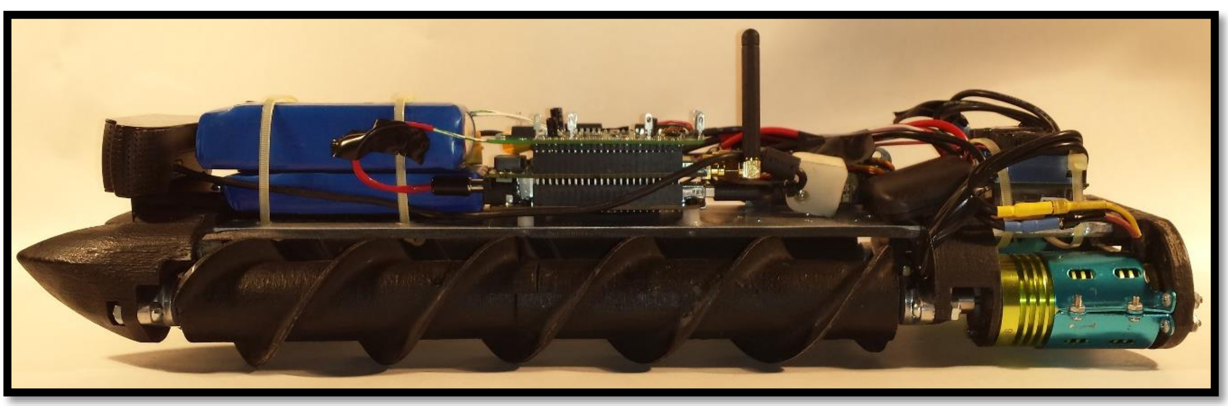


Figure 97. Side View of Rover

Figure 98. Front View of Rover

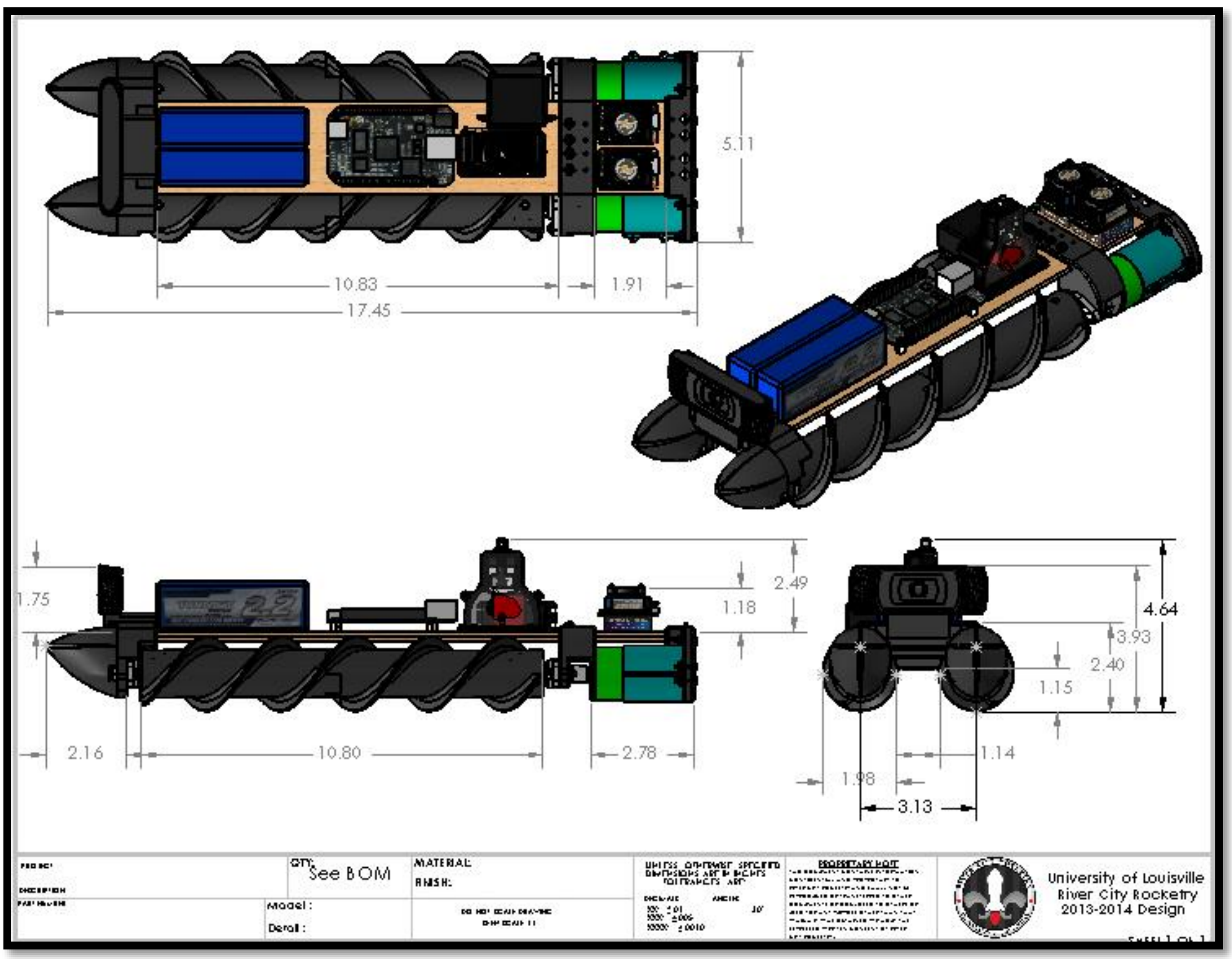


Figure 99. Rover's General Dimensions

As can be seen from the images above, the final rover design differs slightly from the model. The two main structural changes to the rover since CDR were that the electronics platform was changed to aluminum instead of wood and the parachute cam was redesigned by increasing the wall thickness. The rover weighs 5 lbs 1oz, and is 5.11in wide, 4.64in tall, and 17.45in long. The rover's dimensions were driven by the need to fit inside the 6in airframe of the fairing it is housed in.

All of the electronics are placed on top of a 15.5in x 2.5in platform that is 0.25in thick. 6061 Aluminum was chosen due to its improved structural properties compared to wood. Another reason aluminum was chosen is that it is easy to work with.

Due to the rover's weight distribution, the webcam was mounted in front of the rover so that it faces downwards during descent. To attach it onto the rover, the foldable stand it was attached to was cut in half and holes were drilled through it so that screws could be hold the webcam in place. The LiPo batteries were stacked on top of each other so that that holes could be made around them. These holes are used for zip-ties to go through and secure the batteries in place. Velcro was also attached to the bottom LiPo to further insure that it stays in place. Similarly, the ESCs are being held in place by zip-ties which are held in place via notches in the aluminum platform and they have Velcro on the bottom to help retain them in place.

The BeagleBone is located after the LiPos and is attached to the electronics platform via Nylon male-female standoffs. Holes were tapped so that the standoffs could be held in place. Plastic adhesive was used to further prevent the standoffs from falling out. The reason Nylon standoffs were chosen was that it is not electrically conductive which helps protect the BeagleBone since the platform is metallic.

The Parachute Cam is attached to the aluminum platform via metal 4-40 screws. Next, the motors are held in place via clamps that go around them. These clamps are then screwed into the rear plate on the rover.

Power Screw Design

The main mechanical feature of the rover is the use of power screws to move the rover. Each of the power screws was 3D printed from ABS plastic using Selective Laser Sintering (SLS). Due to size limitations, each of the screws was printed in two sections. The screw slope angle was determined to be 16 degrees due to information from a previous study ("Terramechanics-based Propulsive Characteristics of Mobile Robot Driven by Archimedean Screw Mechanism on Soft Soil" 4946-4951). Also based on this study, the pitch for the threads was chosen to be 4 inches, and the blade height is 3/8 inches. The total length of each screw is 10.8 inches.

Each half of the power screws has tabs that allow them to interlock to insure that the threads are aligned. To hold them together, two aluminum hubs are screwed into flanges on the ends of each screw. A 0.25in diameter D-shaft is then inserted through the middle of the hubs and screws. A grub screw attaches the shaft to each of the hubs which causes the screw assembly to stay together. The shaft extends on each side to allow it to rest on aluminum bearings which are screwed into 3D printed plates. To join the motor's shaft to the power screw's shaft, a coupler is being used. An exploded view of this process is shown in Figure 100. Figure 101 shows a bottom view of the rover to better illustrate how the power screws are assembled.

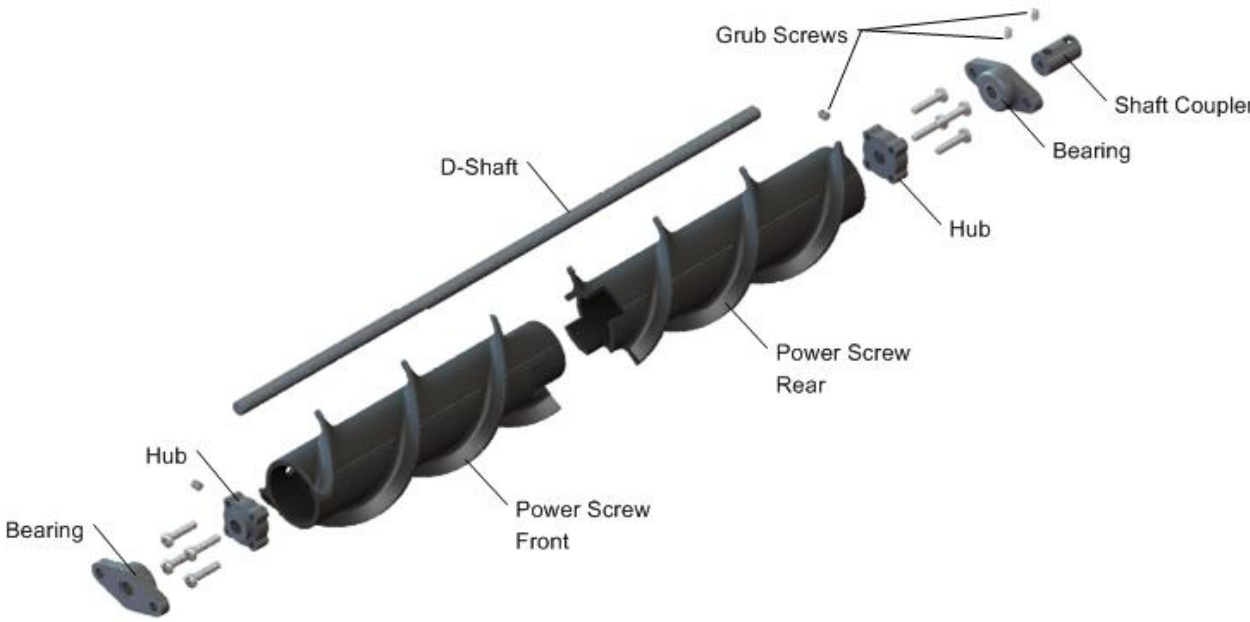


Figure 100. Exploded View of Power Screw Assembly.

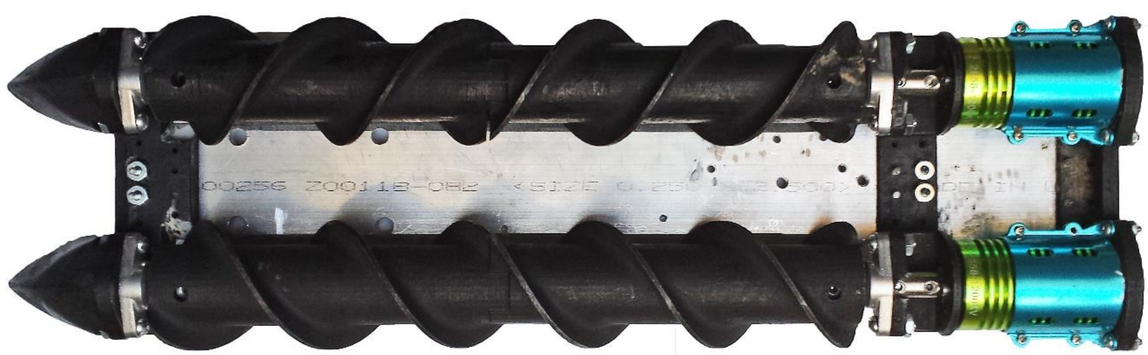


Figure 101. Bottom View of Rover

Parachute Cam Assembly

The parachute cam is responsible for attaching the parachute onto the rover. It is also responsible for detaching the parachute from the rover upon landing so the lines do not get tangled with the rover's screws. A 3D model of the parachute cam is shown in Figure 102. Unfortunately, the parachute cam was the only casualty on the rover from when the rocket crashed. The rover fell without a parachute and the assembly broke upon impact. The only picture that was taken of the finished assembly is shown in

Figure 103. Currently the parachute cam is being 3D printed again and will be ready for the competition. The only modifications will be to increase the wall thicknesses.

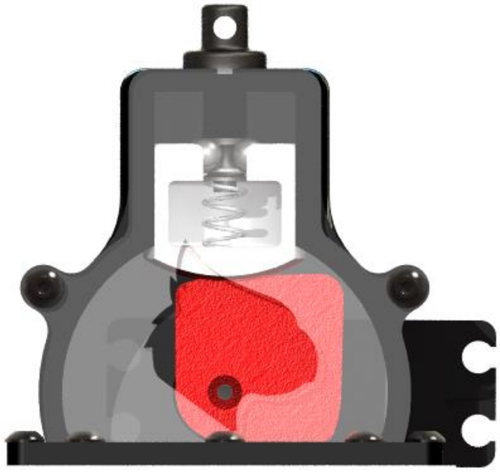


Figure 102. 3D Model of Parachute Cam

Figure 103. Only Picture of Parachute Cam

When the pressure sensor on the custom PCB determines that it has landed, it causes the BeagleBone to activate the servo that is attached. The servo is attached to a cam which holds the piston in place. The spring acts to push the piston downwards, and by rotating the cam 180 degrees, the spring is over powered and the piston is pushed upwards. By pushing the piston upwards, the four ball bearings fall into the empty space beside the spring. The purpose of the ball bearings is to hold the pin as it has a groove for the bearings to fit into. With the ball bearings out of the way, the spring decompresses and ejects the pin. The pin has a hole to allow the parachute lines to go through. To prevent these components from coming out of the housing, a cover made out of clear acrylic screws onto the front. To add to its custom uniqueness, the school's mascot is cut into the cover. An exploded view of the parachute cam is shown in Figure 104.

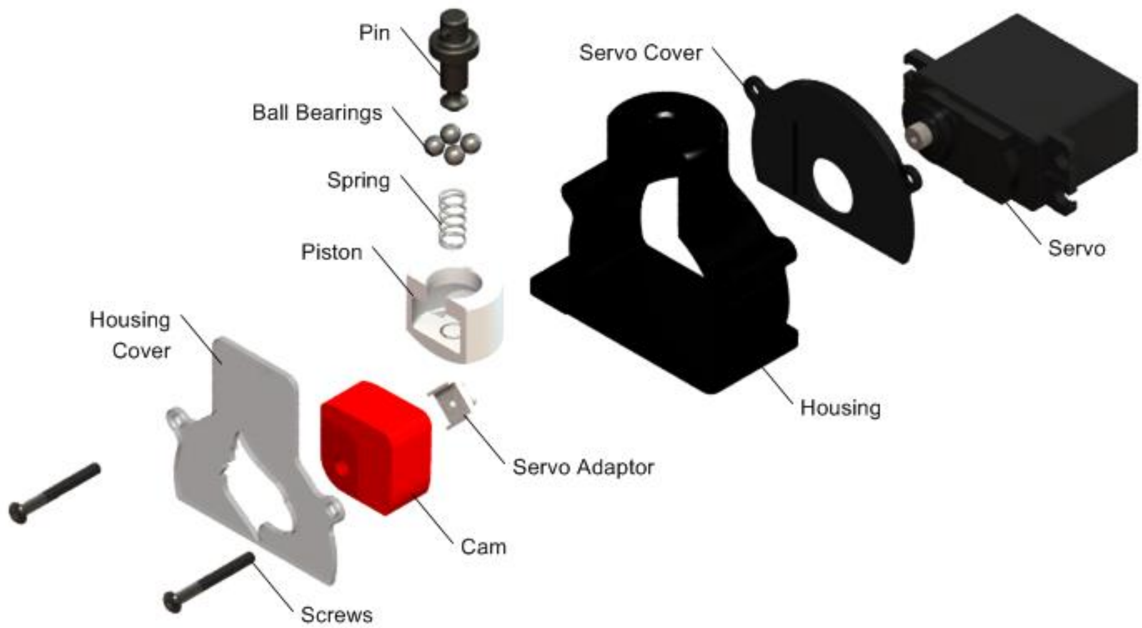


Figure 104. Exploded View of Parachute Cam

All of the plastic components were 3D printed using SLS technology. The pins are machined out of 1018 Low Carbon Steel which has a yield strength of 54,000psi, so it will be able to sustain the force from opening the parachute without any problems.

To insure that the plastic and the entire system as a whole could sustain the impact forces, parachute lines were attached to the pin and the rover was dropped several times. A team member would only hold onto the parachute lines so that the parachute cam would experience the full weight of the rover. During testing, the pin never came out and the housing did not break. To further insure that the plastic can hold up to the impact stresses of opening the parachute, the next version of the parachute cam will be made with thicker walls.

References

Kenji Nagaoka, Masatsugu Otsuki, Takashi Kubota and Satoshi Tanaka. *Terramechanics-based Propulsive Characteristics of Mobile Robot Driven by Archimedean Screw Mechanism on Soft Soil*. Taipei, Taiwan: IEEE, 2010. 4946-4951. Web. 3 Jan. 2014.

Rover’s Electrical Elements

To process all the information that is required to operate the payload, a BeagleBone Black microprocessor was chosen to be the brains of the rover. Off-the-shelve products were obtained to make the payload’s hardware requirements minimal. Figure 105 shows the general layout of the electrical hardware aboard the rover, excluding any power sources.

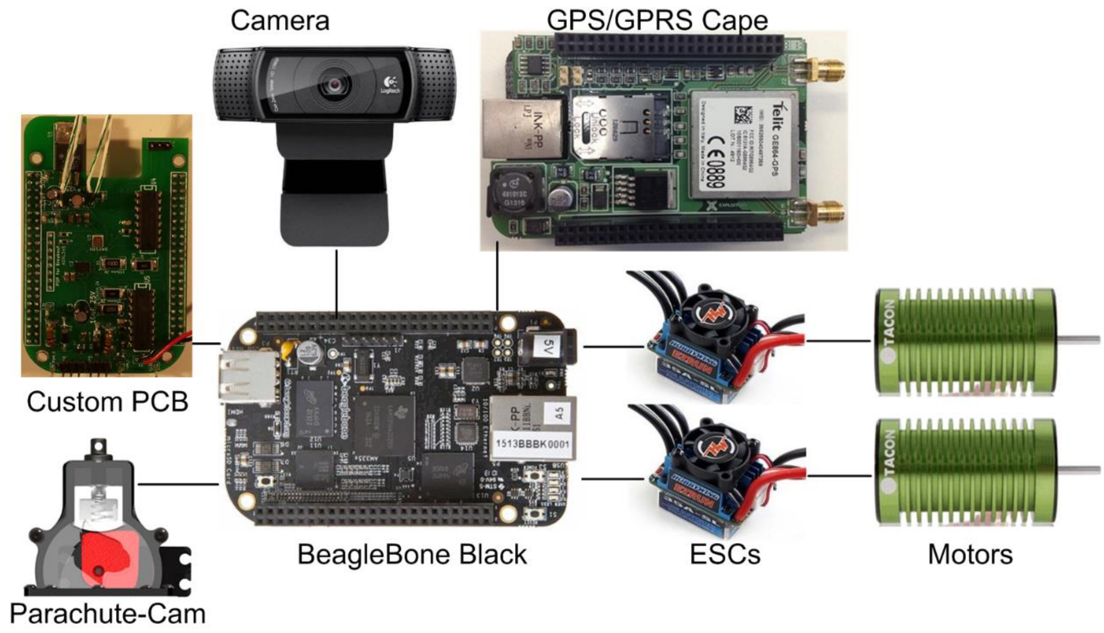


Figure 105. Electronics Layout

BeagleBone Black

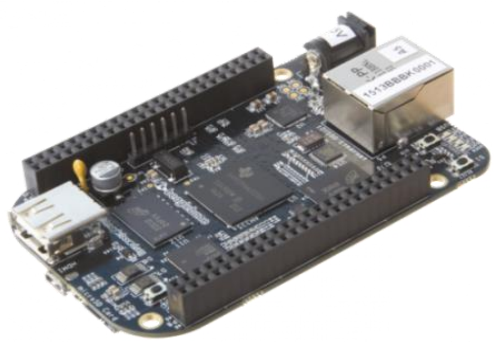


Figure 106. BeagleBone Black

As previously mentioned, the brain of the hazard-detection operation is a BeagleBone Black (BBB) which is a Linux based microprocessor. The BeagleBone is responsible for reading in data from various sensors such as the camera, performing processing on that data, and taking action accordingly. The main reasons the BeagleBone Black was chosen was due to its 1GHz ARM processor, 65 GPIO pins, and compatibility with OpenCV.

The BeagleBone is able to support both of the PCBs we have mounted on top of it without significant performance deterioration. The BeagleBone only requires 460mA @ 5V to operate. It weighs in at 1.4oz and is 3.4in x 2.1in.

OpenCV has been proven to work with the BeagleBone by running several image processing tasks which are discussed later. The BeagleBone has also been operated with both of the PCBs attached and it has been able to operate normally. All of the software code is stored on board of the BeagleBone and is operational.

Logitech C920 HD Pro Webcam

Figure 107. Logitech C920 HD Pro Webcam

The camera is the second most important payload component since it is responsible for obtaining images used for the hazard detection. The C920 attaches via a USB cable to the BeagleBone Black. The USB cable had to be cut since it was 6feet long. After it was cut, the team ran several image processing tasks to insure that it did not suffer any performance deterioration. The C920 weighs in at 4.8oz. The foldable stand it comes with had to be cut to save room on the rover. The team took apart the webcam before cutting and drilling holes to insure no wires would be damaged.

GPS/GPRS Cape

Figure 108. GPS/GPRS Cape

This cape is responsible for obtaining GPS coordinates and then transmitting information back to an Android device. The cape has a Telit GE-864 which obtains and transmits data by using a cell-phone network. The cape attached to the BeagleBone via male-female header which allows our custom PCB to mount on top of it.

By using this cape, the BeagleBone gains GPRS capabilities which stands for General Packet Radio Service and is considered to be in between 2G and 3G networks used for cell-phones. Since the team is sending the hazard and GPS data via SMS, T-Mobile has been chosen as the network provider. The reason T-Mobile was chosen was because it was used last year and proved to be reliable. T-Mobile also offers a $3 pay-per-day plan which allows us to only pay on the days we use the cape. This allows the team to keep the costs down. All that is needed from T-Mobile is a SIM card which attaches onto the cape.

Since the cape uses a cell phone module, the power transmission is controlled remotely by the closest cellular base station. The station dynamically assigns a power level with the intent to maintain good signal-to-noise ratio while limiting interference, overloading, and power consumption. The Telit GE-864 GPRS module is rated for different classes which control the power levels it can be assigned by the base stations. The GPS module is also assigned an operating range called a level but this is not controlled by the base stations. The information for each of the modules onboard is shown below.

Module	Class/Level	Power (W)	Frequency (MHz)	Sensitivity (dBm)
GPRS	1	1	1800/1900	106
	4	2	850/900	107
GPS	L1	---	1572.42	163

Table 39. GPRS and GPS Frequencies, Power, and Sensitivity.

The team has only been able to test the signal strength on the ground since the BeagleBone was not placed on the rover during the first flight which proved to be wise as the rover fell without an open parachute. The team plans to launch the rocket the weekend after the FRR is due and the signal strength at 10k ft will be tested then. T-Mobile offers maps of the areas they provide coverage in and each of the fields the team expects to launch in has decent coverage at the ground level. Figure 109 through Figure 112 shows the coverage maps from T-Mobile’s website.

Figure 109: T-Mobile Coverage for Louisville, KY

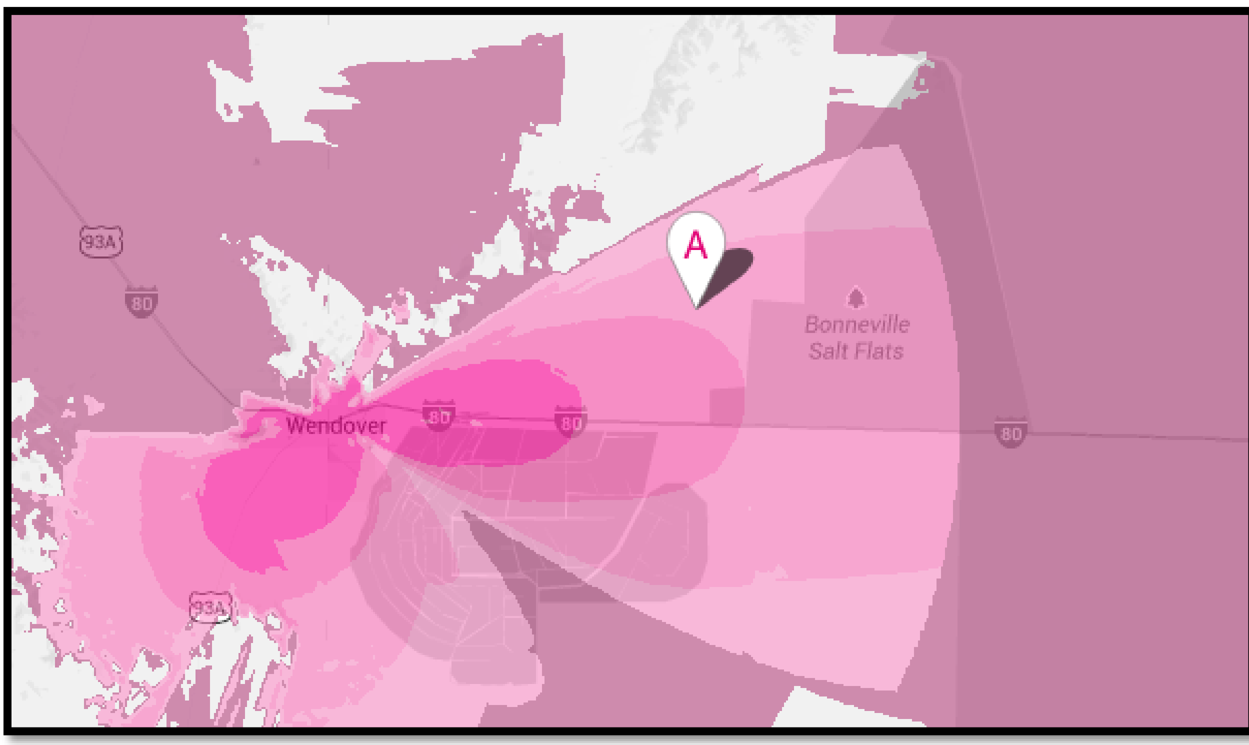


Figure 110: T-Mobile Coverage for Bonneville Salt Flats, Utah

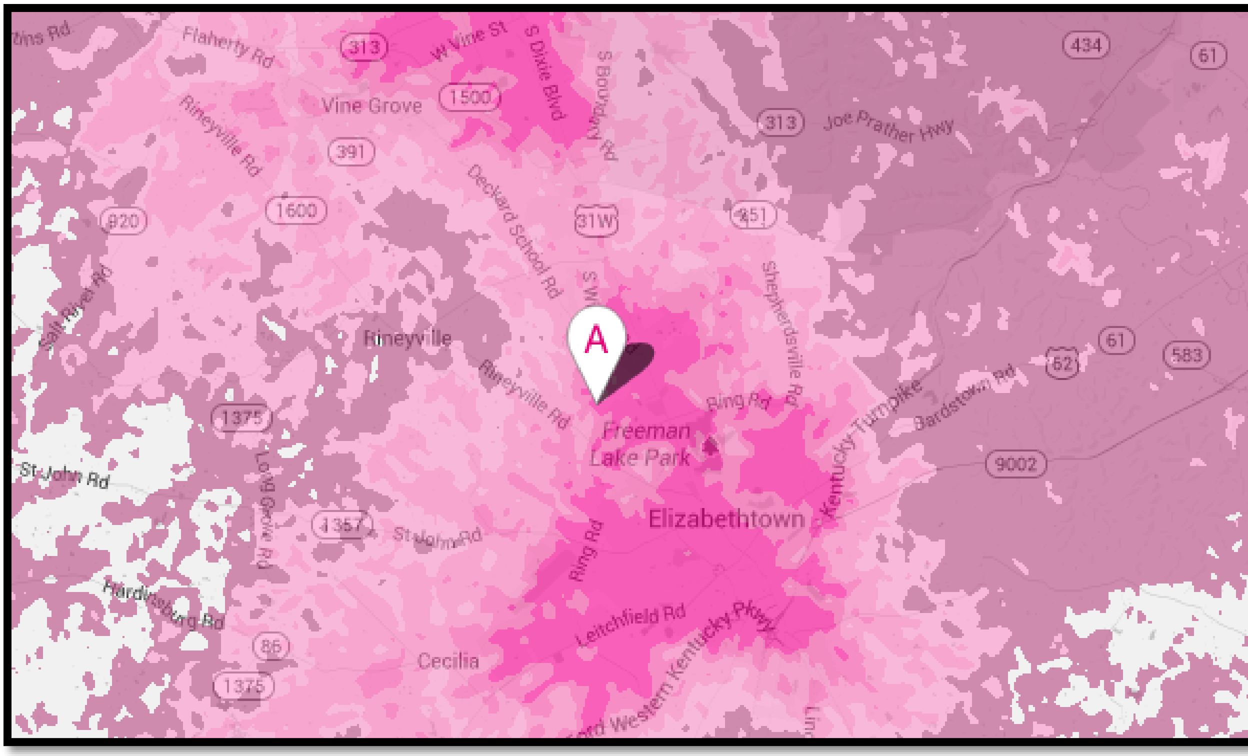


Figure 111: T-Mobile Coverage for Elizabethtown, KY

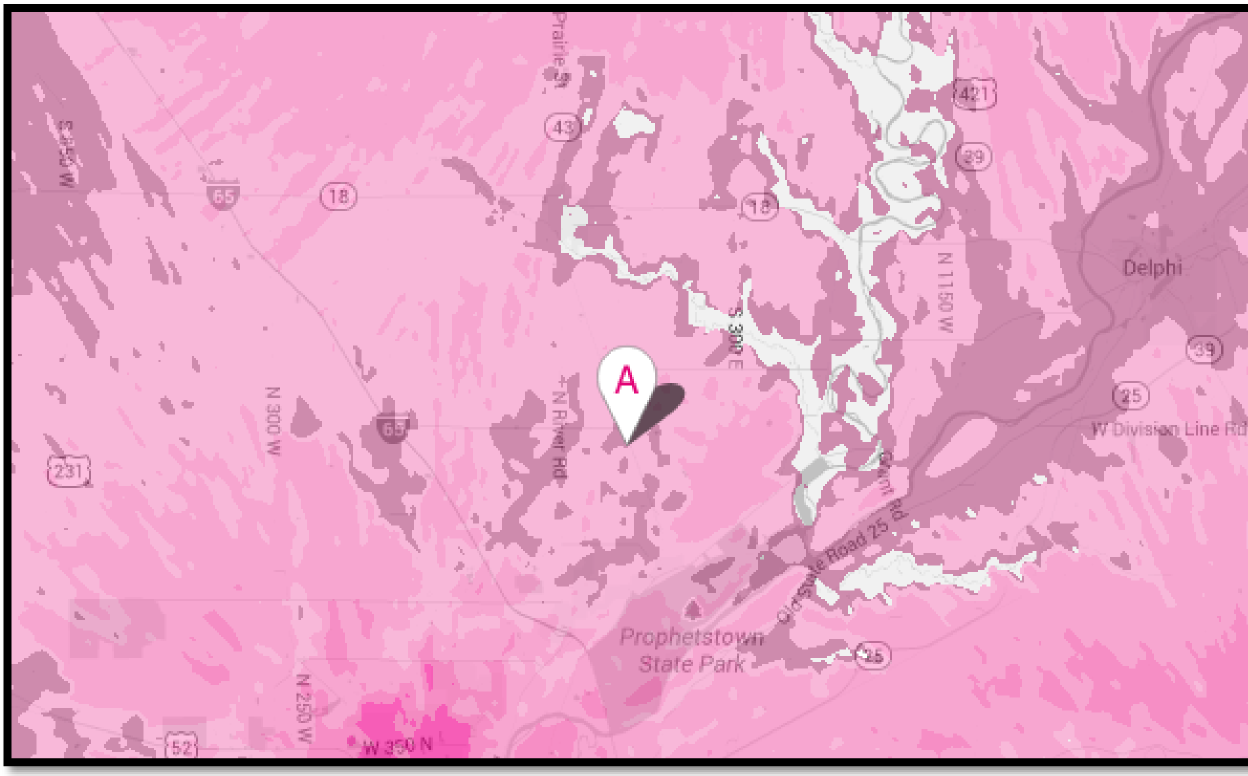


Figure 112: T-Mobile Coverage for Ash Grove, IN

HobbyWing 35A EZRUN ESC

Figure 113. HobbyWing 35A EZRUN ESC

The Electronic Speed Controllers (ESCs) are an off-the-shelve item responsible for generating the 3-phase signal that is required by the motors. A Pulse Width Modulation (PWM) signal from the custom PCB will be sent to the ESCs to control when they are on or off. The ESCs also have a built-in overload protection circuit and feature a small fan unit to cool down the ESC in case it overheats. A 35 amp ESC was chosen since each motor can draw up to 20A, but to protect the ESC from any sudden spikes, a higher value ESC was chosen. The ESCs have been tested to operate with the PWM circuit on the custom PCB.

Tacon 1200KV Brushless Motors

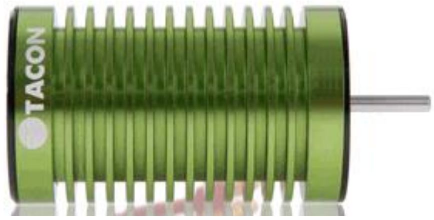


Figure 114: Tacon 1200KV Brushless Motor

The motors that will be used were mainly chosen for the torque they provide. These motors have a 1200KV rating which means they will rotate 1200 times a minute per voltage applied with no load. Their maximum voltage is 12.6V and the maximum current draw is 20A. These motors weigh 213.8 grams, are 36mm in diameter and 60mm in length. The reason that brushless type motors were chosen was because they require little to no maintenance, offer more torque, have better heat dissipation, and experience no power loss across brushes which means better efficiency. The motors have been run aboard the rover and they have proven to be powerful enough to rotate the screws to chew through a corn field the team launched at.

Lithium Polymer Batteries

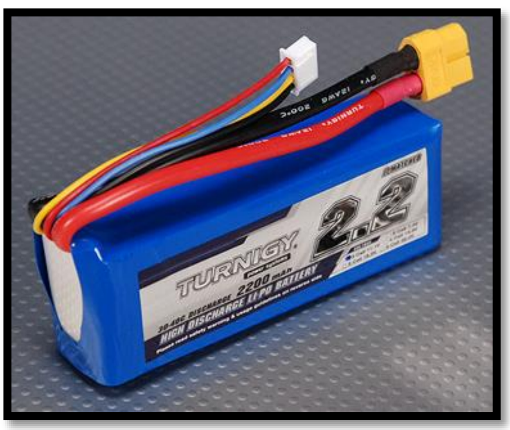


Figure 115: Turnigy LiPo Batteries

Lithium Polymer batteries (LiPo) will power the electronics for this payload. The reason LiPo batteries were chosen was due to their excellent track record in previous competitions.

Only two LiPo batteries will be required for the payload: one for the motors, and one for the BeagleBone and its attached peripheries. Since each cell on a LiPo has a nominal voltage of 3.4V, a 3 cell LiPo will be used for the motors and a 2 cell LiPo for the

BeagleBone. Each LiPo also has a mAh rating which measures the storage capacity for that battery. The mAh value tells you how much current the battery is able to deliver per hour. Each of the batteries will have a 2200mAh rating as this will allow the BeagleBone to run for around 4 hours, thus the payload has enough power to remain on the launch-pad for an hour.

The LiPos have been tested to work with the BeagleBone Black and the ESCs for at least 2 hours each. Therefore, the team is not worried about running out of power as long as the batteries are recharged before each flight.

Payload Power Distribution

In the system level view of the power distribution, our team's largest electrical concerns for the rover are battery life, communications, and allocating power to each component. We are separating the power that runs to each motor, as well as the BeagleBone power by using separate batteries for the microcontroller and battery supply, respectively. Each battery is regulated down from the battery voltage to each respective voltage that the components will need. The power for the microcontroller is regulated by the LM7805 IC. This circuit is located on the custom PCB. The power line for the motors is regulated by the ESC's.

We are utilizing the LM7805 voltage regulator (shown below) to give a regulated power supply to the BeagleBone. The 2200mAh 2-cell LiPo battery, that is being used to power the microcontroller, provides up to 7.4 volts to the board. This voltage is stepped down by the LM7805, and exclusively powers the BeagleBone. Per this regulator's datasheet, it outputs a typical value of 5V (+/- 4%). This tolerance is well within what is needed for input to the BeagleBone microprocessor. With the small delta for input/output voltages to the regulator, heat dissipation is not a concern for powering the "brain" of the rocket/rover for the duration of the competition. The LM7805 uses a maximum quiescent current of 8mA to regulate the voltage; a negligible load when compared to the <1A needed for the cape/micro combination. The BeagleBone has been run connected to a LiPo battery via the regulation circuit without any problems.

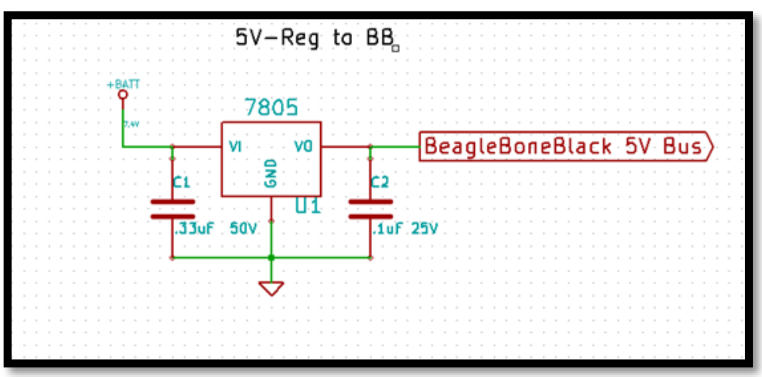


Figure 116: LM7805 Voltage Regulation Circuit

Per the BeagleBone website, it is recommended to run the BeagleBone at 5V (2A) supply when using any peripherals (1A otherwise). Depending on the processing speed, the microcontroller alone can draw up to 465mA. With our milliamp-hour rating, the setup allow us to run at least the BeagleBone for 4 hours with margin enough for other peripherals. The electronics have been tested to run for at least 2 hours

For standby power (and the 1 hour launch standby potential) we will be at an "idle" mode for the controller. The datasheet for the BeagleBone states that idle current draw is around 170mA. At 1 hour, the standby for the board can potentially use less than 10% of our battery life; this allows us a safe margin to power the launch with, or without, a delay.

MODE	USB	DC	DC+USB
Reset	180	60	190
UBoot	363	230	340
Kernel Booting (Peak)	502	350	470
Kernel Idling	305	170	290

Figure 117: BeagleBone Black Power Consumption

Our testing has been concerned with the measurement of standby power with the added power draw of the custom PCB, GPRS cape, and camera. The camera is a Logitech C920 model. It is a commercially available component that will be powered via USB from the payload. The C920 consumes 240mA at 5V.   Although a datasheet was not readily available for the GPRS cape, our team researched the main communications chip on the sensor. Per the GE864 datasheet, the GPRS module uses only 62uA of power when in standby (desirable for idle launch delays). At full power, the maximum load of the cape can reach 420mA. Therefore, the max load for the BB and cape combined to under 1A. So far, the system has been fully operational when running it via the LiPo batteries for at least 2 hours.

The motor systems have been tested at an isolated sub-system level as well as operating via the BeagleBone. The sub-systems include the PWM circuit, battery, ESC, and motors. The isolated testing has validate our intended setup to show that we can power the selected motors at the chosen duty cycle for a liberal amount of time. For testing purposes, we have used equipment made available to us through LVL1 maker-space in Louisville, KY. We are using load components to simulate power consumption. Oscilloscopes are being used to analyze and troubleshoot our PWM signal being sent from the PWM controller to the ESC.

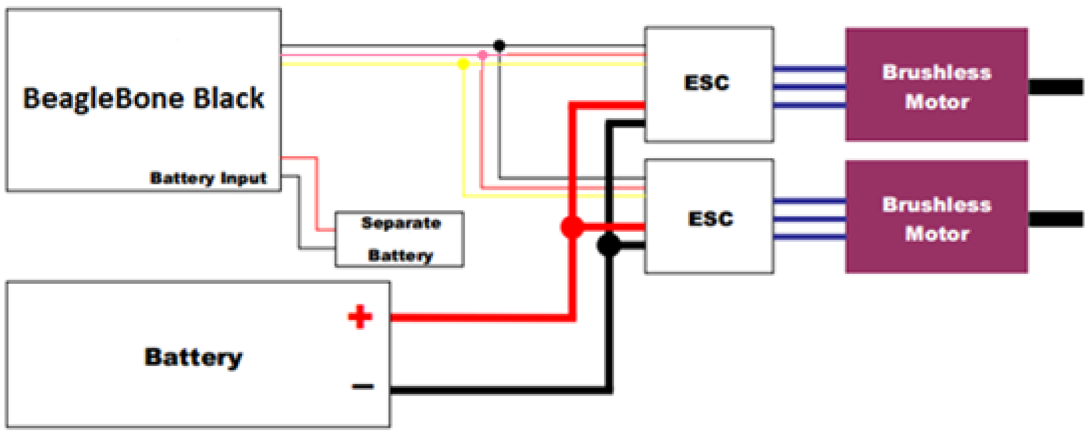


Figure 118: Payload Power Distribution

As shown in Figure 118, we have a distributed power system for the rover. For power sourcing, we have isolated the receiver power bus from the motor power bus. Due to the noisy nature of motor to disrupt sensitive communications circuits, we wanted to keep the sources separate to ensure reliability of signal operations/transmissions. In our power design, we are using a modular ESC (electronic speed controller) to interface the 3 cell LiPo to the brushless motors. A desired feature of the ESC is the built-in overload protection that adds to our safety as well as reliability of the rover. With this overload protection, we can protect against damage to our motors, as well as unfortunate battery discharges that can cause fire and damage to the rover as well as its environment. Our team is making use of modular ESC for the precision of control we will gain with our three-phase motor. While this is a substantial benefit, it does come with its own challenges. We have gained a lot of experience while designing and implementing the interface between the BeagleBone microcontroller (output) to the PWM data input of the ESC. The main research went into generation of a suitable PWM signal to be used to drive the ESC which is described later.

With our current setup, we are able to power both brushless motors with one 3-cell 2200maH battery. With use of the ESC, comes an ability to shut down the substantial power draw of the motors for launch standby. With the allowance of a motor standby we only have to power the ESC (not full motor potential) while awaiting launch. The ESC requires only 120mA at 5V for operation. This allows our team the option to run the ESC from the competition start, or we can "wake up" the device from liftoff. The standby option would allow us to bypass any unforeseen booting issues with powering the motor controller from a cold-boot at launch time.

Custom PCB

Our team designed a custom printed circuit board to contain the voltage regulator IC, a barometric pressure sensor, an accelerometer, and a PWM controller for driving the ESC. We obtained the footprint of the BeagleBone's GPIO pins for the basis of the final PCB. To construct the schematic and layout, our electronics team used KiCAD design software. Advanced Circuits was contracted to create the PCBs and all the components were soldered on by hand. Figure 119 and Figure 120 shows the finished custom PCB.

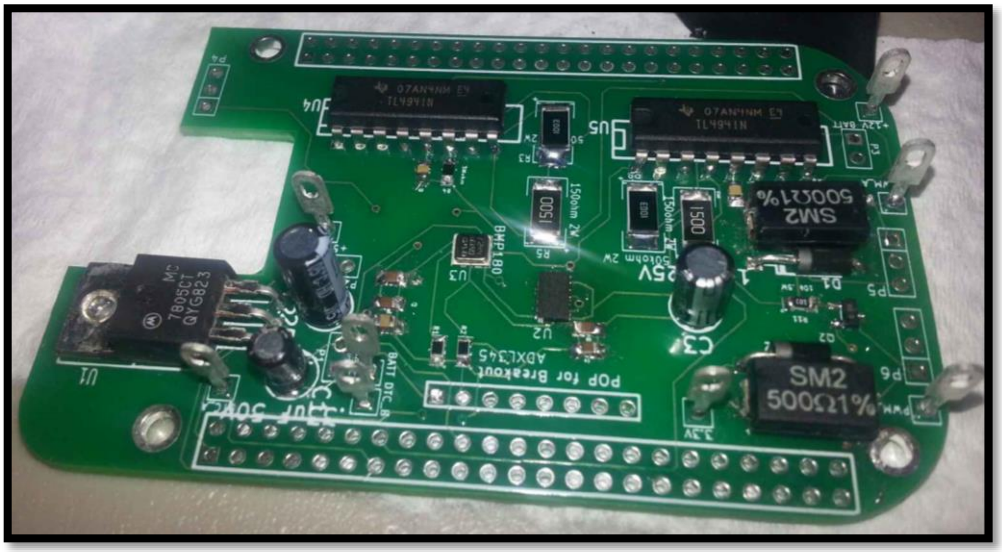


Figure 119. Custom PCB with Components Soldered on

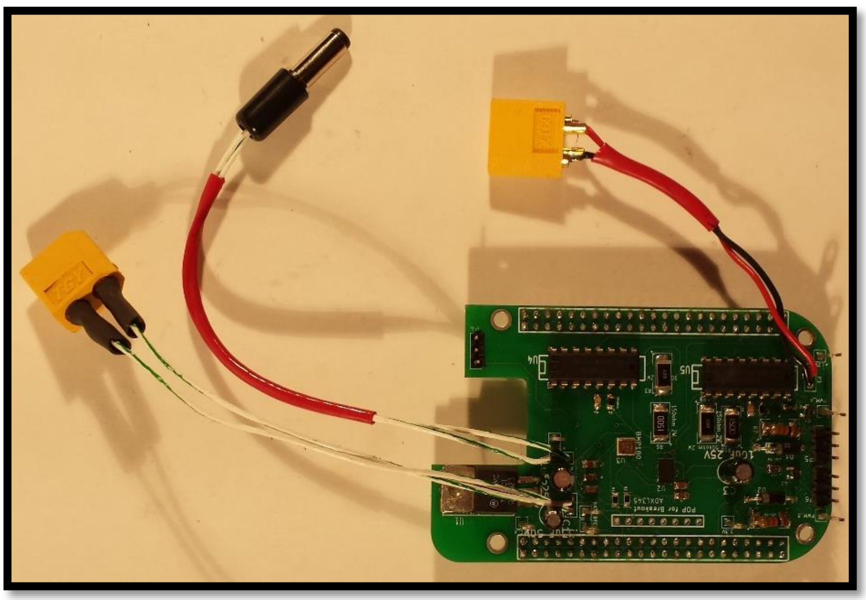


Figure 120. Custom PCB with Connectors Attached

The team decided to implement a hardware PWM setup instead of coding a software dependent PWM generator. The PWM signal is required to operate the ESCs. We have more experience with hardware systems and decided it was the most feasible route for our payload. The PWM control circuit that takes care of the interface is based on the TL494 PWM controller available from Texas instruments. Design considerations for this circuit include generating 1 kHz/5V square wave then inverting the signal through an N-channel MOSFET (BSS138) for it to finally be input into the ESC. Some calculations for this circuit include the resistance/capacitance combination ($frequency_{osc} = 1/(R*C)$) to allow 1 kHz operation and voltage to duty-cycle conversion. From the data sheet provided for the TL494 IC, we found that the DTC (dead time comparator) controlled our duty-cycle output. The correlation found was 100% duty-cycle at 3 volts, and 50% at 0 volts. We then needed to invert the signal through the MOSFET to use a duty-cycle less than 50% (needed for the ESC). The MOSFET also allows us to isolate the PWM circuit from the input of the ESC so that the ESC does not get overloaded. We were successful in controlling the motor with the design explained above. Figure 121 shows the PWM sub-circuit.

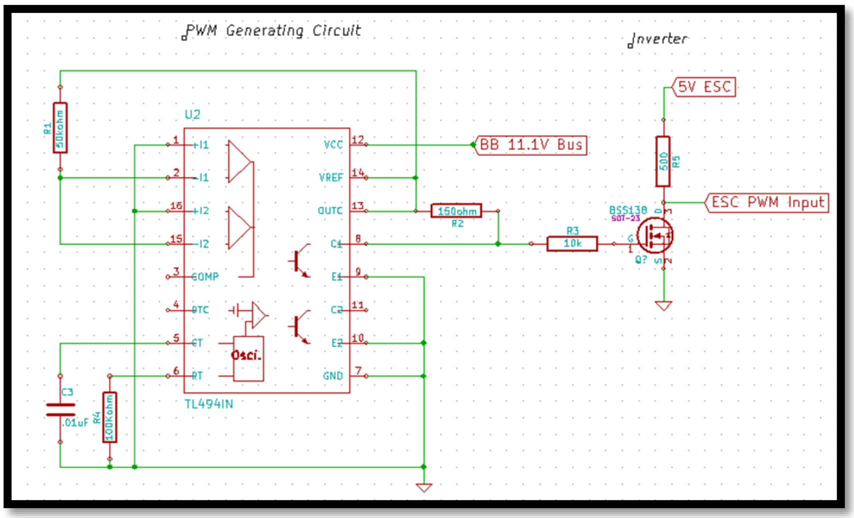


Figure 121. PWM Controller Circuit

The PWM circuit has been tested alone on a breadboard as well as via the PCB. Each time, the PWM circuit has been able to correctly operate the ESCs to run the motors. To insure that the ESCs were receiving the correct signal, an oscilloscope was hooked up the output of the circuit. As seen in Figure 122, the circuit is able to output a clean PWM signal.

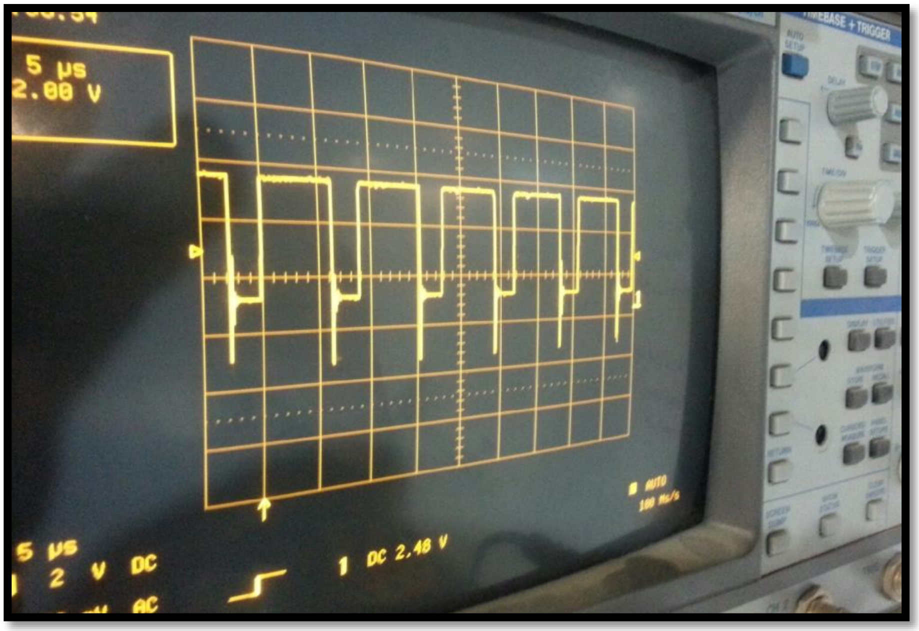


Figure 122. PWM Signal Generated from PCB Circuit

The next circuit of importance aboard the custom PCB is the pressure sensor circuit. A BMP180 pressure sensor is used to detect the landing of the rover. The reason this sensor was chosen is that it has been used previous years and has been shown to be reliable. Figure 123 shows the circuit for the pressure sensor. The sensor has been tested by running example code and is giving expected values.

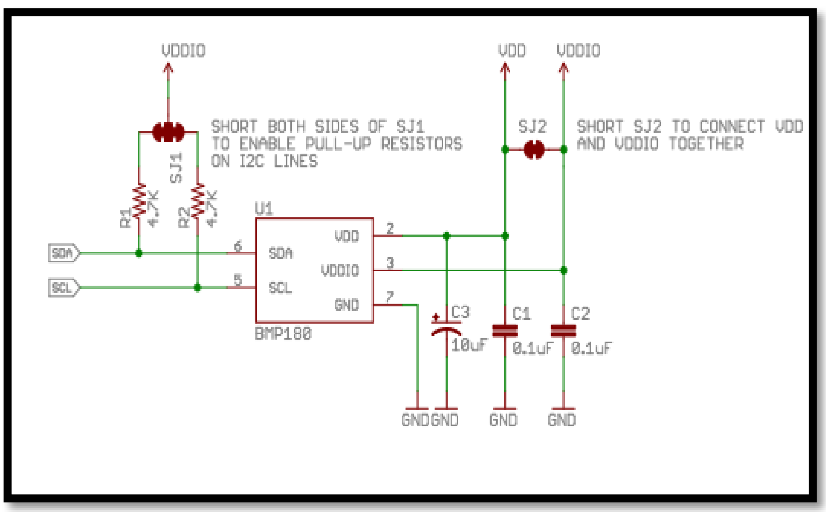


Figure 123. BMP180 Pressure Sensor Circuit

For the custom made PCB, we have designed for external connections. The 3 cell LiPo battery are connected to the ESC's and TL494 PWM controller through 2 pin JST XA model connectors. The connectors are rated for 250V/3A each. The 2 cell battery (7V) are connected with the JST connector as well. It is regulated through the LM7805 on the PCB then routed to another 2 position JST XA header. From the XA header a joining XA housing will be received and connects directly to the microcontroller's barrel plug. Though it would be desired to receive the battery terminals directly to the PCB, our team could not locate a compatible header for the board-side connection. As for the remaining connections (servo, ESC data lines), we are using open 3 position headers. We are designating orientation of the connections (i.e. "Data", "+", "-") through use of silk screen labels to be printed on the manufactured circuit boards. Pins used for the custom PCB are assigned from pins not in use by GPRS cape which is determined from the GPRS cape datasheet. Figure 124 and Figure 125 show the models from KiCad of the custom PCB layout.

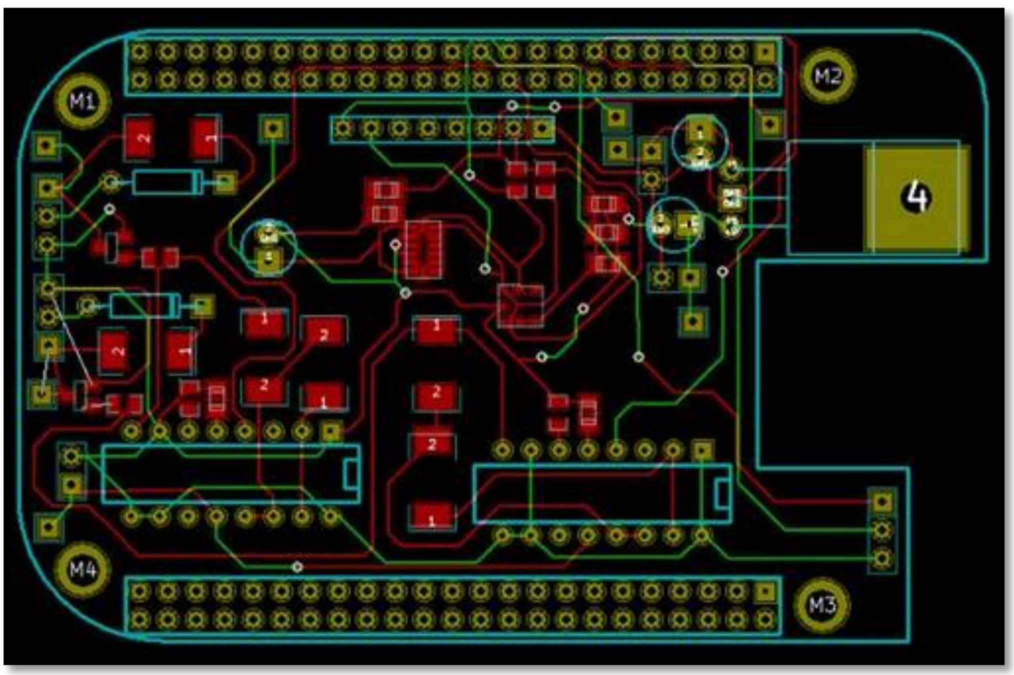


Figure 124. Board Layout of Custom PCB.

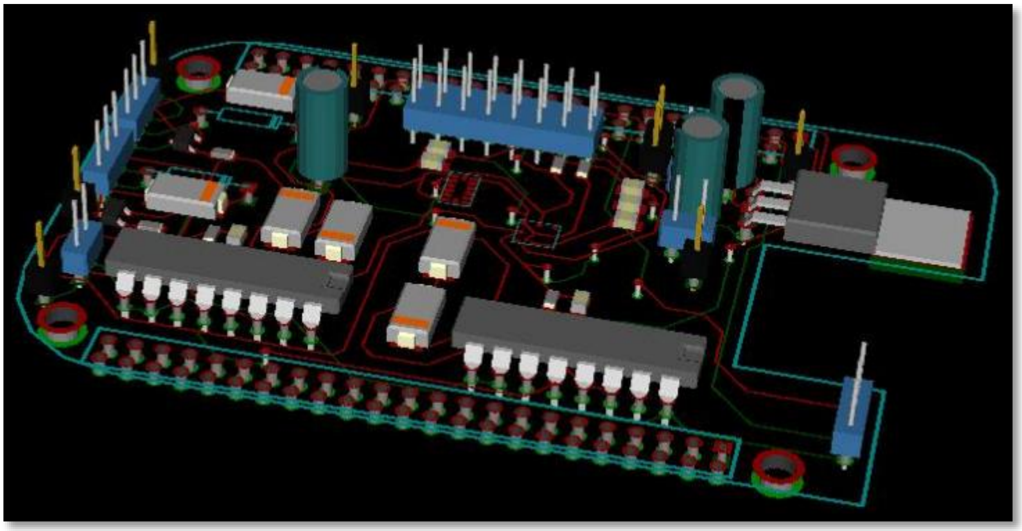


Figure 125. 3D Model of Custom PCB.

Overall Flight Algorithm

The hazard payload will all be controlled by the BeagleBone Black microprocessor which was chosen due to its capabilities for handling the software's expected demands. To control the payload's "brain", the software package the team is developing will be responsible for controlling everything aboard the hazard detection payload from the time it's activated until it is retrieved. The part of the program that will use most of the BeagleBone's resources is the image processing algorithms. To reduce the strain on the BeagleBone, the software will be optimized as much as possible. An overview of how the different parts of the payload software package will operate is described below.

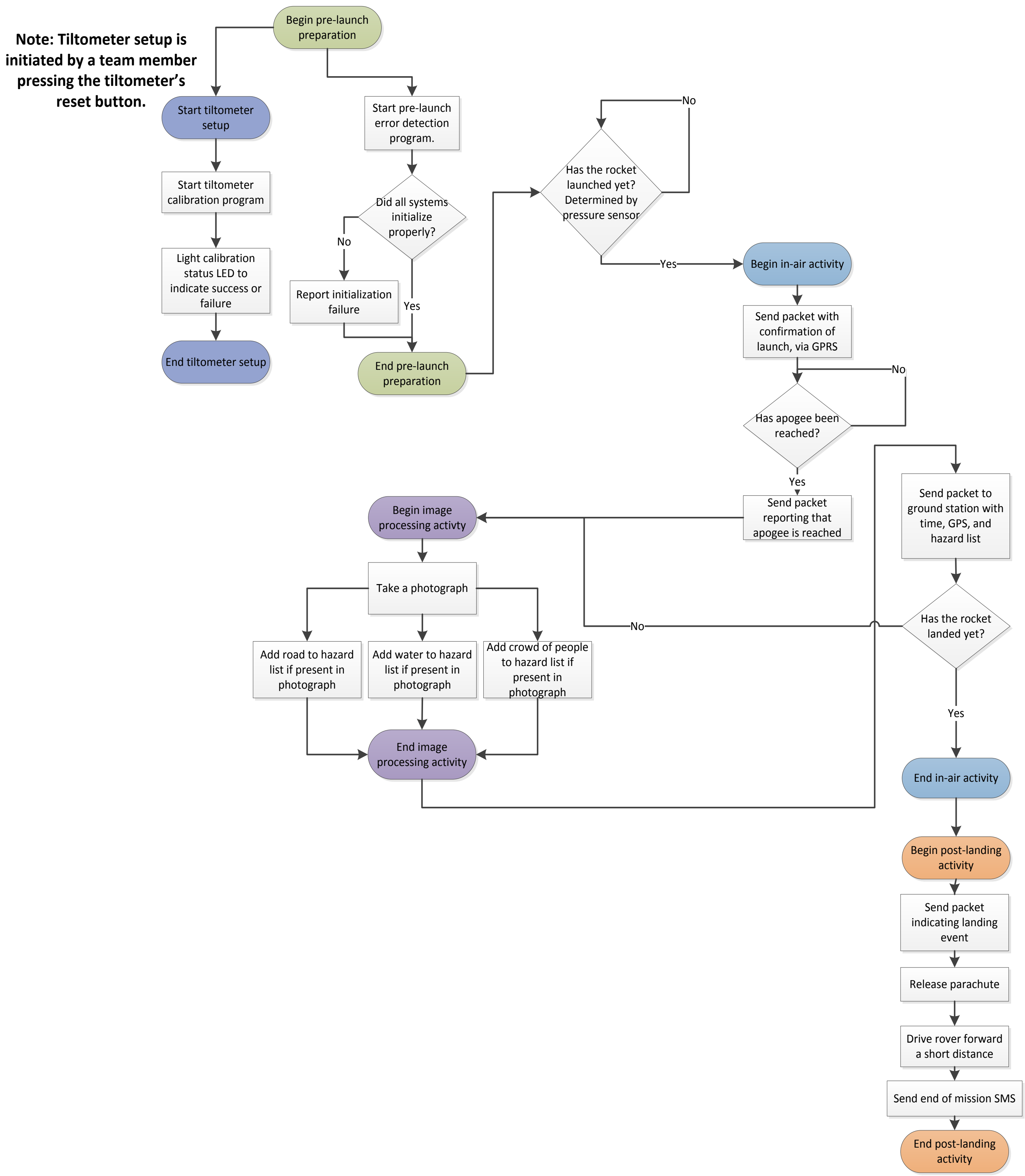

Note: Tiltometer setup is initiated by a team member pressing the tiltometer's reset button.
Begin pre-launch preparation
Start tiltometer setup
Start tiltometer calibration program
Light calibration status LED to indicate success or failure
End tiltometer setup
Start pre-launch error detection program.
Did all systems initialize properly?
No
Report initialization failure
Yes
End pre-launch preparation
Has the rocket launched yet? Determined by pressure sensor
No
Yes
Begin in-air activity
Send packet with confirmation of launch, via GPRS
Has apogee been reached?
No
Yes
Send packet reporting that apogee is reached
Begin image processing activty
Take a photograph
Add road to hazard list if present in photograph
Add water to hazard list if present in photograph
Add crowd of people to hazard list if present in photograph
End image processing activity
Send packet to ground station with time, GPS, and hazard list
Has the rocket landed yet?
No
Yes
End in-air activity
Begin post-landing activity
Send packet indicating landing event
Release parachute
Drive rover forward a short distance
Send end of mission SMS
End post-landing activity

Figure 126. Overall flight algorithm flowchart

Tiltometer setup

The first step in the flight algorithm is to initialize the tiltometer. The setup program will set the proper accelerometer and gyroscope offsets on the tiltometer so that the device considers its orientation on the launch pad as its frame of reference. If tiltometer calibration fails, an LED will be lit indicating that the failure occurred, to alert the team. The tiltometer is not part of the hazard detection payload but is included in the flowchart as it is part of the flight activities for the rocket.

Pre-launch preparation

During pre-launch preparation, every device in the payload will be powered on and checked for successful startup. If any device fails to start, it will be added to a list of devices that failed to start. The failed devices list is then used to light a set of LEDs indicating which devices failed to start, or that no devices failed to start, which allows the team to decide to proceed or not.

Then, the program will continuously poll the pressure sensor to determine if the launch event has occurred. When launch is detected, the rocket will proceed to the in-air activities phase of operation.

In-air activities

As soon as the in-air activities phase begins, the payload will send an SMS to the ground station indicating that the launch event occurred. Then, the program will continuously wait to detect apogee from the pressure sensor. Once apogee is detected, another SMS message will be sent to the ground station indicating this event.

Image processing activities

After apogee is detected, the payload enters its image processing phase. In the image processing phase, an image is taken from the onboard camera. Then, the image is scanned for evidence of water, roads, and crowds of people, and the presence or absence of these hazards is recorded. After the image is scanned for hazards, an SMS is sent to the ground station with hazard detection results. Finally, the program will check for landing through the pressure sensor, and if landing is detected, the post-landing activity phase will begin. If landing is not detected, the program will continue extra image processing steps.

Post-landing activities

After the rover lands, it will first send an SMS to the ground station indicating that landing has occurred. Then, the rover will wait 10 seconds to stabilize before releasing the attached parachute. Once the parachute is released, the rover will drive forward a few feet, and send a final SMS, thus completing the mission.

Data Transmission Testing Results

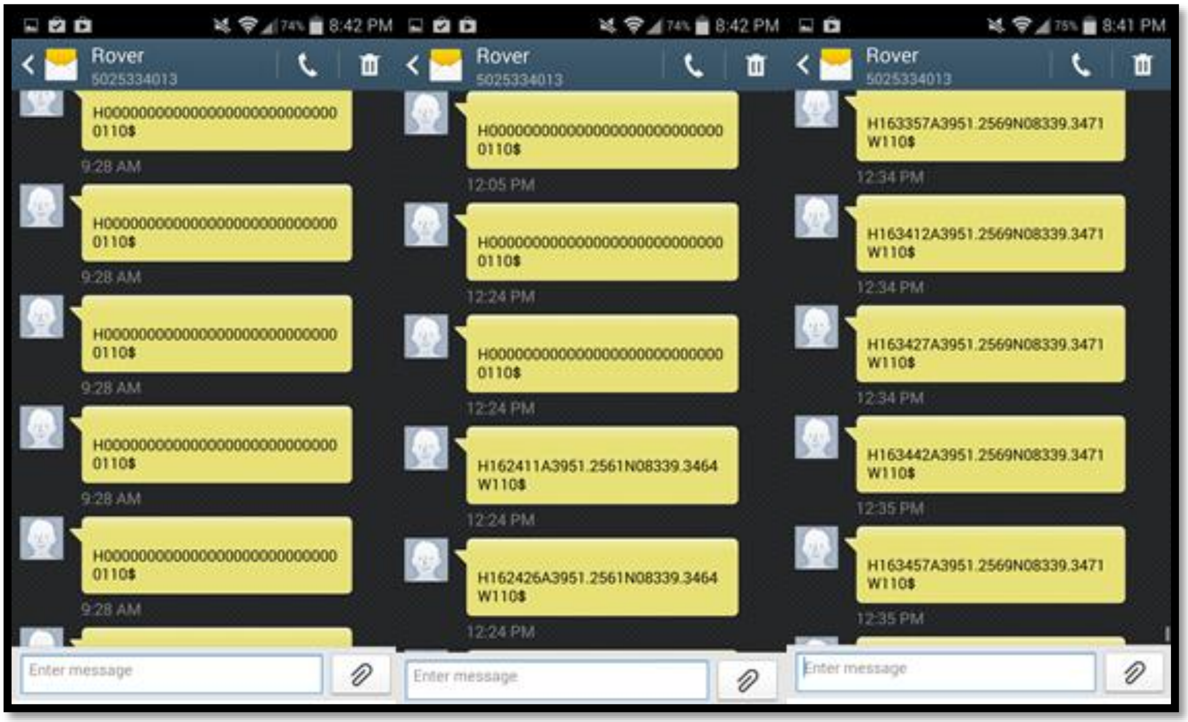


Figure 127. Data transmission results sent to the ground station. (Left) The payload is waiting to get a GPS lock. (Middle) The payload gets a GPS lock after 3 messages. (Right), the payload has a GPS lock for every message sent.

The team has the payload reliably transmitting GPS coordinates and hazard detection data to the ground station. During the payload's boot phase, it will send a series of readings containing mostly 0s, and hazard detection results. These messages indicate that the GPS unit has not yet acquired a lock, and is still trying to retrieve GPS coordinates. This phase usually lasts 1.5 minutes. After this phase completes, the device will continuously send GPS coordinates, the current time in UTC, and hazard detection data, until powered off. This data transmission process has been tested in three locations around the city of Louisville, within a 2 mile radius, and verified to work. The data transmission process was also tested at Scioto farms in Ohio, the site where the team did not launch on 4/12/2014. At this location, the device transmitted the correct GPS location.

The team tested data transmission on the car-ride to Scioto farms. The device did not send data to the ground station during this time. The team suspects that this is due to difficulty acquiring either a GPS or GPRS lock when travelling at highway speeds or there being no data coverage, but neither case has been verified.

The interface between the hazard detection system and the data transmission system has also been tested and verified to work. To test this interface, a program was created that randomly generates hazard detection results, and writes those results to a file. The data transmission system then reads that file, and sends the file's contents along with its normal GPS data in a text message. This is the same system that will be used when the hazard detection program is integrated on the BeagleBone, so the team will be able to drop the hazard detection program straight in, with minimal need for adjustment.

Data transmission has also been tested with multiple target ground stations. Data from the payload was sent to three team members' phones, and it was verified that messages were received without error in each case. The ground station app was installed on two phones, and verified to receive data and parse the received data correctly in each case. The ground station app is described in more detail elsewhere in this document.

GPS Accuracy

Data transmission from the payload's GPRS unit has been verified to work in multiple locations. GPS readings were taken in two locations in Louisville [the team's primary workspace, and a programmer's living location], and in Ohio on the day of an attempted launch. More coordinates will be gathered at the team's next launch and checked for accuracy. Below is a map of expected location versus the location recorded by the GPS unit.

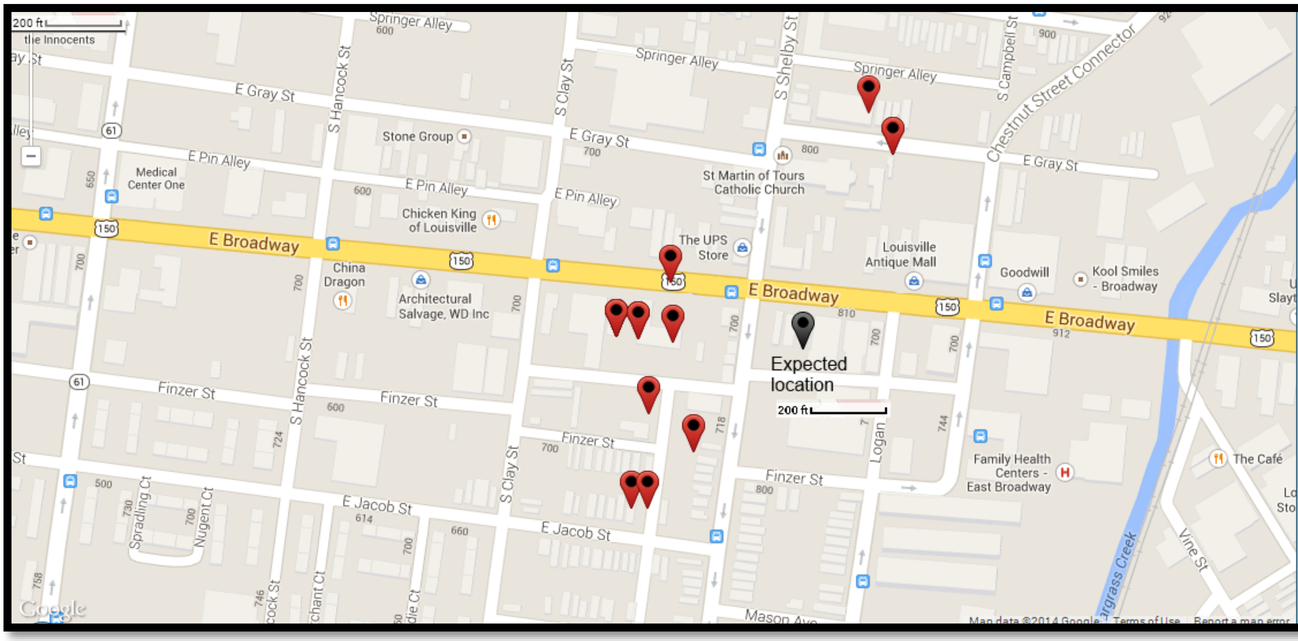


Figure 128. GPS readings taken at LVL1, the team's usual workspace. The black marker indicates the expected GPS reading. Below the black marker is a scale line for reference.

Signal strength

The team has not yet had an opportunity to test GPRS signal strength at 10,000 feet, since the team's rocket has not yet had a successful launch. The team plans to test signal strength at the next launch, and results will be included in an FRR addendum. Last year's USLI team tested signal strength during preliminary flights, and proved that GSM signal strength was at a usable level during flight, at least up to a mile in altitude. To test signal strength, the team will initially use an Android app that records signal strength to the device's SD card. This test will be done to make sure the main payload is not jeopardized by an unsuccessful launch. Once a successful launch occurs, the team will perform signal strength testing with the BeagleBone Black. A program to record signal strength continuously on the BeagleBone Black has been written and tested, but the team is waiting on a launch to record data. The Android app to record signal strength is functional and ready to fly.

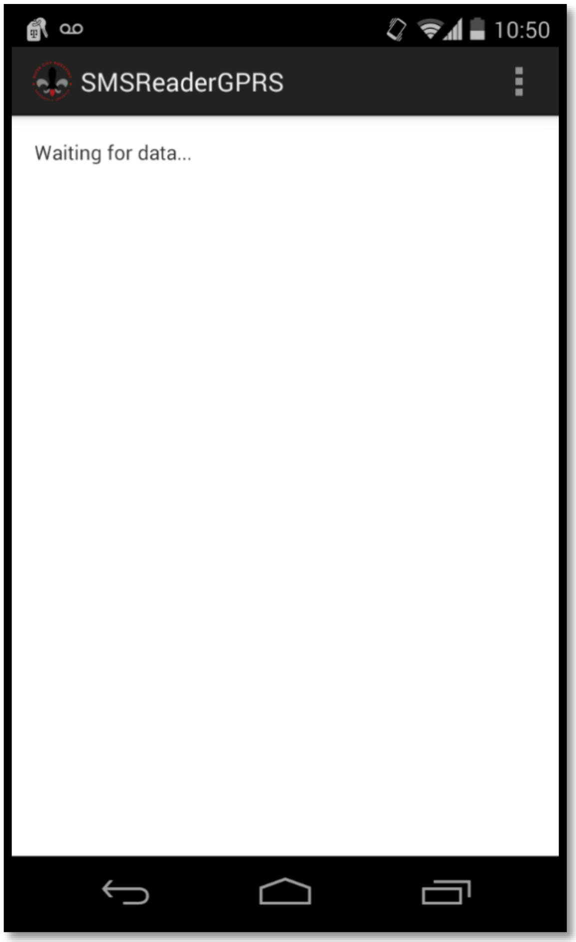
Figure 129. GPS reading from Scioto farms. Reading matches expected location, within a maximum possible error of ~100 feet.

GPS Consistency

The GPS unit was tested several weeks during the development process. At several points, the GPS readings were viewed on a map, and verified to correspond to the expected locations. The team noticed the GPS readings deviating from the physical location by several miles in a few cases, but later found that the team was interpreting the GPS readings incorrectly. After revising the formula used to calculate GPS degrees/minutes/seconds, it was found that GPS readings were consistently accurate.

Hazard Data Android App

The hazard detection app has been completed and multiple tests have been completed from both GPRS and message parsing standpoint. Since the rover will be detaching from the rocket, a system for locating it along with checks for hazard detection needed to be calculated. This was accomplished with this app which listens for calls from the GPRS unit and will feed us with live data. Thus this will act as our ground station device.



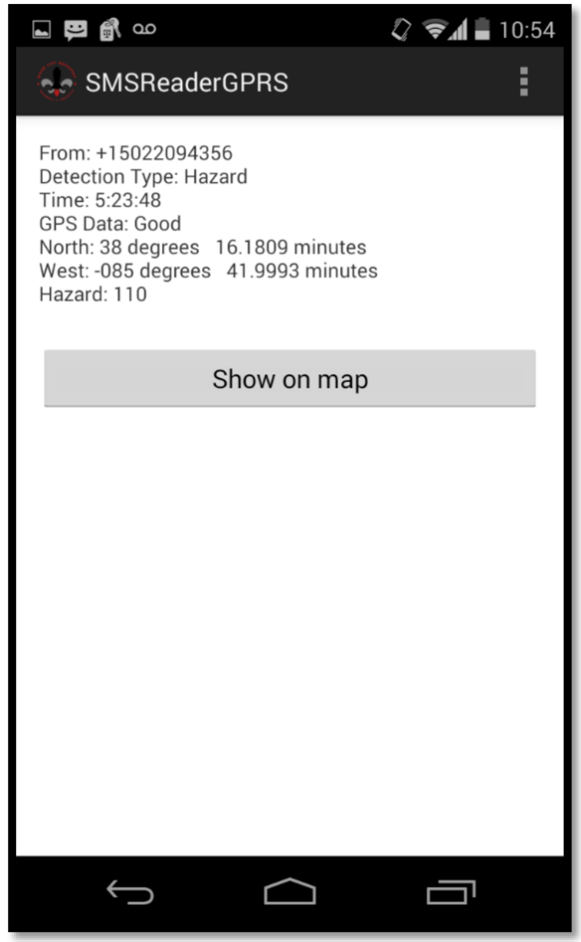


Figure 130. GPRS Data Parsing App - the image on the left shows the app at its initial launch when no data has been transmitted. The image on the right shows the apps state once data is acquired

For the above result, the data sent from GPRS and received by the app in real-time is: **H052348A3816.1809N08541.9993W110$**. Once the result has arrived, a new button also shows up which allows the user to find the rover based on its position at that given time. Once the user clicks on the button, the map application is opened and the user is targeted to that specific location from where the GPRS/Rover sent the data.

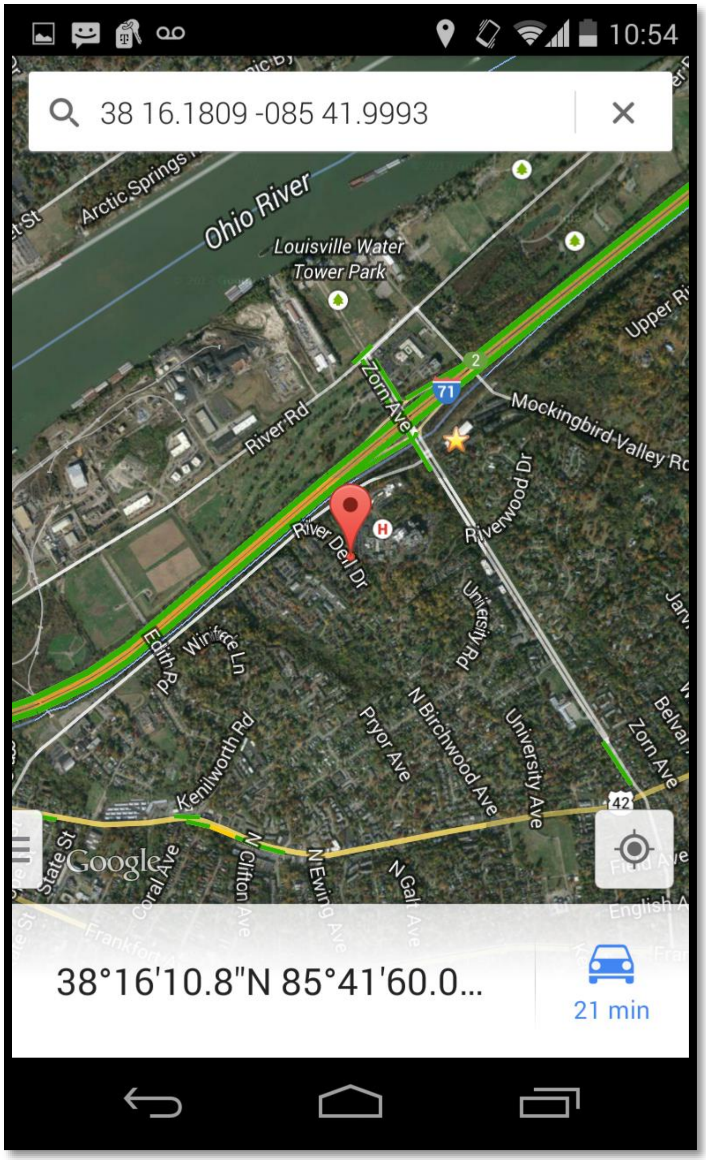


Figure 131. GPRS Data Parsing App map view - Once the Show on Map button is clicked, the user is directed to the returned location at that specific time on a map.

<u>Temperature and pressure sensing</u>

The team has also verified that it can collect temperature and pressure readings on the payload. Programs have been written, tested, and verified to collect data from these two sensors. The team can also convert this data into appropriate units (Fahrenheit/Celsius, and millibars) with no issues. This data has not yet been integrated into messages sent from the payload, but the team will this data to transmissions to the ground station if time allows.

<u>OpenCV Image Processing</u>

The software package that is going to be used is an open source library for image processing called OpenCV, short for "Open Source Computer Vision Library." As the name implies, OpenCV is free to use under the open source BSD license. OpenCV is designed for computational efficiency with a strong focus on real-time image processing applications. Due to its wide popularity, OpenCV languages varying from C, is a cross-platform library which has Linux support. Not only does OpenCV support the same operating system (OS) as the BeagleBone (Linux), but it has a full support for numerous programs written in C++, Python, and Java. OpenCV is currently used in various applications ranging from robotics, motion tracking, and object identification thus making the perfect tool for our requirement. Our choice of language will vary from Python to C++ and will be combined for the most optimal solution on the BeagleBone. This will help us effectively track hazards.

The task of obstacle detection will not be a trivial one as not all hazards can be detected with simple algorithms. The OpenCV library requires two types of pictures, called negative and positives, which will be used in the main algorithm. This process will be compiled using the Cascade Classifier method which will work using hundreds of these two picture types for one object detection that will determine the individual points of the pictures that the program should look for. This Cascade Classifier will include two stages: training and detection. Implementation will be applied on the most common hazards that we expect to encounter when we are in flight. Some of these hazards include power lines, roads, lakes/ponds, buildings, and trees. This scan is the most basic scan.

Color variation and edge detection methods

Another approach that will be taken includes detecting edges and color variation to determine an object. This works by providing an input image from a live camera feed and processing it through numerous image manipulations using OpenCV. One such input would be smoothing the original images using the Gaussian kernel thus making the output with a lot more depth. Then change the image from BGR (Blue, Green,Red) to HSV (Hue, Saturation, Value) using a defined color range thus filtering that out.

Figure 132. Salt Flats unfiltered - launching area

Figure 133. Salt Flats filtered - launching area where the cars and mountains are added to the hazard list and filtered.

Testing Updates - OpenCV

Although we have not done any tests on flights, a decent amount of testing has been completed by attaching the camera to the BeagleBone and verifying multiple simulation results. The algorithm was also improved in a better edge detection system was implemented for a higher detailed result.

Figure 134. Salt Flats unfiltered testing from a separate angle - launching area

Figure 135. Salt Flats filtered - second testing shows more feature detection amongst the clouds. A better edge detection and color filtering methods were applied for better results. A more detailed display of separation between clouds and lines of cars is shown.

Figure 136. Salt Flats unfiltered testing from a separate angle with no hazards - launching area

Figure 137. Salt Flats filtered - testing shows more feature detection amongst the clouds again, but since no valid hazards were detected, a lighter color map is not shown.

OpenCV Process Flowcharts

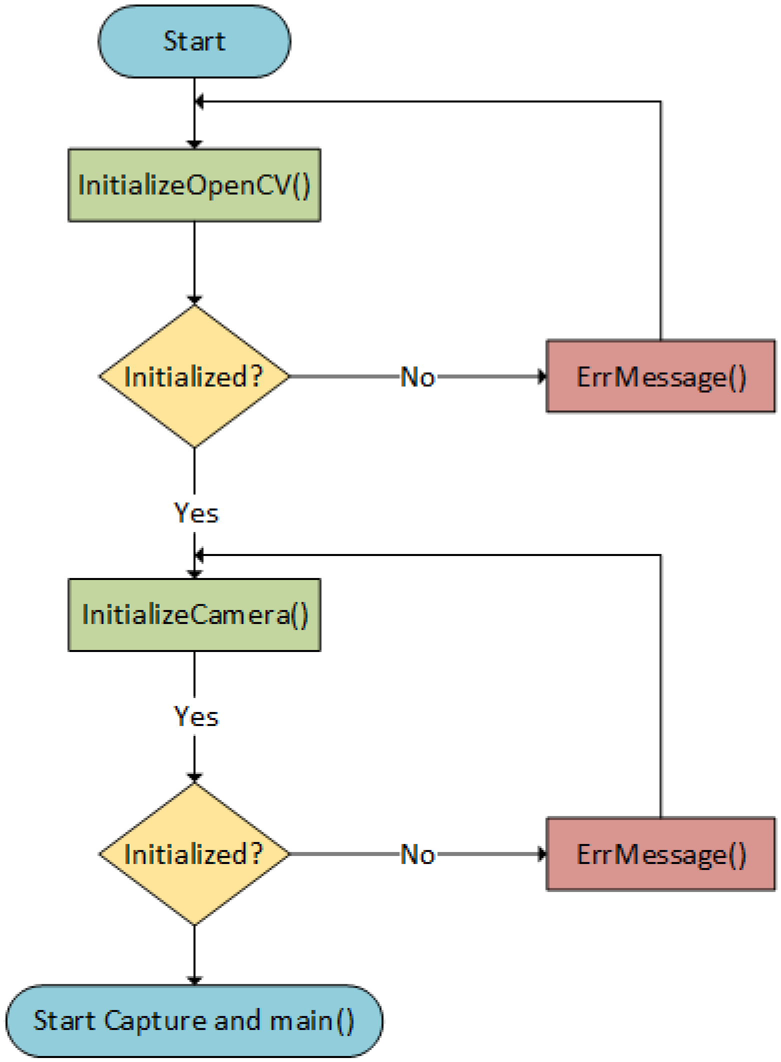


Figure 138. First steps of the object detection. Initialize all the necessary functions while dealing with any errors. Start capture from the main method.

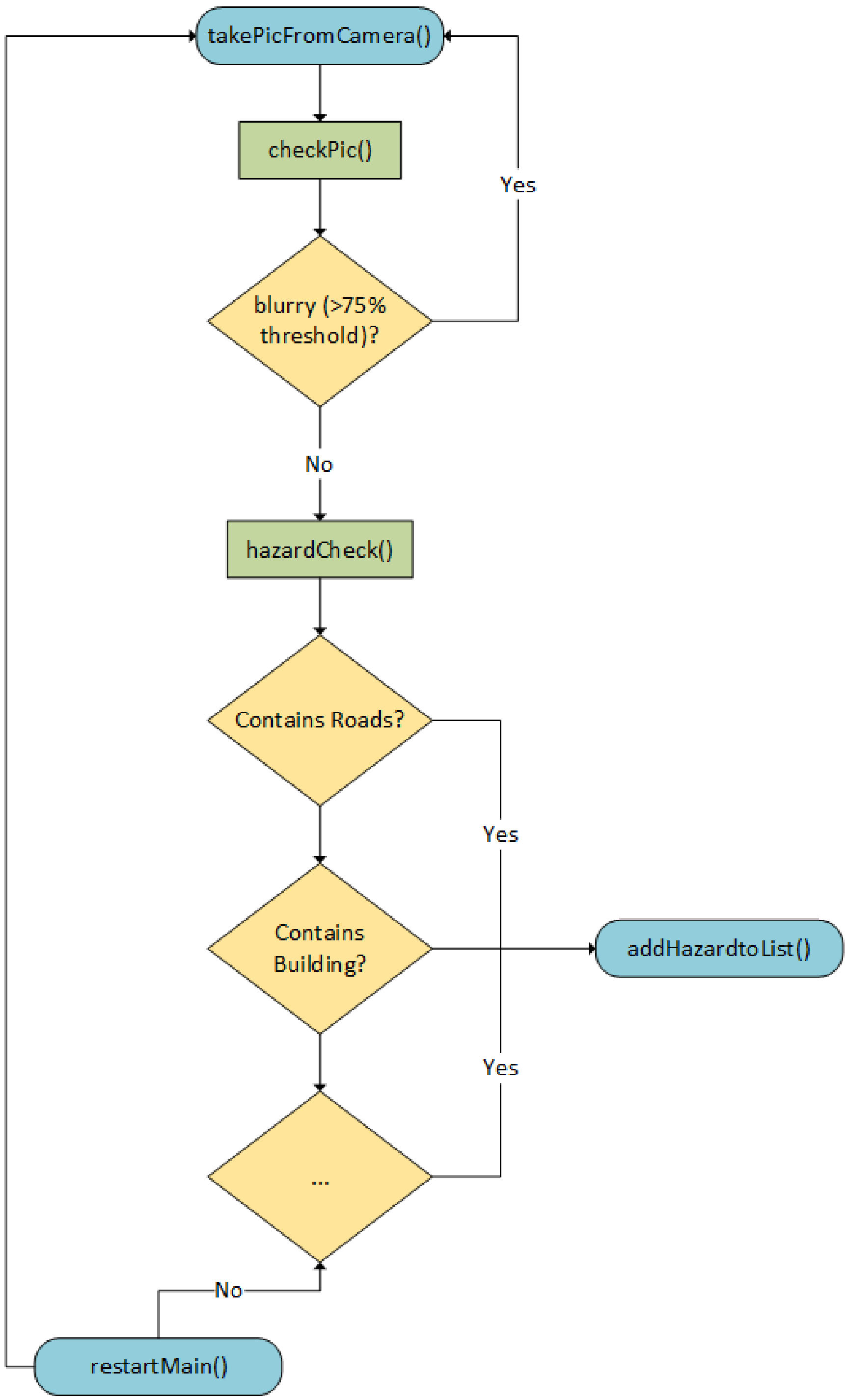


Figure 139. Second steps of the object detection. Start taking input images from the camera feed and start the check for accurate and non-blurry images. Start adding contained hazards a Hazard List. If no hazards found, restart main method

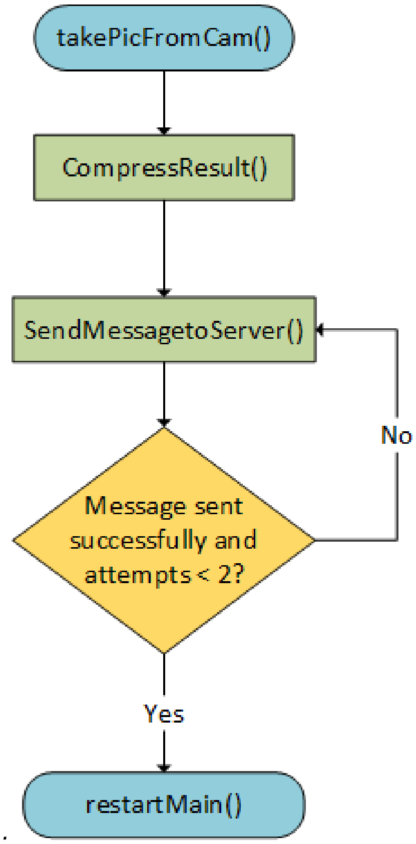


Figure 140. Third steps of the object detection. Capture image from camera and created hazard list and compress the result for remote send. Send message to server and confirm the send. Restart main method again and continue with repeat.

The basic process for the program is outlined above. As pictured, the program will start with the main initializations for both OpenCV and Camera which are integral part of this process. All the error and initialization checking will be done before the program goes forward. After it is verified, the main() program loop will start and the first method, takePicFromCam() will be run. Again, after this method run, another verification method called checkPic() will be initialized which will check for any blurriness which will have a set threshold of greater than 75%. Once this is completed, the main hazardCheck() algorithm loop will begin which will start populating the list of hazards. Once this is completed, if at least one hazard has been detected, the process will continue onto sending the compressed message to the ground station server. Once a link is established, a successful real-time data will be available on the ground station web page. If no hazards are found and/or sending to server completed, the program starts back at the main() method and starts the process again.

Hazard data send

After detecting the different hazards, our program will store a list of these for real-time data feed which we are also implementing on a server which will be the ground station. The ground station will feature a web server with FTP protocol enabled which the program on board the BeagleBone will use to send and receive data to and from the devices. The medium between the two will be a phone which will receive a text message from the BeagleBone which will be forwarded over to the web server using an app which will look for a specific number for the message. This app will then transfer it over to the web server through FTP as mentioned before. Before anything though, this real time data will be first compressed on the BeagleBone into a 0/1 format. This format will then be interpreted and will be send over as separate commands and hazards list will be shown in real-time on the server. With this compression method, we will be able to get a small data transferred over SMS quickly. This is still in testing and more changes will be made upon it.

SAFETY AND ENVIRONMENT (PAYLOAD)

Risk Assessment

Table 40 shows the current payload risk assessment table for the hazard detection payload. The risk matrix is similar to the one described for the vehicle. A severity value between 1 and 4 has been assigned to each hazard with a value of 1 being the most severe. In order to determine the severity of each hazard, the outcome of the mishap was compared to an established set of criteria based on the severity of personal injury, environmental impact, damage to the rocket and/or damage to equipment. A probability value between 1 and 5 has been assigned to each hazard with a value of 1 being most likely. Material Safety Data Sheets for payload components can be found in the Appendix.

Environmental Concerns

The hazards outlined in Table 41 are risks from the environment that could affect the payload or a component of the payload. The hazards that the team can control will be mitigated to attain a low risk level. The hazards outlined in Table 42 are risks that construction, testing or launching of the payload can pose to the environment.

Hazard Detection Payload Risk Assessment						
Hazard	**Cause(s) of Hazard**	**Hazard Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
GPS/GPRS cape is not functional	1. Programming error 2. Electrical issues (battery failure, etc) 3. Physical defect (device is physically compromised during launch)	Results of hazard detection are not transmitted to the ground station and web server.	1	1. 4 2. 4 3. 5 Most Likely: 4	Moderate	All: The hardware initialization failure program that runs on device startup will tell the team if the GPS/GPRS unit is functional when it is on the launch pad. 1. An entry is present on the pre-launch checklist to verify the BeagleBone Black's battery is charged prior to launch.
Hazard detection camera is not functional	1. Programming error causes a crash of the camera code. 2. Electrical error in the camera subsystem (power outage, connection problem) 3. Hazard scanning performance is too slow for the required time frame.	Inability to use the camera would result in mission failure as no hazard data would be collected.	1	1. 3 2. 3 3. 4 Most Likely: 3	Moderate	1., 2.The hardware initialization failure program that runs on device startup will tell the team if the camera unit is functional when it is on the launch pad. 3. Image processing performance has been tested to verify that hazards can be scanned for in the required time frame, on the required hardware.
Data transmission from the GPRS unit is not functional	1. Poor network reception 2. Physical malfunction of the GPRS transmission device 3. The GPS or GPRS antenna is not properly secured to the BeagleBone Black. 4. A programming error causes the GPRS unit not to transmit data.	Data transmission failure would result in the ground station not receiving or recording hazard detection, flight event, or GPS data from the rocket payload. This would result in a mission failure.	1	1. 3 2. 5 3. 4 4. 4 Most Likely: 3	Moderate	1. The team has verified, via T-Mobile's online coverage map, that the launch field at the Bonneville Salt Flats has wireless coverage. 2. An entry has been added to the pre-launch checklist to send a test SMS message with the GPRS unit to a cellular phone. This will verify that no physical defects are preventing the GPRS unit from functioning prior to launch. 3. Entries have been added to the team's pre-launch procedures checklist to verify that the GPS and GPRS antennae are screwed in securely, and held in place with electrical tape. 4. The GPRS unit has been (and will continue to be) tested to verify that the SMS-sending code functions without error.
Ground station does not receive	1. The ground station is not turned on when the data is	Failure of the ground station to receive data	1	1. 4 2. 4	Moderate	1. An item has been added to the team's pre-launch checklist to verify that the ground station is: powered on, fully charged, and

data from BeagleBone Black	transmitted 2. The ground station does not have network reception when the data is transmitted	from the payload would result in not recording hazard detection, flight event, or GPS data from the rocket payload. Such an error would constitute a complete mission failure.		Most Likely: 4		properly receiving text messages before launch. 2. The team has verified, via T-Mobile's online coverage map, that the launch field at the Bonneville Salt Flats as well as other launch fields have wireless coverage.
Web server does not receive data from ground station	1. The web server host experiences internal issues when data is transmitted from the ground station [IE a DOS attack, scheduled or unscheduled maintenance]. 2. The FTP credentials used to upload to the web server are not correct.	Failure of the web server to receive data updates would result in failure to display launch events in real-time to web-based users, which is a partial mission failure.	2	1. 4 2. 5 Most Likely: 4	Low	1. The team will contact the web hosting service to ensure that access should be available during the launch time frame. A pre-launch checklist item has been added to verify that the above has been completed. 2. Added an entry to the team's pre-launch checklist to verify that FTP credentials in the ground station's source code match the current, valid credentials for the web server.
BeagleBone Black fails to boot up or run code.	1. The Linux OS could have been corrupted during previous use. 2. BeagleBone has suffered physical damage.	Inability to use the brain of the rover would result in complete mission failure.	1	1. 4 2. 4 Most Likely: 4	Moderate	All: The team has possession of 3 BeagleBone's which can be swapped out in case one fails. 1. The BeagleBone will be flashed with the latest Linux OS. 2. The BeagleBone will be inspected for any anomalies before each launch.
LiPo battery fails.	1. Battery catches fire due to low or high voltage. 2. Battery is punctured during transportation or landing.	Loss of battery will result in payload electronics to be unpowered. Depending on	1	1. 4 2. 4 Most Likely: 4	Moderate	1. The LiPo batteries will be recharged to safe levels after each use. The batteries will be stored in a special fire-retardant bag. 2. The LiPo batteries will be transported and stored away from parts that could puncture the batteries. The batteries will be inspected before

		when the battery catches fire, the entire payload could be destroyed. Damage to people and property could occur.				and after each launch to insure they are not damaged.
Payload Components fall off during descent	1. Components are not attached securely onto electronics platform	All parts are crucial to payload performance so loss of any part would result in mission failure.	1	5	Low	1. All components will be inspected before flight to insure they are attached securely. Testing will be conducted to insure all parts can withstand parachute opening shock.
Components on Custom PCB do not work.	1. While soldering the components to the PCB, a short could have been made. 2. PCB layout could have been incorrect.	Depending on what parts fail on the custom PCB, failure could range from the BeagleBone not obtaining any power to not being able to control the motors and servo. This would result in mission failure.	1	1. 4 2. 4 Most Likely: 4	Moderate	1. Each component has been carefully soldered onto the PCB and inspected after all parts were placed to insure everything is soldered correctly. 2. The PCB layout was inspected by all electrical engineering students on the team before sending out to be manufactured.
The ESCs become non-operational.	1. The ESCs could have their protection circuit disabled. 2. The input signal from the PWM circuit could have fried the microcontroller onboard the ESC	If the ESC fails to operate, the motors to run the rover would not move. This would result in partial mission failure	2	4	Low	1. The ESCs will be inspected to insure the voltage protection is enabled. 2. An oscilloscope will be used to analyze the signal generated by the PWM circuit.

The Voltage Regulation circuit for the BeagleBone fails to provide the correct amount of power.	1. The LM7805 IC could be damaged resulting in incorrect regulation. 2. While soldering the LM7805 onto the PCB, a short could be created on one of the pins.	The BeagleBone could get damaged from power overload which could cause the payload's brain to become non-operational. This would be a mission failure.	1	4	Moderate	All. The team has access to 3 BeagleBone boards in case one becomes non-operational. 1. The circuit will be tested to insure it correctly regulates voltage before getting hooked up to the BeagleBone 2. The PCB will be inspected to insure all pins are correctly soldered.
Parachute Cam system suffers structural failure upon deployment from fairing.	1. Stresses from opening the parachute exceed the ultimate strength of the components such as ABS housing or metal pin.	The rover will fall without parachute which will result in its destruction upon landing. Damage to property and people could also occur.	1	3	Moderate	1. The parachute cam system has been tested numerous time to insure that it withstands the impact stresses from opening the parachute upon deployment. The thickness of the housing has been changed to better handle the stresses.
Parachute gets tangled with rover during descent.	1. Ejection from fairing could cause the parachute lines to get tangled with rover due to incorrect packing.	The rover could potentially descend without an active parachute leading to its destruction upon landing resulting in mission failure.	1	4	Moderate	1. The rover and its parachute will be carefully placed into the fairing to insure they do not get tangled. Deployment tests will continue to be conducted to insure tangling does not occur upon deployment.
The parachute cam system does not clear the	1. The parachute, after being disconnected, is carried by wind/gravity on top of/in front of the	The rover cannot move forward, thus resulting in failure of this	3	1. 3 2. 4 Most Likely: 3	Low	1. It is not possible for the team to control the weather conditions at the landing location. The team realizes this is a threat, and considers it an acceptable risk considering the time and cost of implementing a system to compensate

chute away from the body of the rover.	rover. 2. The parachute cam system does not supply sufficient force to lift the attached section of the parachute from the body of the rover.	mission objective.				for this problem. 2. The team has verified that the parachute release mechanism will eject the parachute lines from the body of the rover, barring mechanical failure or extraordinary environmental conditions.
The parachute release code executes before the rocket has launched, or during rocket ascent.	1. The code could read incorrect values from the pressure sensor that cause the servo to activate.	The parachute will be completely detached from the rover during descent, leading to probable destruction of the payload.	1	4	Moderate	1. An entry was added to the pre-launch checklist to verify that the servo is rotated in the proper position before launch. This check verifies that this problem did not occur before placement on the launch pad.
The landing event is not detected properly.	1. The pressure sensor physically/electrically/programmatically fails.	The code that ejects the parachute from the rover and drives the rover forward is never executed, causing partial mission failure.	3	4	Low	1. The sensor will be tested multiple times to insure it does not give incorrect readings. When soldering the sensor to the PCB, each pin will be inspected to insure there is no short that could cause the sensor to fail.
The code that rotates the servo does not wait long enough for the servo to rotate	1. The library documentation for the used function (Python's time.sleep()) asserts that the requested wait time can be longer than requested, due to signals being caught	The parachute is not cleared from the body of the rover, leading to a chance that the rover cannot move forward, causing partial mission failure.	3	4	Low	1. The team added a safety window of ~1-2 seconds to the amount of time the servo rotates. This will ensure that, if the servo does not rotate for the entire time length, the parachute will detach. 2. The sleep function will be tested multiple times to insure it works as intended.

	in Python. 2. The sleep function that is used encounters an exception or has a bug, and exits early.					
The code to send the PWM signal to the servo pin fails.	1. The software library used to send PWM signals is not installed on the device. 2. The software library used to send PWM signals to the servo is not the correct version. 3. The software library used to send PWM signals to the servo contains an internal bug.	The parachute is not cleared from the body of the rover, leading to a chance that the rover cannot move forward, causing partial mission failure.	4	1. 4 2. 4 3. 5 Most Likely: 4	Low	1. Added an entry to the pre-launch checklist to ensure that the correct version of the PWM is installed and configured. 2. Added an entry to the pre-launch checklist to ensure that the correct version of the PWM is installed and configured. 3. The PWM code will be tested multiple times to insure there is no bug.
The code that waits for servo rotation to complete fails.	1. The library function used to wait for rotation to complete contains an internal bug. 2. Power loss is experienced.	The servo will continue to rotate to the end of its allowed range [because the PWM signal is never stopped], which could damage the servo's gears.	4	1. 5 2. 5 Most Likely: 5	Low	1. The code will be tested to insure there are no bugs present. 2. The cables will be inspected to insure they are plugged in securely.
An exception is encountered during execution of any function calls in the	1. There are bugs in the programming language implementation used. 2. There are bugs in the PWM library used. 3. There is a	If the exception is thrown before the servo has been started, the servo will not rotate, which	3	1. 5 2. 5 3. 4 Most Likely: 4	Low	All: A try-catch block is placed around the entire servo rotation program. If any exceptions are encountered, the program will exit with a return code indicating an error has occurred. The process executing the servo rotation program will restart the servo rotation program

servo rotation code.	programming error in the servo rotation code.	will lead to the parachute not being released, and possible non-critical mission failure.				up to 3 times if an error is encountered.
The parachute cam servo is rotated in the incorrect direction.	1. During assembly, a team member does not know which way the servo should be oriented to be sure that it rotates.	The servo cam will not rotate the correct direction. This will cause the parachute to not be released from the rover body.	3	3	Low	1. An entry has been added to the pre-launch checklist to verify that the parachute cam servo is oriented completely counter-clockwise. This is verifiable by visual inspection. The assembly will also be tested to ensure that the servo will rotate in the proper direction when used.
Pressure sensor data does not reflect actual pressure.	1. Physical/electrical defect in the sensor hardware 2. Holes to allow air to enter are not present in the pressure sensor bay.	Launch, apogee, and landing detection have a strong possibility of being either incorrectly detected, or not detected. Each case is dealt with separately below.	1	1. 4 2. 4 Most Likely: 4	Moderate	Thorough testing will be done during development to ensure the pressure sensor's readings are accurate. Also, an entry has been added to the pre-launch checklist to take a sample reading from the pressure sensor, to verify that it is accurate.
The determined baseline pressure is not accurate.	Weather changes over time render the baseline pressure determination inaccurate when the rocket launches.	An inaccurate baseline pressure estimation will lead to not accurately detecting the launch time. However, launch should	4	4	Low	An entry has been added to the pre-launch checklist to compare the pressure reading at time of payload initialization with time of launch, to verify the difference is not too large.

		still be detected, before or after launch actually occurs.				
Apogee is not properly detected.	The observed time range is not large enough to detect apogee	Apogee is not detected: The system will continually loop, checking for apogee. Thus, image processing and rover driving steps will never run, constituting partial mission failure. Apogee is detected early: The apogee detection message will be sent at the wrong time, and image processing activities will start early, having no functional impact on payload performance. Apogee is detected late:	2	5	Low	The time range over which the program will attempt to detect apogee will be made as large as possible, so that the odds of the rocket coasting for the entire time period is minimized.

		The image processing step of flight is possibly missed completely, leading to partial mission failure. Landing detection and rover operations should still continue without issue.				
Rocket launch is not properly detected	1. A temporary change in weather causes a large pressure change, falsely triggering launch detection 2. The baseline pressure is not determined properly	If rocket launch is not detected, image processing and rover activities will never occur, constituting partial mission failure. If launch is determined early, it's possible that the rover will attempt to move forward inside its housing and release its parachute, causing destruction of the payload	2	1. 5 2. 4 Most Likely: 4	Low	Mitigations have been added to ensure the detected baseline pressure is accurate.

		after descent. If rocket launch is determined late, it's possible that image processing activities will not occur during rocket descent, leading to partial mission failure.				
SMS sending hardware is not functional	1. Physical/electrical/programmatic error in the SMS sending hardware	The launch, apogee, and landing detection events are not reported to the ground station, leading to partial non-essential mission failure.	2	4	Low	Thorough testing will be done during development to rule out most preventable programming errors.
Rocket landing is not properly detected	1. At apogee, the rocket coasts (nearly) horizontally for an extended period of time 2. The rocket lands on unstable ground, which gives way after a period of time more than 10 seconds	The parachute will not release from the rover, and the rover will not move forward, causing partial mission failure. If landing is improperly detected while the rover is still inside the	2	1. 4 2. 5 Most Likely: 4	Low	The current rocket design is not able to handle unpredictable ground conditions at the landing site. The risk from this error has been deemed acceptable.

		rocket body, the rocket's wheels would turn, possibly causing damage to the foam in the rover's housing. Also, the parachute would be released from the rover on the launch pad, causing almost certain destruction of the rover and payload after descent.				

Table 40. Hazard Detection Payload Risk Assessment

Environmental Hazards to Payload Risk Assessment						
Hazard	**Cause(s) of Hazard**	**Hazard Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Humidity	Humid Weather Conditions	Functionality of the electronics could be interrupted.	1	3	Moderate	The team will attempt to reduce the time that the electronics are exposed to the humidity by keeping them enclosed until they have to be used.
Altitude	At high altitudes there could be no network signal	The team would not obtain the payload's GPS coordinates as well as hazard data which could cause a mission failure	1	4	Moderate	The payload will be test flown to the target altitude or above to insure signal strength is acceptable. Network maps have been consulted and there is available reception at ground level for all launch sites.
High Winds	High winds could cause	The team	2	4	Low	The payload's parachute has been sized properly

	the payload to drift further than intended	would be in violation of the maximum drift distance allowed				to insure that it does not drift farther than what is allowed.
Soil/Ground Conditions	The Salt Flats are a hard surface.	The power screws could not dig into the ground, thus causing the rover to not move.	2	4	Low	The power screws have been tested to work on concrete. Upon arrival to the Salt Flats, the team will do ground tests to insure they operate as intended. If they can't dig into the ground, weights will be added to the rover to allow it to better penetrate the ground.
Electrostatic Discharge	Built up static electricity on team members	The electronics could suffer damage that would cause malfunctions	1	5	Low	Whenever interacting with the electronics, team members will have to touch a grounded metal piece to eliminate electrostatic discharge.

Table 41. Environmental Hazards to Payload Risk Assessment

Payload Hazards to Environment Risk Assessment						
Hazard	**Cause(s) of Hazard**	**Hazard Outcome**	**Severity Value**	**Probability Value**	**Risk Level**	**Mitigation**
Fire	LiPo battery catches fire	Part of the field catches on fire	2	4	Low	The LiPo batteries will be charged to their proper level to insure they do not catch fire.

Table 42. Payload Hazards to Environment Risk Assessment

LAUNCH OPERATIONS PROCEDURES

CHECKLIST

Safety Checklist: Stability and Propulsion

To be checked and initialed by S&P Safety representative.

Stability and Propulsion Representative Signatures:

1. ______________________________ *2.* __________________________________

Prior to leaving for launch site:

Booster Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *75mm Casing*
- *Cesaroni M3100-WT*
- *Aeropack 75mm flanged*
- *Booster Stand*

Required PPE:

- *Nitrile Gloves*

1. ___ The team mentor will be responsible for preparing motor within casing.
   ⚠CAUTION: Protective gloves are to be worn when applying grease to the motor.
2. ___ Slide motor casing fully into the motor mount tube.
3. ___ Attach motor retention ring. Do not over-torque.
4. ___ Set completely assembled bay on stand; do not rest on fins.
5. ___ Inspect each fin fillet for any signs of cracking or fatigue.
   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

⚠ DANGER The motor is not allowed to be handled by personnel without proper certifications. Individuals handling the motor need to ensure assembly is stored in a safe and secure place void of moisture and open flames.

Sustainer Propulsion Bay Assembly Checklist:

Required Equipment:

- *Gorilla Glue*
- *Grease*
- *75mm Casing*
- *Cesaroni L1720-WT*
- *Aeropack 75mm*
- *Lower Sustainer Stand*

Required PPE:

- *Nitrile Gloves*

1. ___ The team mentor will be responsible for preparing motor within casing.
   ⚠CAUTION: Protective gloves are to be worn when applying grease to the motor.
2. ___ Slide motor casing fully into the motor mount tube.
3. ___ Attach motor retention ring. Do not over-torque.
4. ___ Set completely assembled bay on stand; do not rest on fins.
5. ___ Inspect each fin fillet for any signs of cracking or fatigue.
   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

⚠ DANGER The motor is not allowed to be handled by personnel without proper certifications. Individuals handling the motor need to ensure assembly is stored in a safe and secure place void of moisture and open flames.

Safety Checklist: General Pre-Launch Day Preparations

To be checked and initialed by River City Rocketry team member.

River City Rocketry Team Member Signatures:

1. ____________________________ *2.* _______________________________

<u>Prior to leaving for launch site:</u>

Required Equipment:

- *Clear black powder capsules (x24)*
- *E-matches (x24)*
- *Drill*
- *1/8” drill bit*
- *Electrical tape*
- *Scissors*

Required PPE:

- *Safety glasses*

Black Powder Charge Preparation

1. ___ Drill a 1/8” hole in the bottom of each of the clear black powder capsules.
   ⚠**CAUTION**: Safety glasses are to be worn while drilling.
2. ___ Unwind one e-match.
3. ___ Feed wire from the e-match through the hole in the base of a capsule. Ensure the pyrotechnic end of the e-match is inside the capsule.
4. ___ Wrap electrical tape to secure the e-match in place and to ensure that black powder will not leak from the capsule.
   ⚠WARNING If the capsules are not completely sealed, black powder will leak when the capsules are filled. Leakage could potentially result in ejection charges being too small or failing altogether, causing a catastrophic failure in recovery.
5. ___ Repeat steps 2 through 4 23 times.
6. ___ Store modified capsules and e-matches in explosives box.
   ⚠ DANGER E-matches are explosive. The leads must be kept clear from batteries and any open flames in order to avoid accidental firing.

Safety Checklist: Hazard Detection Payload

To be checked and initialed by Payload Safety representative.

Hazard Payload Assembly:

Payload Safety Representative Signatures:

1. ______________________________ 2. ______________________________

Required Equipment:

- *Payload Smartphone with SIM card*
- *BeagleBone Black*
- *Logitech C920 Webcam*
- *2S 2200mAh LiPo Battery*
- *3S 2200mAh LiPo Battery*
- *Parachute Cam*
- *Servo*
- *GPS/GPRS Cape*
- *GPS & GPRS Antennas*
- *Custom PCB*
- *2x ESCs*
- *2x Motors*
- *2x Motor Clamps*
- *Rover Body*
- *Smartphone Charger*
- *LiPo Battery Charger*
- *BeagleBone USB Cable*
- *Mini/small Phillips screwdriver*
- *Pliers*
- *Volt Meter*
- *Toolbox with extra components*

Prior to leaving for launch site:

3. ___ Ensure Lithium Polymer batteries are fully charged
4. ___ Ensure Smartphone is fully charged
5. ___ Go to T-Mobile website and enable/purchase single day call & text service for smart phone ($3/day plan)
6. ___ Turn on Smartphone and make call to activate SIM card
7. ___ Turn off Smartphone and remove SIM card
8. ___ Install SIM card onto GPS/GPRS cape

9. ___ Ensure all libraries are installed and configured on the BeagleBoard.
    a. Libraries
        i. ___OpenCV
        ii. ___SciPy
        iii. ___NumPy
        iv. ___GPRS libraries [see the GPRS unit's user manual for installation instructions]
            1. ppp [Point-to-Point Protocol]
        v. ___Adafruit-beaglebone-io-python [used to control the parachute release servo]
        vi. ___Ensure the revision from Feb. 7th, 2014 is installed and configured. Library revisions are at https://github.com/adafruit/adafruit-beaglebone-io-python/commits/master Installation guide is at http://learn.adafruit.com/setting-up-io-python-library-on-beaglebone-black/
10. ___ Configuration
    a. ___GPRS unit
        i. ___Firmware [section 7.1 in the user manual]
        ii. ___Ensure HDMI is disabled in the file /boot/uEnv.txt. [see section 4 in the user manual]
        iii. ___Ensure the GPRS unit is set up to send data in the 850MHz+1900MHz band. See email from Duarte Carona on Feb 3, 2014. See also 3.5.7.1.56 of the GPRS AT command list.
    b. ___Payload program
    c. ___Does our systemd service point to the correct path of the startup program? See the field ExecStart in /etc/systemd/system/<programName>.service
    d. ___Confirm that the startup script is executable. chmod +x it if not.
    e. ___Confirm that the startup script actually runs on startup, without error.
11. ___ Ensure the payload starts without errors.
    a. If an error occurs, decide if we should abort launch or continue.
12. ___ Verify that the ground station device is:
    a. ___Fully charged (or at least mostly charged).
    b. ___Turned on.
    c. ___Receives text messages from a member's phone.
13. ___Verify that the web server is:
    a. ___Running.
    b. ___Accepting FTP uploads.

At launch site:

1. ___ Insure that SIM card is inserted into GPS/GPRS Cape

2. ___ Screw BeagleBone into electronics platform
3. ___ Attach Cape and Custom PCB onto BeagleBone

4. ____Verify that the GPS antenna and GPRS antenna are:
   a. ___Screwed securely into the GPS/GPRS cape.
   b. ___Secured in place with electrical tape.
5. ___ Insure that both boards are secure
6. ___ Place C-clamps around motors
7. ___ Screw C-clamps onto end plate of rover
8. ___ Attach motor's shaft to coupler using grub screws
9. ___ Insure motors are secure
10. ___ Attach ESCs to electronics platform by using metal cover
11. ___ Assemble Parachute Cam
12. ___ Attach servo to Parachute Cam
13. ___ Screw Parachute Cam assembly to electronics platform
14. ___ Insure Parachute Cam is secure
15. ___ Screw webcam to electronics platform
16. ___ Attach LiPo batteries to electronics platform using metal cover
17. ___ Attach antennas to GPS/GPRS Cape
18. ___ Wire all components to BeagleBone including batteries
19. ___ Insure that boot-up program detects no errors
20. ___ If errors occurred, solve problems
21. ____ Once boot-up program indicates no errors, attach parachute to pin on the Parachute Cam
22. ____ Inspect rover to insure all components are securely mounted
23. ____ Insert Rover into Fairing
24. ____ Say Good-bye
25. ____ Start tracking GPS coordinates for the rover

Post-flight Inspection:

1. ___ Verify all components are still attached to rover and undamaged
   a. ___ Camera
   b. ___ 2 LiPos
   c. ___ BeagleBone and attached Capes
   d. ___ Parachute Cam System
   e. ___ 2 ESCs
   f. ___ 2 Motors
2. ___ Verify Data is saved on Webserver
3. ___ Go over data acquired

Safety Checklist: Recovery

To be checked and initialed by Recovery Safety representatives.

Recovery Representative Signatures:

1. ___________________________ *2.* ______________________________

<u>*Prior to leaving for launch site:*</u>

Parachute Packing

Required Equipment:

- *Small fabric hair ties*
- *Hook*
- *Clamp*
- *Booster parachute*
- *Booster parachute deployment bag*
- *Lower sustainer parachute*
- *Lower sustainer parachute deployment bag*
- *Upper sustainer parachute*
- *Upper sustainer parachute deployment bag*
- *Rover parachute*
- *Rover parachute deployment bag*
- *Swivels*

1. ___ Lay parachute canopy out flat.
2. ___ Inspect canopy and lines for any cuts, burns, fraying, loose stitching and any other visible damage.

   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.
3. ___ Ensure shroud lines are taut and evenly spaced.
4. ___ Fold parachute. Use clamps as necessary to ensure
5. ___ Place folded parachute into respective deployment bag with shroud lines coming directly out of the bag.

   ⚠WARNING Ensure that the shroud lines are not wrapped around the parachute inside the deployment bag. This will result in the parachute getting stuck in the deployment bag. Verify that the parachute fits loosely in the deployment bag.
6. ___ Secure deployment flaps using shroud line and fabric hair ties.

7. ___ Use hook to assist in securing extra length of shroud lines through loops stitched in deployment bag. Continue this pattern in the same direction around the deployment bag in order to prevent tangling.
8. ___ Repeat steps for each parachute.

Booster Avionics Bay:

Required Equipment:

- *Precision flathead screwdriver*
- *Booster altimeter sled*
- *RRC3 Altimeters (x2)*
- *4x40 shear pins (x8)*

1. ___ Verify RRC3 altimeters are properly programed in accordance with file in team Dropbox folder.
2. ___ Mount each altimeter onto standoffs on booster altimeter sled using 4, 4x40 shear pins each. Ensure that each altimeter is securely mounted.
3. ____Aux channels to forward terminal blocks
4. ____Drogue and Main channels to aft terminal blocks

Sustainer Avionics Bay:

Required Equipment:

- *Precision flathead screwdriver*
- *Sustainer altimeter sled*
- *Raven altimeters (x2)*
- *Tiltometer*
- *4x40 shear pins (x4)*
- *Nylon standoffs (x4)*
- *9V battery*

1. ___ Verify Raven altimeters are properly programed in accordance with file in team Dropbox folder.
2. If the tiltometer is logging data to its SD card, verify that the tiltometer is set to record to a new file, so that old data is not mixed in with flight data.
3. ___ Verify that a new or close to new battery is provided for the tiltometer. If not, get a new battery, just in case.
4. ___ Mount tiltometer onto sustainer altimeter sled using 4 nylon standoffs and 4, 4x40 shear pins.

⚠WARNING Ensure that tiltometer is oriented properly, as indicated on the sled. If the tiltometer is oriented incorrectly, it will not be able to function properly, causing the safety feature to be lost.

5. Wire tiltometer output to aft terminal blocks
6. Place the tiltometer on the ground, in the same orientation it will be inside the rocket. Plug in the battery, and wait for the on-board LED to turn purple. This will take 1-2 minutes. This ensures the tiltometer is calibrated properly.

⚠WARNING If the tiltometer is not calibrated properly, it's possible that the second stage motors will not fire when they should, or will fire when they should not.

Lower Fairing Altimeter Housings:

Required Equipment:

- *Precision flathead screwdriver*
- *StratoLogger altimeter (x2)*
- *4x40 shear pins (x16)*
- *Acrylic altimeter housing cover (x2)*

1. ___ Verify StratoLogger altimeters are properly programed in accordance with file in team Dropbox folder for the lower fairing.
2. ___ Mount each altimeter onto standoffs in each altimeter housing in the fairing using 4, 4x40 shear pins each. Ensure that each altimeter is securely mounted.
3. ___Raven 3rd and 4th output channels to Tiltometer "Raven" + and – terminal.
4. ___Raven apo and main channel to forward terminal blocks
5. ___Tiltometer output to aft terminal blocks
6. Install an acrylic cover on each of the altimeter housings. To ensure hole alignment, match the key on each cover to the respective housing. Secure using 4, 4x40 shear pins for each.

Nosecone Altimeter Sled:

Required Equipment:

- *Precision flathead screwdriver*
- *StratoLogger altimeter (x2)*
- *Nosecone altimeter sled*
- *4x40 shear pins (x8)*
- *M3 screws (x2)*
- *Washers (x2)*
- *¼" threaded rod (x2)*

- *¼”-20 nut (x6)*
- *¼”-20 washer (x6)*

1. ___ Verify StratoLogger altimeters are properly programed in accordance with file in team Dropbox folder for the nosecone.
2. ___ Mount each altimeter onto standoffs in each altimeter housing in the fairing using 4, 4x40 shear pins each.
3. ____ Check GPS for full charge.
4. ___ Securely mount GPS to GPS sled using 2 M3 screws and washers.
5. ___ Install threaded rods into bulkhead using a ¼”-20 nut and washer on both sides of the bulkhead for each rod.
6. ___ Slide altimeter sled onto threaded rods and secure in place using a ¼”-20 nut and washer.
7. ___ Install a washer onto each threaded rod, followed by the upper bulkhead.
8. ___ Secure upper bulkhead into place with a ¼”-20 nut and washer on each threaded rod.
9. ___ Install a washer onto each threaded rod followed by the GPS mount.
10. ___ Secure upper bulkhead into place with a ¼”-20 nut and washer on each threaded rod.
11. ___Drogue and Main output channels to aft terminal blocks

Launch day procedures

Booster Parachute Assembly:

Required Equipment:

- *Nomex cloth*
- *Shock chord*

1. ___ Verify motor hardware is attached.
2. ___ Attach longest length of shock chord to motor hardware.
3. ___ Verify motor is installed.
4. ___ Attach other end of shock chord to parachute.
5. ___ Attach shock chord that attached to parachute to the U-bolt.
6. ___ Attach pilot parachute to top of deployment bag.
7. ___ Remove all rubber bands.
8. ___ Wrap deployment bag in Nomex.
9. ___ Insert both parachutes into booster.

Lower Sustainer Parachute Assembly:

Required Equipment:

- *Nomex cloth*
- *Shock chord*

1. ___ Attach parachute to avionics bay.
2. ___ Remove all rubber bands.
3. ___ Wrap deployment bag in Nomex.
4. ___ Insert parachute into airframe.

Rover Parachute Assembly:

1. ___ Attach rover parachute deployment bag to upper bulk plate.
2. ___ Remove all rubber bands.
3. ___ Fit parachute into foam insert.
4. ___ Attach shroud lines to rover.

Fairing Parachute Assembly:

Required Equipment:

- *Nomex cloth*

1. ___ Attach parachute to u bolt on upper bulk plate.
2. ___ Attach parachute to fairing.
3. ___ Attach pilot parachute to deployment bag.
4. ___ Remove all rubber bands.
5. ___ Wrap deployment bag in Nomex.
6. ___ Insert parachute into airframe.

Booster Avionics Bay:

Required Equipment:

- *Multimeter*
- *7/64" allen wrench*
- *Precision flathead screwdriver*
- *Wire strippers*
- *6-32 socket cap screws (x4)*
- *¼"-20 nut (x2)*
- *¼"-20 washer (x2)*
- *Black powder charges (x6)*

1. ___ Ensure that permanently coupled joint of booster is reinforced with 4, 6-32 socket cap screws.

2. ___ Verify battery has charge greater than 5V.
3. ___ Verify proper shielding.

   ⚠WARNING Ensure that the bulkhead is properly shielded in order to protect from interference.
4. ___ Plug a battery into each altimeter.
5. ___ Verify wiring of altimeters is correct.
6. ___ Strip leads on black powder charges and install into designated terminal blocks.
7. ___ Install altimeter bay into airframe using ¼-20 nuts and washers.

Lower Fairing Avionics Bay:

Required Equipment:

- *Multimeter*
- *Precision flathead screwdriver*
- *Black powder charges (x4)*

1. ___ Verify both batteries have a charge greater than 5V.
2. ___ Verify proper shielding.

   ⚠WARNING Ensure that the bulkhead is properly shielded in order to protect from interference.
3. ___ Plug a battery into each altimeter.
4. ___ Verify wiring of altimeters is correct.
5. ___ Strip leads on black powder charges and install into designated terminal blocks.
6. ___ Install altimeter bay into airframe.

Nosecone Avionics Bay:

Required Equipment:

- *Precision flathead screwdriver*
- *¼"-20 nut (x2)*
- *¼"-20 washer (x2)*

1. ___ Verify each battery has charge greater than 5V.
2. ___ Verify proper shielding.

   ⚠WARNING Ensure that the bulkhead is properly shielded in order to protect from interference.
3. ___ Plug a battery into each altimeter.
4. ___ Verify wiring of altimeters is correct.

5. ___ Strip leads on black powder charges and install into designated terminal blocks.
6. ___ Install nosecone avionics bay to threaded rods, securing the bulkhead to the nosecone using 2, ¼-20 nuts and washers.

Safety Checklist: Fairing Payload

To be checked and initialed by Fairing Payload Safety representatives.

Fairing Payload Representative Signatures:

1. ___________________________ *2.* ______________________________

Prior to leaving for launch site:

Fairing Assembly:

1. ___ Check that the airframe is not deformed.
2. ___ Check for cracks in the epoxy fillets to ensure the structural integrity of all bulk plates.
3. ___ Inspect the foam inserts and ensure there is no play or deformations in them.
4. ___ Ensure that the fairing can smoothly open and close.

   Note: If any damage is identified, **immediately** inform both of the team captains and the safety officer. The rocket will be deemed safe to fly or a corrective action will be decided upon and implemented.

Launch day procedures:

Fairing Deployment Mechanism:

Required Equipment

- *U-bolts (x2)*
- *Springs (x2)*
- *Washers (x8)*
- *Nuts (x4)*

1. ___Inspect that sprints have not been warped and still retain their proper spring rate.
2. ___ Ensure that the hinge is free of debris and opens smoothly.
3. ___ Thread 2 springs onto the two U-bolts. Ensure that springs rest in the grooves on the U-bolts.
4. ___ Install U-bolts to upper bulkhead using 4 nuts and washers.

Pyro Cap Assembly:

Required Equipment:

- *Precision flathead screwdriver*
- *3 components of pyro cap*
- *Black powder*

- *E-matches (x4)*
- *4-40 shear pins (x2)*
- *Duct tape*
- *Eye-bolt*
- *Nylon chord*

Required PPE:

- *Nitrile gloves*
- *Safety glasses*

1. ___ Inspect shells for bends, or wear that would cause clearance conflicts.
2. ___ Install e-match into each of the four holes in the cap.
3. ___ Secure e-matches and cover holes on top of cap with duct tape. Cut any excess tape off so that there is no overhanging tape.
4. ___ Fill the two wells of the cap with black powder and cover base with duct tape. Cut any excess tape off so that there is no overhanging tape.

   ⚠WARNING If the cap is not completely sealed, black powder will leak. Leakage could potentially result in the charges being too small to shear the pins, resulting in the payload being unable to deploy.
5. ___ Mount cap to base plates using 2, 4-40 shear pins.

Fairing Assembly:

Required Equipment:

- *Packed rover deployment bag*
- *Nylon chord*
- *Rover*
- *4-40 countersunk screws (x4)*

1. ___ Tie the nylon cord from the deployment bag to the appropriate eyebolt on the upper bulk plate.
2. ___ Tie nylon cord from the pyro cap's eyebolt to the appropriate eyebolt in the adjacent bulk plate.
3. ___ Mount pyro cap assembly to lower bulk plate using 4-40 countersunk screws.
4. ___ Close fairing.

Safety Checklist: Launch Pad

Launch Pad Assembly Checklist (LPA): To be checked and initialed by Launch Pad Safety representative.

Launch Pad Safety Representative Signatures:

1. ____________________________ 2. ________________________________

Prior to launch day:

Required Equipment:

- *Allen Wrench Set – Standard*
- *Upper and Lower Launch Pad sections*
- *Launch Pad legs*
- *9/16" Wrench*
- *Quick release pins*
- *3/4" wrench*
- *Hammer*
- *Stakes*
- *Ladder*
- *Drill with 3/8" or larger bit*
- *Level*
- *Section of airframe*
- *Graphite*

1. ___ Inspect launch pad for any cracked welds.
2. ___ Attach legs to launch pad using quick release pins.
3. ___ Polish mounting pins on lower launch pad section.
4. ___ Slide Upper Launch Pad section onto corresponding mounting pins in the Lower Launch Pad section.
5. ___ Secure brackets to upper and lower launch pad.
6. ___ Position lower Launch Pad enclosure so that it is fastened to both upper and lower sections of the launch pad.
7. ___ Secure lower launch pad enclosure to guide rails using existing hardware.
8. ___ Tighten all 4 leveling screws so that the base is stationary. Be careful not to over torque.
9. ___ Apply graphite to guide rails where rocket contacts rails.

10. ___ Slide section of airframe into launch pad. If section of airframe does not freely slide up and down the entirety of the launch pad, troubleshooting may be necessary.

    ⚠WARNING Launch pad is not to be cleared for launch until the section of airframe moves freely. If the airframe gets hung up on the launch pad, too much friction will be seen by the rocket, risking a successful flight.

11. ___ Upright Launch Pad and level the guide rails using leveling screws. Be sure all screws are tight.
12. ___ Drill four holes in ground for tensioning lines.
13. ___ Stake down tensioning lines using stakes.
14. ___ Fine tune adjustments for tensioning lines using turnbuckles.

Safety Checklist: General Procedures and Before/After Launch

Overall Body Assembly Checklist (OBA): To be checked by Safety Officer upon completion of all sub-team assemblies.

Safety Officer Signatures:

1. ___________________________ *2.* ______________________________

Required Equipment:

- *Allen Wrench Set – SAE*
- *Phillips Head Screwdriver (large)*
- *Flat Head Screwdriver (Large)*
- *Small Screwdriver Set (Small)*
- *Socket Wrench Set for ¼-20 Nuts*
- *Masking tape*

1. ___ Insert and secure SMD bay into the lower airframe. Ensure that all viewing and vent ports are aligned correctly.
2. ___ Insert and secure Recovery bay on top of the SMD bay. Align rod holes and run the rods down until they engage with the transition plate. Attach corresponding ¼-20 nuts to the rods at the transition plate end.
3. ___ Secure down the corresponding ¼-20 nuts. Do not over-torque.
4. ___ Attach all parachutes and shock cables to bulkhead. See Recovery Checklist on proper parachute folding techniques.
5. ___ Attach upper airframe to the bays and secure into place with corresponding bolts.

6. ___ Insert properly folded parachute and deployment bad into bay. Ensure no entanglement with shock lines occurs.
7. ___ Organize and insert shock cables and drogue into upper airframe.
8. ___ Align nose cone with shear pin holes and insert into upper airframe.
9. ___ Insert shear pins into holes utilizing a small, flat-head screw driver. Ensure that all shear pins are tight fitting and will not fall out during ascent.
10. ___ Attach completely assembled propulsion bay to completely assembled transition bay. The acrylic transfer will have to couple with the propulsion bay properly to be seated.
11. ___ Clean transition section of any debris from assembly operations.
12. ___ Tape motor igniter to the outside of the propulsion bay in a place easily seen by the field RSO.
13. ___ A final visual inspection will need to be done to ensure all systems are go.

At Launch Pad Checklist (ALP): To be checked by Safety Officer upon completion of Overall Body Assembly and Launch Pad Assembly.

Safety Officer Signature: ___________________________________

Launch Team Signatures: All signatures must be included for a "Go" at launch.

Stability and Propulsion Representative: ____________________________

Recovery Payload Representative: ________________________________

Electronics Representative: ______________________________________

Launch Pad Representative: ______________________________________

Team Captain: ____

Required Equipment:

- *Pen or pencil*
- *Level 2 Certification card.*
- *Propulsion Bay Stand*
- *Magnetic Switch Magnet*
- *Switch Rods*
- *GoPro camera*

1. ___ Verify flight card has been properly filled out and permission has been granted by RSO to launch.
2. ___Place rocket on launch pad.

3. ___ Tilt and rotate the launch pad in desired direction, or in direction ruled necessary by RSO.
4. ___ Secure all launch pad tie downs.
5. ___ Ensure proper connection has been made with ground station electronics.
6. ___ Arm all altimeters (in order as follows: StratoLoggers in nose cone, StratoLoggers in fairing, RRC3s in booster, and then Ravens for stage separation), cameras, and payloads. Check for correct LED readout, beeping pattern, etc.
7. ___ Remove igniter, separate leads, and run up into motor until igniter is fully seated. Attach yellow plastic cap and run igniter out of the provided hole. Form a loop in the igniter to keep it fully seated within the motor.
8. ___ Tap ignition system leads together to remove any static buildup that could cause ignition. Wrap igniter leads around each clip. Drape the ignition system leads out of the direct path of the exhaust.
9. ___ Before leaving launch pad area, double check for signs that all electronics are still operating correctly.
10. ___ Arm launch pad camera and begin recording.
11. ___ Clear launch pad area and do not return until range has been reopened by the RSO.

Safety Checklist: During and After Flight (DAF):

Flight Timer Signature: ____

First Event Observer Signature: _____________________________ *Time:* _______

Second Event Observer Signature: _________________________ *Time:* _______

Landing Event Observer Signature: _________________________ *Time:* _______

Ground Station Operator Signature: _________________________

Video Recorder Signature: _________________________________

Rapid Retrieval Team Member #1: __________________________

Rapid Retrieval Team Member #2: __________________________

Rapid Retrieval Team Member #3: __________________________

Required Equipment:

- *Stopwatch or phone timer.*
- *Magnetic Switch Magnets*

1. Rapid Retrieval team members are to be within close vicinity to a vehicle ready to move within a few seconds notice.
2. Start stopwatch upon liftoff and call out time in 5 second intervals until T-10 seconds until first event. Continue to call out times until T-10 seconds to second event.
3. Maintain line of sight with rocket at all times. Indicate any observed anomalies out loud to alert spectators.
4. While retrieving rocket, disarm all rocket recovery systems first.
5. Before disturbing the rocket, note any damages and anomalies with root causes. Document these for later examination.
6. Disassemble the rocket looking for any signs of wear, damage, or fatigue. Note what repairs will have to be made, if any.

After Flight Checklist: To be checked and initialed by Recovery Safety representative.

Recovery Representative Signatures:

1. ____________________________ 2. _______________________________

1. ___ Inspect all shroud lines for any damage, or burn marks.
2. ___ Inspect all shroud attachment points for damage.
3. ___ Inspect entire canopy for any damage, or stretching.
4. ___ Inspect deployment bag for damage.

Damage found on shroud lines? Y / N

*Notes:*____

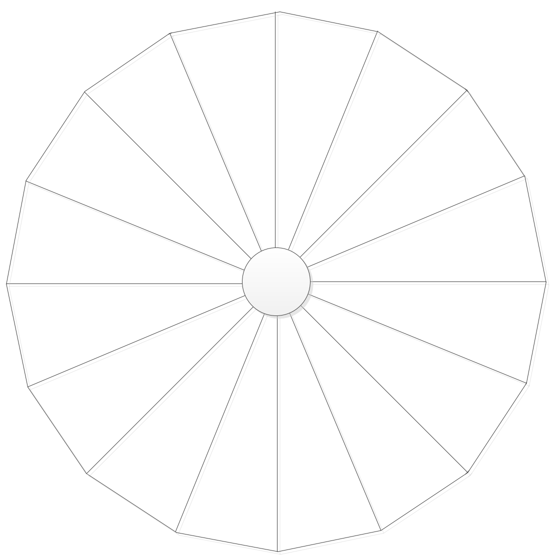
Damage found on attachment points? Y / N

*Notes:*____

Damage found on deployment bag? Y / N

*Notes:*____

Mark area where tearing or stretching was found on canopy



Damage Notes:

____

____

____

Repair Plan:

____

____

____

Altitude Achieved: ________________

Motor Used: _____________________

Location: _______________________

Temperature: ____________________

Pressure: _______________________

Wind Speed: ____________________

Event #1 Success: Y or N

Event #2 Success: Y or N

Captain Approval: 1. ____

2. ____

Project Plan

Status of Activities and Schedule

Vehicle Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
G12 Filament Von Karman Nose Cone	1	$122.55	$122.55
G12 Filament Airframe Tubing (1 ft)	9	$43.94	$395.46
G12 Filament Coupler Tubing (1 ft)	4	$55.76	$223.04
G12 Filament 75 mm Tubing (1 ft)	4	$19.48	$77.92
Acrylic Sheet (1/8" x 12" x 12")	4	$8.63	$34.52
1/4"-20 Hex Nut (Aluminum)	100	$0.06	$6.41
1/4"-20 Washer (Aluminum)	100	$0.07	$6.80
1/4"-20 U-Bolt (Aluminum)	4	$3.22	$12.88

1/4"-20 Threaded Rod (Aluminum) (3 ft)	2	$4.46	$8.92
D-Ring	4	$2.00	$8.00
4-40 x 1/2" Nylon Screws	100	$0.05	$5.34
Epoxy Clay	2	$11.95	$23.90
J-B Weld	10	$5.00	$50.00
Dog Barf Wadding (1 lb)	1	$5.00	$5.00
Cesaroni 75 mm-5G-WT M3100Motor	5	$269.96	$1,349.80
Cesaroni 75 mm-3G-WT L1720 Motor	7	$170.96	$1,196.72
Cesaroni 75 mm 5 Grain Hardware	1	$323.96	$323.96
Cesaroni 75 mm 3 Grain Hardware	1	$260.96	$260.96
Cesaroni Pro 75 mm Wrench	1	$30.29	$30.29
Aero Pack 75 mm Retainer Body	1	$30.00	$30.00
Aero Pack 75 mm Retainer Cap	1	$27.00	$27.00
6" Fiberglass Bulkplate	4	$8.55	$34.20
6" to 75 mm Fiberglass Centering Ring	3	$9.50	$28.50
6" Plywood Coupler Bulkplate	4	$5.90	$23.60
6" to 3.0" Plywood Centering Ring	3	$6.20	$18.60
Total			**$4,304.37**

Table 43. Vehicle budget.

Subscale Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
G12 Filament Von Karman Nose Cone	1	$46.01	$46.01
G12 Filament Airframe Tubing (1 ft)	7	$19.48	$136.36
G12 Filament Coupler Tubing (9 in)	4	$19.74	$78.96
G12 Filament 38 mm Tubing (1 ft)	4	$12.44	$49.76
G12 Filament 1/8" 1'x1' Fiberglass	3	$17.70	$53.10
Acrylic Sheet (1/8" x 12" x 12")	2	$8.63	$17.26
1/4"-20 Forged Eyebolt (Steel)	6	$2.89	$17.34
1/4"-20 Hex Nut (Aluminum)	100	$0.06	$6.41
1/4"-20 Washer (Aluminum)	100	$0.07	$6.80
1/4"-20 U-Bolt (Aluminum)	4	$3.12	$12.48
1/4"-20 Threaded Rod (Aluminum) (3 ft)	2	$4.46	$8.92
D-Ring	4	$2.00	$8.00
4-40 x 1/2" Nylon Screws	100	$0.05	$5.34
J-B Weld	10	$5.00	$50.00
Dog Barf Wadding (1 lb)	1	$5.00	$5.00
Cesaroni 38 mm-2G-IM H100 Motor	6	$28.76	$172.56

Cesaroni 38 mm-2G-WT H225 Motor	8	$29.66	$237.28
Cesaroni 38 mm 2 Grain Casing	2	$35.66	$71.32
Aero Pack 38 mm PML Motor Retainer	2	$29.00	$58.00
3" Fiberglass Bulkplate	4	$4.75	$19.00
3" to 38 mm Plywood Centering Ring	6	$2.63	$15.78
Total			**$1,075.68**

Table 44. Subscale budget.

Recovery Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
Garmin Astro 320 GPS Unit	3	$189.99	$569.97
Ripstop Nylon (62" x 36")	13	$9.50	$123.50
1/4" Dacron Rope (1 ft)	240	$0.36	$86.40
Perfect Flight StratoLogger	4	$85.55	$342.20
Goex FFFFA Black Powder (1lb)	1	$32.45	$32.45
Electric Matches	50	$1.25	$62.50
Lithium Ion Battery	2	$15.95	$31.90
Featherweight Raven	2	$155.00	$310.00
Featherweight Raven Power Perch	2	$35.00	$70.00
MissleWorks RRC3	2	$69.00	$138.00
Total			**$1,766.92**

Table 45. Recovery budget.

Fairing Payload Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
Bulkhead	3	$19.68	$59.04
Centering Ring	1	$6.89	$6.89
Bulkhead	1	$9.00	$9.00
Hinge	1	$27.87	$27.87
Square U-bolt	2	$15.76	$31.52
Hex Nut	8	$9.37	$74.96
Washer	4	$8.09	$32.36
Socket Cap Screw	6	$6.87	$41.22
Split Lock Washer	6	$2.71	$16.26
Hex Nut	6	$7.92	$47.52
Aluminum Stock 6"	1	$94.94	$94.94

Foam Insert	1	$300.00	$300.00
Pyro Cap	1	$200.00	$200.00
O-ring	1	$8.09	$8.09
Eye Bolt	1	$2.89	$2.89
Flat Head Socket	4	$2.71	$10.84
Extension Spring	2	$10.16	$20.32
Eye Bolt	1	$2.28	$2.28
Kevlar String	1	$23.73	$23.73
Heat Shrink Tubing	1	$7.03	$7.03
Total			**$1,016.76**

Table 46. Fairing payload budget.

Hazard Detection Payload Budget			
Unit	***Quantity***	***Unit Cost***	***Total***
BeagleBone Black	2	$45.00	$90.00
ChipQuik 8cc Flux	1	$11.85	$11.85
Mini Solder Spool- 100gram	1	$5.95	$5.95
3-Axis ADXL345 Accelerometer Board	1	$19.95	$19.95
BeagleBoard ProtoCape Kit	1	$9.95	$9.95
Tacon 540XXL 2858 Brushless Motor 1200KV	2	$23.32	$46.64
Sky Lipo 1600mAh 14.8V 40C	2	$20.94	$41.88
XT60 Solid Bullet Connectors	1	$5.50	$5.50
Heat-shrinkable Tubing 04---black	1	$0.40	$0.40
LED Program Card For Brushless ESC	1	$8.99	$8.99
HobbyWing eZRun-35A Brushless ESC	2	$31.99	$63.98
0.125in to 0.25in Shaft Coupler	2	$4.99	$9.98
0.25in x 12in D-Shaft	2	$4.69	$9.38
0.25in x 0.77in Set Screw Hub	4	$4.99	$19.96
Aluminum Mounted Bearings	4	$7.97	$31.88
8-32, 5/8in Length Screws	1	$9.51	$9.51
8-32, 1/8in Height Nuts	1	$3.96	$3.96
4-40, 1/2in Length Screws	1	$1.63	$1.63
4-40, 3/32in Height HexNuts	1	$0.81	$0.81
5-40, 2in Length Screw	1	$13.60	$13.60
5-40, 7/64 Height LockNut	1	$4.43	$4.43
Loctite 680 Retaining Compound	1	$14.81	$14.81
Loctite 7649 Primer	1	$11.88	$11.88
8-32, 1/8in Height Nuts	1	$1.49	$1.49

6-32, 5/8in Length Screws	1	$2.50	$2.50
6-32, 3/32 Height Hex Nuts	1	$2.61	$2.61
SciGrip Plastic Cement	1	$5.71	$5.71
4-40, Male-Female Nylon Standoffs	1	$12.24	$12.24
4-40, 1/4in Length Nylon Screws	1	$5.23	$5.23
12in x 24in Black Acrylic Sheet	1	$18.80	$18.80
3in x 12in MultiPurpose 6061 Aluminum Rod	2	$51.97	$103.94
Logitech C920 HD Pro Webcam	1	$69.99	$69.99
T-Mobile Mobile Plan	30	$3.00	$90.00
Total			**$749.43**

Table 47. Hazard detection payload budget.

Travel Budget	
Expenditure	***Cost***
Vehicle Rental	$2,176.00
Gas	$1,730.65
Hotel	$2,000.00
Total	**$5,906.65**

Table 48. Travel budget.

Total Tentative Budget	
Vehicle	$4,304.37
Recovery	$1,766.92
Fairing Payload	$1,016.76
Hazard Detection Payload	$749.43
Subscale	$1,075.68
Educational Engagement	$1,500.00
Promotional Materials	$2,000.00
Travel Expenses	$5,906.65
Total	**$18,319.81**

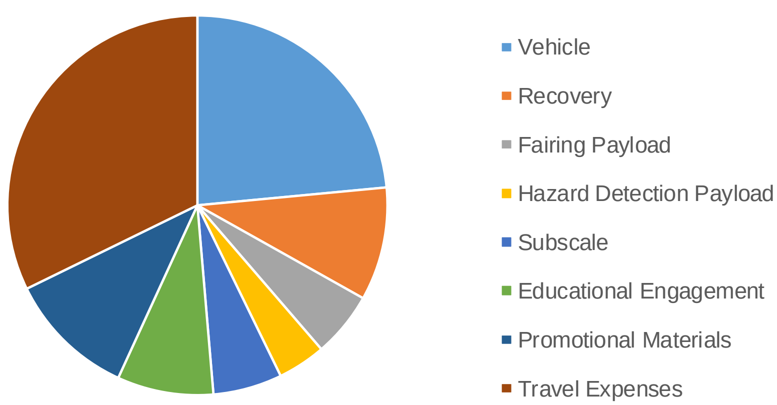


Figure 141. Total tentative budget.

1.1) Educational Engagement

During the 2013-2014 season, the University of Louisville River City Rocketry Team has managed to reach out to many students and adults in the local community. Schools from across the state of Kentucky were able to get a hands on experience with engineering and rocketry working side-by-side with members of the team. The team strove to maintain relationships built with organizations in the community while continuing to reach people in new ways. The focus was not on how many people were could reached, but the quality of education that was brought to each and every individual.

Figure 142 River City Rocketry visiting the Academy at Shawnee. Dhwani assists a student in prepping his rocket for launch at the end of the team's six week program.

Curriculum

The University of Louisville River City Rocketry Team was involved with a variety of programs and events throughout the season. Included is a list of the different activities in which the team has participated.

6 Day Program Curriculum

The main new addition to the team's curriculum includes a six week aerospace program. The team piloted the program early in the season at a local middle school. The program got media attention, drawing interest from three other local middle schools. As the season has progressed, the program has continued to draw attention. The schools that the team has completed the program have already lined the team up to complete the program next year.

Figure 143: A young engineer building a paper rocket at E-Expo.

Day 1: The Space Race and Mercury and Gemini Program History:
This lesson introduces the cold war, the relationship between the United States and the U.S.S.R. and how it propagated the space race. The beginning of space history is discussed, including the missions and objectives from the Mercury and Gemini programs. America's achievements are highlighted such as Alan Shepard becoming the first American in space and John Glenn becoming the first American to orbit the Earth. Rocketry concepts were taught including rocket stability, principles of aerodynamics, Newton's Laws, and basic rocket building techniques. The day concluded with the building and launching of paper rockets.

Day Two: Apollo Program History:
This lesson examined in detail the most monumental program in the history of manned spaceflight. The students will learned about the 17 Apollo missions, from the fatal fire of Apollo 1, mankind's giant leap of Apollo 11, the "successful failure" of Apollo 13, and the rest of the historic moon landings. Core concepts taught during this lesson were:

- Thrust-to-weight ratio.
- Improved rocket building techniques (Advanced paper rocket activity).

Figure 144: Dhwani assisting in the launch of a paper rocket at E-Expo.

Day Three: Shuttle Program, ISS, and Curiosity Rover History:
This lesson examined in detail the movement of NASA from making deep space missions, to mastering low-earth-orbital techniques. The space shuttle was also analyzed from a standpoint of reusability. The International Space Station was followed with a look into what it

takes to sustain life in low earth orbit. Finally, a brief look at the Curiosity Rover mission demonstrated how we land a probe on another planet. Students had the opportunity to do the following:

- Understand the use of composites vs. metals in aerospace applications.
- Design a payload that would fit inside the space shuttle cargo bay.
- Design a space station with the fundamental elements for sustaining life.
- See simulations of extra-terrestrial landing techniques for unmanned missions.
- See videos from inside the International Space Station.

Day Four: OpenRocket Simulation:

The class had the opportunity to model the Estes rocket that they built in the fifth day of the program. A worksheet was prepared with all of the parameters to accurately simulate the rocket. The simulation software allowed the students to learn how to use the same program that the University of Louisville River City Rocketry Team uses to simulate their rocket. This stressed the importance of precisely predicting flight trajectories and altitudes. The following concepts were discussed:

- Understanding how math is applied through software simulations.
- Mass balance.
- Stability margin acceptability.
- The relationship between position, velocity, and acceleration curves and flight events.

Day Five: Rocket Construction:

Each student haf the opportunity to construct and launch their own rocket. Rockets were small Estes model rockets using black powder motors. Each student was be carefully supervised. The students were led through a visual walkthrough of rocket assembly. The following concepts were taught:

- Proper measurement and construction techniques.
- Fin installation.
- Launch lug mounting.
- Shock cable and parachute organization.

Figure 145 One of many fellow students at the Academy at Shawnee working to construct a

Day Six: Final Construction/Rocket Launch:

The students were taken through a safety briefing by a member of the University of Louisville River City Rocketry Team. Any remaining construction work on the rockets was completed during this session. The students were taught how to pack parachutes, load motors, install igniters and develop a pre-launch checklist. Finally, the students launched their rockets.

Figure 147 Carlos helping a student prep her rocket for launch.

Figure 146 A student at the Academy at Shawnee launching her rocket

Outreach Opportunities

Engineering Exposition (E-Expo)

Since 2006, the J.B. Speed School of Engineering Student Council has hosted the larges student-run event on the University of Louisville's campus called Engineering Exposition. The event is geared towards celebrating strides in engineering as well as getting the local youth interested in the field. During the event, the professional engineering societies on UofL's campus set up educational games and scientific demonstrations for the elementary and middle school students to participate in.

The University of Louisville River City Rocketry Team hosted it's second annual water bottle rocket competition for middle school students. Teams from local middles schools participated in teams of up to three students to design and build their own water bottle rockets out of a two liter bottle and other allowable materials. The students brought their rockets to the E-Expo event to show off their rockets throughout the day. At the conclusion of the event, the teams launched their rockets, competing for awards in highest altitude, best constructed rocket, and landing closest to the launch pad. The competition was a huge success. Several schools incorporated the competition into their school curriculum, making the construction of a rocket a class project. Many schools and educators have expressed their interest in participating in the event in the future.

Figure 148 Three students launch a water bottle rocket that they built themselves while at the annual E-Expo.

In addition to the water rocket competition, the team hosted a paper rocket station for people of all ages. This was the most popular station at the exposition. Almost 500 paper rockets were built and launched throughout the day. The team set up the previous year's rocket and the current subscale rocket to talk to students and adults about. Students from all over Kentucky and at a variety of education levels were able to be reached through this event.

Boy Scouts and Cub Scouts:

Throughout the year, the University of Louisville River City Rocketry Team has worked with local Boy Scout and Cub Scout troops to assist the earning of the Space Exploration merit badge. The team has assisted in developing a program that meets the requirements to earn the merit badge. The scouts got to learn about the history of space, current space endeavors, and got to build and launch an Estes rocket. The team has currently worked with a two local scout troops and are going to be working with an additional new group this upcoming summer.

The team has participated in a University of Louisville sponsored event called college for a day. This is an event to give young students an opportunity to take a day and live the college experience, learning about an interesting topic of their choice. The team has organized the day for a group of students to participate in a space and rocketry workshop. This has been tailored for any scouts members that are attempting to earn their merit badge. The team has participated in this event in the past and is currently set up to organize the workshop again this summer.

Figure 149 Emily helping a student at last summer's College for a Day event.

Louisville Science Center Partnership:

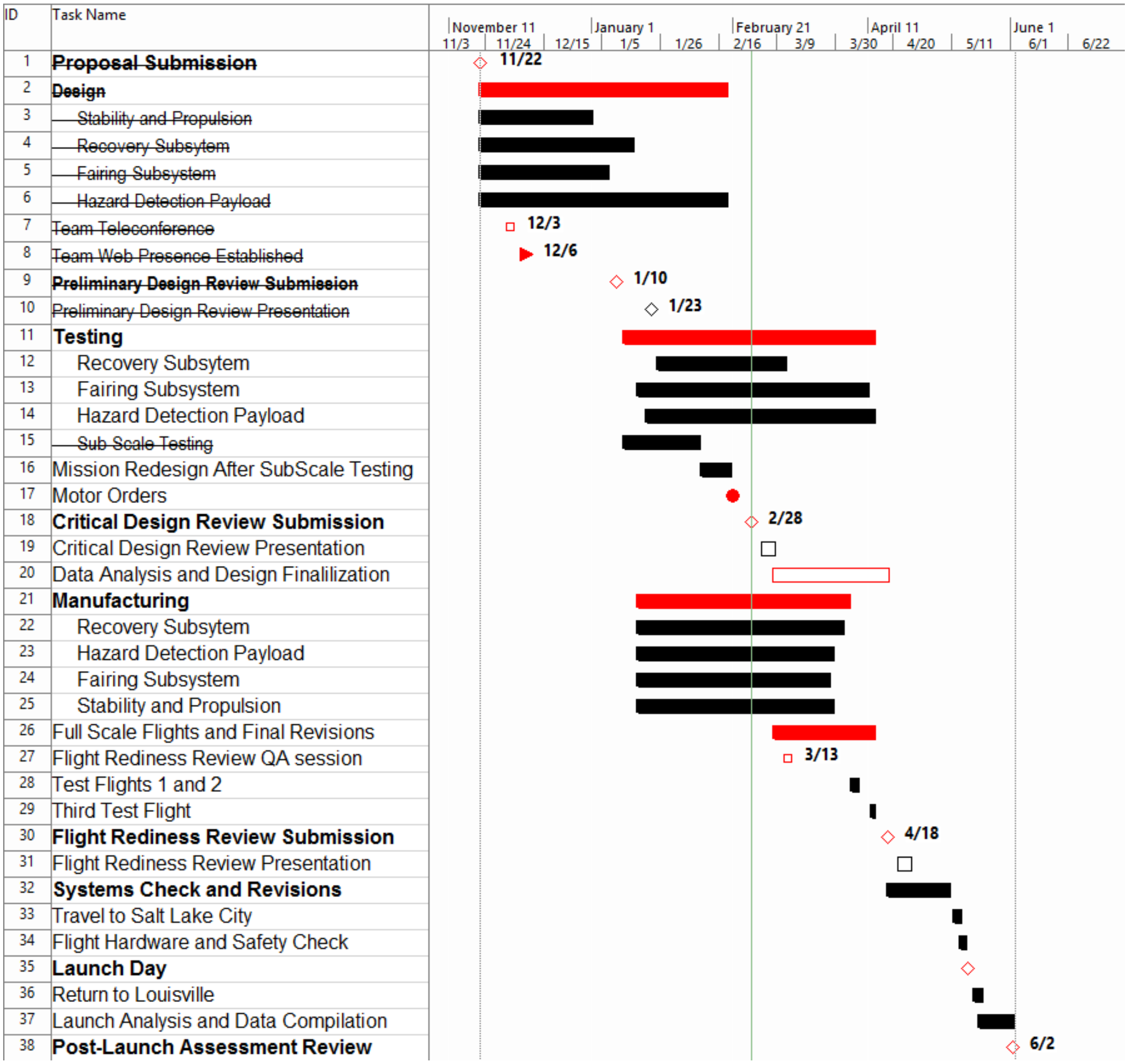
In the Louisville metropolitan area, the Louisville Science Center has heavily promoted STEM topics. The University of Louisville River City Rocketry Team was invited to participate in the Science Center's Engineers Week. The team set up and interactive booth for the weekend to discuss rocketry and to build and launch paper rockets with any visitors. The team was able to answer questions about rocketry concepts, the team's current design, and previous competitions. The team has been invited to come back to the Center to participate in other outreach activities in the future.

Progress

The team has exceeded both personally set goals and those set forth by the competition. As of April 18th, the team has reached out to 1537 students and educators. The team taught classes on a weekly basis to students through the six week aerospace program as well as additional events on the weekends. The team strove to build an interactive program for the students in order to hold their attention, while delivering important core topics. Interactive activities were included to supplement any presentations given.

As previously mentioned, the team has earned great publicity in the area, being published multiple times in various local newspapers. The six week program that was implemented this year has earned an excellent reputation and is a desirable program for most local middle schools. This has secured the team's involvement and carrying the program on into future years. The team is looking into ways to bring new opportunities to students through this program, making it as interactive as possible for the students.
The team will be sponsoring a five day aerospace camp this summer with plans to expand upon the curriculum previously established by the six week program. Additionally, the team will continue to volunteer for a day during multiple engineering camps sponsored by the University of Louisville's Speed School of Engineering.

Timeline



CONCLUSION

After last year's success, River City Rocketry plans to attack the 2013-2014 USLI competition by utilizing the key skills and knowledge the team gained throughout the previous year's competition. The team understands continuous improvement in the quality of the design and manufacturing of the rocket. Therefore, the team will continue to strive for excellence in design efficiency, documentation, educational engagement programs, and safety awareness. River City Rocketry's design this year was designed to with the idea of creating a fully modular rocket that will showcase the team's engineering knowledge, cleverness, and eagerness to learn about rocketry. Our educational outreach has been designed to help spread our passion for rocketry throughout the community while teaching students the importance of math and science in the aerospace industry.

APPENDIX I

Vehicle Verification

Requirements	Features	Verifications
The vehicle shall deliver the research payload to a predetermined altitude appropriate for the associated payload.	The target altitude for our rocket system is 10,000 feet above ground level. This will be achieved by calibrating the mass ballast system to counter the force generated by the booster and sustainer rocket motors.	Following improved simulations, we have verified that our maximum altitude with be at 10,000 feet.
The target altitude shall not exceed 20,000 feet above ground level.	See requirement 1.1. The target altitude is 10,000 feet.	See requirement 1.1.
Teams that have a target altitude exceeding 10,000 feet shall incorporate a secondary motor selection and analysis for a target altitude that shall not exceed 10,000 feet above ground level to be used in the event that the primary launch site is moved to the backup launch site.	Not applicable. Target altitude does not exceed 10,000 feet.	Not applicable.
Teams shall incorporate flight data from the sub-scale launch to verify that the altitude constraints will be met.	As discussed in the CDR, subscale test data is not indicative of full scale altitude parameters due to the lack of conclusive data.	Not applicable.
The vehicle shall carry one commercially available, barometric altimeter for recording the official	The rocket will be utilizing two RRC3 altimeters, four PerfectFlite Stratologgers for use in the nosecone to	Altimeters have been purchased and inspected to ensure that they will function according to the

altitude used in the competition scoring. Teams will be ranked according to the difference between the team's target altitude and the actual altitude earned during the official launch. The team with the least variance in target and actual altitudes will be ranked highest. The team with the largest variance will be ranked lowest. The highest rank will earn the full 100 points toward the altitude portion of the competition. The next highest rank will earn 97 out of the full 100 points, with each successive lower rank earning 3 points less than the next highest rank.	detect the apogee height, and two Featherweight Ravens that will act in parallel to measure and report the altitude to the rest of our systems. We will be designating one of the Stratologgers as the altimeter for the official competition altitude.	design plan.
The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight.	One of the PerfectFlite Stratologgers will be marked as the official competition altimeter.	The PerfectFlite Stratologger has been inspected and found to be functioning correctly.
Teams may have additional altimeters to control vehicle electronics and payload experiments.	See requirement 1.2. Besides the PerfectFlite Stratologger that will be used as the official scoring altimeter, two RRC3s and two Featherweight Ravens will be used.	See requirement 1.2.
At the Launch Readiness Review, a NASA official will mark the altimeter that will be used for the official scoring.	One of the PerfectFlite Stratologgers has been designated for official scoring.	The PerfectFlite Stratologger has been inspected and found to be functioning correctly.
At the launch field, a NASA	The PerfectFlite	The PerfectFlite

official will obtain the altitude by listening to the audible beeps reported by the official competition, marked altimeter.	Stratologger that has been designated for official scoring will not be muted.	Stratologger has been inspected and found to be functioning correctly.
At the launch field, to aid in determination of the vehicle's apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.	The only audible electronics contained on the rocket are the altimeters and Stratologgers, all of which can be muted.	All Stratologgers and altimeters have been inspected and found to be functioning correctly.
The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team's competition flight.	If the designated altimeter is damaged or doesn't report the altitude with a series of beeps, then the rocket will receive a score of zero for the altitude section of the competition.	Not applicable. Requirements understood.
The team does not report to the NASA official designated to record the altitude with their official, marked altimeter on the day of the launch.	If the team does not report to the competition with the officially designated altimeter ready for use, the rocket will receive a score of zero for the altitude section of the competition.	Not applicable. Requirements understood.
The altimeter reports an apogee altitude over 20,000 feet AGL.	If the altimeter reports an altitude of over 20,000 feet, then the rocket will receive a score of zero for the altitude section of the competition.	Not applicable. Requirements understood.
The rocket is not flown at the competition launch site.	If the rocket is not flown at the competition site, then the rocket will receive a score of zero for the altitude section of the competition.	Not applicable. Requirements understood.
Multistage vehicles shall incorporate on all upper stages an ignition inhibitor	The team from the University of Louisville has designed and created a	This system is detailed in the section dedicated to the tiltometer.

system to prevent ignition in the event that the vehicle is unstable or pointed in an unsafe direction (arching over).	tiltometer which measures the angle of the tilt of the rocket periodically. This system is detailed in the section dedicated to the tiltometer.	
The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	The rocket's flight systems are designed to be re-used. Each section has a parachute that is designed to allow it to land safely. Battery systems and motors can be removed and replaced with new units as necessary (each flight if needed).	All parachutes have been tested and found to be in working order.
The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.	Most of the assembly will be completed before arrival at the launch site. The only remaining tasks to complete at the site will be the initialization of the electronic systems, assembly of the motors, assembly of the AV bays by way of installing rivets, and attaching the motor retainers.	Practice runs have been conducted and assembly time meets the requirements.
The launch vehicle shall 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 component.	Provided that new batteries are installed in each slot on the day of the launch, the rocket will be able to last ten hours on the launch pad in a ready-to-launch state without change.	Batteries and electronics have been tested and found to meet the requirements.
The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the NASA-	The rocket has been designed to allow for ignition to be initiated via the standard launching equipment using a 12 volt battery operated trigger.	Launching system verified to work with the standard 12V direct current firing system.

designated Range Services Provider.		
The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by Range Services).	As stated before, the rocket will use a standard commercial igniter, which will be capable of using the standard 12V direct current source.	Launching system verified to work with the standard 12V direct current firing system.
The launch vehicle shall 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).	The motors the team has selected to use in the competition will be a Cesaroni L910 for the sustainer and L1350 for the booster. This choice of Cesaroni as the supplier was based upon team familiarity with motors of this type. Cesaroni motors are known for their ease of use, reliability, and performance.	The motors have been tested and found to be consistent with previous batches.
Pressure vessels on the vehicle shall be approved by the RSO and shall meet the following criteria:	There are no pressure vessels on board of the rocket system.	Not applicable.
The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) shall be 4:1 with supporting design documentation included in all milestone reviews.	Not applicable. See requirement 1.10.	Not applicable.
The low-cycle fatigue life shall be a minimum of 4:1.	Not applicable. See requirement 1.10.	Not applicable.
Each pressure vessel shall include a pressure relief valve that sees the full pressure of the tank.	Not applicable. See requirement 1.10.	Not applicable.
Full pedigree of the tank	Not applicable. See	Not applicable.

shall 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.	requirement 1.10.	
All teams shall successfully launch and recover their full scale rocket prior to FRR in its final flight configuration. 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. The following criteria must be met during the full scale demonstration flight:	On April 6th, 2014, the full scale rocket was launched at the rocket exhibition Thunderstruck. The initial launch was successful, though an error occurred, causing a fatal error in the system. This error will be detailed in the full-scale test flight results section.	Following the event, the team has secured permission to launch the weekend following the FRR due date.
The vehicle and recovery system shall have functioned as designed.	The rocket will function as designed.	Each section will be tested during the substitute launch the weekend following FRR.
If the payload is not flown, mass simulators shall be used to simulate the payload mass.	Not applicable. Payload was included in the full scale test flight.	Not applicable.
The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.	Not applicable. Payload was included in the full scale test flight.	Not applicable.
If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or	The rocket system was flown as it would be at the competition with payload fully active.	Not applicable.

manages the total energy of the vehicle, those systems shall be active during the full scale demonstration flight.		
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 simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.	Not applicable. Full scale motors were used during the full-scale test launch.	Not applicable.
The vehicle shall 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 competition flight.	The full scale test flight was conducted as the competition would be.	Not applicable.
After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).	See the full-scale test flight results section for details on the Thunderstruck test flight. The rocket was rebuilt and improved to avoid repeating the event.	Team will test the full scale the weekend following FRR week.

Payload Verification

Requirements	Features	Verification
The payload shall incorporate a camera system	A Logitech C920 Webcam is mounted in	The C920 webcam has been tested to operate with the

that scans the surface during descent in order to detect potential landing hazards.	the front of the rover.	BeagleBone Black by running image processing tasks. The results are shown in the previous section dealing with OpenCV
The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.	A BeagleBone Black microprocessor has a 1GHz ARM processor that can handle multiple tasks.	The interface between the hazard detection system and the data transmission systems has been tested and verified to work by running several image processing tasks. The results are shown in the previous section dealing with OpenCV.
The data from the surface hazard detection camera and software system shall be transmitted in real time to a ground station.	A GPRS cape gives the rover SMS capabilities to transmit data to a custom made app on an Android device.	Real-time data transmission has been verified to work from the payload to the ground station via an Android app described previously.
The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical onboard component.	Two 2200mAh LiPo batteries were chosen to power the payload's electronics.	The electronics have been run for at least 2 hours without losing power. The LiPo batteries still had sufficient power to last longer if required.
An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.	An off-the-shelve PCB contains a GPS and GPRS module that attaches onto the BeagleBone Black.	This device has been verified to give accurate coordinates, and continuously transmit its position to the ground station. This is described in more detail in the data transmission section.
The electronic tracking device shall be fully functional during the official flight at the competition launch site.	An off-the-shelve PCB contains a GPS and GPRS module that attaches onto the BeagleBone Black. The LiPo battery has been tested to last for more than 2 hours.	The electronic tracking device is currently fully functional, so it will be functional at the competition launch site.
*The rover must successfully	The team has	The software that releases

release its parachute once landed.	designed a system to attach the parachute to the rover and then release it upon landing.	the parachute from the rover has been tested and verified to work. However, the software that detects the landing event still has to be completed. The parachute cam successfully ejects the parachute lines from the rover.
*The rover must travel at least 20 feet once it has landed.	The rover features power screws for movement.	Power screws have been tested to operate on concrete and grass. Further testing will be done on more terrains.
*The system should wait until the launch phase of operation to perform in-flight activities.	An accelerometer and a pressure sensor are added to the custom PCB to detect launch events.	Further development is required before the launch event is properly detected.
*The system should send an acknowledgement of the launch event in real time to an Android device	Sensors are attached to the custom PCB to detect launch events and the GPRS cape is able to send SMS messages.	Further development is required before the launch event is properly detected. Data transmission has been verified to continuously send data.