2015-2016 NASA Student Launch

Alabama Rocket Engineering Systems (ARES) Team

Flight Readiness Review

March 2016

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1. Summary of FRR Report

1.1 Team Summary

Team Name: Alabama Rocket Engineering Systems (ARES) Team

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Level 3 TRA Certification
TRA Section 81

1.2 Launch Vehicle Summary

Length	Diameter	Mass	Motor	Recovery System	Rail Size
93 inches (2.36 m)	5.53 inches (0.141 m)	38.4 lb (17.42 kg)	Cesaroni L851	• 26 inch (.66 m) drogue • 120 inch (3.05 m) main • 21.3 x 84.6 inch (.542 x 2.15 m) payload parafoil	1515, 12 ft

Table 1.1 Launch Vehicle Summary

The Milestone Review Flysheet can be found in Appendix A.

1.3 Payload Summary

Payload Title: Hazard Avoidance Lander (HAL)

HAL will consist of two subsystems, a landing hazards detection subsystem and a guided descent subsystem. HAL will descend using a parafoil and will analyze images of the ground below to detect potential landing hazards. The data collected on potential landing hazards will then be passed to the guided descent system, which will use two servo motors to pull on lines connected to the parafoil, thus steering the payload away from the detected hazards.

2. Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

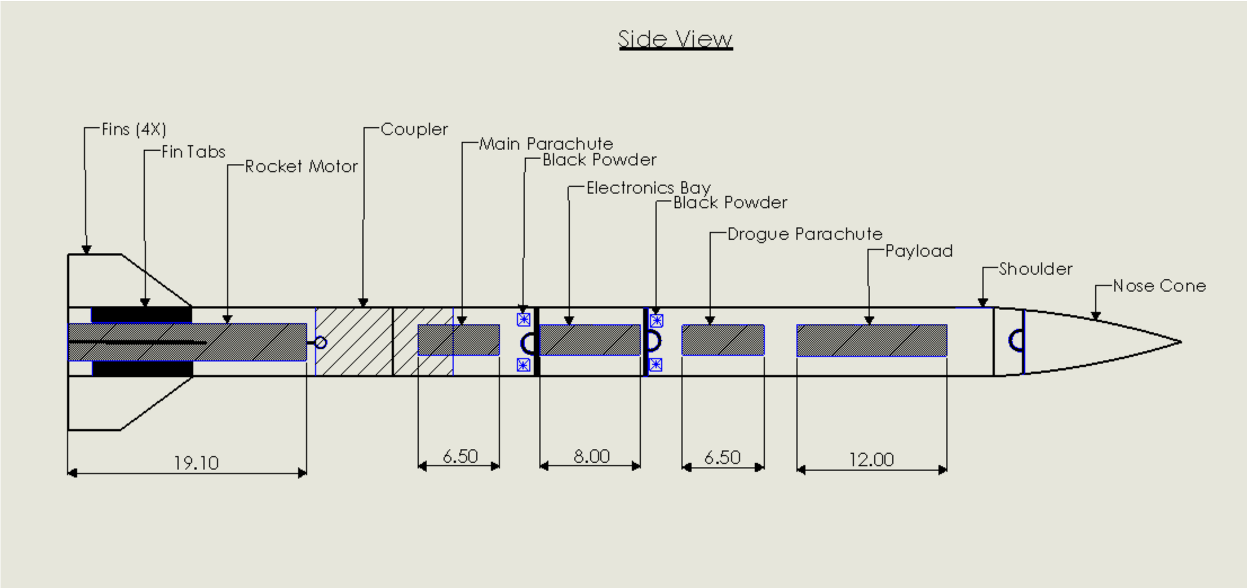

Figure 2.1 Updated Rocket Layout

The ARES Team's design has had several small changes since the CDR. First, the electronics bay has been updated to carry two altimeters rather than four. The previous design with four altimeters was an over-redundant setup. Based on the feedback received from the CDR presentation ARES decided to reduce the number of altimeters. Each altimeter will be wired to both a drogue and a main charge (total of four black powder charges). Also, each altimeter will be connected to its own switch to arm instead of one switch to arm all the altimeters.

The bulkhead originally positioned at the end of the motor casing has been removed from the design and replaced by an eye-bolt screwed into the motor casing itself. The bulkhead was found to be unnecessary and limiting in future motor selection. The fixed centering ring and fin tab assembly has proven to be satisfactory in securing the motor after ignition and in flight.

The drogue parachute size has been reduced from a 56 inch parachute to a 26 inch parachute. This adjustment helps reduce the lateral drift of the descending rocket in high winds. The main parachute has been changed to a 120 inch parachute, to ensure that the descent rate is acceptable.

Lastly, a pound of ballast weight has been added to the nose cone in order to increase the stability of the rocket. The material used as ballast will be sand.

2.2 Changes Made to Payload Criteria

The HAL payload has changed since the CDR. The two most significant changes were the addition of a powered USB hub and a change in the onboard camera. The team came to the realization that the Samsung solid state drive would not receive enough power when plugged into the Raspberry Pi 2. A powered hub was added to power the SSD and to simplify the circuit, the Raspberry Pi will also be powered by the USB hub.

The wires used to run electricity to the payload were also changed. The original plans called for 18 AWG wire. For simplicity, 28 AWG wire from Adafruit with headers that connect to the payload’s components are now being used.

2.3 Changes Made to Project Plan

The project plan timeline has largely stayed the same, although the budget has changed. During the build phase of the project, the team incurred several unexpected expenses and had to utilize expedited shipping, increasing total costs associated with the rocket. The team received no funding from the Student Government Association (SGA) to cover travel expenses, however, is in talks with Orbital ATK in order to negotiate a travel stipend. The amount of this stipend is not yet decided. With regard to timeline, the addition of a second full-scale launch was a major addition that also required the purchase of another motor.

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Design and Construction of Launch Vehicle Features

3.1.1.1 Structural Elements

The structure of the ARES Team's launch vehicle consists of three sections; the aft section, forward section, and nosecone. The aft section contained the following components: the aft body tube, motor mount tube and centering rings, four fins, motor retainer, coupler, and two rail buttons. The motor mount assembly consists of the motor mount, centering rings, and fins. Slots cut into the aft body tube allow this assembly to be slid into the tube, where it is epoxied in place. Epoxy resin mixed with phenolic microspheres compose the fillets along the joint of the fins and body tube. The fins are fiberglassed "tip to tip" to provide extra strength, as shown in *Figure 3.1*.

Figure 3.1 Fin Fillets and Fiberglassing

The 75mm motor retainer is screwed into the aftmost centering ring and the coupler is epoxied with 5 inches inside the aft body tube and 5 inches outside. Last, the rail buttons are screwed in at 3.5 inches and 23 inches from the aft end. *Table 3.1* details the dimensions and method of attachment used for each component of the aft section. The completed aft body section is shown in *Figure 3.2*.

Component	Dimensions	Method of Attachment
Aft Body Tube	5.5 in. diameter 26 in. length	Main structural component.
Motor Mount Tube	3 in. diameter 19 in. length	Epoxied to centering rings.
Centering Rings	3 in. inner diameter 5.38 in. outer diameter	First epoxied to motor mount tube and fins. Then epoxied to inside wall of aft body tube.
Fins	10 in. length 4.5 in. height 8 in. fin tabs	First epoxied to motor mount tube and centering rings. Epoxy/phenolic fillets on fin-body tube joint. “Tip to tip” fiberglassing.
Motor Retainer	75 mm (2.95 in)	Screwed into bottom centering ring.
Coupler	5.38 in. outer diameter 10 in. length	Epoxied 5 inches down onto inside wall of aft body tube.
Rail Buttons	1515 rail buttons 3.5 and 23 inches from aft end	Screwed into aft body tube

Table 3.1 Aft Section Dimensions and Methods of Attachment

Figure 3.2 Completed Aft Section

The structure of the forward section consists of the forward body tube, shear pins, and holes for altimeter air-sampling and switches. The forward body tube will house the main parachute, electronics bay, drogue parachute, and payload, in that order from aft to fore. Four holes are drilled on each end for shear pins, four holes for the altimeters to sample air, and two holes for the altimeter switches. *Table 3.2* details the dimensions and method of attachment of the forward section structural components.

Component	**Dimensions**	**Method of Attachment**
Forward Body Tube	5.5 in. diameter 48 in. length	Main structural component.
Shear pins	2-56 nylon screws	Drilled through forward body tube and coupler/nosecone shoulder
Air-sample holes	3/16 in diameter 4 holes	Drilled through forward body tube and electronics bay housing
Altimeter switch holes	5/16 in diameter 2 holes	Drilled through forward body tube and electronics bay housing

Table 3.2. Forward Section Structural Components

The final structural section is the nosecone, a filament wound 3:1 ogive cone bought from Madcow Rocketry. The nosecone shoulder is epoxied two inches into the cone, with a bulkhead epoxied on the inside end of the shoulder. An eye bolt is fastened to the bulkhead to provide an attachment point for the drogue parachute. *Table 3.3* shows the nosecone section structural components' dimensions and methods of attachment. The completed nosecone is shown in *Figure 3.3* and *3.4* below.

Component	**Dimensions**	**Method of Attachment**
Nosecone	5.5 in. diameter 19 in. length	Main structural component.
Nosecone Shoulder	2 in. inside 4 in. exposed	Epoxied to inside of nosecone
Nosecone Bulkhead	5.38 in. diameter	Epoxied to inside of nosecone, behind shoulder

Table 3.3 Nosecone Section Structural Components

Figure 3.3 Completed Nosecone

Figure 3.4 Nosecone Bulkhead

3.1.1.2 Electrical Elements

The electrical elements onboard the launch vehicle include two Stratologger CF altimeters, two 9V batteries, two switches, a GPS tracking device, and the payload electronics, which will be detailed in section 4.3.1.2. Each Stratologger CF altimeter, shown in *Figure 3.5,* will be secured to the electronics sled, wired to a switch, and wired to two black powder charges, one charge for the drogue parachute and the other for the main parachute.

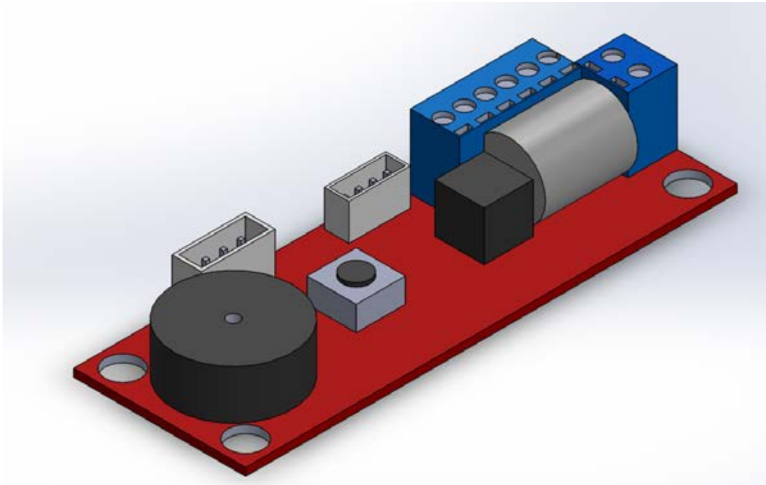

Figure 3.5 Altimeter

The 9V batteries will be secured on the electronics sled with zip-ties, next to the altimeters. The switches are secured onto the inside wall of the electronics bay housing by screws, and the wires that run to each altimeter are soldered to the switches. Screw switches were chosen because of their slim profile, ease of use, and reliability. When ready to arm the altimeters, a small screw is simply screwed into the threaded hole, and the circuit is completed. *Figure 3.6* shows the screw switches used by the ARES Team.

Figure 3.6 Screw Switch

The launch vehicle will also carry a GPS locating device. The ARES Team chose to use a Whistle pet tracker as the rocket locater, and it was successfully tested during the full scale flight tests. A previous rocketry team at the University of Alabama had purchased this tracker, so it was much more affordable for the ARES Team to make use of it instead of buying a new device, especially something rocketry specific. In addition, the Whistle pet tracker can easily be tracked by downloading the Whistle app on any smartphone, making it a very convenient option for locating the rocket after descent. The Whistle device will be secured on the electronics sled with zip-ties, on the side opposite of the altimeters and 9V batteries.

3.1.1.3 Drawing and Schematics

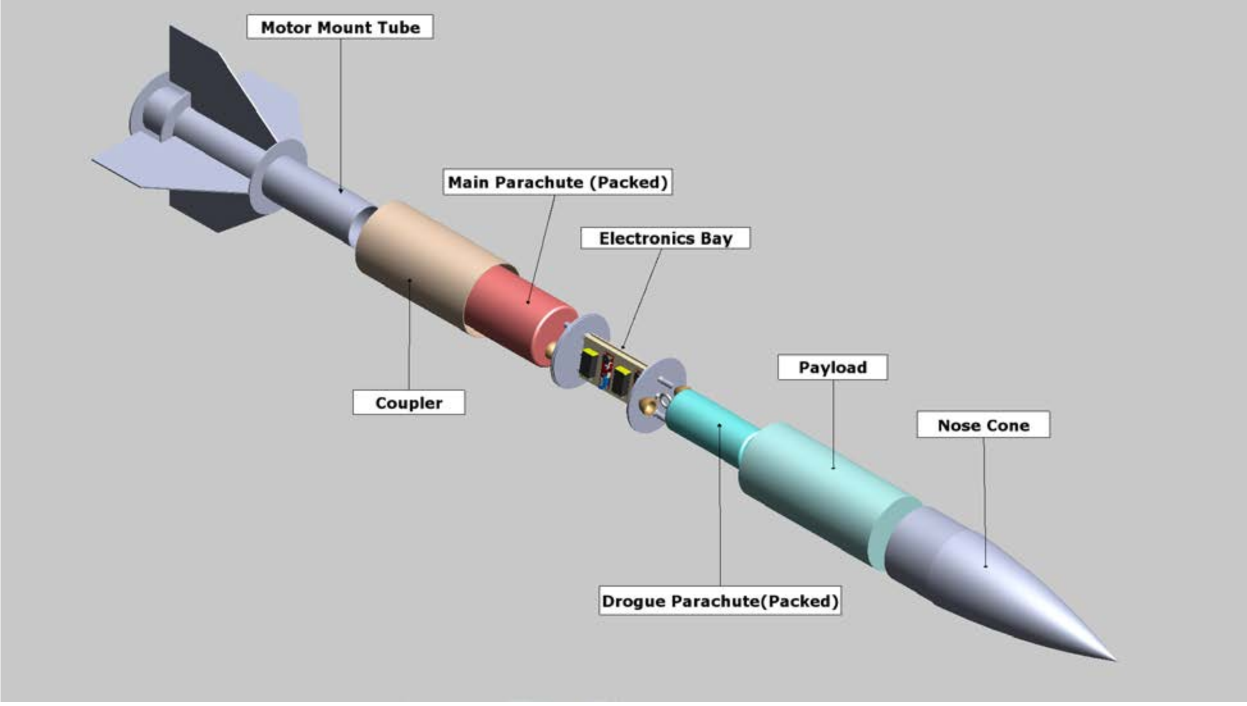

Figure 3.7 Rocket CAD Model Isentropic View

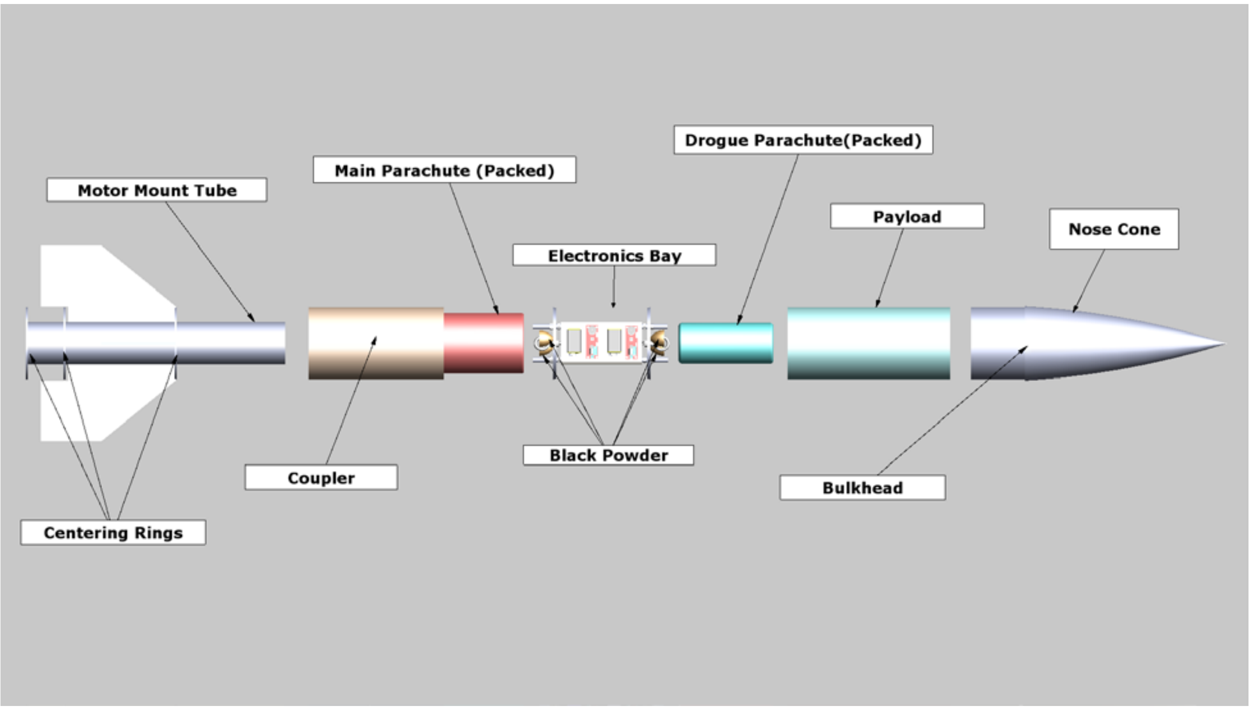

Figure 3.8 Rocket CAD Model Side View

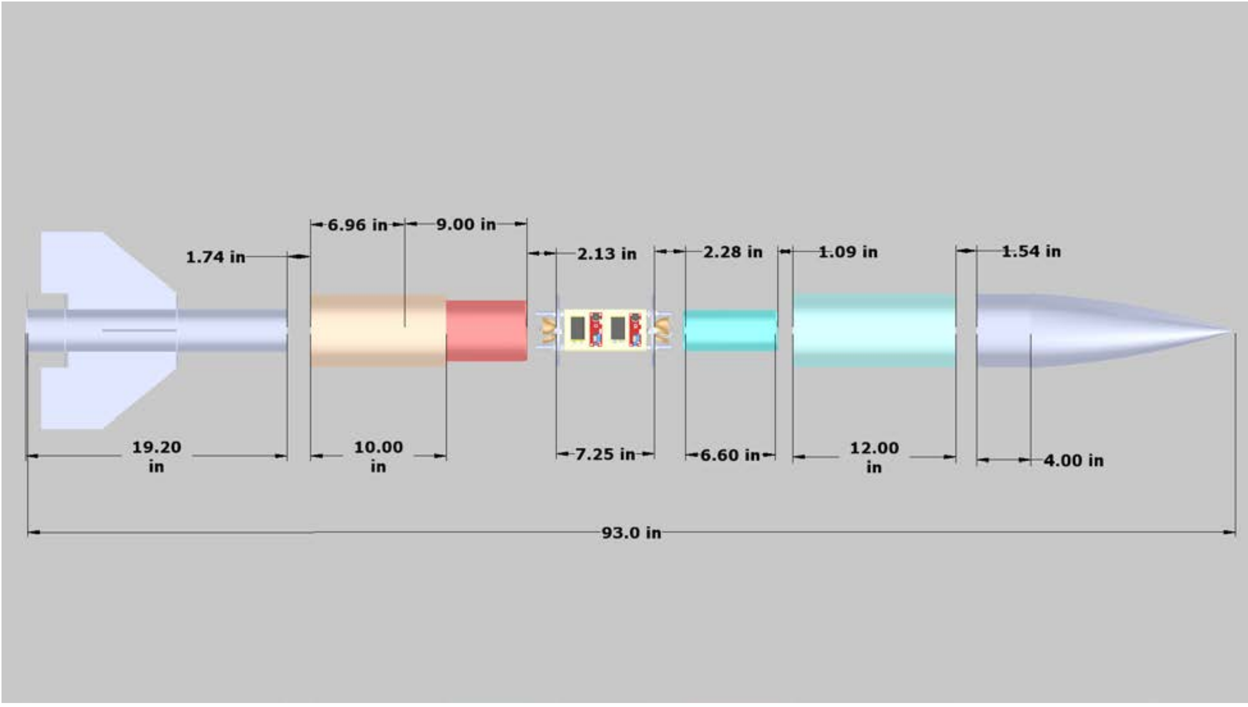

Figure 3.9 Rocket Layout Drawing (inches)

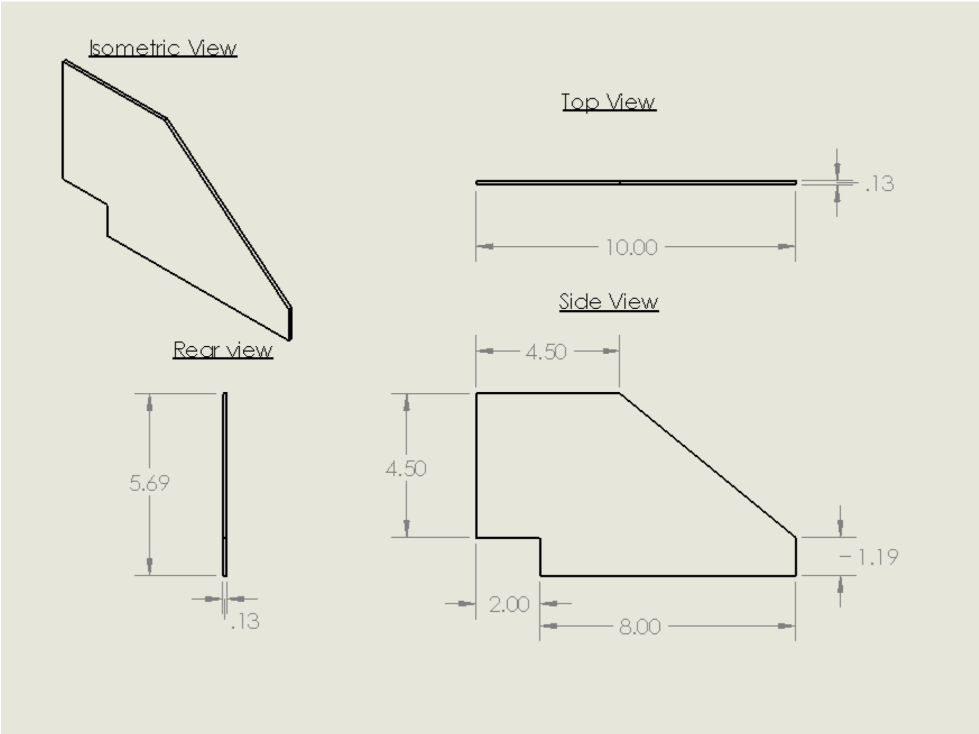

Figure 3.10 Fin Drawing

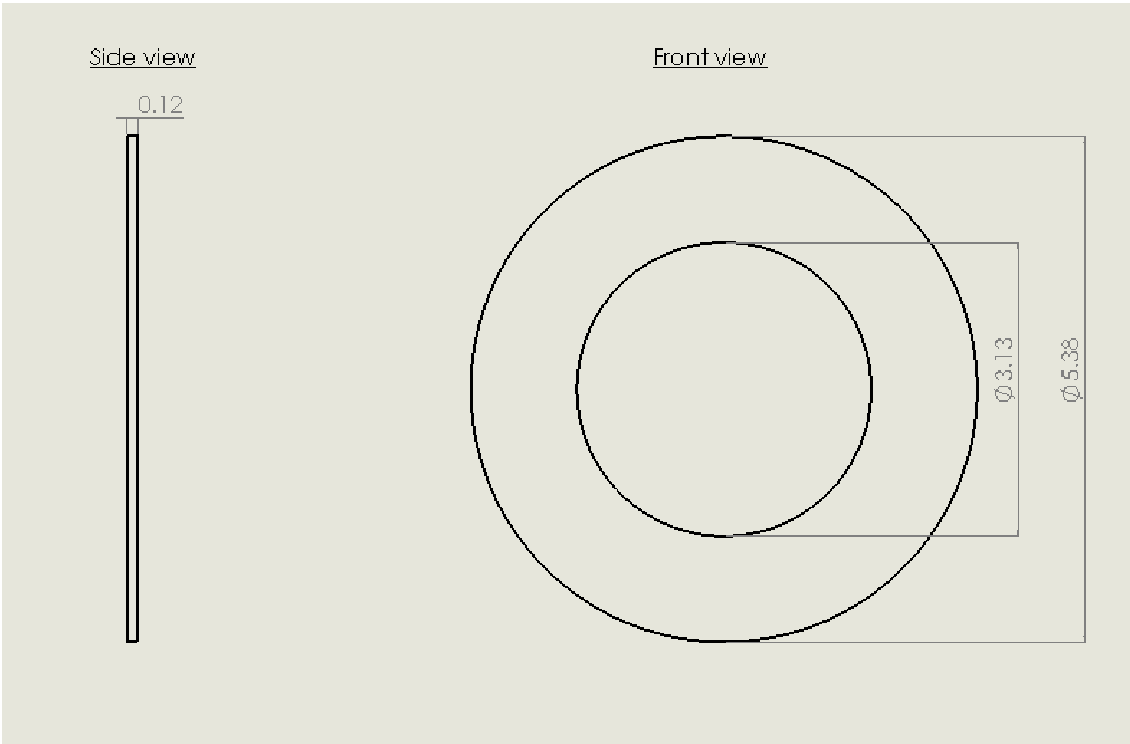

Figure 3.11 Centering Ring Drawing

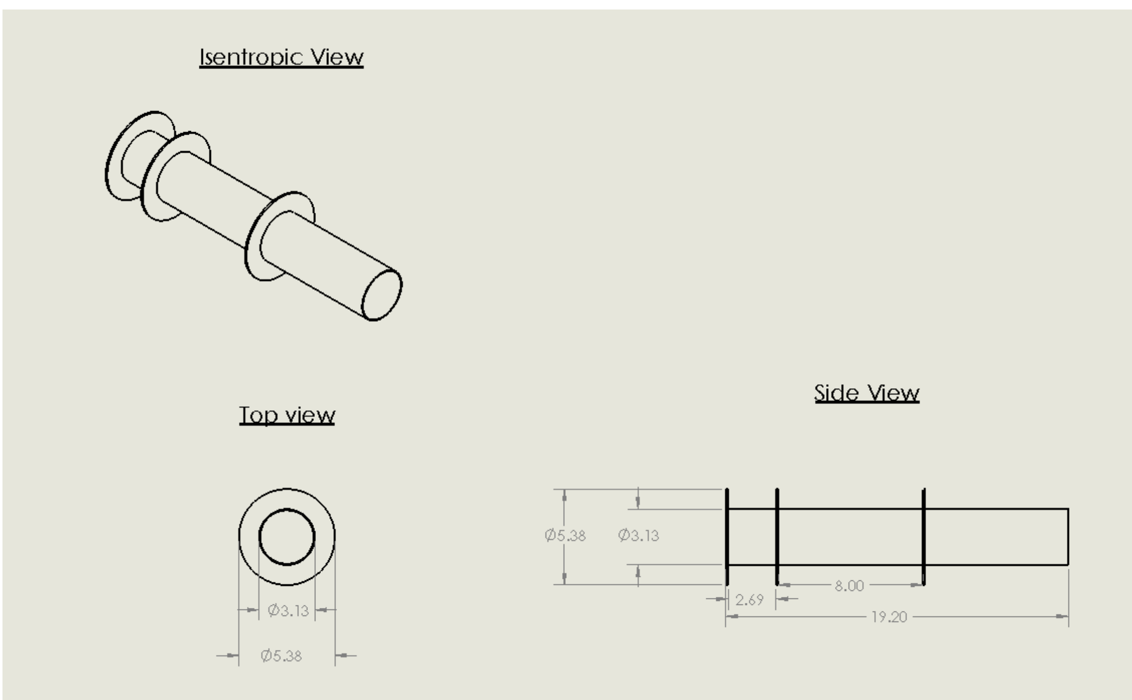

Figure 3.12 Motor Mount Drawing

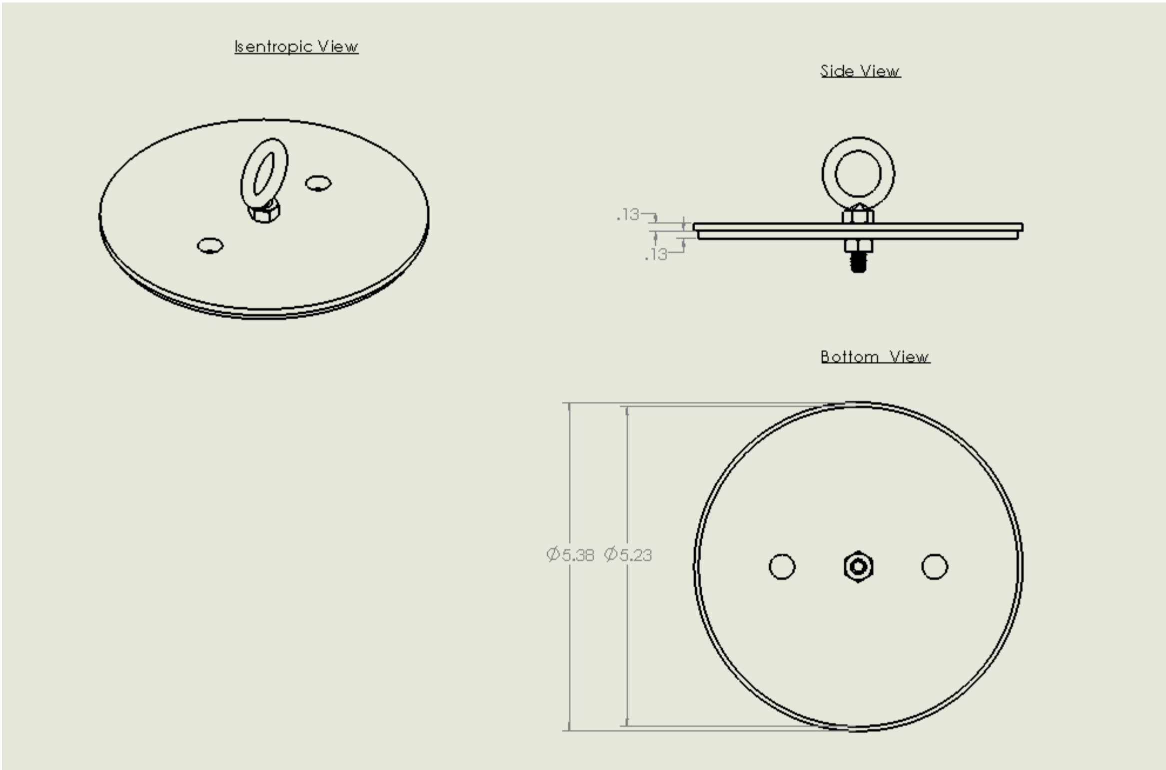

Figure 3.13 Electronic Bay Bulkhead Drawing

3.1.2 Flight Reliability Confidence

The ARES team is exceptionally confident in their launch vehicle. The team has conducted two successful full scale test flights on two different motors. The Cesaroni L851 was tested with “Phoenix Missile Works” in Talladega, AL and the Cesaroni L3200 was tested with “HARA/ Music City Missile Works” in Manchester, TN. The original chosen motor was the L3200, but due to shipping issues this motor was not able to be prepared by the team’s mentor Lee Brock in time for the first full scale test on February 20th in Talladega, AL. The L851 was selected in its place because it delivered similar altitude results in OpenRocket. The motor was purchased from Chris’ Rocket Supplies at the launch site in order to launch and test our systems that day.

For the first full scale flight test, the rocket was launched in its final configuration. The payload housing was launched, including the landing legs (kept in a locked position), with ballast weight inside. The Cesaroni L851 was used for this launch and delivered the launch vehicle and payload to an apogee of 5,415 feet. Both the payload and launch vehicle descended to the ground safely and were recovered at a distance from the pad of less than a quarter mile away. The second full scale flight test saw the same vehicle and payload configuration, but launched using the Cesaroni L3200 motor. In this test, the apogee altitude was 4,876 feet. The launch vehicle was recovered about an eighth of a mile away this time. The recovery distance changed because the main deployment altitude was changed from the first full-scale test, 900 feet, to the second full-scale test, 700 feet. Since the L851 put the launch vehicle closer to the altitude mark of one mile, it was chosen for use in the final competition.

The two full scale tests give the team a great amount of confidence in the structural integrity of the launch vehicle and payload, and the ability of the recovery system to get the rocket safely to the ground without drifting far away. The team has found that the Cesaroni L851 is the best choice for the propulsion system from the two full-scale flight tests conducted.

3.1.3 Test Data and Analysis

Due to the fact that the team opted to buy commercially made launch vehicle components (body tubes, bulkheads, etc.) the team deemed it unnecessary to perform structural testing on these components. Because of this, the ARES Team's testing consisted only of ground tests, the subscale flight test, and full scale flight tests. The subscale flight test was detailed in the CDR, and the ground tests and full scale flight tests will be discussed further in section 3.1.6 and 3.2.2.

3.1.4 Workmanship

Throughout this project, the ARES Team has been dedicated to designing, building, and launching a safe and successful launch vehicle. For this reason, the team has carefully planned the configuration of the vehicle and the specifications of all components included in the design. The team is aware that careful planning and manufacturing ensure a safe and successful launch vehicle, and this has been emphasized throughout the project. During manufacturing of the full scale launch vehicle, the team was careful to follow all proper assembly procedures, and to ensure that all components were of acceptable quality before integrating them into the rocket.

Inspection of components as well as following safety procedures during assembly helped the team create a successful and safe vehicle. This was done using the dimensions and specifications from the CAD models and drawings that the team has created. Each component was visually inspected and, if it was necessary, tested before being integrated into the assembly of the rocket. The ARES Team adopted a "rather safe than sorry" mentality in the construction of the rocket, and great care was taken during all stages of manufacturing and assembly. This mentality carries over to the actual launching of the rocket, when all procedures will be carefully adhered to by all team members. The ARES Team believes that this mentality and the great care taken in the design, construction and launching of this launch vehicle will ensure mission success.

3.1.5 Safety and Failure Analysis

After launching the full-scale launch vehicle twice the ARES team is confident in the survivability of all system components. As can be seen in the data gathered from the Stratologger

CF forward altimeters on temperature during flight, (see Section 3.1.6), the survivability of the payload electronics from heat experienced can be assured as well. The max temperature recorded from both flights was recorded at 73.8 degree Fahrenheit. This is well within the tolerances of the Stratologger CF altimeters, Whistle Pet Tracker, and the payload electronics.

Many Cesaroni manufactured motors have been going CATO lately, according to our mentor Lee Brock and our motor vendor "Chris Rocket Supplies, LLC", most likely due to improper bonding of the motor grains. The L851 motor does not require bonding between motor grains. This was a concern with the L3200 motor but thankfully, the ARES team will avoid this issue with the L851 motor selection.

Given that the construction of the vehicle is complete and no further builds are anticipated by the team, there are no major safety concerns remaining for the rocket construction. All components are proven to be reliable and robust despite repeated full-scale launches, and no faults have to date been detected in the vehicle workmanship. However, the few possible remaining failure modes are discussed in *Table 3.7* below. *Tables 3.4 to 3.6* detail the criteria for failure mode analysis.

Severity Definitions			
Severity Classification	**Personnel Safety and Health Risks**	**Facility/Equipment Risks**	**Environmental Risks**
1-Catastrophic	Loss of life or irreversible disabling injury.	Irrecoverable loss of facility, systems, or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2-Critical	Severe injury or severe occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation

Severity Classification	Personnel Safety and Health Risks	Facility/Equipment Risks	Environmental Risks
3- Marginal	Minor injury or minor occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4-Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 3.4 Severity Definitions

Probability Definitions		
Description	**Qualitative Definition**	**Quantitative Definition**
A-Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B-Probable	Likely to occur or expected to occur frequently within time.	0.1 ≥ Probability > 0.01
C-Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001

Description	Qualitative Definition	Quantitative Definition
D-Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001 ≥ Probability > 0.000001
E-Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001 ≥ Probability

Table 3.5 Probability Definitions

Level of Risk	Level of Permission Required
High Risk	Highly Undesirable. Documented approval from NAR mentor, faculty supervisor, Safety Officer, and Team Lead.
Medium Risk	Undesirable. Documented approval from Safety Officer, Team Lead, and NAR mentor.
Small Risk	Acceptable. Documented approval from Safety Officer and Team Lead.
Minimal Risk	Acceptable. Documented approval not required but highly recommended.

Table 3.6 Risk Levels

Failure Analysis: Vehicle Construction					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
CATO (catastrophic motor over-pressurization)	Catastrophic destruction of motor and rocket body on pad or shortly after lifting off pad	Faulty motor; poorly constructed motor mount; dents in motor casing	1C	Inspect motor closely prior to putting in motor mount; inspect motor mount for any damage or possible trouble points prior to launch; if motor mount or casing displays faults, do not launch rocket	1E
Vibration or excitation of fins and structure	Excessive vibrations in fins or rocket body causing stress to structure and possible cracks or breakage	Improper application of epoxy to fin and body tube joints; poorly reinforced joints between fins and rocket body; poor or weak construction overall	2D	Reinforce fins with tip-to-tip construction; apply epoxy cleanly and thoroughly to all joints, sanding well before application; reinforce rocket body as needed	4E
Bulkheads loose or ripped out	Bulkheads in the nosecone or rocket body being ripped loose during flight	Improper application of epoxy to bulkheads; excessively short shock cords putting undue stress on bulkheads during separation	2D	Apply epoxy cleanly and thoroughly to all joints, sanding well before application; provide adequate length of shock cord to avoid excessive stress on bulkheads	3D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Cracks in or breakage of rocket body	General damage to rocket body from events such as rough landings, dropping rocket, etc.	Failure to reinforce rocket body enough to prevent direct damage; careless handling of rocket body in lab or at launch site	2C	Do not drop or otherwise carelessly handle rocket body or structure; reinforce rocket body as needed	3E
Instability of rocket off rail or in flight	Unstable flight path caused by insufficient stability margin	Low stability margin off rail; strong wind gusts; incorrect launch rail size used at launch site	2C	Check with RSO for appropriate launch rail at launch site; maintain stability margin of approximately 2.0 off the rail; do not launch in high wind conditions	3E

Table 3.7 Failure Analysis of the Vehicle Construction

3.1.6 Full-Scale Flight Test Results

Figures 3.14 and *3.15* below show the altitude and velocity recordings from both Stratologger CF altimeters on the first full scale test flight, which used the Cesaroni L851. The data from the second test flight, which used the Cesaroni L3200, is shown by *Figures 3.16* and *3.17.* The comparison between the simulations projected altitude vs. actual recorded altitude for both motors can be seen below in *Table 8*.

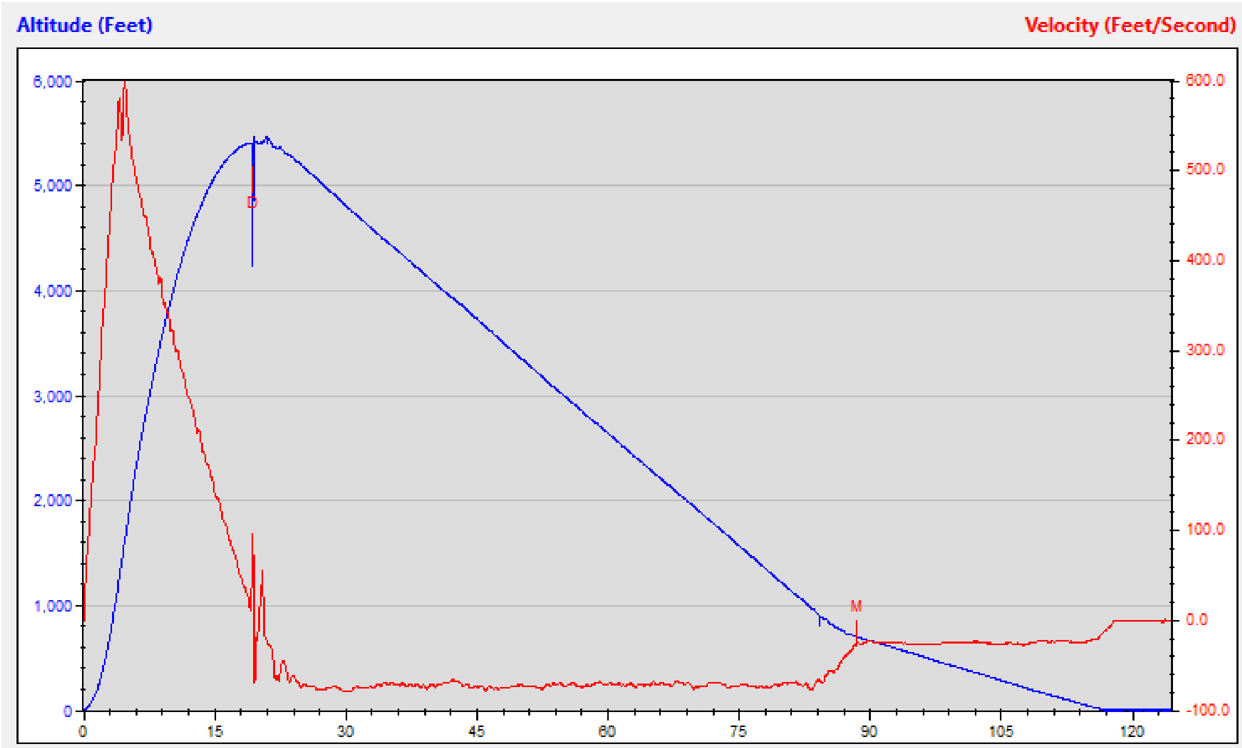

Figure 3.14 L851 Aft Altimeter Flight Record

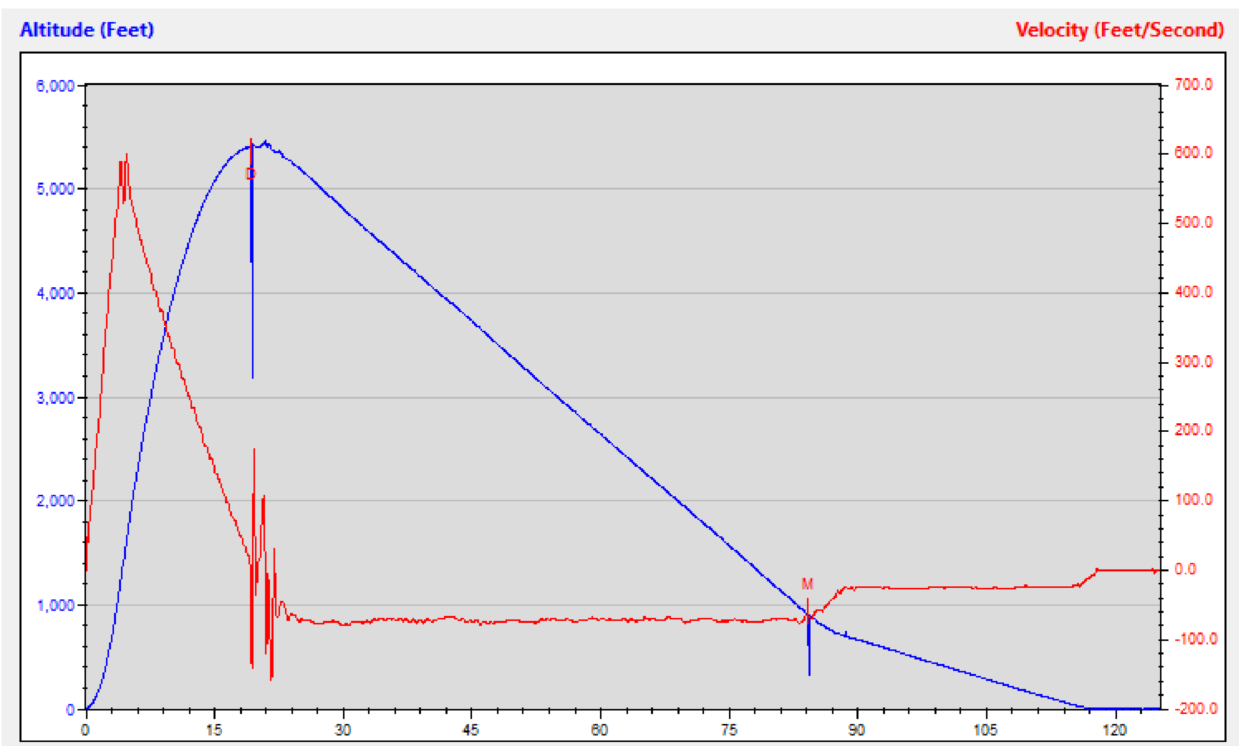

Figure 3.15 L851 Forward Altimeter Flight Record

Notice the spike in the velocity and altitude at about 20 seconds into the flight record for both the forward altimeter and the aft altimeter. This sharp spike comes from the pressurization of the inside of the launch vehicle when the black powder ignites to eject the drogue parachute and payload.

After this pressurization occurs the vehicle has been opened to the atmosphere. It can be inferred the pressure spike from the main charge should be significantly less and is shown to be so in both the L851 and L3200 data.

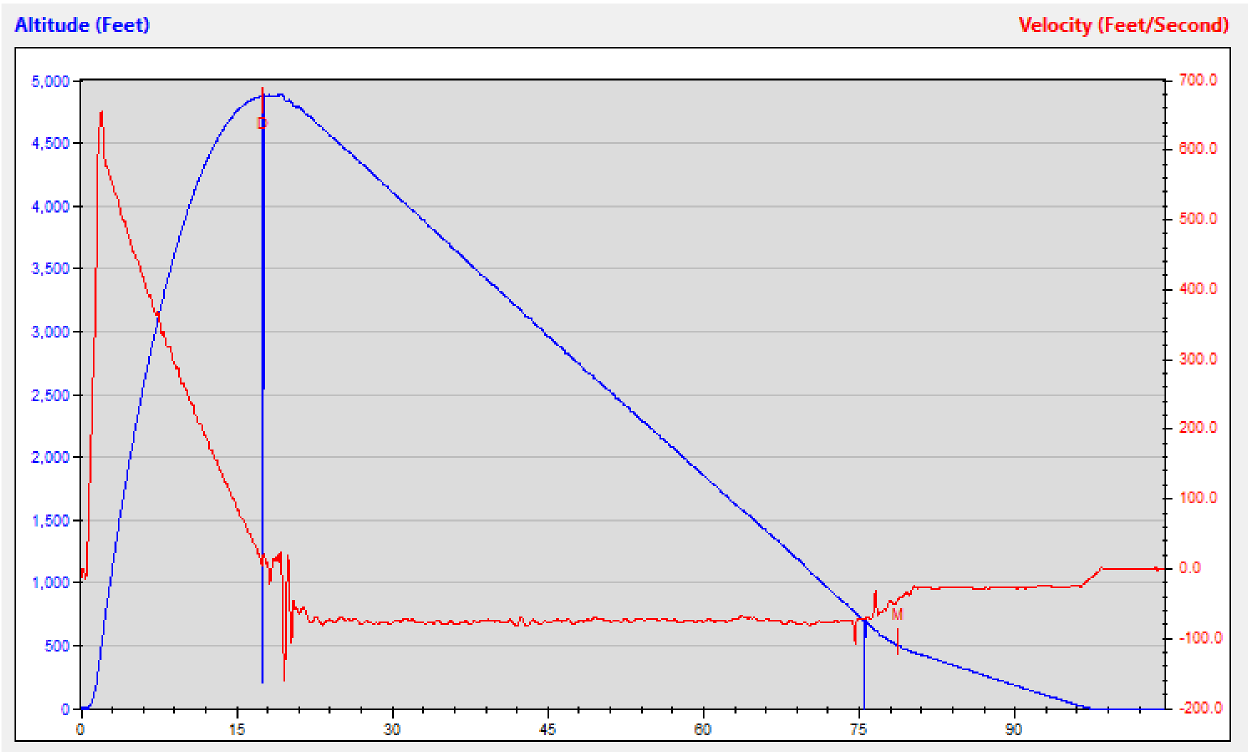

Figure 3.16 L3200 Aft Altimeter Flight Record

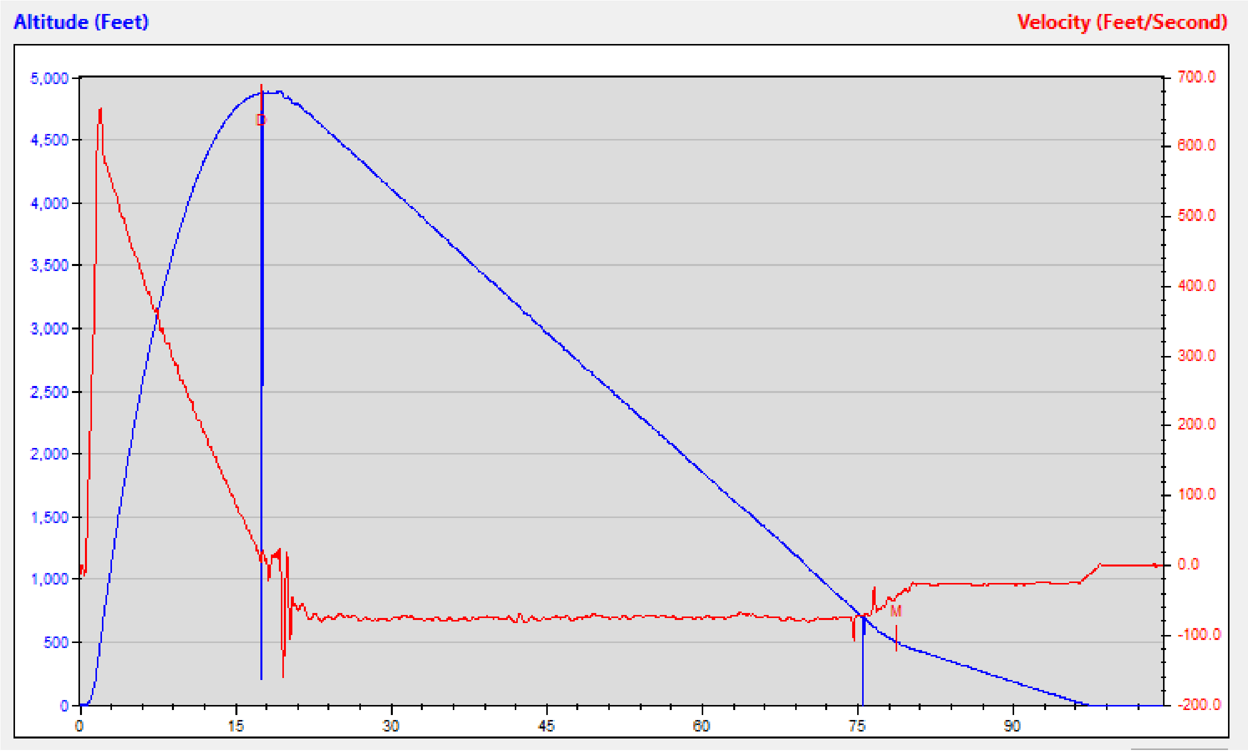

Figure 3.17 L3200 Forward Altimeter Flight Record

Motor	Simulation Altitude (ft)	Actual Altitude (ft)	% difference
L851	4874	5415	9.99%
L3200	4566	4876	6.36%

Table 3.8 Simulation vs. Actual Altitude

The Stratologger CF altimeters also allowed for recording temperature data during the flight. The forward altimeter data for both full-scale flights was examined in detail as critical electronics' operations, in the payload, are sensitive to heat. The temperature data from the forward altimeter from the flight using the L851 motor is in *Figure 3.18*, and the L3200 motor in *Figure 3.19.*

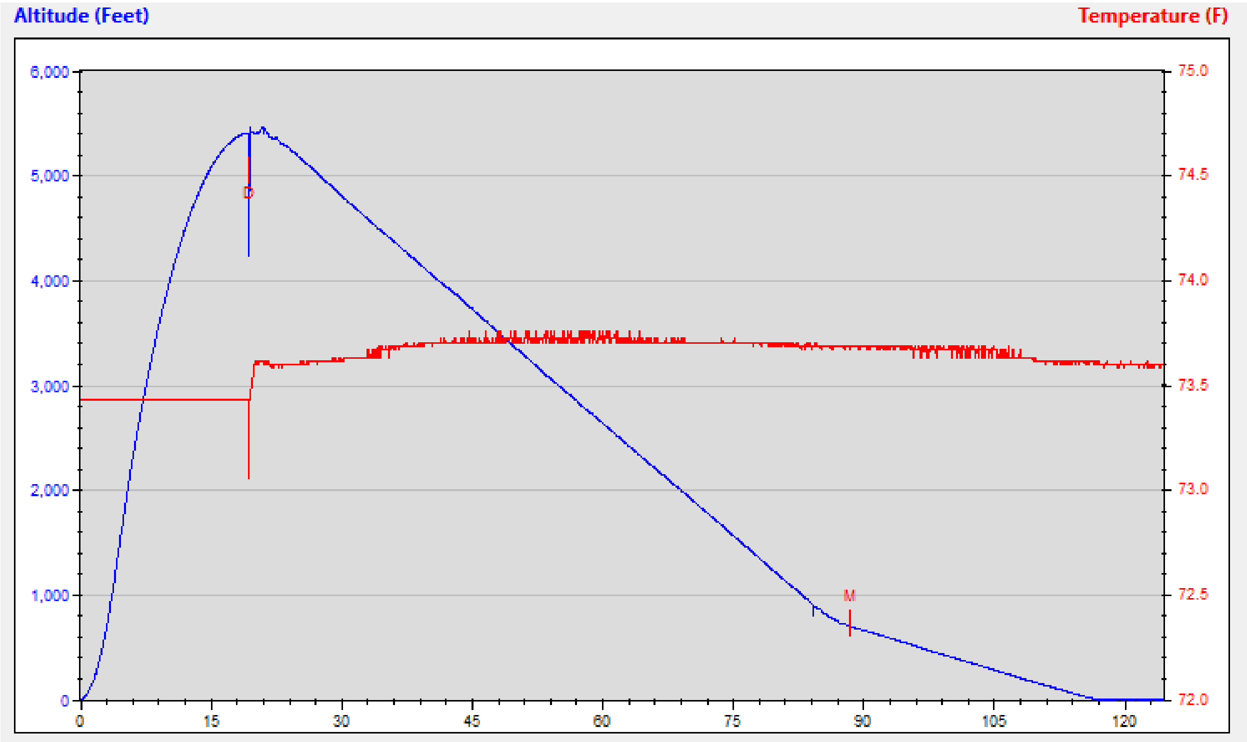

Figure 3.18 L851 Forward Altimeter Temperature Record

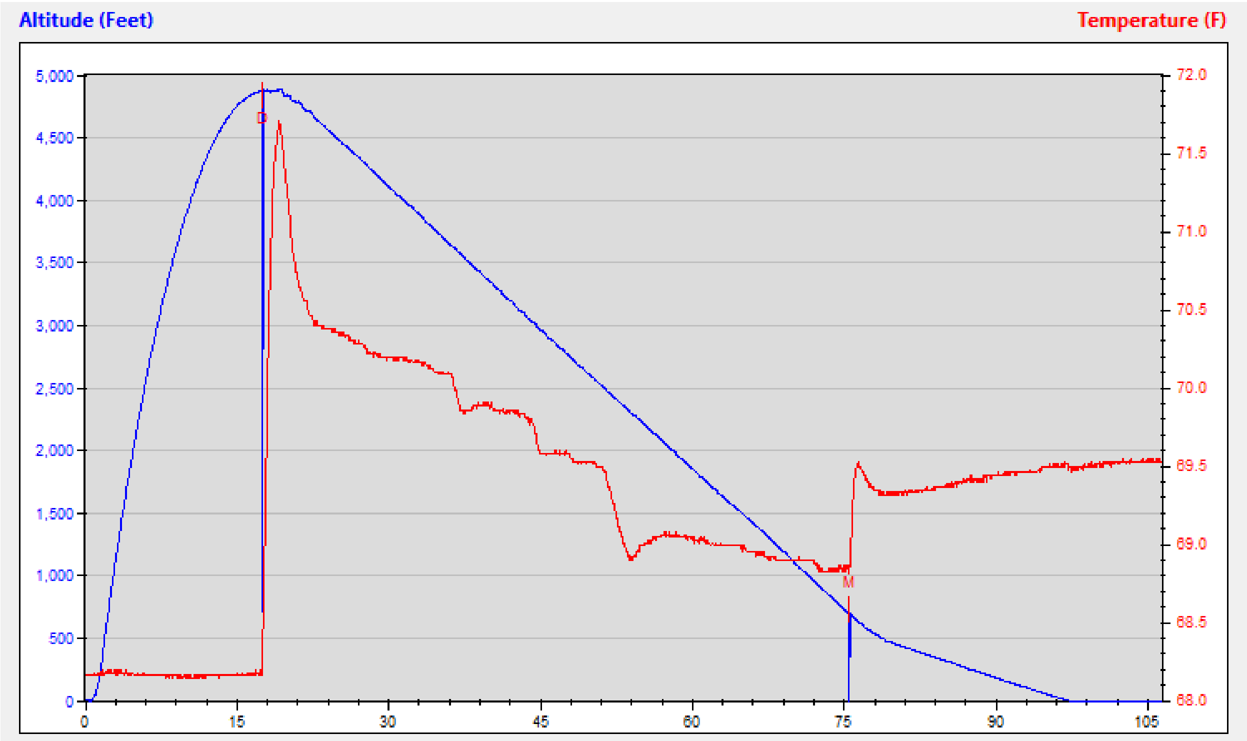

Figure 3.19 L3200 Forward Altimeter Temperature Record

The peak temperature over both flights was recorded at 73.8 degree Fahrenheit. This is well within the Stratologger CF altimeters, Whistle Pet Tracker, and the payload electronic tolerances.

3.1.7 Mass Report

The mass for the launch vehicle as it will stand on the launch pad is detailed in *Table 3.9*. Masses reported are the actual weight of the component/section after construction of the rocket. The team saw a 3.71% increase in mass based off the reported mass of OpenRocket vs. the actual mass measured from the weighed rocket on launch day.

Component	**Mass (lb)**
Nose Cone	4.06
Forward Body Tube	4.5
Aft Body Tube	2.23
Motor Mount	2.41
Fins	1.86
Payload	7.0
Electronics Bay	2.69
Main Parachute (Packed)	2.81
Drogue Parachute (Packed)	1.5
Motor w/ Propellant	8.35
Motor Propellant	4.84
Simulation Total	37.0
Actual Total Measured	38.4

Table 3.9 Mass Statement

3.2 Recovery Subsystem

3.2.1 Robustness of Recovery System

3.2.1.1 Structural Elements

The structural elements of the recovery system consist of the electronics bay housing and sled, the drogue and main parachutes, shock cords, and the bulkheads. The electronics bay housing, shown below in *Figure 3.20*, is comprised of an 8 inch phenolic tube enclosed by bulkheads on each side. Each bulkhead consists of two fiberglass plates. Each bulkhead has two black powder charge cups epoxied onto it, and an eye bolt secured in the middle. The eye bolt is threaded through the bulkhead and secured with nuts epoxied to the thread and the bulkhead. The electronics bay is secured in place in the launch vehicle by four 6-32 screws.

Figure 3.20 Electronics Bay Housing

The electronics sled supports the altimeters, 9V batteries, and the Whistle GPS device. These are all secured to the sled with zip-ties, making it easy to detach each component if necessary. Threaded rods support the electronics sled, and run through the bulkheads. The threaded rods are secured on the outside of the housing with wing nuts.

The main parachute is a 120 inch parachute made of ripstop nylon and will be housed in the section of the forward body tube below the electronics bay. A 50 foot shock cord connects the main parachute to the eye bolts on the motor bulkhead and the electronics bay bulkhead. The connection is made by quick links. The drogue parachute is 26 inches, and is housed in the section of the forward body tube above the electronics bay. The drogue is connected to the electronics bay bulkhead and nose cone bulkhead with 50 feet of shock cord, also using quick links to make the connection. This is shown by *Figure 3.21*.

Figure 3.21 Quick Link Connection

3.2.1.2 Electrical Elements

The electrical elements of the recovery system are described in section 3.1.1.2. These include the two Stratologger CF altimeters, two screw-switches, two 9V batteries, and the Whistle locating device.

3.2.1.3 Redundancy features

The electronics bay includes two altimeters, each connected to its own switch. Two black powder charges are wired to each altimeter, one for the drogue parachute and one for the main parachute. This setup limits the chance for a failed separation and deployment of the recovery parachutes. If one switch loses connection or one altimeter malfunctions, there will still be one working altimeter that will fire a black powder charge for each of the sections. In the case that both altimeters work, there will be redundant black powder charges to ensure that at least one is ignited. The ARES Team has confirmed that this recovery system will provide adequate redundancy, and ensure that proper separation and deployment is attained. During both full scale launches the secondary charge was observed to ignite after the main parachute had already been deployed confirming the success of the recovery system. After recovery of the launch vehicle all charges including those at apogee were found to have been ignited during flight for both full-scale launches proving the redundancy features of the launch vehicle.

3.2.1.4 Parachute Sizes and Descent Rates

The descent rates were simulated in OpenRocket. The parachutes were given a drag coefficient of 1.5 which assumes elliptical or circular parachute design. The drogue parachute size is sufficient in slowing the rocket down to an acceptable speed to deploy the main parachute at 700 feet. This data can be found in *Table 3.10.*

Parachute	Size (in)	Descent Rate (ft/s)	Deployed Altitude (ft)
Drogue	26	73.07	Apogee
Main	120	14.49	700

Table 3.10 Parachute Size and Descent Rate

3.2.1.5 Drawings and Schematics of the Electrical and Structural Assemblies

Figure 3.22 Electronics Bay Assembly

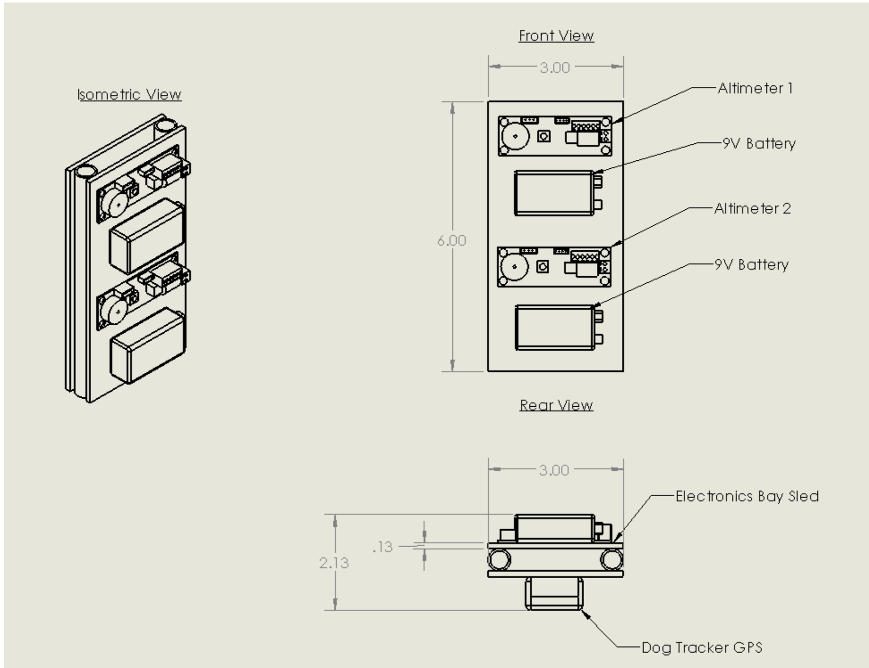

Figure 3.23 Electronics Bay Assembly

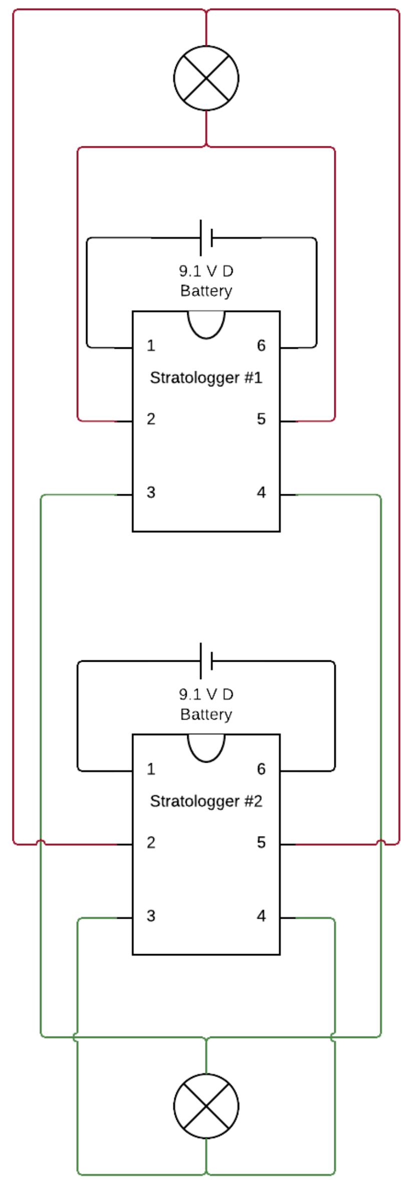

Figure 3.24 Recovery System Electronics Schematic

3.2.1.6 Rocket-Locating Transmitters

The ARES Team has elected to use a Whistle pet tracker as the GPS locator for the launch vehicle. The Whistle pet tracker is used with a smartphone application that provides the location of the tracker. This device was chosen because of its cost effectiveness and ease of use. Since the device had been left by a previous rocketry team at the University of Alabama, the ARES Team needed only to purchase a subscription to the service. Furthermore, the device is waterproof and built ruggedly, and its battery is capable of lasting up to ten days which will be more than enough for the team's needs. In addition, it is much less expensive than many of the rocketry specific GPS devices on the market. The tracker was tested during both full scale test flights and provided very accurate information on the location of the rocket. *Table 3.11* below compares some of options that were considered for the rocket-locating transmitter, and a CAD model of the Whistle pet tracker is shown in *Figure 3.25.*

Device	**Cost**	**Method of Use**
Whistle pet tracker	Already owned; $10/month for subscription	Smartphone app
TeleGPS	$214	GPS Ground Station
TeleMetrum	$321	GPS Ground Station

Table 3.11 Rocket Locator Options

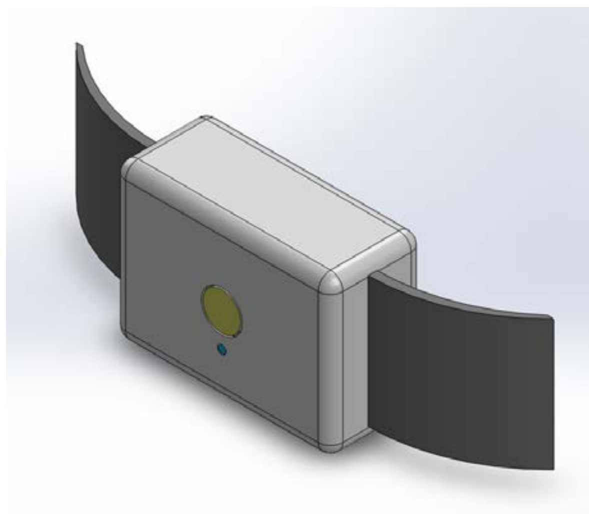

Figure 3.25 Whistle Pet Tracker

3.2.1.7 Sensitivity to Electromagnetic Fields

The main onboard devices that will generate electromagnetic fields are components of the payload. Because there will be the payload housing, the drogue parachute, and the electronics bay housing in-between the payload electronics and the recovery electronics, the team is confident that there will be no interference problems from the electromagnetic fields.

3.2.2 Suitable Parachute Size, Attachment Scheme, Deployment Process, and Test Results

The ARES team is using a 120 inch main parachute and 26 inch drogue parachute. The 26 inch drogue parachute will slow down the rocket to a speed that will be safe for the 120 inch main parachute to be deployed at 700 feet and the secondary deployment altitude of 500 feet. The 120 inch main parachute will safely land the rocket back on the ground under the allowable 75 ft-lb margin.

Both parachutes will be attached to eye bolts with quick-links. 50 feet of shock cord will be used for the main parachute and for the drogue parachute. Using this much shock cord for each parachute will allow the decrease the impulse the components feel and allow them to decelerate in the atmosphere so that a minimal load is applied to the connection at the eye bolts, ensuring that both the eye bolts and bulkheads will be capable of taking the load.

Each parachute is prepared to be stored safely inside the launch vehicle using the "Burrito Method." See Appendix B - Launch Preparation Checklist: Parachute Prep Checklist for more details. The "Burrito Method," ensures successful ejection and opening upon deployment from the launch vehicle. It is named such because of the similarity in the preparation of a burrito with the parachute protector and the parachute.

When the altimeters sense that the rocket has reached apogee, an electric charge will be sent to the black powder charges in the upper section of the forward body tube. A delay of 1 second will be set so that both charges do not ignite at the same time. The pressure created by the charge will shear the nylon screws holding the nose cone and forward body tube together, and will push out the payload and drogue parachute, in that order. The second charge will ignite after the delay for redundancy, ensuring that separation and ejection of the payload and drogue occurs. The separated launch vehicle will then descend with the drogue parachute slowing its descent and the payload will descend separately controlled and slowed via parafoil. When the altimeters sense that the rocket has reached an altitude of 700 feet, one of the black powder charges in the lower section of the forward body tube will ignite and pressurize the section, shearing the nylon screws and deploying the main parachute. A second black powder charge will ignite at 500 feet to ensure separation and deployment of the main parachute. The rocket will then descend to the ground safely, landing with less than 75 ft-lbs of kinetic energy.

Testing of the recovery system has occurred via ground tests, the subscale flight test, and the full scale flight tests. The ARES Team conducts a ground test of the ejection system before each launch. In this test, one of the forward black powder cups is loaded and a 25 foot wire is run to the e-match inserted in the black powder cup. The forward body tube is inclined at an angle to prevent damage to the structure from an ejection on the ground. The tube is pointed away from all spectators and testers. All members and immediate spectators are asked to remain behind the tester, (at least 25 feet). After a 5 second countdown from the tester; a 9V battery is connected to the wire, igniting the black powder charge. The team then is able to observe whether the parachute is ejected properly. A proper ejection is 3 feet clearance from the body tube. The ground test setup at Talladega is shown in *Figure 3.26* below.

Figure 3.26 Ground Test Setup

In addition, the recovery system as a whole was tested during the subscale and full scale test flights. In the subscale test flight, the recovery system worked as planned and the rocket was recovered about ¾ of a mile away. In the first full scale test flight, all recovery operations went smoothly, and the vehicle was located about ¼ a mile away from the launch pad. In the second full scale test, the rocket only drifted about ⅛ of a mile. Based on these results, the team is very confident that the recovery system will successfully deploy both parachutes and that the rocket will be easily recoverable in a reusable condition.

3.2.3 Safety and Failure Analysis

The team is confident in the deployment abilities of all components, including the drogue parachute, the main parachute, and the payload. Successful ground ejection tests were conducted for each full scale launch, resulting in successful deployment of the vehicle's recovery subsystem and the payload. The ground ejection tests preceded, for both full-scale launches, successful deployment of recovery subsystems in-flight. The redundancy built in to the recovery system was shown to have worked for the subscale and both full-scale flights as well giving an added layer of safety. Given that these results are repeatable, and have been proven as reliable, the safety officer concludes that complete and proper deployment of these subsystems is no longer a main failure mode.

Remaining major failure modes for the recovery subsystems of both the rocket and payload are summarized below in *Table 3.15*. The criteria for the failure mode analysis is in *Tables 3.12 - 3.14*.

Severity Definitions			
Severity Classification	**Personnel Safety and Health Risks**	**Facility/Equipment Risks**	**Environmental Risks**
1-Catastrophic	Loss of life or irreversible disabling injury.	Irrecoverable loss of facility, systems, or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2-Critical	Severe injury or severe occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation
3- Marginal	Minor injury or minor occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4-Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 3.12 Severity Definitions

Probability Definitions		
Description	**Qualitative Definition**	**Quantitative Definition**
A-Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B-Probable	Likely to occur or expected to occur frequently within time.	$0.1 \geq$ Probability > 0.01
C-Occasional	Expected to occur several times or occasionally within time.	$0.01 \geq$ Probability > 0.001
D-Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	$0.001 \geq$ Probability > 0.000001
E-Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	$0.000001 \geq$ Probability

Table 3.13 Probability Definitions

Level of Risk	Level of Permission Required
High Risk	Highly Undesirable. Documented approval from NAR mentor, faculty supervisor, Safety Officer, and Team Lead.
Medium Risk	Undesirable. Documented approval from Safety Officer, Team Lead, and NAR mentor.
Small Risk	Acceptable. Documented approval from Safety Officer and Team Lead.
Minimal Risk	Acceptable. Documented approval not required but highly recommended.

Table 3.14 Level of Risk

Failure Analysis: Recovery Subsystems					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Shroud lines	Shroud lines may get tangled in flight and/or deployment or be burned by black powder discharge	Improper packing or folding of shroud lines within fireproof protector	2B	Follow safety guidelines for proper parachute and parafoil folding; allow safety officer to verify parachute folding prior to packing within rocket body	2E

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Deployment of recovery systems from rocket body	Incomplete deployment of one or both parachutes	Failure to test fit recovery systems; failed or absent ground ejection tests; improper packing of recovery systems; tangled shock cords or shroud lines	2D	Conduct ground ejection tests prior to each full-scale flight; test fit all recovery system components; follow safety checklists and guidelines at all times; do not attempt to launch on unverified recovery systems	3D
Shock cords	Short shock cords may interfere with recovery deployment and/or cause damage to the rocket body itself	Failure of team to provide adequate length of shock cord, either through not bringing it to the launch or not having it to begin with	2E	Double check length of shock cords prior to travel to launch site; fit test all shock cords before launch	4E
Black powder damage	Black powder may bypass fireproof coating and either burn through completely or scorch one or both parachutes, shroud lines, etc.	Improper folding of fireproof protector around parachutes; failure to include large enough protector	2D	Fit test all fireproof protectors, when wrapped around parachutes, prior to launch; double check to ensure complete coverage of parachute; follow safety guidelines for proper folding procedures	4D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Parachute not fully deploying in flight	Tangling of shroud lines and/or shock cord, or partially failed deployment of recovery systems, leads to parachutes not fully deploying and unfolding	Improper packing of parachutes within rocket body; improper packing of shock cords; failure to test fit recovery systems	2E	Test fit all parachutes when packed; allow safety officer to verify correct folding of parachutes; follow safety guidelines for parachute folding and packing	4E
Altimeter failure	Failure of altimeter to signal deployment at desired altitudes in-flight; failure of altimeter to set to correct deployment altitudes on ground	Faulty altimeter wiring in electronics bay; misuse of altimeter or failure to set altimeter as user manual prescribes	3D	Redundant altimeters provide backup in case of failure; follow safety guidelines and altimeter user manuals when setting altimeter altitudes; allow safety officer to verify all altimeter wiring prior to flight	4D

Table 3.15 Failure Analysis of Recovery Subsystems

3.3 Mission Performance Predictions

3.3.1 Mission Performance Criteria

The mission performance criteria are based on the competition requirements. These criteria are listed as follows:

- The launch vehicle must have an apogee altitude of 5,280 feet.
- The launch vehicle must deploy a drogue parachute at apogee and a main parachute at 700 feet.

- The launch vehicle must have no more than 75 ft-lb kinetic energy upon contact with the ground.
- The launch vehicle must be recovered in a reusable condition.

3.3.2 Flight Profile Simulations, Altitude Predictions, Component Weights, and Motor Thrust Curve

The ARES Team used OpenRocket to simulate the flight of the launch vehicle. The launch was simulated for four different scenarios: Bragg Farms with no wind, 5 mph wind, 10 mph wind, 15 mph wind, and 20 mph wind. The results of these simulations are shown in *Table 3.16.* The altitude and vertical velocity vs. time for each scenario are shown in *Figures 3.27, 3.28, 3.29, 3.30, and 3.31*. In addition, the thrust curve for the Cesaroni L851 motor is displayed in *Figure 3.32* and the L851 motor properties are displayed in *Table 3.17*. These simulations show in that the current rocket design reaches slightly below the the 5280 ft altitude mark with a percent difference of approximately 7.9%. Since the full scale test reached 5415 ft, we believe the simulation slightly underestimates the actual altitude that can be achieved. Considering the simulation data and full scale flight test observations, the Cesaroni L851 motor is a valid choice for our propulsion subsystem.

Simulation	**Apogee (ft)**	**Max Velocity (ft/s)**	**Time to Apogee (s)**	**Flight Time (s)**	**Ground Hit Velocity (ft/s)**
Bragg Farms (0 mph)	4874	562	18.6	119	14.49
Bragg Farms (5mph)	4854	561	18.6	118	14.49
Bragg Farms (10 mph)	4802	561	18.5	117	14.50
Bragg Farms (15 mph)	4727	559	18.3	116	14.49
Bragg Farms (20 mph)	4659	558	18.2	116	14.48

Table 3.16 Flight Simulation Data

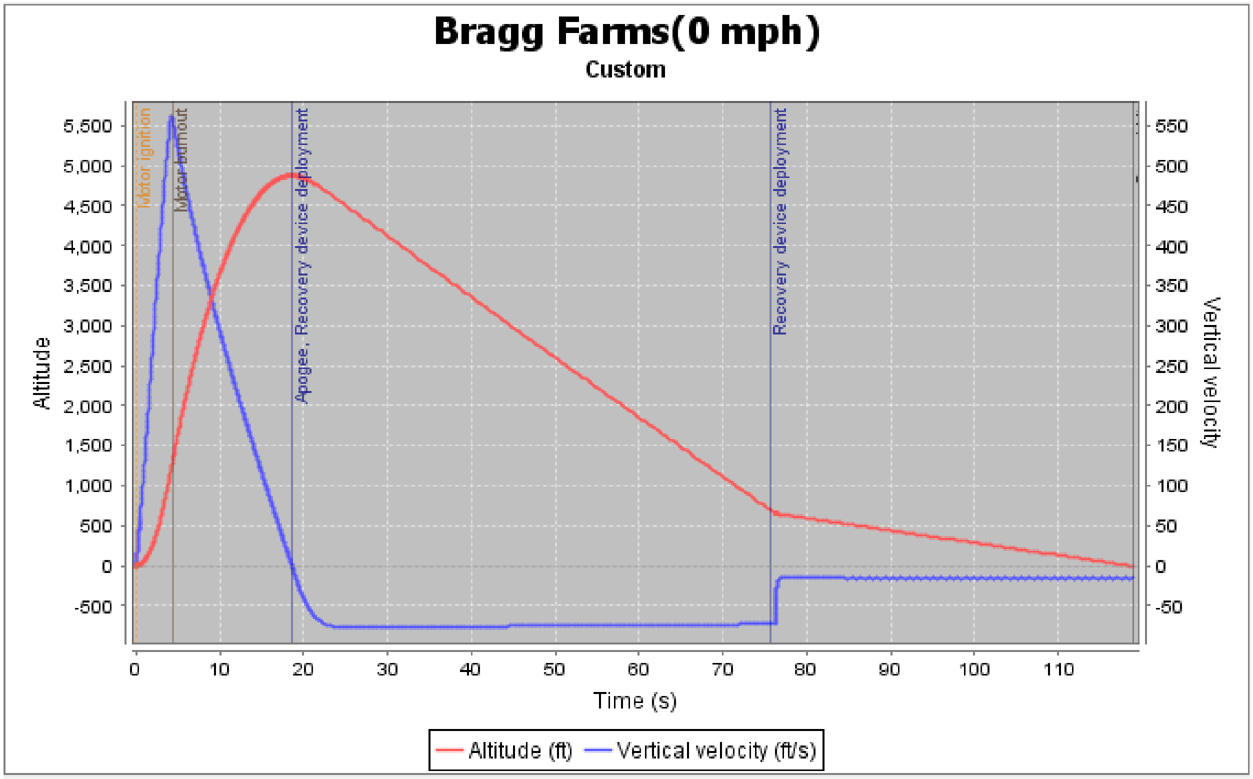

Figure 3.27 Bragg Farms (0 mph)

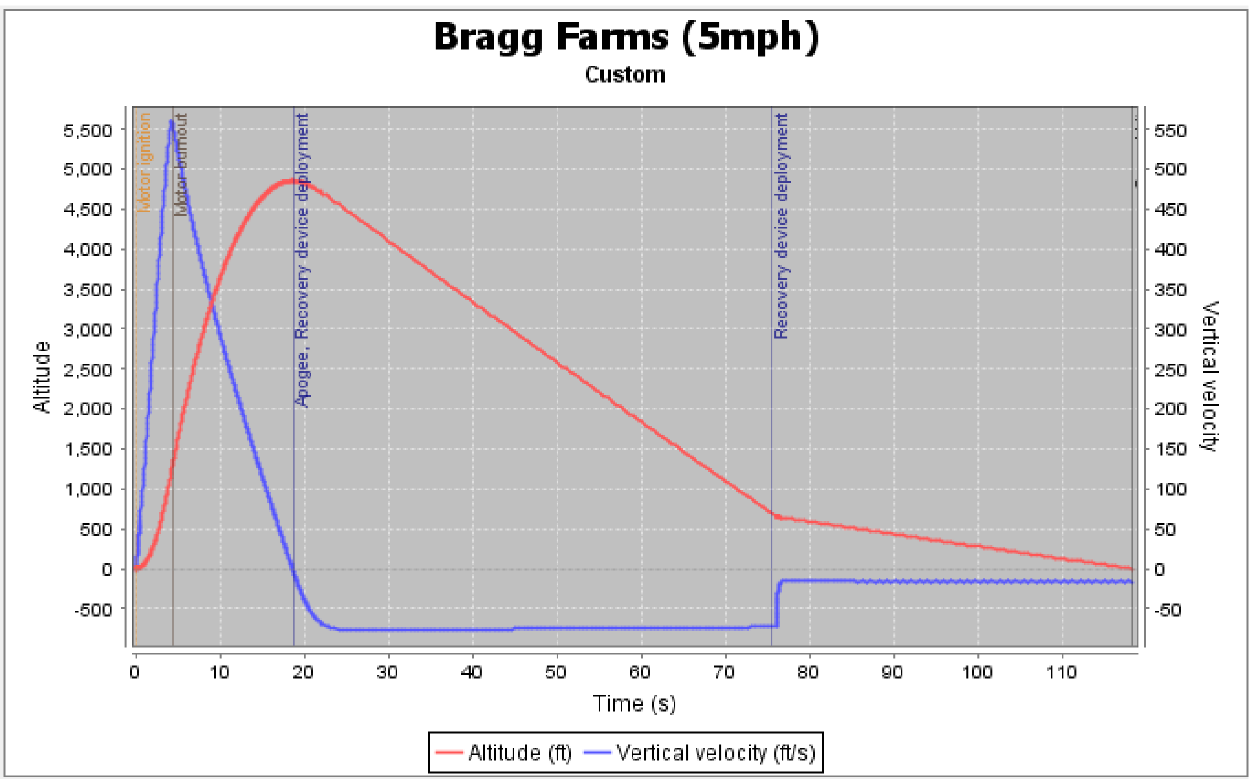

Figure 3.28 Bragg Farms (5 mph)

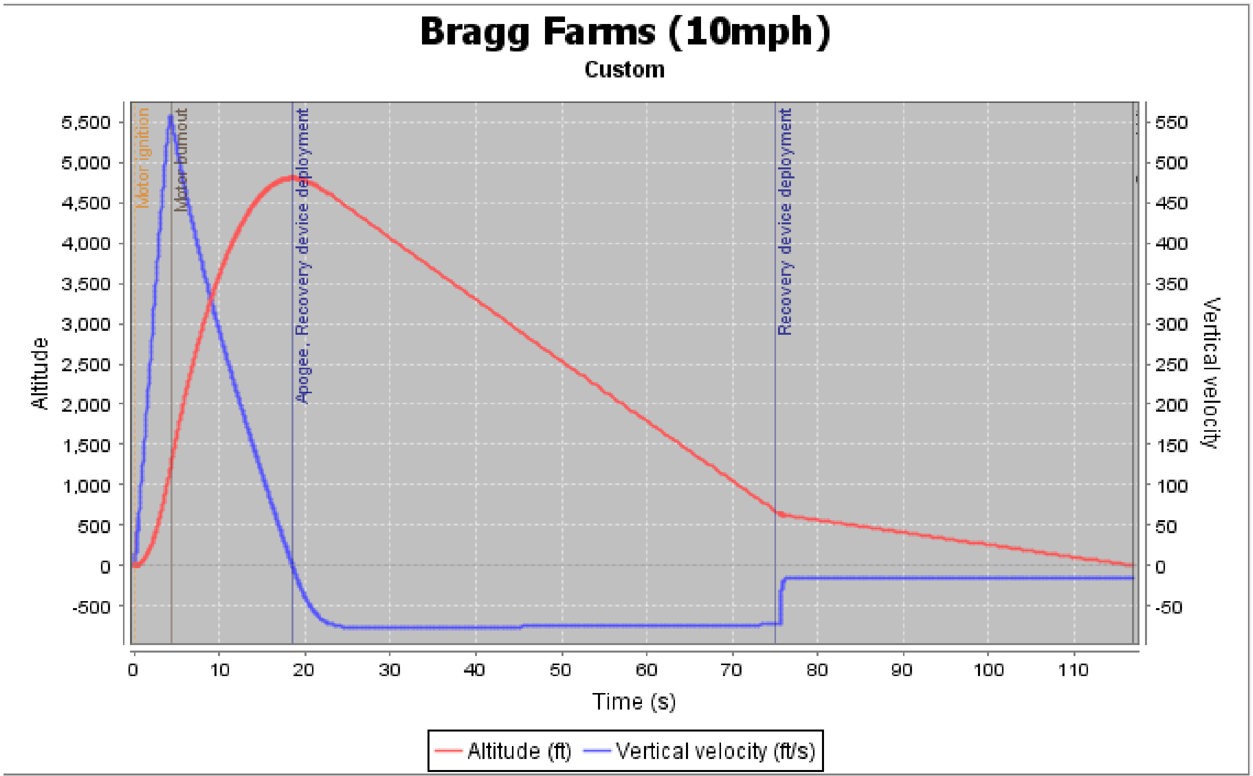

Figure 3.29 Bragg Farms (10 mph)

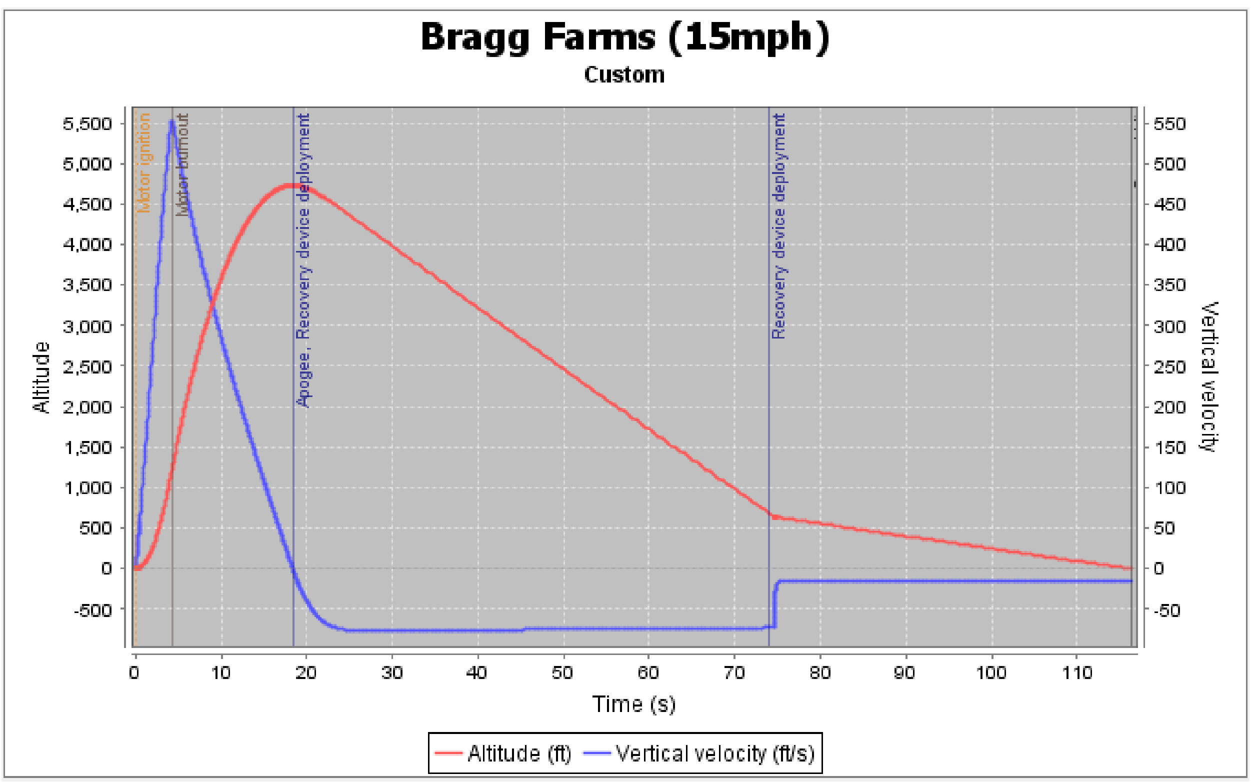

Figure 3.30 Bragg Farms (15 mph)

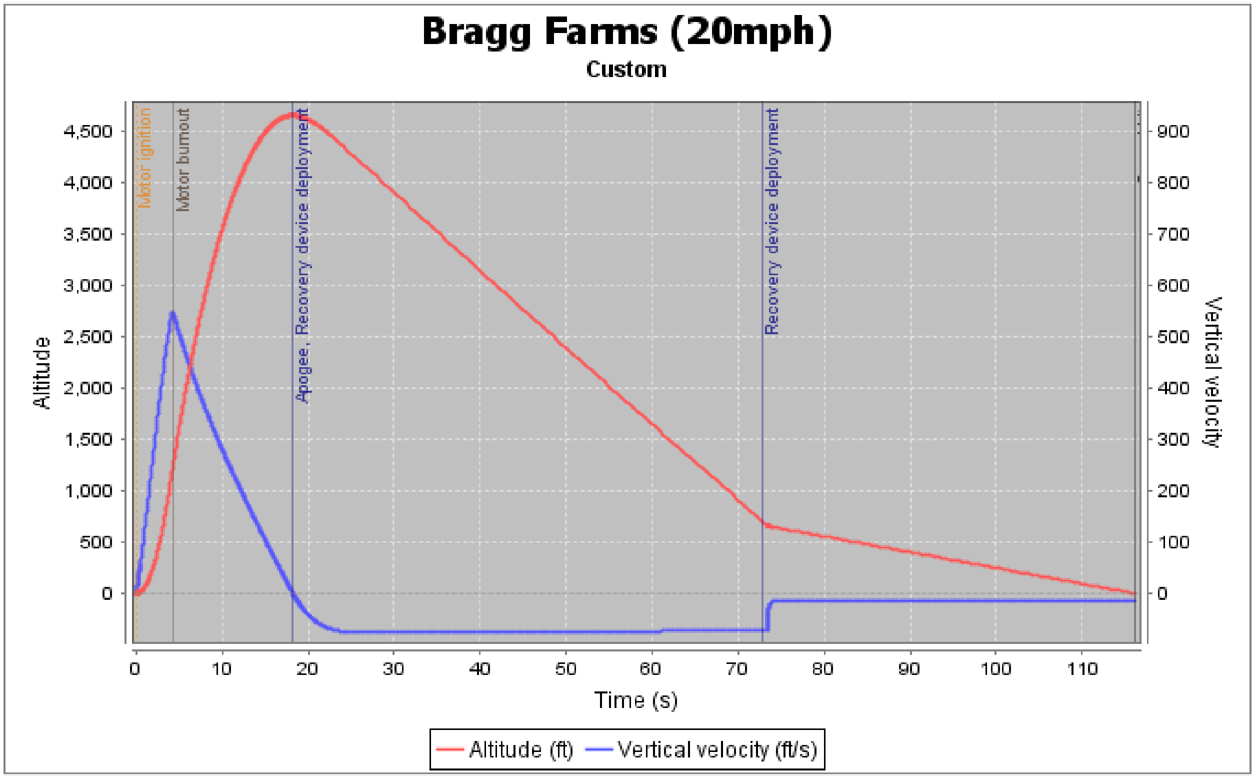

Figure 3.31 Bragg Farms (20 mph)

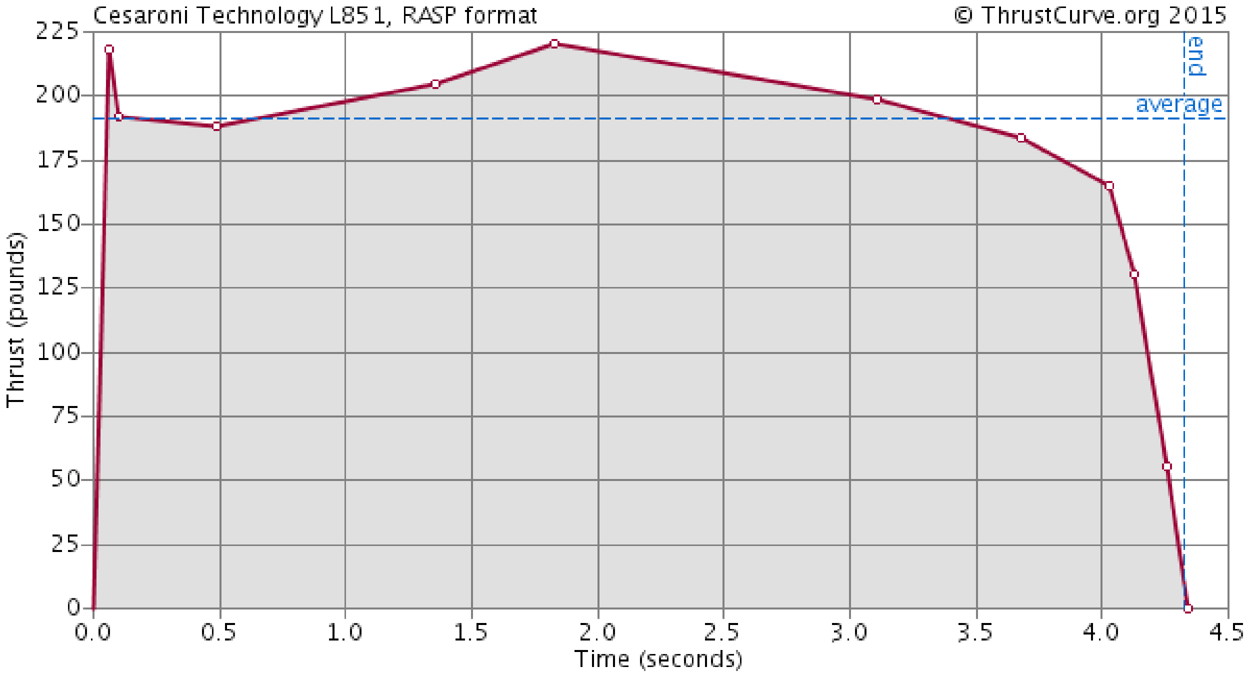

Figure 3.32 L851 Thrust Curve

Avg. Thrust (lb, N)	*Max Thrust (lb, N)*	*Impulse (lb-s, N-s)*	*Burn time (s)*
190.9, 849.1	222.5, 989.9	828.0, 3683.2	4.3

Table 3.17 L851 Motor Properties

Drift calculations were performed in OpenRocket at the latitude, longitude, and altitude of Bragg Farms in Huntsville, Alabama. The drift calculations were simulated at various wind speeds and the results of these simulations can be seen in *Table 3.18*, below.

Wind Speed	**0 mph**	**5 mph**	**10 mph**	**15 mph**	**20 mph**
Max Lateral Distance (ft)	9.24	215.6	502.3	812.3	1273.6

Table 3.18 Bragg Farms Drift Calculations

3.3.3 Thoroughness and Validity of Analysis, Drag Assessment, and Scale Modeling Results

The analysis of the vehicle depends on three key components: OpenRocket simulations, knowledge available from the team's mentors, and the subscale and full-scale flight tests.

The OpenRocket simulations give a reasonable estimate of altitude, drift, velocity, stability, and other factors affecting the launch vehicle. OpenRocket simulates the stability and control of the rocket with an atmospheric model. OpenRocket builds on Barrowman's equations but OpenRocket takes steps to correct for large changes in relative angle of attack. The ARES Team was able to take this information into account and make changes to the design in order to better achieve the success criteria.

Lee Brock and Chris Short provided an excellent sounding board and provided exceptionally useful advice for the design and construction of our rocket. Mr. Brock advised us to pursue the "tip-to-tip," method. Chris Short and Lee Brock demonstrated a similar switch design that allows easy access to the electronics bay. Mr. Short and Mr. Brock given many suggestions and provided help with loading and preparing the motor and black powder for all our flights. Without their help ARES literally would have never left the ground.

The subscale vehicle tests the recovery system, the payload ejection, and aerodynamically similar forces to test the feasibility of the full-scale rocket design. The subscale vehicle proved the feasibility of the full-scale launch vehicle design. The recovery system worked successfully, the simulated weight of the payload was ejected successfully, and the flight characteristics experienced were encouraging for the chosen full-scale launch vehicle design.

The full-scale launch vehicle tests further demonstrated the safety and workmanship of the ARES team. The recovery system worked adequately for both flights. The redundant charges were observed to have ignited for both the drogue and the main parachute. The payload was ejected successfully at apogee for both flights. The drift of the vehicle was reduced from about ¼ a mile away to about ⅛ of a mile away from the launch pad. This was achieved by lowering the deployment altitude of the main parachute from 900 feet to 700 feet. The full-scale launch vehicle was launched and recovered successfully for both flights.

The drag assessment of the rocket was also done through OpenRocket. The launch vehicle during flight currently has a drag coefficient of approximately 0.453 and a max total drag force under of 28.39 lb (126.3 N). This drag assessment is in *Table 3.19* below.

Max Drag Force (lb)	Drag Coefficient	Axial Drag Coefficient	Friction Drag Coefficient	Pressure Drag Coefficient	Base Drag Coefficient
28.39	0.453	0.452	0.288	0.043	0.129

Table 3.19 Drag Assessment

3.3.4 Stability Margin

The center of gravity and the center of pressure of the rocket are located 56.40 and 68.27 inches (1.433 and 1.734 m) from the tip of the nose cone, respectively. *Figure 3.33* shows the OpenRocket diagram of the launch vehicle, including the center of gravity (blue and white circle) and the center of pressure (red circle). This creates a favorable stability margin of 2.14 calibers.

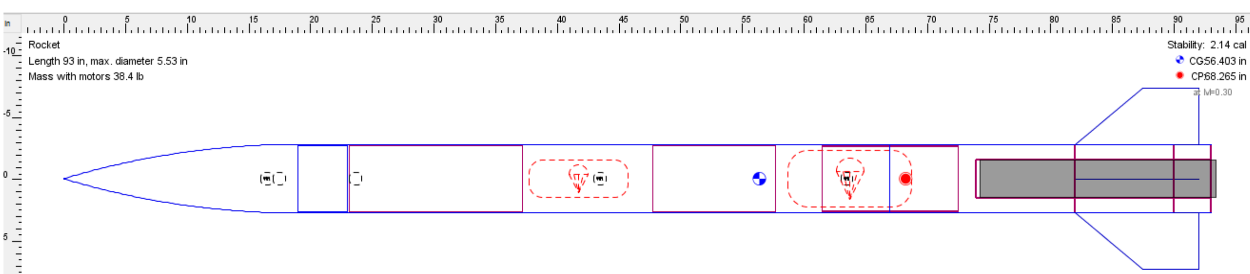

Figure 3.33 OpenRocket Diagram

3.3.5 Kinetic Energy Calculations

Given that the maximum kinetic energy of any individual section of the launch vehicle cannot exceed 75 ft-lb, the maximum allowable ground hit velocity can be calculated with the equation

$$v = \sqrt{\frac{2*KE}{m}}$$

The max ground hit velocity is determined for each individual system: nose cone, forward body sections, aft body section, total rocket. Using the "fruitychutes.com Descent Rate Calculator" we determined the appropriate sized parachutes needed to put each section at a decent rate below the max ground hit velocities. A coefficient of drag of 1.5 was used; this assumes an elliptical or circular parachute design. The elliptical shape was chosen because the team already possesses an elliptical parachute and its performance is satisfactory for the criteria set by the competition. The results from this analysis can be seen in *Table 3.20.*

System	Mass (lbf)	Allowable Velocity (ft/s)	Minimum Parachute Diameter (in)	Drag Reduction Velocity from Minimum Parachute (ft/s)
Nose Cone	4.06	34.49	24	27.52
Forward Body Section	11.5	20.49	60	18.53
Aft Body Section	10.95	21.00	54	20.09
Total Rocket	26.51	13.50	115	13.22

Table 3.20 Parachute Selection

Therefore a 120 inch (3.08 m) main parachute for the total descending rocket is justified to safely land each individual system under the 75 ft-lb.

3.3.6 Altitude and Drift of Launch Vehicle

The ARES team performed two full scale tests, one with "Phoenix Missile Works" in Talladega, AL and one with "HARA/ Music City Missile Works" in Manchester, TN. The data from the test flights can be seen below in *Table 3.21*. Reaching an apogee of 5415 ft with the L851 motor places the rocket within 2.52% of the targeted altitude of 5280 ft. Reaching an apogee of 4876 ft with the L3200 motor places the rocket within 7.96% of the targeted altitude of 5280 ft. Based on these results the ARES team has determined that the L851 motor is best suited for completing the mission successfully.

Full Scale Test Site	Motor	Apogee (ft)	Lateral Drift (ft)	Time to Apogee (s)	Flight Time (s)
“Phoenix Missile Works Site” (10 mph)	L851	5415	1380	19.75	117
“HARA/ Music City Missile Works” (5 mph)	L3200	4876	660	18.00	97.25

Table 3.21 Full Scale Test Flight Data

3.4 Verification (Vehicle)

3.4.1 Requirement Verification

All requirements for the launch vehicle are listed in *Table 3.22* below, along with the design feature responsible for meeting each requirement and how each requirement will ultimately be verified. The requirements are taken directly from the 2016 NASA Student Launch Handbook.

#	Requirement	Design Feature	Verification	Verification Status
1.1	The vehicle shall deliver the payload to an apogee altitude of 5,280 feet AGL	Launch Vehicle Structure and Motor Selection	OpenRocket simulations, Subscale Launch, and 2 Full-Scale Test Launches	Verified
1.2	The vehicle shall carry one commercially available, barometric altimeter for recording the official altitude used in the competition scoring. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight	Redundant Altimeters in the Electronics Bay.	Altimeters tested on the Subscale and Full-Scale Launch Tests	Verified
1.3	The launch vehicle shall be designed to be recoverable and reusable	Launch Vehicle Structure	Subscale and full scale launch tests	Verified
1.4	The launch vehicle shall have a maximum of four independent sections	Launch vehicle consists of two independent sections (Payload and Launch Vehicle)	Design of launch vehicle	Verified

#	Requirement	Design Feature	Verification	Verification Status
1.5	The launch vehicle shall be limited to a single stage	Motor Selection	Launch Vehicle is designed to reach desired altitude under one motor	Verified
1.6	The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the FAA flight waiver opens	Launch Vehicle Structure	The launch vehicle will have the majority of sections assembled prior to arrival at the launch site. Assembly of the Launch Vehicle during the 2 Full-Scale Launch Tests at the launch site will be timed	Verified
1.7	The launch vehicle shall be capable of remaining in a launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on board component	Altimeters, Black Powder Charges, and Payload Components will be designed to hold for a minimum of 1 hour	Subscale and two Full Scale Launch Tests will verify	Verified
1.8	The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system	All igniters will be compatible with a standard 12 volt direct current firing system	Subscale and full scale launch tests	Verified
1.9	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)	Cesaroni L851 motor	Design	Verified
1.10	The total impulse provided by a launch vehicle shall not exceed 5,120 Newton-seconds (L-class)	Motor Selection	Motor choice is a Cesaroni L851. The total impulse is 3683 Newton-seconds	Verified

#	Requirement	Design Feature	Verification	Verification Status
1.11	Pressure vessels on the vehicle shall be approved by the RSO	No pressure vessels are included in the design of the rocket or payload	Design	Verified
1.12	All teams shall successfully launch and recover a subscale model of their full-scale rocket prior to CDR. The subscale model should resemble and perform as similarly as possible to the full-scale model, however, the full-scale shall not be used as the subscale model	Subscale launch on January 16	Subscale launch test	Verified
1.13	All teams shall successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown at FRR must be the same rocket to be flown on launch day. A successful flight is defined as a launch in which all hardware is functioning properly	Full scale launch on February 20	Full scale launch test	Verified
2.1	The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a much lower altitude	Recovery System	Ground tests, subscale and full scale launch tests	Verified
2.2	Teams must perform a successful ground ejection test for both the drogue and main parachutes. This must be done prior to the initial subscale and full scale launches	Recovery System	Ground tests	Verified
2.3	At landing, each independent section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lb	Parachutes	OpenRocket simulations, kinetic energy calculations	Verified
2.4	The recovery system electrical circuits shall be completely independent of any payload electrical circuits	Electronics Bay	Design	Verified

#	Requirement	Design Feature	Verification	Verification Status
2.5	The recovery system shall contain redundant, commercially available altimeters	Redundant altimeters will be used	Design	Verified
2.6	Motor ejection is not a permissible form of primary or secondary deployment. An electronic form of deployment must be used for deployment purposes	Motor ejection will not be used as a form of deployment	Design	Verified
2.7	A dedicated arming switch shall arm each altimeter, which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad	Electronics Bay and Launch Vehicle Structure will be designed to allow for two arming switches	Design	Verified
2.8	Each altimeter shall have a dedicated power supply	Separate battery for each altimeter	Design	Verified
2.9	Each arming switch shall be capable of being locked in the ON position for launch	The arming switch will be designed to allow locking	Inspection	Verified
2.10	Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment	Launch Vehicle Structure will use removable shear pins where separation will occur. Separation will be over the parachute compartments	Design	Verified
2.11	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. Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device	Each separate section will carry an electronic tracking device	Design	Verified

#	Requirement	Design Feature	Verification	Verification Status
2.12	The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing)	Recovery system electronics will be separated and shielded from other electronics	Inspection	Verified

Table 3.22 Launch Vehicle Requirements

3.5 Safety and Environment (Vehicle)

3.5.1 Safety and Mission Assurance Analysis

The overall safety of the vehicle itself has been assured at both full-scale launches. The vehicle, for both events, has accomplished its mission successfully without any damage to the body, recovery systems, or payload from the vehicle itself. No team member has been injured or incapacitated in any way while handling the vehicle or its subsystems. All team members' safety at any subsequent launches will be assured by following the checklists provided in Section 5.1 when handling the vehicle.

Table 3.23 below is a summary of the major failure modes remaining for the vehicle. The table lists only those of primary concern, i.e. failure modes most likely to occur or most catastrophic in the event of occurrence.

Failure Analysis: Vehicle					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Failed separation of rocket body	Kinetic energy of rocket and/or payload may exceed limit; possible damage to rocket or payload upon landing; rocket may cause severe injury or death if a failed separation occurs over a crowded area	Delayed or failed detonation of black powder; failure of shear pins to break as expected	1C	Ensure e-matches will be able to detonate black powder at desired altitude; double-check e-match setup prior to launch; avoid choosing shear pins strong enough to prevent rocket separation; Add a secondary black powder charge for drogue and main separation	1E
Black powder (early or unexpected detonation)	Damage to rocket, payload, and equipment; severe injury to team members including burns or death	Improper storage of black powder; exposure of black powder to flame, temperature, or impact prior to expected detonation	1B	Store black powder securely in explosives safe container; keep black powder away from possible sources of heat or impact; ensure black powder charges are properly secured within rocket	2E

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Launch vehicle weathercocks	The vehicle has the potential to enter an improper flight path; would lead to a lower altitude or possible issues with the deployment of the payload with a minor weathercocking	The launch vehicle becomes unstable	1E	Stability margin will be maintained around 2.0 calibers off the rail as designed in order to avoid any potential weathercocking	3E
Wind gusts affect launch vehicle stability	More prone to instability if there is wind; greater chance of vehicle not flying vertically	The angle of attack exceeds the angular margin of stability	1D	Monitor the weather before all launches; listen to the RSO at all times, and specifically if conditions become questionable	3D
Incorrect determination of forces on launch vehicle	Would supply an incorrect determination of the CP and could affect the rocket flight	Incorrect calculations for CP; final or most recent data not included in calculations	2C	Utilize OpenRocket to determine the forces on the launch vehicle using the most up to date information	3D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Altimeters	Failure to correctly read altitude; possible effect on parachute and payload deployment	Altimeter malfunction; faulty wiring or code which may incorrectly read a working altimeter	3D	Utilize altimeter redundancy to ensure functionality; consult altimeter manual for common altimeter defects and errors; check all wiring and code to ensure it is compatible with the altimeter data	4E

Table 3.23 Failure Analysis of the Vehicle

3.5.2 Updated Personnel Hazards

An updated discussion and analysis of remaining personnel hazards may be found in *Table 3.24*. Again, the hazards discussed are those of greatest significance to the team; in this case, the included hazards are those that carry the ability to cause injury to an affected team member at any time while the team members are in contact with the hazard.

Personnel Hazards: Vehicle					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Black powder	Serious burns and/or possible death of team members from fire or explosions	Mishandling of black powder, including dropping or otherwise disturbing loaded powder cups; leaving black powder unobserved near source of fire, heat, electricity, etc.; failure to store black powder according to safety guidelines	1C	Allow only NAR mentor to handle black powder; store powder in a secure explosives box when not in use; keep loaded powder cups away from sources of fire, heat, and electricity; do not jostle or disturb loaded powder cups or black powder supply	2E
Electric shock	Potentially damaging or debilitating shocks to team members handling electronics	Failure to wear appropriate PPE; failure to ensure wires and electronics are not hot before handling; exposed wiring left unprotected or unobserved by team members	2D	Wear rubber gloves when handling hot electronics; do not leave wiring exposed; do not directly handle hot wiring if it may be avoided; follow safety guidelines for electronics prep at all times	3D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Fiberglass	Damage or injury to respiratory systems, skin, or eyes of team members, depending on method of contact	Failure to wear proper PPE when handling fiberglass; inhalation of fiberglass dust or repeated contact between skin/eyes and fiberglass	3D	Wear masks when near fiberglass dust; wear gloves when handling fiberglass directly; follow all safety and PPE guidelines as set forth by fiberglass MDS sheet	4E
Motor	Potentially catastrophic or deadly burns to team members in the event of motor misfire or explosion	Mishandling of motor when loading into rocket; improper storage of motor; leaving motor unattended near source of fire, heat or electricity	1C	Only allow NAR mentor to handle motor; do not leave motor unattended or stored in a location not approved for explosives; do not place motor near source of fire, heat, or electricity at any time	2E
Physical damage from direct contact	Bruises, cuts, scrapes, etc. from sharp edges or from dropping and/or allowing the rocket to fall onto a team member	Failure to wear PPE such as gloves when handling sharp edges; failure to secure rocket body in a stable position without danger of falling	3C	Always wear PPE when handling sharp edges; do not leave rocket in precarious position (i.e. table edge); do not leave rocket body unattended	4C

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Hot components post-launch	Minor to severe burns to team members from handling hot components post-launch without allowing adequate cooling	Failure to wear protective gloves to shield team member from heat; failure to allow for adequate cooling time post-launch before direct contact	2D	Always wear protective gloves when handling potentially hot components; allow sufficient time after landing for all rocket components to cool before handling	4D

Table 3.24 Vehicle Personnel Hazards

3.5.3 Remaining Environmental Concerns

The vehicle has repeatedly demonstrated its capability to have minimal impact on the environment, and vice versa. That being said, remaining environmental concerns are discussed below in *Table 3.25*. At this stage, general environmental impact is considered minimal except in the case of an accident involving environmental damage.

Environmental Hazards: Vehicle					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Fire	Serious to catastrophic burns to surrounding crops, bystanders, or other plant and animal life	Motor misfire; black powder spill; any flammable material or component being left unattended near source of heat or flame	1C	Store all potentially flammable materials or components away from heat or fire, and in explosives-safe container if needed	3D
Physical damage to crops and/or bystanders	Direct physical damage (i.e. bruises, cuts, breaks, etc.) to surroundings from rocket landing	Failure of recovery systems to properly slow rocket kinetic energy to acceptable levels;	2D	Request heads-up warnings when rocket is in descent; visually track both rocket and payload at all times during descent; launch only in areas with adequate clearance on all sides	3D
Pollution	Contamination of nearby plant life, animal life, or waterways due to toxic spills from rocket	Leakage of toxic substances such as paint, fiberglass, lipo batteries, etc.; failure to properly dispose of toxic substances	2E	Store all potentially toxic substances as outlined in MDS sheets; do not leave toxic substances unattended or exposed to environment	4E

Table 3.25 Vehicle Environmental Hazards

3.6 Payload Integration

3.6.1 Integration of Payload into Launch Vehicle

The launch vehicle has designated area for the Hazard Avoidance Lander (HAL) to be stored during flight. *Figure 3.34* below shows the configuration of the payload integration. The payload is placed in the forward body tube in front of the drogue parachute to allow clearance of the launch vehicle and avoid any possible tangling with the launch vehicle or the launch vehicle's recovery system. The payload, when deployed, should be able to eject cleanly, (avoid getting caught inside the forward body tube), and clear the rest of the sections of the launch vehicle. This is why a ground ejection test before every flight checks for a 3 foot clearance. The payload has its own internal altimeters, so that the payload can operate without using any of the components of the launch vehicle's electronic systems. HAL's electronic systems will be housed in a fiberglass tube 12 inches (.305 m) in length. The lander leg feet are constructed to provide a fin-like shape to decrease its decent rate and prevent tumbling during flight. The payload will be positioned with the feet toward the nose cone to avoid "sticking" inside the forward body tube upon ejection. The payload will be ejected by a black powder charge immediately following apogee. The nose cone will be ejected first, followed by the payload, and then the drogue parachute.

3.6.2 Compatibility of Elements

The maximum diameter of the payload, including the landing legs, will be 5.30 inches, which is smaller than the diameter of the body tube by 0.08 inches. This will give the payload enough space to be smoothly ejected from the forward body tube by the ejection charge. This also provides enough room for a shock cord to run past the payload from the drogue parachute to the nosecone.

3.6.3 Payload-Housing Integrity

The payload instruments will be protected by a fiberglass housing and the folded lander legs during ejection. The payload structure has proven to be able to withstand the pressure and heat produced by the black powder charges during ground tests and the full scale flight tests. The max temperature recorded from both flights was recorded at 73.8 degree Fahrenheit. This is well within the tolerances of the payload electronics. In addition, the payload housing proved capable of withstanding ground impact during the full scale flight tests. Because of these results, the team is confident in the integrity of the housing.

3.6.4 Diagram of Components and Assembly with Documented Process

Proper integration of the payload is vital to the successful deployment of the payload. The payload payload integration configuration is below in *Figure 3.34*. The procedures for proper integration are below *Figure 3.34*.

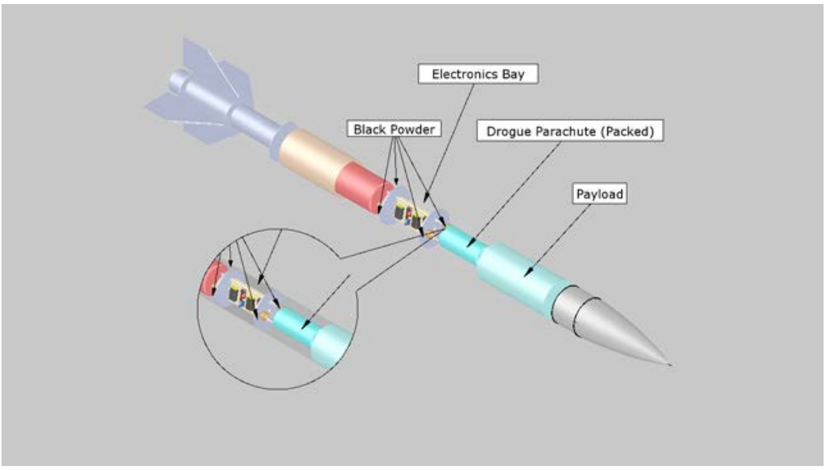

Figure 3.34 Payload Integration

1. Check that the payload legs are in place and properly latched. Make sure wingnuts on both ends of the payload housing are tightened.
2. Fold parafoil into launch configuration.
3. After drogue parachute is loaded into forward section, slide parafoil protector over drogue parachute shock cord.
4. Wrap parafoil in protector, creating a “burrito”.
5. Insert payload into forward section, parafoil first, with the shock cord running alongside it.
6. Ensure that payload is able to slide in and out of body tube.
7. Attach shock cord to nosecone bulkhead and slide nose cone into place.

4. Payload Criteria

4.1 Experiment Concept

4.1.1 Creativity and Originality

The landing hazard detection system was an option for a challenge given by the NASA student launch, but the ARES Team chose to design their own task by adding a guided descent challenge to the payload as well. The team felt that if landing hazards were going to be detected, it was a logical second challenge to steer away from any hazards detected. While guided descent systems have been created and implemented on larger scales, the ARES Team would like to create an original design that can work on a smaller scale and contribute to the research done on this type of system. This allowed the team to come up with its own method for controlling the descent of the payload and the team settled in on using a parafoil. Another original aspect of the payload is the design of the landing system. The landing system of the payload consists of 5 individual legs and features 10 contact points with the ground, which creates a wide base. This system was designed so that the payload could land on many types of terrain while maintaining balance and minimizing the chances of damaging the hardware inside.

4.1.2 Uniqueness or Significance

The ARES Team feels that their design for a payload that can steer itself away from landing hazards during descent could be an invaluable asset on missions to Mars or any other destination. The system could, potentially, be adapted to work with a steering system utilizing thrusters for a payload being sent to a destination without an atmosphere. The combination of the landing hazard detection and parafoil could also be utilized for other purposes, such as relief missions to areas affected by natural disaster or war. Payloads containing food and supplies could be dropped and guided to safe landing locations to ensure safe delivery. The ARES Team also aims to show that an efficient landing hazard detection and avoidance system can be made inexpensively.

4.2 Science Value

4.2.1 Payload Objectives

The HAL payload's mission during descent from apogee is to take images and analyze these images to detect potential landing hazards, and to then use this data and the parafoil to steer away from the detected landing hazards. The complete requirements for the payload are listed below.

- The payload must eject from the launch vehicle at apogee.

- The payload must take images of the ground and analyze these images to determine the locations of landing hazards.
- The payload must use the locations of detected landing hazards to steer itself away from those hazards.
- The payload must store all data onboard and transmit all data to the ARES Team's ground station.
- The payload must land in a safe location, with a kinetic energy no greater than 75 ft-lb.

4.2.2 Mission Success Criteria

For the mission to be considered a success, the payload must complete the objectives listed in Section 4.2.1 within a reasonable margin defined below.

- The payload must eject from the launch vehicle within 250 feet of apogee.
- The payload must take images of the ground and analyze these images to determine the locations of landing hazards.
- The payload must use the locations of detected landing hazards to steer itself away from large hazards.
- The payload must store all data onboard and transmit at least 80% of stored data to the ARES ground station.
- The payload must land in a safe location, with a kinetic energy no greater than 75 ft-lb.
- The cost of the payload must be within the team's budget specified in Section 5.

4.2.3 Experimental Logic, Scientific Approach, and Method of Investigation

4.2.3.1 Landing Hazards Detection Task

The experimental logic of the landing hazards detection task is based on potential rovers, probes, and landers that need to come in for a landing. Although research can be done in advance to mitigate the chances of landing in an area with dangerous debris, it is important for landing vehicles to be able to detect hazards autonomously during descent. This problem will be addressed from both a hardware and software standpoint. While they are certainly intertwined, the data from each side must be analyzed individually, though still within in the context of the operation as a whole. The investigation begins at the moment the payload is deployed, which happens at rocket apogee. At this altitude, ideally 5280 feet, the camera will start acquiring images and transmitting them back to the Pi. The software will integrate data from the altimeter to know the size of the objects it has identified. The software will then classify the likelihood that a certain object is a hazard.

4.2.3.2 Guided Descent Task

The use of a parafoil was based on the parafoils used by the military to drop supplies in a given location. Unlike traditional parachutes, parafoils generate lift, which, in turn, generates a horizontal velocity. Manipulating the outermost sections of the parafoil allows the parafoil to steer. Because the parafoil will allow the Hazard Avoidance Lander to change its direction, HAL can avoid any potential hazards detected by the Landing Hazards Detection Subsystem. The investigation begins when the first landing hazard is detected. Once the size and direction of the landing hazard is determined, the servo motors will be activated, forcing the payload to turn and avoid the landing hazard.

4.2.4 Test and Measurements

4.2.4.1 Landing Hazards Detection Task

Since this task is not a traditional experiment, measurement is not conducted in a physical sense. Rather, the task is deemed to have been completed successfully, and then the data is analyzed to understand what worked and what didn't. Bearing this in mind, the measurements for this task are the data that is stored in the SSD to be transmitted to the ground station. Since radio transmission is slow, only one image will be stored for every ten seconds. In addition, data will be stored when a potential hazard is detected, identified, and classified. All of this data will be transmitted wirelessly back to the ground station. The raw image data can be compared to the hazard identification results to serve as a control variable.

4.2.4.2 Guided Descent Task

The task of steering the payload is not a traditional experiment and measurement cannot be taken. The task will be judged on whether it can successfully avoid the hazards detected. Images taken from the landing hazards detection subsystem will be used to determine whether the payload was successfully able to steer around landing hazards. For the task of limiting landing velocity, measurements taken by the altimeter on board the payload will be used to if the task was successful. Wind speed is a big variable when limiting landing speed. The velocities obtained during tests drops will be used as control variables.

4.2.5 Relevance of Expected Data and Accuracy/Error Analysis

4.2.5.1 Landing Hazards Detection Task

The relevance of the data depends on the intended application of the results. For example, if this combination of hardware and software is being evaluated for eventual use on Mars, then the use of color to distinguish between features would not be reliable as currently configured, which is one of the ways the system identifies a hazard. However, the ability to detect and identify hazards is certainly relevant to a multitude of engineering applications in the abstract, and using colors and altitude is a useful configuration for UAVs and satellites specifically.

The accuracy of the software will be determined upon post-flight analysis. Each raw image will be compared to the amount of potential hazards detected and identified. A post-flight inspection of the area will be done to identify what hazards actually exist. All of these hazards will then be organized into bins classifying them by their size, color, and location. Comparing these bins to the raw images will give the amount of hazards the hardware was able to capture based on height and size of the object to be detected. The hazards that are captured by the raw image will then be compared to the software results yielding the percent of hazards properly identified. Because the hazards are classified, further data mining will be done to determine if the payload struggled with certain categories of hazard.

4.2.5.2 Guided Descent Task

The results of the guided descent task is relevant in any guided payload system that must react to hazards in real time. This experiment will show the ability of a parafoil to deliver a payload near a predetermined area while being able to avoid hazards in real time. These concepts can be relevant to many engineering applications such as military supply drops and the landing of rovers on other planets.

The data from the Landing Hazards Detection Subsystem will pave the way for future landing detection systems for use on other worlds. By analyzing the raw pictures taken by the Pixy CMUcam5 and comparing them to the pictures analyzed by the Raspberry Pi and the Pixy CMUcam5, we can determine how accurately the system detected the hazards.

By aiming for a 50 yard radius around the launch pad, the accuracy of the Guided Descent Subsystem can be determined.

4.2.6 Experiment Process Procedures

Prior to launch, all of the payload components will be tested. The ARES Team will ensure that the Pixy CMUcam5 takes pictures and will identify appropriate hazards while conducting drop tests. The Raspberry Pi's code will be tested using pictures taken from the Pixy CMUcam5. The XBee Pro 900 will be tested by placing the two XBees at various distances and transmitting data to a computer. The team can then ensure that the XBees will communicate at a large enough distance to reach the maximum expected distance the payload will be away from the ground station. The parafoil's gliding and turning abilities will be tested during low altitude drop with a dummy payload with the same weight as the actual payload. The parafoil deployment will be tested with low altitude drop tests. The landing legs' strength and deployment will be tested with drops and ground testing. All electronics will be calibrated to verify that results received from them are accurate and precise. After rigorous ground testing, the payload will be tested on the full sized rocket prior to the final launch date.

4.3 Payload Design

4.3.1 Design and Construction of Payload

4.3.1.1 Structural Elements

Figure 4.1 shows the upper bracket for the interior of the payload. The wires for the servo motors could not fit in the previous design, so holes were dremeled for the wires to fit into. The servoless payload release also had trouble fitting between the blocks, so the space between them was dremeled to widen the gap. *Figure 4.2* shows the upper bracket with the servo motors and servoless payload release attached.

Figure 4.1: Upper Bracket

Figure 4.2: Upper Bracket with components

Figure 4.3 shows the main bracket for the interior of the payload with the Proto-Board and I2C-PWM breakout attached. The main bracket will also have the XBee screwed onto it. The Proto-Board has all wiring correctly soldered in place to make the electronics more stable for the vibrations during takeoff and landing.

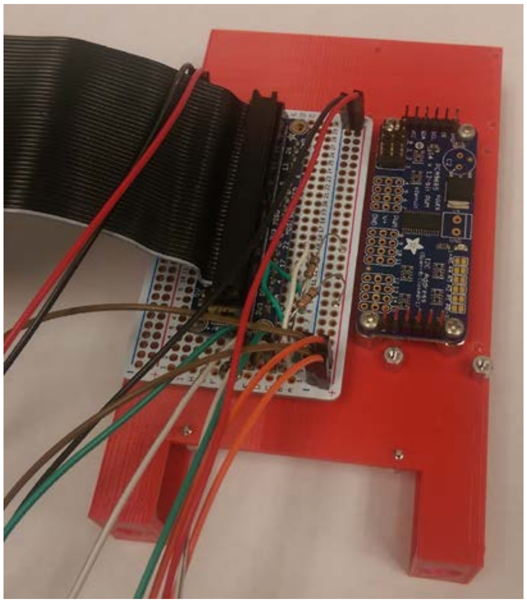

Figure 4.3: Main Bracket with 12C-PWM breakout and Proto-Board

The XBee Pro is shown in *Figure 4.4*. The XBee will be used to transfer the data collected by the Raspberry Pi and send them via radio. The XBee will be connected to an antenna to help transfer the data, as shown in *Figure 4.5*. The XBee will be connected to the main bracket.

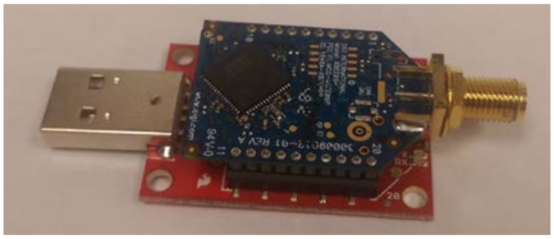

Figure 4.4: XBee Pro

Figure 4.5: XBee Pro with antenna

Figure 4.6 and *Figure 4.7* show the main bracket of the interior of the payload with no components from the front and back view, respectively. The main bracket will have the Proto-Board, the I2C-PWM breakout, XBee Pro and Raspberry Pi screwed to it. The Camera will be placed under the main bracket and the upper bracket will be placed on top of it.

Figure 4.6: Main Bracket Front View

Figure 4.7: Main Bracket Back View

Figure 4.8 shows the top plate of the payload. The Allthreads will be fed through the holes on either side. The fiberglass tube will be placed in the circular ridge around the plate. The toggle lines of the parafoil will be fed through the center hole and will be connected to the servo motors.

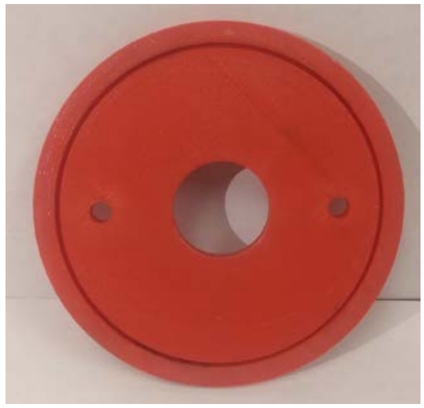

Figure 4.8: Top Plate

<u>4.3.1.2 Electrical Elements</u>

There are many electrical elements used in the HAL payload. The 6600 mAh 2S2P and the 5000 mAh 4S lithium polymer batteries will be used to power the payload. The 6600 mAh battery will power the Raspberry Pi 2 that controls the payload, the powered USB hub, the Samsung solid state drive, the GPS, and the XBee Pro which sends data back to the ground station, and the onboard camera. The battery will first run through a voltage regulator that will reduce the voltage to 5 V and will allow up to 3.5 A to flow through the circuit. The electricity will then go to the powered USB hub which powers the Samsung solid state drive and the Raspberry Pi 2. The XBee Pro, the Adafruit GPS, and the onboard camera will be connected via USB to the Raspberry Pi 2. The USB connections are shown in *Figure 4.9.*

The 5000 mAh battery will also be run through a voltage regulator. The servo motors used to control the parafoil, the servoless payload release used to release the landing legs, and the AltIMU gyro used to determine attitude, altitude, and accelerations will be powered by this battery. All connections will be connected by 28 AWG jumper wires from Adafruit. All the wiring connections are shown in *Figure 4.10*.

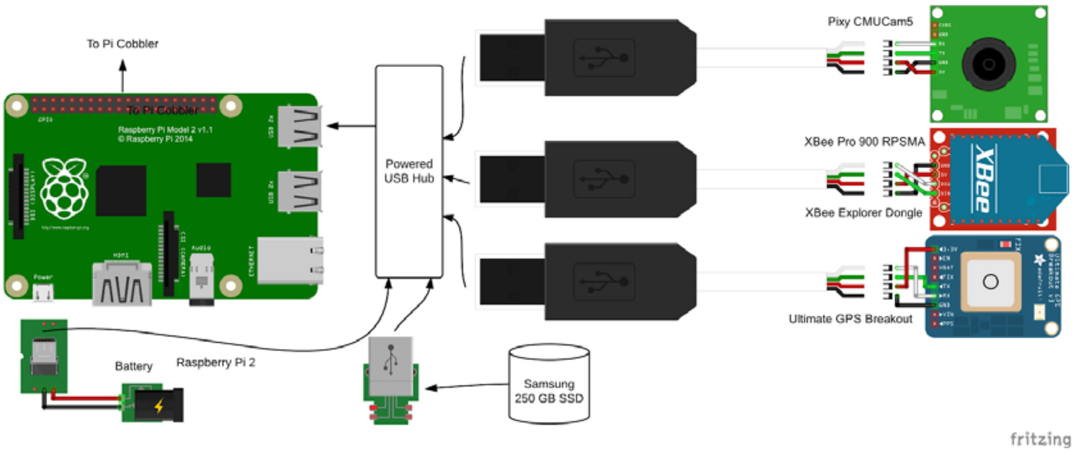

Figure 4.9. Payload USB Interfaces

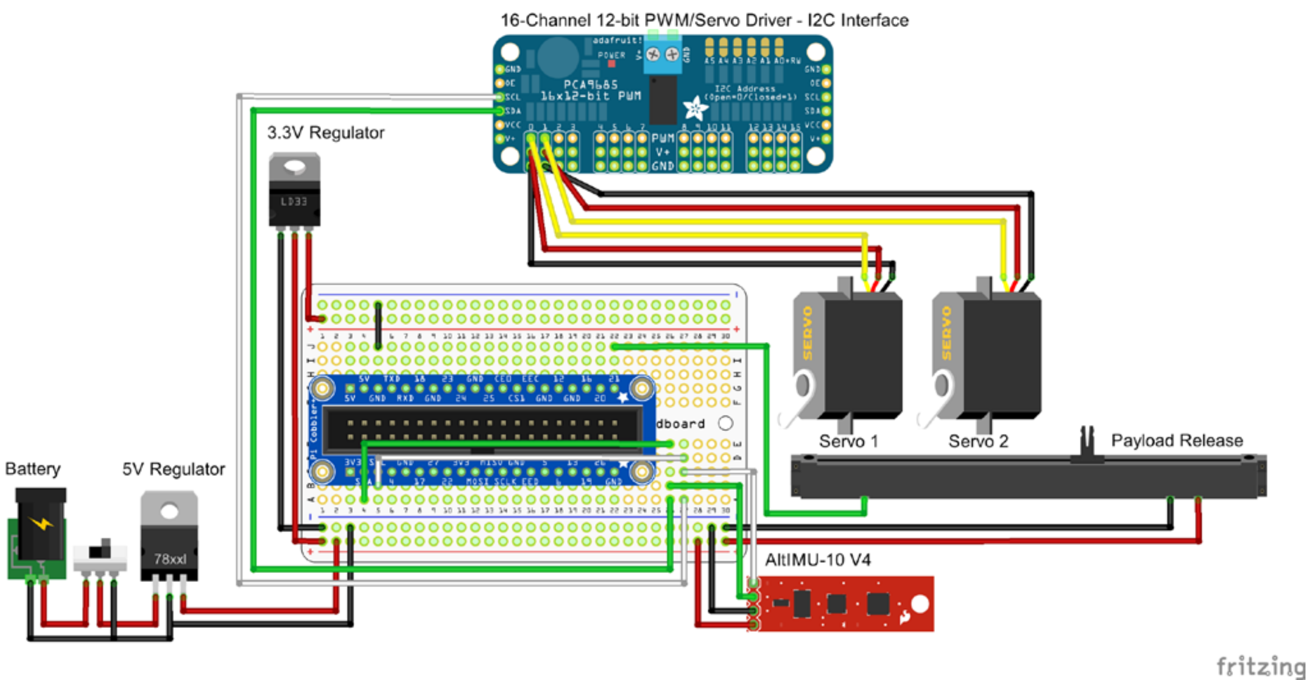

Figure 4.10 Payload wiring schematic

Figure 4.11 shows how the components will be wired together.

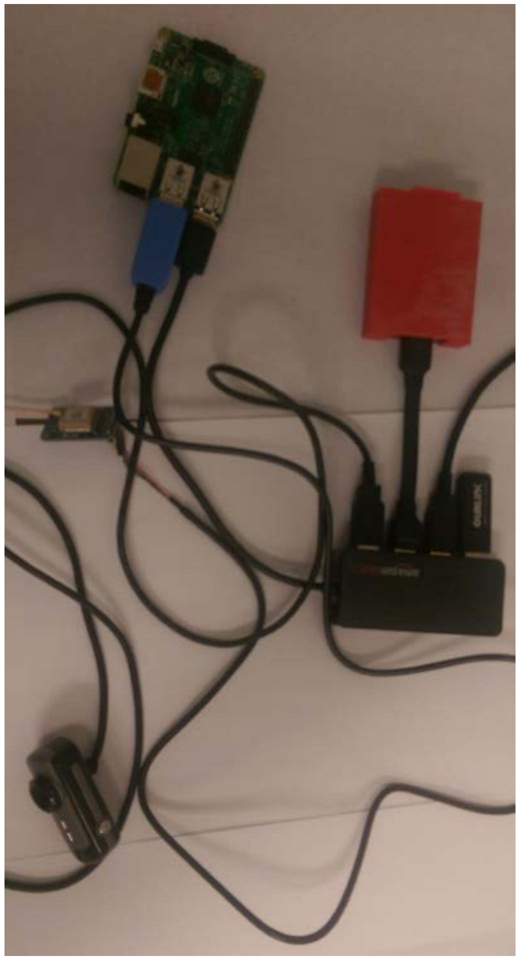

Figure 4.11: Component Wiring

<u>4.3.1.3 Drawings and Schematics</u>

Figures 4.12 and *4.13* show a detailed diagram of the payload assembly. The payload assembly is described in detail in section 4.1.6.

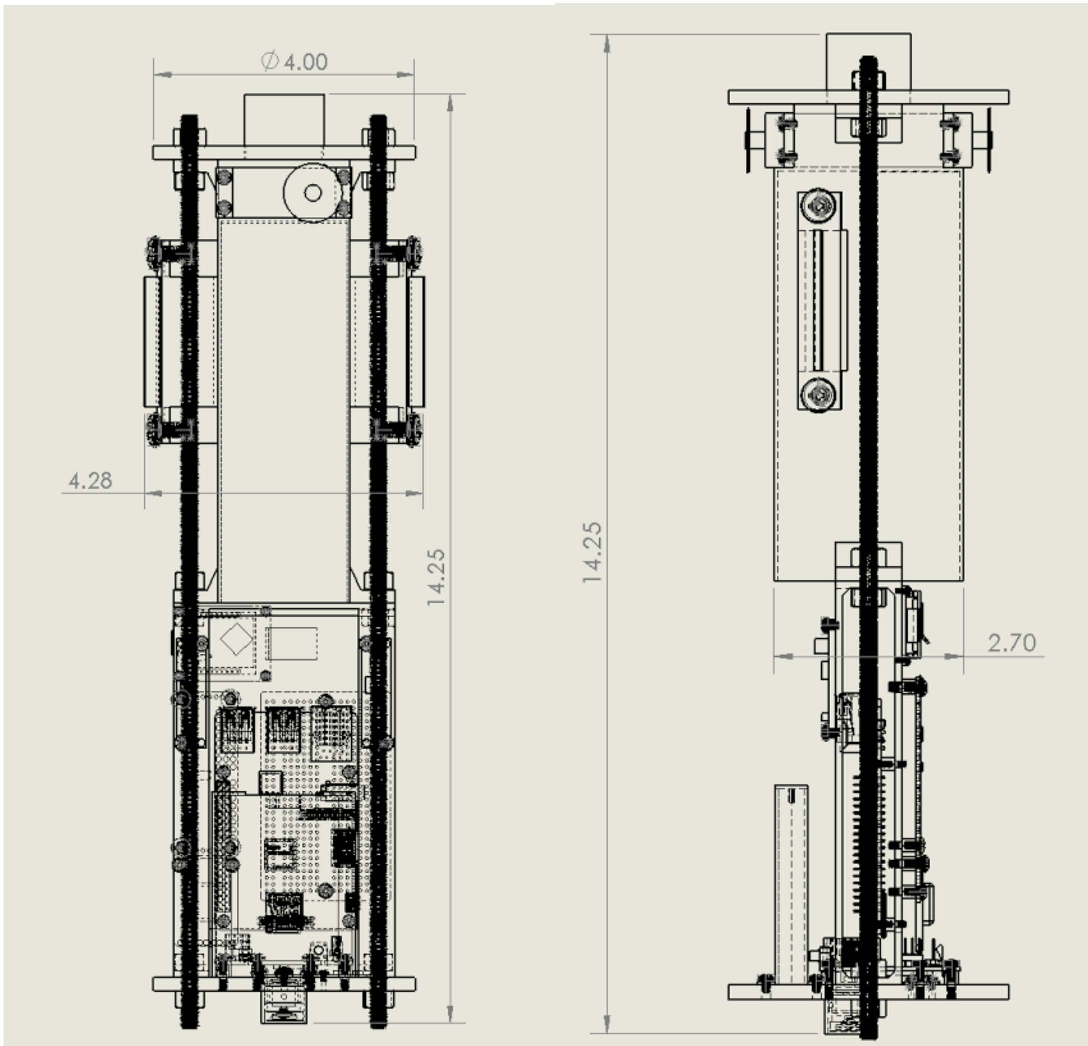

Figure 4.12 Front and Right Views of the Assembled Payload

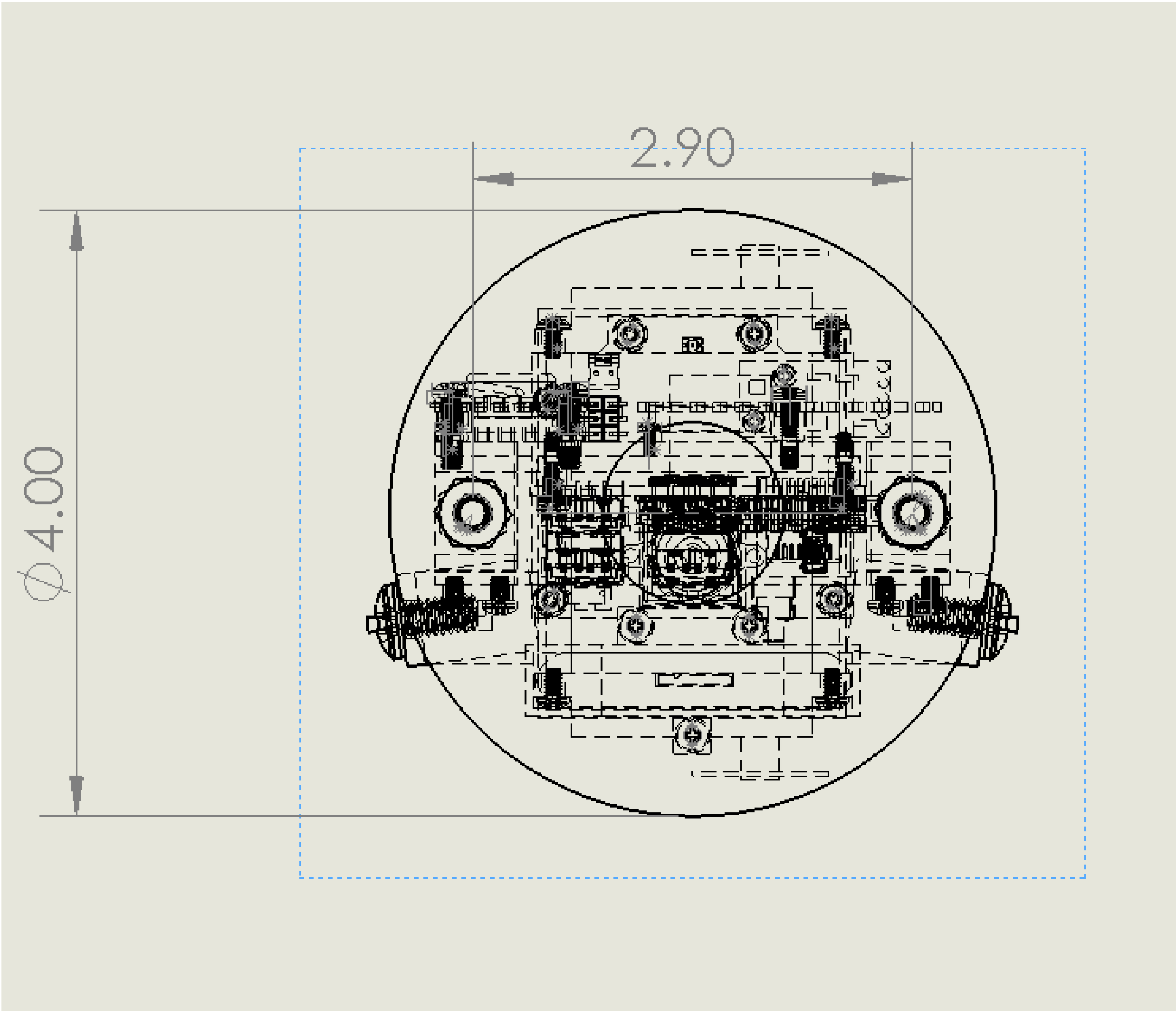

Figure 4.13 Top Model-View of the Assembled Payload.

4.3.2 Precision of Instrumentation and Repeatability of Measurement

The instrumentation on the payload is key to the ability to perform both of the selected experiments. The Landing Hazards Detection Subsystem requires data from the altimeter to assess the size of shapes that it detects, an essential step to identifying a hazard. Furthermore, the data must be stored on board and also transmitted back to a ground station wirelessly. Finally, a camera is needed to acquire the images. The Guided Descent Subsystem needs to know its location, heading, and orientation in order to plan course adjustments. Servo motors are then required to execute this motion. If any of these instruments fail, the ability of the payload to perform its specified tasks will be significantly impaired. As such, proper understanding of the payload instrumentation is imperative to the mission. A summary of the payload instrumentation is listed in *Table 4.1* below.

Payload Subsystem	Instrumentation	Precision	Repeatability of Measurement	Recovery System
Guided Descent	Ultimate GPS Breakout	3 m position accuracy 0.1 m/s velocity accuracy	Can be repeated with every launch	Recovered upon safe landing of the payload
Landing Hazards Detection	Pixy CMUcam5	Captures 1280x800 image frame 50 times a second		
Landing Hazards Detection	XBee Pro 900	156 Kbps data rate 6 mile range		
Payload Control	AltIMU-10 v4	Gyro - ±245, ±500, or ±2000°/s Accelerometer: ±2, ±4, ±6, ±8, or ±16 g Magnetometer: ±2, ±4, ±8, or ±12 gauss Barometer: 26 kPa to 126 kPa		
Guided Descent	HS-645MG Ultra Torque Servo Motors	Operating speed of 0.233 sec/60° with stall torque of 8.02 kg*cm		
Payload Control	250 GB Portable Solid State Drive	450 MB/s read-write speed		
Landing	Servoless Payload Release	Payload Weight limit of 340 g		

Table 4.1 Payload Instrumentation

4.3.3 Flight Performance Predictions

There are two tasks for the HAL payload. The goal is for the payload to autonomously identify hazards upon descent, and then steer to avoid those hazards while navigating to a waypoint. First, the payload must successfully separate from the main rocket assembly. Upon separation, the parafoil will inflate, slowing the payload's descent and allowing it to control its direction. The GPS data will be used to navigate the payload towards the waypoint. When the payload is close to the waypoint, or to the ground, the data being obtained from the image analysis module will be used to make the payload steer away from danger.

4.3.4 Approach to Workmanship

Proper workmanship is one of the keys to the ARES mission being successful. As such, there are three aspects of workmanship that the team is focusing on to ensure a high-quality process of payload construction. The first focus is having a full design and manufacturing plan. By having a plan to follow, and a design to verify against, the process of manufacturing will become repeatable, and therefore much more precise. While experimenting with different ideas in a garage is fun, and certainly appropriate for an enthusiast or hobbyist in the model rocketry field, it is not the approach that ARES, as an engineering group, desires to follow. The second focus is summed-up best by the old adage, “measure twice, cut once.” Every mistake costs the team time, money, and resources. As such, every step must be double-checked, or two people must be present for the process. This duplicity will increase the time to manufacture each part, but it is still much faster than having to re-manufacture a part. The third and final focus is that of experience. Ideally, no work on a component for mission use should be done by a team member with no experience in that manufacturing process. If that is not possible, the worker must first consult with appropriate experts such as our NAR mentor or the machine shop staff for advice. In addition, some practice should be done before that process is undertaken. Not only will this reduce the chance of a part being manufactured incorrectly, it also decreases the chance of injury to the team member doing the work.

4.3.5 Test and Verification Program

The ARES Verification Testing plan for the payload is as follows.

1. Component Testing
    a. Payload Control
        i. The Raspberry Pi will be configured to run from the SSD and tested.
        ii. Configure the AltIMU to verify hardware and software accuracy.
    b. Landing Hazards Detection System
        i. Load test data into the SSD and transmit the data through the XBee.
        ii. Test images will be run through the hazard detection software.
        iii. Test images will be acquired from the camera.
    c. Guided Descent
        i. The GPS will be tested from stationary location
        ii. Parafoil will be test dropped with a dummy payload.
        iii. Servo motors will be tested on a breadboard to ensure functionality.
    d. Landing
        i. The 3-D printed parts will be inspected for defects.

2. Subsystem Testing
    a. Payload Control
        i. GPS, AltIMU and XBee will be tested while in motion
        ii. Payload electronics system will be tests in complete connection
    b. Landing Hazards Detection System
    c. Guided Descent
        i. Parafoil turning radius will be measured
    d. Landing
        i. Leg spring forces will be measured
        ii. Leg deployment method will be tested
3. Prototype Testing
    a. Payload will be fully assembled and run through a battery cycle to ensure component functionality
    b. Low altitude drop testing will be done to test the flare maneuver and landing legs
    c. Perform weather balloon drop testing
    d. Complete payload will be tested on shake table to ensure durability of connections
4. Full-Scale Test
    a. The payload will be loaded into the rocket and deployed using launch day procedures.
    b. Extra data will be stored for analysis after the flight, although it may not be transmitted due to battery life concerns
5. Launch Day
    a. Launch day procedures will be carried out.
    b. The payload will be recovered.

4.4 Verification

4.4.1 Requirement Verification

Payload requirements were decided by the entire payload team and a verification method was decided. These requirements and rationale can be seen in *Table 4.2*.

Subsystem	Functional Requirement	Selection Rationale	Selected Concept	Characteristics	Verification Method
Guided Descent	Descend at a controlled velocity	Payload must descend at a safe velocity that is held relatively constant	Parafoil will be used instead of traditional parachute	Parafoil fills with air and resembles an airfoil. The parafoil will be deployed in a turning state to mitigate the effects of a control failure.	Testing
	Guide payload descent	Payload must be able to avoid any landing hazards detected			Inspection
	Deploy parafoil in a reliable manner during payload descent	Deployment must limit risk of tangling and limit number of black powder charges used	Deploy parafoil while payload releases	Upon deployment, parafoil will fill with air and begin working	Analysis
	Limit landing velocity	Payload must land with less than 75 ft-lb kinetic energy, so velocity must be minimized before landing	Flare Technique	Pulling on both parafoil wires, will slow the payload down when landing	Analysis
	Angle of incidence	Payload must descend at a slow vertical speed and with a good glide ratio.	Angle of incidence of -3.75° (See *Figures 4.14 and 4.15*)	Lines will be sewn to maintain consistent angle of incidence.	Testing
Landing Hazards	Detect hazards	See Appendix E	Pixy CMUcam5	Take images of the ground	Testing
	Identify hazards	See Appendix E	Pixy CMUcam5 Raspberry Pi	Analyze images taken by the camera	Testing
	Store data onboard	See Appendix E	250GB USB Portable Solid State Drive	Stores onboard data quickly, uses less power, resistant to vibrations	Testing

Subsystem	Functional Requirement	Selection Rationale	Selected Concept	Characteristics	Verification Method
Landing Hazards	Transmit data to ground station	See Appendix E	XBee Pro 900	The XBee on the payload will communicate with another XBee at the ground station	Testing
Control	Run software in real time	Allows for the fast response times	Python code	Allows for more up to date information	Analysis
	Know altitude	See Appendix E	AltIMU-10 v4	The barometer will receive pressure readings and will output altitude	Testing
	Know orientation	See Appendix E		The gyro will provide payload attitude	Testing
	Know location	See Appendix E	Adafruit Ultimate GPS Breakout	The GPS is accurate to 3 m	Testing
	Know velocity	See Appendix E		The GPS is accurate to 0.1 m/s	Testing
	Have 1 hour and 30 minutes of power available	Contains enough charge to last one hour on the pad, launch and land the payload, and transmit data	USB Battery Pack for Raspberry Pi and LiPo battery	The batteries should last longer than what will be required with all electronics powered on	Analysis
Landing	Deploy legs at a specified altitude	Minimizes drag and moments on payload	Payload Release	Release lander legs when current passes through	Testing
	Keep upright and stable upon touchdown	Allow for ease of communication between the payload and the ground station	Use lander with large leg spread	Longer legs will increase the difficulty of tipping the payload	Testing

Landing Hazards	**Landing Hazards**	**Landing Hazards**	**Landing Hazards**	**Landing Hazards**	**Landing Hazards**
Landing	Absorb forward momentum	Allow for the legs to release as well as absorb some of the impact when landing	Torsion springs	Upon landing, the springs will coil up and absorb some of the energy to protect the payload	Testing

Table 4.2 Payload System Functional Requirements

4.4.2 Results of Analysis, Inspection, and/or Test

The results of the payload analysis and inspection can be found in *Table 4.3*, while the results of the testing is in *Table 4.4*.

Object of Interest	**Concern to be Considered**	**Analysis and Inspection Summary**
Landing Leg Deployment Mechanism	Deployment may not be reliably successful.	The solenoids on the previous design have been replaced with a servoless payload release. The servoless payload release requires power to lock the legs, so if the electronics disconnect or power is lost, the legs will automatically deploy.
Payload electronics system	Electronics may not stay connected.	All wires connected to the breadboard will soldered to keep all wires attached. Tests will be conducted on the shake table to verify the durability of the electronic connections.
Parafoil	Parafoil may not deploy correctly	Multiple parafoil deployment methods have been researched and will be tested. All methods will be tested several times and the most reliable method will be chosen. Packing the parafoil with the chosen method will be practiced with testing to minimize the risk of deployment failure.
Landing Leg Weight	The landing legs made up nearly half of the total payload weight	The previous design for solid landing legs has been modified to make the legs hollow. The thickness of the shell for the calves and thighs was determined for the design that best balanced the weight of the component and the yield force. For both the calf and thigh the optimum shell thickness was determined to be 0.15 inches.

Object of Interest	Concern to be Considered	Analysis and Inspection Summary
Limiting Landing Velocity	Payload must land with less than 75 ft-lb kinetic energy and electronics need to be protected to ensure reusability.	During one of the launches, the parafoil broke, and was only attached by one line. Despite this, the payload still came down slower than the rocket, which is much heavier.
Software Language	The language must be able to easily implement an efficient image analysis code on the Raspberry Pi.	Although C++ is a more powerful language, and there are libraries available for image processing, Python comes native to the Raspberry Pi, and there are many more examples of using the python image processing libraries for projects on the Pi.
Battery Duration	Must have enough battery power to last one hour on the pad, launch and land the payload.	Calculations have been done that show the batteries will give the payload 2 hours and twenty minutes of battery life. This will cover the hour before launch, the time on the pad and in the air, and the time after landing to broadcast data, with some time to spare.
Guided Payload Descent	Parafoil must be able to turn payload in order to avoid hazards.	When one toggle line is shorter than the other the parafoil will turn during drop tests.

Table 4.3 Inspection and Analysis Results

Test Phase	Test	Result
Component Testing	Verify that Pi will run from the SSD (Appendix G.1)	Complete. (Appendix H.1)
	Calibrate and test AltIMU (Appendix G.2)	Complete. (Appendix H.2)
	Transmit test data through XBee (Appendix G.3)	Complete. (Appendix H.3)
	Run test image through hazard detections software (Appendix G.4)	In progress.
	Test stationary GPS (Appendix G.5)	Complete. (Appendix H.4)
	Parafoil drop test (Appendix G.6)	Complete. (Appendix H.5)
	Test servo motors (Appendix G.7)	In Progress.
	Test Pixy CMUCam5 (Appendix G.8)	Complete. (Appendix H.6)

Test Phase	Test	Result
Component Testing	Parafoil deployment test (Appendix G.9)	Complete. (Appendix H.7)
	Parafoil angle of incidence test	Complete.
Subsystem Testing	Test GPS and AltIMU while in motion and send data from XBee (Appendix G.10)	Complete. (Appendix H.8)
	Test complete payload electronics system (Appendix G.11)	Scheduled.
	Measure leg spring forces (Appendix G.12)	In Progress.
	Leg deployment test (Appendix G.13)	In progress.
	Low altitude turning drop test (Appendix G.14)	In Progress.
Prototype Testing	Battery test on complete payload (Appendix G.15)	Scheduled.
	Flare maneuver test (Appendix G.16)	Scheduled.
	Landing legs test (Appendix G.17)	Scheduled.
	Weather balloon drop test (Appendix G.18)	Scheduled.
	Shake table test (Appendix G.19)	Scheduled.
Full-Scale Testing	Complete payload test (Appendix G.20)	Scheduled.

Table 4.4 Test Results

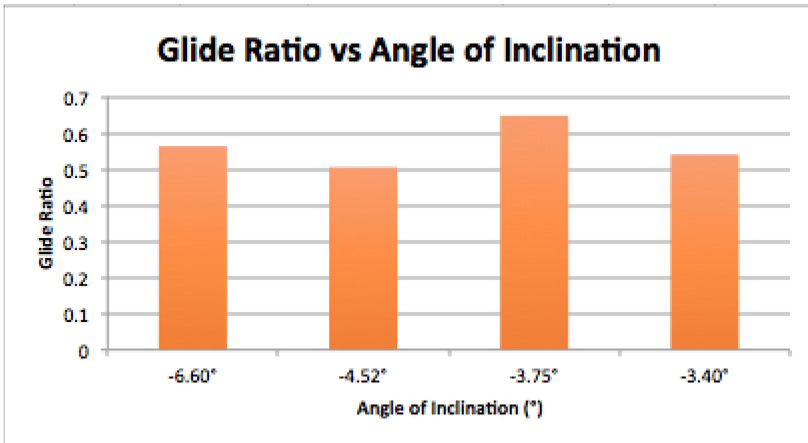

Figure 4.14. Glide Ratio vs. Angle of Inclination

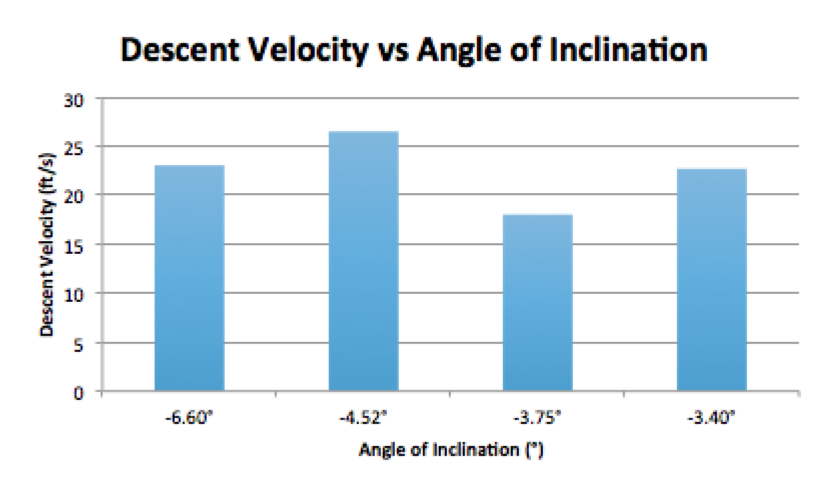

Figure 4.15. Descent Velocity vs. Angle of Inclination

4.5 Safety and Environment (Payload)

4.5.1 Safety and Mission Assurance Analysis

The overall safety of the payload has been supported by both full-scale launches. Payload deployment has been one of the main concerns in the past. Both launches indicate both the potential dangers, but also that the ARES team has taken the proper steps to mitigate these factors. During the first launch, half of the parafoils support lines were ripped from the payload's top. Despite this, the parafoil functioned as a streamer, and actually slowed the descent of the parafoil to the point that it landed after the main body of the rocket did. During the second launch, the parafoil was not wrapped properly during a ground ejection test, leading to some of the support lines being incinerated. This emphasizes the need for ground ejection tests, as the issues was able to be addressed before the main launch, but also shows that the mitigation techniques used by the ARES team have been successful. No team member thus far has been injured or incapacitated in any way while handling the payload or its subsystems. All team members' safety at any subsequent launches will be assured by following the checklists provided in Section 5.1 when handling the payload.

Table 4.8 below is a summary of the major failure modes remaining for the payload. The table lists only those of primary concern, i.e. failure modes most likely to occur or most catastrophic in the event of occurrence. The description of the hazard codes are reprinted here for convenience, in *Tables 4.5- 4.7*.

Severity Definitions			
Severity Classification	**Personnel Safety and Health Risks**	**Facility/Equipment Risks**	**Environmental Risks**
1-Catastrophic	Loss of life or irreversible disabling injury.	Irrecoverable loss of facility, systems, or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2-Critical	Severe injury or severe occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation
3- Marginal	Minor injury or minor occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.

Severity Classification	Personnel Safety and Health Risks	Facility/Equipment Risks	Environmental Risks
4-Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 4.5 Severity Definitions

Probability Definitions		
Description	**Qualitative Definition**	**Quantitative Definition**
A-Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B-Probable	Likely to occur or expected to occur frequently within time.	0.1 ≥ Probability > 0.01
C-Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001
D-Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001 ≥ Probability > 0.000001
E-Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001 ≥ Probability

Table 4.6 Probability Definitions

Level of Risk	Level of Permission Required
High Risk	Highly Undesirable. Documented approval from NAR mentor, faculty supervisor, Safety Officer, and Team Lead.
Medium Risk	Undesirable. Documented approval from Safety Officer, Team Lead, and NAR mentor.
Small Risk	Acceptable. Documented approval from Safety Officer and Team Lead.
Minimal Risk	Acceptable. Documented approval not required but highly recommended.

Table 4.7 Risk Levels

Failure Analysis: Payload					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Lipo batteries	Swelling or leakage of batteries either on the ground or in-flight; chemical fire started by battery	Improper charging of batteries; leaving batteries unattended while charging; failure to properly store batteries when not in use	2C	Only charge batteries according to safety guidelines set by manufacturer; do not leave batteries unattended while charging; only store batteries according to manufacturer guidelines. Place the battery in a fire-proof bag and under a sandbag while charging. Do not overcharge.	4D
Rasberry Pi, Xbee Pro and payload control systems	Inability to correctly steer payload away from ground hazards; insufficient time for the processor to analyze and navigate away from hazards; the payload descends without guidance	Loss of power to Pi or Xbee; bugs in code used to guide payload on descent; loose or faulty wiring	2C	Run code repeatedly to check for bugs; ensure code is working properly at time of full scale launch; check all wiring to ensure none is faulty or exposed; test all batteries and power supplies prior to launch. Set the parafoil to default into a turn, so a loss of control will only result in a in-place spin.	3D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Parafoil and motor deployment and functionality	Ballistic payload; possible loss of payload due to damage from landing; inability to correctly steer payload	Incorrect parafoil packing; failure of rocket separation; breakage or burning of shroud lines or parafoil itself	2B	Double check folding and packing of parafoil prior to launch; ensure parafoil folding is supervised and verified by safety officer; follow all mitigation steps for failed rocket separation. Use ground deployment tests to increase the chances of a successful payload deployment.	3D
Camera and hazard detection software	Poor image processing; inability to detect ground hazards at altitude; partial experimental failure	Power failure to payload and/or camera; bugs in code which prevent proper hazard recognition and response; payload tumbling or instability	1C	Run code repeatedly to check for bugs; ensure code is working properly at time of full scale launch; secure camera to payload and use parafoil to minimize tumbling and instability	3D

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Landing legs	Rough landing of payload; damage to payload or equipment contained within; injury to any surrounding team members or bystanders in event of premature deployment on ground	Failure of landing legs' release mechanisms, either by releasing on the ground or failing to release in air	2D	Test all landing legs' release mechanisms prior to launch to ensure successful deployment; follow safety checklists for payload prep and packing within rocket body	4D

Table 4.8. Failure Analysis of the Payload

4.5.2 Updated Personnel Hazards

Table 4.9 lists the updated personnel hazards of primary concern when handling the payload and its components.

Personnel Hazards: Payload					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Lipo batteries	Serious chemical or fire burns in the event of lipo battery leakage or fire	Failure to follow lipo battery safety guidelines; failure to store or charge lipo batteries according to manufacturer instructions; leaving lipo battery unattended while charging or near source of fire/heat	2C	Follow manufacturer guidelines at all times for proper charging and storage of lipo batteries; do not leave lipo batteries unattended or near sources of fire or heat; wear PPE in case of spill, leakage, or fire	4D
Electric shock	Mild to serious shocks to team members from exposed wiring or hot wiring	Failure to wear appropriate PPE; failure to ensure wires and electronics are not hot before handling; exposed wiring left unprotected or unobserved by team members	2C	Wear rubber gloves when handling hot electronics; do not leave wiring exposed; do not directly handle hot wiring if it may be avoided; follow safety guidelines for electronics prep at all times	3D
Physical injury	Cuts, scrapes, bruises, etc. caused by sharp edges on payload and/or dropping payload on team member or bystander	Failure to wear PPE such as gloves when handling sharp edges; failure to secure payload in a stable position without danger of falling	3C	Always wear PPE when handling sharp edges; do not leave rocket in precarious position (i.e. table edge); do not leave payload unattended	4C

Failure Mode	Hazard	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Uncontrolled Descent	Ballistic payload trajectory. Potential damage to people or possessions.	Improper loading of the payload; Hardware malfunction; Software error.	2B	Use ground ejections tests to decrease the likelihood of the payload being loaded improperly. Set the parafoil to default into a turn, so a loss of control will only result in a in-place spin. Ensure the range safety officer informs bystanders to pay special attention during the launch and descent.	4C

Table 4.9. Personnel Hazards of the Payload

4.5.3 Remaining Environmental Concerns

The primary environmental concerns associated with the payload are discussed in *Table 4.10* below.

Environmental Hazards from Payload					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Chemical Fire	Serious chemical or fire induced burns to surrounding plant and animal life, including team members or bystanders	Failure to follow lipo battery safety guidelines; failure to store or charge lipo batteries according to manufacturer instructions; leaving lipo battery unattended while charging or near source of fire/heat	1C	Follow manufacturer guidelines at all times for proper charging and storage of lipo batteries; do not leave lipo batteries unattended or near sources of fire or heat; wear PPE in case of spill, leakage, or fire	3E
Physical Damage to Crops/ Bystanders	Cuts, bruises, breakage, etc. caused by impact or rough landing of payload on nearby plant or animal life, including team members or bystanders	Failure of parafoil to slow payload and decrease kinetic energy to acceptable levels; failure to heed heads-up warnings and move away from landing zone of payload	2D	Follow safety guidelines for proper folding and packing of parafoil; ensure parafoil deploys properly; keep visual contact with descending payload at all times to avoid getting caught in landing zone	3D
Electronics Fire	Serious or catastrophic burns to nearby plant or animal life, including team and bystanders	Faulty or exposed wiring in payload; hot wiring placed near flammable material; explosive materials such as black power being left unattended near hot electronics	1C	Keep hot electronics away from flammable and explosive materials at all times; double check to ensure no wiring remains exposed prior to launch; follow safety guidelines for electronics and payload prep	3E

Table 4.10. Environmental Hazards of the Payload

5. Launch Operations Procedures

5.1 Checklist

5.1.1 Recovery Preparation

5.1.1.A Ejection Charge Test:

- ❏ Assemble the rocket as if it were to launch. Dummy weights for the payload can be used, and only the motor casing should be in place.
- ❏ Receive permission from the RSO to perform the test and go to the designated area for such a test.
- ❏ Pour in the required amount of black powder into the black powder cup around the e-match and pack the remaining space in the cup with “dog barf ”.
- ❏ Attach at least 10 feet of wire to each e-match wire. The person running the test will stand at the end of the wire, all spectators should stand another 10 feet back.
- ❏ After announcing the test, a countdown from 10 should be completed for each charge.
- ❏ If the drogue parachute and the payload are ejected out of the forward body tube, approximately three feet, then it was a successful test.
- ❏ Use the tested black powder quantity for launch preparations.

5.1.1.B Electronics Bay Preparation and Installation

- ❏ Using the multi-meter, test the voltage from the batteries for a voltage of at least 9.1 V.
- ❏ Connect a battery to the holder and wire the switch and battery to the altimeter. (2X)
- ❏ Turn the altimeters on and listen for the beeps to ensure that the main charge are set to the specified altitudes (700 ft).
- ❏ Turn the altimeters off
- ❏ Check to see if dog tracker is on and accurately relays its position
- ❏ Connect fresh batteries and zip tie all components to the e-bay sled
- ❏ Connect switches to altimeters
- ❏ Connect e-matches to appropriate the main and drogue ports for each altimeter and run the e-matches through the wire access port in the e-bay bulkheads
- ❏ Bolt on e-bay bulkheads to e-bay assembly
- ❏ Check that the switches are not armed.
- ❏ Insert the head of each e-match into a black powder cup attached to the electronics bay bulkheads. Pour in the required amount of black powder around the e-match and pack the remaining space in the cup with “dog barf.”
- ❏ Seal the tops of the cups with tape. Do this for each black powder cup.
- ❏ Seal the wire access ports using putty.
- ❏ Insert the e-bay into the aft facing end of the forward body tube.

- ❏ Align the e-bay inside the body tube to align with the atmospheric, attachment, and switch ports in the forward body tube.
- ❏ Screw in the 4 bolts that secure the e-bay to the body tube.

5.1.1.C Parachute Preparation and Installation

- ❏ Attach the drogue parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ❏ Fold the drogue parachute and shock cord and wrap it inside the parachute protector leaving enough of the shroud line to connect to the quick link attached to the e-bay.
- ❏ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ❏ Connect the drogue parachute shock cord to the forward facing side of the e-bay eye-bolt using a quick link.
- ❏ Slide the wrapped drogue parachute down the forward facing end of the forward body tube. Make sure the buddle can slide with ease in and out of the body tube.
- ❏ Connect the other end of the shock cord to the nose cone eyebolt using a quick-link.

- ❏ Attach the main parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ❏ Fold the main parachute and shock cord and wrap it inside the parachute protector leaving enough of the shroud line to connect to the quick link attached to the e-bay.
- ❏ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ❏ Connect the main parachute shock cord to the aft facing side of the e-bay eye-bolt using a quick link.
- ❏ Slide the wrapped main parachute down the aft facing end of the forward body tube. Make sure the buddle can slide with ease in and out of the body tube.
- ❏ Connect the other end of the shock cord to the motor casing eyebolt using a quick-link.

- ❏ Connect the forward and aft body tubes with shear pins.
- ❏ Connect the nose cone and forward body tube with shear pins after the payload has been loaded.

5.1.2 Motor Preparation

- ❏ Check for dents in the motor casing.
- ❏ Open reloadable motor reload package.
- ❏ Push motor into the casing, forward end first.
- ❏ Screw on the aft enclosure.
- ❏ Screw on the motor retainer.
- ❏ Ensure everything is tight and secure.

- ❏ Once all rivets and shear pins are in place, place the rocket on the ground. Ensure the nose cone is pointed in a direction opposite of any crowds or vehicles.

5.1.3 Setup on Launcher

- ❏ Speak with the RSO to determine which launch pad to set up on.
- ❏ Have the rocket inspected by the RSO.
- ❏ Once approved by the RSO, take the rocket to the pad.
- ❏ Disarm the launch box.
- ❏ Carefully load the rocket onto the launch rail and check to make sure it slides smoothly down the length of the rail.
- ❏ Adjust the pad if necessary.
- ❏ Arm the electronics bay by turning on both switches. Wait to hear chirping from both altimeters.

5.1.4 Igniter Installation

- ❏ Place the igniter inside the motor. Push the igniter into the motor till it hits the top and then secure it in place using the motor cap.
- ❏ Attach the igniter leads to the launch controller.
- ❏ Arm the launch box

5.1.5 Launch Procedure

- ❏ Retreat to the necessary safe distance.
- ❏ Have RSO launch the rocket.
- ❏ Be observant where the rocket goes on ascent and descent

5.1.6 Troubleshooting

- ❏ Follow instructions of the RSO at all times during troubleshooting.
- ❏ If vehicle is on the launch pad, ensure the igniter and launch box are disarmed before approaching.
- ❏ Once vehicle is safely removed from the launch pad and taken back to the team’s onsite workspace, proceed as necessary.
- ❏ If vehicle is not on the launch pad, ensure all black powder charges and other explosives are not armed before handling.
- ❏ Determine the cause of the error or failure mode (i.e. faulty wiring, incorrect packing of payload or parachute, etc.).
- ❏ Isolate the associated part of the payload or launch vehicle for examination.
- ❏ Consult appropriate safety and preparation checklists to ensure preparations were done correctly and completely.

- ❑ If failure cannot be corrected with checklists, consult available resources, including part manuals, NAR mentor, etc., for further information.
- ❑ Repeat as necessary to fix all issues.
- ❑ Once troubleshooting is complete, reassemble rocket and continue with launch prep and launch procedures.

5.1.7 Post-Flight Inspection

- ❑ Recover the rocket and payload. **Caution: MOTOR CASING WILL BE HOT.**
- ❑ Any or all of these may not be recovered in the event of a hazardous landing (water landing, power lines, etc.).
- ❑ Inspect for damage.
- ❑ Wait until the motor casing has cooled. Carry rocket off launching field.
- ❑ Go to the competition tent to have the altimeter read and determine the rocket apogee.
- ❑ Recover the payload data for analysis.

5.2 Safety and Quality Assurance

5.2.1 Data Demonstrating Acceptable Risk Levels

Listed below are the main data points considered of value when determining acceptable risk levels. In all cases, the data confirms that all safety procedures are being followed correctly and effectively.

- To date, 0 team members have been incapacitated or seriously injured while working on the vehicle or payload.
- To date, 0 minor injuries have occurred while handling the vehicle or payload within the team laboratory or in a similar controlled environment.
- To date, 1 - 5 minor injuries have occurred while handling the vehicle or payload at the full-scale launch sites.
- Of those injuries, 0 were serious enough to require immediate medical attention.
- Injuries were in the class of minor cuts, scrapes, or bruises, and did not in any way incapacitate or affect the team members inflicted.
- Injuries were determined to be accidental in cause; i.e. bumping a knee against a table, hand slipping and getting scratched, etc.
- No injuries were determined to be resulting from a lack of adequate safety procedures or general negligence of the team.
- To date, 0 incidents have been recorded where safety negligence led to direct damage to the vehicle or payload.

Given the above data, the safety officer has determined that no team member is at high or unacceptable levels of risk, either in a controlled environment or in a launch environment. It was also determined that all safety checklists are complete and are being followed adequately due to lack of injury due to oversight.

The overall safety rating of the project, based on the data, is currently determined to be a 4D, using the same rating system as the failure mode analyses for the vehicle and payload. This indicates that any safety risks associated with the project itself are currently negligible, and while unlikely, may occur at some point within time, simply accounting for probability. In general terms, the safety officer strongly believes that the ARES team is prepared to launch with minimal or no safety risks to the mission or team.

5.2.2 Risk Assessment for Launch Operations

The risk assessment for ARES launch operations is provided below in *Table 5.4*. Risk assessment follows the stages of launch operations as outlined by the safety checklist; that is, it discusses the individual risk assessment levels for ejection tests, electronics bay preparation, recovery systems preparation, motor preparation, setup on launcher, igniter installation, launch procedures. Post-flight inspection is assumed to be minimal risk levels following a successful flight and is therefore negligible.

For this analysis, black powder and associated risks were left unaddressed. This is a direct consequence of only allowing the team's NAR mentor to handle black powder at all times. Wherever black powder is present, an assumed risk is as well, and therefore it must be treated with extreme caution at all times, even when direct contact is not made.

The criteria for assessing the failure modes are listed below in *Tables 5.1 - 5.3.*

Severity Definitions			
Severity Classification	**Personnel Safety and Health Risks**	**Facility/Equipment Risks**	**Environmental Risks**
1-Catastrophic	Loss of life or irreversible disabling injury.	Irrecoverable loss of facility, systems, or associated hardware.	Irreversible severe environmental damage that violates law and regulation.
2-Critical	Severe injury or severe occupational-related illness.	Major damage to facilities, systems, or equipment.	Reversible environmental damage causing a violation of law or regulation
3- Marginal	Minor injury or minor occupational-related illness.	Minor damage to facilities, systems, or equipment.	Mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.
4-Negligible	First aid injury or occupational-related illness.	Minimal damage to facility, systems, or equipment.	Minimal environmental damage not violating law or regulation.

Table 5.1 Severity Definitions

Probability Definitions		
Description	**Qualitative Definition**	**Quantitative Definition**
A-Frequent	High likelihood to occur immediately or expected to be continuously experienced.	Probability is > 0.1
B-Probable	Likely to occur or expected to occur frequently within time.	0.1 ≥ Probability > 0.01
C-Occasional	Expected to occur several times or occasionally within time.	0.01 ≥ Probability > 0.001
D-Remote	Unlikely to occur, but can be reasonably expected to occur at some point within time.	0.001 ≥ Probability > 0.000001
E-Improbable	Very unlikely to occur and an occurrence is not expected to be experienced within time.	0.000001 ≥ Probability

Table 5.2 Probability Definitions

Level of Risk	Level of Permission Required
High Risk	Highly Undesirable. Documented approval from NAR mentor, faculty supervisor, Safety Officer, and Team Lead.
Medium Risk	Undesirable. Documented approval from Safety Officer, Team Lead, and NAR mentor.
Small Risk	Acceptable. Documented approval from Safety Officer and Team Lead.
Minimal Risk	Acceptable. Documented approval not required but highly recommended.

Table 5.3 Level of Risk

Risk Assessment: Launch Procedures					
Stage	**Hazards or Failure Modes Summary**	**Causes or Factors for Failure Summary**	**Initial Risk**	**Mitigations**	**Post Mitigation Risk**
Ejection tests	Failure of the payload, parafoil or drogue parachute to properly eject; damage to the payload, parafoil or drogue from black powder	Failure of team to properly fit test components; improper packing of drogue parachute or parafoil; inappropriate amount of black powder used for ejection tests	2C	Test fit all components prior to tests; allow safety officer to verify drogue and parafoil packaging; allow only NAR mentor to dispense black powder	3D
Electronics bay prep and installation	Failed altimeter prep and inability to set altitudes; inability to power altimeters; minor shocks to team members from wiring; possible cuts or burns from handling electronics	Team members unable to set altimeters; only dead batteries available to team; wires are left hot and exposed, or electronics are left unsecured	3C	Follow safety checklists at all times to ensure completion of all steps; consult manuals as needed	4D

Stage	Hazards or Failure Modes Summary	Causes or Factors for Failure Summary	Initial Risk	Mitigations	Post Mitigation Risk
Recovery prep and installation	Improper or incomplete deployment of recovery systems; damage to the recovery systems due to improper packing; tangling of shroud lines and/or shock cords	Failure to test fit recovery systems when packed; black powder coming into direct contact with recovery systems and igniting on launch; failure to correctly pack shroud lines and/or shock cords	3D	Always follow safety checklists; double check folding of all parachutes and parafoils; allow safety officer to verify correct folding; test fit all recovery components	4D
Motor prep	Possible accidental ignition or damage of motor in event of careless handling	Dropping the motor, or leaving the motor exposed near a source of fire, heat, or electricity	1E	Only allow the NAR mentor to handle the motor; at all times follow safety checklists and procedures; do not leave motor unattended or place in a precarious position	3E

Stage	Hazards or Failure Modes Summary	Causes or Factors for Failure Summary	Initial Risk	Mitigations	Post Mitigation Risk
Setup on launcher	Improper or incorrect fit of rail buttons on launch rail; damage to vehicle and/or payload due to dropping the rocket while attempting to mount on launch rail	Failure to test fit rail buttons with launch rail; careless handling of rocket by team members	3E	Test fit rail buttons prior to launch; preferably use rail buttons already attached to rocket, a known fit; handle rocket with care at all times	4E
Igniter installation	Failure to properly ignite or premature ignition	Failure to follow safety checklists and procedures for igniter installation	2E	Allow only NAR mentor or similarly experienced person to install igniter; follow safety checklists closely at all times	4E

Stage	Hazards or Failure Modes Summary	Causes or Factors for Failure Summary	Initial Risk	Mitigations	Post Mitigation Risk
Launch procedures	Catastrophic motor failure on launch; failure to ignite motor and leave the launch rail; severe injury to team members due to inability to clear range; lost rocket and/or payload	Faulty or damaged motor; poor or absent connections in launch system electronics; failure to listen for launch warnings; failure to track rocket following launch	1D	Check motor thoroughly for damage prior to installation; follow instructions of RSO at all times during imminent launch; have all team members visually track rocket and/or payload in flight	4D

Table 5.4 Risk Assessment of Launch Procedures

5.2.3 Environmental Concerns

Tables 5.5 and 5.6 below illustrate the environmental hazards presented by the interactions of the rocket with the environment and the environment with the rocket, respectively.

Rocket and Payload Hazards to Environment					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Pollution	Contamination and/or death of nearby plant and animal life; possible contamination of water if leak occurs near water source; possible sickness or serious harm to team members	Paint, epoxy, or other hazardous pollutant materials left unattended or allowed to leak	2C	Ensure hazardous materials are properly stored; avoid using hazardous materials near water; enforce team usage of proper PPE and safety guidelines	2E
Fire	Burns and/or death to any plant and animal life, including team members, within range of the fire	Unexpected firing of motor or detonation of black powder charges under exceptionally dry conditions; ignition of black powder or motor when left unattended; rocket explosion on pad or crash landing	1B	Do not allow handling of motor except by NAR mentor; do not leave black powder or motor unattended without proper storage in explosives container; ensure all launch procedures are followed correctly	1E
Physical plant/crop damage	Minor to major damage to nearby plant life on landing, including broken tree limbs, crops crushed by rocket, etc.	Rough landing or crash of rocket, payload, or nosecone on crops or plant life	3B	Ensure proper parachute deployment and proper function of guided landing systems to minimize potential crash landings	3D

Hazard	Consequence	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Noise	Excessive noise from launch could disturb or harm nearby people and/or animals (emotional distress, hearing damage, etc.)	Use of large motor in close proximity to populated areas	3C	Select launch site based both on size of field and proximity to civilization; avoid choosing sites which may cause disturbance or distress to nearby residents based on noise levels	4E
Chemical Fire	Burns and/or death to any plant and animal life, including team members, within range of the fire, including in a building	Improper charging or storage of the LiPo battery;		Follow proper guidelines for LiPo battery storage and charging	

Table 5.5 Rocket and Payload Hazards to Environment

Environmental Hazards to Rocket and Payload					
Hazard	**Consequence**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Adverse weather (i.e. thunderstorm)	Launch is delayed or cancelled due to weather	Failure to check weather conditions prior to conducting team launches	3A	Check weather prior leading up to launch date to ensure favorable conditions; consider having alternate locations ready in the event of repeated adverse weather	3D

Hazard	Consequence	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Heavy wind	Launch is delayed or cancelled due to wind	Failure to check wind speeds and conditions prior to team launches	3A	Check weather and wind conditions leading up to launch date; consider having alternate locations ready in the event of repeated adverse winds	3D
Excessive landing hazards	Payload is unable to sufficiently steer away from hazards; possible damage to payload on landing; incomplete mission	Failure to secure appropriately sized launch area for rocket	3C	Field is selected according to safe distance guidelines set forth by NAR; clear field of appropriate size is secured for launches; drifting of rocket and payload is kept to a minimum (i.e. low-wind conditions)	3E
Water	Rocket or payload unable to be recovered on water landing	Selection of a launch area in close proximity to a body or bodies of water	3C	Launch only in an appropriately sized field; attempt to avoid launch sites bordered by large bodies of water; conduct launches on low-wind days to ensure minimal drifting of rocket	3E

Hazard	Consequence	Cause	Initial Risk	Mitigation	Post Mitigation Risk
Power lines	Rocket or payload unable to be recovered on power line landing	Selection of a launch area in close proximity to above ground power lines	3C	Launch only in an appropriately sized field; attempt to avoid launch sites with nearby power lines; conduct launches on low-wind days to ensure minimal drifting of rocket	3E

Table 5.6 Environment Hazards to Rocket and Payload

5.2.4 Safety Officer

Safety Officer Contact Information:

Desiree Kiss
Undergraduate in Aerospace Engineering and Mechanics
Email: dmkiss@crimson.ua.edu
Phone: (228) 243-8772

Desiree Kiss is the Safety Officer for the team. It is her responsibility to compose all safety procedures checklists and to ensure that all safety procedures are followed by the team at every launch. This will be verified by her signature on every completed safety procedures checklist. Her signature indicates that she was present at and supervised the preparation of both the rocket and payload at the launch, and that all safety benchmarks for a successful launch were met by the team. She may be contacted in regards to any potential safety concerns or questions about team safety procedures using the information listed above.

6. Project Plan

6.1 Budget Plan

The ARES Team recently finished its purchasing for the full-scale system and payload. With the exception of any unforeseen purchases, the expenses will now be oriented towards travel costs such as hotel fees and van rentals. The materials section of the budget has $1,588.04 remaining, while the travel has $2,500. *Table 6.1* details additional purchases that were not budgeted. Since the team has completed three successful launches since the CDR, two full-scale and one subscale, there were several on-site purchases made at the launch events. With the addition of the second full-scale launch, an extra motor had to be purchased as well. Expedited shipping was again used in the build phase of the full-scale project, increasing total costs.

Component Added	Total Cost
Quick link	$9.80
Electric Match	$7.50
Shock cord protector	$7.00
Chute protector	$10.95
Shock cord	$16.95
Euro to USA plug adapter	$4.99
T plugs	$6.99
Parafoil	$20.40
Additional Motor	$189.95
Coupler	$45.00
Centering Rings	$9.00
Bulkheads	$8.00
E-Bay Shell	$10.00
Black Powder Cups	$0.38
Rail Buttons	$2.50
Shock Cord	$17.50
Parachute Protector	$14.95
Data Link	$22.46
GPS	$200.00
Hinge w/spring	$ 7.20
Torsion Spring 90	$ 8.39
Torsion Spring 180	$ 8.22
Total:	**$628.13**

Table 6.1 Components added to the budget since PDR

All items in *Table 6.1* are added to the itemized budget. In *Table 6.2*, the full, itemized budget is given. The budget does not include the effects of shipping costs because multiple items per purchase order placed, making it difficult to assign the shipping costs to individual items. These expenses are considered in the Funding Plan section (Section 6.2).

Structure						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Ogive Nose Cone	Madcow Rocketry	Improves aerodynamics	$115.00	1	$115.00
	Motor Retainer	Apogee Components		$44.00	1	$44.00
	Motor Case	Apogee Components		$84.69	1	$84.69
	Motor	Apogee Components	Powers rocket ascent	$189.95	3	569.85
	Black Powder	Gander Mountain	Separates stages	$39.99	1	$39.99
:	5.5" Fiberglass Tubes	Madcow Rocketry	Body structures	$150.00	2	$300.00
	Fins		Improves stability	$15.00	4	$60.00
	Motor Tube	Apogee Components	Locks in motor	$70.00	1	$70.00
	Coupler	Madcow Rocketry	Mates body tubes	$45.00	1	$45.00
	Centering Rings	Madcow Rocketry	Centers Motor	$9.00	3	$27.00
	Bulkheads	Madcow Rocketry	Separates Bays	$8.00	8	$64.00
	E-Bay Shell	Performance Hobbies	Protects Electronics	$10.00	1	$10.00
	Black Powder Cups	Home Depot	Holds BP	$0.38	4	$1.52
	Rail Buttons	Railbuttons.c om	Bond to launch rail	$2.50	2	$5.00
	Shock Cord	Chris' Rocket Supplies	Connects parachute to body	$17.50	1	$17.50
	Parachute Protector	Chris' Rocket Supplies	Prevents BP burns	$14.95	1	$14.95
	Data Link	Perfectflite	Data Download	$22.46	1	$22.46
	GPS	Chris' Rocket Supplies	Rocket Tracking	$200.00	1	$200.00
				Structure Total:		**$1,840.96**

Hazard Detection Payload						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Camera	Amazon	Provides data for landing hazard detection	$69.00	1	$69.00
	Solid State Drive	Newegg	Records data	$99.99	1	$99.99
	Battery	Adafruit	Powers payload systems	$24.95	1	$24.95
	LiPo Battery	HobbyKing	Powers payload systems	$29.99	1	$29.99
	Raspberry Pi 2	Adafruit	Processes imaging	$39.95	1	$39.95
	Antenna	Sparkfun	Receives transmissions	$7.95	2	$15.90
	Dongle	Sparkfun		$24.95	2	$49.90
	Half-size Breadboard	Adafruit	Platform for wiring	$5.00	1	$5.00
	Breadboarding Wire Bundle	Adafruit	Wiring	$6.00	1	$6.00
	Pi Cobbler Plus for Pi 2	Adafruit		$6.95	1	$6.95
	Electrical Wiring	Home Depot		$5.00	1	$5.00
	XBee Pro 900	Sparkfun	Signal Transmitter	$109.90	1	$109.90
	DC Barrel Jack	Adafruit		$0.95	1	$0.95
	Interface Cable	Sparkfun		$4.95	2	$9.90
	GPS	Adafruit	Tracking	$39.95	1	$39.95
	USB to TTL Cable	Adafruit	Pi Testing	$9.95	1	$9.95
	Instrument Board	Pololu	Measurements	$27.95	1	$27.95
	Servo Driver	Adafruit	Servo Control	$14.95	1	$14.95
	Lock-Style Solenoid	Adafruit	Securing Payload	$14.95	1	$14.95
	Transistors	Adafruit		$2.50	1	$2.50
	Diodes	Adafruit		$1.50	1	$1.50
	6600mA lipo Pack	Hobbyking	Smaller Battery	$48.95	1	$48.95
	Step Down Voltage Regulator	Pololu		$14.95	1	$14.95
	Lipo Touch Balance Charger	Fancy Cost		$48.75	1	$48.75
	6 ft USB Cable	Amazon Basics	Testing ease	$4.80	1	$4.80

Category	Component	Vendor	Description	Cost per Unit	Quantity	Total Cost
	Large Solenoid	Adafruit	Landing leg release	$29.90	2	$59.80
	Euro to USA plug adapter	Amazon Basics		$4.99	1	$4.99
	T plugs	Amazon Basics		$6.99	1	$6.99
				Hazard Detection Payload Total:		**$774.36**

Guided Descent Payload

Category	Component	Vendor	Description	Cost per Unit	Quantity	Total Cost
Purchase:	Servo Motors	RobotShop	Control payload steering	$50.00	2	$100.00
	Parafoil	HobbyKing	Controlled descent for payload	$20.40	3	$61.20
				Guided Descent Payload Total:		**$161.20**

Recovery

Category	Component	Vendor	Description	Cost per Unit	Quantity	Total Cost
Purchase:	Accelerometers		Measures Acceleration	$45.00	2	$90.00
	Drogue Chute	Fruity Chutes	Stage separation and deceleration	$60.00	1	$60.00
	Hinge	Home Decor Hardware	Attach upper leg to payload	$1.44	10	$14.40
	Torsion Spring (Thigh to Calf)	Grainger	Packs of 6	$8.16	4	$32.64
	Torsion Spring (Calf to Foot)	Grainger	Packs of 6	$8.34	4	$33.36
	3D Printed Landing Legs	The Cube	Main landing support	300.00	1	$300.00
Pre-Owned:	Main Parachute	Fruity Chutes	Rocket body deceleration in descent	$265.00	2	$530.00
				Recovery Total:		**$1,022.61**

Subscale Rocket						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Centering Ring	Madcow Rocketry	Holds Motor Tube	$7.00	2	$14.00
	Fiberglass 4x60 Tube	Madcow Rocketry	Body	$110.00	1	$110.00
	Ogive Nosecone	Madcow Rocketry	Aerodynamics	$65.00	1	$65.00
	Coupler	Madcow Rocketry	Body	$23.00	1	$23.00
	Fiberglass 3x49 tube	Madcow Rocketry	Body	$78.00	1	$78.00
	4” G10 Airframe Plate	Madcow Rocketry	Separates bays	$6.00	6	$36.00
	Stratologger CF	Perfectflite	Altimeter	$48.89	4	$195.56
	Cesaroni L Motor	Chris’ Rocket Supplies	Propulsion	$169.95	1	$169.95
	Quick link	Chris’ Rocket Supplies	Binding	9.80	1	$9.80
	Electric Match	Chris’ Rocket Supplies	Ignition	$7.50	1	$7.50
	Shock cord protector	Chris’ Rocket Supplies	Protects from BP Burns	$7.00	1	$7.00
	Chute protector	Chris’ Rocket Supplies	Protects from BP Burns	$10.95	1	$10.95
	Shock cord	Chris’ Rocket Supplies	Holds it together	$16.95	1	$16.95
Pre-Owned/ Manufactured :	Parachute		Vehicle recovery	$160.00	1	$160.00
				Estimated Subscale Total:		**$903.71**
Safety						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Pre-Owned:	Safety Eyewear	Home Depot	Packs of 4	$19.97	3	$59.91
	Work Gloves	Home Depot		$10.00	3	$30.00
	Plastic Sheeting	Home Depot		$20.97	1	$20.97
	Aprons	Home Depot		$6.00	10	$60.00
				Safety Total:		**$170.88**

Outreach						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Demonstration Supplies	Various		$35.00	1	$35.00
	Model Rocket B Motors	Hobby Linc		$50.19	1	$50.19
	Launch Pad	Hobby Linc		$14.69	1	$14.69
	Model Kits	Hobby Linc		$52.39	3	$157.17
				Outreach Total:		**$257.05**
Travel						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Van Rental	University of Alabama	Travel from Tuscaloosa to Huntsville	$100.00	3	$300.00
	Hotel Costs	Holiday Inn	3 night stay for 11 people	$100.00	12	$1200.00
	Food		Average of $15 per person per meal	$150.00	9	$1350.00
				Travel Total:		**$2,850.00**
				Purchase Total:		$7,290.77
				Pre-Owned Total:		$690.00
				Rocket/Payload Total:		**$3,790.83**
				Project Total:		**$7,980.77**

Table 6.2. Estimated Project Costs

Table 6.3 compares the current expenses in each category to the budgeted expenses from the CDR to compare the team's performance to what was expected. In particular, the Structures and Recovery accounts were over budget as the result of last minute purchases as the build phase of the project went on. These numbers do not reflect shipping costs incurred.

Category	Current Expenses	Budgeted Expenses	Difference
Structures	$1,840.96	$1,438.95	-$402.01
Hazard Detection Payload	$774.36	$920.18	$145.82
Guided Descent Payload	$161.20	$155.80	-$5.40
Recovery	$1,022.61	$720.20	-$302.41
Subscale	$743.71	$851.51	$107.80
Safety	$89.91	$170.88	$80.97
Outreach	$257.05	$500.00	$343.95
Travel	-	$2,850.00	$2,850.00
Total Expenditures:	**$4,889.80**	**Total Remaining in Budget:**	**$2,818.76**

Table 6.3 Current Spending Review

6.2 Funding Plan

The funding plan has remained largely unchanged since the CDR. To date, the funding contributions have come from the Alabama Space Grant Consortium (ASGC) and the University of Alabama Department of Aerospace Engineering and Mechanics. The team sought further funding from the Student Government Association (SGA) in order to cover travel expenses that will be incurred during the competition. This funding will not be received. A travel stipend will be received from Orbital ATK to help with competition expenses. The final amount is not known yet. The team is still projected to be within budget. In the case of a large, unexpected expense that does expend the budget, the team will utilize fundraising efforts. The updated funding plan is in *Table 6.4* below.

Funding Source	Amount	Status
ASGC	$7,650.00	Confirmed
Department of Aerospace Engineering and Mechanics	$650.00	Confirmed
SGA	$2,400.00	Denied
Orbital ATK	Unknown	Confirmed
Fundraising	$500.00	Contingency
Projected Total:	**$8,300.00**	
Confirmed Total:	**$8,300.00**	

Table 6.4 Updated Funding Plan

Table 6.5 shows the expenses charged to each fund and the remaining funds in the account. These numbers include the shipping expenses incurred throughout the project.

Fund Name	Sum	Expenses	Remaining Total
ASGC	$7,650.00	$3,576.12	$4,073.88
Department of Aerospace Engineering and Mechanics	$650.00	$635.83	$14.17
Orbital ATK Travel Stipend	----	----	----

Table 6.5 Updated Fund Totals

6.3 Timeline

Now that the build and testing phase is almost complete, the ARES Team will begin to prepare for the Student Launch competition. Final preparations for travel considerations are being made and should be finalized by the end of March.

A few factors affected the timeline between the CDR and the FRR. A weather delay for the subscale rocket launch pushed the launch window to the following weekend, delaying the full-scale build. The original full - scale launch date was also moved back one week by the hosting rocketry club.

The team also added another full - scale launch, which was successful, on March 5th as a chance to test the payload deployment again. Software development is still being refined, although the expected completion date has passed. This will be complete by the LRR.

The updated Gantt Chart is below in *Figure 6.1*.

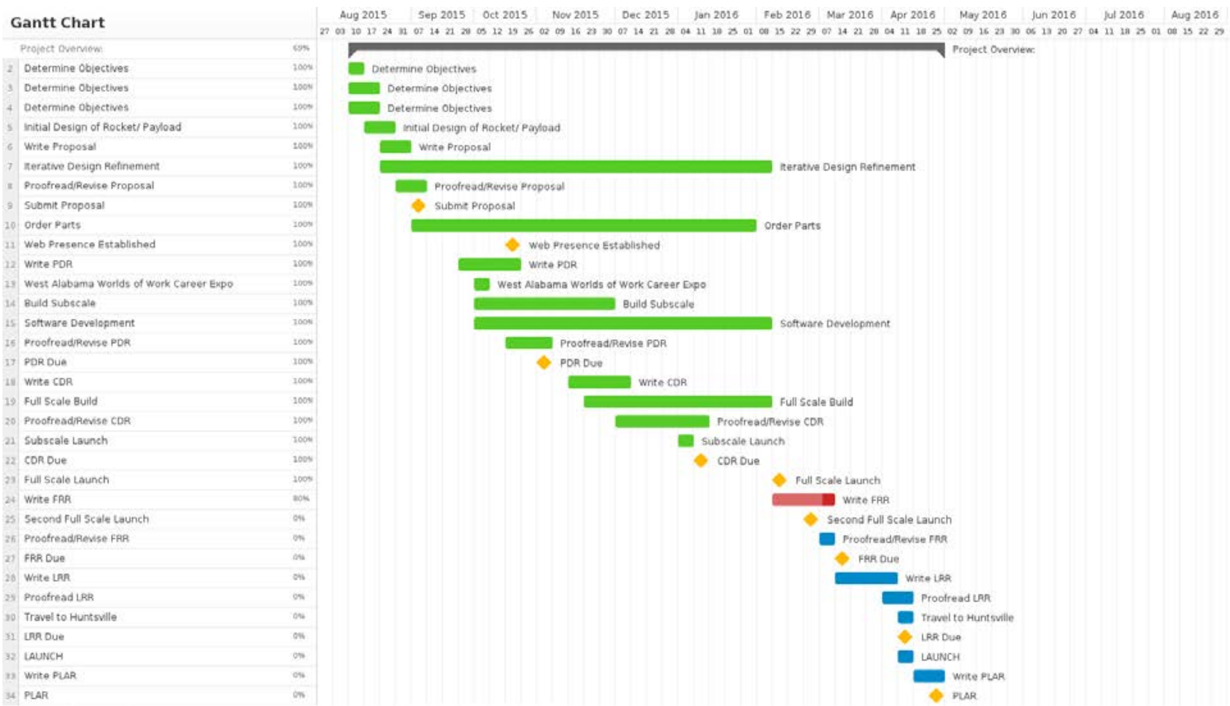

Figure 6.1 - Overall Project Gantt Chart

6.4 Educational Engagement Plan and Status

Although the team met and exceeded the required number of students reached through direct educational engagement in the fall, maintaining a presence in the Tuscaloosa community and in the schools is an important focus for the team.

6.4.1 Completed Events

The team has coordinated and attended many events that have reached a variety of students who may not have otherwise been exposed to rocketry. A complete list of outreach events can be seen in *Table 6.6* below.

Name of Event	Date(s)	Number of Students Reached	Grades of Students	Direct or Indirect
Get on Board Day	8/27/2015	211	12+	Indirect
Boy Scouts	9/22/2015, 10/6/2015	18	5-9	Direct
E-Day	10/1/2015	186	5-9, 10-12	Indirect
West Alabama Works WOW Expo	10/8/2015, 10/9/2015	573	5-9, 10-12, 12+, educators	Indirect
Northridge High School	10/23/2015, 11/13/2015	25	10-12	Direct
Hillcrest High School	10/29/2015	50	10-12	Direct
Al’s Pal’s	11/9/2015, 11/10/2015, 11/12/2015	270	1-5	Direct
Girl Scouts “Women in Science” Day	11/14/2015	130	1-5, 5-9	Direct
Northridge High School	2/25/2016	19	10-12	Direct
SEDS Tuscaloosa Rocketry Challenge	2/25/2016, 3/2/2016, 3/3/2016	71 See *6.7* for details	6-8	Direct

Table 6.6 Completed Outreach Events

6.4.2 Collaboration

To reach the largest variety of students, the ARES team partnered with many local organizations, including the Girl Scouts, Boy Scouts, Al’s Pals, and Students for the Exploration and Development of Space (SEDS).

The University of Alabama chapter of SEDS organized the Tuscaloosa Rocketry Challenge (TRC)- a lecture series and bottle rocket competition among 3 local middle schools. For three separate weeks- one in February and two in March- members of SEDS as well as the ARES team visited one of the three local middle schools, taught lectures about space and rocketry, and helped the students design and build a bottle rocket. These lessons gave a brief history of space exploration and rocketry, and taught about the basic principles behind the success of a bottle rocket. These lectures were presented in a way that engaged the students, showing them that science is something creative and fun.

Below is a table of two of the three schools that participated in the Tuscaloosa Rocketry Challenge, and the outreach information regarding these schools.

School Name	Dates	Number of Students	Grades
Hillcrest Middle School	2/25/2016	21	6
Duncanville Middle School	3/2/2016, 3/3/2016	50	6-8

Table 6.7 TRC Participating Schools

6.4.2 Outreach Sustainability

A priority of the team regarding outreach, is to continue and build upon it, rather than starting over every year. In order to do this, the team has fostered connections with organizations and schools to partner with regularly even once this year has passed.

While the team reached a large number of students, there were many schools who wanted the team to visit, but time or logistics made it difficult to work out. The contact information for the teachers at these schools will be passed down to future teams so that further outreach opportunities are available to more students.

6.4.3 Social Media

In an effort to keep people up to date on the team's work on the project, the team frequently posts pictures and updates on their Facebook, Twitter, and Instagram accounts. All documentation, as well as general information is available on the ARES website. Below is a table of the social media platforms that the team utilizes to engage to public.

Platform	Name
Website	ares.cs.ua.edu
Facebook	Alabama Rocket Engineering Systems
Instagram	@alabama_rocketry
Twitter	@alabamarocketry

Table 6.8 Social Media Platforms

7. Conclusion

In conclusion, after the successful construction of the full scale launch vehicle and a successful full scale test flight, the ARES Team feels very confident in their ability to produce a successful launch on the competition day in Huntsville.

Appendix A - Milestone Review Flysheet

Milestone Review Flysheet

Institution	The University of Alabama
Milestone	Flight Readiness Review

Vehicle Properties	
Total Length (in)	93
Diameter (in)	5.5
Gross Lift Off Weigh (lb)	38.4
Airframe Material	Fiberglass
Fin Material	Fiberglass
Drag Coefficient	0.453

Motor Properties	
Motor Manufacturer	Cesaroni Technology Inc.
Motor Designation	L851
Max/Average Thrust (lb)	222.5 / 190.9
Total Impulse (lbf-s)	828
Motor Mass Before/After Burn(kg)	3.79 / 1.59
Liftoff Thrust (lb)	129.5

Stability Analysis	
Center of Pressure (in from nose)	68.27
Center of Gravity (in from nose)	56.4
Static Stability Margin	2.14 calibers
Static Stability Margin (off launch rail)	2.02 calibers
Thrust-to-Weight Ratio	4.97
Rail Size and Length (in)	144
Rail Exit Velocity (ft/s)	55.8

Ascent Analysis	
Maximum Velocity (ft/s)	562
Maximum Mach Number	0.5
Maximum Acceleration (ft/s^2)	158
Target Apogee (From Simulations)	4874
Stable Velocity (ft/s)	37.9
Distance to Stable Velocity (ft)	5.53

Recovery System Properties				
Dogue Parachute				
Manufacturer/Model	Giant Leap Rocketry/TAC-1			
Size (in)	26			
Altitude at Deployment (ft)			Apogee	
Velocity at Deployment (ft/s)			2.77	
Terminal Velocity (ft/s)			73.05	
Recovery Harness Material			Nylon	
Harness Size/Thickness (in)			0.625	
Recovery Harness Length (ft)			50	
Harness/Airframe Interfaces	Parachute harness will be secured to an eye bolt on the electronics bay bulk plate			
Kinetic Energy of Each Section (Ft-lbs)	Nose Cone	Forward	Aft	Total
	336.32	952.65	901.08	1863.9

Recovery System Properties				
Main Parachute				
Manufacturer/Model	Giant Leap Rocketry/TAC-1			
Size (in)	120			
Altitude at Deployment (ft)			700	
Velocity at Deployment (ft/s)			73.05	
Terminal Velocity (ft/s)			14.49	
Recovery Harness Material			Nylon	
Harness Size/Thickness (in)			0.625	
Recovery Harness Length (ft)			50	
Harness/Airframe Interfaces	Parachute harness will be secured to eye bolts on the electronics bay bulk plate and aft section bulk plate			
Kinetic Energy of Each Section (Ft-lbs)	Nose Cone	Forward	Aft	Total
	13.23	37.49	35.69	73.36

Recovery Electonics	
Altimeter(s)/Timer(s) (Make/Model)	Perfectflite Stratologger
Redundancy Plan	Team will use two altimeters to ensure ignition of black powder charges
Pad Stay Time (Launch Configuration)	1 hour and 30 minutes

Recovery Electonics	
Rocket Locators (Make/Model)	Adafruit Ultimate GPS Breakout
Transmitting Frequencies	900 Hz
Black Powder Mass Drogue Chute (grams)	4
Black Powder Mass Main Chute (grams)	4

Milestone Review Flysheet

Institution	The University of Alabama	Milestone	Flight Readiness Review

Payload

	Overview
Payload 1	Payload 1 will be a landing hazards detection system. This system will use a camera to take images of the ground during descent and analyze these images to detect landing hazards.
	Overview
Payload 2	Payload 2 will be a guided descent system. This system will use the data from the landing hazards detection system and the Raspberry Pi to control servo motors, which will in turn control the payload's parafoil.

Test Plans, Status, and Results

Ejection Charge Tests	The team plans to use ground testing of the black powder charges to ensure the charge will produce the correct pressure to eject the parachutes. The test will be a static ignition of full scale charges at the Pheonix Missile Works launch area.
Sub-scale Test Flights	The team built and tested a sub-scale launch vehicle with a scaled payload, weight, and motor. The sub-scale model was designed as close as possible to the full scale.
Full-scale Test Flights	The team will test all sub-systems and components of the full scale rocket, and at least one full scale mission will be flown. Full scale flights will provide the team with data on altitude, stability, and performance of the recovery system of the rocket.

Milestone Review Flysheet

Institution	The University of Alabama	Milestone	Flight Readiness Review

Additional Comments

Appendix B - Launch Preparation Checklist and Procedures

Ejection Charge Test:

- ❑ Build the rocket as if it were to launch. Dummy weights for the payload can be used, and only the motor casing should be in place.
- ❑ Build the squibs (see Electronics Bay Prep Checklist) for deployment of the parachute and separation of the payload bay. Instead wiring the squibs to the electronics bay run them through the switch holes in the electronics body tube.
- ❑ Receive permission from the RSO to perform the test and go to the designated area for such a test.
- ❑ Attach 10 feet of wire to each e-match wire. The person running the test will stand at the end of the wire, all spectators should stand another 10 feet back.
- ❑ After announcing the test, a countdown from 10 should be completed for each charge.
- ❑ If the parachute is pulled out between the electronics and booster bay, approximately three feet, then it was a successful test. The three feet rule will be used to deem the payload separation successful.

Electronics Bay Preparation Checklist:

- ❑ Using the multi-meter, test the voltage from the batteries for a voltage of at least 9.1 V.
- ❑ Using the multi-meter, test the resistance of the two e-matches to be at least 1 Ω.
- ❑ Connect a battery to the holder and wire the switch and battery to the altimeter.
- ❑ Turn the altimeter on and listen for the beeps to ensure that the drogue and main charge are set to the specified altitudes.
  Drogue/Payload: _____, Main: _______
- ❑ Turn the altimeters off
- ❑ Connect a fresh battery and zip tie it to the sled
- ❑ Use the cup attached to the electronics bay and place the head of the e-match just inside the bottom of the cup. Pour in the required amount of black powder around the e-match and seal the top. Be sure to mark each cup as the drogue or main.
- ❑ Run the main e-match through the hole in the bulk plate.
- ❑ Tape the e-match down and seal the hole using putty.
- ❑ Cut the e-matches so that they are 1 inch longer than is required.
- ❑ Allow no exposed wiring to show.
- ❑ Connect the e-match to the altimeters in the main port.
- ❑ Put the coupler/body tube between the drogue bulk plate and the electronics in the bay.
- ❑ Use the cup attached to the electronics bay and place the head of the e-match just inside the bottom of the cup. Pour in the required amount of black powder around the e-match and seal the top. Be sure to mark each cup as the drogue or main.
- ❑ Run the main e-match through the hole in the bulk plate.
- ❑ Tape the e-match down and seal the hole using putty.

- ❑ Cut the e-matches so that they are 1 inch longer than is required.
- ❑ Allow no exposed wiring to show.
- ❑ Connect the e-match to the altimeters in the drogue port.
- ❑ Place the drogue bulk plate on the threaded rods and begin to work it into place. Ensure the belt is aligned with the switch holes in the body tube.
- ❑ Place the bulk plate on the coupler and bolt it together.

Motor Loading Procedures Checklist:

- ❑ Check for dents in the motor casing.
- ❑ Open reloadable motor reload package.
- ❑ Push motor into the casing, forward end first.
- ❑ Screw on the aft enclosure.

Parachute Prep Checklist:

- ❑ Fold the parachute so that all the shroud lines are aligned.

- ❑ Lay the shroud lines inside the parachute so that just enough is exposed to attach to a quick link.
- ❑ Attach the quick link.

- ❑ Fold the parachute while continuing running a forearm over the fabric to force out air from the parachute.
- ❑ Fold to a small bundle.

- ❑ Place the parachute protector down and pull the protected portion of the shock cord through the cut in the fabric so that no unprotected portion is exposed towards the black powder end.
- ❑ Loop the remaining shock cord so that only enough needed to connect to the other eyebolt is exposed.

❏ Place/Connect the parachute to the shock cord on top of this bundle.

❏ Fold two ends of the parachute protector over the parachute.

- ❏ Wrap the burrito! Try to take one end of the parachute protector and pull the parachute inside to the point where it is completely covered.

- ❏ Roll.

- ❏ Insert the burrito into the body tube and connect the necessary quick-links.

- ❏ Now repeat all these steps for the other parachute and attach again to the necessary eyebolts in the bulkheads. (The "Burrito Method," illustrated above is applied for the drogue parachute in the pictures.)

Recovery Prep Checklist:

- ❑ Fold the drogue parachute and wrap it leaving enough of the shroud line to connect to the quick link.
- ❑ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ❑ Attach the parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ❑ Connect the parachute shock cord to the coupler eye-bolt using a quick link.
- ❑ Fold the shock cords to the point just below the parachute quick link, tape together using one layer of painters tape.
- ❑ Put dog barf in the parachute bay before sliding the drogue parachute and shock cord into the parachute bay, then place more dog barf in the bay prior to sliding the electronics coupler in place.
- ❑ Bolt the forward electronics bay bulk plate in place.
- ❑ Fold the main parachute and wrap it leaving enough of the shroud line to connect to the quick link.
- ❑ Prepare electronics bay as outlined; ensure it is secure on both ends.
- ❑ Attach the parachute shroud lines and parachute protector using a quick link to the desired point on the shock cord.
- ❑ Connect the parachute shock cord to the coupler eye-bolt using a quick link.
- ❑ Fold the shock cords to the point just below the parachute quick link, tape together using one layer of painters tape.
- ❑ Put dog barf in the parachute bay before sliding the main parachute and shock cord into the parachute bay, then place more dog barf in the bay prior to sliding the electronics coupler in place.
- ❑ Bolt the aft electronics bay bulk plate in place.
- ❑ Connect the two body tubes with shear pins.

Motor Installment Procedures:

- ❑ Once all rivets and shear pins are in place, place the rocket on the ground. Ensure the nose cone is pointed in a direction opposite of any crowds or vehicles.
- ❑ Push the motor into place.
- ❑ Screw on the motor retainer.
- ❑ Ensure everything is tight and secure.

Setup on Launcher and Igniter Installation Procedures:

- ❑ Arrive at the selected launch site.
- ❑ Speak with the RSO to determine where to set up the launch pad.
- ❑ Place the pad in the specified location.
- ❑ Have the rocket inspected by the RSO.
- ❑ Once approved by the RSO, take the rocket to the pad.

- ❏ Disarm the launch box.
- ❏ Carefully load the rocket onto the launch rail and check to make sure it slides smoothly down the length of the rail.
- ❏ Adjust the pad if necessary.
- ❏ Arm the electronics bay. Wait to hear chirping from both altimeters.
- ❏ Place the igniter inside the motor. Push the igniter into the motor till it hits the top and then secure it in place using the motor cap.
- ❏ Attach the igniter leads to the launch controller.

Launch and Post-Flight Inspection Procedures:

- ❏ Retreat to the necessary safe distance.
- ❏ Launch.
- ❏ Recover the rocket, nose cone, and payload. **Caution: MOTOR CASING WILL BE HOT.**
- ❏ Any or all of these may not be recovered in the event of a hazardous landing (water landing, power lines, etc.).
- ❏ Inspect for damage.
- ❏ Wait until the motor casing has cooled. Remove it and then clean it thoroughly.
- ❏ Go to the competition tent to have the altimeter read and determine the rocket apogee. For the subscale and full scale launches, the altimeter will be read by team members.
- ❏ Recover the payload data for analysis.

Troubleshooting Procedures:

- ❏ Follow instructions of the RSO at all times during troubleshooting.
- ❏ If vehicle is on the launch pad, ensure the igniter and launch box are disarmed before approaching.
- ❏ Once vehicle is safely removed from the launch pad and taken back to the team's onsite workspace, proceed as necessary.
- ❏ If vehicle is not on the launch pad, ensure all black powder charges and other explosives are not armed before handling.
- ❏ Determine the cause of the error or failure mode (i.e. faulty wiring, incorrect packing of payload or parachute, etc.).
- ❏ Isolate the associated part of the payload or launch vehicle for examination.
- ❏ Consult appropriate safety and preparation checklists to ensure preparations were done correctly and completely.
- ❏ If failure cannot be corrected with checklists, consult available resources, including part manuals, NAR mentor, etc., for further information.
- ❏ Repeat as necessary to fix all issues.
- ❏ Once troubleshooting is complete, reassemble rocket and continue with launch prep and launch procedures.

Safety Officer Signature for Checklists and Procedures:
X____

Appendix C - Safety Data Sheets

C.1 ProFire Igniter

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MATERIAL SAFETY DATA SHEET

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ProFire Igniter

1.0 PRODUCT / COMPANY IDENTIFICATION

Product Name:	ProFire Igniter
Synonyms:	Igniter, Initiator
Proper Shipping Name:	Igniters
Part Number:	INI-150
Product Use:	Igniter for solid fuel rocket motor
Manufacturer:	Cesaroni Technology Inc. P.O. Box 246 2561 Stouffville Rd. Gormley, Ont. Canada L0H 1G0

Telephone Numbers:

Product Information: 1-905-887-2370

24 Hour Emergency Telephone Number: 1-613-996-6666 (CANUTEC)

2.0 COMPOSITION / INFORMATION ON INGREDIENTS

Overdip composition

Ingredient Name	CAS Number	Percentage
Barium chromate	10294-40-3	31-32 %
Magnesium powder	7439-95-4	42-43 %
Viton fluoroelastomer	n/a	26-27 %

3.0 HAZARDS IDENTIFICATION

Emergency Overview:

The igniter functions by burning rapidly at high temperature, releasing hot gas and particles that ignite the propellant of a rocket motor when in close proximity. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced personnel in accordance with all applicable federal, state and local laws and regulations.

General Appearance:

Cardboard tubes containing one igniter. Igniter has coiled wire leads terminating in the ignition device itself. Ignition device consists of a small electrical initiator (fuse head) dipped in a rubbery, silver-grey composition. All parts are essentially odourless solids, though trace odors of process solvents may be present.

Potential Health Effects:

Eye:
Not a likely route of exposure. May cause eye irritation.

Skin:
Not a likely route of exposure. Low hazard for usual industrial handling.

Ingestion:
Not a likely route of exposure.

Inhalation:
Not a likely route of exposure. May cause respiratory tract irritation.

4.0 FIRST AID MEASURES

Eyes:
Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin:
Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists.

Ingestion:
Induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

Inhalation:
Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Burns: Burns can be treated as per normal first aid procedures.

5.0 FIRE FIGHTING MEASURES

Extinguishing Media:
In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam to contain surrounding fire.

Exposure Hazards During Fire:
Exposure to extreme heat may cause ignition.

Combustion Products from Fire:
During a fire, irritating and toxic gases may be generated by thermal decomposition or combustion.

Fire Fighting Procedures:
Keep all persons and hazardous materials away. Allow material to burn itself out. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.

Special Instructions / Notes:
Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

6.0 ACCIDENTAL RELEASE MEASURES

Safeguards (Personnel):

Spills: Clean up spills immediately. Replace articles in packaging and boxes and seal securely. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Sweep or scoop up using non-sparking, non-static producing tools.

7.0 HANDLING AND STORAGE

Handling: Keep away from heat, sparks and flame. Avoid contamination. Do not get in eyes, on skin or on clothing. Do not taste or swallow. Avoid prolonged or repeated contact of black powder with skin.

Storage: Store in a cool, dry place away from sources of heat, spark or flame. Keep in shipping packaging when not in use.

8.0 EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Controls:
Use adequate explosion proof ventilation to keep airborne concentrations low. All equipment and working surfaces must be grounded.

Personal Protective Equipment:

Eyes:
Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin:
Wear appropriate gloves to prevent skin exposure if handling pellets.

Clothing:

Wear appropriate protective clothing to prevent skin exposure if handling pellets. Clothing should be appropriate for handling pyrotechnic substances.

Respirators:

A respirator is not typically necessary. Follow the OSHA respirator regulations found in 29CFR1910.134 or European Standard EN 149. Always use a NIOSH or European Standard EN 149 approved respirator when necessary.

9.0 PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	solid
Appearance:	Rubbery silver-grey composition
Odour:	May have residual odor of process solvents.
Odour Threshold:	Not available.
pH:	6.0-8.0
Vapour Pressure:	Not available.
Vapour Density:	Not available.
Viscosity:	Not available.
Evaporation Rate:	Not available.
Boiling Point:	Not available.
Freezing/Melting Point:	Not available.
Coefficient of water/oil distribution:	Not available.
Autoignition Temperature:	Approximately 285°C (550°F).
Flash Point:	Not available.
Explosion Limits, lower (LEL):	Not available.
Explosion Limits, upper (UEL):	Not available.
Sensitivity to Mechanical Impact:	Composition can be ignited by impact
Sensitivity to Static Discharge:	Composition – low. Initiator may be activated by static discharge
Decomposition Temperature:	Not available.
Solubility in water:	soluble in water
Specific Gravity/Density:	1.7-2.1
Molecular Formula:	Not applicable.
Molecular Weight:	Not available.

10.0 STABILITY AND REACTIVITY

Chemical Stability:

Stable under normal temperatures and pressures.

Conditions to Avoid:

Heat, static electricity, friction, impact

Incompatibilities with Other Materials:

Combustible or flammable materials, explosive materials

Hazardous Products Of Decomposition:

Oxides and fluorides of barium, magnesium. Chromium.

Hazardous Polymerization:

Will not occur.

11.0 TOXICOLOGICAL INFORMATION

Routes of Entry:

Skin contact – not likely
Skin absorption – not likely
Eye contact – not likely
Inhalation – not likely
Ingestion – not likely

Effects of Acute Exposure to Product:

No data available

Effects of Chronic Exposure to Product:

No data available

Exposure Limits:

Overdip composition

Ingredient Name	CAS Number	OSHA PEL	ACGIH TLV
Barium chromate	10294-40-3		
Magnesium powder	7439-95-4		
Viton fluoroelastomer	n/a		

Irritancy of the Product:
No data available
Sensitization to the Product:
No data available
Carcinogenicity:
Not listed by IARC, NTP, or OSHA
Reproductive Toxicity:
No data available
Teratogenicity:
No data available
Mutagenicity:
No data available
Toxically Synergistic Products:
No data available
LD50:
No data available

12.0 ECOLOGICAL INFORMATION

Environmental Data:
Ecotoxicity Data:
Not determined.
EcoFaTE Data:
Not determined.

13.0 DISPOSAL CONSIDERATIONS

Product As Sold: Pack firmly in hole in ground with nozzle pointing up. Ignite motor electrically from a safe distance and wait 5 minutes before approaching. Dispose of spent components in inert trash.

Product Packaging: Dispose of used packaging materials in inert trash.
Special Considerations: Consult local regulations about disposal of explosive materials.

14.0 TRANSPORT INFORMATION

Shipping Information – Canada

TDG Classification: Class 1.4 Explosive
Proper Shipping Name: Igniters
UN Number: 0454
UN Classification Code: 1.4 S
Packing Group: II
UN Packing Instruction: 142

Shipping Information - USA / IATA / IMO

Proper Shipping Name: Igniters
UN Number: 0454
UN Classification Code: 1.4 S
US DOT Classification Reference Number: EX2002100114
DOT / IMO / IATA Label: Class 1 – Explosive – Division 1.4 S

15.0 REGULATORY INFORMATION

Canada

This product has been classified according to the hazard criteria of the Canadian Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

WHMIS Classification: Not Controlled (explosive)

CAS# 10294-40-3 ($BaCrO_4$) is listed on Canada's DSL List.
CAS# 10294-40-3 ($BaCrO_4$) is not listed on Canada's Ingredient Disclosure List.
CAS# 7439-95-4 (Mg) is listed on Canada's DSL List.
CAS# 7439-95-4 (Mg) is not listed on Canada's Ingredient Disclosure List.

Canadian Explosives Classification: Class 6.1
This product is an authorized explosive in Canada. (File # XP 2050-C50 03091601)

This product may be considered "Controlled Good" in Canada under the Controlled Goods Regulations.

United States of America

TSCA Inventory Status:

CAS# 10294-40-3 ($BaCrO_4$) is listed on the TSCA inventory.
CAS# 7439-95-4 (Mg) is listed on the TSCA inventory

Hazardous Chemical Lists

CERCLA Hazardous Substance (40 CFR 302.4)	No
SARA Extremely Hazardous Substance (40CFR 355)	No
SARA Toxic Chemical (40CFR 372.65)	No

European/International Regulations

The product on this MSDS, or all its components, is included on the following countries' chemical inventories:
EINECS – European Inventory of Existing Commercial Chemical Substances

European Labelling in Accordance with EC Directives

Hazard Symbols: Explosive.

Risk Phrases:

R 2	Risk of explosion by shock, friction, fire or other sources of ignition.
R 44	Risk of explosion if heated under confinement.

Safety Phrases:

S 1/2	Keep locked up and out of the reach of children.
S 8	Keep container dry.
S 15	Keep away from heat.
S 16	Keep away from sources of ignition – No smoking.
S 17	Keep away from combustible material.
S 18	Handle and open container with care.
S 33	Take precautionary measures against static discharges.
S 41	In case of fire and/or explosion do not breathe fumes.

16.0 OTHER INFORMATION

US DoD Hazard Characteristic Code (HCC): E2 (Explosives, Low Risk)

MSDS Prepared by:

Regulatory Affairs Department
Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, ON
Canada L0H 1G0

Telephone: 905-887-2370 x239
Fax: 905-887-2375
Web Site: www.cesaronitech.com www.Pro38.com

C.2 ProX Rocket Motor Reload Kits

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MATERIAL SAFETY DATA SHEET

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ProX Rocket Motor Reload Kits & Fuel Grains

1.0 PRODUCT / COMPANY IDENTIFICATION

Product Name: Pro29, Pro38, Pro54, Pro75, and Pro98 Rocket Motor Reload Kits
Synonyms: Rocket Motor
Proper Shipping Name: Articles, Explosive, N.O.S. (Ammonium Perchlorate)
Part Numbers: Reload kits: P29R-Y-#G-XX, P38R-Y-#G-XX, P54R-Y-#G-XX, P29R-Y-#GXL-XX, P38R-Y-#GXL-XX, P54R-Y-#GXL-XX,
Propellant grains: P75AC-PG-XX, P98AC-PG-XX, P98AC-MB-PG-XX
Where: Y = reload type (A = adjustable delay, C = C-slot)
\# = number of grains &
XX = propellant type

Product Use: Solid fuel motor for propelling rockets

Manufacturer: Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, Ont.
Canada L0H 1G0

Telephone Numbers:
Product Information: 1-905-887-2370
24 Hour Emergency Telephone Number: 1-613-996-6666 (CANUTEC)

2.0 COMPOSITION / INFORMATION ON INGREDIENTS

Propellant

Ingredient Name	CAS Number	Percentage
Ammonium Perchlorate	7790-98-9	40-85 %
Metal Powders		1-45 %
Synthetic Rubber		10-30 %

Black Powder Ignition pellet

Ingredient Name	CAS Number	Percentage
Potassium Nitrate	7757-79-1	70-76 %
Charcoal	n/a	8-18 %
Sulphur	7704-34-9	9-20 %
Graphite	7782-42-5	trace

3.0 HAZARDS IDENTIFICATION

Emergency Overview:
There articles contain cylinders of ammonium perchlorate composite propellant, encased in inert plastic parts. The forward closure also contains a few grams of black powder. ProX Rocket motor reload kits are classified as explosives, and may cause serious injury, including death if used improperly. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced personnel in accordance with all applicable federal, state and local laws and regulations. Avoid inhaling exhaust products.

General Appearance:
Cardboard tubes contain various plastic parts. Inside the plastic tube are cylinders of composite propellant (rocket fuel). The forward closure also contains a small quantity of black powder. All parts are odourless solids.

Potential Health Effects:

Eye:
Not a likely route of exposure. May cause eye irritation.

Skin:
Not a likely route of exposure. Low hazard for usual industrial/hobby handling.

Ingestion:
Not a likely route of exposure.

Inhalation:
Not a likely route of exposure. May cause respiratory tract irritation. Do not inhale exhaust products.

4.0 FIRST AID MEASURES

Eyes:
Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin:
Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists.

Ingestion:
Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

Inhalation:
Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

Burns: Burns can be treated as per normal first aid procedures.

5.0 FIRE FIGHTING MEASURES

Extinguishing Media:
In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam to contain surrounding fire.

Exposure Hazards During Fire:
Exposure to extreme heat may cause ignition.

Combustion Products from Fire:
During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.

Fire Fighting Procedures:
Keep all persons and hazardous materials away. Allow material to burn itself out. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.

Special Instructions / Notes:
These articles burn rapidly and generate a significant flame for a short period of time. Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement. Do not inhale exhaust products.

6.0 ACCIDENTAL RELEASE MEASURES

Safeguards (Personnel):

Spills: Clean up spills immediately. Replace articles in packaging and boxes and seal securely. Sweep or scoop up using non-sparking tools.

7.0 HANDLING AND STORAGE

Handling: Keep away from heat, sparks and flame. Avoid contamination. Do not get in eyes, on skin or on clothing. Do not taste or swallow. Avoid prolonged or repeated contact with skin. Follow manufacturer's instructions for use.

Storage: Store in a cool, dry place away from sources of heat, spark or flame. Keep in shipping packaging when not in use.

8.0 EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Controls:
Use adequate explosion proof ventilation to keep airborne concentrations low. All equipment and working surfaces must be grounded.

Personal Protective Equipment:

Eyes:
Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.

Skin:
Clothing should be appropriate for handling pyrotechnic substances.

Clothing:
Clothing should be appropriate for handling pyrotechnic substances.

Respirators:
A respirator is not typically necessary. Follow the OSHA respirator regulations found in 29CFR1910.134 or European Standard EN 149. Always use a NIOSH or European Standard EN 149 approved respirator when necessary.

9.0 PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	solid
Appearance:	rubber cylinders inside plastic parts
Odour:	none
Odour Threshold:	Not available.
pH:	Not available.
Vapour Pressure:	Not available.
Vapour Density:	Not available.
Viscosity:	Not available.
Evaporation Rate:	Not available.
Boiling Point:	Not available.
Freezing/Melting Point:	Not available.
Coefficient of water/oil distribution:	Not available.
Autoignition Temperature:	280°C
Flash Point:	Not available.
Explosion Limits, lower (LEL):	Not available.
Explosion Limits, upper (UEL):	Not available.
Sensitivity to Mechanical Impact:	unprotected black powder can be ignited by impact
Sensitivity to Static Discharge:	unprotected black powder can be ignited by static discharge
Decomposition Temperature:	> 400°C
Solubility in water:	black powder is soluble in water
Specific Gravity/Density:	black powder = 1.7-2.1 Propellant = not available
Molecular Formula:	Not applicable
Molecular Weight:	Not applicable.

10.0 STABILITY AND REACTIVITY

Chemical Stability:
Stable under normal temperatures and pressures.

Conditions to Avoid:
Heat, static electricity, friction, impact

Incompatibilities with Other Materials:
Combustible or flammable materials, explosive materials

Hazardous Products Of Decomposition:
Oxides of nitrogen

Hazardous Polymerization:
Will not occur.

11.0 TOXICOLOGICAL INFORMATION

Routes of Entry:
Skin contact – not likely
Skin absorption – not likely
Eye contact – not likely
Inhalation – not likely
Ingestion – not likely

Effects of Acute Exposure to Product:
No data available

Effects of Chronic Exposure to Product:
No data available

Exposure Limits:

Black Powder Pellets

Ingredient Name	CAS Number	OSHA PEL	ACGIH TLV
Potassium Nitrate	7757-79-1	not established	not established
Charcoal	n/a	not established	not established
Sulphur	7704-34-9	not established	not established
Graphite	7782-42-5	2.5 mg/m^3	15 mmpct (TWA)

Propellant

Ingredient Name	CAS Number	OSHA PEL	ACGIH TLV
Ammonium Perchlorate	7790-98-9	not established	not established
metal powder		varies	varies
Synthetic Rubber		not established	not established

Irritancy of the Product:
No data available

Sensitization to the Product:
No data available

Carcinogenicity:
Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA

Reproductive Toxicity:
No data available

Teratogenicity:
No data available

Mutagenicity:
No data available

Toxically Synergistic Products:
No data available

LD50:
No data available

12.0 ECOLOGICAL INFORMATION

Environmental Data:
Ecotoxicity Data:
Not determined.

EcoFaTE Data:
Not determined.

13.0 DISPOSAL CONSIDERATIONS

Product As Sold: Pack firmly in hole in ground with nozzle pointing up. Ignite motor electrically from a safe distance and wait 5 minutes before approaching. Dispose of spent components in inert trash.

Product Packaging: Dispose of used packaging materials in inert trash.

Special Considerations: Consult local regulations about disposal of explosive materials.

14.0 TRANSPORT INFORMATION

Shipping Information – Canada

TDG Classification:	Class 1.4 Explosive
Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
Packing Group:	II
UN Packing Instruction:	101

Shipping Information - USA / IMO

Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
DOT / IMO Label:	Class 1 – Explosive – Division 1.4C

Shipping Information - IATA

Proper Shipping Name:	Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number:	0351
UN Classification Code:	1.4 C
IATA Labels:	Class 1 – Explosive – Division 1.4C Cargo Aircraft Only

15.0 REGULATORY INFORMATION

Canada

This product has been classified according to the hazard criteria of the Canadian Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

WHMIS Classification: Not Controlled (explosive)

Domestic Substance List (DSL) Status:
All ingredients are listed on Canada's DSL List.

Canadian Explosives Classification: Class 7.2.5
This product is an authorized explosive in Canada.

These products are not considered "Controlled Good" in Canada under the Controlled Goods Regulations.

United States of America

TSCA Inventory Status:
All ingredients are listed on the TSCA inventory.

Hazardous Chemical Lists

CERCLA Hazardous Substance (40 CFR 302.4)	No
SARA Extremely Hazardous Substance (40CFR 355)	No
SARA Toxic Chemical (40CFR 372.65)	No

European/International Regulations

The product on this MSDS, or all its components, is included on the following countries' chemical inventories:
EINECS – European Inventory of Existing Commercial Chemical Substances

European Labelling in Accordance with EC Directives
Hazard Symbols: Explosive.
Risk Phrases:

R 2	Risk of explosion by shock, friction, fire or other sources of ignition.
R 11	Highly flammable
R 44	Risk of explosion if heated under confinement.

Safety Phrases:

S 1/2	Keep locked up and out of the reach of children.
S 8	Keep container dry.
S 15	Keep away from heat.
S 16	Keep away from sources of ignition -- No smoking.

S 17	Keep away from combustible material.
S 18	Handle and open container with care.
S 33	Take precautionary measures against static discharges.
S 41	In case of fire and/or explosion do not breathe fumes.

16.0 OTHER INFORMATION

MSDS Prepared by: Regulatory Affairs Department
Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, ON
Canada L0H 1G0

Telephone: 905-887-2370 x239
Fax: 905-887-2375
Web Sites: www.cesaronitech.com
www.Pro38.com

The data in this Material Safety Data Sheet relates only to the specific material or product designated herein and does not relate to use in combination with any other material or in any process.

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no way shall the company be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if the company has been advised of the possibility of such damages.

C.3 Fibre Glast Style 120 E-Glass

Fibre Glast
Developments Corporation

GHS SAFETY DATA SHEET (SDS)

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: PART #573 Style 120 E-Glass

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
FOR CHEMICAL EMERGENCY
CALL (800) 424-9300 24 HRS.

RECOMMENDED USE: Woven textile product for use with Standard Composite Manufacturing

SECTION 2 – HAZARDS IDENTIFICATION

GHS CLASSIFICATION

This finished product has not been tested. Hazards identified are based on hazards of the ingredients. This product contains a hazardous chemical, as defined by OSHA at 29 CFR 1910.1200.

Skin irritation : Category 3

Specific target organ toxicity – single exposure : Category 3 (Respiratory tract irritation)

GHS Label Element
Hazard pictograms :

Signal word : Warning

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PDCT-MSDS-00082-05/15-AB

Hazard statements	:	H316 Causes mild skin irritation. H335: May cause respiratory tract irritation.
Precautionary statements	:	P261 Avoid breathing dusts or fibers. P271 Use only outdoors or in a well-ventilated area. P304+P340: IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. P312: Call a POISON CENTER or doctor/physician if you feel unwell. P332+P313: If skin irritation occurs, get medical advice/attention. P501: Dispose of contents/container in accordance with local/regional/ national/international regulations.
Relevant route of exposure and/or target organs	:	Dermal, Inhalation

SECTION 3 – COMPOSITION/INFORMATION ON INGREDIENTS

COMPONENT	CAS#	%
Glass, oxide, chemicals	65997-17-3	$\geq$99.4
Fibrous glass dust	Not assigned	Not assigned
Werner chrome complex[A] (Cr^{+3})	Not assigned	$\leq$0.3
Silane Coupling Agents[A]	Not assigned	$\leq$0.3

* Amount will be dependent upon method of handling.

[A] – Chemically bound to the fiberglass

SECTION 4 – FIRST AID MEASURES

Skin contact: Flush with ample cool water followed by washing with mild soap to remove accumulated fibers.

Eye contact: Flush with flowing water for 15 minutes—seek medical attention.

Inhalation: Move to fresh air.

Ingestion: Not likely to occur through normal use. Should ingestion occur, seek medical attention.

Most important symptoms/effects: Direct skin contact with fibrous glass or its dust may cause mechanical irritation and transitory dermatitis. Breathing of fibers or dust may cause mechanical irritation of the mouth, nose, and throat.

Indication of immediate medical attention and special treatment needed: Get medical attention if product comes into contact with skin or eyes, or if it is inhaled or ingested.

SECTION 5 – FIRE-FIGHTING MEASURES

Extinguishing media: Water, dry powder, or foam (needed for packaging only)

Hazardous combustion products: Not applicable

Protective equipment: Firefighters should be equipped with self-contained breathing apparatus and turn-out gear.

Fire-fighting procedures/precautions: Fiberglass itself will not support combustion, but in a sustained fire, proper protection against products of combustion from the fuel must be worn.

SECTION 6 – ACCIDENTAL RELEASE MEASURES

Personal precautions: A release of this product is not expected to pose risks to workers under normal circumstances. If the material is involved in a fire, or if dusts are produced, no action shall be taken involving any personal risk or without suitable training. Keep unnecessary and unprotected personnel from entering. Put on appropriate personal protective equipment.

Protective equipment: Wear protective gloves/eye protection/skin protection.

Methods/Materials for containment and cleaning up: Dust or loose fibers can be vacuumed or swept with the aid of a dust suppressant. Dispose of in accordance with all government regulations. Do not discharge into waterways or sewer systems without proper authority.

SECTION 7 – HANDLNG AND STORAGE

Precautions: This product should be handled under conditions of good industrial hygiene and in conformity with any local regulations to avoid unnecessary exposure. Use in a well-ventilated area. Do not breathe dust. Avoid contact with skin.

Storage: Store in a well-ventilated, dry location.

SECTION 8 – EXPOSURE CONTROLS/PERSONAL PROTECTION

EXPOSURE CONTROLS
Component: Fibrous dust
OSHA/PEL: 5 mg/m³
ACGIH/TLV: 5 mg/m³
*Dust may be produced during handling.

Engineering controls: Normal area ventilation is sufficient in most cases to keep dust and fiber levels below the TLV or PEL.

PERSONAL PROTECTION MEASURES/EQUIPMENT

Skin protection: Barrier creams, gloves, and long-sleeve, loose-fitting clothing may be required for certain workers who have sensitive skin or contact dermatitis. Work clothing should be laundered separately from other clothing before reuse.

Eye protection: Not normally required, but as a good safety work practice, eye protection such as safety glasses/side shields or equivalent whenever use of the product releases airborne fibrous glass.

Respiratory protection: If airborne fibrous glass exceeds the regulatory limits, or if upper respiratory irritation occurs, use a N95 particulate filtering respirator.

Other protection: Observe good personal hygiene.

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

Appearance	: Solid
Color	: White
Odor	: Odorless
Odor Threshold	: None
pH	: None
Freezing Point (Melting point/freezing point)	: >800⁰C (>1472⁰F)
Initial Boiling Point	: Not applicable
Flash point	: Not applicable
Evaporation rate	: Not applicable
Upper/Lower Flammability	: Not applicable
Upper/Lower Explosive Limits	: Not applicable
Vapor pressure	: Not applicable
Vapor Density	: Not applicable

Relative Density/ Specific Gravity	:	2.4 to 2.7
Solubility	:	Insoluble
Partition Coefficient	:	Not known
Auto-ignition Temperature	:	Not known
Decomposition Temperature	:	Not known
Volatility	:	Not known
Viscosity	:	Not applicable

SECTION 10 - STABILITY AND REACTIVITY

Reactivity: Not self-reactive, water-reactive, or spontaneously combustible.

Chemical stability: This product is stable.

Hazardous reactions: Under normal conditions of storage and use, hazardous reaction will not occur.

Conditions to avoid: When exposed to high temperatures, may produce hazardous decomposition products.

Incompatible products: None known.

Hazardous decomposition products: Fiberglass products may release small amounts of acetic acid and other organic materials at elevated temperatures.

Hazardous polymerization: Will not occur.

SECTION 11 – TOXICOLOGICAL INFORMATION

Relevant route of exposure/Target organs: Dermal, Inhalation

Symptoms: Causes mild skin irritation. May cause irritation of the mouth, nose, and throat after inhalation exposure.

Delayed and immediate effects: Not known

Chronic effects (short and long term exposure): Not known

Numerical measures of toxicity: None

Carcinogenicity: No ingredient is listed as a carcinogen by the NTP, IARC, or OSHA at 29 CFR 1910 Subpart Z.

Mutagenicity: No data available

Reproductive Toxicity: No data available

SECTION 12 - ECOLOGICAL INFORMATION

No data available

SECTION 13 - DISPOSAL CONSIDERATIONS

Do not discharge into waterways or sewer systems without proper authority. Dispose of in accordance with all government regulations.

SECTION 14 - TRANSPORT INFORMATION

Not regulated as a hazardous material/dangerous good for transportation in all modes of transportation (US DOT, ICAO/IATA, IMO).

SECTION 15 - REGULATORY INFORMATION

TSCA Inventory Status: Exempt per section 8 (a), 710.2 (f), and 704.5 (a)
SARA Title III Section 302: None
SARA Title III Section 304: None
SARA Title III Section 311/312 Hazard Categories: Immediate (acute)
SARA Title III Section 313: This product does not contain components that are subject to the reporting requirements of Section 313 of the Emergency Planning and Community Right to Know Act of 1986 (ESCRA or SARA Title III) and 40 CFR 372.
CERCLA RQ: Not listed
California Proposition 65: Not known
Massachusetts Right to Know: Less than reportable quantity
New Jersey Right to Know: Less than reportable quantity
Pennsylvania Right to Know: Less than reportable quantity

Canada: All components of this product are included on the Domestic Substances List (DSL) or are not required to be listed on the Canadian DSL.

Europe: All components of this product are included on the European Inventory of Existing Commercial Chemical Substances (EINECS) or are not required to be listed on the EINECS.

China: All components of this product are included on the Chinese Inventory (IECSC) or are not required to be listed on the Chinese IECSC.

Japan: All components of this product are included on the Japanese (ENCS) inventory or are not required to be listed on the Japanese inventory.

Korea: All components of this product are included on the Korean (ECL) inventory or are not required to be listed on the Korean ECL.

Philippines: All components of this product are included on the Philippine (PICCS) or are not required to be listed on the Philippine PICCS.

Australia: All components of this product are included on the Australian (AICS) or are not required to be listed on the Australian AICS.

SECTION 16 – OTHER INFORMATION

This product is classified as a Skin Irritant Category 3. However, OSHA does not include Category 3 substances in its hazard classification system.

Abbreviations	
ACGIH/TLV	American Conference of Industrial Hygienists Threshold Limit Value
CAS	Chemical Abstracts Service
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	US Code of Federal Regulations
DOT	US Department of Transportation
EPCRA	Emergency Planning and Right to Know Act
GHS	UN Globally Harmonized System of Classification and Labeling of Chemicals
HCS	Hazard Communication Standard
IARC	International Agency for Research and Cancer
ICAO/IATA	International Civil Aviation Organization/International Air Transport Association
IMO/IMDG	International Maritime Organization/International Maritime Dangerous Goods Code
LD_{50}	Lethal dose to half of test animals
NTP	National Toxicology Program
OSHA	US Occupational Safety Health Administration
PEL	Permissible exposure limit
RQ	Reportable quantity
SARA	Superfund Amendments and Reauthorization Act
SDS	Safety data sheet
TSCA	Toxic Substances Control Act
UN	United Nations
US/USA	United States (of America)

The information accumulated herein is believed to be accurate but is not warranted to be, whether originating with **Fibre Glast Developments Corporation** or not. Recipients are advised to confirm in advance of need that the information is current, applicable, and suitable to their circumstances.

C.4 Fibre Glast System 2000 Epoxy Resin

Fibre Glast
Developments Corporation

GHS SAFETY DATA SHEET (SDS)

SECTION 1 - PRODUCT AND COMPANY IDENTIFICATION

PRODUCT: Part #2000 System 2000 Epoxy Resin

FIBRE GLAST DEVELOPMENTS CORP.
385 CARR DRIVE
BROOKVILLE, OH 45309

TELEPHONE: (937) 833-5200
FAX: (937) 833-6555
FOR CHEMICAL EMERGENCY
CALL (800) 424-9300 24 HRS.

RECOMMENDED USE: Industrial Epoxy Resin supplied exclusively for workplace use.

SECTION 2 – HAZARDS IDENTIFICATION

GHS CLASSIFICATION

Eye Irritation	:	Category 2A
Acute Toxicity (Oral)	:	Category 5
Skin Irritation	:	Category 2
Skin Sensitizer	:	Category 1
Chronic Aquatic Toxicity	:	Category 2

GHS Label Element
Hazard pictogram :

Signal Word : Warning

Hazard statements : H319 Causes serious eye irritation.
H303 May be harmful if swallowed.
H315 Causes skin irritation.
H317 May cause an allergic skin reaction.
H411 Toxic to aquatic life with long lasting effects.

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PDCT-MSDS-00130-01/15-AB

Precautionary statements : P202 Do not handle until all safety precautions have been read/understood.
P261 Avoid breathing dust/fume/gas/mist/vapours/spray.
P270 Do not eat, drink or smoke when using this product.
P281 Use personal protective equipment as required.
P285 In case of inadequate ventilation wear respiratory protection.
P273 Avoid release to the environment.

NO.	CANCER	REPRO-TOX	TARGET ORGANS	ACGIH/TLV	OSHA/PEL
P	NO	NO	UNKNOWN	N.A.mg/M^3	N.A.mg/M^3
2	NO	NO	UNKNOWN	N.A.mg/M^3	N.A.mg/M^3

NOTE: CONTAINS MATERIAL(S) REGULATED AS DUST HAZARDS, DISPERSED IN A NON-HAZARDOUS FORM. IF DUST IS RECREATED, APPROPRIATE RESPIRATORY AND/OR EXPLOSION PRECAUTIONS MUST STILL BE USED.

SECTION 3 – COMPOSITION / INFORMATION ON INGREDIENTS

UNDER GHS-OSHA §4.11 THE PRECISE COMPOSITION OF THIS PRODUCT IS WITHHELD AS CONFIDENTIAL BUSINESS INFORMATION (CBI). A MORE COMPLETE DISCLOSURE CAN BE PROVIDED TO A HEALTH, OR SAFETY PROFESSIONAL WHEN NECESSARY.

Substance/Mixture: Mixture

NO.	COMPONENT	CAS. NO.	PERCENT
P	EPOXY RESIN BASED MIXTURE	N.A.	< 100%
2	MULTIFUNCTIONAL ACRYLATE	15625-89-5	< 2%

SECTION 4 – FIRST AID MEASURES

EMERGENCY AND FIRST AID PROCEDURES:

- **EYES:** IMMEDIATELY FLUSH EYES WITH LARGE AMOUNTS OF WATER FOR 15 MINUTES. GET MEDICAL ATTENTION.
- **SKIN:** WASH AFFECTED AREA IMMEDIATELY WITH LARGE AMOUNTS OF SOAP AND WATER. REMOVE AND WASH CONTAMINATED CLOTHING BEFORE REUSE. CONTACT A PHYSICIAN IF IRRITATION OCCURS.
- **INHALATION:** REMOVE VICTIM TO FRESH AIR AND PROVIDE OXYGEN IF BREATHING IS DIFFICULT. GET MEDICAL ATTENTION.
- **INGESTION:** DO NOT INDUCE VOMITING. GIVE LARGE QUANTITIES OF WATER. CALL A PHYSICIAN IMMEDIATELY. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON.

SECTION 5 – FIRE-FIGHTING MEASURES

FLASH POINT: ≥210°F (FOR PRODUCT OR LOWEST FLASH POINT INGREDIENT)
FLAMMABILITY CLASSIFICATION: COMBUSTIBLE CLASS (IIIB)
EXTINGUISHING MEDIA: WATER FOG, DRY CHEMICAL, CARBON DIOXIDE, OR FOAM.
NOTE: EITHER ATMOSPHERE-SUPPLY OR AIR-PURIFYING RESPIRATORS SHOULD BE AVAILABLE FOR FIRE FIGHTERS (20 CFR 1910.134).

SECTION 6 – ACCIDENTAL RELEASE MEASURES

- **IF MATERIAL IS SPILLED:** AVOID CONTACT WITH MATERIAL. PERSONS NOT WEARING PROPER PROTECTIVE EQUIPMENT (SEE BELOW) SHOULD BE EXCLUDED FROM THE AREA UNTIL CLEAN UP IS COMPLETE. DIKE AREA TO PREVENT SPILL SPREADING AND SCOOP UP EXCESS TO RECOVERY CONTAINERS. ABSORB REMNANT ON NONCOMBUSTIBLE MATERIAL SUCH AS CLAY AND SHOVEL INTO CONTAINERS FOR DISPOSAL.
- **WASTE DISPOSAL METHOD:** DISPOSE OF ANY WASTE(S) GENERATED ABOVE IN ACCORDANCE WITH FEDERAL, STATE, AND LOCAL REGULATIONS.

SECTION 7 – HANDLING AND STORAGE

- AVOID SKIN AND EYE CONTACT.
- AVOID BREATHING VAPOR, MIST OR FUMES.
- ENSURE THAT ALL CONTAINERS ARE PROPERLY LABELED TO PREVENT ACCIDENTAL INGESTION OR IMPROPER DISPOSAL.
- RESEAL PARTLY USED CONTAINERS.
- WASH WITH SOAP AND WATER BEFORE EATING, DRINKING OR USING TOILET FACILITIES.
- STORE UNDER COOL, DRY CONDITIONS AND AWAY FROM OPEN FLAMES AND HIGH TEMPERATURES.
- OBSERVE CONDITIONS OF GOOD INDUSTRIAL HYGIENE AND SAFE WORKING PRACTICE.

SECTION 8 – EXPOSURE CONTROLS/PERSONAL PROTECTION

- **RESPIRATORY PROTECTION:** NOT NORMALLY NECESSARY UNLESS THE MATERIAL IS BEING USED IN SUCH A WAY AS TO PRODUCE DUST, MIST, VAPOR, FUMES, OR SMOKE, IN WHICH CASE NIOSH APPROVED RESPIRATORY PROTECTION SHOULD BE USED.
- **VENTILATION:** SHOULD BE SUFFICIENT TO CONTROL ANY DUST, MIST, VAPOR OR FUMES PRODUCED BY PROCESSING OR HANDLING METHOD. BREATHING OF VAPOR MUST BE AVOIDED.
- **HAND PROTECTION:** IMPERVIOUS GLOVES, NEOPRENE OR NILRILE RUBBER GLOVES.
- **EYE PROTECTION:** SPLASH PROOF GOGGLES OR SAFETY GLASSES WITH SIDE SHIELDS.
- **OTHER PROTECTIVE EQUIPMENT:** CLEAN, BODY COVERING CLOTHING AND FOOTWEAR.

SECTION 9 – PHYSICAL AND CHEMICAL PROPERTIES

- PHYSICAL STATE……: LIQUID
- ODOR……………………..: BLAND
- COLOR……………………: AMBER
- pH…………………………: NEUTRAL
- SP. GR………………..: 1.14
- DENSITY………………: 9.5 lbs. / gal.
- VAPOR PRESSURE….: NEGLIGIBLE

NOTE: OTHER PROPERTIES ARE EITHER NOT AVAILABLE, OR DO NOT APPLY.

SECTION 10 – STABILITY AND REACTIVITY

- **STABILITY:** STABLE UNDER NORMAL STORAGE CONDITIONS. UNSTABLE AT ELEVATED TEMPERATURES.
- **INCOMPATIBILITY:** STRONG OXIDIZING AGENTS, STRONG LEWIS OR MINERAL ACIDS, AND STRONG MINERAL AND ORGANIC BASES / ESPECIALLY ALIPHATIC AMINES.
- **HAZARDOUS DECOMPOSITION PRODUCTS:** CARBON OXIDES, ALDEHYDES, ACIDS, PHENOLICS, AND OTHER UNKNOWN COMPOUNDS.

SECTION 11 – TOXICOLOGICAL INFORMATION

EFFECTS OF OVEREXPOSURE:

ACUTE:

- **EYES:** PRODUCT IS MODERATELY IRRITATING TO THE EYES.
- **SKIN:** PRDUCT IS MODERATELY IRRITATING TO THE SKIN AND MAY CAUSE SKIN SENSITIZATION.
- **INHALATION:** BECAUSE OF ITS LOW VOLATILITY THIS PRODUCT IS NOT LIKELY TO BE AN INHALATION HAZARD.
- **INGESTION:** PRODUCT IS CONSIDERED TO HAVE A LOW ORDER OF ACUTE ORAL TOXICITY.

CHRONIC:

- NO SPECIFIC HAZARDS KNOWN. PREEXISTING EYE, SKIN, OR LUNG DISORDERS MAY BE AGGRAVATED BY EXPOSURE TO THIS PRODUCT.

SECTION 12 – ECOLOGICAL INFORMATION

ECOTOXICITY EFFECTS:

- **AQUATIC TOXICITY:** NO DATA IS AVAILABLE ON THE PRODUCT ITSELF.
- **TOXICITY TO OTHER ORGANISMS:** NO DATA AVAILABLE.

PERSISTANCE AND DEGRADABILITY:

- **MOBILITY:** NO DATA IS AVAILABLE ON THE PRODUCT ITSELF.
- **BIOACCUMULATION:** NO DATA IS AVAILABLE ON THE PRODUCT ITSELF.

SECTION 13 – DISPOSAL CONSIDERATIONS

- **WASTE DISPOSAL METHOD:** DISPOSE OF WASTE IN ACCORDANCE WITH ALL FEDERAL, STATE, AND LOCAL REGULATIONS.
- **CONTAINER DISPOSAL:** SINCE EMPTIED CONTAINERS RETAIN PRODUCT RESIDUE, ALL LABELED HAZARD PRECAUTIONS MUST BE OBSERVED. CONSULT WITH FEDERAL, STATE, AND LOCAL AUTHORITIES FOR DEFINITIONS OF "EMPTY" AND PROPER DISPOSAL PRACTICES.

SECTION 14 – TRANSPORT INFORMATION

- **U.S. Department of Transportation Ground (49 CFR)**

UN NUMBER.......................................: N.A.
PROPER SHIPPING NAME.........................: PLASTIC MATERIAL LIQUID, N.O.I.
CONTAINS.......................................: NOT REGULATED*
HAZARD CLASS..................................: N.A.
PACKAGING GROUP..............................: N.A

- **International Air Transportation (ICAO/IATA)**

UN NUMBER.......................................: N.A.
PROPER SHIPPING NAME.........................: PLASTIC MATERIAL LIQUID, N.O.I.
CONTAINS.......................................: NOT REGULATED*
HAZARD CLASS..................................: N.A.
PACKAGING GROUP..............................: N.A.

- **Water Transportation (IMO/IMDG)**

UN NUMBER.......................................: N.A.
PROPER SHIPPING NAME.........................: PLASTIC MATERIAL LIQUID, N.O.I.
CONTAINS.......................................: NOT REGULATED*
HAZARD CLASS..................................: N.A.
PACKAGING GROUP..............................: N.A
MARINE POLLUTANT.............................: NO

*Non-Bulk Packages may be shipped as Non-Regulated under §49 CFR 173.150(f).

SECTION 15 – REGULATORY INFORMATION

CAL SAFE DRINKING WATER & TOXIC ENFORCEMENT ACT OF 1986

NO.	CHEMICAL NAME	CAS. NO.	CANCER/REPRO.TOX	QUANTITY

THIS PRODUCT MAY CONTAIN TRACES OF PROP. 65 LISTED CHEMICALS AS IMPURITIES. HOWEVER, ANY USED AS INGREDIENTS ARE LISTED ABOVE.

CERCLA — §40 CFR 302.4
RELEASES EXCEEDING THE REPORTABLE QUANTITY **(RQ)** MUST BE REPORTED TO THE NATIONAL RESPONSE CENTER. (800)424-8802

RQ NOT ESTABLISHED OR REQUIRED FOR THIS PRODUCT.

RCRA — §40 CFR 261.33

NOT A HAZARDOUS WASTE BY RCRA CRITERIA (40CFR261.20-24).

SARA TITLE III — §52 CFR 13378, §52 CFR 21152

NO.	RQ(lbs.) (•1)	TPQ(lbs.) (•2)	SEC.313 (•3)	313 CAT. (•4)	311/312 (•5)
P	NONE	NOT LISTED	NOT LISTED	NONE	H1
2	NONE	NOT LISTED	NOT LISTED	NONE	H1

•1 = REPORTABLE QUANTITY OF EXTREMELY HAZARDOUS SUBSTANCE, SEC. 302
•2 = THRESHOLD PLANNING QUANTITY, EXTREMELY HAZARDOUS SUBSTANCE, SEC. 302
•3 = TOXIC CHEMICAL, SEC. 313 (INDIVIDUAL CHEMICAL LISTED)
•4 = TOXIC RELEASE INVENTORY FORM CATEGORY SEC. 313 (40 CFR 372.65 C)
•5 = HAZARD CATEGORY FOR SARA SEC. 311/312 REPORTING
H1 = IMMED. (ACUTE) HEALTH HAZARD **H2** = DELAYED (CHRONIC) HEALTH HAZARD
P3 = FIRE HAZARD **P4** = SUDDEN PRESSURE RELEASE HAZARD **P5** = REACTIVE HAZ.

VOC — SCAQMD RULES

NO.	CHEMICAL	QUANTITY	VP mm HG	gms./l. @ 20ºC
	NIL			

NOTE: THIS PRODUCT DOES NOT CONTAIN SOLVENTS, BUT MAY CONTAIN INGREDIENTS WITH VP'S LOW ENOUGH TO BE EMITTED IF HEATED ALONE. WHEN 2 PART RESINS AND HARDENERS ARE PROPERLY MIXED TOGETHER THESE INGREDIENTS REACT TOGETHER AND ARE CONSUMED WITHOUT SIGNIFICANT ATMOSPHERIC EMISSIONS.

INTERNATIONAL CHEMICAL INVENTORY STATUS:

EINECS-EU	Listed, Exempted, Polymer substance, or as no longer polymer.
AICS-AUSTRALIA	All components are listed or exempted.
ENCS-JAPAN	All components are listed or exempted.
ISHL-JAPAN	All components are listed or exempted.
KECI/ECL-KOREA	All components are listed or exempted.
IECSC/SEPA-CHINA	All components are listed or exempted.
PICCS-PHILIPPINES	All components are listed or exempted.
DSL-CANADA	All components are listed or exempted.
TSCA-USA	All components are listed or exempted.

WHMIS (CANADA)

- WHMIS: D2B Materials Causing Other Toxic Effects – Toxic Material

SECTION 16 – OTHER INFORMATION

HMIS III CODES:		**RATINGS:**
HEALTH.................................=**2**	0 = MINIMAL	3 = SERIOUS
FLAMMABILITY..................=**1**	1 = SLIGHT	4 = SEVERE
REACTIVITY.......................=**0**	2 = MODERATE	

PERSONAL PROTECTION RATING TO BE SUPPLIED BY USER DEPENDING ON CONDITIONS OF USE.

The information accumulated herein is believed to be accurate but is not warranted to be, whether originating with **Fibre Glast Developments Corporation** or not. Recipients are advised to confirm in advance of need that the information is current, applicable, and suitable to their circumstances.

C.5 Spray Paint

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Safety Data Sheet	RUST-OLEUM CORPORATION * Trusted Quality Since 1921 * www.rustoleum.com

1. Identification

Product Name:	STRUST SSPR 6PK FLEXIDIP RED	**Revision Date:**	4/21/2015
Product Identifier:	276291	**Supercedes Date:**	New SDS
Product Use/Class:	Topcoat/Aerosols		
Supplier:	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA	**Manufacturer:**	Rust-Oleum Corporation 11 Hawthorn Parkway Vernon Hills, IL 60061 USA
Preparer:	Regulatory Department		
Emergency Telephone:	24 Hour Hotline: 847-367-7700		

2. Hazard Identification

EMERGENCY OVERVIEW: Extremely flammable liquid and vapor. Vapors may cause flash fire or explosion. Harmful if inhaled. May affect the brain or nervous system causing dizziness, headache or nausea. Contents Under Pressure. May cause eye, skin, or respiratory tract irritation. KEEP OUT OF REACH OF CHILDREN. Harmful if inhaled. Harmful if swallowed. Causes eye irritation. Use ventilation necessary to keep exposures below recommended exposure limits, if any. Vapor Harmful. Causes Eye, Skin, Nose, and Throat Irritation.

Classification

Symbol(s) of Product

Signal Word

Danger

Possible Hazards

58% of the mixture consists of ingredient(s) of unknown acute toxicity

GHS HAZARD STATEMENTS

Flammable Aerosol, category 1	H222	Extremely flammable aerosol.
Flammable Liquid, category 1	H224	Extremely flammable liquid and vapour.
Acute Toxicity, Oral, category 5	H303	May be harmful if swallowed.
Acute Toxicity, Dermal, category 5	H313	May be harmful in contact with skin.
Skin Irritation, category 2	H315	Causes skin irritation.
Eye Irritation, category 2	H319	Causes serious eye irritation.
Acute Toxicity, Inhalation, category 4	H332	Harmful if inhaled.
STOT, single exposure, category 3, RTI	H335	May cause respiratory irritation.
STOT, single exposure, category 3, NE	H336	May cause drowsiness or dizziness.
Aspiration Hazard, category 2	H305	May be harmful if swallowed and enters airways.
Eye Irritation, category 2B	H320	Causes eye irritation.
Flammable Aerosol, category 1	H280	Contains gas under pressure; may explode if heated

Germ Cell Mutagenicity, category 1B	H340	May cause genetic defects. Classified as mutagenic Category 1 if one ingredient is present at or above 0.1%. Applies to liquids, solids (w/w units) and gases (v/v). The substance may also have its own exposure limit. Routes of exposure are dependent on ingredient form.
Carcinogenicity, category 1B	H350	May cause cancer. Classified as carcinogenic Category 1 on the basis of epidemiological and/or animal data. Mixtures are classified as carcinogenic when at least 1 ingredient has been classified as carcinogenic and is present at 0.1% or above Routes of exposure are dependant on ingredient form.

GHS PRECAUTIONARY STATEMENTS

P211	Do not spray on an open flame or other ignition source.
P220	Keep/Store away from clothing/.../combustible materials.
P235	Keep cool.
P251	Pressurized container: Do not pierce or burn, even after use.
P375	Fight fire remotely due to the risk of explosion.
P102	Keep out of reach of children.
P103	Read label before use.
P202	Do not handle until all safety precautions have been read and understood.
P234	Keep only in original container.
P260	Do not breathe dust/fume/gas/mist/vapours/spray.
P261	Avoid breathing dust/fume/gas/mist/vapours/spray.
P262	Do not get in eyes, on skin, or on clothing.
P264	Wash ... thoroughly after handling.
P270	Do not eat, drink or smoke when using this product.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/protective clothing/eye protection/face protection.
P281	Use personal protective equipment as required.
P285	In case of inadequate ventilation wear respiratory protection.
P312	Call a POISON CENTER or doctor/physician if you feel unwell.
P351	Rinse cautiously with water for several minutes.
P374	Fight fire with normal precautions from a reasonable distance.
P402	Store in a dry place.
P210	Keep away from heat/sparks/open flames/hot surfaces. - No smoking.
P410+P412	Protect from sunlight. Do not expose to temperatures exceeding 50°C / 122°F.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ventilating/lighting/.../ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P303+P361+P353	IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.
P370+P378	In case of fire: Use ... for extinction.
P403+P235	Store in a well-ventilated place. Keep cool.
P501	Dispose of contents/container to ...
P321	Specific treatment (see ... on this label).
P352	Wash with plenty of soap and water.
P362	Take off contaminated clothing and wash before reuse.
P332+P313	If skin irritation occurs: Get medical advice/attention.
P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337+P313	If eye irritation persists: Get medical advice/attention.
P304+P340	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P405	Store locked up.
P403+P233	Store in a well-ventilated place. Keep container tightly closed.
P201	Obtain special instructions before use.
P308+P313	IF exposed or concerned: Get medical advice/attention.
P302+P350	IF ON SKIN: Gently wash with plenty of soap and water.

3. Composition/Information On Ingredients

HAZARDOUS SUBSTANCES

Chemical Name	CAS-No.	Wt.% Range	GHS Symbols	GHS Statements
Aliphatic Hydrocarbon	64742-89-8	10-25	GHS08	H340-350
Propane	74-98-6	10-25		
n-Butyl Acetate	123-86-4	10-25	GHS02-GHS07	H225-336
Methyl Isobutyl Ketone	108-10-1	10-25	GHS02-GHS06	H225-331-335-319
Methyl Acetate	79-20-9	10-25	GHS02-GHS06	H225-310-336-319
n-Butane	106-97-8	2.5-10		
Ethyl Acetate	141-78-6	2.5-10	GHS02-GHS06	H225-310-336-319
Ethylbenzene	100-41-4	0.1-1.0	GHS02-GHS07	H225-332
Titanium Dioxide	13463-67-7	0.1-1.0		

The text for GHS Hazard Statements shown above (if any) is given in the "16. Other Information" section.

4. First-aid Measures

FIRST AID - EYE CONTACT: Immediately flush eyes with plenty of water for at least 15 minutes holding eyelids open. Get medical attention. Do NOT allow rubbing of eyes or keeping eyes closed.

FIRST AID - SKIN CONTACT: Wash skin with soap and water. Remove contaminated clothing. Get medical attention if irritation develops or persists.

FIRST AID - INHALATION: Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get immediate medical attention. Do NOT use mouth-to-mouth resuscitation. If you experience difficulty in breathing, leave the area to obtain fresh air. If continued difficulty is experienced, get medical assistance immediately.

FIRST AID - INGESTION: Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. Get immediate medical attention. If swallowed, get medical attention.

5. Fire-fighting Measures

EXTINGUISHING MEDIA: Alcohol Film Forming Foam, Carbon Dioxide, Dry Chemical, Dry Sand, Water Fog

UNUSUAL FIRE AND EXPLOSION HAZARDS: FLASH POINT IS LESS THAN 20°F. EXTREMELY FLAMMABLE LIQUID AND VAPOR!Water spray may be ineffective. Closed containers may explode when exposed to extreme heat due to buildup of steam. Closed containers may explode when exposed to extreme heat. Vapors may form explosive mixtures with air. Vapors can travel to a source of ignition and flash back. Isolate from heat, electrical equipment, sparks and open flame. Perforation of the pressurized container may cause bursting of the can. No unusual fire or explosion hazards noted. Keep containers tightly closed.

SPECIAL FIREFIGHTING PROCEDURES: Full protective equipment including self-contained breathing apparatus should be used. Evacuate area and fight fire from a safe distance. Water may be used to cool closed containers to prevent pressure buildup and possible autoignition or explosion. Use water spray to keep fire-exposed containers cool. Containers may explode when heated.

6. Accidental Release Measures

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED: Contain spilled liquid with sand or earth. DO NOT use combustible materials such as sawdust. Isolate the hazard area and deny entry to unnecessary and unprotected personnel. Remove all sources of ignition, ventilate area and remove with inert absorbent and non-sparking tools. Dispose of according to local, state (provincial) and federal regulations. Do not incinerate closed containers. Ventilate area, isolate spilled material, and remove with inert absorbent. Dispose of contaminated absorbent, container, and unused contents in accordance with local, state, and federal regulations.

7. Handling and Storage

HANDLING: Wash thoroughly after handling. Wash hands before eating. Remove contaminated clothing and launder before reuse. Use only with adequate ventilation. Follow all MSDS/label precautions even after container is emptied because it may retain product residues. Avoid breathing fumes, vapors, or mist. Avoid contact with eyes, skin and clothing.

STORAGE: Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame. Contents under pressure. Do not store above 120 ° F. Store large quantities in buildings designed and protected for storage of NFPA Class I flammable liquids. Product should be stored in tightly sealed containers and protected from heat, moisture, and foreign materials. Store in a dry, well ventilated place. Keep container tightly closed when not in use. Keep away from heat, sparks, flame and sources of ignition. Avoid excess heat.

8. Exposure Controls/Personal Protection

Chemical Name	CAS-No.	Weight % Less Than	ACGIH TLV-TWA	ACGIH TLV-STEL	OSHA PEL-TWA	OSHA PEL-CEILING
Aliphatic Hydrocarbon	64742-89-8	20.0	350 ppm	N.E.	500 ppm	N.E.
Propane	74-98-6	20.0	1000 ppm	N.E.	1000 ppm	N.E.
n-Butyl Acetate	123-86-4	15.0	150 ppm	200 ppm	150 ppm	N.E.
Methyl Isobutyl Ketone	108-10-1	15.0	20 ppm	75 ppm	100 ppm	N.E.
Methyl Acetate	79-20-9	15.0	200 ppm	250 ppm	200 ppm	N.E.
n-Butane	106-97-8	10.0	1000 ppm	1000 ppm	N.E.	N.E.
Ethyl Acetate	141-78-6	10.0	400 ppm	N.E.	400 ppm	N.E.
Ethylbenzene	100-41-4	1.0	20 ppm	125 ppm	100 ppm	N.E.
Titanium Dioxide	13463-67-7	1.0	10 mg/m3 (Total Dust)	N.E.	15 mg/m3 [Total Dust]	N.E.

PERSONAL PROTECTION

ENGINEERING CONTROLS: Use explosion-proof ventilation equipment. Provide general dilution of local exhaust ventilation in volume and pattern to keep TLV of hazardous ingredients below acceptable limits. Prevent build-up of vapors by opening all doors and windows to achieve cross-ventilation. Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.

RESPIRATORY PROTECTION: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use. A NIOSH/MSHA approved air purifying respirator with organic vapor cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits.

SKIN PROTECTION: Use gloves to prevent prolonged skin contact. Nitrile or Neoprene gloves may afford adequate skin protection.

EYE PROTECTION: Use safety eyewear designed to protect against splash of liquids.

OTHER PROTECTIVE EQUIPMENT: Refer to safety supervisor or industrial hygienist for further guidance regarding types of personal protective equipment and their applications.

HYGIENIC PRACTICES: Wash thoroughly with soap and water before eating, drinking or smoking. Remove contaminated clothing immediately and launder before reuse.

9. Physical and Chemical Properties

Appearance:	Aerosolized Mist	**Physical State:**	Liquid
Odor:	Solvent Like	**Odor Threshold:**	N.E.
Relative Density:	0.738	**pH:**	N.A.
Freeze Point, °C:	N.D.	**Viscosity:**	No Information
Solubility in Water:	Negligible	**Partition Coefficient, n-octanol/ water:**	No Information
Decompostion Temp., °C:	No Information		
Boiling Range, °C:	-11 - 999	**Explosive Limits, vol%:**	0.9 - 16.0
Flammability:	Does not Support Combustion	**Flash Point, °C:**	-105
Evaporation Rate:	Faster than Ether	**Auto-ignition Temp., °C:**	No Information
Vapor Density:	Heavier than Air	**Vapor Pressure:**	No Information

(See "Other information" Section for abbreviation legend)

10. Stability and Reactivity

CONDITIONS TO AVOID: Avoid temperatures above 120 ° F. Avoid contact with strong acid and strong bases. Avoid all possible sources of ignition.

INCOMPATIBILITY: Incompatible with strong oxidizing agents, strong acids and strong alkalies.

HAZARDOUS DECOMPOSITION: Contains solvents which may form carbon monoxide, carbon dioxide, and formaldehyde. By open flame, carbon monoxide and carbon dioxide. When heated to decomposition, it emits acrid smoke and irritating fumes.

HAZARDOUS POLYMERIZATION: Will not occur under normal conditions.

STABILITY: May form peroxides of unkown stability. This product is stable under normal storage conditions.

11. Toxicological Information

EFFECTS OF OVEREXPOSURE - EYE CONTACT: Causes Serious Eye Irritation

EFFECTS OF OVEREXPOSURE - SKIN CONTACT: May cause skin irritation. Allergic reactions are possible.

EFFECTS OF OVEREXPOSURE - INHALATION: High gas, vapor, mist or dust concentrations may be harmful if inhaled. High vapor concentrations are irritating to the eyes, nose, throat and lungs. Harmful if inhaled. Avoid breathing fumes, spray, vapors, or mist. Prolonged or excessive inhalation may cause respiratory tract irritation.

EFFECTS OF OVEREXPOSURE - INGESTION: Harmful if swallowed.

EFFECTS OF OVEREXPOSURE - CHRONIC HAZARDS: IARC lists Ethylbenzene as a possible human carcinogen (group 2B). Contains Titanium Dioxide. Titanium Dioxide is listed as a Group 2B-"Possibly carcinogenic to humans" by IARC. No significant exposure to Titanium Dioxide is thought to occur during the use of products in which Titanium Dioxide is bound to other materials, such as in paints during brush application or drying. Risk of overexposure depends on duration and level of exposure to dust from repeated sanding of surfaces or spray mist and the actual concentration of Titanium Dioxide in the formula. (Ref: IARC Monograph, Vol. 93, 2010)May cause central nervous system disorder (e.g., narcosis involving a loss of coordination, weakness, fatigue, mental confusion, and blurred vision) and/or damage. Reports have associated repeated and prolonged occupational overexposure to solvents with permanent brain and nervous system damage. High concentrations may lead to central nervous system effects (drowsiness, dizziness, nausea, headaches, paralysis, and blurred vision) and/or damage.

PRIMARY ROUTE(S) OF ENTRY: Eye Contact, Ingestion, Inhalation, Skin Absorption, Skin Contact

ACUTE TOXICITY VALUES
The acute effects of this product have not been tested. Data on individual components are tabulated below:

CAS-No.	Chemical Name	Oral LD50	Dermal LD50	Vapor LC50
64742-89-8	Aliphatic Hydrocarbon	N.I.	3000 mg/kg Rabbit	N.I.
74-98-6	Propane	N.I.	N.I.	658 mg/L Rat
123-86-4	n-Butyl Acetate	N.I.	>17600 mg/kg Rabbit	N.I.
108-10-1	Methyl Isobutyl Ketone	2080 mg/kg Rat	>16000 mg/kg Rabbit	8.2 mg/L Rat
79-20-9	Methyl Acetate	>5000 mg/kg Rat	>5 g/kg Rabbit	N.I.
141-78-6	Ethyl Acetate	5620 mg/kg Rat	>20 mL/kg Rabbit	N.I.
100-41-4	Ethylbenzene	3500 mg/kg Rat	15354 mg/kg Rabbit	17.2 mg/L Rat
13463-67-7	Titanium Dioxide	>10000 mg/kg Rat	N.I.	N.I.

N.I. - No Information

12. Ecological Information

ECOLOGICAL INFORMATION: Product is a mixture of listed components.

13. Disposal Information

DISPOSAL INFORMATION: Dispose of material in accordance to local, state, and federal regulations and ordinances. Do not allow to enter waterways, wastewater, soil, storm drains or sewer systems.

14. Transport Information

	Domestic (USDOT)	International (IMDG)	Air (IATA)	TDG (Canada)
UN Number:	N.A.	1950	1950	N.A.
Proper Shipping Name:	Paint Products in Limited Quantities	Aerosols	Aerosols	Paint Products in Limited Quantities
Hazard Class:	N.A.	2.1	2.1	N.A.
Packing Group:	N.A.	N.A.	N.A.	N.A.
Limited Quantity:	Yes	Yes	Yes	Yes

15. Regulatory Information

U.S. Federal Regulations:

CERCLA - SARA Hazard Category

This product has been reviewed according to the EPA 'Hazard Categories' promulgated under Sections 311 and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:

Fire Hazard, Pressure Hazard, Reactive Hazard, Acute Health Hazard, Chronic Health Hazard

Sara Section 313:

This product contains the following substances subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR part 372:

Chemical Name	CAS-No.
Methyl Isobutyl Ketone	108-10-1
Ethylbenzene	100-41-4

Toxic Substances Control Act:

This product contains the following chemical substances subject to the reporting requirements of TSCA 12(b) if exported from the United States:

Chemical Name	CAS-No.
Acetaldehyde	75-07-0

CALIFORNIA PROPOSITION 65:

Chemical Name	CAS-No.
Methyl Isobutyl Ketone	108-10-1
Ethylbenzene	100-41-4
Titanium Dioxide	13463-67-7
Ethanol	64-17-5

CALIFORNIA PROPOSITION 65 REPRODUCTIVE TOXINS

Chemical Name	CAS-No.
Ethanol	64-17-5

International Regulations:

CANADIAN WHMIS:

This SDS has been prepared in compliance with Controlled Product Regulations except for the use of the 16 headings.

16. Other Information

HMIS RATINGS

Health:	2*	**Flammability:**	4	**Physical Hazard:**	0	**Personal Protection:**	X

CANADIAN WHMIS CLASS: AB5 D2A

NFPA RATINGS

Health:	2	**Flammability:**	4	**Instability**	0

VOLATILE ORGANIC COMPOUNDS, g/L: 656

MSDS REVISION DATE: 4/21/2015

REASON FOR REVISION: No Information

Legend: N.A. - Not Applicable, N.E. - Not Established, N.D. - Not Determined

Text for GHS Hazard Statements shown in Section 3 describing each ingredient:

H225	Highly flammable liquid and vapour.
H310	Fatal in contact with skin.
H319	Causes serious eye irritation.
H331	Toxic if inhaled.
H332	Harmful if inhaled.
H335	May cause respiratory irritation.
H336	May cause drowsiness or dizziness.
H340	May cause genetic defects <state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard>.
H350	May cause cancer <state route of exposure if it is conclusively proven that no other routes of exposure cause the hazard>.

Icons for GHS Pictograms shown in Section 3 describing each ingredient:

GHS02

GHS06

GHS07

GHS08

Rust-Oleum Corporation believes, to the best of its knowledge, information and belief, the information contained herein to be accurate and reliable as of the date of this safety data sheet. However, because the conditions of handling, use, and storage of these materials are beyond our control, we assume no responsibility or liability for personal injury or property damage incurred by the use of these materials. Rust-Oleum Corporation makes no warranty, expressed or implied, regarding the accuracy or reliability of the data or results obtained from their use. All materials may present unknown hazards and should be used with caution. The information and recommendations in this material safety data sheet are offered for the users' consideration and examination. It is the responsibility of the user to determine the final suitability of this information and to comply with all applicable international, federal, state, and local laws and regulations.

C.6 Black Powder

OWEN COMPLIANCE SERVICES, INC.

Material Safety Data Sheet
(MSDS-BP)

PRODUCT IDENTIFICATION	
Product Name	BLACK POWDER
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX, Inc. (Doyline, LA) & various international sources
Transportation Emergency	**800-255-3924 (24 hrs — *CHEM • TEL*)**

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully handled and used following approved safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, or ordinances. If you have any questions or doubts as to how to use any explosive product, **DO NOT USE IT** before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

HAZARDOUS COMPONENTS				
Material or Component	**%**	**CAS No.**	**TLV**	**PEL**
Potassium nitrate[1]	70-76	007757-79-1	NE	NE
Sodium nitrate[1]	70-74	007631-99-4	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[2]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3
N/A = Not assigned NE = Not established				

[1] Black Powder contains either potassium nitrate ***or*** sodium nitrate in the percentages indicated. Black powder ***does not contain both***.

[2] Not contained in all grades of black powder.

PHYSICAL DATA	
Boiling Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Solubility in Water	Good
Specific Gravity	1.70 - 1.82 (mercury method) • 1.92 - 2.08 (pycnometer)
PH	6.0 - 8.0
Evaporation Rate	N/A
Appearance and Odor	Black granular powder. No odor detectable.

HAZARDOUS REACTIVITY	
Instability	Keep away from heat, sparks, and open flame. Avoid impact, friction, and static electricity.
Incompatibility	When dry, black powder is compatible with most metals; however, it is hygroscopic, and when wet, attracts all common metals except stainless steel. Black powder must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials, and other similar materials, situations, and equipment.
Hazardous decomposition	Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization	Polymerization will not occur.

FIRE AND EXPLOSION DATA	
Flashpoint	Not applicable
Auto ignition temperature	Approx. 464°C (867°F)
Explosive temperature (5 sec)	Ignites @ approx. 427°C (801°F)
Extinguishing media	Water
Special fire fighting procedures	**ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES.** Try to keep fire from reaching explosives. Isolate area. Guard against intruders. Division 1.1 Explosives (heavily encased): Evacuate the area for 5000 feet (1 mile) if explosives are heavily encased. Division 1.1 Explosives (not heavily encased): Evacuate the area for 2500 feet (½ mile) if explosives are not heavily encased. Division 1.1 Explosives (all): Consult the *2000 Emergency Response Guidebook, Guide 112* for further details.
Unusual fire and explosion hazards	Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, and ordinances.
Carcinogenicity	None of the components of Black powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	*Not a likely route of exposure.* If inhaled, remove to fresh air. If not breathing, give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention.
Eye and skin contact	*Not a likely route of exposure.* Flush eyes with water. Wash skin with soap and water.
Ingestion	*Not a likely route of exposure..* If ingested, induce vomiting immediately by giving two glasses of water and sticking finger down throat.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in cleanup procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with federal regulations under the authority of the *Resource Conservation and Recovery Act* (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation.
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves.
Other	Metal-free *and* non-static producing clothes

SPECIAL PRECAUTIONS
• Keep away from friction, impact, and heat. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials. • Contaminated equipment must be thoroughly water cleaned before attempting repairs. • Use only non-spark producing tools. • No smoking.

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of *Subpart K, ATF: Explosives Law and Regulations* (27 CFR 55.201-55.219).

SHIPPING INFORMATION		
Proper shipping name	Black powder	
Hazard class	1.1D	
UN Number	UN0027	
DOT Label & Placard	DOT Label	EXPLOSIVE 1.1D
	DOT Placard	EXPLOSIVES 1.1
Alternate shipping information	Limited quantities of black powder may be transported as "Black powder for small arms", NA0027, class 4.1 pursuant to U.S. Department of Transportation authorization EX-8712212.	

The information contained in this Material Safety Data Sheet is based upon available data and believed to be correct; however, as such has been obtained from various sources, including the manufacturer and independent laboratories, it is given without warranty or representation that it is complete, accurate, and can be relied upon. OWEN COMPLIANCE SERVICES, INC. has not attempted to conceal in any manner the deleterious aspects of the product listed herein, but makes no warranty as to such. Further, OWEN COMPLIANCE SERVICES, INC. cannot anticipate nor control the many situations in which the product or this information may be used; there is no guarantee that the health and safety precautions suggested will be proper under all conditions. It is the sole responsibility of each user of the product to determine and comply with the requirements of all applicable laws and regulations regarding its use. This information is given solely for the purposes of safety to persons and property. Any other use of this information is expressly prohibited.

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MSDS prepared by:
David W. Boston
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Revision date: 12/12/05
12/03/03

Appendix D - Hazardous Material Operating Procedures

Igniter:

- ❏ Store in cool, dry place away from heat or flame. An explosives box is the preferred method of storage.
- ❏ Avoid extensive contact with skin; do not ingest or rub in eyes.
- ❏ Wear Personal Protective Equipment (PPE) when handling, including safety glasses and lab gloves. Also be sure to wear clothing safe for pyrotechnics.
- ❏ Do not rub or abruptly hit as friction or impact can cause ignition.
- ❏ Dispose of spent materials and packaging in inert trash.

Rocket Motor:

- ❏ Store in cool, dry place away from heat or flame. Explosives box is required.
- ❏ Do not handle directly. The team's NAR mentor will handle the purchase and transport of all motors.
- ❏ Avoid contact via skin, eyes, or mouth.
- ❏ Wear safety glasses and pyrotechnic safe clothing at all times when near the motor in case of unexpected ignition.
- ❏ Do not rub or abruptly hit as friction or impact can cause ignition.
- ❏ Dispose of spent materials and packaging in inert trash.

Fiberglass:

- ❏ Store and handle only in well-ventilated areas.
- ❏ Do not breathe in dust; fibers are damaging to lungs. Avoid extensive contact with skin as fibers can also cause skin irritation.
- ❏ Wear PPE when handling, including safety glasses, lab gloves, and respirator. Sleeves are also recommended.
- ❏ Dispose of spent materials in inert trash. Do not release materials into waterways.

Epoxy:

- ❏ Store in cool, dry place.
- ❏ Avoid contact with skin or eyes. Do not breathe in any vapor or fumes epoxy may produce.
- ❏ Wear PPE when handling, including safety glasses and lab gloves.
- ❏ Wash hands thoroughly after working with or handling epoxy and before eating.
- ❏ Dispose of excess epoxy and containers in inert trash.

Spray Paint:

- ❑ Keep containers tightly closed and store in cool, dry place away from sources of heat or flame.
- ❑ Store and use only in well-ventilated areas.
- ❑ Avoid breathing fumes or mist. Avoid contact with eyes and skin. Paint can stain clothing; bear this in mind when handling.
- ❑ Wear PPE when handling, including safety glasses, lab gloves, and respirator.
- ❑ Wash hands thoroughly after working with or handling paint and before eating.
- ❑ Do not allow disposal into waterways.
- ❑ Dispose of excess paint and containers in inert trash.

Black Powder:

- ❑ Store only in cool, dry place away from sources of heat or flame. Explosives box storage required.
- ❑ Wear PPE when handling, including safety glasses and lab gloves. Avoid ingestion or contact with skin or eyes.
- ❑ Do not rub or hit as friction or impact can cause ignition.
- ❑ Dispose of excess or spent powder in inert trash.

Appendix E - Weighted Ratings Tables

Weighted Rating of Flight Controller							
		Raspberry Pi 2		**Arduino Uno**		**Beagleboard**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
USB Ports	17	5	0.85	1	0.17	1	0.17
RAM	17	5	0.85	1	0.17	2	0.34
GPU	20	5	1	1	0.2	3	0.6
Power Consumption	12	2	0.24	5	0.6	5	0.6
Size	12	4	0.48	5	0.6	4	0.48
Weight	12	4	0.48	5	0.6	4	0.48
Cost	10	4	0.4	5	0.5	1	0.1
Total	100	NA	4.3	NA	2.84	NA	2.77

Weighted Rating of Camera							
		Pixy CMUcam5		**5MP Camera Module**		**NoIR Camera Module**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Resolution	10	3	0.3	5	0.5	5	0.5
Size	30	5	1.5	5	1.5	5	1.5
Interface Options	20	5	1	2	0.4	2	0.4
Processing Speed	20	5	1	3	0.6	3	0.6
Weight	10	2	0.2	5	0.5	5	0.5
Cost (total)	10	2	0.2	5	0.5	4	0.4
Total	100	NA	4.2	NA	4	NA	3.9

Weighted Rating of GPS					
		Adafruit Ultimate GPS Breakout		**GlobalSat BU-353 S4 GPS**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Sensitivity	10	5	0.5	4	0.4
Position Accuracy	15	4	0.6	5	0.75
Velocity Accuracy	15	4	0.6	4	0.6
Reacquisition rate	16	4	0.64	4	0.64
Size	16	4	0.64	3	0.48
Weight	16	5	0.8	2	0.32
Cost (total)	12	3	0.36	2	0.24
Total	100	NA	4.14	NA	3.43

Weighted Rating of Communications Device					
		XBee Pro 900		**XBee Pro 60mW**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Range	40	5	2	1	0.4
Data rate	20	4	0.8	5	1
Power Consumption	15	4	0.6	4	0.6
Size	15	4	0.6	5	0.75
Cost (total)	10	3	0.3	4	0.4
Total	100	NA	4.3	NA	3.15

Weighted Rating of Orientation Device					
		MinIMU-9 v3		**AltIMU-10 v4**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Gyro Accuracy	22	4	0.88	4	0.88
Accelerometer Accuracy	22	4	0.88	4	0.88
Magnetometer Accuracy	20	4	0.8	4	0.8
Barometer Accuracy	22	1	0.22	4	0.88
Cost (total)	14	4	0.56	3	0.42
Total	100	NA	3.34	NA	3.86

Weighted Rating of Storage Device							
		Samsung 250 GB SSD		**Transcend 256 GB SSD**		**SanDisk 240 GB SSD**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Storage Capacity	30	4	1.2	4	1.2	3	0.9
Size	30	4	1.2	3	0.9	2	0.6
Weight	25	4	1	3	0.75	2	0.5
Cost (total)	15	3	0.45	4	0.6	3	0.45
Total	100	NA	3.85	NA	3.45	NA	2.45

Weighted Rating of Battery System							
		2 6V Lantern Batteries (26000mAh)		**USB Battery Pack for Raspberry Pi (3300mAh) & 4s LiPo battery (6000mAh)**		**USB Battery Pack for Raspberry Pi (4400mAh) & 4s LiPo battery (5000mAh)**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Overall Storage Capacity	25	5	1.25	3	0.75	3	0.75
Size	25	1	0.25	4	1	5	1.25
Weight	25	2	0.5	3	0.75	4	1
Rechargeability	20	1	0.2	5	1	5	1
Cost	5	5	0.25	2	0.1	3	0.15
Total	100	NA	2.45	NA	3.6	NA	4.15

Weighted Rating of Servo Motors							
		HS-645MG Ultra Torque		**Power HD AR-1201MG Robot Servo**		**Continuous Rotation Servo - FeeTech FS5103R**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Stall Torque	15	3	0.45	5	0.75	1	0.15
Operating Voltage	10	4	0.4	4	0.4	4	0.4
Operating Speed	15	4	0.6	4	0.6	3	0.45
Rotation Angle	25	5	1.25	2	0.5	5	1.25
Size	15	4	0.6	4	0.6	2	0.3
Weight	15	3	0.45	3	0.45	5	0.75
Cost (total)	5	1	0.05	5	0.25	4	0.2
Total	100	NA	3.8	NA	3.55	NA	3.5

Weighted Rating of Payload Control System							
		Parafoil		Traditional Parachute		Deployable Glider Wings	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Reliable Deployment	25	5	1.25	5	1.25	1	0.25
Control	25	5	1.25	1	0.25	4	1
Descent Speed	25	4	1	5	1.25	2	0.5
Weight	15	5	0.75	5	0.75	2	0.3
Cost (total)	10	4	0.4	5	0.5	2	0.2
Total	100	NA	4.65	NA	4	NA	2.25

Weighted Rating of Calf Wall Thickness											
		Solid Rectangle		Hollow (t=.2 in)		Hollow (t=.15 in)		Hollow (t=.1 in)		Hollow (t=.05 in)	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Yield Force	65	5	3.25	5.0	3.2	4.8	3.1	4.2	2.7	2.7	1.8
Mass	35	0	0	0.5	0.2	1.3	0.5	2.3	0.8	3.5	1.2
Total	100	NA	3.3	NA	3.4	NA	3.6	NA	3.5	NA	3.0

Weighted Rating of Thigh Wall Thickness											
		Solid Rectangle		Hollow (t=.2 in)		Hollow (t=.15 in)		Hollow (t=.1 in)		Hollow (t=.05 in)	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Yield Force	65	5.0	3.3	5.0	3.2	4.8	3.1	4.1	2.7	2.7	1.7
Mass	35	0.0	0.0	0.6	0.2	1.5	0.5	2.4	0.9	3.6	1.3
Total	100	NA	3.3	NA	3.5	NA	3.6	NA	3.5	NA	3.0

Appendix G - Test Procedure Forms

The following test procedure forms are stored in Adobe Forms, so that the test personnel can easily log the test data.

G.1 - Verify that Pi will run from the SSD

Test Procedure:	Verify Raspberry Pi will run from the SSD
Test Category:	Component
Test Subsystem:	Control
Test Components:	Samsung Solid State Drive
Required Components:	Raspberry Pi 2, Solid State Drive
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Follow the steps listed at https://learn.adafruit.com/external-drive-as-raspberry-pi-root/overview to set up Raspberry Pi 2 to run from SSD
2. Set-up
   a. Connect SSD to Raspberry Pi 2 via USB port
3. Test Procedure
   a. Power on Raspberry Pi 2
   b. Confirm Raspberry Pi 2 will run from the SSD
4. Break-down
   a. Unplug SSD from Raspberry Pi 2
   b. Store SSD in packaging

Test Results:

Does the Raspberry Pi 2 run from SSD? ☐

G.2 - Calibrate and Test AltIMU

Test Procedure:	AltIMU-10 Component Test
Test Category:	Component
Test Subsystem:	Control
Test Components:	AltIMU-10 V4
Required Components:	Raspberry Pi 2, Breadboard, Pi Cobbler
Test Personnel:	
Safety Hazards:	Electricity
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Follow the steps listed at http://blog.davidegrayson.com/2012/11/orientation-sensing-with-raspberry-pi.html to prepare the Pi for the AltIMU to connect through the I2C interface
2. Set-up
   a. Put the the four header pins of the AltIMU into the breadboard.
   b. Wire the GND pin of the AltIMU to the ground pin (#6) of the Pi Cobbler
   c. Wire the VDD pin of the AltIMU to the 3.3V power pin (#1) of the Pi Cobbler
   d. Wire the SCL pin of the AltIMU to the GPIO 3 pin (#5) of the Pi Cobbler
   e. Wire the SDA pin of the AltIMU to the GPIO 2 pin (#3) of the Pi Cobbler
   f. Attach the Pi Cobbler to the GPIO pins of the Raspberry Pi 2
   g. Verify that the AltIMU is properly connected by running **i2cdetect –y 1**
   h. Follow the tutorial at https://github.com/DavidEGrayson/minimu9-ahrs/wiki to calibrate the sensors on the AltIMU
3. Test Procedure
   a. Place the AltIMU on a table with the Z axis facing down, and the X axis facing magnetic North. This is the "home" position. Output the Euler angles using **altimu10-ahrs –output euler.** Verify that the angles are close to zero.
   b. Rotate the board about the X-axis, stopping to check the output every 90® until the AltIMU returns to the home position. This is "roll."
   c. Rotate the board about the Y-axis, stopping to check the output every 90® until the AltIMU returns to the home position. This is "pitch."

   d. Rotate the board about the Z-axis, stopping to check the output every 90° until the AltIMU returns to the home position. This is "yaw."
4. Break-down
   a. Detach the wires. Remove the Pi Cobbler and the AltIMU and carefully return them to their packaging.

Test Results:

I2cdetect verification? ☐

X- Rotation/Roll:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

Y- Rotation/Pitch:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

Z- Rotation/Yaw:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

G.3 - Transmit test data through XBee

Test Procedure:	XBee Communications Test
Test Category:	Component
Test Subsystem:	Landing Hazards Detection
Test Components:	XBee Pro 900 RPSMA
Required Components:	Raspberry Pi 2, XBee Pro 900 RPSMA, 900MHz Duck Antenna, XBee Explorer Dongle
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Initialize both XBees with X-CTU
2. Set-up
   a. Connect both XBees to separate Sparkfun XBee Explorer Dongles
   b. Connect one Explorer Dongle to Raspberry Pi 2
   c. Connect second Explorer Dongle to computer
3. Test Procedure
   a. Run python code to send text files and picture files from Raspberry Pi 2
   b. Run python code or use X-CTU to receive test files
4. Break-down
   a. Unplug Explorer Dongle from Raspberry Pi 2 and computer
   b. Remove XBees from Explorer Dongles
   c. Place back in packaging

Test Results:

File Type	File Size (KB)	Transfer Time (s)	Transfer Success?

G.4 - Run Test Image through Hazard Detections Software

Test Procedure:	Hazard Detection Software Test
Test Category:	Component
Test Subsystem:	Hazard Detection
Test Components:	None
Required Components:	Raspberry Pi 2
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Write code to analyze picture for hazards
2. Set-up
   a. Power Raspberry Pi 2
   b. Add code to Raspberry Pi 2
3. Test Procedure
   a. Run test images through code
4. Break-down
   a. No break-down required

Test Results:

Inputs	Ouputs	Hazards Detected?	Notes:

G.5 - Test Stationary GPS

Test Procedure:	Stationary GPS Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	Adafruit Ultimate GPS Breakout

Required Components: Raspberry Pi 2, Breadboard, USB to TTL Cable, Adafruit Ultimate GPS Breakout

Test Personnel:

Safety Hazards: Electricity

Mitigating Equipment: None

Test Procedure:

1. Pre-Test
   a. Follow steps listed at https://learn.adafruit.com/adafruit-ultimate-gps-on-the-raspberry-pi to prepare the Pi for the GPS
2. Set-up
   a. Put the header pins of the GPS into the breadboard
   b. Attach wires to the end of TTL cable
   c. Wire GND pin of the GPS to the ground wire of the TTL cable
   d. Wire VIN pin of the GPS to the VIN wire of the TTL cable
   e. Wire RX pin of the GPS to the RX wire of the TTL cable
   f. Wire TX pin of the GPS to the TX wire of the TTL cable
3. Test Procedure
   a. Use **cgps –s** to verify that the GPS has a fix on its location
   b. Use code supplied by Adafruit to receive time, altitude, speed, climb, latitude, longitude, and heading
4. Break-down
   a. Detach the wires. Remove GPS from breadboard. Return all components to their packaging

Test Results:

Fix? ☐

Category	Expected Value	Actual Value	% Difference
Time			
Altitude			
Speed			
Climb			
Latitude			
Longitude			
Heading			

G.6 - Parafoil Drop Test

Test Procedure:	Parafoil Drop Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	Parafoil
Required Components:	Parafoil, Dummy weight
Test Personnel:	
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Caution Tape

Test Procedure:

1. Pre-Test
    a. Create a dummy weight with a mass as close to the payload as possible
2. Set-up
    a. Connect Parafoil lines to the top of the dummy weight
    b. Adjust and record the angle of attack
    c. Measure the height the parafoil system will be dropped from
    d. Make sure no bystanders are in the drop area
    e. Put up caution tape around drop area to prevent bystanders from entering
3. Test Procedure
    a. Drop the parafoil
    b. Record the time it takes for the parafoil to reach the ground, this will be used to calculate the average velocity
    c. Record the distance the parafoil glided, this will be used to calculate the gliding ratio
4. Break-down
    a. Detach the parafoil from the dummy weight
    b. Make sure there are no tangles in the lines
    c. Carefully pack the parafoil

Test Results:

Run	Horizontal Distance	Hang Time	Notes:
1			
2			
3			
4			
5			
Average			

G.7 - Test Servo Motors

Test Procedure:	Servo Motor Component Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	HS-645MG Ultra Torque Servo Motor
Required Components:	Raspberry Pi, PWM/Servo Driver, Servo Motor
Test Personnel:	
Safety Hazards:	Electricity
Mitigating Equipment:	none

Test Procedure:

1. Pre-Test
   a. Follow steps listed at https://learn.adafruit.com/adafruits-raspberry-pi-lesson-8-using-a-servo-motor/overview to prepare the Pi for the PWM/Servo Driver
2. Set-up
   a. Wire the VDD pin of the servo to the 5V pin of the Pi Cobbler
   b. Wire the GND pin of the servo to the GND pin of the Pi Cobbler
   c. Wire the PWM pin of the servo to the PWM pin of the Pi Cobbler
3. Test Procedure
   a. Send pulse to the servo motor
   b. Record the duration of the pulse
   c. Record the angle of rotation
4. Break-down
   a. Detach the wires. Remove the PWM/Servo Driver and the servo motors and carefully return them to their packaging

Test Results:

Pulse Duration	Angle of Rotation

G.8 - Test Pixy CMUCam5

Test Procedure:	Pixy CMUcam5 Test
Test Category:	Component
Test Subsystem:	Landing Hazard Detection
Test Components:	Pixy CMUcam5
Required Components:	Raspberry Pi 2, Pixy CMUcam5
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Use http://cmucam.org/projects/cmucam5/wiki/Hooking_up_Pixy_to_a_Raspberry_Pi to set up Raspberry Pi for Pixy use
2. Set-up
   a. Connect Pixy to Pi via USB
3. Test Procedure
   a. Take test images from the Pixy CMUcam5
4. Break-down
   a. Disconnect Pixy from Raspberry Pi and store

Test Results:

Did the Pixy take pictures? ☐

G.9 - Parafoil Deployment Test

Test Procedure:	Parafoil Deployment Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	Parafoil
Required Components:	Parafoil, Dummy weight
Test Personnel:	
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Deep Sea Fishing Line

Test Procedure:

1. Pre-Test
   a. Create a dummy weight with a mass as close to the payload as possible
2. Set-up
   a. Connect Parafoil lines to the top of the dummy weight
   b. Pack parafoil in manner to be tested
   c. Set angle of attack to preferred value
   d. Measure the height the parafoil system will be dropped from
   e. Cut a length of fishing line 10 feet shorter than the drop height
   f. Connect fishing line to the top of the dummy weight
3. Test Procedure
   a. Drop the parafoil
   b. Record how the parafoil deployed or if the parafoil failed to deploy
4. Break-down
   a. Detach the parafoil from the dummy weight
   b. Make sure there are no tangles in the lines
   c. Carefully pack the parafoil
   d. Detach the fishing line from the dummy weight

Test Results:

Run	Deployment Height	Notes:
1		
2		
3		
4		
5		

G.10 - Test GPS and AltIMU while in Motion and Send Data from XBee

Test Procedure:	GPS, AltIMU, and XBee Motion Test
Test Category:	Ground
Test Subsystem:	Control, Landing Hazards Detection, Guided Descent
Test Components:	Ultimate GPS Breakout, AltIMU-10 v4, XBee 900 Pro RPSMA
Required Components:	Ultimate GPS Breakout, AltIMU, XBee, XBee Explorer Dongle, Raspberry Pi 2, Breadboard, TTL to USB cable, Pi Cobbler
Test Personnel:	
Safety Hazards:	Electricity
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Write code for Pi to run GPS, AltIMU, and XBee autonomously
2. Set-up
   a. Connect Pi Cobbler to breadboard
   b. Connect a XBee and Explorer Dongle to Raspberry Pi and one to a computer
   c. Connect AltIMU to breadboard
   d. Connect TTL to USB cable to breadboard and to the Raspberry Pi 2
   e. Connect GPS to breadboard
3. Test Procedure
   a. Drive around campus with setup in car
   b. Rotate AltIMU and receive attitude
   c. Receive acceleration and altitude from AltIMU
   d. Receive time, speed, altitude, longitude, latitude, and heading from GPS
   e. Send AltIMU data and GPS data to remote computer via XBee
4. Break-down
   a. Unplug XBee and Explorer Dongle from Raspberry Pi
   b. Disconnect wires
   c. Remove GPS and AltIMU from breadboard
   d. Return components to packaging

Test Results: ☐

Fix on GPS? ☐

Was data sent? ☐

Receive GPS data? ☐

Receive AltIMU data? ☐

G.11 - Test Complete Payload Electronics System

Test Procedure:	Complete Payload Electronics Test
Test Category:	Ground
Test Subsystem:	Payload Control, Landing Hazards Detection, Guided Descent
Test Components:	Raspberry Pi 2, Samsung Solid State Drive, XBee Pro 900 RPSMA, Ultimate GPS Breakout, Ultra Torque Servos, AltImu-10 v4, Servoless Payload Release, Pixy CMUcam5
Required Components:	Raspberry Pi 2, Samsung Solid State Drive, XBee Pro 900 RPSMA, XBee Explorer Dongle, Ultimate GPS Breakout, Ultra Torque Servos, AltImu-10 v4, Servoless Payload Release, Pixy CMUcam5, 900MHz Duck Antenna, GPS Antenna, USB to TTL cable, Pi Cobbler Plus, I^2C board, Breadboard
Test Personnel:	
Safety Hazards:	Electricity
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a.
2. Set-up
    a. Connect SSD to Raspberry Pi 2 via USB
    b. Connect a 900MHz Duck Antenna to each XBee
    c. Connect one XBee and Explorer Dongle to Computer and one to Raspberry Pi 2
    d. Connect GPS antenna to Ultimate GPS Breakout
    e. Connect GPS to TTL to USB cable and plug USB into Raspberry Pi 2
    f. Connect Pixy CMUcam5 to Raspberry Pi 2 via USB
    g. Connect Pi Cobbler to breadboard
    h. Connect Servos to I^2C board
    i. Connect Servoless Payload Release to VIN, GND, and GPIO pins
    j. Connect AltImu-10 v4 to breadboard
3. Test Procedure
    a. Run Raspbian from SSD
    b. Send test text files and test image files from Raspberry Pi to ground station computer
    c. Verify that GPS can get a fix on its location and receive wanted information
    d. Take pictures with Pixy CMUcam5

    e. Control servos with python code
    f. "Release" payload by controlling Servoless Payload Release
    g. Rotate AltIMU about X, Y, and Z axes and check output every 90°
4. Break-down
    a. Unplug all USB components
    b. Detach all wires
    c. Store all components

Test Results: ☐

Did Raspbian run from SSD? ☐

Were test files sent? ☐

Were test files received? ☐

Able to get a fix on GPS? ☐

Were pictures taken? ☐

Did servos move as intended? ☐

Did servoless payload release unlock? ☐

X- Rotation/Roll:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

Y- Rotation/Pitch:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

Z- Rotation/Yaw:

Actual Rotation	Listed Rotation
0	
90	
180	
270	

G.12 - Measure Leg Spring Forces

Test Procedure:	Landing Spring Force Test
Test Category:	Subsystem Testing
Test Subsystem:	Landing
Test Components:	Hinge and Springs
Required Components:	Thigh, Calf, and Feet
Test Personnel:	
Safety Hazards:	Flying objects and sharp objects
Mitigating Equipment:	Gloves

Test Procedure:

1. Pre-Test
   a. Create a dummy payload to attach the hinge to.
2. Set-up
   a. Attach the thigh to the payload by screwing the hinge into each.
   b. Use the 180° springs to attach the thigh to each calf.
   c. Use the 90° springs to attach each foot to the correct calf.
3. Test Procedure
   a. With the thigh attached to the payload make these measurements use a Newton scale to measure the force required to have the thigh in position for launch.
   b. With the thigh and calves attached measure the force required to have the calf in position for launch.
   c. With the calf and feet attached measure the force required to have the feet in position for launch.
   d. With the legs fully assembled measure the amount of force required to achieve each angle (angle is defined as from the payload to the thigh). The force should be applied at the feet.
   e. Measure the amount of force required to hold the entire assembly flat against the payload. This measurement should be done from 8 inches above the hinge.
4. Break-down
   a. Carefully remove all springs and place the springs back in their respective bags.

Test Results:

Individual Spring Forces	
Spring	Force (lb)
Hinge (Thigh to launch position)	
180° Spring (Calf to launch position)	
90° Spring (Feet to calf position)	

Assembly Forces	
Degree	Force (lb)
100°	
90°	
70°	
60°	
45°	

G.13 - Leg Deployment Test

Test Procedure:	Leg Deployment Test
Test Category:	Subsystem
Test Subsystem:	Landing
Test Components:	Payload release, fiber glass ring
Required Components:	Hinge, springs, calf, legs, and feet
Test Personnel:	
Safety Hazards:	Fast moving parts
Mitigating Equipment:	Payload release will be controlled from a distance.

Test Procedure:

1. Pre-Test
    a. Test payload release capability.
2. Set-up
    a. Fully assemble all legs and attach to dummy payload.
        i. Attach thigh to payload using hinge and screws.
        ii. Attach thigh and calves using 180° spring.
        iii. Attach each foot to a calf using 90° spring.
        iv. Repeat 5 times.
    b. Suspend payload and legs in the air to simulate release timing.
3. Test Procedure
    a. Place legs into launch position.
        i. Pull all legs up and attach payload releases.
    b. Clear the area.
    c. Wait 10 minutes to ensure that legs are stable and will not deploy while waiting for launch.
    d. Initiate payload release.
        i. If unsuccessful identify issue, adjust, and repeat from start.
    e. Repeat release process until successful without issue.
4. Break-down
    a. Remove payload from suspension system.
    b. Remove legs from payload, legs can remain intact.

Test Results:

Did legs release prematurely? ☐

Did legs release when payload release was initiated? ☐

G.14 - Low Altitude Turning Drop Test

Test Procedure:	Low Altitude Turning Drop Test
Test Category:	Subsystem
Test Subsystem:	Guided Descent
Test Components:	Parafoil, Servo Motors
Required Components:	Parafoil, Servo Motors, Dummy Weight
Test Personnel:	
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Caution Tape

Test Procedure:

1. Pre-Test
   a. Create a dummy weight with a mass as close to the payload as possible
2. Set-up
   a. Connect Parafoil lines to the top of the dummy weight
   b. Connect trailing edge toggle lines to servo motors
   c. Set angle of attack to preferred value
   d. Set and record angle of each servo motor
   e. Measure and record the height to be dropped from
   f. Put up caution tape around drop area to prevent bystanders from entering
3. Test Procedure
   a. Drop the parafoil
   b. Measure and record the turn radius of parafoil
4. Break-down
   a. Remove trailing edge toggle lines from servo motors
   b. Detach the parafoil from the dummy weight
   c. Make sure there are no tangles in the lines
   d. Carefully pack the parafoil

Test Results:

Drop Height

Drop #	Angle of left servo	Angle of right servo	Turning radius
Drop 1			
Drop 2			
Drop 3			
Drop 4			
Drop 5			
Drop 6			
Drop 7			
Drop 8			
Drop 9			
Drop 10			
Drop 11			
Drop 12			
Drop 13			
Drop 14			
Drop 15			

G.15 - Battery Test on Complete Payload

Test Procedure:	Battery test on complete payload
Test Category:	Prototype
Test Subsystem:	All
Test Components:	All
Required Components:	All
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
   a. Carefully configure payload
2. Set-up
   a. Fully charge both batteries
3. Test Procedure
   a. Run all systems on payload
   b. Record time systems run before batteries deplete
4. Break-down
   a. Carefully store payload

Test Results:

Test #	Turnigy nan-tech 6600mAh run time	Turnigy 5000 mAh 14.8 V run time
Test 1		
Test 2		
Test 3		
Test 4		
Test 5		

G.16 - Flare Maneuver Test

Test Procedure:	Flare Maneuver Test
Test Category:	Prototype
Test Subsystem:	Guided Descent
Test Components:	Parafoil
Required Components:	Parafoil, AltIMU, Raspberry Pi, Servo Motors
Test Personnel:	
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Caution Tape

Test Procedure:

1. Pre-Test
    a. Program Raspberry Pi to activate servo motors when payload reaches 20 feet
2. Set-up
    a. Connect parafoil lines to the top of the payload
    b. Connect trailing edge lines to servo motors
    c. Set angle of attack to preferred value
    d. Measure the height the parafoil system will be dropped from
    e. Make sure no bystanders are in the drop area
    f. Put up caution tape around drop area to prevent bystanders from entering
3. Test Procedure
    a. Drop the parafoil
    b. Use data gathered by the AltIMU to track the velocity of the payload as it falls
    c. Record the difference in velocity at the beginning and end of flare maneuver in the **x**, **y**, and z directions
    d. Evaluate effect of flare maneuver on velocity of payload
4. Break-down
    a. Detach the parafoil from the dummy payload
    b. Detach parafoil lines from servo motors
    c. Make sure there are no tangles in the lines
    d. Carefully pack the parafoil

Test Results:

Drop #	ΔV_X	ΔV_Y	ΔV_Z	Notes
Drop 1				
Drop 2				
Drop 3				
Drop 4				
Drop 5				
Drop 6				
Drop 7				
Drop 8				
Drop 9				
Drop 10				
Drop 11				
Drop 12				
Drop 13				
Drop 14				
Drop 15				

G.17 - Landing Legs Test

Test Procedure: Landing Legs Test

Test Category: Prototype

Test Subsystem: Landing

Test Components: Thigh, calf, feet, spring, hinges

Required Components:

Test Personnel:

Safety Hazards: Falling objects

Mitigating Equipment: Caution tape

Test Procedure:

1. Pre-Test
    a. Test that the string is strong enough to hold the payload weight with assembled legs.
2. Set-up
    a. Create a clear space in a grassy area to perform drop test.
    b. Set up a ladder in this area.
3. Test Procedure
    a. Attach a string to the top of the payload.
    b. With the legs deployed, lift the payload up to a height of approximately 2 feet.
    c. With the area clear drop the payload.
    d. Check legs for any negative effects of the drop.
    e. Repeat drop test.
4. Break-down
    a. Remove ladder from area and disassemble leg setup.

Test Results:

Drop #	Landing Successful? (Y/N)	Negative Effects? (Y/N)
Drop 1		
Drop 2		
Drop 3		
Drop 4		
Drop 5		

G.18 - Weather Balloon Drop Test

Test Procedure:	Weather Balloon Drop Test
Test Category:	Prototype
Test Subsystem:	All
Test Components:	All
Required Components:	All, Weather Balloon
Test Personnel:	
Safety Hazards:	If parafoil fails to deploy, ballistic descent
Mitigating Equipment:	Safe area to drop payload

Test Procedure:

1. Pre-Test
    a. Complete coding for Raspberry Pi
    b. Carefully configure payload
2. Set-up
    a. Carefully pack parafoil
    b. Attach payload to release mechanism on weather balloon
    c. Inflate weather balloon
3. Test Procedure
    a. Release payload when test height is reached
    b. Record all data received from payload during descent
    c. Record performance of landing legs
    d. Record distance between payload's landing position and landing target
4. Break-down
    a. Collect debris from weather balloon
    b. Carefully store payload

Test Results:

Drop #	Data Transmitted (Y/N)	Hazards Detected (Y/N)	Landing Successful (Y/N)	Distance from Target
Drop 1				
Drop 2				
Drop 3				
Drop 4				
Drop 5				

G.19 - Shake Table Test

Test Procedure:	Shake table test
Test Category:	Prototype
Test Subsystem:	All
Test Components:	All
Required Components:	All
Test Personnel:	
Safety Hazards:	Listed shake table hazards
Mitigating Equipment:	Follow shake table guidelines

Test Procedure:

1. Pre-Test
    a. Become familiar with shake table and how to operate correctly.
2. Set-up
    a. Fully assemble payload with legs in launch position.
3. Test Procedure
    a. Turn on shake table for 25 seconds to simulate launch.
    b. Check if there were any detrimental effects from the test.
    c. Repeat as necessary
4. Break-down
    a. Disassemble payload and cleanup work space.

Test Results:

Were there any detrimental effects from the shake test? Yes ◯ No ◯

If so, what went wrong and how was it fixed?

G.20 - Complete Payload Test

Test Procedure:	Complete Payload Test
Test Category:	Full-Scale
Test Subsystem:	All
Test Components:	All
Required Components:	All, Rocket
Test Personnel:	
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Safe area to drop payload

Test Procedure:

1. Pre-Test
   a. Carefully configure payload
2. Set-up
   a. Carefully pack parafoil
   b. Pack payload inside of rocket
3. Test Procedure
   a. Launch rocket
   b. Deploy payload at apogee
   c. Record all data received from payload descent
   d. Record performance of landing legs
   e. Record distance between payload's landing position and landing target
4. Break-down
   a. Carefully store payload

Test Results:

Drop #	Data Transmitted (Y/N)	Hazards Detected (Y/N)	Landing Successful (Y/N)	Distance from Target
Drop 1				
Drop 2				
Drop 3				
Drop 4				
Drop 5				

Appendix H - Completed Test Procedure Forms

The following forms are for the test procedures that have been completed.

H.1 - Verify that the Pi will run from the SSD

Test Procedure:	Verify Raspberry Pi will run from the SSD
Test Category:	Component
Test Subsystem:	Control
Test Components:	Samsung Solid State Drive
Required Components:	Raspberry Pi 2, Solid State Drive
Test Personnel:	Ryan Weiner
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a. Follow the steps listed at https://learn.adafruit.com/external-drive-as-raspberry-pi-root/overview to set up Raspberry Pi 2 to run from SSD
2. Set-up
    a. Connect SSD to Raspberry Pi 2 via USB port
3. Test Procedure
    a. Power on Raspberry Pi 2
    b. Confirm Raspberry Pi 2 will run from the SSD
4. Break-down
    a. Unplug SSD from Raspberry Pi 2
    b. Store SSD in packaging

Test Results:

Does the Raspberry Pi 2 run from SSD? ☑

H.2 – Calibrate and Test AltIMU

Test Procedure:	AltIMU-10 Component Test
Test Category:	Component
Test Subsystem:	Control
Test Components:	AltIMU-10 V4
Required Components:	Raspberry Pi 2, Breadboard, Pi Cobbler
Test Personnel:	Mark Koren
Safety Hazards:	Electricity
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a. Follow the steps listed at http://blog.davidegrayson.com/2012/11/orientation-sensing-with-raspberry-pi.html to prepare the Pi for the AltIMU to connect through the I2C interface
2. Set-up
    a. Put the the four header pins of the AltIMU into the breadboard.
    b. Wire the GND pin of the AltIMU to the ground pin (#6) of the Pi Cobbler
    c. Wire the VDD pin of the AltIMU to the 3.3V power pin (#1) of the Pi Cobbler
    d. Wire the SCL pin of the AltIMU to the GPIO 3 pin (#5) of the Pi Cobbler
    e. Wire the SDA pin of the AltIMU to the GPIO 2 pin (#3) of the Pi Cobbler
    f. Attach the Pi Cobbler to the GPIO pins of the Raspberry Pi 2
    g. Verify that the AltIMU is properly connected by running **i2cdetect –y 1**
    h. Follow the tutorial at https://github.com/DavidEGrayson/minimu9-ahrs/wiki to calibrate the sensors on the AltIMU
3. Test Procedure
    a. Place the AltIMU on a table with the Z axis facing down, and the X axis facing magnetic North. This is the "home" position. Output the Euler angles using **altimu10-ahrs –output euler.** Verify that the angles are clost to zero.
    b. Rotate the board along the X-axis, stopping to check the output every 90° until the AltIMU returns to the home position. This is "roll."
    c. Rotate the board along the Y-axis, stopping to check the output every 90° until the AltIMU returns to the home position. This is "pitch."

d. Rotate the board along the Z-axis, stopping to check the output every 90° until the AltIMU returns to the home position. This is "yaw."

4. Break-down
   a. Detach the wires. Remove the Pi Cobbler and the AltIMU and carefully return them to their packaging.

Test Results:

I2cdetect verification? ☑

X- Rotation/Roll:

Actual Rotation	Listed Rotation
0	0.0
90	89.7
180	180.5
270	270.1

Y- Rotation/Pitch:

Actual Rotation	Listed Rotation
0	0.0
90	90.2
180	179.9
270	269.6

Z- Rotation/Yaw:

Actual Rotation	Listed Rotation
0	0.0
90	90.4
180	180.2
270	270.2

H.3 - Transmit test date through Xbee

Test Procedure:	XBee Communications Test
Test Category:	Component
Test Subsystem:	Landing Hazards Detection
Test Components:	XBee Pro 900 RPSMA
Required Components:	Raspberry Pi 2, XBee Pro 900 RPSMA, 900MHz Duck Antenna, XBee Explorer Dongle
Test Personnel:	Ryan Weiner
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a. Initialize both XBees with X-CTU
2. Set-up
    a. Connect both XBees to separate Sparkfun XBee Explorer Dongles
    b. Connect one Explorer Dongle to Raspberry Pi 2
    c. Connect second Explorer Dongle to computer
3. Test Procedure
    a. Run python code to send text files and picture files from Raspberry Pi 2
    b. Run python code or use X-CTU to receive test files
4. Break-down
    a. Unplug Explorer Dongle from Raspberry Pi 2 and computer
    b. Remove XBees from Explorer Dongles
    c. Place back in packaging

Test Results:

File Type	File Size (KB)	Transfer Time (s)	Transfer Success?
txt file	6.5	3	Yes
png file	2	13	No

H.4 - Test Stationary GPS

Test Procedure: Stationary GPS Test

Test Category: Component

Test Subsystem: Guided Descent

Test Components: Adafruit Ultimate GPS Breakout

Required Components: Raspberry Pi 2, Breadboard, USB to TTL Cable, Adafruit Ultimate GPS Breakout

Test Personnel: Ryan Weiner

Safety Hazards: Electricity

Mitigating Equipment: None

Test Procedure:

1. Pre-Test
    a. Follow steps listed at https://learn.adafruit.com/adafruit-ultimate-gps-on-the-raspberry-pi to prepare the Pi for the GPS
2. Set-up
    a. Put the header pins of the GPS into the breadboard
    b. Attach wires to the end of TTL cable
    c. Wire GND pin of the GPS to the ground wire of the TTL cable
    d. Wire VIN pin of the GPS to the VIN wire of the TTL cable
    e. Wire RX pin of the GPS to the RX wire of the TTL cable
    f. Wire TX pin of the GPS to the TX wire of the TTL cable
3. Test Procedure
    a. Use **cgps –s** to verify that the GPS has a fix on its location
    b. Use code supplied by Adafruit to receive time, altitude, speed, climb, latitude, longitude, and heading
4. Break-down
    a. Detach the wires. Remove GPS from breadboard. Return all components to their packaging

Test Results:

Fix? ☑

Category	Expected Value	Actual Value	% Difference
Time	03/01/2016, 21:32:21	03/01/2016, 21:32:21	0
Altitude	66.67 m	121.4 m	82.1
Speed	0 kph	0.4 kph	
Climb	0 m/min	-6 m/min	
Latitude	33.213484 deg	33.213486667 deg	0.000008
Longitude	-87.544604 deg	-87.54447 deg	0.00179
Heading		146.6 deg	

H.5 - Parafoil Drop Test

Test Procedure:	Parafoil Drop Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	Parafoil
Required Components:	Parafoil, Dummy weight
Test Personnel:	Nick Kling/Harrison Hughes
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Caution Tape

Test Procedure:

1. Pre-Test
   a. Create a dummy weight with a mass as close to the payload as possible
2. Set-up
   a. Connect Parafoil lines to the top of the dummy weight
   b. Adjust and record the angle of attack
   c. Measure the height the parafoil system will be dropped from
   d. Make sure no bystanders are in the drop area
   e. Put up caution tape around drop area to prevent bystanders from entering
3. Test Procedure
   a. Drop the parafoil
   b. Record the time it takes for the parafoil to reach the ground, this will be used to calculate the average velocity
   c. Record the distance the parafoil glided, this will be used to calculate the gliding ratio
4. Break-down
   a. Detach the parafoil from the dummy weight
   b. Make sure there are no tangles in the lines
   c. Carefully pack the parafoil

Test Results:

Test #	AoI	Time (s)	Distance (ft)	Height (ft)	Glide Ratio	Descent Velocity (ft/s)
1	-3.75	2.75		20		7.27
2	-3.75			35	0.00	0.00
3	-3.75	2.61	34.7	35	0.99	13.41
4	-3.75	3.42	36	35	1.03	10.23
5	-3.75	2.8	24	35	0.69	12.50
6	-3.75	2.6	21.5	35	0.61	13.46
7	-3.75		41.5	50	0.83	0.00
8	-3.75	2.6	30.5	50	0.61	19.23
9	-6.6	2.2	18	50	0.36	22.73
10	-6.6	2.2	21.5	50	0.43	22.73
11	-6.6	1.3	23	35	0.66	26.92
12	-6.6	1.5	26	35	0.74	23.33
13	-6.6	1.7	24.5	35	0.70	20.59
14	-6.6	1.8	24	35	0.69	19.44
15	-6.6	1.5	19.5	35	0.56	23.33
16	-6.6	1.5	24	35	0.69	23.33
17	-6.6	1.4	9	35	0.26	25.00
18	-4.52		19.5	35	0.56	0.00
19	-4.52	1.4	19	35	0.54	25.00
20	-4.52	1.4	21	35	0.60	25.00
21	-4.52	1.25	15	35	0.43	28.00
22	-4.52	1.25	14	35	0.40	28.00
23	-3.4	1.7	25.5	35	0.73	20.59
24	-3.4	1.7	17	35	0.49	20.59
25	-3.4		18	35	0.51	0.00
26	-3.4	1.5	18.5	35	0.53	23.33
27	-3.4	1.5	19	35	0.54	23.33
28	-3.4	1.5	20	35	0.57	23.33
29	-3.4	1.4	14.5	35	0.41	25.00
30	-3.75	1.8	20.5	35	0.59	19.44
31	-3.75	1.6	23.5	35	0.67	21.88
32	-3.75	3.6	50	50	1.00	13.89
33	-3.75	2	33.5	50	0.67	25.00
34	-3.75	2.15	25.5	50	0.51	23.26
35	-3.75	2.1	30	50	0.60	23.81
36	-3.75	2	27	50	0.54	25.00
37	-3.75	2.1	31	50	0.62	23.81
38	-3.75		21	50	0.42	0.00

H.6 - Test Pixy CMUCam5

Test Procedure:	Pixy CMUcam5 Test
Test Category:	Component
Test Subsystem:	Landing Hazard Detection
Test Components:	Pixy CMUcam5
Required Components:	Raspberry Pi 2, Pixy CMUcam5
Test Personnel:	
Safety Hazards:	None
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a. Use http://cmucam.org/projects/cmucam5/wiki/Hooking_up_Pixy_to_a_Raspberry_Pi to set up Raspberry Pi for Pixy use
2. Set-up
    a. Connect Pixy to Pi via USB
3. Test Procedure
    a. Take test images from the Pixy CMUcam5
4. Break-down
    a. Disconnect Pixy from Raspberry Pi and store

Test Results:

Did the Pixy take pictures? ☐

H.7 – Parafoil Deployment Test

Test Procedure:	Parafoil Deployment Test
Test Category:	Component
Test Subsystem:	Guided Descent
Test Components:	Parafoil
Required Components:	Parafoil, Dummy weight
Test Personnel:	Nick Kling/Harrison Hughes
Safety Hazards:	If parafoil fails to open, ballistic descent
Mitigating Equipment:	Deep Sea Fishing Line

Test Procedure:

1. Pre-Test
    a. Create a dummy weight with a mass as close to the payload as possible
2. Set-up
    a. Connect Parafoil lines to the top of the dummy weight
    b. Pack parafoil in manner to be tested
    c. Set angle of attack to preferred value
    d. Measure the height the parafoil system will be dropped from
    e. Cut a length of fishing line 10 feet shorter than the drop height
    f. Connect fishing line to the top of the dummy weight
3. Test Procedure
    a. Drop the parafoil
    b. Record how the parafoil deployed or if the parafoil failed to deploy
4. Break-down
    a. Detach the parafoil from the dummy weight
    b. Make sure there are no tangles in the lines
    c. Carefully pack the parafoil
    d. Detach the fishing line from the dummy weight

Test Results:

Run	Deployment Height	Notes:
1	20	Caught well but dropped sharply
2	20	Turned during descent
3	35	Ballistic descent, error during release
4	35	Caught well and flew straight
5	50	Caught well but turned due to toggle lines

H.8 - Test GPS and AltIMU while in motion

Test Procedure:	GPS, AltIMU, and XBee Motion Test
Test Category:	Ground
Test Subsystem:	Control, Landing Hazards Detection, Guided Descent
Test Components:	Ultimate GPS Breakout, AltIMU-10 v4, XBee 900 Pro RPSMA
Required Components:	Ultimate GPS Breakout, AltIMU, XBee, XBee Explorer Dongle, Raspberry Pi 2, Breadboard, TTL to USB cable, Pi Cobbler
Test Personnel:	Ryan Weiner
Safety Hazards:	Electricity
Mitigating Equipment:	None

Test Procedure:

1. Pre-Test
    a. Write code for Pi to run GPS, AltIMU, and XBee autonomously
2. Set-up
    a. Connect Pi Cobbler to breadboard
    b. Connect a XBee and Explorer Dongle to Raspberry Pi and one to a computer
    c. Connect AltIMU to breadboard
    d. Connect TTL to USB cable to breadboard and to the Raspberry Pi 2
    e. Connect GPS to breadboard
3. Test Procedure
    a. Drive around campus with setup in car
    b. Rotate AltIMU and receive attitude
    c. Receive acceleration and altitude from AltIMU
    d. Receive time, speed, altitude, longitude, latitude, and heading from GPS
    e. Send AltIMU data and GPS data to remote computer via XBee
4. Break-down
    a. Unplug XBee and Explorer Dongle from Raspberry Pi
    b. Disconnect wires
    c. Remove GPS and AltIMU from breadboard
    d. Return components to packaging

Test Results:	☑
Fix on GPS?	☑
Was data sent?	☑
Receive GPS data?	☑
Receive AltIMU data?	☑