2015-2016 NASA Student Launch

Alabama Rocket Engineering Systems (ARES) Team

Critical Design Review

January 15, 2016

Table of Contents

1. Summary of CDR Report 1
1.1 Team Summary 1
1.2 Launch Vehicle Summary 1
1.3 Payload Summary 1
2. Changes Made Since PDR 2
2.1 Changes Made to Vehicle Criteria 2
2.2 Changes Made to Payload Criteria 3
2.3 Changes Made to Project Plan 3
3. Vehicle Criteria 4
3.1 Design and Verification of Launch Vehicle 4
3.1.1 Mission Statement, Requirements, and Mission Success Criteria 4
3.1.2 Major Milestone Schedule 5
3.1.3 System Level Design Review 5
3.1.4 System Level Functional Requirements 11
3.1.5 Approach to Workmanship 11
3.1.6 Additional Component, Functional, and Static Testing 12
3.1.7 Manufacturing and Assembly Plans 12
3.1.8 Integrity of Design 13
3.2 Subscale Flight Results 24
3.3 Recovery Subsystem 24
3.3.1 Parachute, Harnesses, Bulkheads, and Attachment Hardware 24
3.3.2 Electrical Components 24
3.3.3 Drawings, Diagrams, and Electrical Schematics 24
3.3.4 Kinetic Energy Calculations 28
3.3.5 Test Results 28
3.3.6 Safety and Failure Analysis 29
3.4 Mission Performance Predictions 29
3.4.1 Mission Performance Criteria 29

3.4.2 Flight Profile Simulations, Altitude Predictions, Drift Calculations, and Thrust Curve 29
3.4.3 Thoroughness and Validity of Analysis, Drag Assessment, and Scale Modeling Results 33
3.4.4 Static Stability Margin 33
3.5 Payload Integration 34
3.5.1 Integration Plan 34
3.5.2 Compatibility of Elements 35
3.5.3 Simplicity of Integration Procedure 35
3.5.4 Changes to Payload Resulting from Subscale Test 35
3.6 Launch Concerns and Operation Procedures 35
3.6.1 Final Assembly and Launch Procedures 35
3.7 Safety and Environment 36
3.7.1 Identification of Safety Officer 36
3.7.2 Updated Failure Mode Analysis 36
3.7.3 Updated Personnel Hazards 43
3.7.4 Environmental Concerns 45
4. Payload Criteria 49
4.1 Testing and Design of Payload Equipment 49
4.1.1 System Level Design Review 49
4.1.2 System Level Functional Requirements 55
4.1.3 Approach to Workmanship 57
4.1.4 Component, Functional, and Static Testing 57
4.1.5 Manufacturing and Assembly Plans 58
4.1.6 Integration Plan 77
4.1.7 Precision of Instrumentation and Repeatability of Measurement 78
4.1.8 Payload Electronics 79
4.1.9 Safety and Failure Analysis 84
4.1.10 PDR Feedback 86
4.2 Payload Concept Features and Definition 87
4.2.1 Creativity and Originality 87

4.2.2 Uniqueness or Significance 87
4.2.3 Suitable Level of Challenge 87
4.3 Science Value 88
4.3.1 Payload Objectives 88
4.3.2 Payload Success Criteria 88
4.3.3 Experimental Logic, Approach, and Method of Investigation 89
4.3.4 Test and Measurement, Variables, and Controls 89
4.3.5 Relevance of Expected Data and Accuracy/Error Analysis 90
4.3.6 Experiment Process Procedures 91
5. Project Plan 92
5.1 Budget Plan 92
5.2 Funding Plan 97
5.3 Timeline 99
5.4 Educational Engagement 102
6. Conclusion 105
Appendix A - Milestone Review Flysheet 106
Appendix B - Launch Preparation Checklist and Procedures 107
Appendix C - Safety Data Sheets 114
C.1 ProFire Igniter 114
C.2 ProX Rocket Motor Reload Kits 119
C.3 Fibre Glast Style 120 E-Glass 125
C.4 Fibre Glast System 2000 Epoxy Resin 132
C.5 Spray Paint 138
C.6 Black Powder 145
Appendix D - Hazardous Material Operating Procedures 149
Appendix E - Weighted Ratings Tables 151
Appendix F - Expanded Gantt Chart 156
Appendix G - Test Procedure Forms 158
G.1 - Verify that Pi will run from the SSD 159
G.2 - Calibrate and Test AltIMU 160
G.3 - Transmit test data through XBee 162

G.4 - Run Test Image through Hazard Detections Software 164
G.5 - Test Stationary GPS 165
G.6 - Parafoil Drop Test 167
G.7 - Test Servo Motors 169
G.9 - Parafoil Deployment Test 172
G.10 - Test GPS and AltIMU while in Motion and Send Data from XBee 174
G.11 - Test Complete Payload Electronics System 176
G.12 - Measure Leg Spring Forces 178
G.13 - Leg Deployment Test 180
G.14 - Low Altitude Turning Drop Test 182
G.15 - Battery Test on Complete Payload 184
G.16 - Flare Maneuver Test 185
G.17 - Landing Legs Test 187
G.18 - Weather Balloon Drop Test 188
G.19 - Shake Table Test 190
G.20 - Complete Payload Test 191

1. Summary of CDR Report

1.1 Team Summary

Team Name: Alabama Rocket Engineering Systems (ARES) Team

Mailing Address: Department of Aerospace Engineering and Mechanics
The University of Alabama
Box 870280
Tuscaloosa, AL 35487-0280

NAR/TRA Mentor: Lee Brock
Level 3 TRA Certification
TRA Section 81

1.2 Launch Vehicle Summary

Length	Diameter	Mass	Motor	Recovery System	Rail Size
89 inches (2.26 m)	5.53 inches (0.141 m)	32.2 lb (14.61 kg)	Cesaroni L3200	● 54 inch (1.37 m) drogue parachute ● 110 inch (2.79 m) main parachute ● 21.3 x 84.6 inch (.542 x 2.15 m) payload parafoil	1515, 12 ft.

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 PDR

2.1 Changes Made to Vehicle Criteria

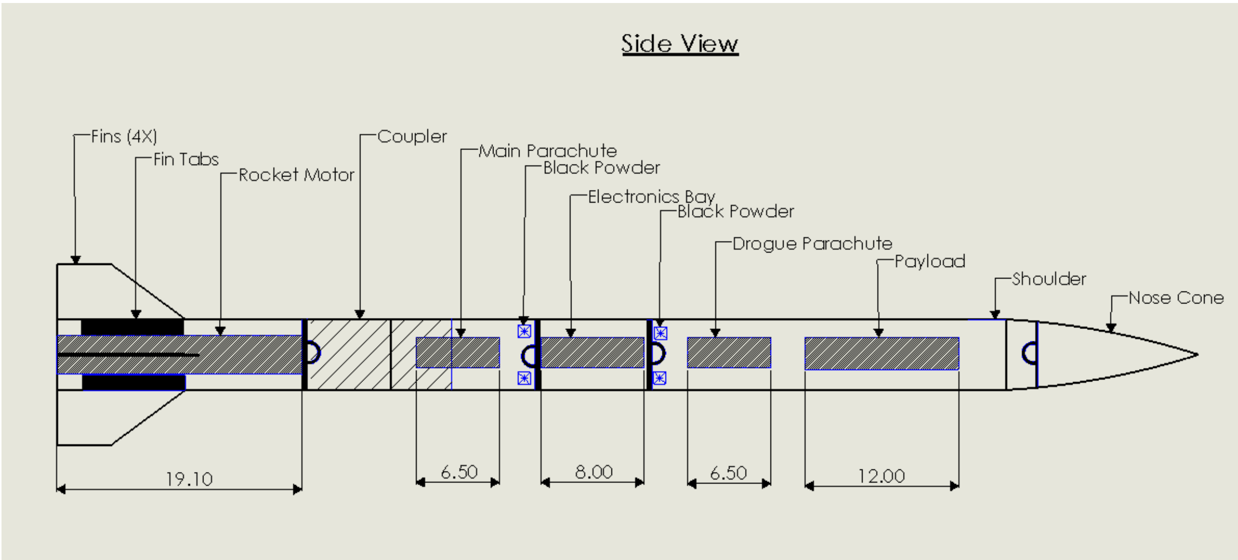

Figure 2.1 Updated Rocket Layout (inches)

The ARES Team's rocket will use four black powder charges, two on either side of the electronics bay, a decision based on feedback received from the PDR. The charges that were to be placed between the drogue parachute and the payload, and between the payload and the nose cone were found to be unnecessary. The charges in front of the electronics bay will push the drogue parachute, payload, and nose cone out of the forward body section. The parachute located in the nose cone was removed because of uncertainty that it could be deployed safety. The nose cone will now be connected to the electronics bay's eyebolt by a shock cord.

The fin design, seen in *Figure 3.5*, was changed to create a higher stability margin of 2.00. The body length of the fin is 10 inches (.254 m) and the opposite side of the fin is 4.5 inches (.114 m). The height of the fin is 4.5 inches (.114 m). Fin tabs now extend all the way to the motor mount tube with centering rings on either side of the fin tabs.

The aft section was shortened because of a change in the motor, causing the overall length of the rocket to change to 89 in. ARES rocket team selected the Cesaroni L3200 over the Cesaroni L805 because OpenRocket simulations showed this motor to put the launch vehicle closer to the goal of 5280 ft. above ground level (AGL).

2.2 Changes Made to Payload Criteria

The ARES Team will no longer use a solenoid to deploy the landing legs, but will instead use two servoless payload release devices to deploy the legs. The switch to payload release devices provides for more reliable release of the landing legs. The team added an external GPS antenna to the payload. The external antenna will add an extra 28 dB of gain, which will ensure that the GPS will be able to be located in flight. A rotary switch will be placed after the battery in both circuits, which will allow the team to turn the circuits on and off with ease. A major change in the payload design was the batteries. The team will now be using two lithium-polymer batteries; a 5000mAh, 14.8V battery, and a 6600mAh, 7.4V battery. Voltage regulators will be used to reduce the voltages to appropriate levels.

2.3 Changes Made to Project Plan

The subscale launch date was changed to January 16th. This delay is attributed to the inability to access the funds granted by the Alabama Space Grant Consortium (ASGC), which were needed to purchase components to build the subscale, and the cancellation of a launch on January 9th due to weather. Also as a result of the delay, many of components were ordered with expedited shipping, which increased costs beyond the team’s original estimates.

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3. Vehicle Criteria

3.1 Design and Verification of Launch Vehicle

3.1.1 Mission Statement, Requirements, and Mission Success Criteria

The Alabama Rocket Engineering Systems Team's mission is to design, build, and launch a high power rocket that will ascend to an apogee altitude of 5,280 feet while carrying a payload that will complete two tasks. The payload will eject at apogee and descend to the ground using a parafoil. During descent, the payload will scan the ground for landing hazards and then use the data collected to steer away from detected hazards. The requirements for this mission are listed below.

Mission Requirements

- The launch vehicle must reach an apogee of 5,280 feet.
- The launch vehicle must deploy a drogue parachute and the payload at apogee.
- The launch vehicle must deploy a main parachute at 900 feet AGL.
- The payload must take images of the ground during descent and analyze these images to detect potential landing hazards.
- The payload must transmit the collected data to the team's ground station, as well as store the data onboard.
- The payload must be able to steer away from the detected landing hazards.
- The rocket must be reusable after landing.

Success Criteria

- The launch vehicle reaches within 1% of the required apogee.
- The payload correctly identifies landing hazards, stores the data onboard and transmits the data to the ground station.
- The payload steers away from all landing hazards and lands in a safe area.
- All sections of the rocket and payload are reusable after landing.

3.1.2 Major Milestone Schedule

The major milestones for the project are listed in *Table 3.1* below.

Date	Milestone	Description
8/19/2015	Project Initiation	Began determining project requirements
9/11/2015	Proposal Submission	Submitted proposal for admittance into competition
11/6/2015	PDR Document Submission	Submitted PDR report, flysheet, and presentation slides
11/17/2015	PDR Presentation	Presented PDR to NASA SL review panel
12/14/2015	Subscale Build	Began building subscale launch vehicle
1/15/2015	CDR Document Submission	Submit CDR report, flysheet, and presentation slides
1/16/2015	Subscale Launch	Launch subscale rocket
1/21/2015 - 2/1/2015	CDR Presentation	Present CDR to NASA SL review panel
2/1/2015	Full Scale Build	Begin building full scale rocket
2/13/2015	Full Scale Launch	First Full Scale Launch
3/14/2015	FRR Document Submission	Submit FRR report, flysheet, and presentation slides
3/17/2015 - 3/30/2015	FRR Presentation	Present FRR to NASA SL review panel
4/13/2015 - 4/16/2015	Competition	Travel to Huntsville for NASA SL competition

Table 3.1 Major Milestones

3.1.3 System Level Design Review

3.1.3.1 Final Drawings and Specifications

The final CAD model of the launch vehicle is shown below in *Figures 3.1* and *3.2*. As can be seen from these models, all of the components will fit inside of the determined dimensions for the rocket, with room left to account for estimation error.

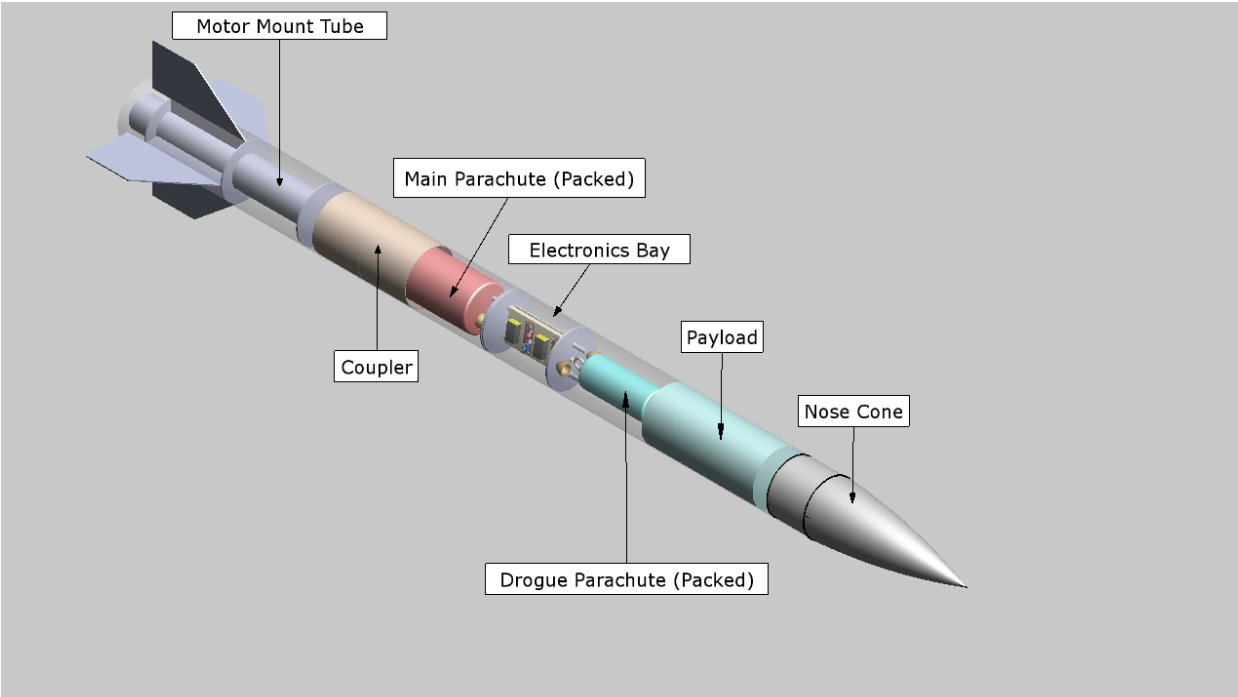

Figure 3.1 Rocket CAD Model Isentropic View

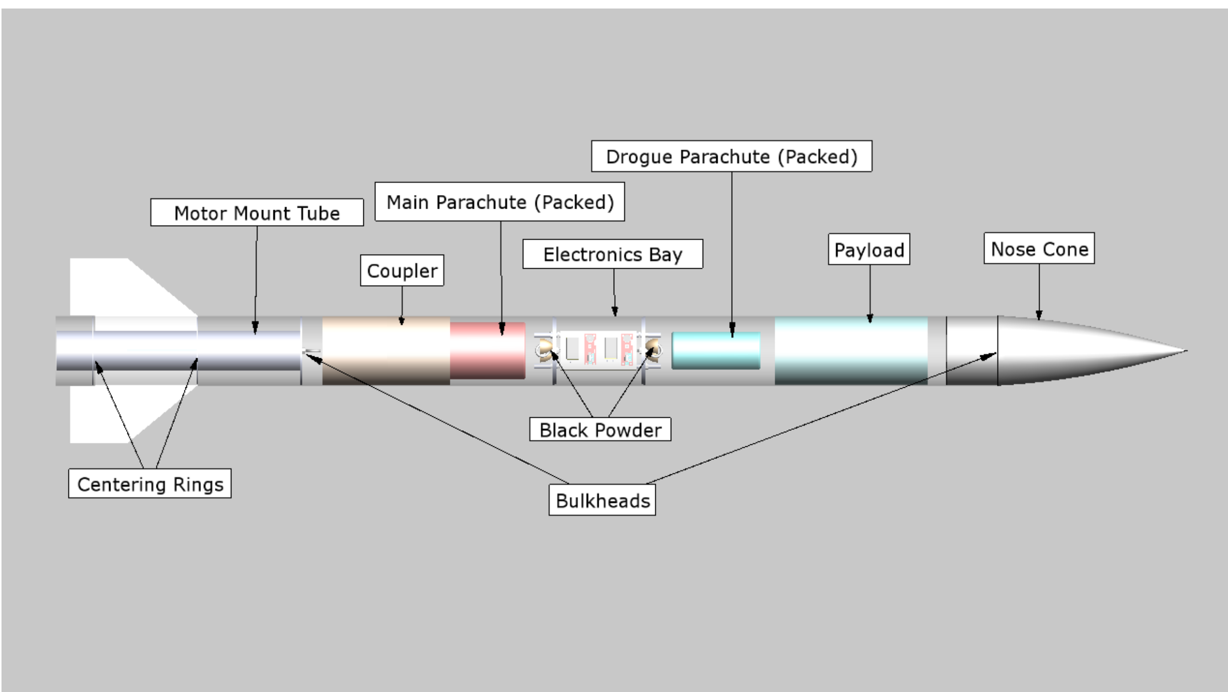

Figure 3.2 Rocket CAD Model Side View

The aft section of the launch vehicle contains the motor mount and the fins. A 75 mm motor retainer will be epoxied onto the aft end of the motor mount tube and a bulkhead will be epoxied onto the forward end. Two centering rings will be epoxied onto the motor mount tube and to the inside wall of the aft body tube. The fin tabs will be epoxied to the motor mount tube, and epoxy will be applied to the joint of the aft body tube and the face of the fin to create a fillet. Four 2-56 nylon shear pins will be screwed into the coupling section between the aft body tube and the forward body tube at a distance of .5 inches from the end of the forward body tube. The electronics bay will be housed in a fiberglass tube and secured by two screws spaced at 180 degrees from each other. Four 0.286 inch holes will be drilled through the body tube and the electronics bay housing to allow the atmospheric pressure to be sampled by the altimeters. The main parachute, drogue parachute, and payload will be ejected by the pressure created from the ignition of the black powder charges. A shock cord will run from the motor mount bulkhead and the aft side of the electronics bay to the main parachute. Another shock cord will secure the drogue parachute to the forward side of the electronics bay and to the bulkhead in the nose cone. A drawing detailing the layout and dimensions of the launch vehicle and its components is shown in *Figure 3.3.*

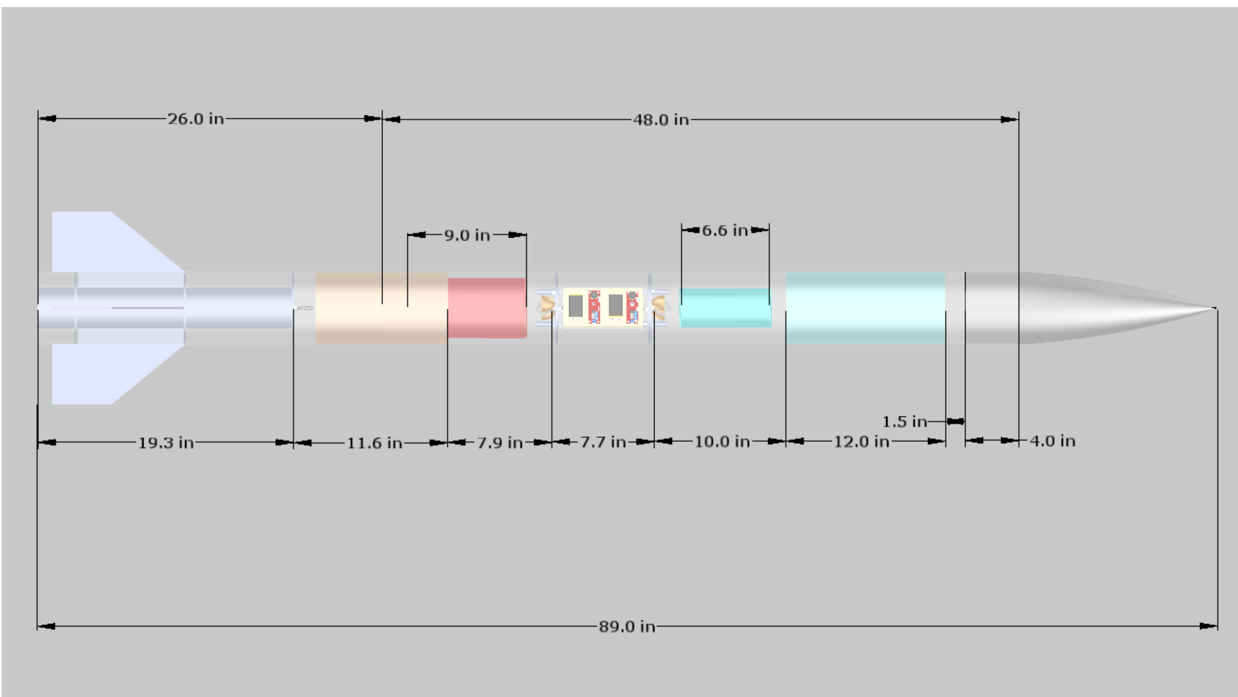

Figure 3.3 Rocket Layout Drawing (inches)

Table 3.2, shown below, details the mass, length, and width/diameter of each of the main components of the rocket.

Component	Mass (lb)	Length (in)	Width or Diameter (in)
Nose Cone	1.31	15	5.5
Forward Body Tube	4.12	48	5.53
Aft Body Tube	2.23	26	5.53
Payload	6.2	12	5.38
Electronics Bay	2.4	7.7	5.38
Main Parachute (Packed)	1.2	9.0	4.5
Drogue Parachute (Packed)	0.948	6.6	3
Motor w/ Propellant	7.2	19.1	2.95
Motor Propellant	3.66	19.1	2.95

Table 3.2 Full Scale Launch Vehicle Component Information

3.1.3.2 Final Analysis and Model Results

The ARES Team was not able to launch their subscale rocket before the CDR, and therefore the results will be submitted after the launch as an addendum to the report. Analysis and simulation of the launch vehicle was done using OpenRocket. A summary of the apogee estimates is shown in Section 3.1.3.4, and the OpenRocket results are covered in full in Section 3.4.2.

3.1.3.3 Test Description and Results

The subscale model will be launched on January 16th at the Phoenix Missile Works (TRA Section 81) launch site in Talladega, Alabama. The subscale model test will verify that the recovery system and payload ejection are able to perform to ARES Team's standards. The subscale model test will also verify that flight characteristics are similar to the ARES Team's expectations of a normal flight. A successful test will demonstrate a stable flight and a successful recovery. The motor used for the subscale will be the Cesaroni L585. The component mass and dimensions of the subscale can be found in *Table 3.3*.

Component	Mass (lb)	Length (in)	Width or Diameter (in)
Nose Cone	0.75	16	4.0
Forward Body Tube	1.825	35	4.0
Aft Body Tube	0.988	19	4.0
Payload	4.75	8	3.97
Electronics Bay	2.4	7.7	3.97
Main Parachute (Packed)	1.2	9.0	3
Drogue Parachute (Packed)	0.948	6.6	3
Motor w/ Propellant	6.14	13.8	2.95
Motor Propellant	3.36	13.8	2.95

Table 3.3 Subscale Launch Vehicle Component Information

In order create similar flight characteristics, the aerodynamic forces experienced by the full scale and subscale must be similar. Geometric similarity was preserved between the subscale and full scale using a 0.727 scaling factor and the ARES Team matched the expected Mach numbers to preserve dynamic similarity. The Mach number was matched as opposed to the expected Reynolds number based on the effect on the coefficient of drag. It was decided that the subscale should not exceed Mach .80 so that it would not experience compressible effects, but this presented a problem with scaling down the rocket if Reynolds number was to be matched. Because of this problem, the team used a graph showing the change in coefficient of drag with change in Reynolds number and found that the estimated change between the full scale and subscale Reynolds numbers at the same velocity would produce a negligible change in drag. This meant that matching the Reynolds numbers was not necessary and in order for the subscale to experience similar aerodynamic forces, the expected Mach number (0.65) should be matched. The team aimed to get the estimated Mach number as close as possible with the available selection of motors, and were able to get to an estimate of Mach .60.

The impulse to weight ratio (22.9 [s]) was matched based on the National Association of Rocketry's (NAR) recommendation on subscale building. The impulse to weight ratio gives the specific impulse. The specific impulse is a measure of the efficiency of the propulsion system and is given in units of time. The specific impulse matching allows for an adequate comparison of the flight characteristics of the subscale and full scale's propulsion system.
The expected max Mach number (0.65) the impulse to weight ratio (22.9 [s]) and geometric similarity were preserved between the subscale and full scale version of the launch vehicle.

The recovery system on the subscale rocket consists of four black powder charges, four altimeters, four batteries, a drogue parachute, and a main parachute. Based on the requirement for maximum energy upon impact to be 75 ft-lbs, the minimum size main parachute for the subscale was determined to be 72 inches using the "fruitychutes.com Descent Rate Calculator". The team chose to use an 84 in. main parachute. The drogue parachute will be a 42 inch parachute. Before the subscale is launched, a ground test of the primary altimeters, secondary altimeters, and ejection of the parachutes and payload will be run to determine the adequacy of the recovery system. The recovery system will be deemed successful if the ground test proves adequacy and if the subscale vehicle is reusable after recovery from the flight.

The full scale payload will not fly on the subscale, instead, a "dummy weight" with the same approximate shape as the HAL payload scaled to subscale dimensions will be used. The payload will be ejected from the rocket, but will be attached by a shock cord to the drogue parachute and the nose cone. This will test the ARES Team's ability to eject the payload. The team will conduct a ground test before flight to ensure ejection from the forward body tube with the drogue parachute. Payload ejection will be deemed a success if the payload ejects correctly during the ground test and in-flight.

3.1.3.4 Final Motor Selection

The ARES team plans to use the Cesaroni L3200 in the full scale rocket. This is a 75 mm (2.95 in), three grain motor with a total impulse of 3300 Newton-seconds (741.9 lb-seconds). This motor will be purchased from "Chris' Rocket Supply, LLC" and handled by Mr. Lee Brock, the teams NAR/TRA Mentor. Through simulations performed in OpenRocket using a L3200 motor, the current launch vehicle design reaches slightly above the 5280 ft. altitude mark with a standard deviation of approximately 6.135 ft. The results of these simulations can be seen in *Table 3.3.* With a confidence interval of 97%, plus or minus 6.6565 from 5306.25 ft., places the vehicle well within the ARES goal of plus or minus 52.8 ft. of 5280 ft. The plus or minus 52.8 ft. is obtained from the ARES goal of 1% within the required altitude. This verifies that the Cesaroni L3200 motor is a valid choice for our propulsion subsystem from the simulation data. **Note: All simulations performed in OpenRocket are at the correct latitude, longitude, and altitude for each launch site.*

Simulation	**Apogee (ft.)**
Bragg Farms (0 mph)	5306
Bragg Farms (5-10 mph)	5293
Manchester (0 mph)	5319
Manchester (5-10 mph)	5307

Table 3.4 OpenRocket Apogee Simulations

3.1.4 System Level Functional Requirements

The functional requirements for each system are listed in *Table 3.5* below, along with the selection rationale for fulfilling the requirement, the selected design concept, and the characteristics of the design concept.

Subsystem	Functional Requirement	Selection Rationale	Selected Concept	Characteristics
Recovery	Eject drogue parachute at apogee and main parachute at 900 feet AGL	Must have reliable ejection system	Redundant altimeters	Altimeter 1 fires a black powder charge at a specified altitude. Altimeter 2 sends a charge to the black powder at a reserve altitude if Altimeter 1 fails
	Slow descent of all sections so that kinetic energy does not exceed 75 ft-lbs	Parachutes must provide adequate drag to ensure slow enough landing velocity	110 inch (2.79 m) main parachute	The parachute expands and slows the launch vehicle by drag force to a suitable landing velocity
Propulsion	Deliver launch vehicle and payload to an apogee altitude of 5,280 feet	Motor must provide proper thrust to weight ratio	Cesaroni L3200	The selected motor provides a thrust to weight ratio of 22.1
Structures	Withstand aerodynamic loading	Must provide adequate strength to handle loads	Fiberglass	The launch vehicle will be constructed of Fiberglass, which will provide the strength to withstand aerodynamic loads
	Land undamaged	Must provide adequate strength to handle landing impact	Fiberglass	Fiberglass provides adequate strength to withstand the shock of landing

Table 3.5 Functional Requirements

3.1.5 Approach to Workmanship

The ARES Team is dedicated to building 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. The team is aware that careful planning and manufacturing can ensure this, and so this will be emphasized throughout the project. During manufacturing, the team will follow all assembly procedures, and will make sure that all components are of acceptable quality before integrating them into the rocket. This will be done using the dimensions and specifications from the CAD model and drawings that the team has created, shown in Section 3.1.1. and 3.1.8.6. A visual examination of all pieces once received will be undertaken before adding the piece to our inventory.

3.1.6 Additional Component, Functional, and Static Testing

The ARES Team plans to purchase components and materials from reputable vendors such as Madcow Rocketry and Apogee Components to ensure quality of the materials. This will eliminate the need for extensive testing of the components, as they have already been checked for quality by the vendor. In addition, purchasing components from rocketry-specific vendors will ensure that all components are capable of handling the conditions that the launch vehicle will encounter.

The team plans to conduct ground ejection tests to determine the effectiveness of the vehicle's recovery and ejection system. These tests will be conducted in a safe area away from people and buildings, and under the supervision of Lee Brock, the team's NAR/Tripoli mentor. The ground tests will show whether the amount of black powder used is enough to separate the body tubes and eject the parachutes and payload. These tests will also reveal any complications that may occur due to the pressure in the body tube.

3.1.7 Manufacturing and Assembly Plans

The team plans to purchase the body tubes for the rocket from Madcow Rocketry. Originally, the team had discussed using vacuum bagging to manufacture the body tubes and fiberglass sheets, but since none of the team members have experience with this process it was determined to be an unnecessarily time consuming and risky option. By purchasing materials from a reputable rocketry vendor, the team can be assured that the materials will be of acceptable quality. Purchasing the fiberglass components will also save a significant amount of time. The fins will be cut out of the purchased fiberglass sheet. This will be done by the College of Engineering Machine Shop.

During assembly, all of the safety measures outlined in the PDR and those described in this document will be followed. The team's Safety Officer, Desiree Kiss, will ensure that all members follow the correct procedures during assembly.

3.1.8 Integrity of Design

3.1.8.1 Suitability of Shape and Fin Style

The shape of the launch vehicle was determined based on the mission requirements. The ogive nose cone was chosen based on the team's experience and knowledge gained from previous rocketry teams at The University of Alabama. This nose cone shape is conventional for subsonic flights, and is available from multiple rocketry vendors.

The fin style was also chosen because it is a conventional fin style for subsonic flight. The shape of the fins was also chosen based on its simplicity. The team aims to make all components as easy to manufacture as possible, while still maintaining effective performance. The dimensions of the fins were determined through many iterations of simulations using OpenRocket. The team found that changing the fin size was the easiest way to alter stability margin, and so the dimensions of the fins were driven by creating a stability margin as close to 2.0 as possible.

3.1.8.2 Proper Use of Materials in Fins, Bulkheads, and Structural Elements

The ARES launch vehicle will consist mainly of components made of fiberglass. Fiberglass was selected by the team by means of a weighted rating table, which is shown in *Table 3.6* below.

Weighted Rating of Carbon Fiber and Fiberglass					
		Carbon Fiber		**Fiberglass**	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Low Weight	35	4	1.4	3	1.05
Low Cost	20	1	0.2	5	1
Easy Production	10	1	0.1	4	0.4
High Strength	35	5	1.75	4	1.4
Total	100	NA	3.45	NA	3.85

Rating	*Value*
Unsatisfactory	*1*
Just tolerable	*2*
Adequate	*3*
Good	*4*
Very good	*5*

Table 3.6 Weighted Rating of Materials

It was determined that fiberglass would provide adequate strength and ease of manufacturing at a much more affordable price than carbon fiber. These components will be purchased from a rocketry-specific vendor, such as Madcow Rocketry or Apogee Components, to ensure quality of the materials and that the materials will be capable of handling the conditions associated with rocketry.

3.1.8.3 Proper Assembly Procedures, Attachment and Alignment of Elements, Solid Connection Points, and Load Paths

During assembly of the launch vehicle, all safety procedures, including those outlined by Safety Data Sheets of the materials used, NASA guidelines, and University of Alabama guidelines, will be carefully followed. All work will be inspected by the Safety Officer and Team Lead to ensure quality and durability.

The aft and forward body tubes will be attached by a coupler, with four shear pins screwed in at 90 degree intervals to keep the sections from separating prematurely. The nose cone's shoulder will be inserted into the forward body tube just tight enough so that the drogue parachute will be able to push it out once deployed. The electronics bay will be secured by two screws that will penetrate the body tube and the electronics bay casing. These screws will be placed at 90 degree angles either way from the rail buttons to ensure that they will not contact the launch rail. The centering rings epoxied to the motor mount tube will align the tube inside the aft body tube. The centering rings will be positioned such that the fin tabs will fit snugly in between them. A bulkhead epoxied at the end of the motor mount will transfer the thrust from the motor to body of the launch vehicle.

3.1.8.4 Motor Mounting and Retention

The motor mount, seen in *Figure 3.8 & 3.9,* has two centering rings around the motor mount tube. The centering rings are epoxied to the inside of the aft body tube to ensure the motor does not move laterally during flight. A bulkhead will be epoxied to the top of the tube and to the aft body tube walls. A 75 mm motor retainer will be epoxied on to the bottom of the motor mount tube to ensure the motor will not fall out after it expends all its propellant.

3.1.8.5 Status of Verification

All requirements for the launch vehicle are listed in *Table 3.7* 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	OpenRocket verified. Launch tests pending
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 will undergo vacuum testing prior to launches to ensure they read pressure changes. Altimeters will also be tested on the Subscale and Full Scale Launch Tests	Pending
1.3	The launch vehicle shall be designed to be recoverable and reusable	Launch Vehicle Structure	Subscale and full scale launch tests	Pending
1.4	The launch vehicle shall have a maximum of four independent sections	Launch vehicle consists of four sections	Design of launch vehicle	Verified
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	Pending
1.7	The launch vehicle shall be capable of remaining in a launch-ready configuration at the pad for	Altimeters, Black Powder Charges, and Payload	Subscale and two Full Scale Launch Tests will	Pending

	a minimum of 1 hour without losing the functionality of any critical on board component	Components will be designed to hold for a minimum of 1 hour	verify	
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	Pending
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 L3200 motor	NA	NA
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 L3200. The total impulse is 3300 Newton-seconds	Verified
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	NA	NA
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	Pending
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 14	Full scale launch test	Pending

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	Pending
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	Pending
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	NA	NA
2.5	The recovery system shall contain redundant, commercially available altimeters	Redundant altimeters will be used	NA	NA
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	NA	NA
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 an arming switch	NA	NA
2.8	Each altimeter shall have a dedicated power supply	Separate battery for each altimeter	NA	NA
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	NA	NA
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	NA	NA

		occur. Separation will be over the parachute compartments		
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	NA	NA
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	NA	NA

Table 3.7 Status of Verification

3.1.8.6 Drawings of Launch Vehicle, Subsystems, and Components

Figure 3.4 shows the layout and dimensions of the launch vehicle. Detailed drawings of the fins, nose cone, centering rings, motor mount, and electronics bay bulkheads are shown in *Figures 3.5, 3.6, 3.7, 3.8,* and *3.9,* respectively, shown on the following pages.

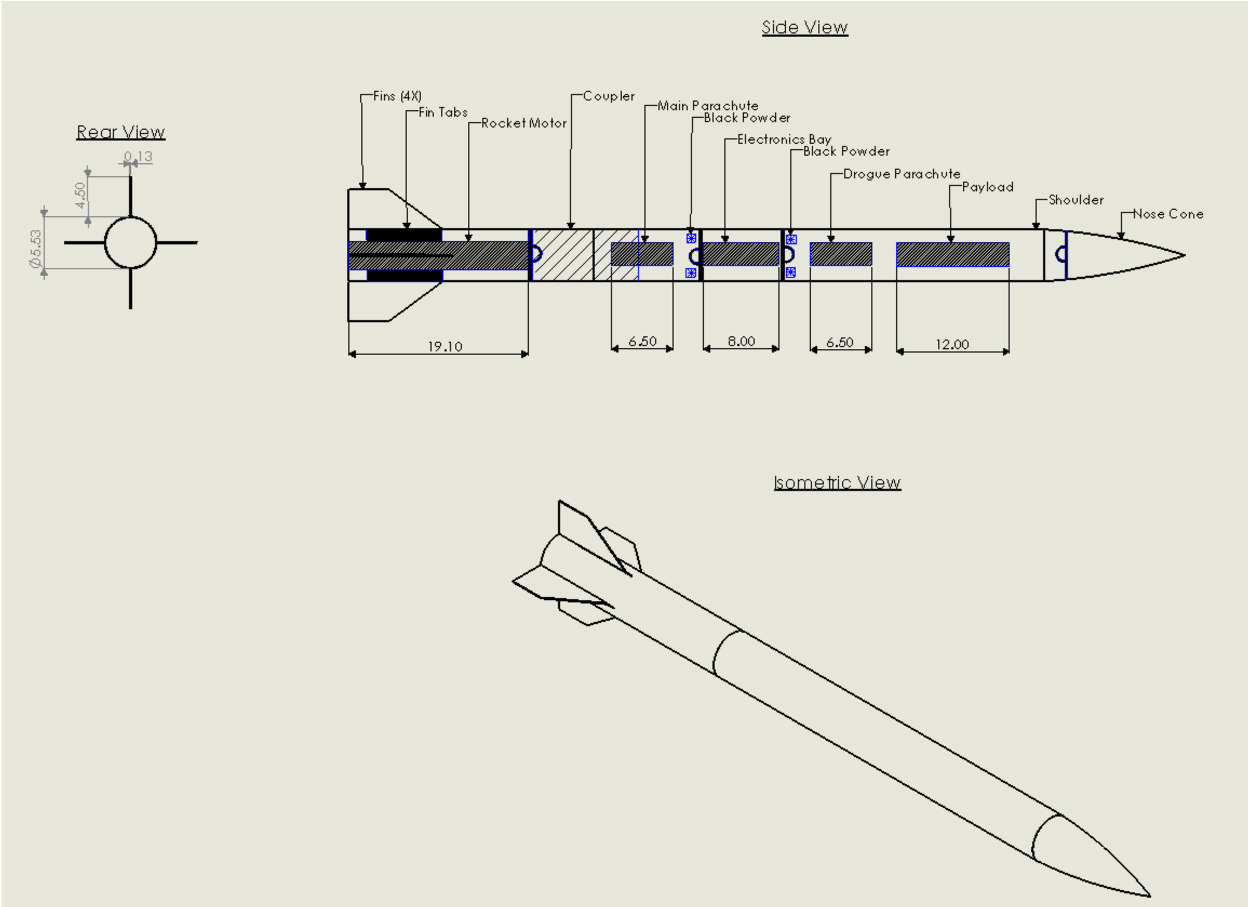

Figure 3.4 Rocket Layout Drawing (inches)

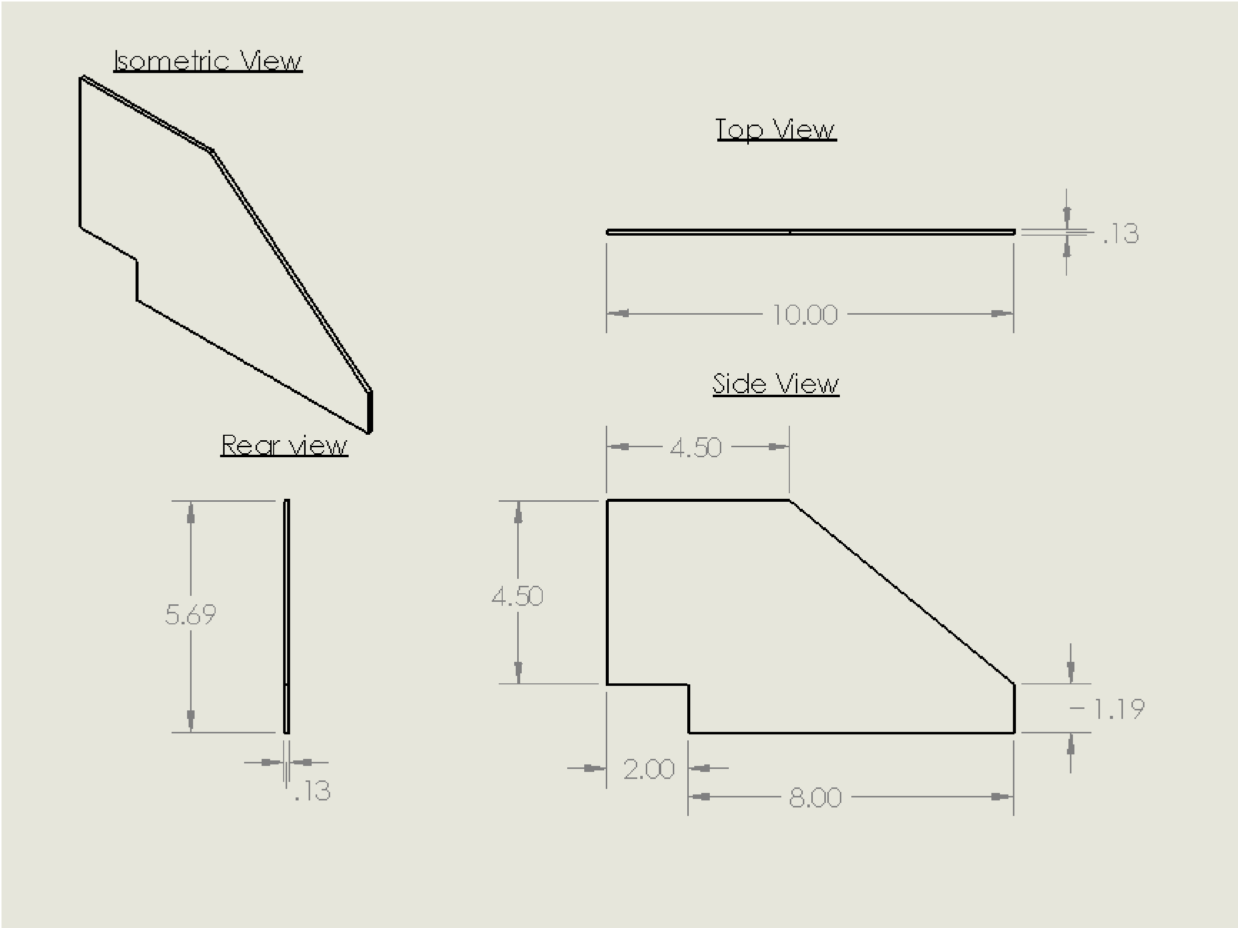

Figure 3.5 Fin Dimensions (inches)

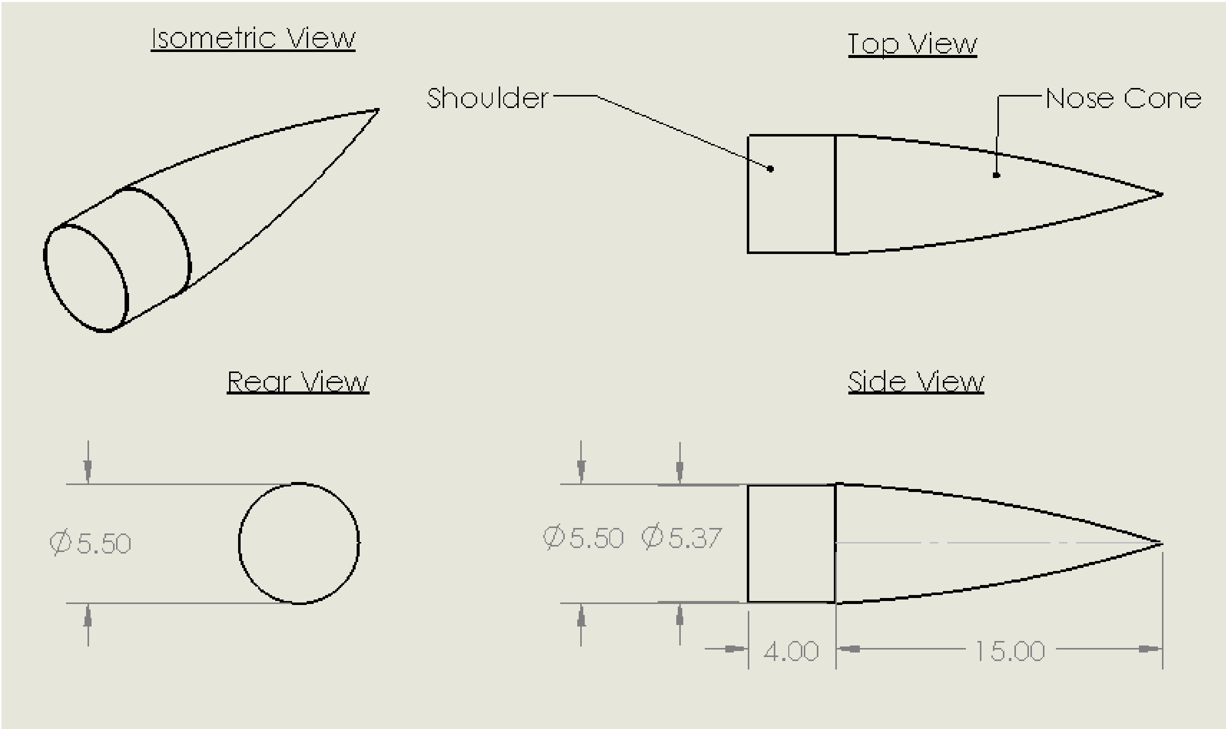

Figure 3.6 Nose Cone Dimensions (inches)

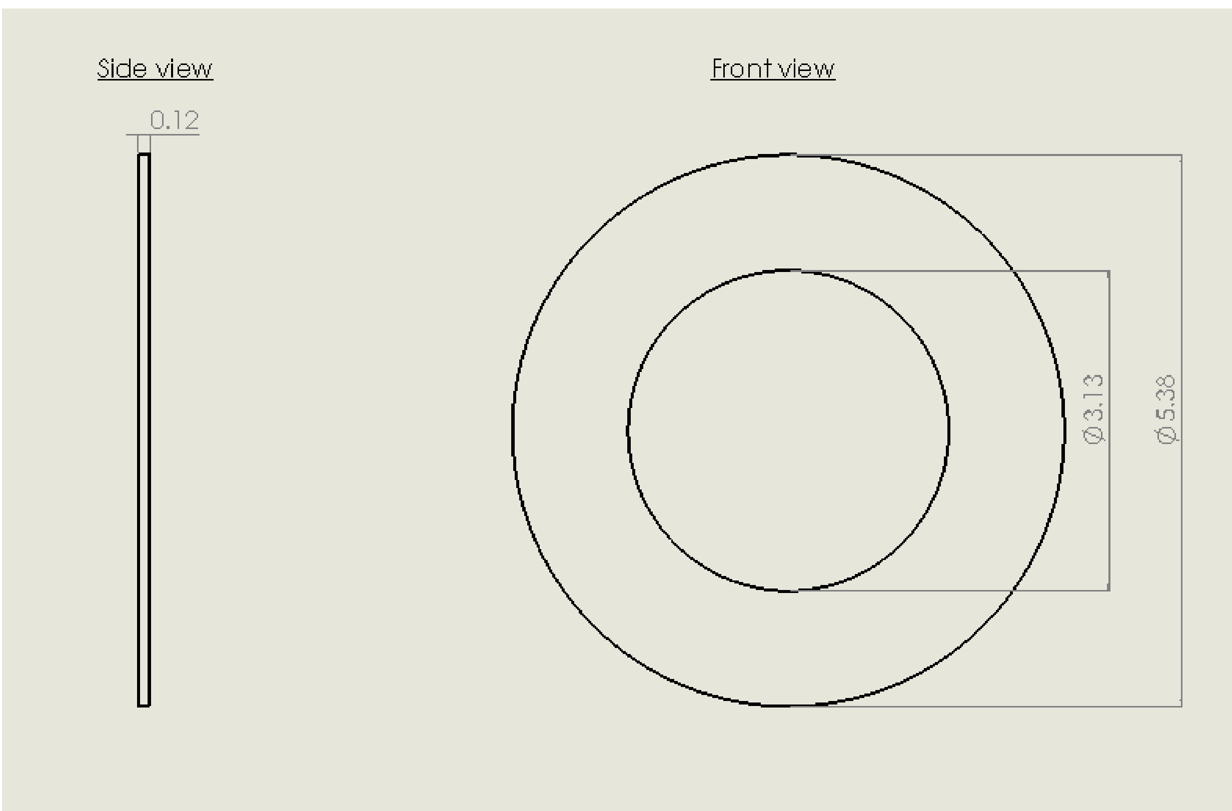

Figure 3.7 Centering Ring Dimensions (inches)

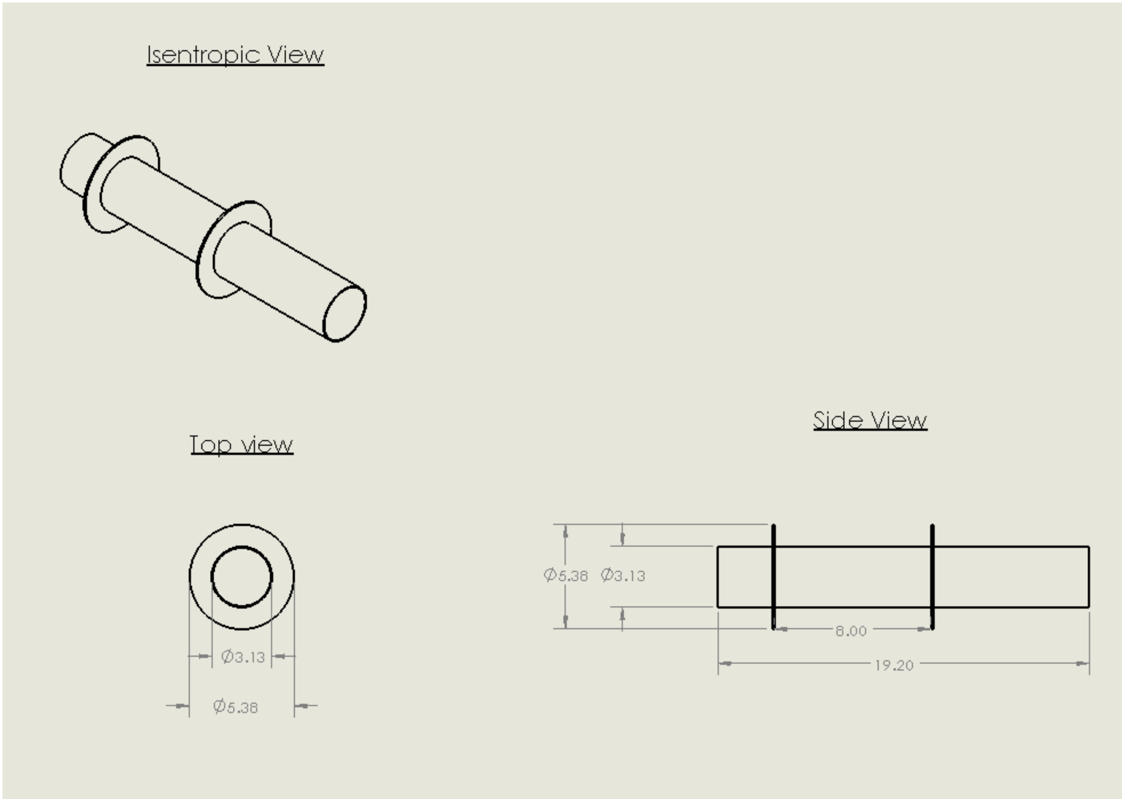

Figure 3.8 Motor Mount Dimensions (inches)

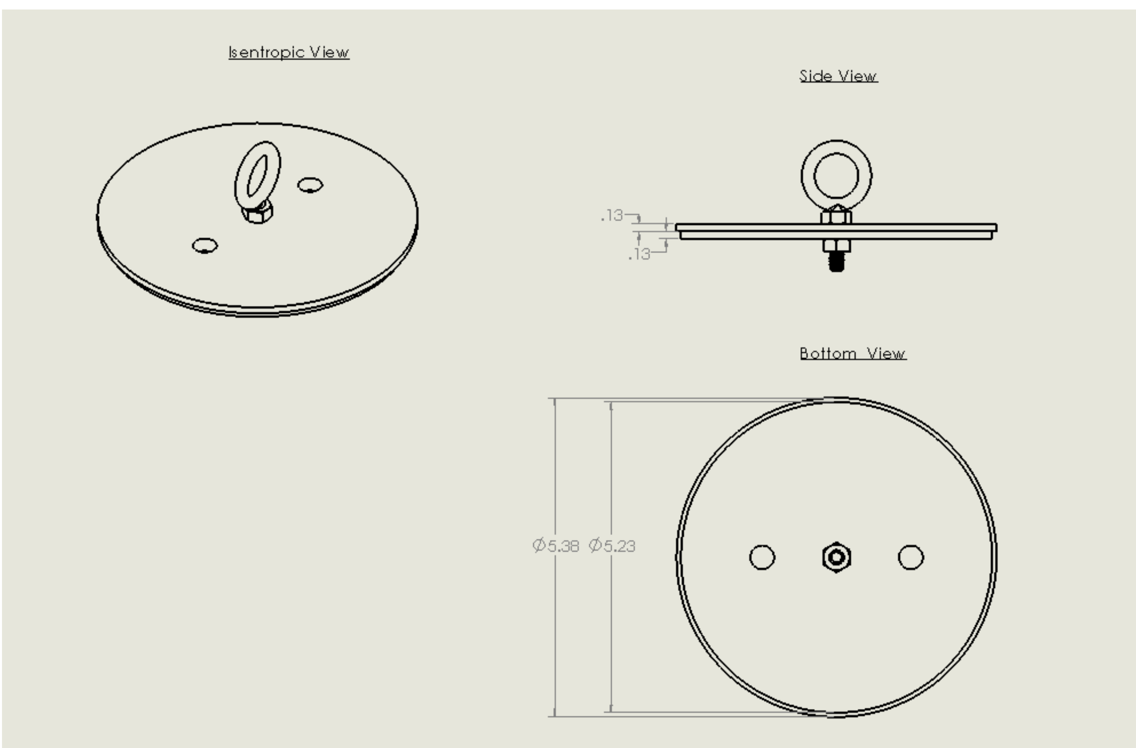

Figure 3.9 Electronics Bay Bulkhead Dimensions (inches)

3.1.8.7 Mass Statement

The mass for the launch vehicle as it will stand on the launch pad is detailed in *Table 3.8*. Masses are based on values given by OpenRocket and the specifications of all components chosen by the team. The team is confident in the accuracy of this estimate, as OpenRocket bases masses on product specifications. The verification of parts from the design of the subscale and the accuracy of the ARES Team's estimation gives an added level of confidence. The team expects a 5% increase in mass based off reported mass of the OpenRocket subscale simulation vs. the actual mass measured of the built subscale; so this increase is added to the final mass statement.

Component	**Mass (lb)**
Nose Cone	1.31
Forward Body Tube	4.12
Aft Body Tube	2.23
Motor Mount	2.41
Fins	1.86
Payload	7.0
Electronics Bay	2.96
Main Parachute (Packed)	1.93
Drogue Parachute (Packed)	1.68
Motor w/ Propellant	7.2
Motor Propellant	3.66
Current Total	32.70
Total w/ Expected Increase	34.34

Table 3.8 Mass Statement

3.1.8.8 Safety and Failure Analysis

Failure mode analysis for the launch vehicle consists of possible points of failure associated with the launch vehicle itself (as opposed to the payload, which has failure modes addressed in Section 4.1.9). All failure modes were given a cause, consequence, a rating based on likelihood and magnitude of consequence, a mitigation, and a post-mitigation rating. Refer to Section 3.7 for a comprehensive safety and failure analysis pertaining to all aspects of the launch vehicle, including information regarding the team's failure mode rating system.

3.2 Subscale Flight Results

The ARES Team will complete their subscale flight on January 16th with Phoenix Missile Works at their launch site in Talladega, Alabama. The team will then submit an addendum to this document containing the complete results of the flight.

3.3 Recovery Subsystem

3.3.1 Parachute, Harnesses, Bulkheads, and Attachment Hardware

When the launch vehicle reaches apogee, the recovery system will eject the 54 inch drogue parachute along with the payload. The drogue parachute will be attached to the eye bolt on the electronics bay forward bulkhead with a shock cord. This shock cord will also be connected to the eye bolt on the nose cone bulkhead. This will ensure the nose cone does not free fall on its own. The 110 inch main parachute will be deployed from the forward body tube at 900 ft. The main parachute will be attached by a shock cord to the eye bolt on the electronics bay aft bulkhead. This shock cord will also be connected to the eye bolt on the motor mount bulkhead in the aft section. This will ensure the aft section does not free fall on its own.

3.3.2 Electrical Components

The electronics bay, as seen in *Figure 3.11* and *Figure 3.12*, will contain four Stratologger altimeters and four nine volt batteries. Two of the altimeters and their corresponding batteries are redundant to ensure black powder charge detonation. The primary altimeters will be responsible for setting off the black powder charges to deploy the drogue parachute at apogee and deploy the main parachute at 900 ft. above ground level, AGL. The secondary altimeters will deploy the parachutes if they have not already been deployed. The secondary altimeter for the drogue parachute will fire at apogee. The secondary altimeter for the main parachute will fire at 700 ft. AGL. The charges placed forward of the electronics bay will eject the drogue parachute. These charges will also eject the payload. The charges placed aft of the electronics bay will shear the nylon shear pins and separate the forward and aft section. All four altimeters will record the altitude the rocket reaches. In addition, every independent section will have a GPS locator attached. This includes the forward body section, aft body section, and the payload.

3.3.3 Drawings, Diagrams, and Electrical Schematics

The recovery system electronics sled is shown below in *Figure 3.10*, and in *Figure 3.11* the entire electronics bay is shown as a SolidWorks model. The dimensions of the sled can be seen in *Figure 3.12*.

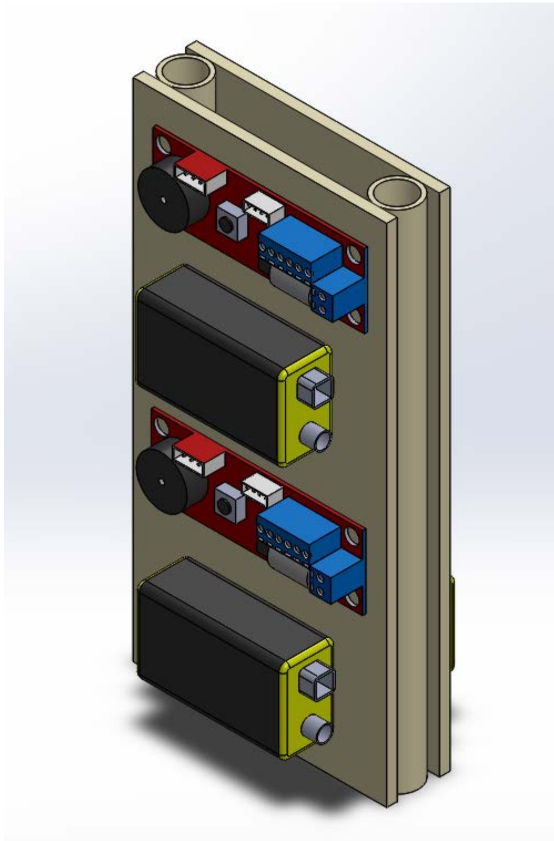

Figure 3.10 Recovery Electronics Sled Model

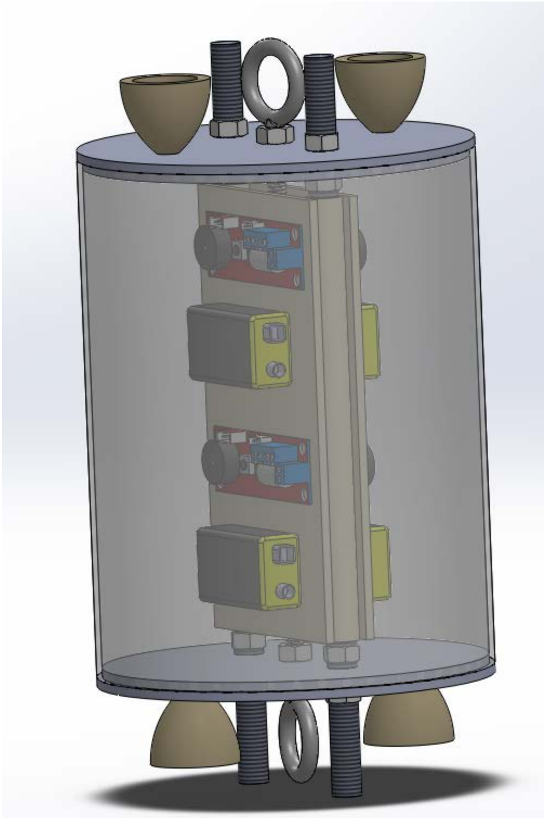

Figure 3.11 Recovery Electronics Bay Assembly

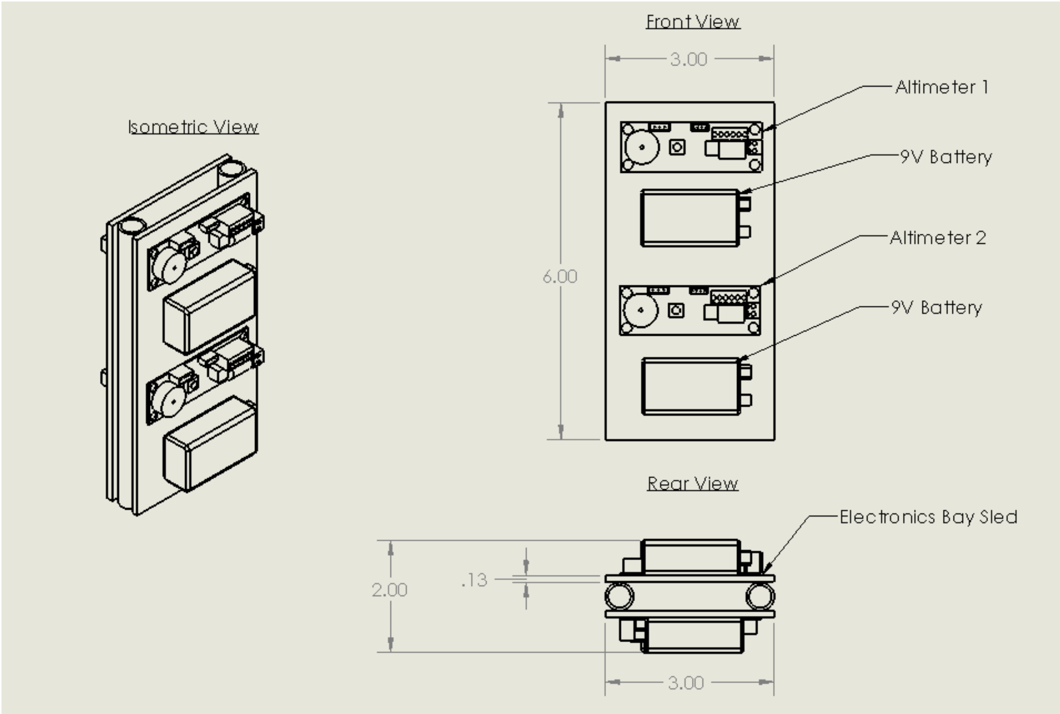

Figure 3.12 Recovery Electronics Sled Drawing

Figure 3.13 below shows the one side of the electrical schematic of the recovery system electronics bay. The electronics bay includes four PerfectFlite Stratologger altimeters wired to four black powder charges and four batteries. The black powder charges are represented by the circle with and X inside.

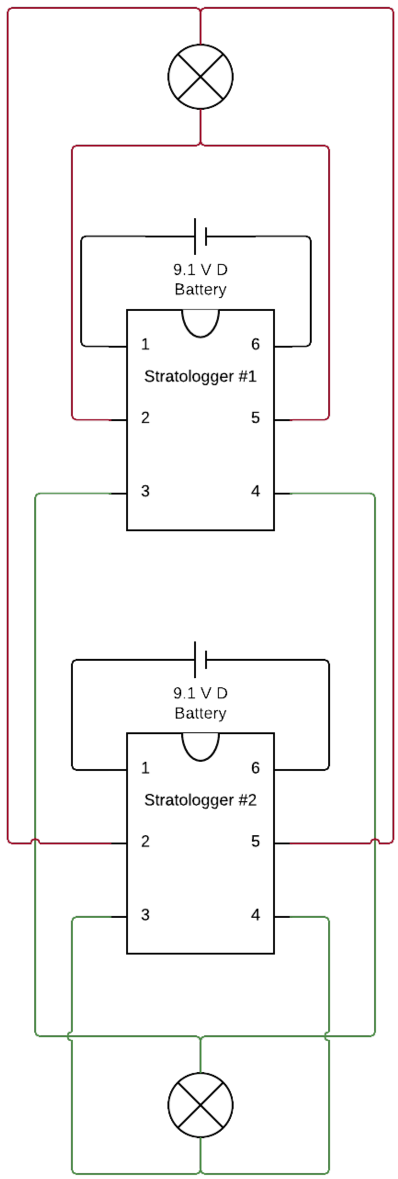

Figure 3.13 Recovery System Electronics Schematic

3.3.4 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 3.9.*

System	Mass (lbf)	Allowable Velocity (ft./s)	Minimum Parachute Diameter (in)	Drag Reduction Velocity from Minimum Parachute (ft./s)
Nose Cone	1.31	60.72	12	33.34
Forward Body Section	8.43	23.94	42	22.66
Aft Body Section	9.99	21.98	54	19.19
Total Rocket	19.73	15.64	96	15.17

Table 3.9 Parachute Selection

Therefore a 110 inch (2.79 m) main parachute for the total descending rocket is justified to safely land each individual system under the 75 ft-lb.

3.3.5 Test Results

The ARES Team will test the recovery system during the subscale and full scale launches. Ground ejection tests will be conducted to determine whether the planned amount of black powder will be enough. The recovery system in full will be tested during the flight. The results from the subscale test will be included as an addendum after the subscale launch on January 16th.

3.3.6 Safety and Failure Analysis

Safety and failure analysis for the recovery system includes any failure modes that may affect, either directly or indirectly, deployment and execution of the vehicle and payload recovery systems. This failure mode analysis primarily deals with failure of the black powder charges to ignite or failure of the parachutes to deploy. Refer to Section 3.7 for a comprehensive safety and failure analysis, including all safety analyses pertaining to the recovery system.

3.4 Mission Performance Predictions

3.4.1 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 900 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.

3.4.2 Flight Profile Simulations, Altitude Predictions, Drift Calculations, and 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, Bragg Farms with 5-10 mph wind, Manchester, TN with no wind, and Manchester, TN with 5-10 mph wind. The results of these simulations are shown in *Table 3.10.* The altitude and vertical velocity vs. time for each scenario are shown in *Figures 3.14, 3.15, 3.16, and 3.17*. In addition, the thrust curve for the Cesaroni L3200 motor is displayed in *Figure 3.18*. These simulations show in that the current rocket design reaches slightly above the 5280 ft. altitude mark with a standard deviation of approximately 6.135 ft. As previously stated, with a confidence interval of 97%, plus or minus 6.6565 from 5306.25 ft., places the vehicle well within the ARES goal of plus or minus 52.8 ft. of 5280 ft. The plus or minus 52.8 ft. is obtained from the ARES goal of 1% within the required altitude. This verifies that the Cesaroni L3200 motor is a valid choice for our propulsion subsystem.

**Note: All simulations performed in OpenRocket are at the correct latitude, longitude, and altitude for each launch site.*

Simulation	Apogee (ft.)	Max Velocity (ft./s)	Time to Apogee (s)	Flight Time (s)	Ground Hit Velocity (ft./s)
Bragg Farms (0 mph)	5306	723	17.3	210	15.1
Bragg Farms (5-10 mph)	5296	723	17.3	211	14.2
Manchester (0 mph)	5319	723	17.3	210	13.5
Manchester (5-10 mph)	5304	723	17.3	210	14.0

Table 3.10 Flight Simulation Data

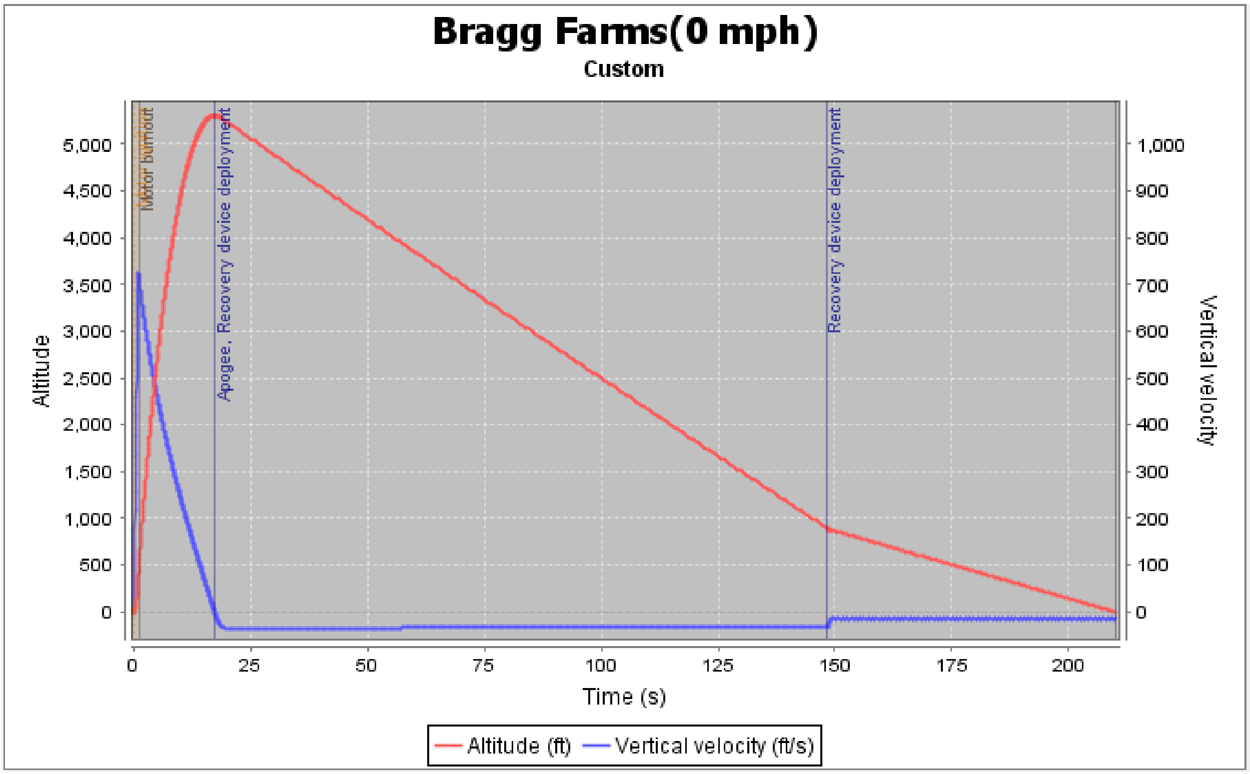

Figure 3.14 Bragg Farms (0 mph)

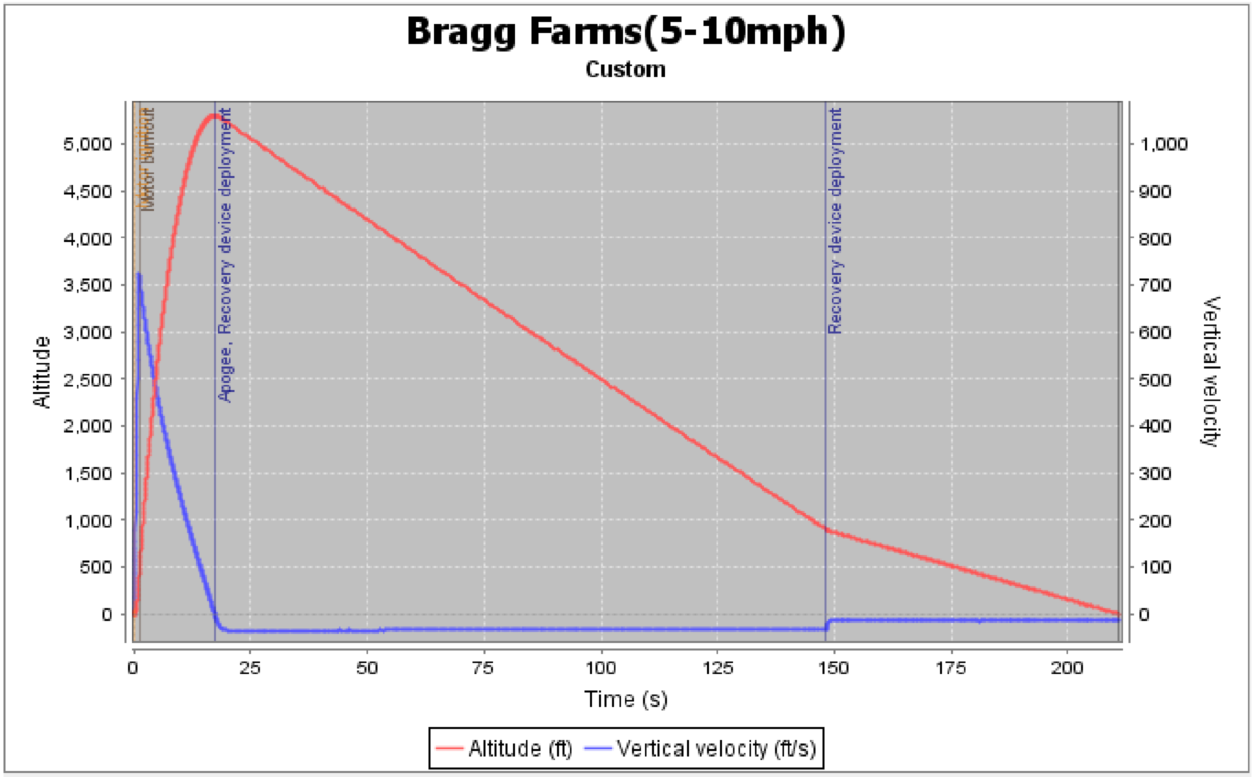

Figure 3.15 Bragg Farms (5-10 mph)

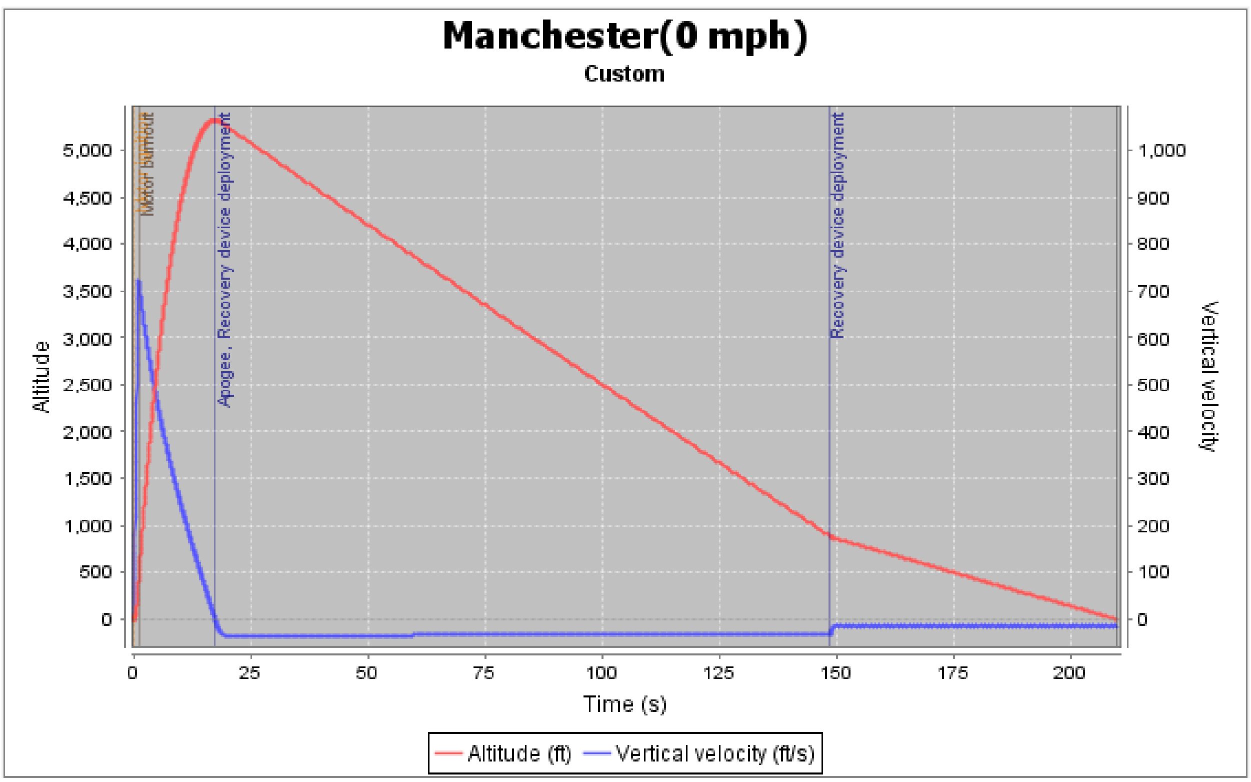

Figure 3.16 Manchester (0 mph)

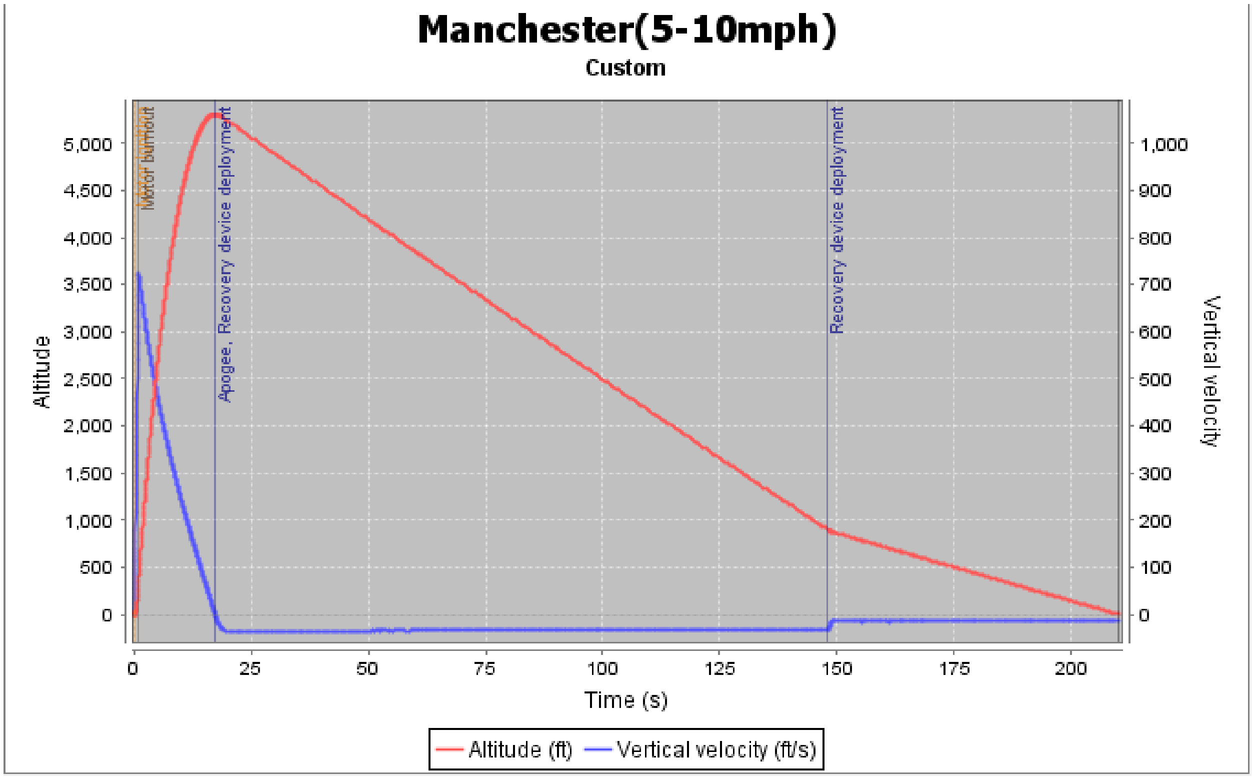

Figure 3.17 Manchester (5-10 mph)

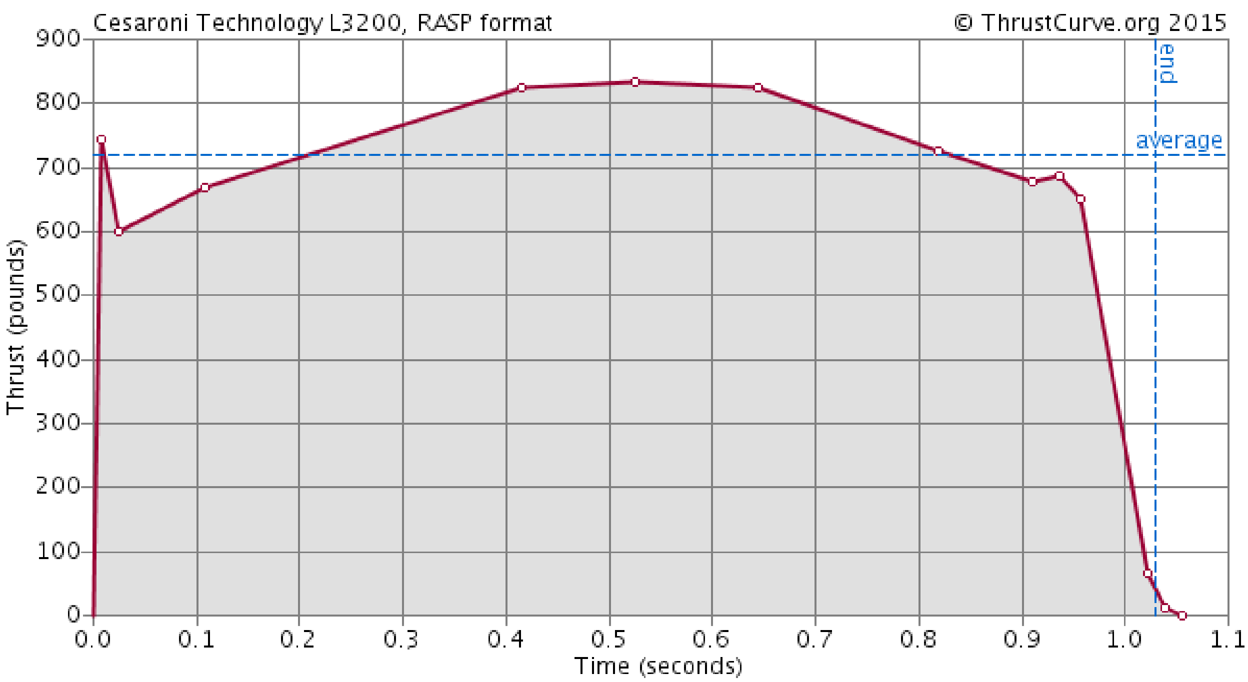

Figure 3.18 L3200 Thrust Curve

Drift calculations performed in OpenRocket at latitude, longitude, and altitude of Bragg Farms, Huntsville, Alabama and a sod farm in Manchester, Tennessee. The sod farm in Manchester, TN is a site jointly managed by Huntsville Area Rocketry Association, (HARA), and Music City Missile Club, (MCMC), for high-powered rocketry. The drift calculations for both locations at various wind speeds can be seen in *Table 3.11* and *Table 3.12*

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Max Lateral Distance (ft.)	6.42	1294	2593	3903	5207

Table 3.11 Bragg Farms Drift Calculations

Wind Speed	0 mph	5 mph	10 mph	15 mph	20 mph
Max Lateral Distance (ft.)	6.39	1295	2589	3889	5199

Table 3.12 Manchester Drift Calculations

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

The analysis of the vehicle hinges on three key components: OpenRocket simulations, knowledge available from the team's mentors and past experience with rockets, and the subscale model flight test. The OpenRocket simulations give a reasonable estimate of altitude, drift, and other factors affecting the launch vehicle. OpenRocket simulates the stability and control of the rocket with an atmospheric model. OpenRocket builds on equations similar to Barrowman's equations, which give the stability of the vehicle, but OpenRocket takes steps to correct for large changes in relative angle of attack. OpenRocket gives an accurate estimate of altitude, range, and other key data. The ARES Team is then able to take these into account and make changes to the computational design to better achieve the success criteria. The drag assessment of the rocket was also done through OpenRocket. The launch vehicle during flight currently has a drag coefficient of approximately 0.467 and a max total drag force under of 49.5 lb (220 N).The subscale vehicle tests the recovery system, the payload ejection system, and that the flight characteristics are similar to the ARES rocket team's expectations of a normal flight. The subscale vehicle will prove the feasibility of the launch vehicle design.

3.4.4 Static Stability Margin

The center of gravity and the center of pressure of the rocket are located 53.72 and 64.76 inches (1.36 and 1.64 m) from the tip of the nose cone, respectively. *Figure 3.19* shows the OpenRocket diagram of the launch vehicle, including the center of gravity (the blue and white circle) and the center of pressure (the red circle). This creates a favorable stability margin of 2.0 calibers.

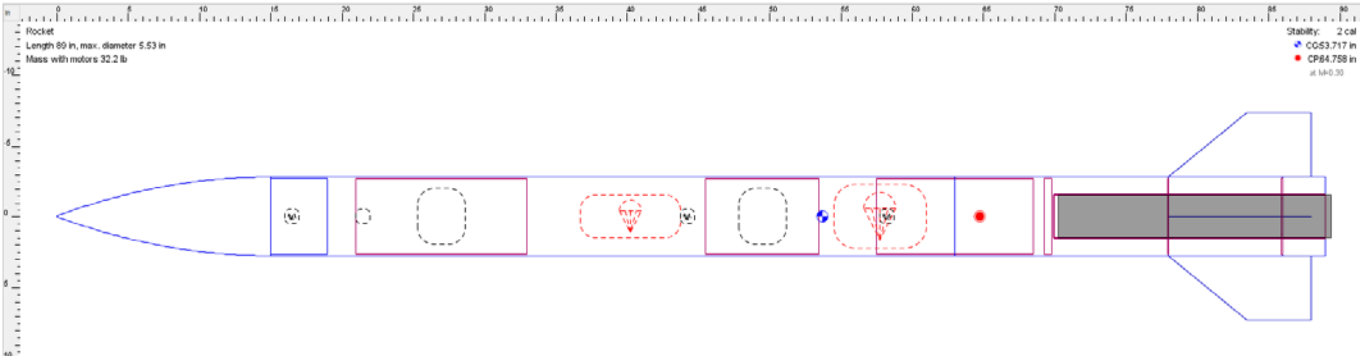

Figure 3.19 OpenRocket Diagram

3.5 Payload Integration

3.5.1 Integration Plan

The launch vehicle has designated space for the Hazard Avoidance Lander, HAL, to be stored. This designated space is illustrated in *Figure 3.1*. The payload, when deployed, should be able to eject cleanly (avoid "sticking" inside the forward body tube), and be clear of the rest of the sections of the launch vehicle. The payload has its own internal altimeters, which means the payload can operate without using any of the components of the launch vehicle 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 of sorts to help slow or prevent tumbling from the vehicle. These feet will be positioned towards the nose cone. The feet will be positioned prior to insertion to avoid "sticking" inside the forward body tube upon ejection.

The payload will be ejected by a black powder charge immediately following apogee. Squibs, (a cup of duct tape containing black powder charge and an electronic match) will be used for all necessary ejection charges. At apogee the nose cone will be ejected, followed by the payload, and then the drogue parachute. The payload will be protected by the fiberglass housing, and will be designed and constructed to withstand these charges. The payload is placed in the forward body tube in front of the drogue chute to allow clearance of the launch vehicle and avoid any possible tangling with the launch vehicle or its recovery system.

3.5.2 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.

3.5.3 Simplicity of Integration Procedure

The integration procedure for the HAL payload is meant to be as simple as possible. The ARES Team has decided that rails or other mechanisms to guide or eject the payload present too much of a risk of complications, and thus will not be used. The team hopes to avoid any such complications through the simplicity of the integration of the payload.

3.5.4 Changes to Payload Resulting from Subscale Test

The subscale ground tests and flight test will test the ability of the black powder charges to eject the payload from the body tube. The results and any changes made to the payload will be submitted as an addendum to this report after the ARES Team completes their subscale flight on January 16th.

3.6 Launch Concerns and Operation Procedures

3.6.1 Final Assembly and Launch Procedures

The team has prepared a final checklist of safe assembly and launch procedures to be used immediately prior to launch. For this checklist, see Appendix B. Each team member will be provided with a copy of this checklist at a safety briefing to be held during the week prior to the subscale launch. Safety briefings before both the full scale and competition launch will reiterate these safety procedures.

The team has also prepared a checklist of operating procedures for hazardous materials based on the Safety Data Sheets that can be found in Appendix C. This checklist includes specific procedures for each material and can be found in Appendix D.

3.7 Safety and Environment

3.7.1 Identification of 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.

3.7.2 Updated Failure Mode Analysis

The following Failure Mode Analysis in *Table 3.16* assesses potential safety risks and failure modes from the rocket vehicle itself. Risks and failure modes specifically caused by the payload are listed in Section 4.1.9. Each failure mode receives an initial risk assessment and a post-mitigation risk assessment, both of which are given a number, letter, and color ranking according to *Table 3.13-3.15*. The mitigations listed for each failure mode have been derived from team safety procedures, SDS sheets for hazardous materials, tool handling manuals, etc. Any questions about the analysis may be posed either to the team captain or the team safety officer.

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 3.13 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.	$0.000001 \geq$ Probability

Table 3.14 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 3.15 Risk Levels.

Failure Analysis: Vehicle					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Nose cone parachute	Ballistic nosecone; possible loss of nose cone due to damage on landing; possible injury to bystanders from nose cone landing	Incorrect parachute packing and folding; failure of shear pins to break as planned (shear pins too strong and do not allow separation)	2D	Ensure parachute is properly packed and correct shear pins are used; double check shear pins and parachute prior to launch; ensure safety officer supervises parachute folding	4D
Payload deployment	Incomplete experiment and/or full experimental failure due to failure of payload to deploy	Failure of black powder charges to detonate; failure of altimeter altitude readings; failure of shear pins to separate	1D	Ensure payload is secure within payload bay; double check setup of altimeters and black powder charges to avoid mistakes;	1E

				ensure correct shear pins are used; double check shear pins	
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	Consult altimeter manual for common altimeter defects and errors; check all wiring and code to ensure it is compatible with the altimeter data	4E
Rocket separation (early)	Deployment of payload and/or parachutes prior to apogee; full apogee not reached	Early detonation of black powder; failure to secure suitable shear pins for rocket; early breakage of shear pins	3C	Check black powder and e-match setup to ensure early detonation will not occur; choose shear pins of proper strength for rocket and charge size	4E
Rocket separation (late or failed)	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	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	2E

				properly secured within rocket	
Black powder (late or failed detonation)	Delayed or failed deployment of parachutes and/or payload; delayed or failed rocket separation	Failed altimeter readings; failure of e-matches to ignite black powder	2C	Ensure altimeter data is correctly read by onboard software; ensure proper setup of e-matches and black powder charges prior to launch	2E
Unsuitable launch pad for launch vehicle	The launch vehicle would be unable to launch due to the safety issues involved	Rail buttons and launch rail are not compatible	1D	Ensure that all rail guides fit standard rail launching systems. The ARES team will also look into purchasing its own launch pad to ensure successful launch	3E
Incorrect determination of center of gravity	Launch vehicle is either unstable or is susceptible to weathercocking at the extreme. A minor error in the determination is acceptable	Center of gravity is found before the final weight is calculated; the design in simulation engine is not updated	3D	Center of gravity will be found by testing the launch vehicle multiple times; design of the launch vehicle in OpenRocket will be updated with real measurements	4E
Incorrect determination of center of pressure	The rocket is either unstable or is susceptible to weathercocking at the extreme. A minor error in the determination is acceptable	The Barrowman method used in the simulation engine, OpenRocket	3D	Launch vehicle in OpenRocket will be updated with real measurements; OpenRocket uses a modified Barrowman method to determine center of pressure.	4D
Launch vehicle weathercocks	The vehicle has the potential to enter an improper flight path; would lead to a lower altitude	The launch vehicle became unstable	1D	Stability margin will be maintained around 2.0 calibers throughout design iterations in order to	3D

	or possible issues with the deployment of the payload with a minor weathercocking			avoid any potential weathercocking	
Improper motor selection	Could lead to underthrust or overthrust. Underthrust would lead to a lower than desired altitude. Overthrust has the potential to make the rocket highly unstable and a danger to observers. Overthrust would lead to a higher than predicted altitude and the possibility of moderate to severe structural damage	From simulations in OpenRocket, a weaker or stronger motor than needed was selected	1C	Utilize OpenRocket to simulate the different motors to predict the effect of different impulses; use knowledge from NAR mentor; ensure the Mach number and impulse-to-weight of subscale match those of full scale	3D
Launch vehicle fails to be stable	The vehicle will pose an extreme hazard and danger to bystanders and observers; the payload may not deploy or operate properly	The stability margin is not close to 2.0; components shifted during launch	1D	Constantly verify that the stability margin is around 2.0 calibers	2D
Structure prevents deployment of payload	Payload is unable to be deployed	Structural components got in the way of the payload ejection	2D	Fit all the parts of the rocket together; assemble the rocket with payload inside; check for any possible parts that may inhibit ejection; ensure safety officer	3E

				supervises assembly of payload	
Motor mount fails	If the motor mount becomes loose, the motor may move in the rocket; may result in misfire or an unstable launch	Improper attachment of motor mount; excessive use	1D	Ensure the motor mount is secured properly inside the rocket	3E
Incorrect determination of forces on launch vehicle	Will supply an incorrect determination of the CP	Incorrect calculations; final data not included in calculations	2C	Utilize OpenRocket to determine the forces on the launch vehicle using the most up to date information	3D
Fins improperly mounted	More prone to instability if fins are uneven or become detached	Error in measurement of fin placement; improper or impatient attachment of fins	1D	Check size and placement of fins in OpenRocket; ensure they are positioned on the launch vehicle symmetrically and in the designated locations	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	2D
Wind gusts affect deployment of payload	Heavy swinging of payload once deployed; difficult for camera to analyze hazards; tangle cords of parafoil; blown too far from homebase	Wind gusts tangle the parafoil cords; wind catches parafoil and carries it far from intended location	2D	Monitor all weather conditions before launch; pack the parafoil so cords do not become tangled	3D

Wind gusts affect deployment of recovery system	Launch vehicle drifts far off course; rocket may cause severe injury or death if rocket drifts over a crowded area, especially if recovery system deploys late; wind tangling recovery system	Wind gusts can suddenly change the direction of the rocket	1D	Monitor all weather conditions prior to launch; ensure recovery system is packed so it will not be constricted or tangled upon deployment	2D

Table 3.16 Failure Mode Analysis: Vehicle

3.7.3 Updated Personnel Hazards

Personnel hazards encompass direct risks to the team members, whether the cause is a rocket malfunction, a hazardous material leak, or a tool or power tool accident in the lab. Below in *Table 3.16* is a list of personnel hazards, ranked by risk using the same ranking system from the Vehicle Failure Mode Analysis in Section 3.7.2. A mitigation is listed for each situation, and a post-mitigation risk assessment is also provided. For any further information on risks posed to team members by hazardous materials as well as actions to be taken in the event of a spill, the SDS sheets provided in Appendix X may be consulted. Likewise, tool or power tool manuals may be consulted for proper use of lab equipment as needed. All team members were required to complete a lab safety course in order to minimize potential personnel risks; this was successfully accomplished.

Personnel Hazards					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Rocket separation (late or failed)	Impact of rocket pieces would present a direct danger to nearby people; ballistic rocket could seriously or fatally harm team	Delayed or failed detonation of black powder; failure of shear pins to break as expected	1C	Ensure e-matches will detonate black powder at desired altitude; double-check e-match setup prior to launch; avoid choosing shear pins strong enough to	1E

	members and bystanders			prevent rocket separation	
Black powder (early or unexpected detonation)	Detonation of black powder could seriously or fatally burn nearby team members and bystanders	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	2E
Hand tools (hand saws, sandpaper, clamps, etc.)	Injury to team members including but not limited to lacerations, fractured/broken/ severed limbs, eye injuries, burns, and respiratory irritation	Improper use and/or handling of tools; failure to follow team hand tool safety guidelines; failure to wear proper PPE	2D	Follow all team safety guidelines for handling of tools; complete lab safety course (already completed); attend all team safety briefings; do not use tools alone and unsupervised; wear PPE when using tools; store all tools in appropriate and safe locations when not in use	2E
Power tools (circular and table saws, drills, power sanders, etc.)	Injury to team members including but not limited to lacerations, fractured/broken/ severed limbs, eye injuries, burns, and respiratory irritation; possible electric shock	Improper use and/or handling of tools; failure to follow team power tool safety guidelines; failure to wear proper PPE	2D	Follow all team safety guidelines for handling of power tools; complete lab safety course (already completed); attend all team safety briefings; do not use power tools alone and unsupervised; wear PPE when using power tools; store all power tools in appropriate and	2E

				safe locations when not in use; ensure tools are off and unplugged when not in use	
Hazardous materials (epoxy, fiberglass, spray paint, etc.)	Irritation/Injury to eyes and/or respiratory system; skin irritation and/or burns; material induces sickness in affected team member	Failure to follow team hazardous material safety guidelines and SDS guidelines; failure to wear proper PPE	3D	Follow all team safety guidelines and SDS guidelines for safe handling of hazardous materials; do not handle materials without PPE; do not handle materials alone and unsupervised; store all hazardous materials in appropriate and safe locations when not in use	4D
Batteries	Battery acid may leak and burn skin	Improper storage or handling	2C	Batteries must be handled with care and stored in a safe, isolated location	3D
Soldering Iron	Burns to skin; irritation from fumes	Improper use; inadequate safety protection	2B	Follow soldering iron instructions for use; Wear protective glasses, gloves, and respiratory mask.	3D

Table 3.16 Personnel Hazards.

3.7.4 Environmental Concerns

The rocket presents several safety hazards to the environment; likewise, the environment has the potential to adversely affect the flight and mission of the rocket. Rocket hazards to the environment primarily concern possible environmental damage in the form of pollutants or physical damage to the natural surroundings. These would be caused due to some failure either in the rocket itself or the team's ability to control either the rocket or hazardous materials associated with the rocket, and the team can actively prevent these risks. Environmental hazards to the rocket include any natural phenomenon or state that may negatively affect flight conditions. While the team cannot directly prevent these, safety measures have been prepared in the event the launch is negatively affected by the environment, dictating countermeasures for each situation. All hazards are provided below in *Tables 3.18* and *3.19*. The same criteria used in the Failure Mode Analysis in Section 3.7.2 was used to determine environmental risk levels. All risks apply to the subscale, full scale, and competition launches.

Rocket 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	3D

				minimize potential crash landings	
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

Table 3.18 Rocket Hazards to Environment.

Environmental Hazards to Rocket					
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
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
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 3.19 Environmental Hazards to Rocket.

4. Payload Criteria

4.1 Testing and Design of Payload Equipment

4.1.1 System Level Design Review

The payload system is responsible for performing the two experiments selected by the ARES team. The first experiment is to detect landing hazards under the payload. The second experiment is to guide the descent to the initial launch point. The payload is divided into four distinct subsystems. The Payload Control subsystem interfaces with the other three, and runs the software for the payload. The Landing Hazards Detection Payload acquires images of the ground to be analyzed, stores the data, and transmits it back to a ground station. The Guided Descent Subsystem steers the payload to a GPS waypoint, and also avoids hazards that are detected in the area. Finally, the Payload Landing Subsystem is responsible for mitigating any velocity at landing to keep the components safe. The functional requirements of the payload are covered in *Table 4.1*.

4.1.1.1 Drawings and Specifications

Figure 4.1 shows the free-body diagram of a parafoil with no thrust acting on it. γ represents the flight path angle, shown negative, ϕ represents the canopy rigging angle, and α represents the angle of attack. L_c represents the lift generated by the canopy. D_c represents the drag force generated by the canopy and D_P represents the drag force generated by the payload. W represents the weight. R_{cg} is the distance from the parafoil's center of gravity to the center of gravity of the system. R_{sp} is the distance from the payload's center of gravity to the center of gravity of the system.

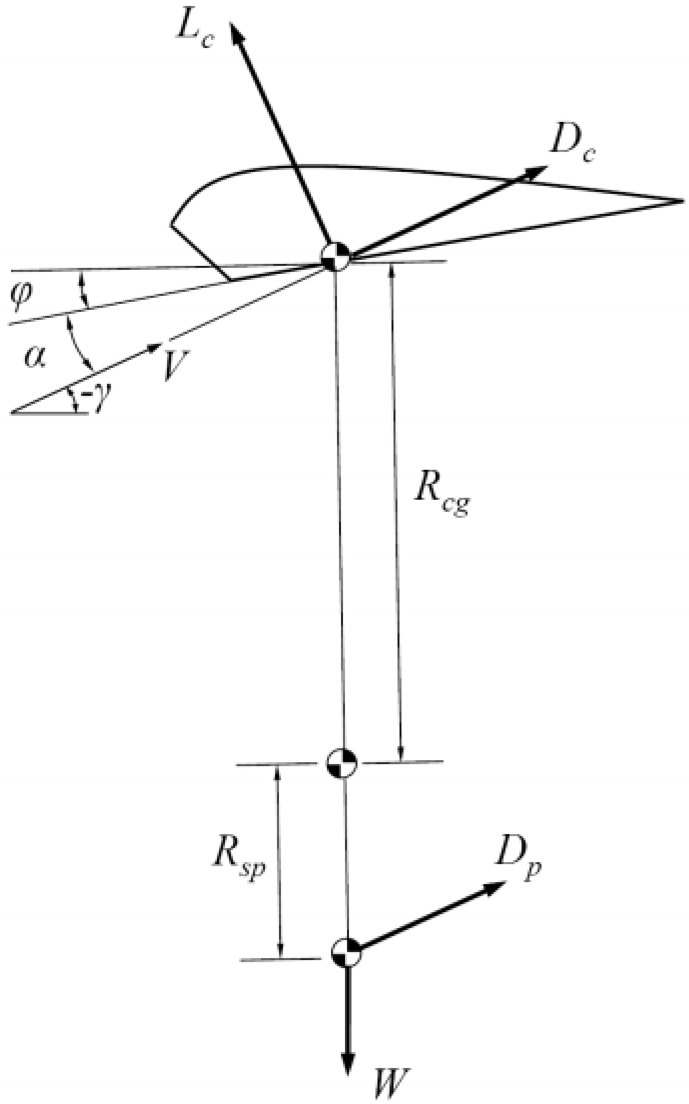

Figure 4.1 Free body diagram of parafoil system[1]

Figure 4.2 demonstrates how one set of landing legs will deploy. *Figure 4.3* shows the final position with all legs displayed. The legs are designed to give a wide landing base to avoid tipping over during landing. Five legs were chosen to help absorb the forward momentum of the payload. Each of the calves has an external block that acts to hold in the calf and thigh that are next to it. Two of the calves will be attached to servoless payload releases, these calves will also be holding part of a 5 inch diameter fiberglass tube. The tube, blocks, and payload releases will hold in the entire set of legs. As soon as the payload releases are disabled all of the legs will be

[1] *Branden James Rademacher"In-flight trajectory planning and guidance for autonomous parafoils" Iowa State University 2009.*

released and will deploy of their own accord. The partial fiber glass tubes will be epoxied to the calves.

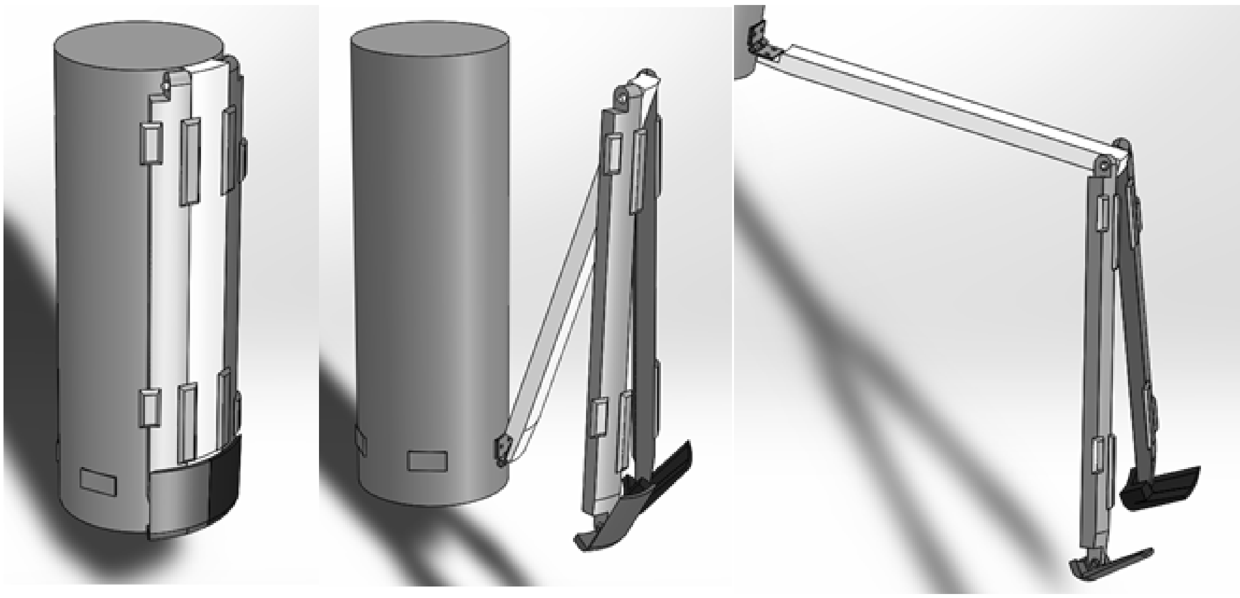

Figure 4.2 a) Position during launch and most of decent. b) Position immediately after legs are released. c) Final position before landing.

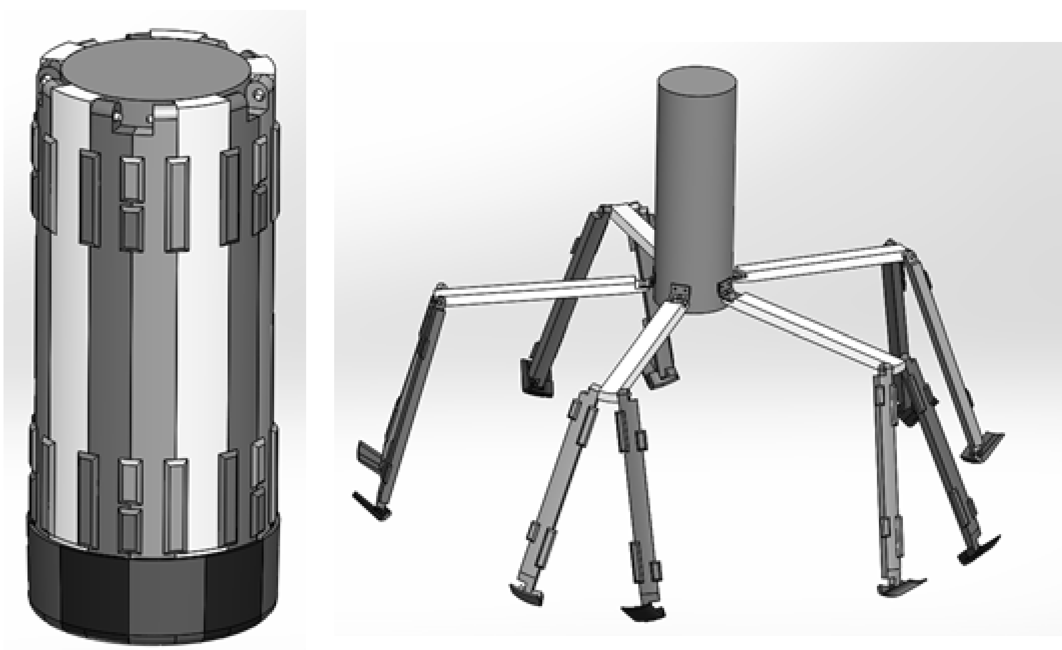

Figure 4.3 Isometric view of initial and final leg positions.

4.1.1.2 Analysis Results

Table 4.1 shows descriptions of the analyses done on the payload.

Object of Analysis	Concern to be Considered	Analysis 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.

Table 4.1 Analysis Results

The weight of the landing legs was an issue, so in an effort to decrease the overall weight of the legs an analysis was done investigating the viability of having a hollow beam for both the thigh and calf parts of the landing subsystem. To judge the effects of having a hollow beam the thigh and calf parts were approximated to be rectangles of similar shape. To measure the relative strength in comparison to mass a constant flexural yield strength was used to determine force at yield for various rectangle shapes. In *Table 4.2* and *4.3* the relationship can be seen for thigh and calf respectively.

Thickness (in)	**Mass Decrease %**	**Force %**
Solid Rectangle	0.00%	100.00%
0.20	12.66%	99.49%
0.175	20.36%	98.17%
0.15	29.02%	95.36%
0.125	38.51%	90.38%
0.10	48.98%	82.36%
0.075	60.38%	70.43%
0.05	72.67%	53.50%

Table 4.2 Thigh beam shape mass and strength comparison.

Thickness (in)	Mass Decrease %	Force %
Solid Rectangle	0.00%	100.00%
0.20	10.64%	99.57%
0.175	17.72%	98.41%
0.15	25.97%	95.85%
0.125	35.38%	91.15%
0.10	45.96%	83.45%
0.075	57.72%	71.72%
0.05	70.64%	54.79%

Table 4.3 Calf beam shape mass and strength comparison.

The weighted rating tables used to decide the wall thickness for the calf and thigh can be found in Appendix E.

4.1.1.3 Test Results

All component, subsystem, prototype and full-scale testing results for the payload is given in *Table 4.4*.

Test Phase	**Test**	**Result**
Component Testing	Verify that Pi will run from the SSD (Appendix G.1)	In progress
	Calibrate and test AltIMU (Appendix G.2)	In progress
	Transmit test data through XBee (Appendix G.3)	In progress
	Run test image through hazard detections software (Appendix G.4)	In progress
	Test stationary GPS (Appendix G.5)	In progress
	Parafoil drop test (Appendix G.6)	In progress
	Test servo motors (Appendix G.7)	Planned
	Test Pixy CMUCam5 (Appendix G.8)	In progress
	Parafoil deployment test (Appendix G.9)	Planned
Subsystem Testing	Test GPS and AltIMU while in motion and send data from XBee (Appendix G.10)	Planned
	Test complete payload electronics system (Appendix G.11)	Planned
	Measure leg spring forces (Appendix G.12)	Planned
	Leg deployment test (Appendix G.13)	Planned
	Low altitude turning drop test (Appendix G.14)	Planned
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 Payload Tests

4.1.1.4 Integrity of Design

Structural integrity of the payload will be tested using The University of Alabama's shake table. The ARES Team will then be able to ensure that all connections hold during flight.

4.1.2 System Level Functional Requirements

Table 4.5 shows all functional requirements for the payload and the concepts to meet said requirements.

Subsystem	Functional Requirement	Selection Rationale	Selected Concept	Characteristics
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	Parafoils fill with air and resemble
	Guide payload descent	Payload must be able to avoid any landing hazards detected		
	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
	Limit landing velocity	Payload must land with less than 75 ft-lb kinetic	Flare Technique	Pulling on both parafoil wires, will slow the payload

		energy, so velocity must be minimized before landing		down when landing
Landing Hazards	Detect hazards	See Appendix E	Pixy CMUcam5	Take images of the ground
	Identify hazards	See Appendix E	Pixy CMUcam5 Raspberry Pi	Analyze images taken by the camera
	Store data onboard	See Appendix E	250GB USB Portable Solid State Drive	Stores onboard data quickly, uses less power, resistant to vibrations
	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
Control	Run software in real time	Allows for the fast response times	Python code	Allows for more up to date information
	Know altitude	See Appendix E	AltIMU-10 v4	The barometer will receive pressure readings and will output altitude
	Know orientation	See Appendix E		The gyro will provide payload attitude
	Know location	See Appendix E	Adafruit Ultimate GPS Breakout	The GPS is accurate to 3 m
	Know velocity	See Appendix E		The GPS is accurate to 0.1 m/s
	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
Landing	Deploy legs at a specified altitude	Minimizes drag and moments on payload	Payload Release	Release lander legs when current passes through
	Keep upright and stable upon	Allow for ease of communication	Use lander with large leg spread	Longer legs will increase the

	touchdown	between the payload and the ground station		difficulty of tipping the payload
	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
	Absorb vertical momentum			

Table 4.5 Payload System Functional Requirements

4.1.3 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 mismanufactured, it also decreases the chance of injury to the team member doing the work.

4.1.4 Component, Functional, and Static Testing

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.

4.1.5 Manufacturing and Assembly Plans

4.1.5.1 Component Manufacturing

While many of the components for the payload were ordered, some were designed and manufactured in house. These are found in *Table 4.6.*

Subsystem	Component	Expected Time	Estimated Cost (each)	Manufacturing Process
Landing	Thigh (Upper Leg)	19 days	$21.12	3D Printing
Landing	Calf (Lower Leg)	18 days	$11.28	3D Printing
Landing	Foot	16 days	$2.07	3D Printing
N/A	Top Plate	20 days	$13.44	3D Printing
N/A	Bottom Plate	21 days	$13.87	3D Printing
N/A	Top Bracket	23 days	$25.11	3D Printing
N/A	Bottom Bracket	25 days	$19.84	3D Printing
N/A	SSD Bracket	26 days	$14.92	3D Printing

Table 4.6 Component Manufacturing

4.1.5.2 Payload Assembly Plan

1. Pre-Assembly
   a. Lower Plate Construction (*Figure 4.4*)
      i. Tap holes 1, 2, 4, and 8-12 (marked in green) with an M3 thread
      ii. Tap holes 3 and 5 (marked in red) with an M2 thread
      iii. Tap holes 6 and 7 (marked in blue) with a ¼”-20 thread

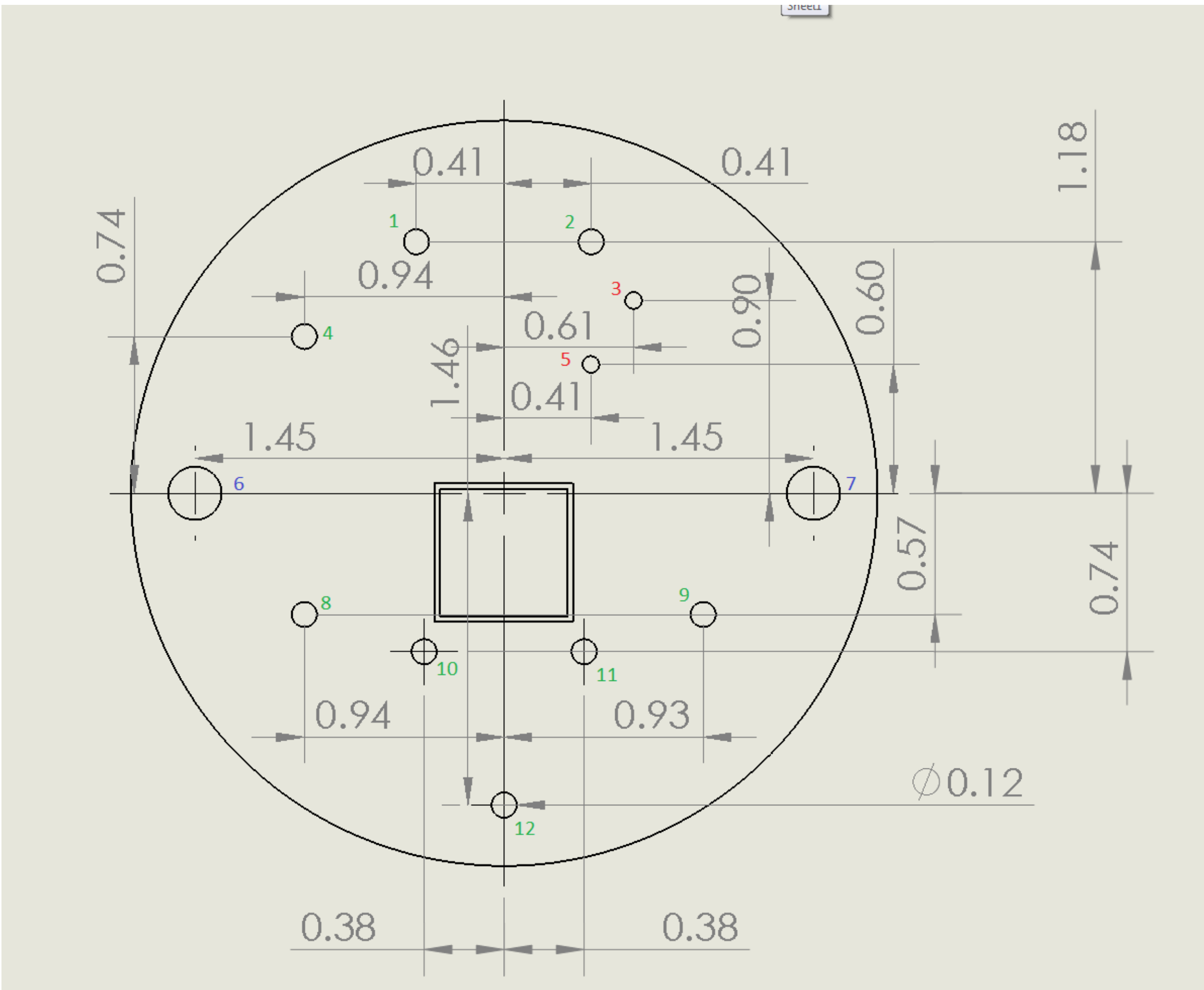

Figure 4.4 Lower Plate Construction

b. Main Bracket Construction (*Figure 4.5*)

i. Tap holes 1-4, 8, 9, 15, and 16 (marked in red) with an M2 thread

ii. Tap holes 5-7, and 10-14 (marked in green) with an M3 thread

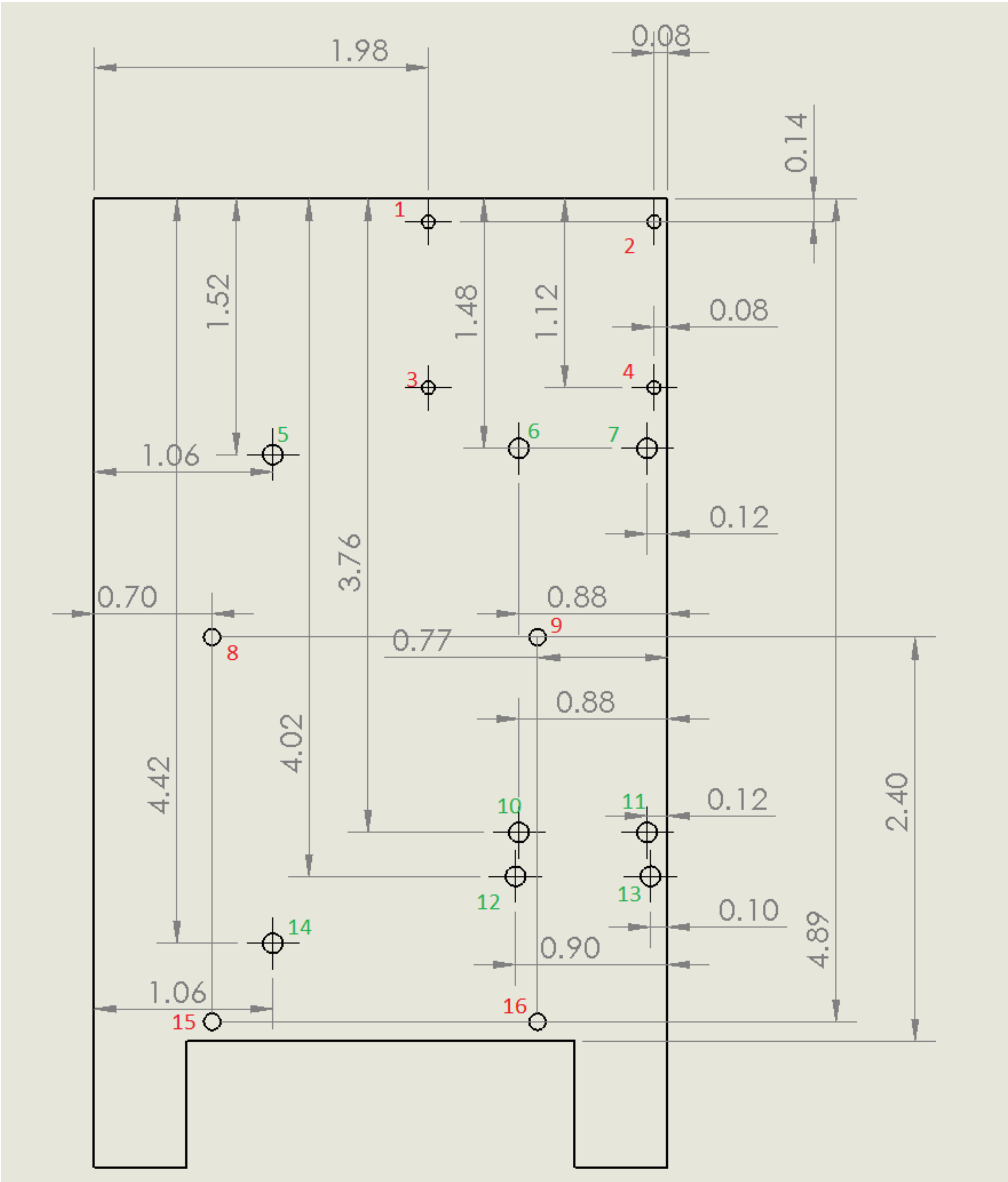

Figure 4.5 Main Bracket Construction

2. Internal Assembly
    a. Attach the AltIMU to the lower plate using 2M screws in holes 3 and 5.

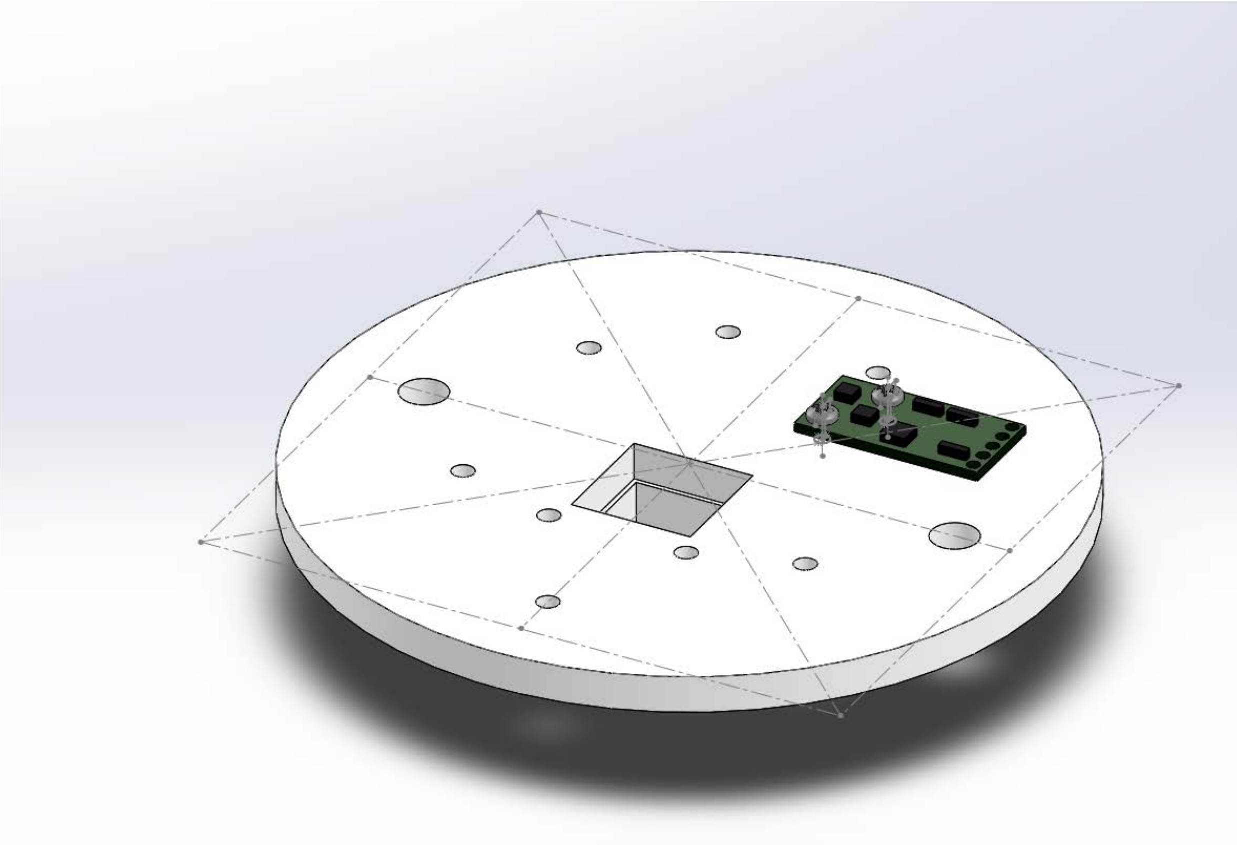

Figure 4.6 Internal Assembly (a)

b. Attach the CMUCam 5 using 3M screws and 5mm standoffs in holes 1, 2, 4, 8, and 9.

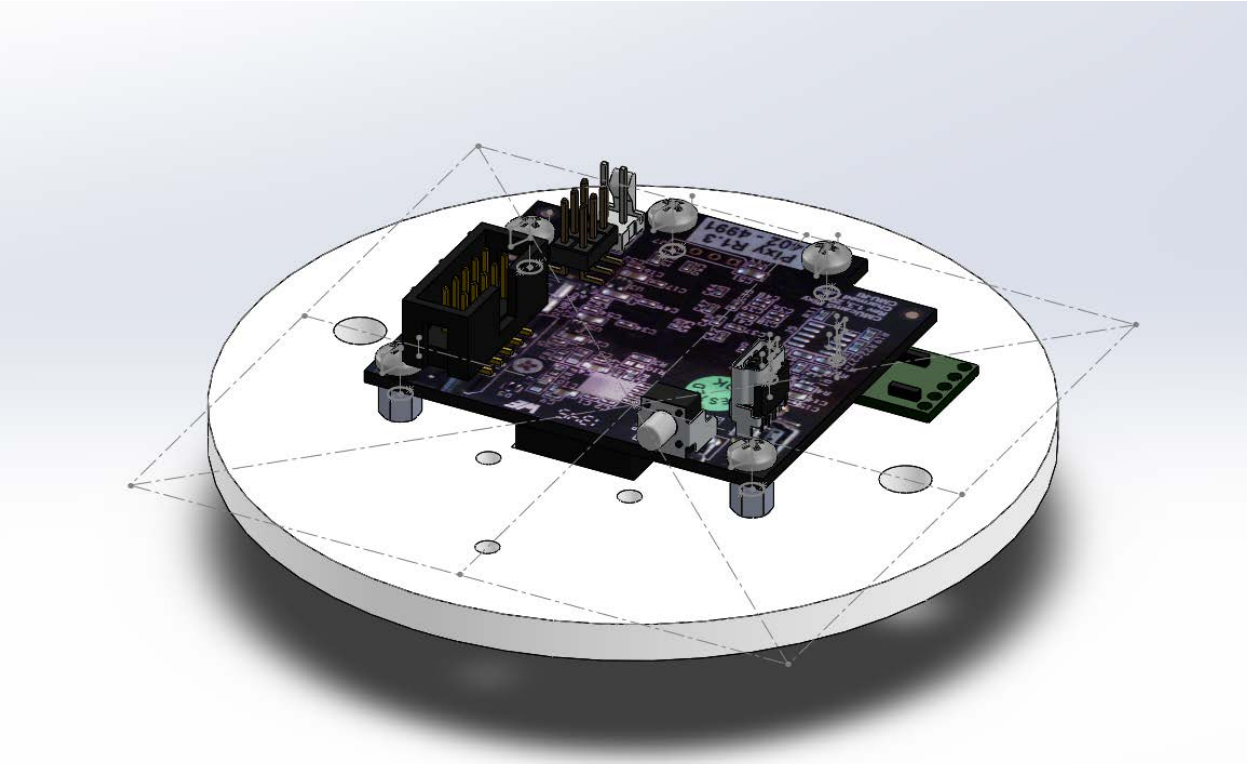

Figure 4.7 Internal Assembly (b)

c. Place the SSD in its bracket. Attach the SSD bracket to the lower plate using 3M screws in holes 10, 11, and 12.

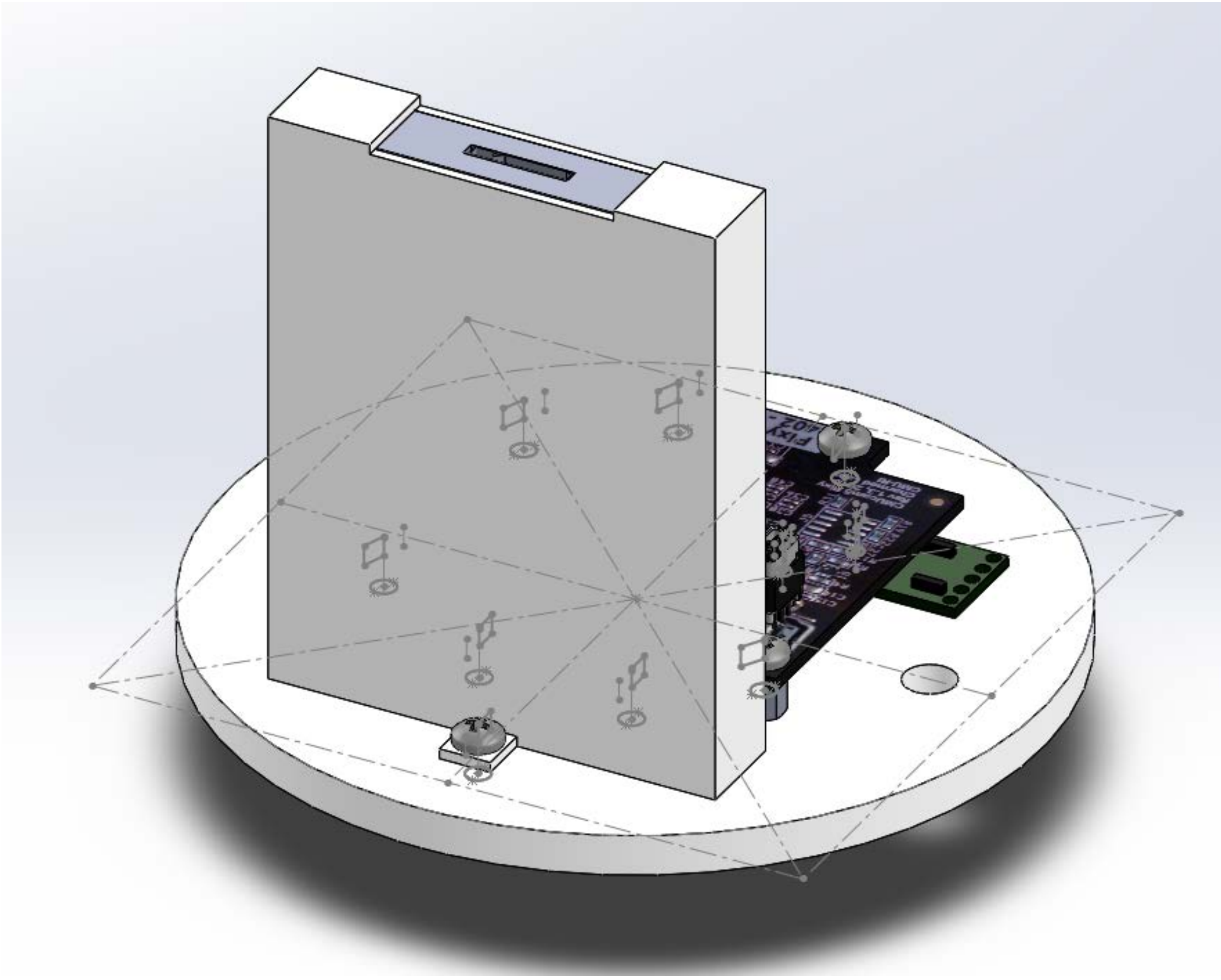

Figure 4.8 Internal Assembly (c)

d. Attach the center bracket to the lower plate by sliding it along the ¼”-20 Allthreads, which are placed through holes 6 and 7 on the lower plate. Tighten down with the ¼”-20 nuts.

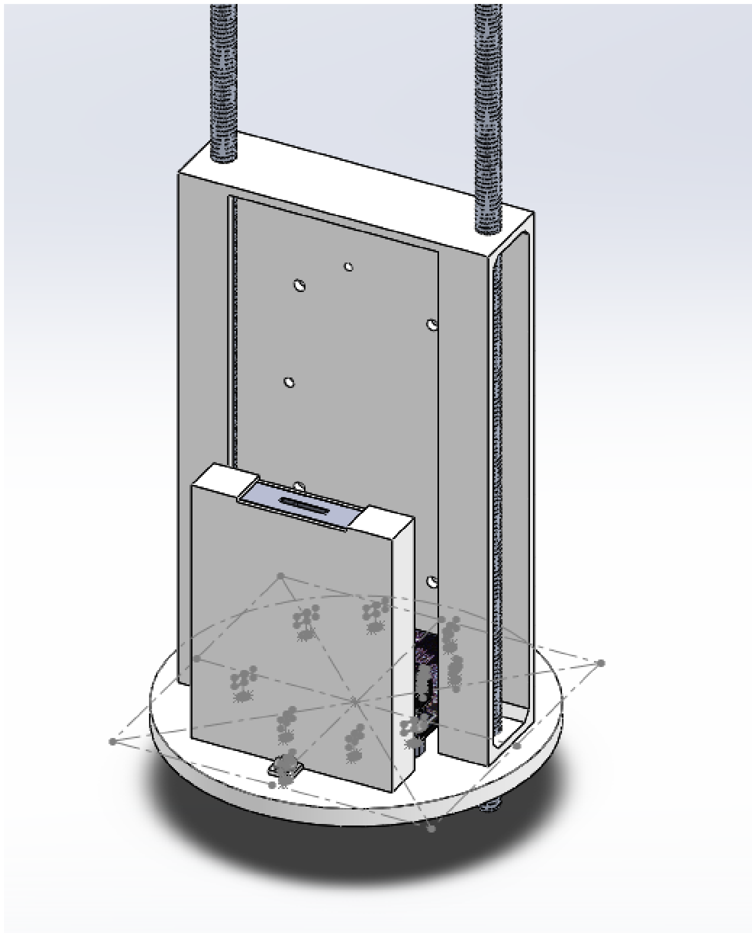

Figure 4.9 Internal Assembly (d)

e. Attach the Raspberry Pi using 2M screws and 5mm standoffs in holes 8, 9, 15, and 16.

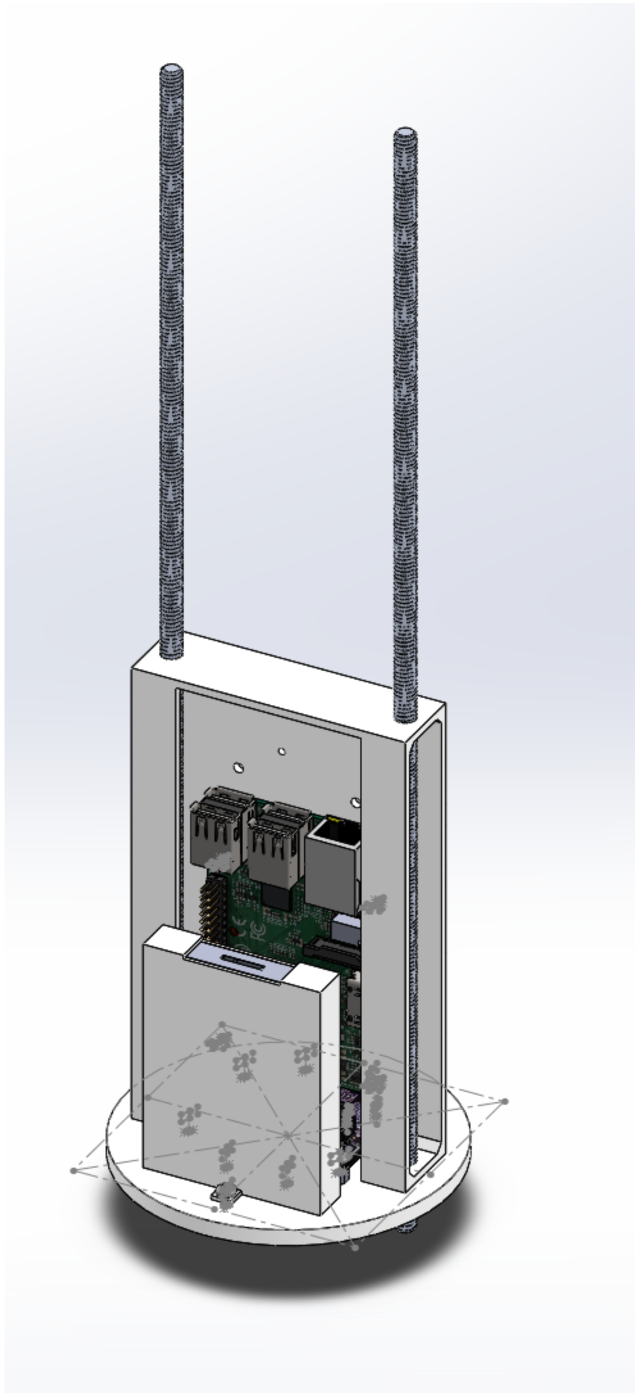

Figure 4.10 Internal Assembly (e)

f. Attach the Proto-Board using 3M screws and 5mm standoffs in holes 5 and 14.

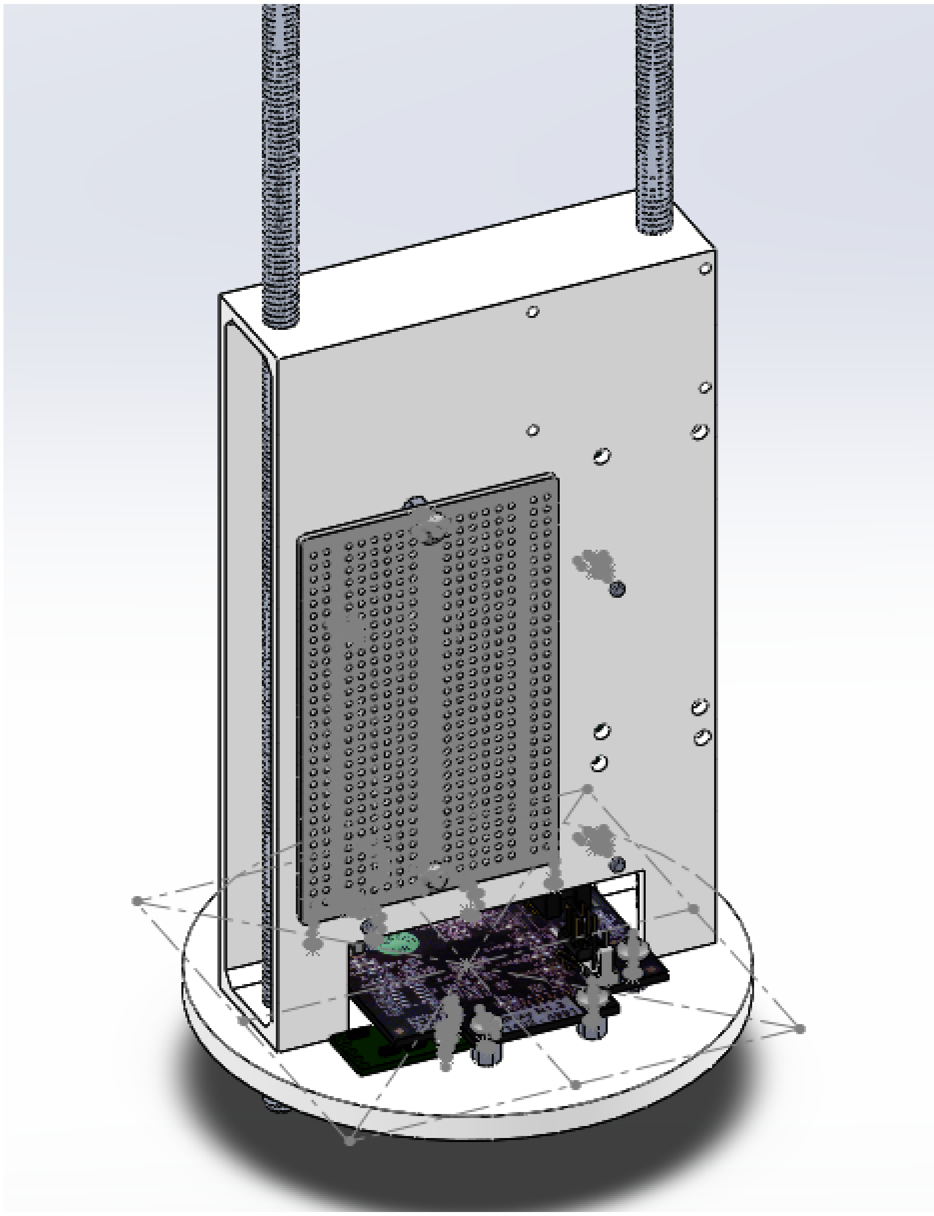

Figure 4.11 Internal Assembly (f)

g. Attach the I2C-PWM breakout using 3M screws and 5mm standoffs in holes 6, 7, 10, and 11.

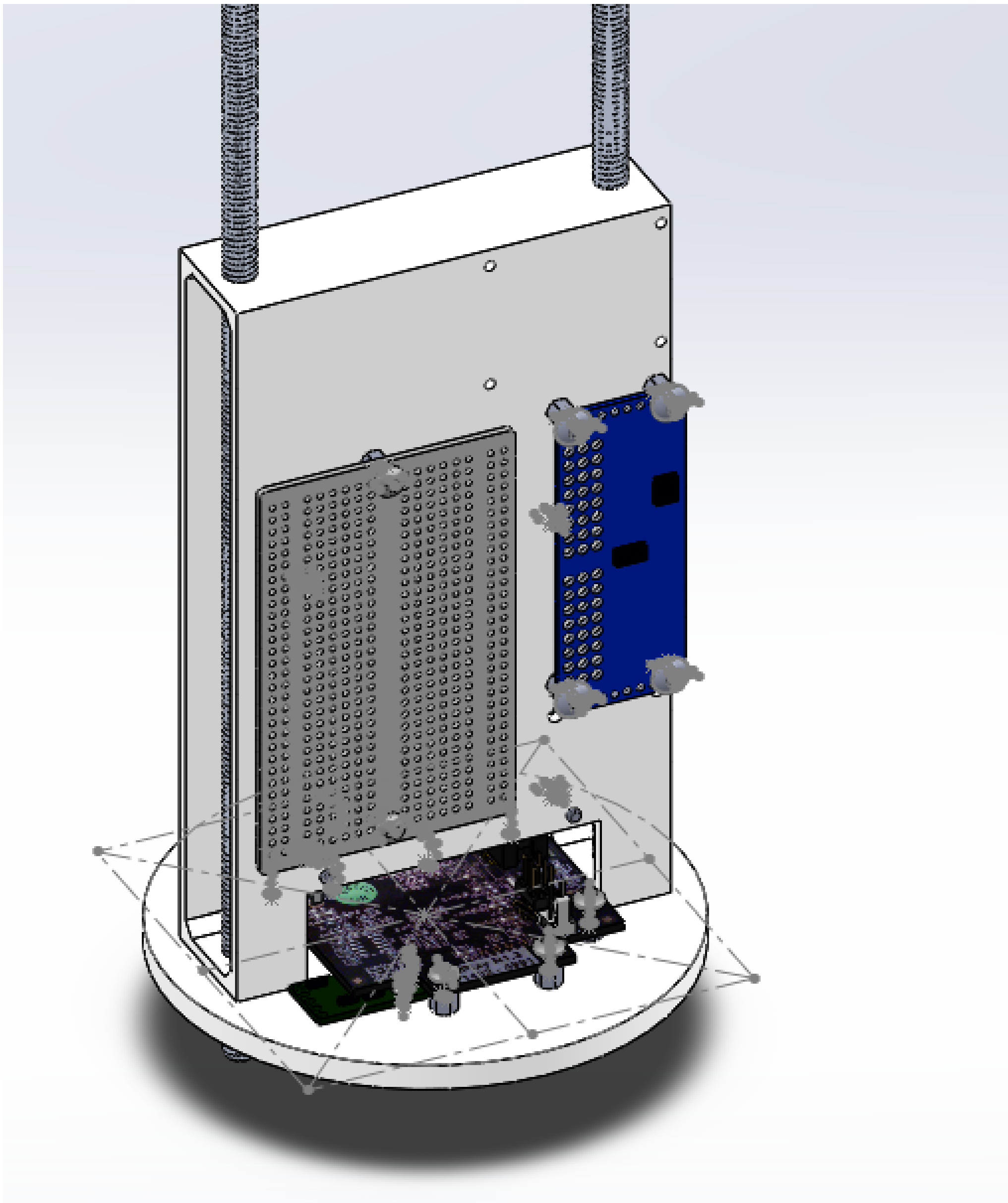

Figure 4.12 Internal Assembly (g)

h. Attach XBee using 2M screws in holes 1, 2, 3, 4.

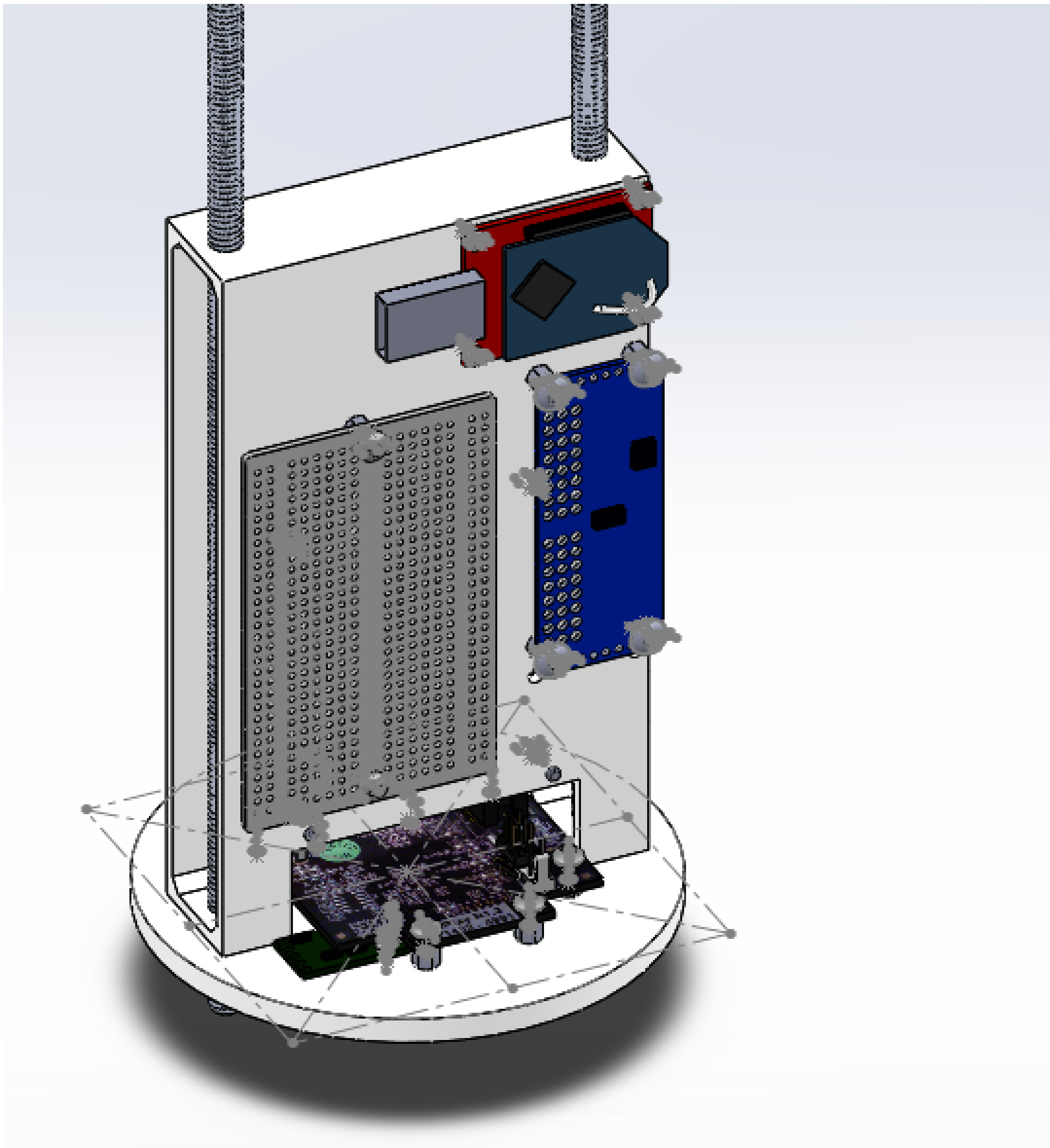

Figure 4.13 Internal Assembly (h)

i. Attach the GPS using 3M screws and 5mm standoffs in holes 12 and 13.

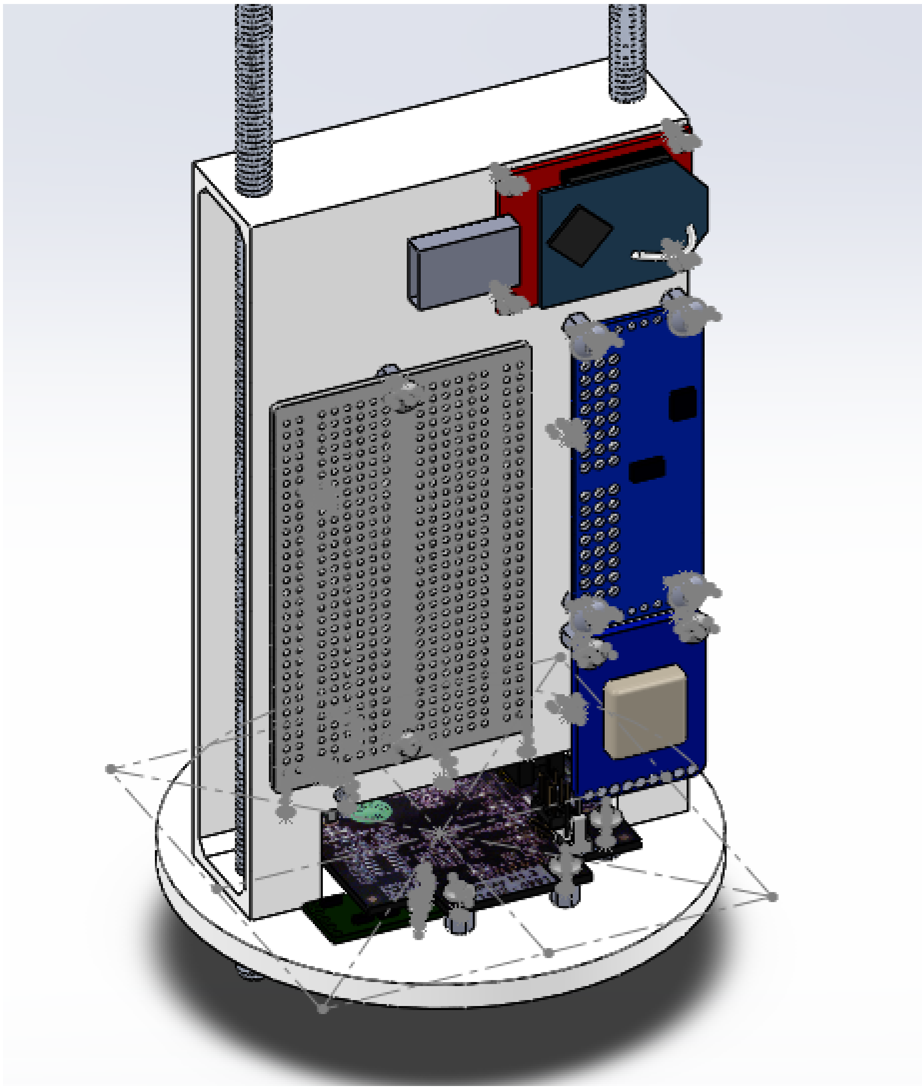

Figure 4.14 Internal Assembly (i)

j. Attach the top bracket by sliding it onto the allthreads, and then tightening down the nuts.

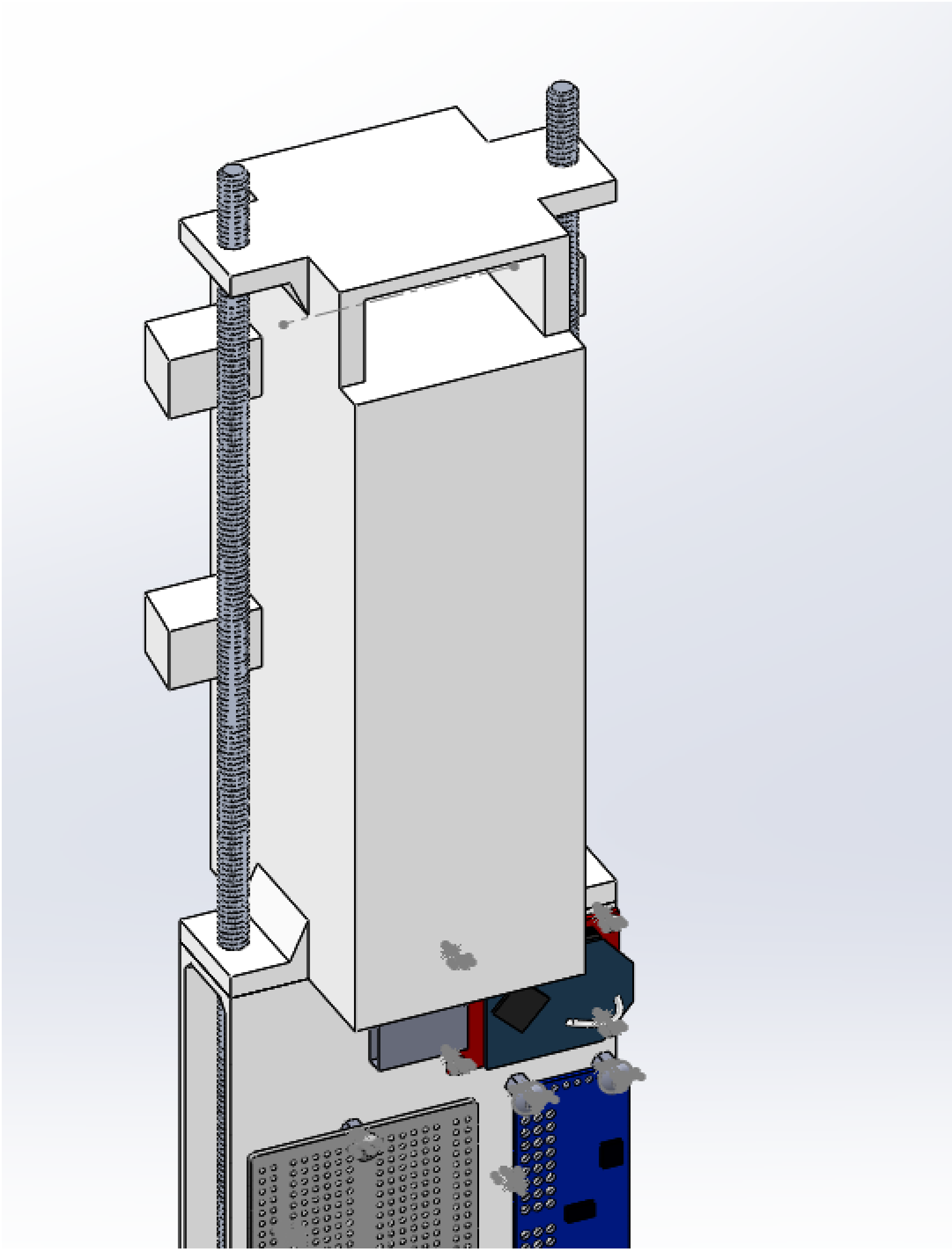

Figure 4.15 Internal Assembly (j)

k. Attach the top plate by sliding it onto the allthreads, and then tightening down the nuts.

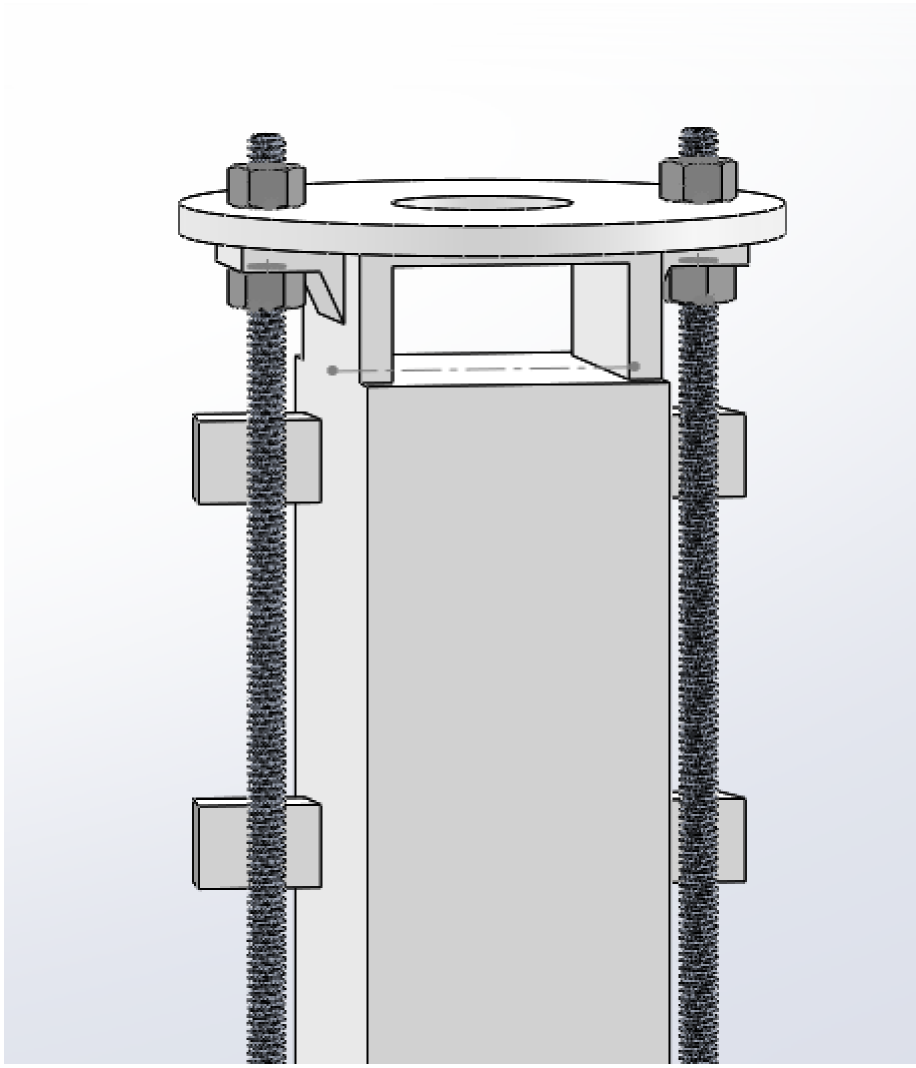

Figure 4.16 Internal Assembly (k)

l. Attach the servo motors using 4-40 screws.

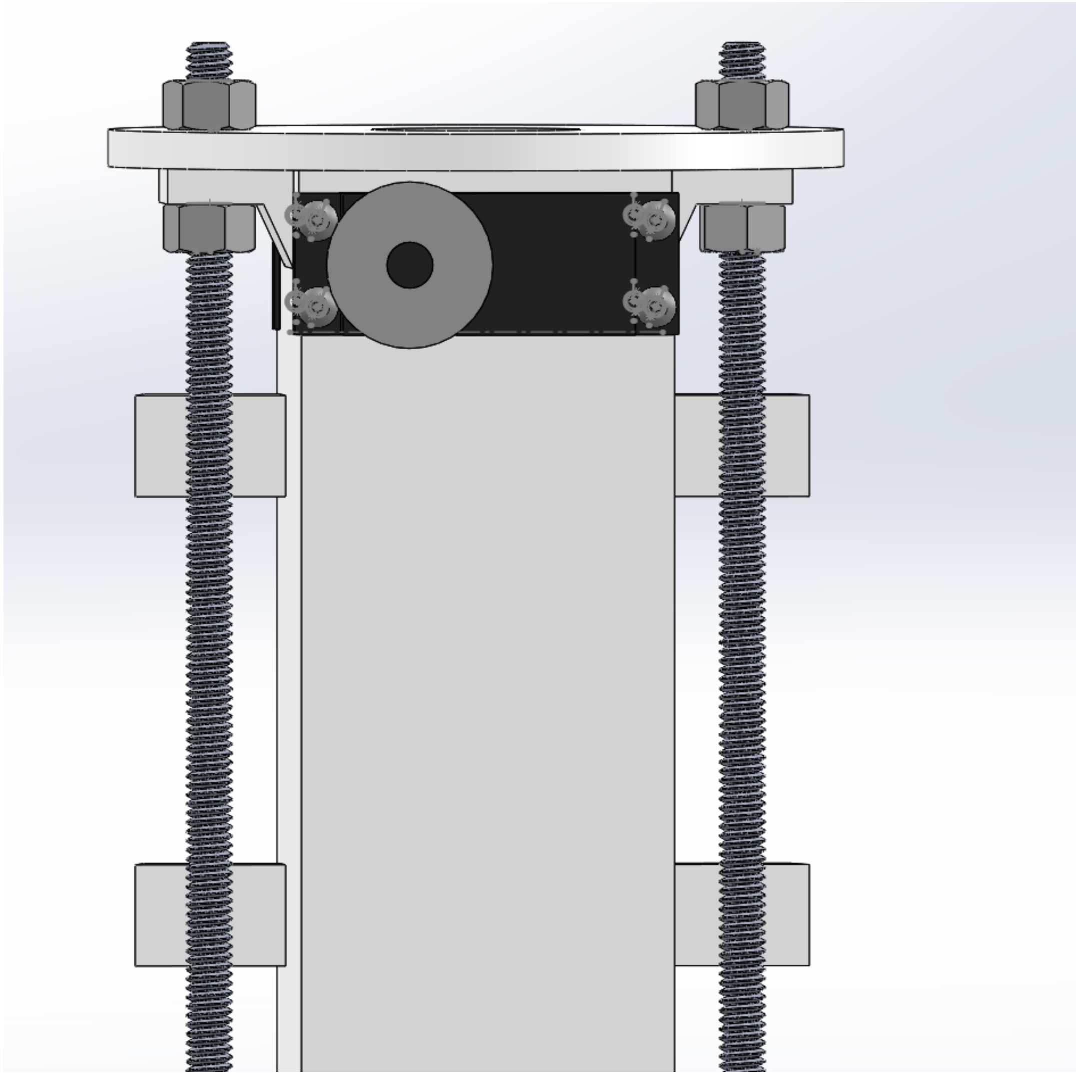

Figure 4.17 Internal Assembly (l)

m. Attach the release mechanisms using ¼”-20 screws.

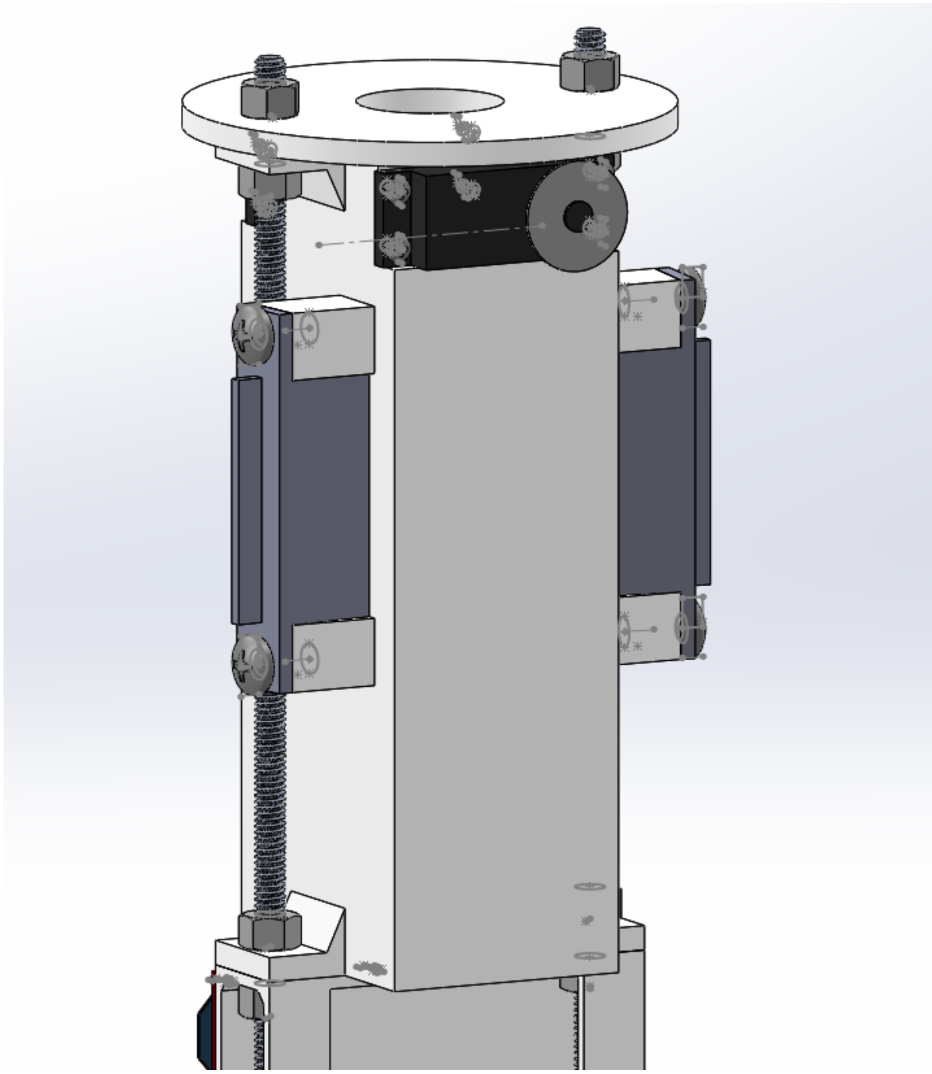

Figure 4.18 Internal Assembly (m)

n. Attach the voltage regulators using 3M screws.

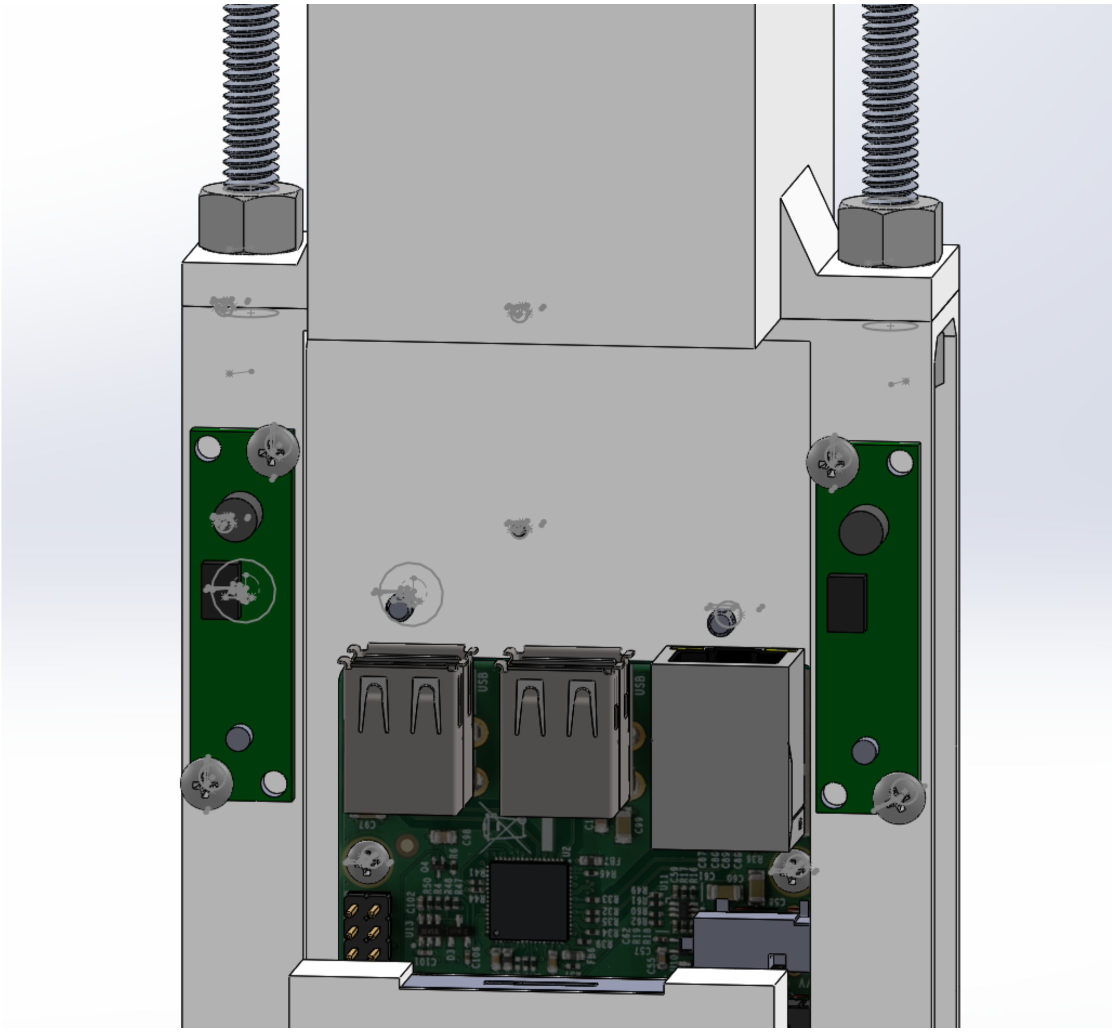

Figure 4.19 Internal Assembly (n)

o. Attach the rotary switch to the top plate using epoxy.

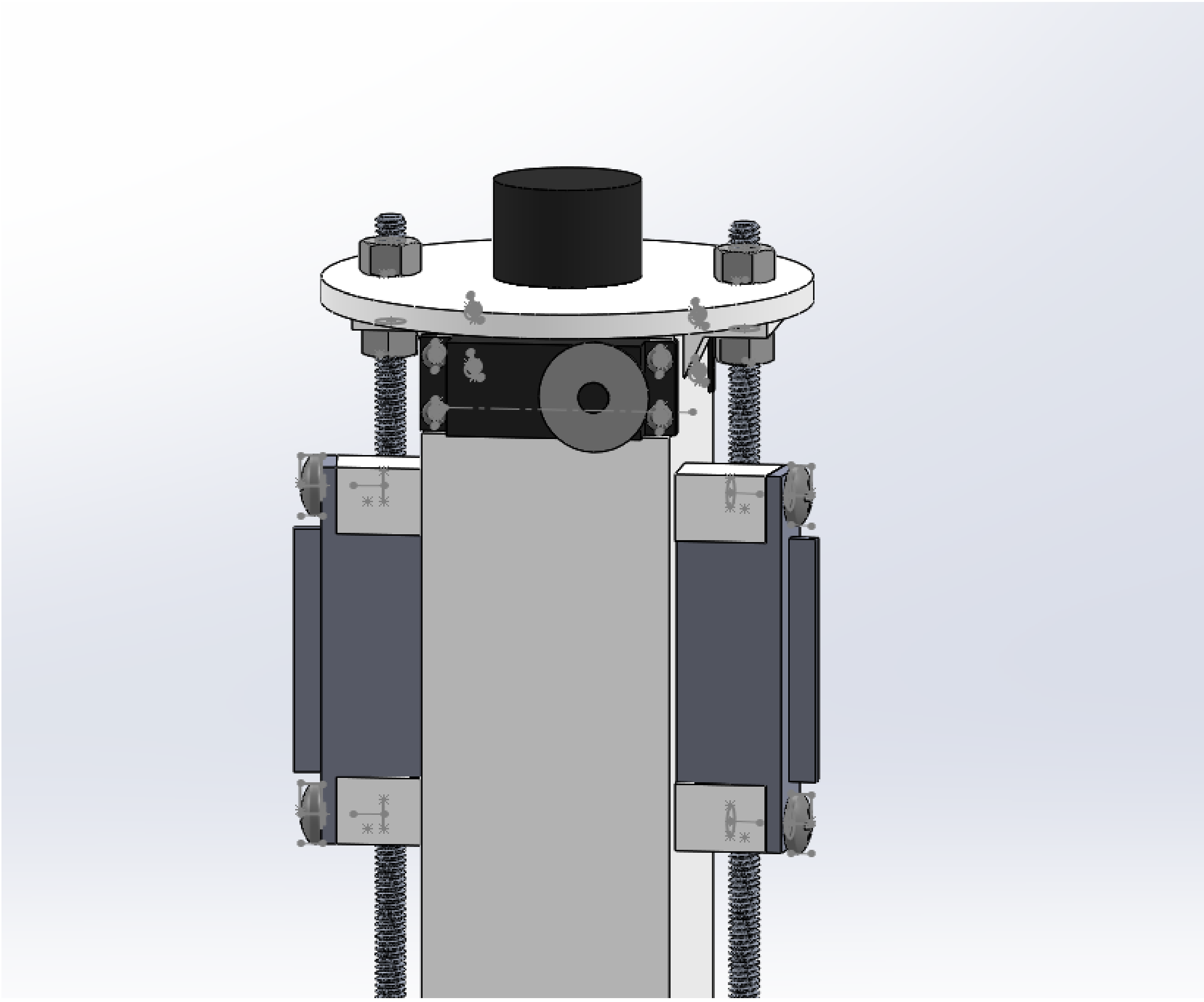

Figure 4.20 Internal Assembly (o)

4.1.5.3 Guided Descent Subsystem

The trailing edge toggle lines of the parafoil will be connected to the arm of the servo motors. Holes will need to be drilled on the top of the payload so the toggle lines can be connected. All other lines for the parafoil will be connected to the nuts and bolts on top of the payload.

4.1.5.4 Payload Landing Subsystem

The largest difficulty in the manufacturing and assembly of the landing legs will be the time it takes for a part to be printed by The Cube. The parts can also break or be misprinted which adds even more time. So far, 5 parts have been printed, one full leg, and there have been both a broken part and a misprinted part. After both of these errors, the model was adapted to make future print jobs easier. To account for these delays, all part requests will be given three weeks to be completely printed. During the assembly process, there will be a final check of both the structural integrity of each piece and the functionality of the leg as a whole.

4.1.6 Integration Plan

Figure 4.21 shows a model-view of the assembled payload. Detailed diagrams can be found in *Figures 4.22* and *4.23*, in Section 4.1.8. The top and the bottom of the assembly will be 4 inch fiberglass discs. They are supported by two 0.25 inch all thread aluminum rods attached with twelve hex nuts of the same size. The bracket that supports the majority of the components will be made out of aluminum. The Raspberry Pi, Ultimate GPS Breakout, and Servo Driver are all mounted with M3 screws on 10mm standoffs. The Pixy CMUCam5 is mounted to the bottom fiberglass disc with M3 screws on 25mm brackets, with a hole cut in the bottom to allow pictures to be taken of the ground. The AltIMU-10 V4 is also mounted to the bottom plate, with 2M screws and no standoffs. The Perma-Proto breadboard and XBee Pro are mounted to the bracket with M2 screws and no standoffs. The servos, payload releases, batteries, and SSD are all mounted in specially designed brackets that will be 3D printed. A 4 inch diameter fiberglass sleeve will surround the components. The legs will be mounted with hinges onto the fiberglass sleeve, and the legs are held in place by the ring. During landing procedures, the payload releases will releases the calves and the legs will deploy. The legs will have torsion springs at each joint, which will be placed there upon assembly. Each of the parafoil’s toggle lines will be attached to a servo motor, and the guidelines will be attached to the nuts on the top of each bolt.

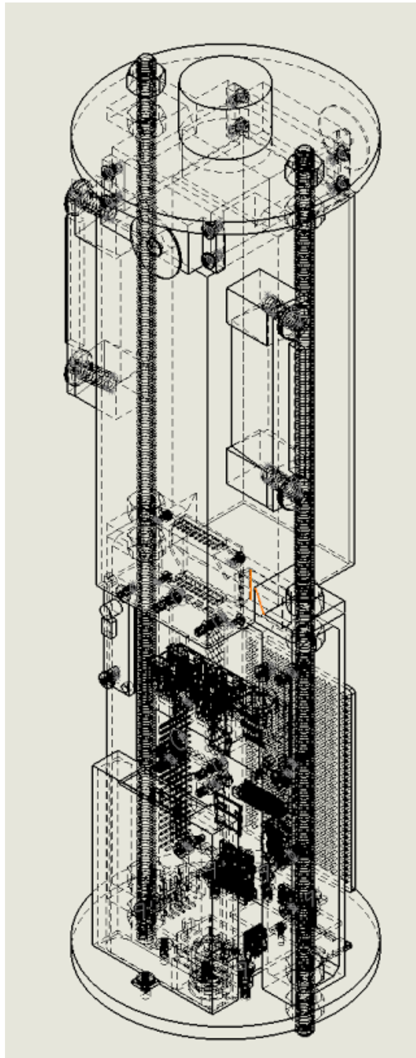

Figure 4.21 Model-View of the assembled HAL Payload

4.1.7 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 4.7* 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 4.7 Payload Instrumentation

4.1.8 Payload Electronics

4.1.8.1 Drawings and Schematics

Figures 4.22 and *4.23* show a detailed diagram of the payload assembly. The payload assembly is described in detail in section 4.1.6.

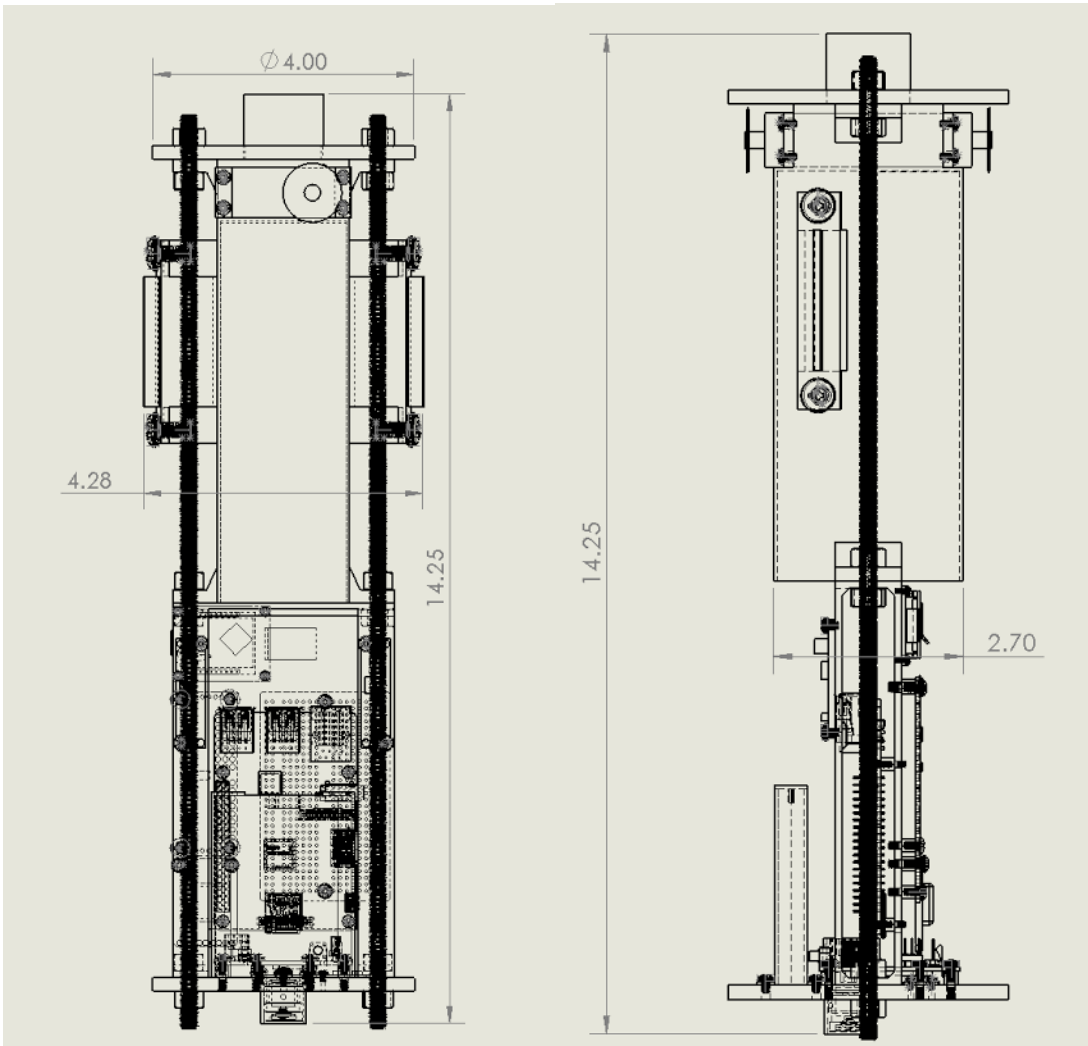

Figure 4.22 Front and Right Views of the Assembled Payload

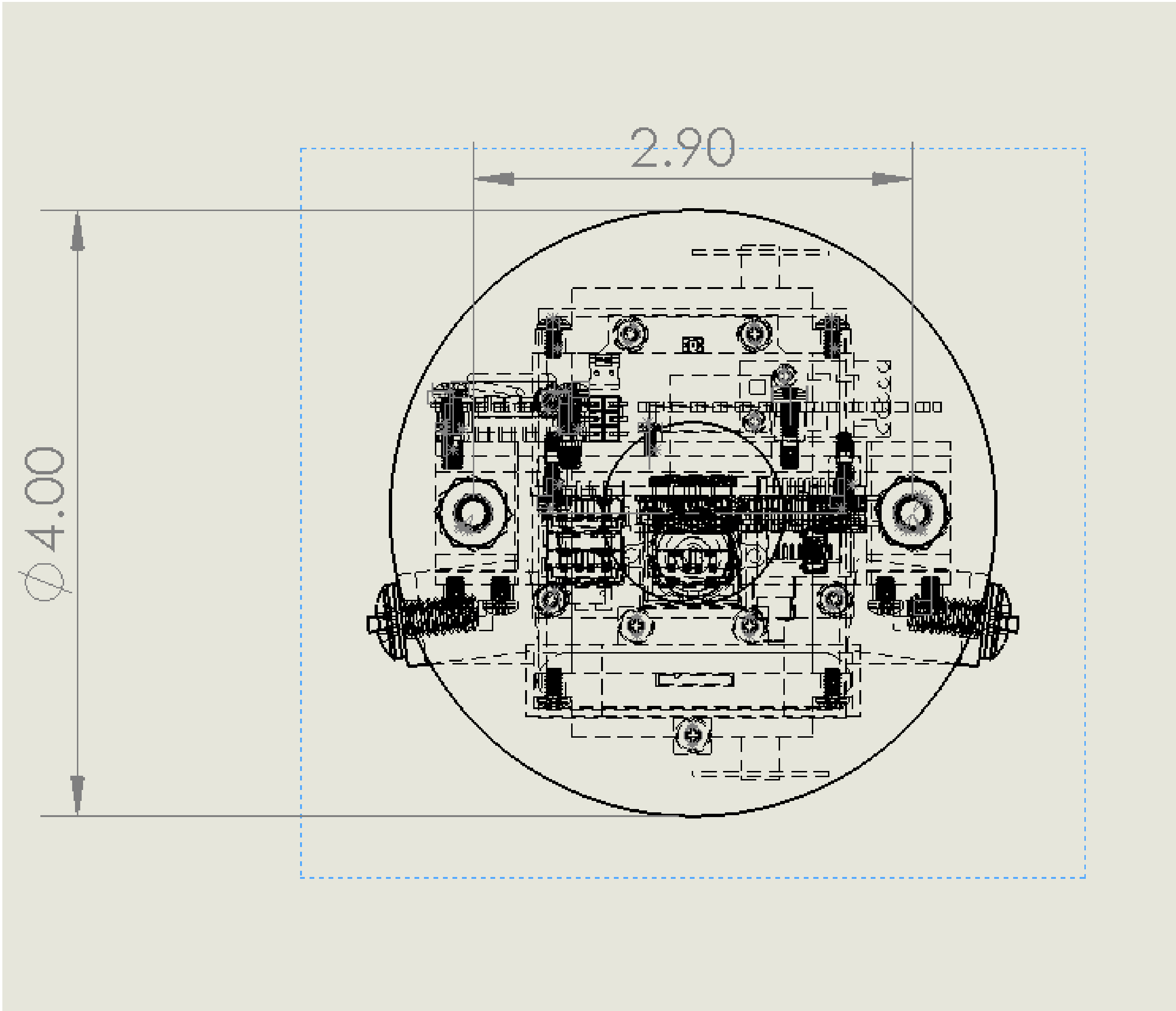

Figure 4.23 Top Model-View of the Assembled Payload.

4.1.8.2 Block Diagrams

Figure 4.24 shows how the Raspberry Pi will interface with the different components. All four USB ports on the Pi will be used by the Pixy CMUCam5, the XBee Pro 900 RPSMA mounted on the XBee Explorer Dongle, the Adafruit Ultimate GPS Breakout, and the Samsung 250 GB SSD. In addition, the Pi will be powered by a battery connecting into the Micro-USB port. Finally, the Pi Cobbler cable connects the 24 GPIO pins into the Perma-Proto Breadboard.

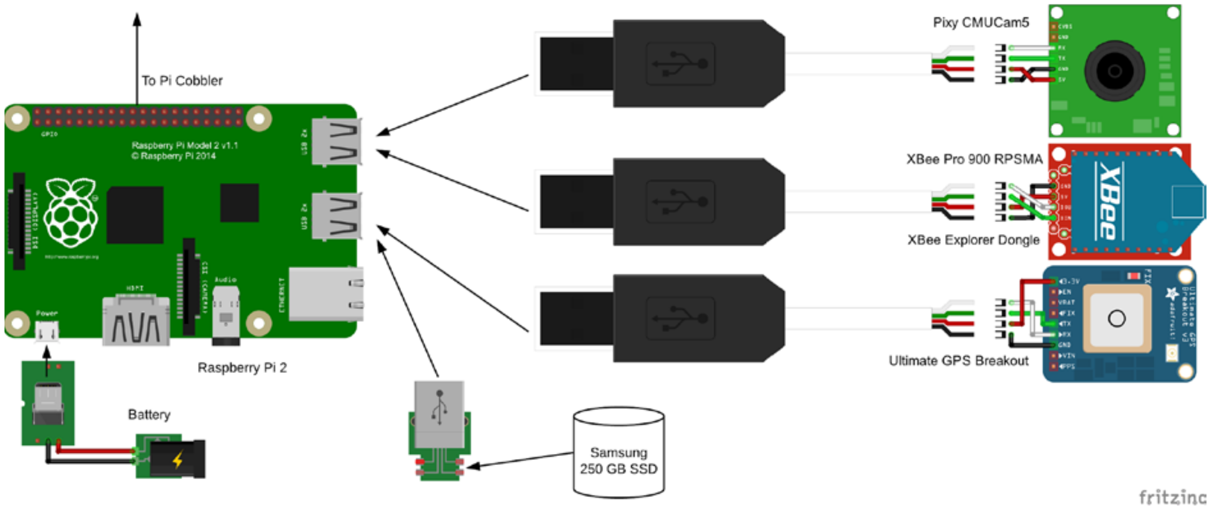

Figure 4.24 Raspberry Pi interfaces

Figure 4.25 shows how the electrical components of the payload will be wired together. For simplicity all components will be connected with 18 AWG wire. The 18 AWG wire will be able to carry any current that will run through the payload. The Perma-Proto Breadboard is connected to the Pi through the Pi Cobbler. A drawback of the Pi is that it only has one Pulse Width Modulation (PWM) pin, which is required to drive a servo. To address this, the 16-channel 12-bit PWM/Servo driver is used. It can drive up to 16 PWM components, the servos in this case, using the I^2C interface. The servo motors are then wired into the servo driver. The AltIMU-10 V4 is also connected through I^2C, so these two components must be in parallel. The servoless payload release will be connected to GPIO pins on the breadboard. Finally, the battery will be wired into the power rails.

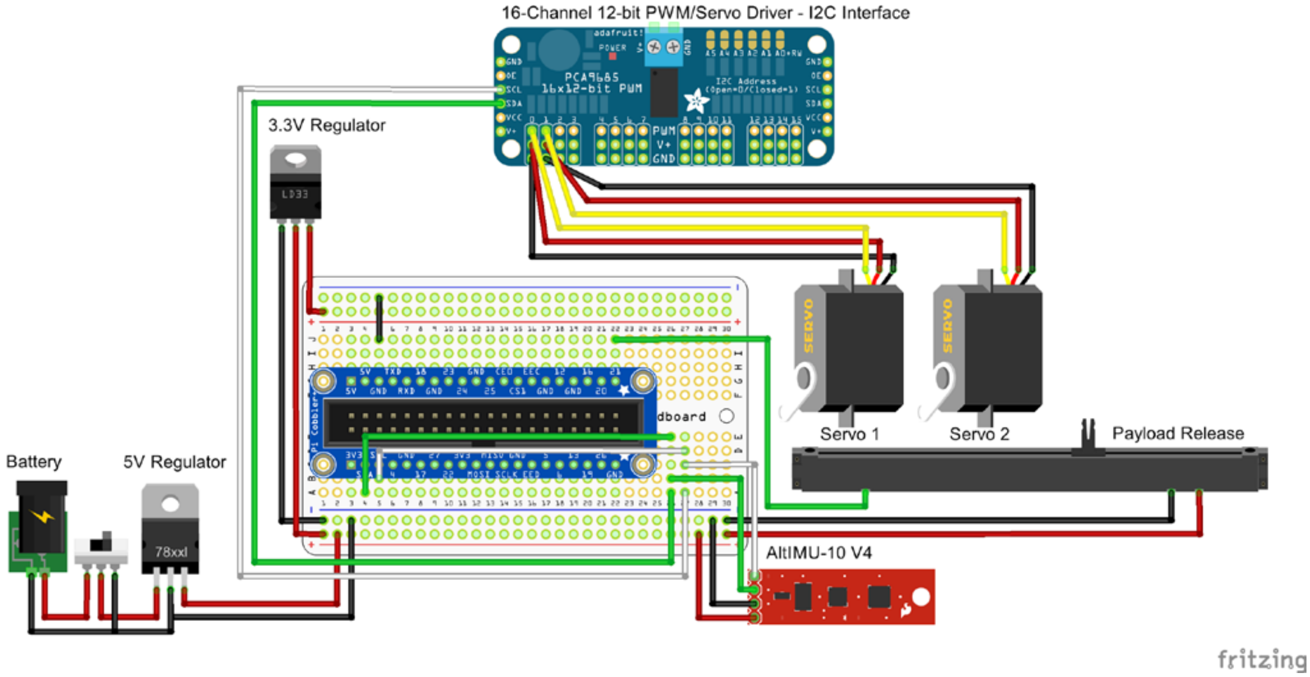

Figure 4.25 Payload wiring schematic

4.1.8.3 Batteries/Power

The ARES team will use two batteries to power the payload. The Raspberry Pi 2 and all devices connected to it via USB will be powered using a Turnigy nano-tech 6600mAh 7.4V lithium polymer battery. A voltage regulator will be connected to the battery to reduce the voltage to 5V, as the Raspberry Pi cannot handle voltages much larger than that. The 6600mAh will allow us to provide power to the Raspberry Pi and its USB devices for 2 hours and 8 minutes. This allows enough time for the rocket to launch, the payload to descend, and for the payload to transfer all data to the ARES ground station after sitting on the launch pad for an hour.

The second battery will be a Turnigy 5000mAh 14.8V lithium polymer battery. This battery will be hooked up to a step-down voltage regulator and will power the Ultra Torque Servos, the servoless payload release, and the AltIMU Gyro. If all of these devices are being continuously used, the 5000mAh battery will provide power for 4 hours and 20 minutes. The run time is sufficient for a one hour wait time on the launch pad and for the duration of the payload's descent.

4.1.8.4 Switch and Indicator Wattage and Location

A rotary switch will be located after the batteries in each circuit. The switch is rated up to 16A at 12V.

4.1.8.5 Test Plans

To test the payload, the team will begin by testing each component individually. Once each component has been verified to work, all components will be connected to the Raspberry Pi and tests will be run to ensure that all the components will work together.

4.1.9 Safety and Failure Analysis

The failure analysis in *Table 4.8* describes possible failure points for the rocket payload, using the same rating system from Sections 3.7.2 - 3.7.4. Once again, each failure mode is provided with a risk assessment, a mitigation, and a post-mitigation risk assessment. Sources used to compose mitigations are similar to those used for the vehicle failure mode analysis.

Failure Analysis: Payload					
Failure Mode	**Hazard**	**Cause**	**Initial Risk**	**Mitigation**	**Post Mitigation Risk**
Parafoil deployment	Ballistic payload; possible loss of payload due to damage from landing; inability to correctly steer payload	Incorrect parafoil packing; failure of rocket separation	1D	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	1E
Parafoil control software	Inability to correctly steer payload away from ground hazards	Power failure to payload; bugs in code which prevent proper steering and response	3C	Run code repeatedly to check for bugs; ensure code is working properly during full scale launch; follow mitigation steps for payload power failure	4D
Parafoil motors	Inability to control parafoil; uncontrolled descent of payload;	Power failure to payload; breakage or failure of the motors themselves	3D	Check motor manuals and possibly speak with manufacturer to prepare for and	4E

	partial experimental failure			prevent common motor malfunctions	
Hazard detection software	Inability to detect ground hazards at altitude; partial experimental failure	Power failure to payload; bugs in code which prevent proper hazard recognition and response	3C	Run code repeatedly to check for bugs; ensure code is working properly at time of full scale launch; follow mitigation steps for payload power failure	4D
Payload power supply	Failure of hazard detection software and/or hazard avoidance system; partial or full experimental failure	Loose or faulty wiring; failure to test power supply prior to rocket launch	2D	Check to ensure all internal wiring is secure prior to launch; test power supply beforehand to ensure ample and reliable power delivery to payload in flight	2E
Tumbling of the payload	The camera will have poor images for the processor to analyze and use to navigate away from hazards	Parafoil cords became tangled; loss of payload guidance system	2C	Pack parafoil to prevent tangling; ensure parafoil folding is verified by safety officer; test to ensure there is enough power for the entire launch time	3D
Payload guide fails	The payload descends without guidance; could cause injury if descending towards a crowd; no guarantee it will land somewhere recoverable	Loss of power; bugs in code used to guide payload on descent	1D	Ensure that the batteries used can last the entire launch time; ensure batteries can withstand forces at launch; test batteries for both previously described conditions; run testing on software	2D
Incorrect payload deployment time	Insufficient time for the processor to analyze and navigate away from hazards; too high a kinetic energy upon impact	Black powder charge failed to ignite	2C	Test all black powder charges prior to launch	3C

Table 4.8 Failure Mode Analysis: Payload.

4.1.10 PDR Feedback

There were some key concerns raised during the PDR phase that have been addressed during the CDR phase. While these have been addressed throughout the report, the payload specific concerns are highlighted here for ease of access on a point-by-point basis.

- How will you ensure that all of the payload legs will open?

There will be two Servoless Payload Release mechanisms that are attached to two of the leg calves. Each mechanism is able to hold 0.7497 pounds of force. The two calves that are attached to the release mechanisms will also hold a partial fiberglass tube that wraps around the other legs and restrains them.

- How is the parafoil controlled? Are there riser lines? If so, what are they connected to? How is the rest of the foil connected to the payload?

The parafoil is controlled by two toggle lines, one attached to the right side of the parafoil and one attached to the left side. These toggle lines are each attached to a servo motor, which will control the parafoil by winding or unwinding the toggle line, depending on the situation. In addition, there are further guidelines that give the airfoil structural support and help to support the weight of the payload. These lines are attached to the bolts that run through the payload using the nuts on top of the upper fiberglass disc.

- If the parafoil steering fails, how does it affect the kinetic energy? What about drift?

If the steering fails, the kinetic energy of the craft will not change. As long as the parafoil deploys, the payload descent rate will be controlled. While the possibility of the parafoil not deploying properly is a risk, this risk is also present when using a normal round parachute to slow a falling rocket. Proper packing and practice can mitigate the chances of parachute deployment failure. The issue of drift depends on the failure mode of the parafoil. If the parafoil deploys correctly, but the issue is software based, then the craft can be programmed to go into a circle to control its drift. However, if the failure is a loss of motor control, or a tangled guideline, the effects on drift will be harder to quantify. While it is theoretically possible for the craft to break in such a way that it flies straight out in a direction that will maximize drift, it seems much more likely that the craft will continue to turn and bank in different ways, which could actually mitigate drift relative to a normal round parachute. The team is currently exploring ways to further reduce this risk before the FRR phase.

- Where is the payload designed to land?

While this is a topic that is open for further consultation, the current plan is to set a GPS waypoint where the rocket is launched from, and have the payload attempt to return to this spot.

4.2 Payload Concept Features and Definition

4.2.1 Creativity and Originality

While the landing hazard detection system was an option given by the NASA Student Launch, the ARES Team has designed their own second task, being a guided descent system used to avoid detected hazards. The team believed that this was a logical second task, as detecting hazards does not help much if you cannot avoid them. 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. In addition to the unique concept as a whole the ARES Team is using a creative and original landing subsystem that has a total of 10 legs. This landing system will provide a wide base and allow for landing of many types of terrain while retaining the ability to balance the payload without the risk of damaging it.

4.2.2 Uniqueness or Significance

A payload that can steer itself away from landing hazards during descent could be an invaluable asset on a mission to Mars, or any other destination. The landing hazards detection could potentially work with a steering system using thrusters for a payload that is being sent to a destination with no atmosphere. The hazard detection and parafoil steering system could also be used 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 a safe landing location. The ARES Team aims to prove that an efficient landing hazard detection and avoidance system can be made inexpensively.

4.2.3 Suitable Level of Challenge

The HAL payload poses many serious challenges concerning both the software and hardware. The ARES Team will be building custom hazard detection and parafoil guidance software, an immensely challenging task. The team is fully aware of the complexity image analysis software necessary and the difficulty of guiding a descending object away from hazards. The team also has restrictions on the size of the payload and thus the size and placement of all components included in the payload must be optimized. The deployment of the landing legs also presented many challenges for the payload team. Nevertheless, the ARES Team is determined to be successful in creating a useful, scientific payload.

4.3 Science Value

4.3.1 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.

4.3.2 Payload Success Criteria

For the mission to be considered a success, the payload must complete the objectives listed in Section 4.3.1 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.

4.3.3 Experimental Logic, Approach, and Method of Investigation

4.3.3.1 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.

4.3.3.2 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.

4.3.4 Test and Measurement, Variables, and Controls

4.3.4.1 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.

4.3.4.2 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.

4.3.5 Relevance of Expected Data and Accuracy/Error Analysis

4.3.5.1 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.

4.3.5.2 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.

4.3.6 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 the final launch date.

5. Project Plan

5.1 Budget Plan

The ARES team has entered the building phase of the project plan, necessitating a large number of purchases. These purchases are catalogued in *Table 5.1*. Additional components were added to the budget since the submission of the PDR are listed in *Table 5.1*. It is important to note that the total $722.62 was not necessarily added to the budget because many of the subscale components in the PDR version of the budget were replaced by the new components.

Component Added	Total Cost
Turnigy nanotech 6600mA lipo pack	$ 48.95
Step Down Voltage Regulator	$ 14.95
Lipo Touch Balance Charger	$ 48.75
6 ft. USB Cable	$ 4.80
Large Solenoid	$ 59.80
Centering Ring	$ 14.00
Fiberglass 4x60 tube	$ 110.00
Ogive	$ 65.00
Coupler	$ 23.00
Fiberglass 3x49 tube	$ 78.00
4" G10 Airframe Plate	$ 36.00
StrattologgerCF	$ 195.56
Hinge w/spring	$ 7.20
Torsion Spring 90	$ 8.39
Torsion Spring 180	$ 8.22
Total:	**$722.62**

Table 5.1 Components added to the budget since PDR

The team's access to the funding provided by the Alabama Space Grant Consortium (ASGC) was delayed for a month and a half, leaving limited time to build the subscale before the required submission date, January 15. In order to provide more time for the team to build, expedited shipping was used on several purchase orders, increasing incurred costs. Although these additional costs were not anticipated, the total budget is still within the confirmed funding for the team. It is not anticipated that another event such as the aforementioned will occur as all the confirmed funding is now fully accessible to the team.

Structure						
Category	**Component**	**Vendor**	**Description**	**Cost per Unit**	**Quantity**	**Total Cost**
Purchase:	Ogive Nose Cone	Madcow Rocketry	Improves aerodynamics	$115.00	1	$115.00
	Payload Bay		Holds payload	$150.00	1	$150.00
	Motor Closure	Apogee Components		$42.75	1	$42.75
	Motor Case	Apogee Components		$84.69	1	$84.69
	Motor	Apogee Components	Powers rocket ascent	$120.86	2	$241.72
	Resin			$34.80	1	$34.80
	Black Powder	Gander Mountain	Separates stages	$39.99	1	$39.99
Pre-Owned/ Manufactured :	4.5" Fiberglass Tubes	Fabricated in lab	Body structures	$150.00	4	$600.00
	Fins		Improves stability	$15.00	4	$60.00
	Motor Tube			$70.00	1	$70.00
				Structure Total:		**$1,438.95**

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
	Large Solenoid	Adafruit	Landing leg release	$29.90	2	$59.80
				Hazard Detection Payload Total:		**$920.18**

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	2	$40.80
	Mesh	Home Depot	Connects parachute to payload	$45.00	1	$45.00
				Guided Descent Payload Total:		**$155.80**

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	5	$7.20
	Torsion Spring (Thigh to Calf)	Grainger	Packs of 6	$8.16	2	$16.32
	Torsion Spring (Calf to Foot)	Grainger	Packs of 6	$8.34	2	$16.68
Pre-Owned:	Main Parachute	Fruity Chutes	Rocket body deceleration in descent	$265.00	2	$530.00
	Thigh (Upper landing section)	The Cube	Main landing support	$0.00	5	$0.00
	Calf (Lower landing section)	The Cube	Secondary landing support	$0.00	10	$0.00
	Landing Feet	The Cube	Tertiary landing support	$0.00	10	$0.00
				Recovery Total:		**$720.20**

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
	Strattologger CF	Perfect Flite	Altimeter	$48.89	4	$195.56
	Cessaroni L Motor	Chris’ Rocket Supplies	Propulsion	$169.95	1	$169.95
Pre-Owned/ Manufactured :	Parachute		Vehicle recovery	$160.00	1	$160.00
				Estimated Subscale Total:		**$851.51**

Safety

Category	Component	Vendor	Description	Cost per Unit	Quantity	Total Cost
Purchase:	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		$500.00	1	$500.00
				Outreach Total:		**$500.00**
			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:		$6,187.52
				Pre-Owned Total:		$1,420.00
				Rocket/Payload Total:		**$3,235.13**
				Project Total:		**$7,607.52**

Table 5.2. Estimated Project Costs

To date, most of the team's purchases have been related to the HAL payload and the structural supplies for the subscale build. Once the subscale launch is completed, the team will move forward with purchasing the full scale components, which fall under the Structures category. The majority of the team's outreach has been completed, so the expenses are not expected to approach the allotted $500.00. The numbers in *Table 5.2* do not include shipping costs.

Category	Current Expenses	Budgeted Expenses	Difference
Structures	-	$1,438.95	$1,438.95
Hazard Detection Payload	$911.02	$920.18	$9.16
Guided Descent Payload	$140.78	$155.80	$15.02
Recovery	$23.81	$720.20	$696.39
Subscale	$521.56	$851.51	$329.95
Safety	$89.91	$170.88	$80.97
Outreach	$48.93	$500.00	$451.07
Travel	-	$2,850.00	$2,850
Total Expenditures:	**$1,736.08**	**Total Remaining in Budget:**	**$5,871.44**

Table 5.3 Current Spending Review

Table 5.3 details the overall changes in the budget through the competition so far. Although the budget has increased, as seen in *Table 5.4*, it is still within the confirmed $8,300 the team has received in support. The ARES team intends to keep costs down to preserve a margin between the budget total and the funding total as a buffer for contingencies, such as component failures.

Report	Budget Total
Proposal	$7,454.12
PDR	$7,188.32
CDR	**$7,607.52**

Table 5.4 Budget Totals among Reports

5.2 Funding Plan

The ARES Team has thus far received funding from the Alabama Space Grant Consortium (ASGC) and the University of Alabama Department of Aerospace Engineering and Mechanics.

The ASGC has agreed to fund the team to the fullest of their ability, totaling $7,650. The categorical spending requirements of the ASGC's funding are detailed in *Table 5.5*.

Category	**Amount**
Materials	$4,500.00
Travel	$2,500.00
Outreach	$650.00
Total	*$7,650.00*

Table 5.5 ASGC Funding

Funding from the Alabama Student Government Association (SGA) is awarded on a per semester basis and requires the funding to be used within a 60 day period after allotment. The team will present before the SGA funding committee in early January in order to appeal for grants to cover the full-scale launch, which is planned for mid- February. Later in the semester, the team will again apply for additional aid from the SGA to cover expenses for the competition. The maximum funding the team is eligible to receive from SGA totals $2,400.00. Funding information can be seen in *Table 5.6* and *5.7*.

Other team fundraising initiatives would be on an as needed basis, although the funding already received is projected to cover all anticipated expenses.

Funding Source	**Amount**	**Status**
ASGC	$7,650.00	Confirmed
Department of Aerospace Engineering and Mechanics	$650.00	Confirmed
SGA	$2,400.00	Pending
Fundraising	$500.00	Contingency
Projected Total:	**$11,200.00**	
Confirmed Total:	**$8,300.00**	

Table 5.6 Updated Funding Plan

Fund Name	Sum	Expenses	Remaining Total
ASGC	$7,650.00	$1,271.33	$6,378.67
Department of Aerospace Engineering and Mechanics	$650.00	$464.75	$185.25
SGA	$2,400.00	-	-

Table 5.7 Updated Fund Totals

5.3 Timeline

The team managed to endure the setbacks from the funding delay and meet all objectives set for the CDR, albeit delayed several weeks. The period of low activity previously given in the PDR project plan for the University of Alabama's winter break provided a buffer time that proved necessary to accomplish all the team's goals.

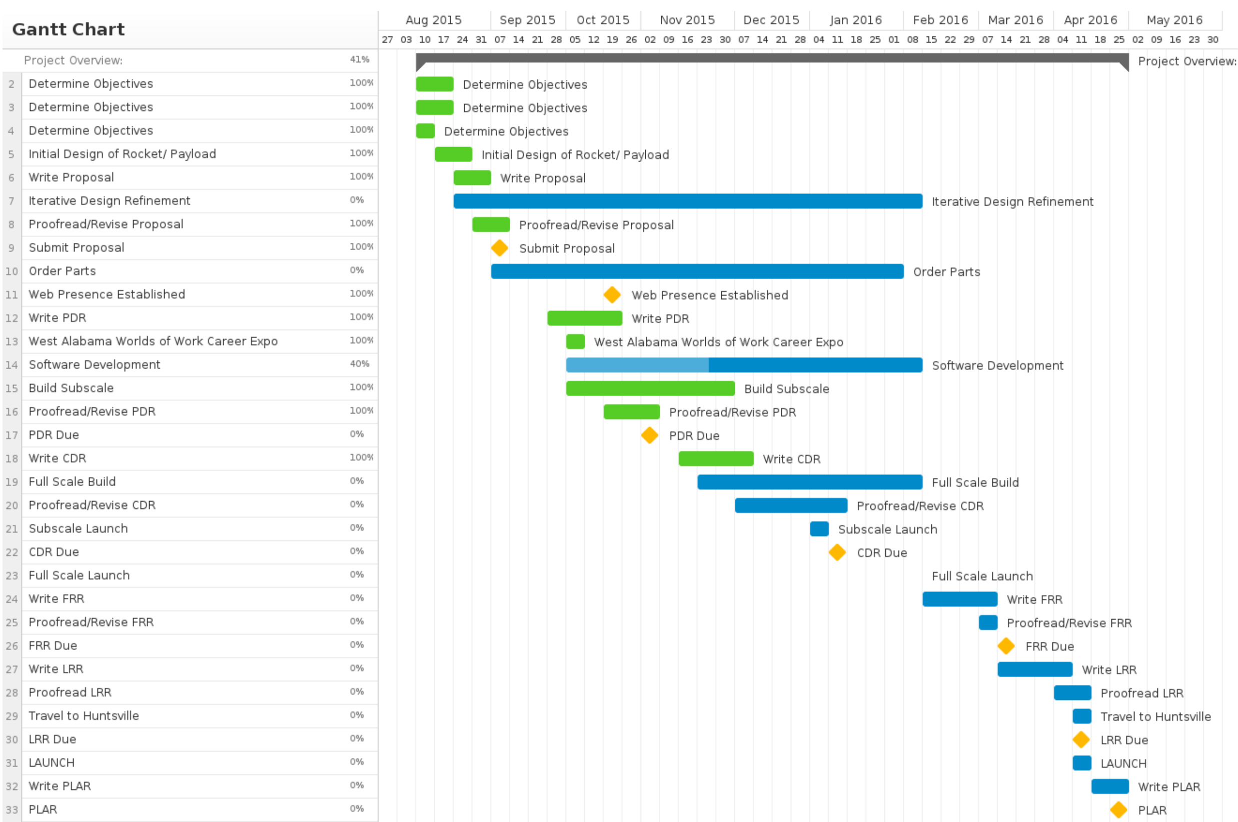

Figure 5.1: Full updated Gantt Chart

Moving forward into the operational and building phases of the project, more contingency time has been allotted, particularly for the event of a full-scale launch failure. As seen in *Figure 5.1*, the majority of the activities between the CDR and LRR submission dates are scheduled to be completed before February 14th, which is the scheduled date for the first full - scale launch. In the event of a failure, the team would have until March 5th, a secondary launch date, to build another full - scale vehicle.

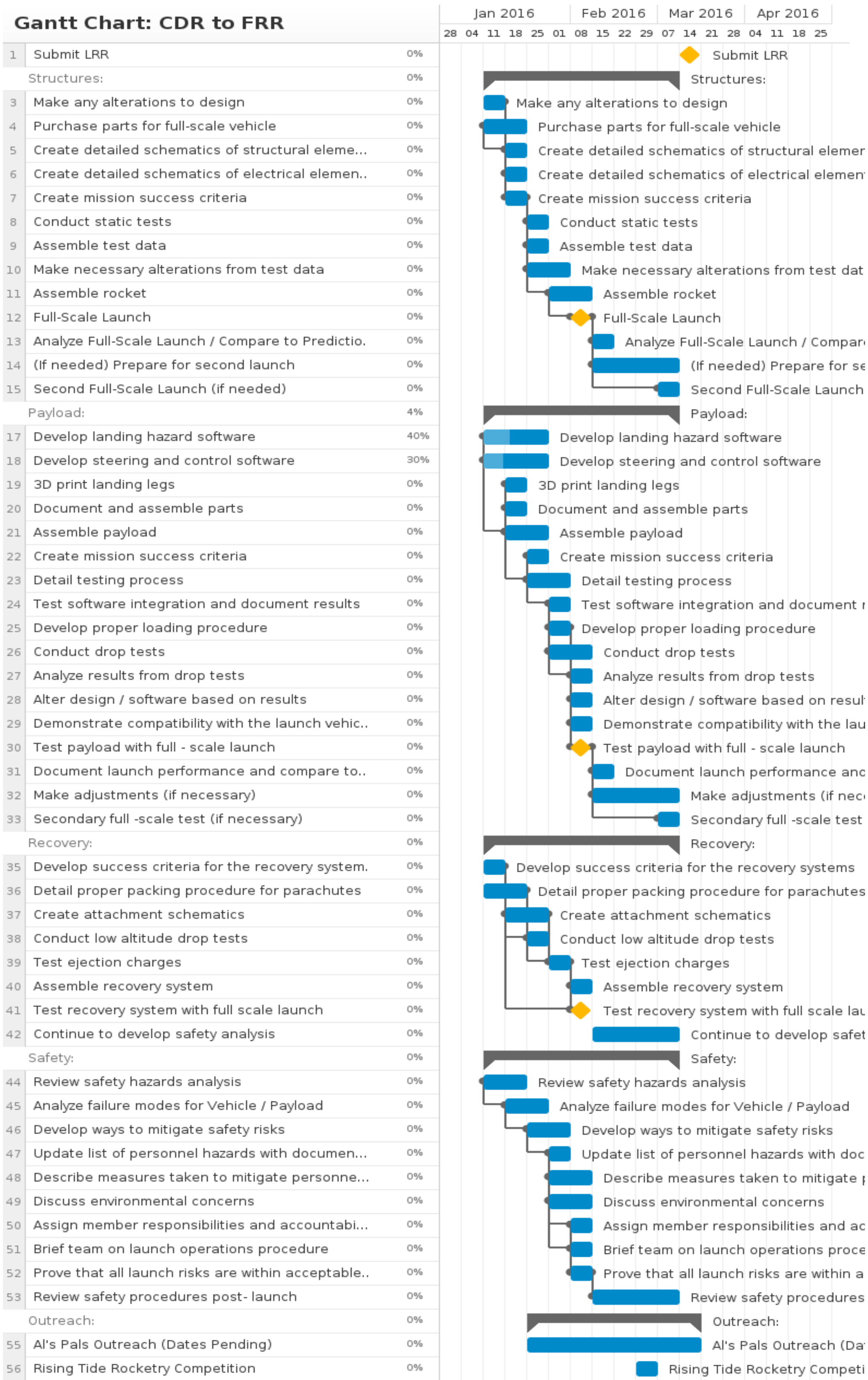

Figure 5.2 CDR to FRR Gantt Chart

More detailed gantt charts are provided in *Appendix F*. Yellow diamonds denote milestones and the critical path is marked by the grey lines connecting tasks. Light blue demonstrates the progress on a task that has been started but not yet completed.

5.4 Educational Engagement

The team has exceeded the required 200 students reached through direct educational engagement, by reaching a total of 493 students this far. The team has reached out to students of many different ages and backgrounds in an effort to teach rocketry to students who may not have ever had access to such a program. While the team has met the competition requirements for educational outreach, there are future events planned, including a competition for all of our previous students.

5.4.1 Completed Events

Since the PDR, the ARES team has competed two additional outreach events, one with Al's Pals mentoring, and the other with the Girl Scouts, which brought in a total of 400 additional students. A summary of each event along with accompanying photos can be found on the team's website. Table 5.8 shows all completed events to date.

Name of Event	**Date**	**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

Table 5.8 Completed Events

5.4.2 Upcoming Events

In the early spring, the ARES team will be visiting a few more local schools. The exact dates are not set, but they will be set in the upcoming weeks. These schools are listed in table 5.9.

School
Pickens Academy
Gordo High School
Echols Middle School
Marion County High School
Northridge High School

Table 5.9 Locations of Future Events

The UA chapter of Students for the Exploration and Development of Space (SEDS) will be hosting the Tuscaloosa Rocketry Challenge, a bottle rocket competition in the spring for local middle and high school students. The ARES team will assist SEDS by helping one local school with their bottle rockets.

5.4.3 Rising Tide Rocketry Program

In an effort to give the students of schools in and around Tuscaloosa a chance to use the knowledge that the team's visits provided them about rocketry, the team will be hosting a competition for all students on March 5th, 2016, at Northridge High School.

The competition will be broken into different age groups of grades 1-3, 4-6, 7-9, and 10-12. The students can either build a rocket on their own, or in groups. Scoring will be done similar to how it is done at a TARC competition, with a panel (member of the team) judging each rocket and launch on a variety of specifications. The team is currently finalizing the specifics of the competition including supplies, registration fees, and prizes.

5.4.4 Evaluation

After each educational engagement event, the team administers an evaluation form to the teacher, leader, or mentor who invited the team to come. The evaluation asks for them to rate the team on a scale of 1-5, with 5 being the best, on preparedness, helpfulness, organization, and knowledge. They are also asked if the presentation was what they expected, if anything could be improved, and if they would like to receive information about the team's Rising Tide Rocketry Program.

5.4.5 Social Media

The team has created a Facebook profile and an Instagram to show the progress of the ARES rocket, as well as give updates on outreach events. These can both also be reached through our website. *Table 5.10* provides the ARES Team's social media pages.

Platform	**Name**
Facebook	Alabama Rocket Engineering Systems
Instagram	@alabama_rocketry
Twitter	@alabamarocketry

Table 5.10 Social Media Platforms

6. Conclusion

The ARES Team has designed an 89 inch (2.26 m) rocket capable of carrying the Hazard Avoidance Lander (HAL). The rocket will deliver this payload to an apogee of 5,280 feet. After ejection from the launch vehicle at apogee, HAL will take and analyze images during its descent to detect and identify landing hazards on the ground. Using a parafoil controlled by two servo motors, HAL will then steer itself away from the detected landing hazards. The ARES launch vehicle and HAL will be recoverable and reusable.

The ARES Team has spent the time since the PDR iterating the design and refining the plans for the rest of the project. Despite the funding issues that were experienced, the team has done their best to stay on schedule. The team is confident in their current design, and has a detailed plan for the coming months. Over the following months, the team will develop the payload software, build the full scale rocket, and conduct a full scale launch. The team is prepared and excited to take on any new challenges that arise, and looks forward to the next phase of design.

Appendix A - Milestone Review Flysheet

Milestone Review Flysheet

Institution	The University of Alabama

Milestone	Critical Design Review

Vehicle Properties	
Total Length (in)	89
Diameter (in)	5.5
Gross Lift Off Weigh (lb)	32.2
Airframe Material	Fiberglass
Fin Material	Fiberglass
Drag Coefficient	0.467

Motor Properties	
Motor Manufacturer	Cesaroni Technology Inc.
Motor Designation	L3200
Max/Average Thrust (lb)	834.9 / 721.4
Total Impulse (lbf-s)	749.1
Motor Mass Before/After Burn(kg)	3.26 / 1.61
Liftoff Thrust (lb)	630

Stability Analysis	
Center of Pressure (in from nose)	64.8
Center of Gravity (in from nose)	53.7
Static Stability Margin	2.00 calibers
Static Stability Margin (off launch rail)	1.66 calibers
Thrust-to-Weight Ratio	22.4
Rail Size and Length (in)	144
Rail Exit Velocity (ft/s)	130.5

Ascent Analysis	
Maximum Velocity (ft/s)	723
Maximum Mach Number	0.65
Maximum Acceleration (ft/s^2)	824
Target Apogee (From Simulations)	5290
Stable Velocity (ft/s)	77.22
Distance to Stable Velocity (ft)	4.82

Recovery System Properties				
Drogue Parachute				
Manufacturer/Model		Giant Leap Rocketry/TAC-1		
Size (in)		54		
Altitude at Deployment (ft)			5290	
Velocity at Deployment (ft/s)			3.21	
Terminal Velocity (ft/s)			35.66	
Recovery Harness Material			Kevlar	
Harness Size/Thickness (in)			0.5	
Recovery Harness Length (ft)			4.17	
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
	25.9	166.5	197.3	389.6

Recovery System Properties				
Main Parachute				
Manufacturer/Model		Giant Leap Rocketry/TAC-1		
Size (in)		110		
Altitude at Deployment (ft)			900	
Velocity at Deployment (ft/s)			32.75	
Terminal Velocity (ft/s)			14.52	
Recovery Harness Material			Kevlar	
Harness Size/Thickness (in)			0.625	
Recovery Harness Length (ft)			5.58	
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
	4.29	27.6	32.7	64.5

Recovery Electronics	
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 Electronics	
Rocket Locators (Make/Model)	Adafruit Ultimate GPS Breakout
Transmitting Frequencies	900 Hz
Black Powder Mass Drogue Chute (grams)	5
Black Powder Mass Main Chute (grams)	5

Payload	
Payload 1	Overview
	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.
Payload 2	Overview
	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 Phoenix Missile Works launch area.
Sub-scale Test Flights	The team has built a sub-scale model at .727 scale. The sub-scale motor was chosen to match the full scale flight Mach number as closely as possible. The subscale launch will occur on January 16th.
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	Critical Design Review

Additional Comments
Stability Velocity, Distance to stable velocity, and Static stability margin (off launch rail) were all calculated at a wind speed of 20 mph.

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.

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 launchpad and taken back to the team's onsite workspace, proceed as necessary.
- ❏ If vehicle is not on the launchpad, 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

MSDS – Pro150 Igniter   Page 1/1   Version 2.01
Revision Date. 7 July 2007

==

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

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.2 ProX Rocket Motor Reload Kits

MSDS – ProX Rocket Motor Reload Kits   Page 1/6   Version 2.02
Revision Date. 8 Feb 2010

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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

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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

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

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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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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 the dust. Avoid contact with skin.

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

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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)	: >800°C (>1472°F)
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

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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.

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00082.doc
PDCT-MSDS-00082-05/15-AB

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.

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00082.doc
PDCT-MSDS-00082-05/15-AB

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.

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00130.doc
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.

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PDCT-MSDS-00130-01/15-AB

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.

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00130.doc
PDCT-MSDS-00130-01/15-AB

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

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00130.doc
PDCT-MSDS-00130-01/15-AB

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.

L:\Product Introduction (PDCT)\PDCT-MSDS\MSDS Working Docs\MSDS Word Docs\PDCT-MSDS-00130.doc
PDCT-MSDS-00130-01/15-AB

C.5 Spray Paint

Date Printed: 4/21/2015 Page 1 / 7

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.

MSDS-BP PAGE 1 Issued 12/08/93 Revised 12/12/05

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.

For further information contact:	David W. Boston, President *OWEN COMPLIANCE SERVICES, INC.* 12001 County Road 1000 P.O. Box 765 Godley, TX 76044	
	Telephone number:	817-551-0660
	FAX number:	817-396-4584
MSDS prepared by:	David W. Boston	
	Original publication date:	12/08/93
	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

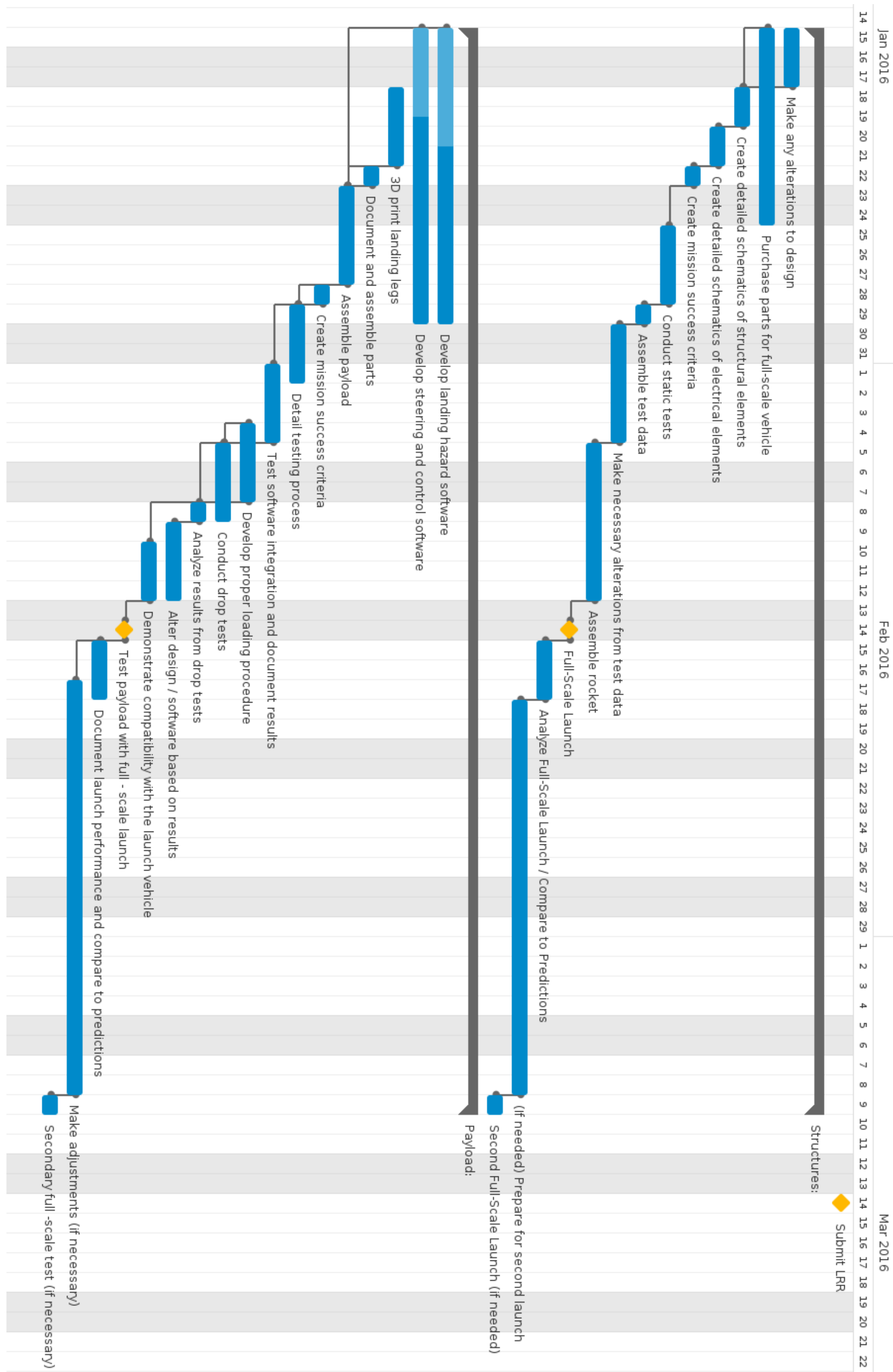
Weighted Rating of Payload Control System							
		Parafoil		Traditional Parachute		Deployable Glider Wings	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*
Reliable Deployment	25	5	1.25	5	1.25	1	0.25
Control	25	5	1.25	1	0.25	4	1
Descent 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

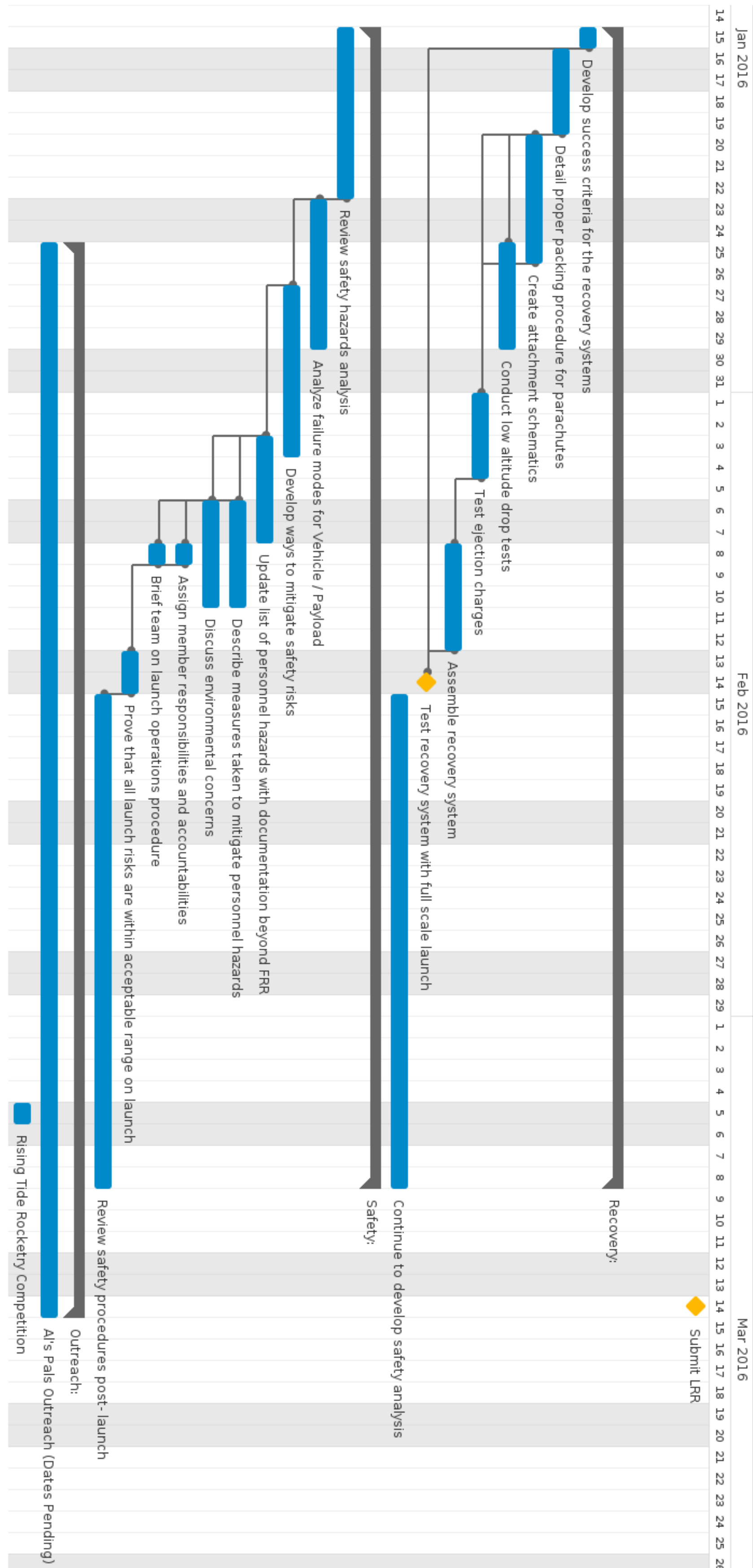
Weighted Rating of Calf Wall Thickness											
		Solid Rectangle		Hollow (t=.2 in)		Hollow (t=.15 in)		Hollow (t=.1 in)		Hollow (t=.05 in)	
Criteria	*Importance Weight (%)*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted Rating*	*Rating*	*Weighted 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 F - Expanded Gantt Chart

All gantt charts were generated using the Instagantt app. The chart will be found on the following pages.




Jan 2016
Feb 2016
Mar 2016
Recovery:
Develop success criteria for the recovery systems
Detail proper packing procedure for parachutes
Create attachment schematics
Conduct low altitude drop tests
Test ejection charges
Assemble recovery system
Test recovery system with full scale launch
Continue to develop safety analysis
Submit LRR
Safety:
Review safety hazards analysis
Analyze failure modes for Vehicle / Payload
Develop ways to mitigate safety risks
Update list of personnel hazards with documentation beyond FRR
Describe measures taken to mitigate personnel hazards
Discuss environmental concerns
Assign member responsibilities and accountabilities
Brief team on launch operations procedure
Prove that all launch risks are within acceptable range on launch
Review safety procedures post-launch
Outreach:
Al's Pals Outreach (Dates Pending)
Rising Tide Rocketry Competition

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