NASA University Student Launch Initiative

University of Alabama in Huntsville 2013-2014

Preliminary Design Review

January 10, 2014

THE UNIVERSITY OF
ALABAMA IN HUNTSVILLE

Propulsion Research Center, Huntsville, AL 35805, 256.701.4665

# Table of Contents

# Table of Figures, Tables, and Equations

# 1. PDR Summary

## 1.1. Team Summary

| | |
|---|---|
| Charger Rocket Works<br>University of Alabama in Huntsville<br>301 Sparkman Drive<br>Huntsville, AL 35899 | NAR-TRA Mentor:<br>Mr. Jason Winningham, Comp. Sys. Engineer<br>(Level 2 NAR: 89526/TRA: 13669)<br>Engineering Dept., UAH<br>Jason.Winningham@uah.edu<br>(Currently Level 2, Will be level 3 by CDR) |

## 1.2. Launch Vehicle Summary

The Length of the *Prometheus* Rocket will be 122 inches and the outer diameter will be 4.7 inches. Calculations were performed using a target mass of 29.3 pounds. The Motor that will propel *Prometheus* is a M4770-Vmax by Cesaroni Technology Inc. This motor provides 7357 Newton-seconds of Total Impulse and a maximum thrust of 5854 Newtons. *Prometheus'* nosecone is a 40.16 inch Von-Karman nosecone. It uses four trapezoidal fins and a dual-deployment recovery system that utilizes a drogue chute and a main chute and a main chute deployed by black powder charge.

The *Prometheus* will leave the launch rail at roughly 131 feet-per-second and reaches a maximum velocity of 1960 feet-per-second. The rocket will experience a maximum G loading of 44 G's. The rocket will coast to an apogee of about 14,800 feet, after a 1.53 second burn.

**Milestone Review Flysheet**

See section 15 Appendix I: Flight Sheet

## 1.3. Payload summary

**Payloads**

| Name | Reqt # | Description |
|---|---|---|
| Landing Hazard Detection System | 3.1 | Hazard Detection Camera using onboard processor and live data feed |
| Microgravity Propellant Management System | 3.2.1.2 | Demonstrate the ability to control the position of a simulated propellant in a microgravity spacecraft tank, using Dielectrophoresis. |
| Supersonic Effects on Vehicle Coatings | 3.2.2.4 | Various common external coatings will be analyzed preflight and post flight to analyze the effect of supersonic flight on rocket coatings. |
| Transonic Vehicle Aerodynamics | NA | Vehicle will collect flight data through the transonic region in order to determine Axial, Normal, and Pitching Moment Coefficients. |

# 2. Changes made since Proposal

## 2.1. Vehicle Changes

### 2.1.1. **Motor**

The motor category has been fixed at level 3, as it is the only level with motors capable of accelerating the vehicle into the transonic regime. The motor selected is the CTI M4770-Vmax.

## 2.2. Payload Changes

### 2.2.1. **Effect of Supersonic Flight on Paint/Coatings**

The number of different paints was decreased from four to two. This was done to lower cost and increase ease of manufacturing. Additional temperature changing tape has been added as a third "coating" to test the feasibility of using self-adhesive mediums on the outside of rockets during supersonic flight. This tape, if determined feasible, would provide a cheap method of verifying skin temperature of rockets during flight.

## 2.3. Project Plan Changes

### 2.3.1. **Landing Hazard Detection System**

The Landing Hazard Detection System (LHDS) was determined to require a dedicated team of programmers. To accommodate this realization the Landing Hazard Detection System will be presented to a second Senior Design team from the University of Alabama in Huntsville, who will be brought on to the team as a secondary team under the supervision of the avionics/payload sub-team.

# 3. Vehicle Criteria

## 3.1. Selection, Design, and Verification of Launch Vehicle

### 3.1.1. **Mission Statement**

The mission of Charger Rocket Works and the *Prometheus* Student Launch Team is to safely launch and recover a vehicle that geometrically replicates the Nanolaunch 1200 NASA prototype for the purpose of collecting aerodynamic data in flight, as well as meeting the Payload requirements of Student Launch, and the safety guidelines of both Student Launch and NAR/TRA.

### 3.1.2. **Vehicle Requirements**

*Prometheus* will be geometrically similar to the Nanolaunch 1200. It will safely launch under high acceleration of at least 44 G's, and subsequently be recovered in a condition suitable for re-launching. It will carry several payloads, including a comprehensive data collection suite, a low gravity experiment studying dielectrophoretic collection of fuel analogous material, a landing hazard detection system, and a study of the effects of supersonic flight on exterior coatings, and return these payloads safely to the ground.

### 3.1.3. **Success Criteria**

A successful mission will include the following:

1.) Safe launch, and recovery in suitable condition to be re-launched

2.) All payloads returned intact

3.) Maintain geometrical similarity to the Nanolaunch 1200 prototype

### 3.1.4. **Review of Design Components**

The objective of *Prometheus* is to geometrically replicate the Nanolaunch 1200 NASA prototype. Accurately scaling the Nanolaunch is a guiding force in most of the design decisions. The scale was chosen to allow the use of a 4-inch Pro98 Cesaroni motor case, while leaving room inside the body tube for sensor wiring to pass the motor case to allow for base drag pressure measurements. A small diameter was chosen due to the large fineness ratio of the Nanolaunch 1200 to minimize length. A small diameter will also reduce total drag on the vehicle, which will maximize time in the transonic velocity range for the collection of data. Once *Prometheus*'s final diameter was chosen, the rest of the exterior profile, length, etc. were chosen to follow the profile of Nanolaunch.

Very little space will be left between the motor case and the interior of the body tube to minimize diameter. This will necessitate an unusual fin design to allow for secure fin attachment. The fins will be made of carbon fiber in two mirrored halves each, which will include flanges for attachment to the body tube. The fins will then be adhered together and the assemblies will be adhered to the body tube. Using large flanges will add a minor geometrical discontinuity from Nanolaunch's profile, but allows for dramatically larger wetted area for the adhesive joint. Relying on adhesive only for attachment of the fins presents unusual risks for fin failure, which will be discussed in the Risk Mitigation section below.

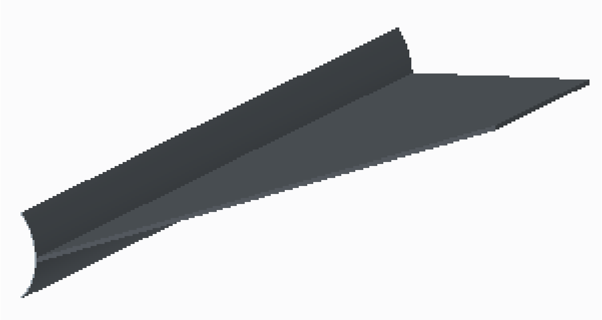

Figure 3-1: Fin with Flange

Figure 3-2: Fin Profile

The body tube will be made of carbon fiber. The tube diameter was dictated by the scaling decisions discussed above, as was the length of the rocket, and subsequently the body tube itself. Several other materials were considered, including fiberglass, aluminum, printed titanium and blue tube, but all were discounted for reasons of strength, weight, difficulty of fabrication, or unavailability of equipment.

*Prometheus* will experience large accelerations. In order to pass these forces from the motor case into the body tubes, two force paths will be used. The less significant of which will be a small printed titanium boat tail adapting the outside diameter of the motor case to the inside diameter of the lowest body tube. This is traditionally the primary motor force path into a hobby rocket body, however it was decided to add a second due to the high forces imparted by the VMAX motor chosen. To provide this path, a threaded aluminum shaft will be run from the motor retention bung at the top of the motor case, through a threaded bulk plate epoxied into the top of the fin can. Additionally, both of the internal payload bays will also be threaded onto this shaft. It will then pass through a bulkhead forming the bottom of the recovery system bay, and an eye nut for the parachute will then be used to retain all of the parts together.

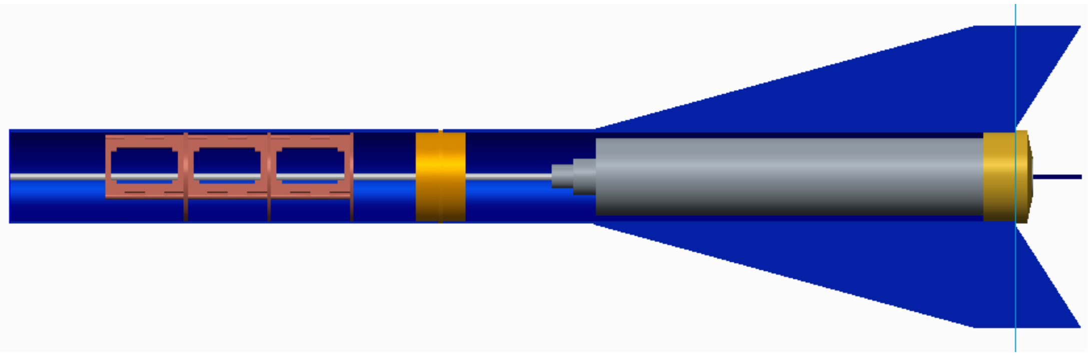

**Figure 3-3: Base of Rocket Showing Payload Shaft**

Because the payload shaft transfers forces axially through the vehicle, a single separation point was chosen to deploy the recovery system. To make this possible the drogue will be deployed first along with the nose cone using a black powder charge. The main chute will then be retained inside the body with a redundant solenoid device until the appropriate deployment altitude is reached. An example of this deployment configuration is shown in Figure 3-6. Thanks to a well characterized flight trajectory, the team feels comfortable controlling the parachute deployments with two Perfectflite timers and two altimeters for redundancy.

The nose cone profile was defined by the Nanolaunch experiment. It will be made of fiberglass so that it will be transparent to radio transmission. As such, all transmission equipment will be located there. The nose cone will also contain a portion of the Nanolaunch data acquisition system, along with several associated sensors and the pressure vessel based attitude perturbation system.

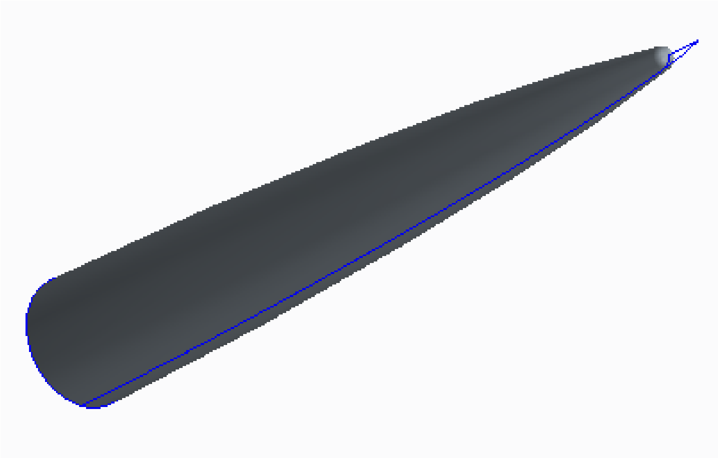

**Figure 3-4: *Prometheus* Nose Cone**

### 3.1.5. **Flight Simulations**

During the early stages of the project, a simple trajectory algorithm was programed to quickly compare motor performance to mission requirements. A MATLAB® Monte Carlo algorithm was utilized for independent variable fluctuation and motor variation to run batch test cases to determine design validity. The driving goal was to create a time effective method to analyze fluctuations on system inputs and to compare them to OpenRocket Simulations and Baseline Mission requirements. When the rocket was constructed in OpenRocket, the results were very close to those obtained through the MATLAB Monte Carlo code. The OpenRocket model is shown in Figure 3-5 below.

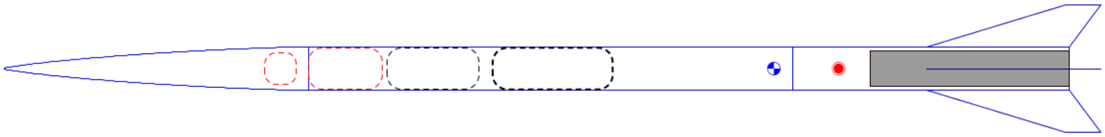

**Figure 3-5: Open Rocket Flight Simulation Model**

The physics algorithm, which predicts altitude, speed, and acceleration, applied simplified Newtonian mechanics to translational motion only. A piecewise, 1st order, linear set of differential equations define the motion and is integrated using MATLAB's built-in "ode45" function. ODE45 function is a Runge Kutta scheme with Backwards Differentiation Formulas to account for the piecewise partition points.

### 3.1.6.**Simulation Result Requirements**

The team simulated approximately 30 different motors and ended up selecting a CTI M4770. This VMAX propellant based motor will provided the necessary thrust to achieve a supersonic speed of approximately Mach 1.7 (1960 ft/s), a max acceleration of 44 G's, and an altitude of 14,800 feet contains the motor specifications.

### 3.1.7. **Mass Statement**

The projected weight estimates are intentionally greater than the actual weight the team expects. As the design matures, the mass estimates will become less conservative and more accurate. The team projects final weights will be lower. For example, the mass estimate for the body tube assumed use of .1 inch thick material, but based upon previous rocket designs this is over estimated. Throughout the design process, FEA and hand calculations will be used to finalize these estimates.

**Table 3-1: Current Mass Estimates**

| Component | Weight (lbs) |
|---|---:|
| CG Payload | 1.16 |
| Forward Payload | 0.67 |
| Dielectrophoresis | 1.11 |
| Perturbation System | 0.65 |
| LHDS | 0.50 |
| Drogue/ Shock Chord/ Black Powder Charge | 0.31 |
| Main Parachute/ Shock Chord | 1.78 |
| Motor/Motor Mount | 14.34 |
| Fin Set | 3.02 |
| Body Tubes/ Bulk-plates/Nosecone | 10.70 |
| **Total:** | 34.23 |

### 3.1.8.**Materials Testing**

In order to ensure the survivability of the vehicle as it undergoes supersonic flight, a number of tests will be conducted to verify that the materials chosen for construction will not degrade due to high temperatures, or fail due to the thrust produced during takeoff or parachute deployment. Body tube samples will be placed under tension to simulate the force applied due to parachute deployment, both at room temperature and at the anticipated maximum temperature the vehicle will undergo during supersonic flight of roughly 620$^0$ F. A sample body tube will also be subjected to compression tests to simulate the stresses that the vehicle will undergo during the launch phase. The main bulkheads and payload shaft will also undergo tensile and compressive tests to ensure that they will survive the G-loading from the launch, as they will carry the majority of the load the vehicle will encounter. The fins will also be tested to failure to ensure that they will endure the aerodynamic forces generated by supersonic flight. A preliminary test schedule can be found in Appendix G.

Another consideration is flutter at supersonic speeds. Using Apogee Rocket's analytical method, the team has developed an algorithm to determine the necessary fin shearing modulus to withstand predicted vehicle velocities. Zachary Howard, writer for *Peak of Flight* magazine, posted a descriptive article for predicting the speed at which the fin will flutter based on fin dimensions and dynamic pressure.

$$V_f = a\sqrt{\frac{\dfrac{G}{1.337AR^3P(\lambda+1)}}{2(AR+2)\left(\dfrac{t}{c}\right)^3}}$$

Where “P” is the atmospheric pressure, “a” is the speed of sound, “G” is the shear modulus, “AR” is the aspect ratio, “t” is the thickness, and “c” is the mean chord length. Estimating our max speed is 1960 ft/s and adjusting for 20% safety, it is expected that the shear modulus should be 2.0E6 psi.

## 3.2. Recovery Subsystem

The Recovery system will be triggered by a set of dedicated timers and altimeters. The trajectory predictions were performed by 2 different methods and were within reasonable error. This consistency allowed the choice to use a timer for the drogue deployment and an altimeter for the main parachute deployment. Using a timer to deploy the drogue also meant that no tap holes in the rocket body would needed to equalize the internal pressure. This keeps the outer surface of the rocket uniform and consistent with the Nanolaunch design that *Prometheus* is based on. The drogue timer will be started at launch and it will trigger deployment at 1 to 2 seconds after apogee. The parachute bay will then be exposed to the external conditions allowing a pressure and temperature based altimeter to trigger deployment of the main parachute at 1000 ft above ground level.

The recovery system will consist of two main components, a drogue and main parachute. The drogue will be attached to a shock chord which tethers nose cone and body tube. The main parachute will be attached to the same anchor as the drogue. The recovery system will use black powder ejection charges to separate the nose cone from the parachute body tube. The black powder charges will be ignited by redundant sources in order to reduce the risk of the recovery system failing. During drogue deployment, the nose cone then will pull the shock cord and the drogue from the airframe. Then the main parachute will be deployed with a mechanical release. This recovery system design allows the rocket to only require one separation point and one set of event triggers which will utilize Perfect Flight® altimeters. The recovery system will be tested multiple times to ensure that it will operate properly on the launch day. UAH's Propulsion Research Center will be used for all recovery system testing before flight. After the recovery system is working consistently at the Propulsion Research Center it will be launched on a subscale rocket for testing. Figure 3-6 depicts a packing arrangement that is being considered.

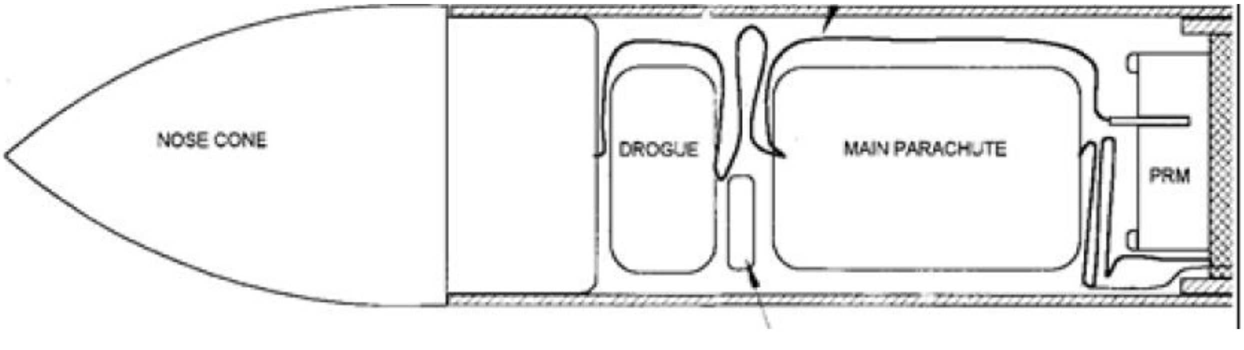

**Figure 3-6: Example Parachute Packed Arrangement**[1]

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[1] Newlands, Rick. AspireSpace.co.uk . Web. 09/2011 http://www.ricknewlands.webspace.virginmedia.com

### 3.2.1. **Drogue**

The drogue is designed to allow a maximum descent velocity of 100 feet per second. This will ensure the loading during main parachute deployment is within the vehicle’s structural limits. Current mission parameters estimated the drogue to be made of a fabric that is 12 inches filled diameter and will be deployed at apogee. The gores will be composed of a nylon paratrooper cord medium weight.

Rip-stop nylon was selected because it is inexpensive and light weight. It is less prone to damage as compared to silk or standard nylon. If a tear occurs the weave that rip-stop nylon uses prevents the tear from growing and causing complete material failure. The drogue will use two plies of the rip-stop nylon. Using two plies of the rip-stop nylon will improve resistivity to ripping.

### 3.2.2. **Main parachute**

The main parachute will be deployed at 1000 feet on descent. Deploying the main parachute at a low altitude will minimize the wind drift that the rocket will experience on decent and allow the rocket to be able to achieve a minimum recovery distance. The main parachute will be 15 feet in diameter and constructed of rip-stop nylon. The seams will be double stitched to minimize the possibility of the seams failing and causing the recovery system to fail. The main parachute will have a vent hole that is approximately one percent of the main canopy's area increasing the descent sway stability. Special consideration in manufacturing will be analyzed to ensure the vent hole reinforcement is strong enough to ensure 100% reliability.

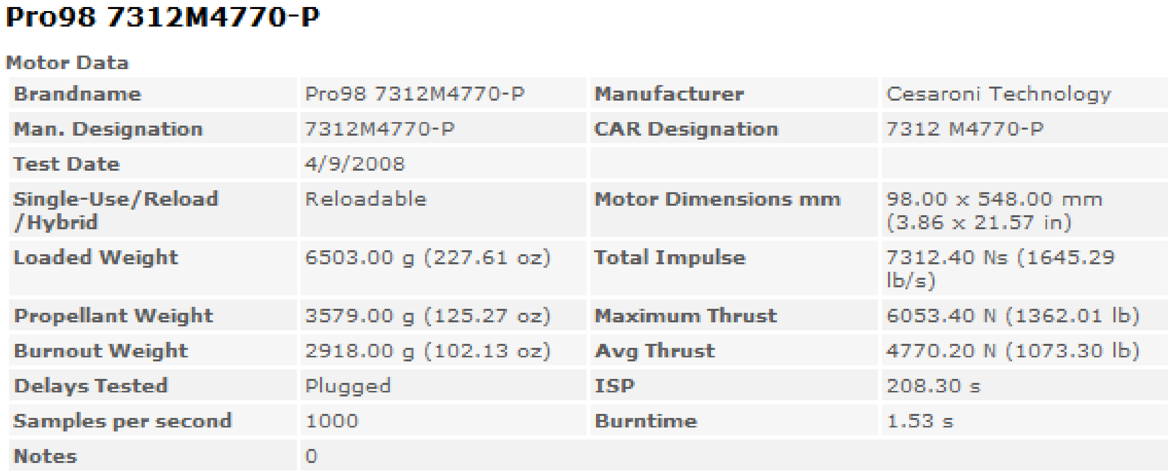
## 3.3. Mission Performance Predictions

*Prometheus* has several requirements to achieve not only the payload requirements but to also stay within the boundaries set by the competition parameters. Below is a list with the flight requirements.

- Attain supersonic speeds ( Payload Requirement)
- Stay under 20,000 feet ceiling (Competition Requirement)
- Significant time in transonic regime (Payload Requirement)
- Pitch rocket during transition region (Payload Requirement)
- Optimize descent profile ( Payload Requirement)

### 3.3.1.**Propulsion System**

*Prometheus* is a slender rocket with a length of 10.25 feet and 4.7 inch outer diameter. The motor case is a three grain Pro98 designed for VMAX propellant mixture. Figure 3-7 contains the motor specifics.



**Pro98 7312M4770-P**

**Motor Data**

| | | | |
|---|---|---|---|
| **Brandname** | Pro98 7312M4770-P | **Manufacturer** | Cesaroni Technology |
| **Man. Designation** | 7312M4770-P | **CAR Designation** | 7312 M4770-P |
| **Test Date** | 4/9/2008 | | |
| **Single-Use/Reload /Hybrid** | Reloadable | **Motor Dimensions mm** | 98.00 x 548.00 mm (3.86 x 21.57 in) |
| **Loaded Weight** | 6503.00 g (227.61 oz) | **Total Impulse** | 7312.40 Ns (1645.29 lb/s) |
| **Propellant Weight** | 3579.00 g (125.27 oz) | **Maximum Thrust** | 6053.40 N (1362.01 lb) |
| **Burnout Weight** | 2918.00 g (102.13 oz) | **Avg Thrust** | 4770.20 N (1073.30 lb) |
| **Delays Tested** | Plugged | **ISP** | 208.30 s |
| **Samples per second** | 1000 | **Burntime** | 1.53 s |
| **Notes** | 0 | | |

**Figure 3-7: Motor Statistics**

This level 3 NAR certified motor features a large maximum thrust and a very short burn time. This will induce a large acceleration during powered flight of approximately 44Gs for a pre-launch weight of 29.3 pounds. This thrust magnitude is necessary to achieve supersonic flight but the short burn time will ensure the coasting distance will be small enough to keep the rocket under the 20,000 feet ceiling. Since the target wet mass at launch is 29.3 pounds, the thrust to weight ratio is 36.5.

Figure 3-8 is the thrust characteristic curve provided by the manufacturer, Cesaroni Technology Incorporated.

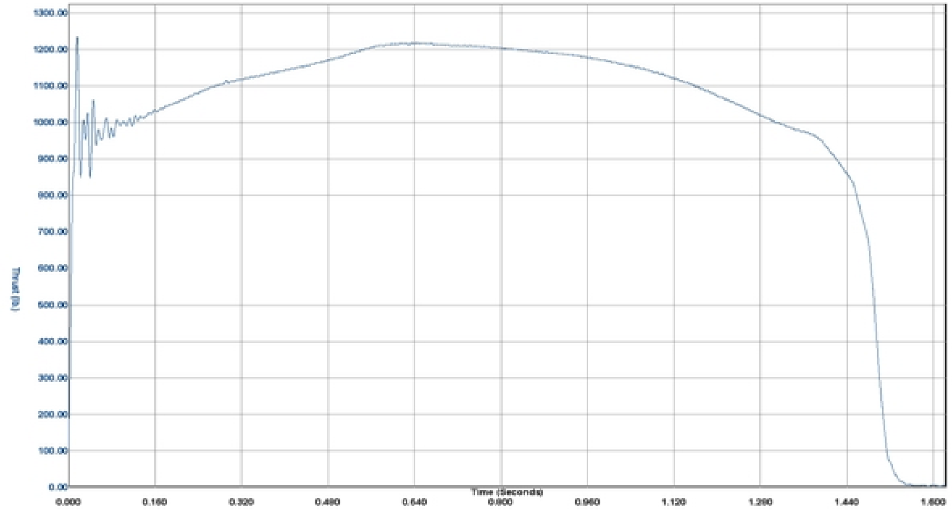


**Figure 3-8: Thrust Curve**

### 3.3.2. **Flight Prediction**

Figure 3-9 shows a predicted flight path for *Prometheus*.

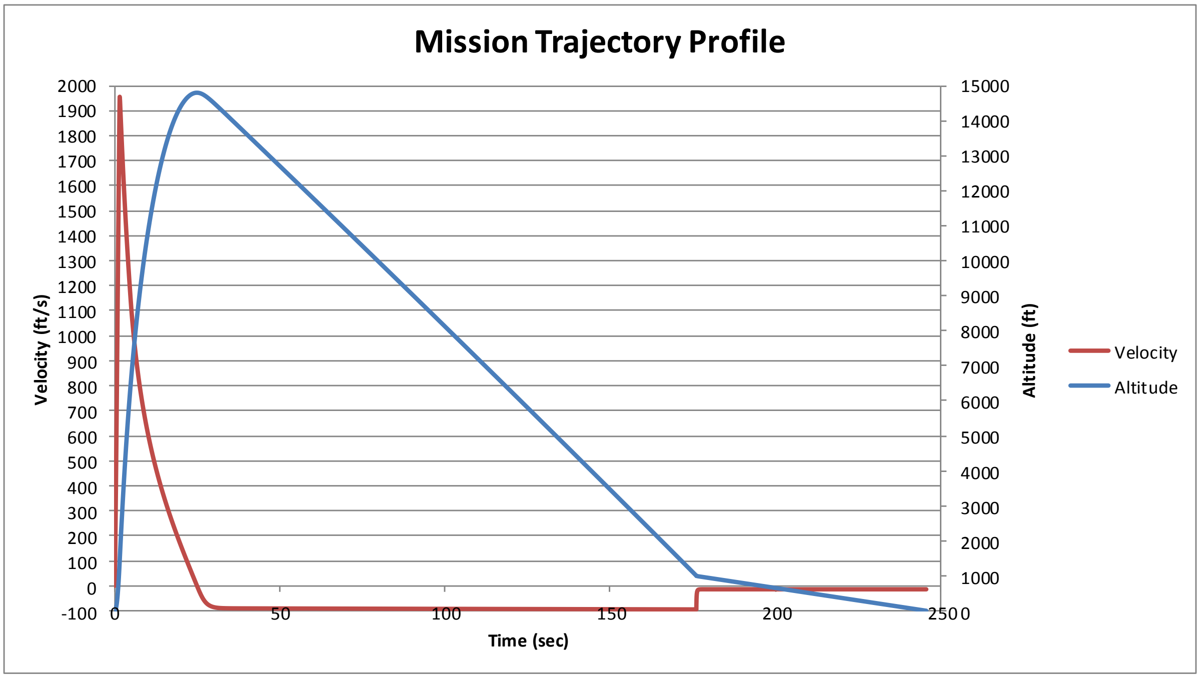


**Figure 3-9: Trajectory**

As explained above, the selected motor will induce high acceleration over a short amount of time which will drive the vehicle to a maximum velocity of 1960 feet-per-second (Mach 1.7). Figure 3-10 shows the vehicle's flight path before apogee. The target burnout mass of 22 pounds combined with the vehicle's aerodynamic shape induces an economic ballistic coefficient which is the root factor in high altitude through which the vehicle coasts. The flight time is reduced by allowing the vehicle to fall with a drogue chute at 100 feet per second.

Figure 3-10 details the flight pattern up to apogee.

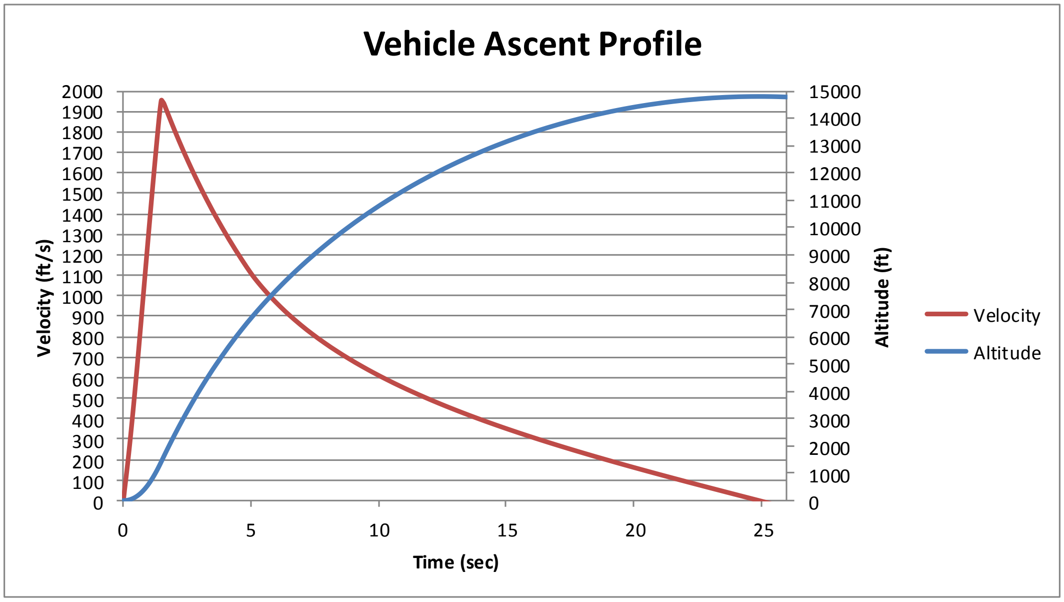


**Figure 3-10: Vehicle Ascent Profile**

Figure 3-11 details the powered flight which induces the acceleration in the vehicle.

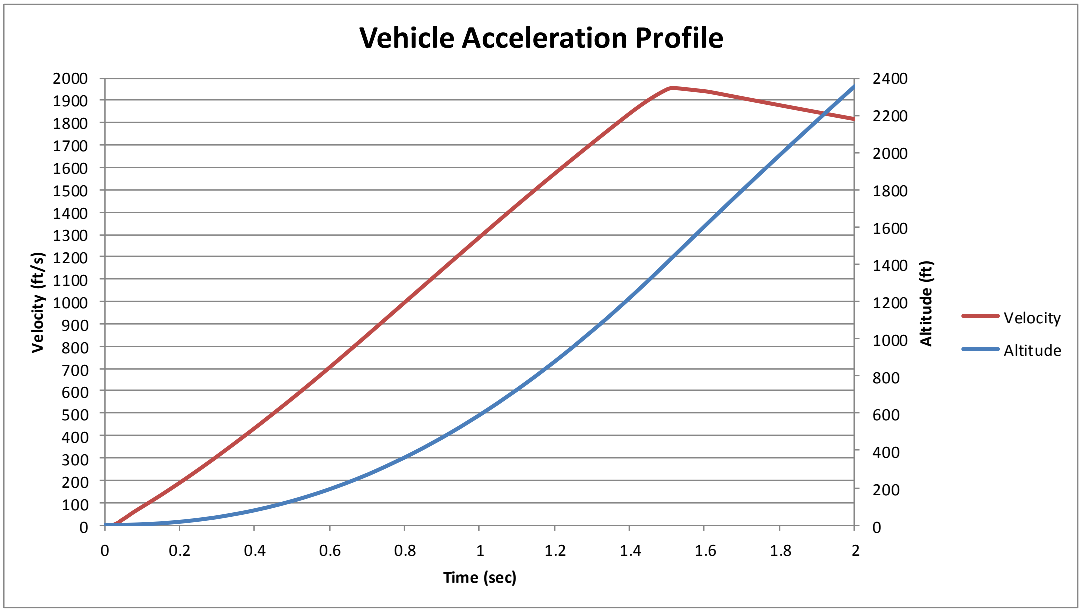


**Figure 3-11: Vehicle Acceleration Profile**

Figure 3-11 clearly shows that max speed is attained before burn out. This correlates to the point at which the thrust curve begins to drop off in Figure 3-8. There is a small startup burn time in the motor during which the thrust produced isn't large enough to live the rocket.

### 3.3.3. **Chronology of Flight Events**

Table 3-2 details key events and their respective critical values.

**Table 3-2: Chronological Trajectory Events**

| Event | Value | Units |
|---|---|---|
| Time to Lift Off | 0.02 | seconds |
| Launch Rail Exit Speed | 130 | ft/s |
| Max Speed | 1960 | ft/s |
| Max Kinetic Energy | 1.275E6 | ft-lbf |
| Time To Apogee | 24.9 | seconds |
| Apogee | 14800 | ft |
| High Altitude Descent Speed | 100 | ft/s |
| High Altitude Descent Energy | 2988 | ft-lbf |
| Time at Main Deploy | 176 | seconds |
| Main Chute Deployment Altitude | 1000 | ft |
| Ground Impact Speed | 7.0 | ft/s |
| Nose Cone Impact Energy | 0.83 | ft-lbf |
| Body Impact Energy | 15.9 | ft-lbf |

These values confirm that *Prometheus* is within the specified requirement set forth by the restrictions on max altitude and impact energy. Structural analysis using a software package will be used to verify that the desired structure and subcomponent

### 3.3.4. **Drift Calculation**

Depending on the launch conditions, *Prometheus* is expected to drift up to 8,991 feet during a 25 mph constant cross wind. Figure 3-12 details cross wind conditions between 5 and 25 miles per hour.

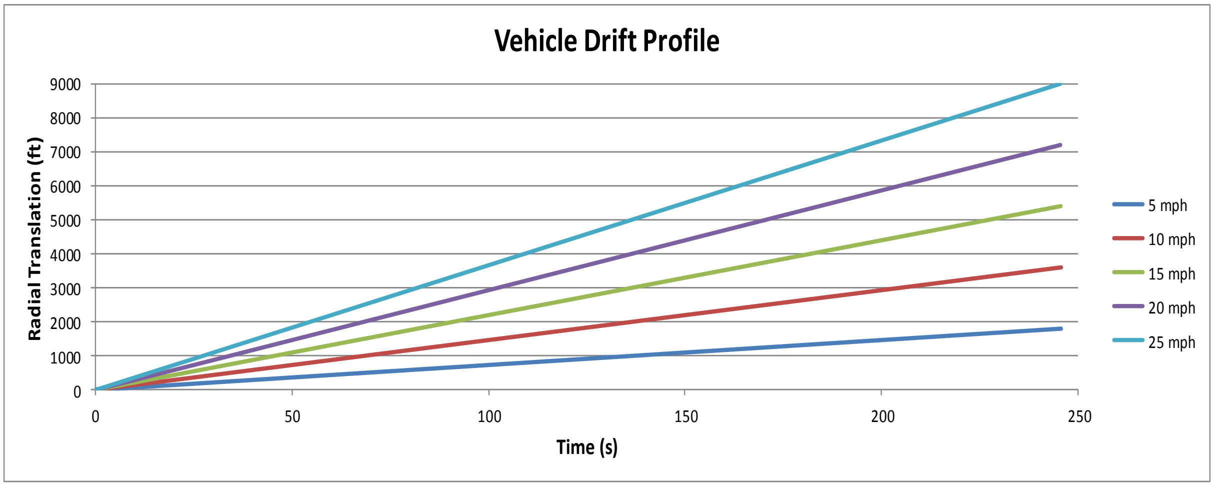


**Figure 3-12: Radial Translation Vs Time**

Figure 3-13 characterizes the vehicle's translational velocity radially from the launch site.

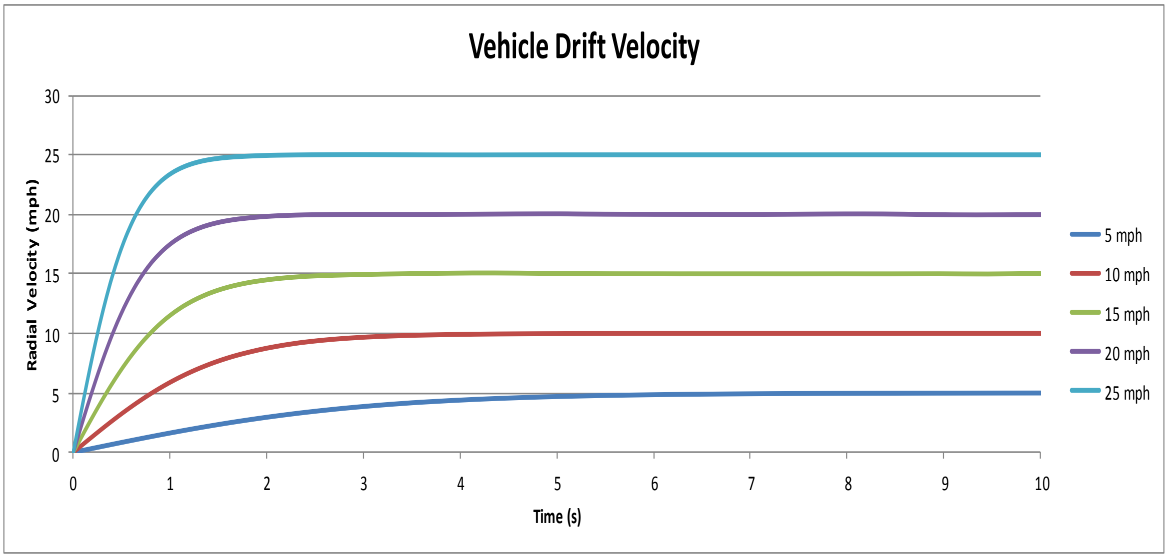


**Figure 3-13: Vehicle Drift Velocity**

The summary of vehicle drift due to cross wind is estimated in Table 3-3.

**Table 3-3 : Cross Wind Drift Summary**

| Cross Wind | 5 mph | 10 mph | 15 mph | 20 mph | 25 mph |
|---|---|---|---|---|---|
| Feet | 1787.7 | 3590.4 | 5391.9 | 7190.9 | 8991.7 |
| Miles | 0.33858 | 0.68 | 1.021193 | 1.361913 | 1.702973 |

The vehicle's drift distance is minimized by allowing the fastest fall rate capable of the system. At apogee, the drogue chute permits the vehicle to fall at a terminal velocity of 100 feet per second. This reduces the flight time during which the vehicle can drift.

### 3.3.5. **Monte Carlo Simulations**

An attempt to simulate variation in expected launch conditions was made to analyze how apogee, maximum Mach value, and max acceleration were affected. This early in the project, the largest unknown is launch mass weight. Figures 3-14 through 3-16 depict the changes as the initial launch mass is varied.

The Monte Carlo simulation employs a uniformly distributed random mass variation with a standard deviation of 5% with a mean value of 29.3 pounds. The results are plotted over 150 test cases.

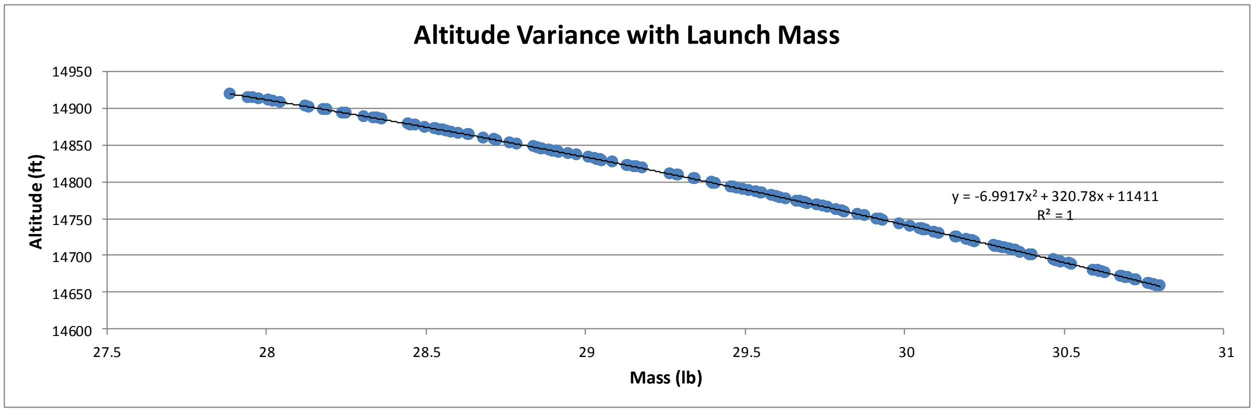


Figure 3-14: Altitude Variance with Launch Mass

Figure 3-14 shows the expected curve that altitude is a 2$^{nd}$ order polynomial fit to the mass. This is due to the natural physics driving the acceleration. Since acceleration is inversely proportional to mass, and altitude is the second integration from acceleration the observed upside parabola is expected.

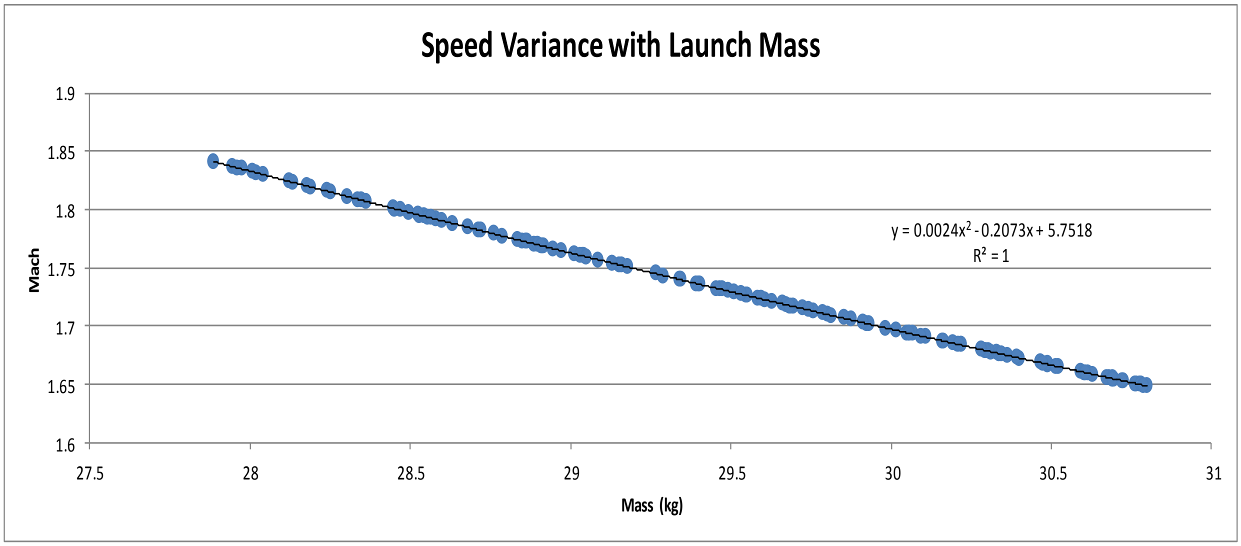


Figure 3-15: Speed Variance with Launch Mass

Figure 3-15 shows a more linear trend to the data. While the fit is best with quadrat fit, the fit is within acceptable standard to be a linear fit. Linear fit produces an $R^2$ value of 0.99912. The plot specifically reveals that variation in mass is acceptable in that the speed requirements will be met.

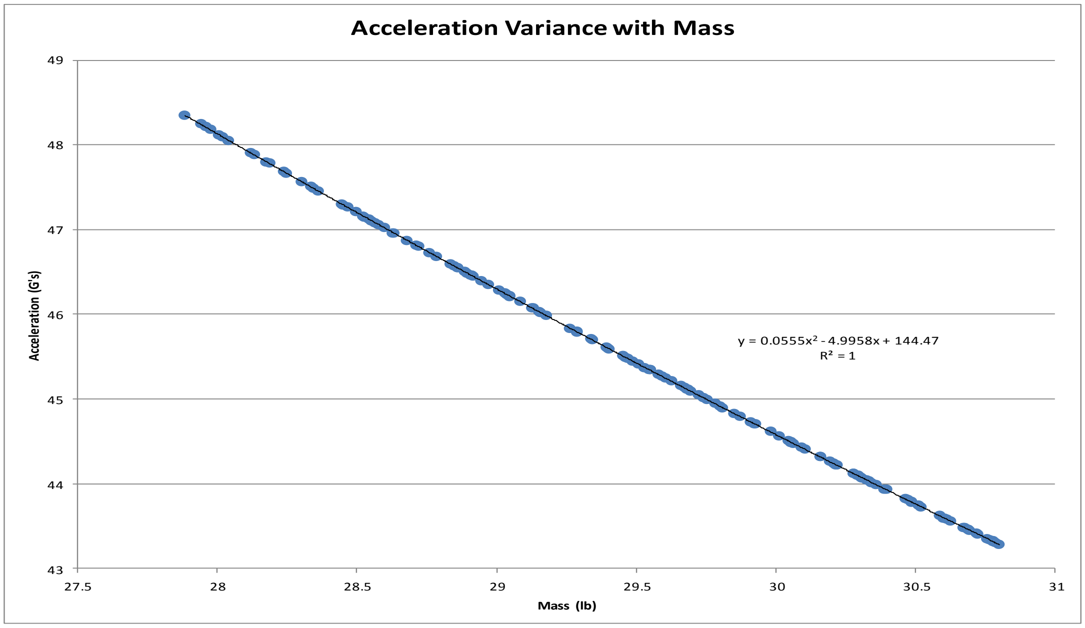


**Figure 3-16: G-Loading Simulation**

Figure 3-16 reveals that the launch mass may not want to be reduced with the increased in loading. As current G loading has been accounted for, further testing may be required to ensure payload and airframe will survive predicted load conditions.

## 3.4. Interfaces and Integration

Integration is covered 4.7 Preliminary Integration Plan

Interfaces is covered in 4.10 Interfacing Payload Components

## 3.5. Launch Operation Procedures

All full and sub-scale launches will utilize a launch rail and rail buttons to provide the rocket with its initial trajectory. The CRW team will utilize the launch rails provided on launch day and two of the appropriately sized rail buttons will be permanently mounted to the side of the rocket to ensure a vertical trajectory.

The team safety officer will compile a Launch Procedures Handbook to be on-hand for all full and sub-scale test flights. This handbook will use the same format as all other standard operating procedures (SOPs) employed by the CRW team. The procedures will identify the CRW personnel responsible for assembly of the vehicle, and the members possessing the necessary NAR/ TRA certification in order to install the motor and ejection charges.

In addition to identifying all of the parties responsible for the assembly of the vehicle, the launch procedures handbook will contain illustrated step-by-step instructions for the vehicle and payload assembly. The launch operations handbook will also contain MSDSs for all materials the CRW members may come in contact with during the assembly. The Launch Procedures Handbook will be reviewed by the launch team and the Safety Officer no fewer than two days prior to any scheduled launch. The CRW

Regulatory Handbook will also be included as a part of the Launch Procedures Handbook. The CRW Regulatory Handbook will contain all of the materials included in Appendix C.

## 3.6. Safety and Environment (Vehicle)

### 3.6.1.**Safety Officer**

The CRW has identified Brian Roy as the Safety Officer and Test Engineer, who will be responsible for keeping an updated account of all SOPs, MSDSs, and all state and federal regulations governing high powered rocketry. He will also be responsible for scheduling all ground tests to take place before any test launches and reviewing the procedures for those tests and launches with all CRW members who will be present.

### 3.6.2. **Failure Modes and Mitigations**

The rocket could fail if the materials selected for construction are not robust enough to withstand the 44 G's of acceleration that the rocket is predicted to experience at launch. If the rocket is not constructed to handle 44 G's of acceleration, the body tube could delaminate at a low altitude or be sufficiently fatigued to withstand the stresses caused by supersonic flight. If the rocket is destroyed at a low altitude, the launch spectators could be injured by the descending parts of the rocket. If structural damage occurs but does not prevent the rocket from launching, the stresses caused by supersonic flight could cause catastrophic failure during flight. Failure of the materials during flight will also put viewers in danger of falling debris. In order to reduce this risk the team will be conducting FEAs on the components of the rocket along with material tests. The FEAs will identify any areas on the rocket that could require reinforcement in order to withstand 44 G's of acceleration and supersonic flight. The CRW made composites will also be tested to ensure they have the expected strengths and that no imperfections are present from manufacturing. Additionally, all components of the vehicle will be designed to a factor of safety of 1.5, at minimum.

Aside from failures due to high G loading, the fins could possibly become delaminated from the rocket body during flight due to aerodynamic forces or from the impact at landing. If a fin delaminates during flight, the rocket will become unstable and unsafe for supersonic flight. The delaminated fin would also be a hazard to people in the area as it will be free-falling and difficult to see. However, it is far more likely for a fin to become delaminated during landing. If a fin delaminates after landing the rocket would be unfit for flight until the proper repairs can be made. The fins will be thoroughly tested by placing them under tension to determine their breaking strength to ensure that they will withstand the aerodynamic forces that will occur due to supersonic flight.

After the rocket has been constructed, damage can occur during shipping and transportation. If damage occurs from shipping the rocket may become unsafe and unworthy of flight. In order to reduce the risk of shipping damage a special built crate will be used when moving the rocket. The crate will use expandable foam to make an exact profile of the rocket, so that the rocket will not be able to move freely during transportation.

Of major concern is that the recovery system fails during any flight. In order to ensure that the recovery system will function properly, ground testing will be conducted at the Propulsion Research Center at UAH under the supervision of properly trained personnel. The recovery system will incorporate at least two separate ignition sources for the black powder charges. The black powder charges will be kept to a minimum operating point, so that the detonation will not harm any part of the rocket. A summary of the vehicle risk assessment is presented in Table 3-2, which calculates the risk for a particular failure event from its likelihood and impact on the success of the mission with 1 being least likely or severe, and 5 being most likely or most severe.

**Table 3-2: Risk Assessment**

| Event | Likelihood | Impact | Total Risk |
|---|---|---|---|
| Material Failure on Launch | 2 | 4 | 8 |
| Fin Delamination During Flight | 1 | 4 | 4 |
| Fin Delamination During Landing | 4 | 4 | 16 |
| Motor Failure on Launch | 2 | 5 | 10 |
| Recovery System Failure | 4 | 5 | 20 |
| Damage from Shipping | 4 | 2 | 8 |

### 3.6.3. **Hazardous Materials**

Outside of the hazards associated with launching the vehicle are those associated with the construction and testing of the vehicle and its various components. In order to ensure that no CRW members are unnecessarily exposed to hazardous chemicals or other potential risks, all pertinent SOP's and MSDS will be reviewed in advance of any tests or component manufacturing. All current MSDSs can be found in Appendix C.

### 3.6.4. **Environmental Concerns**

As several of the launch sites used by the CRW team operate on privately owned farms, responsible removal and disposal of all spent motors, batteries, black powder capsules, and any other refuse is of primary concern. While the exhaust gasses expelled by the rocket motors do present some environmental concerns, they are an unavoidable byproduct of this type of project. However, they can be minimized by using a smaller sized motor wherever possible. Many components of the vehicle's payload will utilize rechargeable batteries, which carry significant environmental impacts if not disposed of properly. The use of a proper recycling facility will mitigate these concerns.

## 4. Payload Criteria

The design of each payload at a system level was analyzed and each of the system's functional requirements was covered. The four independent payloads addressed in this section are as follows: dielectrophoresis, effects of supersonic flight on coatings, a ground hazard detection system, aerodynamic coefficients for the Nanolaunch 1200.

### 4.1. Selection, Design, and Verification of Dielectrophoresis

The purpose of the payload experiment to be flown on *Prometheus* is to simulate the collection of liquid propellant within fuel tanks in microgravity applications by means of dielectrophoresis. Dielectrophoresis is the use of electric fields to move fluids. Various fluids such as corn oil, silicone oil, and peanut oil will be evaluated as the fluid to be flown in the experiment because their dielectric constants are similar to those of several liquid propellants.

The use of dielectrophoresis to collect fuels for engine restart would be an excellent alternative to current systems involving inertial rockets. The same dielectrophoresis system could also aid in preventing heat transfer to the fuel from the walls of the container, reducing boil-off of cryogenic fuels on long missions such as one to Mars. This also reduces the need for bulky insulation by using the gas already in the tank. The power required to establish a high voltage electric field is low, and it is operable at any time.

Safety concerns about the use of high voltage in this experiment are addressed in Section 4.13.1

#### 4.1.1. **Dielectrophoresis Subsystems**

The experiment is organized to demonstrate that dielectrophoretic displacement of the fluid within the tanks is indeed significant in microgravity, where significance is measured by the volume of fluid that moves to the desired location as determined by the geometry of the electrodes. The motion of the fluid in flight is recorded with video cameras. The behavior of the fluid in the electric field will be compared to the behavior of the control fluid with no electric field in order to show dielectrophoretic displacement. An accumulation of fluid between the electrodes in microgravity will verify that fluids can be effectively controlled with dielectrophoresis.

The payload system consists of dielectric fluid contained in plastic bottles, a high voltage power supply, video cameras, and other electronics for experiment control and data collection. The structure of the payload assembly will be built from polycarbonate sheet. The entire payload assembly will be surrounded by a copper mesh acting as a Faraday cage to eliminate electromagnetic interference to other parts of the rocket. The three variables that have the strongest influence on the experiment are:

- Voltage – The squared voltage of the system drives the strength of the electric field.
- Dielectric constant of fluid – The dielectric constant of the fluid determines how strongly the fluid is influenced by dielectrophoresis.
- Electrode geometry – The gradient of the electric field is dependent on the geometry of the electrodes.

The experiment will be activated automatically after launch. The high voltage supply will become powered after launch has been detected by the accelerometer and microcontroller. The cameras will also begin recording video at that time as directed by the microcontroller.

To accomplish the mission the payload has 3 phases, or modes of operation: Launch Detect System (LDS), Experiment Operation, and Idle. Each phase uses different hardware capabilities and code. These phases are related to vehicle events as shown in Figure 4-1.

The LDS's primary function is to determine whether a legitimate launch has occurred. For safety reasons we do not want to have the system turn the experiment on unless the rocket is actually launching. To accomplish this, the microcontroller will poll the accelerometer to compare the g level in the launch oriented axis to a threshold of 3.8gs. If the measured value exceeds the threshold then the program will check again after a brief delay. After three positive checks the program will move into the Experiment phase.

The Experiment Phase is where data is collected and the only phase where the high voltage power supply is active. When launch is detected the microcontroller powers on the HV supply, triggers the cameras to record, and begins writing accelerometer data to the SD card. When 30 seconds have passed since the beginning of the Experiment phase power is removed from the high voltage system and the cameras are told to cease recording.

### 4.1.2. **Experiment Configurations**

Two electrode configurations of different geometries are currently being considered for future use on the rocket's payload. The first case under consideration is that of a cylindrical wall that surrounds a rod which is aligned axially with the cylinder as shown in Figure 4-1. The cylinder and the rod are the two electrodes.

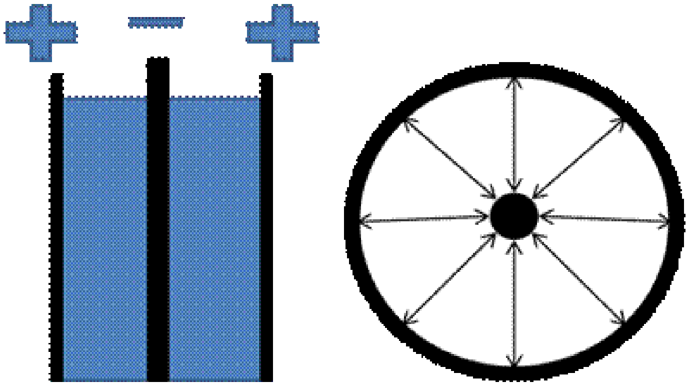


**Figure 4-1 Cylindrical Electrode Configuration**

This cylindrical electrode configuration is the simplest case for mathematical predictions because it has the most straight forward geometry. The electric field lines between the wall and center rod are straight radial lines. According to Blackmon[2], the voltage distribution of the cylindrical electrodes is

$$V(r) = \frac{V * \ln\left(\frac{r}{r_2}\right)}{\ln\left(\frac{r_1}{r_2}\right)}$$

Then the force per unit volume becomes

$$F_v = \frac{\epsilon_0 * (K-1) * (K+2) * V^2}{3 * \left(\ln\left(\frac{r_2}{r_1}\right)\right)^2 * r^3}$$

The cylindrical electrode configuration will be implemented by assembling a copper tube around a plastic jar containing the liquid. A small copper tube will be used as the center rod electrode. The outside copper tube electrode establishes an electric field with the center rod, and the plastic jar insulates the electrodes from each other. No electric current flows between the electrodes. The dielectrophoretic force is established only by the electric field.

The other case under consideration is that of a jar that contains two parallel electrodes of opposite charge.

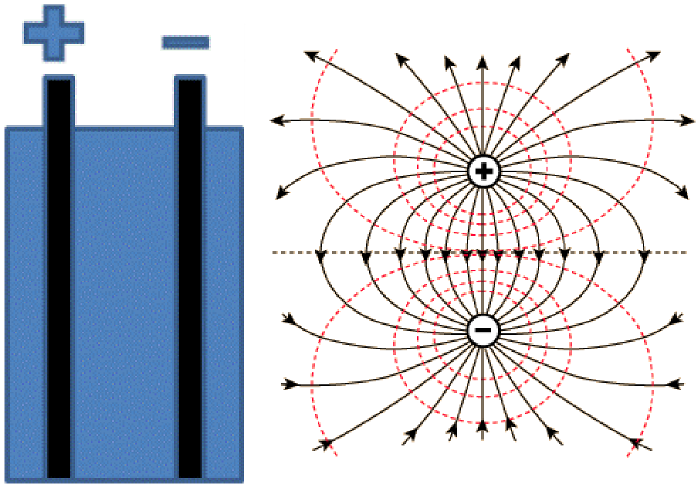


**Figure 4-2: Parallel Rods2**

For the parallel rod case, two cylindrical rods of small diameter (approximately .25 in) will be fixed to a plastic container and spaced approximately .125 in apart so a high electric field concentration develops between the rods as shown in Figure 4-2[2]. Once the concentration has developed, the fluid will be attracted to the concentration and will be pulled up and isolated between the rods. The

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[2] Image Credit: “Equipotential Lines.” Hyperphysics. <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/equipot.html>

mathematical predictions of the fluid behavior are more complicated for this case as there are two sets of field lines and the geometry is more complicated than the cylindrical case.

The parallel rod case was used by the USLI team at UAH last year. It is expected that the coaxial cylindrical electrode configuration will be more effective for demonstrating the dielectrophoretic effect because the consistent electric field should be better for drawing fluid from all regions of the jar volume.

### 4.1.3.**Scientific Method Analysis**

The scientific method will be used to analyze the experiment. The Hypothesis is that dielectrophoretic force will be the dominant force on a liquid in reduced gravity and that it will collect that liquid at the predicted locations. The behavior of fluid in a control container with no applied voltage will be compared the behavior of fluid in a container subjected to a strong magnetic field. Video footage of each container will be used to study the fluid behaviors. Measuring tapes in view of the cameras will serve as reference lengths by which to compare the results to values predicted from the dielectrophoretic force equations. The predictions would be the locations where fluid would collect, namely the locations where the electric field is strongest.

### 4.1.4.**Spaceflight Applicability**

As mentioned in the payload overview, this experiment was chosen for its applicability to microgravity and spacecraft applications. When conducting long term spaceflight, one of the most difficult problems that has to be dealt with is the system for managing fuel and oxidizer. Most fuels used by NASA today are kept at very cold or cryogenic temperatures. When a liquid is being held in a cryogenic state, the heat transfer that occurs between the storage tank walls and the fluid causes the fluid constantly undergo boil off. If the system does not have a relief mechanism, the boil off causes both the pressure and temperature to rise within the tank, which then leads to an increased rate of boil off. This process can continue infinitely in a self-sustaining process that can eventually lead to a rupture of the tank. Most vehicles currently deal with this issue by constantly relieving the excess pressure and gas by releasing it into the outside environment which results in a loss of propellant and vehicle efficiency. In addition, spacecraft that operate in microgravity environments that utilize liquid fuels have great difficulty with ensuring that the fluid is distributed within the fuel tank in such a way that the propulsion system inlet draws in only fluid without drawing in gas. This is due to the increased role of surface tension in microgravity environments. On earth, or in any environment with gravity, gravity exerts a body force on the fluid that causes it to always move towards the lowest point possible. In space, this force is not present so the only force being exerted on an undisturbed fluid are the viscous forces – such as surface tension – which results in the fluid having a tendency toward bubble like coagulations with gas between bubbles. When a propulsion system tries to pull fuel from such an environment, the fluid flow into the motor is not regular and can result in significant restart issues.

A dielectrophoretic fuel management system reduces the effects of both of these issues. If the double rod configuration were to be used, the ability of the system to draw fluid to a center location within the tank could prevent the vaporization of much of the fuel because there would be no contact between the fluid and the container walls which would eliminate the majority of the heat transfer to the fluid from sources such as solar radiation. Also, the column of fluid would be surrounded by air which would act as another layer of insulation from the walls, thus reducing the amount of insulation needed for the tank exterior. This would in turn reduce the vehicle mass and material efficiency while increasing the overall efficiency. The mass savings would allow more fuel to be transported and used during the duration of the flight. This is very important for interplanetary travel. Mars could be much more accessible with this technology.

The dielectrophoretic fuel management system would also use dielectrophoretic forces to direct spacecraft fuel to the best location within the fuel tank for propulsion system injection without requiring heavy baffles or inertial ullage motors. The system would operate until the engine was started and thrust was generated, at which point the acceleration from the thrust would collect the fuel. The system would be reusable at any time and requires volumetrically small power supplies. The only mass associated with the system would be the mass of the small rod electrodes, high voltage supply, and batteries, all of which are minimal.

Although the fluid container and the amount of fluid to be used in the rocket payload are small compared to the amount of fuel that would be used in a space vehicle, the difference in scale will not mathematically impact the experiment. The difference in scale can also be addressed by scaling the magnitude of the voltage use to match the amount of fluid desired to be transported within the tank. Any of the electrode configurations listed above would be equally valid if used in either the small scale application on the CRW rocket or a full-scale application on a spacecraft.

The high voltage required to employ dielectrophoresis in a fuel collection system could pose a danger of electrical arcing leading to ignition of the fuel. This risk would be mitigated by ensuring that the geometry of the electrodes is such that there are sufficiently large distances between the electrodes beyond the possible range for electrical breakdown of the air and tank gases. Unlike real fuels, the fluids to be used in the CRW experiments are non-volatile in temperatures below 200 degrees Fahrenheit and do not ignite even when arcs pass through the liquid. Arcing will still be prevented in the experiments because the electric field is lost when an arc develops and the experiment cannot run.

### 4.1.5.**Components**

The components that will be used in the payload are listed in Table 4.2 and described in further detail below.

Table 4-1: Components

| Item Name | Total Weight (lbs) | Total Cost ($) | QTY | Vendor | mass (g) |
|---|---|---|---|---|---|
| Transistor PN2222ATF | 0.000 | 0.20 | 1 | Digikey | 0.05 |
| Pro Micro DEV-11098 | 0.004 | 24.95 | 1 | Sparkfun | 2 |
| Accelerometer SEN-09836 | 0.002 | 27.95 | 1 | Sparkfun | 0.8 |
| SEN-11171 FlyCamOne | 0.031 | 39.95 | 1 | Sparkfun | 14 |
| Plastic container | 0.088 | 4.05 | 2 | McMaster | 20 |
| Electrodes (total) | 0.022 | 0.55 | 2 | MSC | 5 |
| MINIMAX7 (HV Supply) | 0.198 | 34.95 | 1 | Info Unlim. | 90 |
| LED (backlight) | 0.000 | 0.95 | 1 | Sparkfun | 0.1 |
| Small LiPo Battery | 0.073 | 11.95 | 2 | Sparkfun | 16.5 |
| Big LiPo Battery | 0.304 | 12.95 | 1 | Sparkfun | 138 |
| Peanut oil (2 tbsp) (1 container) | 0.029 | 0.08 | 2 | Walmart | 6.5 |
| Farraday Cage Material | 0.022 | 10.83 | 1 | MSC | 10 |
| Garrolite mounting plate | 0.116 | 1.11 | 4 | McMaster | 13.16 |
| Carbon Fiber Containment Tube | 0.044 | 60 | 1 | carbonfibertubeshop | 20 |
| Minor components | 0.04 | NA | 1 | NA | 20 |
| TOTALS: | 1.0 | 230.47 | | | 356.11 |

### 4.1.6.**Camera**

Figure 4-3: FlyCamOne eco V2

The camera that has been chosen to record video of the liquid containers in-flight is the FlyCamOne eco V2, available from Sparkfun. One camera per fluid container will be used for flights. The cameras will be attached to a control board via a ribbon cable. The control board has a microphone, micro SD card slot, power switch, status LED, mini-USB connection, and battery connection on it. The FlyCamOne is capable of recording at a resolution of 720 x 480px at 30 frames per second. At that rate, with the maximum size micro SD card of 8 GB, the camera should record about 80 minutes of video. Testing will be done to confirm that time. The cameras should not need to be on that long if they are interfaced with the microcontroller to turn them on when flight occurs. Also the cameras do not come with dedicated power supplies, so they connected to either the microcontroller for power or connected to a battery supply.

### 4.1.7.**HV power supply**

The high voltage power supply chosen to conduct the payload experiment is a MINIMAX7. It can operate at 7 kV at 10 mA with a frequency of about 50 kHz. The HV supply is the driving force behind the payload. It generates the electric field necessary for dielectrophoresis.

Figure 4-4: High Voltage Supply

### 4.1.8.**Fluid container selection**

The containers selected to contain the liquid during flight are clear plastic jars. It has a base diameter of 2” and a height of 3 5/8”. They will have to be stacked on top of one another to have more than one within the rocket.

### 4.1.9.**Safety Switch**

To ensure the payload will not be able to activate until it is ready for flight, a switch will be connected to the batteries, so that the circuit can be broken by the switch and not allow power to flow from the batteries to the rest of the payload system. Currently, the switch will be a button switch accessible from the outside of the rocket through a small hole in the body tube and payload capsule tube. The copper mesh will still cover the hole, but the mesh can be deformed enough to depress the button when pushed from the outside. This will mitigate risk of electrical shock to personnel.

Pending the results of electromagnetic interference (EMI) testing as described in Appendix G: EMI Test Plan, the safety switch may be implemented differently. Ideally, the safety switch could be placed outside of the Faraday cage mesh so as to be more accessible from outside the rocket as a remove-before-flight pin switch. This would require that wires from the battery come out of the Faraday cage at some point, which could be a possible leak for electromagnetic waves causing interference with other electronics on the rocket. Since any interference on these wires would have to have been received from the high voltage wires and would have to be retransmitted outside of the Faraday cage while battery current was already running through them, it is unlikely that any significant radiation would be present. However, testing is required to determine the validity of this assumption.

### 4.1.10. **Transistor**

A transistor, PN2222A, is going to be used as a switch for the HV supply to receive power. The transistor will receive a voltage from the microcontroller when the accelerometer indicates preset conditions. That voltage applied constantly will allow transistor to run the voltage from the HV supply's battery to the supply itself.

### 4.1.11. **Faraday cage**

In order for the components of the payload to be isolated from the other components of the rocket, the payload will be wrapped in a copper mesh that will act as a Faraday cage. This will keep any high frequency electromagnetic noise from the HV supply from interfering with electrical components of the recovery system.

### 4.1.12. **Backlight**

A backlight will be used to ensure that the cameras record useful video. White LEDs will be on the opposite sides of the liquid containers from the cameras. White paper or some other opaque material will be used to diffuse the light.

### 4.1.13. **Accelerometer**

The accelerometer being used in the payload is the Triple Axis ADXL345. It is a triple axis accelerometer that can detect +-16 g. The rocket may experience more than 16 g during the boost phase, but the accelerometer is only used, at this point, to tell that the rocket is Launching in order to determine when the payload can be fully switched on. The increased resolution is useful during the coast phase to determine the quality microgravity achieved.

**Figure 4-5: Accelerometer**

### 4.1.14. **Accelerometer live readout**

The accelerometer will be interfacing with the microcontroller at all times during the flight. In order to provide a visual feedback for the cameras, and multicolored LED will be used with the microcontroller and accelerometer. It will be place in clear view of the cameras. The LED will light up different colors determined by how many g's that the accelerometer is experiencing at the time.

### 4.1.15. **Power line buzzer**

A buzzer that is connected to the same battery as the high voltage supply will be used for auditory feedback.

### 4.1.16. **Accelerometer data storage**

In order for data from the accelerometer to be stored, a micro SD card slot is needed to be interfaced with the microcontroller. The data taken off the SD card can then be compared to the visual data given by the cameras.

### 4.1.17. **Fluid selection**

The fluid to be flown in the rocket will be peanut oil. It has a low dielectric constant so it can be used as a replacement to fuel that would be used in the real world application.

### 4.1.18. **Battery selection**

Two different batteries will be needed to power the payload. Both of the batteries will be Li-Poly batteries. The microcontroller will be running off one battery. The microcontroller will use that power to power the accelerometer, camera, and backlighting. The other battery will be used to power the HV supply and buzzer. The HV supply will require more power so it will take multiple Li-Poly batteries. Safety concerns associated with Li-Poly batteries are addressed in Section 4.1.13 below.

### 4.1.19. **Microcontroller selection**

The microcontroller that will serve as the primary flight computer for the payload will be the Pro Micro from Sparkfun. This is an Arduino-compatible microcontroller, which means the microcontroller can be programmed using the Arduino programming language and development environment. Its ease of use and open-source platform makes it ideal for students. The microcontroller will be used to interface with the accelerometer, in order to power the payload on and off. It will also be used to right the data taken from the accelerometer during flight and write it to a microSD card using attachable microSD card board.

**Figure 4-6: Pro Micro Microcontroller**

## 4.2. Selection, Design, and Verification of Supersonic Flight Vehicle Paint/Coatings

The purpose of this payload is to observe and analyze the effects of supersonic flight on paint coatings. Coatings were selected on film thickness, adhesion, and heat resistance. *Prometheus* will be coated with a two part epoxy primer and a urethane base paint. The epoxy is a two part system that is activated by mixing catalyst with a reducing agent. Epoxy offers very good adhesion, build thickness, and corrosion resistance on metals and composites.

The urethane is a single stage topcoat paint which allows it to cover a surface using less paint. It offers excellent retention along with abrasion resistance with a smooth finish. Urethane, with the proper additives, can self-repair minor surface abrasion. It has excellent UVA protection with quicker drying than epoxy. Both of the paint systems have the options to go over different substrates with excellent corrosion resentment properties.

### 4.2.1. **Supersonic Flight Paint/Coatings Subsystems**

The coatings will each cover half of the rocket to analyze the effects of the flight. Coatings will be applied in two separates ways. The Urethane will have as a smooth surface and the epoxy will have a rough surface. This gives the ability to test the paints durability during flight, and its surface efficiency. The coatings will then be analyzed for any defects associated with the flight.

**Figure 4-7: THERMOTAB Temperature Tape**

Along with the coatings, a temperature tape will be applied to the rocket as shown in Figure 4-7. This will allow a visual reference to the temperature changes along the rocket body. The tape will act as a visual reference to our thermal analysis to help verify the surface temperatures. Tape will be selected by referencing a heat and mass transfer analysis conducted by the team.

## 4.3. Selection, Design, and Verification of LHDS

The LHDS will be a self-contained system with independent power and data transmission capabilities. It will deploy with the main parachute approximately 1000 feet above ground level and scan the area beneath the vehicle for potential landing hazards. To complete the requirement, CRW will enlist the efforts of another senior design class from the University of Alabama in Huntsville. The additional senior design team will be responsible for designing, testing and verifying the custom software, and also testing the structural capabilities of the components. The team will be held to a schedule similar to the NASA Student Launch but time compressed to allow CRW to receive and review their designs. A preliminary design review along with a critical design review will be required to explain their design and verification to CRW. To view the exact requirements presented to the senior design class refer to Appendix F: Landing Hazard Detection System (LHDS).

#### 4.3.1. **LHDS Subsystems**

For more information on LHDS subsystems refer to Appendix F: Landing Hazard Detection System (LHDS).

## 4.4. Selection, Design, and Verification of Aerodynamic Coefficients

The design of the Aerodynamic Coefficients Payload for the Nanolaunch 1200 contract was based on accomplishing the functional requirement of using flight recorded accelerometer, gyroscope, and pressure data to extrapolate the aerodynamic coefficients. To calculate the pitching moment of the rocket when perturbed using compressed gas, the acceleration during the perturbation will be monitored at a precise level. This perturbation method of measuring the pitching moment is simulated in Figure 4-8 by demonstrating how the process would be done in a wind tunnel test for a rocket with canards. In the figure, the restoring moment was measured mechanically using a spring and a damper system. The canards in the figure would be analogous to the gas perturbation that will be implemented in the flight of *Prometheus*.

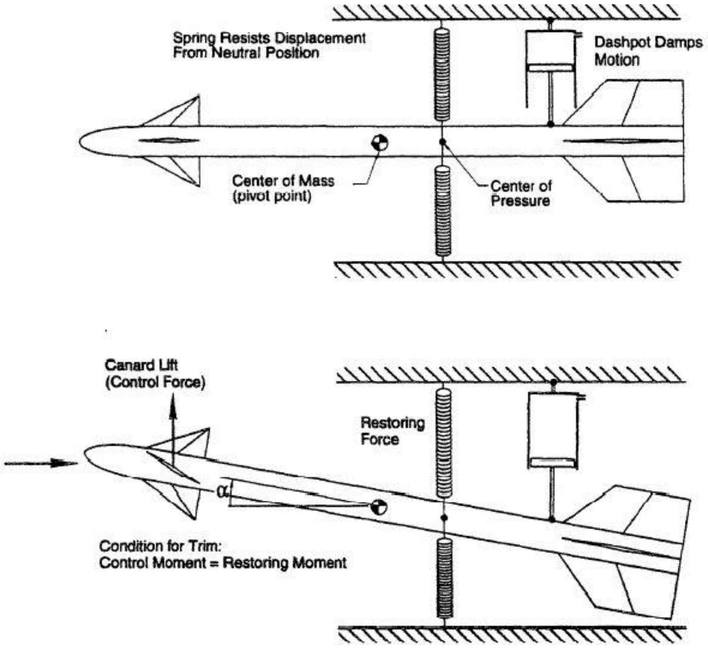


Figure 4-8: Simulated Wind Tunnel Pitching/Restoring Moment

To monitor this, two accelerometers will be used in conjunction with each other, one at a 2 G setting and the other at a 200 G level. The lower g accelerometer will provide higher precision with less uncertainty, while the higher g accelerometer will provide full definition of the acceleration during flight. Two gyroscopes one mounted at the CG and one mounted at the FWD end of the rocket will serve to fulfill the main functional requirement of extrapolating the angle of attack of the rocket during flight, also during perturbance. The gyroscopes provide instantaneous angle measurements of all three axes which will be crucial in calculating the angle of attack and thus the pitching moment. Figure 4-9 demonstrates the relationship between the gyroscope angles Yaw, Pitch, and Roll and the angle of attack.

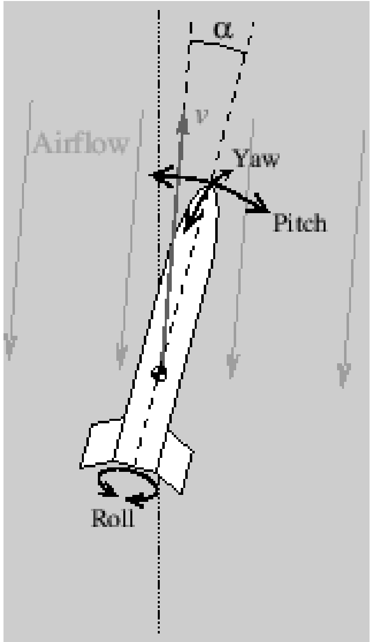


Figure 4-9: Angle of Attack

The pressure sensors provide means to extrapolate both the base drag and other general aerodynamic coefficients from the flight data. The two main locations that were required to retrieve these coefficients were at the base and the nose of the rocket. A Pitot-static probe was chosen to capture the pressure differential at the nose of the rocket. To accommodate for variations and inconsistencies with using a single differential pressure sensor, two individual absolute pressure sensors will be used to measure the pressure difference in the pressure at the nose in comparison with the pressure at a location adjacently on the side of the nose. A Pitot-static probe example was shown in Figure 4-10 below. Pt represents the pressure at the nose, and Ps would represent the pressure at the side of the nose cone. An in-house Pitot-static probe will be made in order to fit the nose cone.

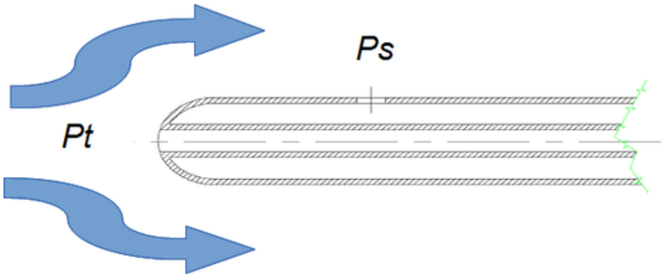


Figure 4-10: Pitot-static Probe

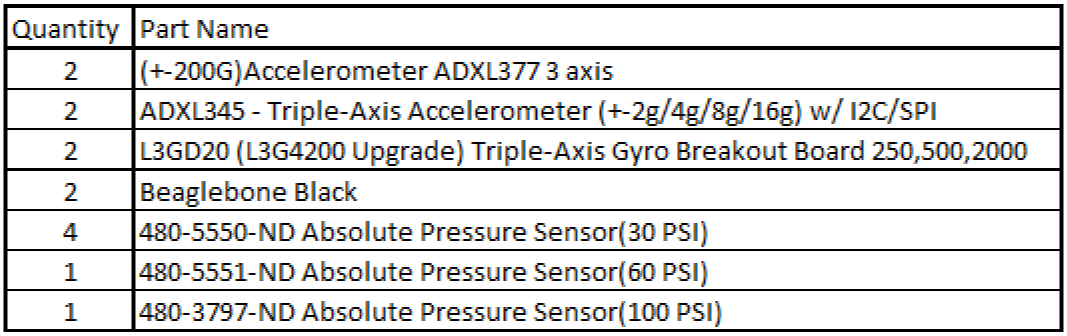
The base drag will be calculated using an accumulation of several pressure measurements along the base of the rocket.

### 4.4.1.**Aerodynamic Coefficients Payload Subsystems**

The Nanolaunch 1200 payload subsystems were made up of 6 main components that were all crucial to meeting the payload objectives. The subsystems/components are as follows: Beaglebone

Black, ADXL345, ADXL377, L3GD20, absolute pressure sensors, and remote data transmission system. These components/subsystems all play a vital role in extrapolating the aerodynamic coefficients and all of the parts are indicated in Table 4-2. The Beaglebone black was chosen as the main processor because it was at affordable price of $45.00 and had a fast processor of 1GHz. The Beaglebone's fast processor speed and the fact that it operates directly in C/C++ through its Linux operating system ensures that the required data sample rate of 200Hz during the transonic region will be achieved. The Beaglebone also provides 92 pins to allow for ease of access.

**Table 4-2: Sensors**



| Quantity | Part Name |
|---|---|
| 2 | (+-200G)Accelerometer ADXL377 3 axis |
| 2 | ADXL345 - Triple-Axis Accelerometer (+-2g/4g/8g/16g) w/ I2C/SPI |
| 2 | L3GD20 (L3G4200 Upgrade) Triple-Axis Gyro Breakout Board 250,500,2000 |
| 2 | Beaglebone Black |
| 4 | 480-5550-ND Absolute Pressure Sensor(30 PSI) |
| 1 | 480-5551-ND Absolute Pressure Sensor(60 PSI) |
| 1 | 480-3797-ND Absolute Pressure Sensor(100 PSI) |

The ADXL345 Triple-Axis Accelerometer was chosen because of its ability to provide several different ranges of G loading: 2G, 4G, 8G, and 16G. The ADXL345 was necessary because in order for the on-board compressed gas perturbance to be detected by the accelerometer for the use in post flight processing, the accelerometer must be able to detect slight acceleration changes in the rocket. This function was one that the ADXL345 provides due to its low 2G setting providing a low uncertainty.

The rocket also needed a high G accelerometer in order to be able to fully define the acceleration throughout the flight, since the G loading expected from analytical trajectory calculations was 42 which exceed the limit of most accelerometers. The ADXL377 3 axis accelerometer was chosen for its ability to measure high G loadings up to 200G. This accelerometer would provide a means to fully define the acceleration of the flight by using both accelerometers in conjunction with each other.

The L3GD20 Triple-Access Gyro was chosen because in order to fulfill the requirements of calculating the angle of attack of the rocket, as well as being able to fully define the position of the rocket. The triple access gyro allows the angles of the rocket to be measured, and with two gyros being at the CG of the rocket and the other upward towards the nose, the exact orientation of the rocket will be used to extrapolate the angle of attack of the rocket.

To accommodate for calculating the aerodynamic coefficients, the pressure at the nose of the rocket was required. To fulfill this requirement, a Pitot-static probe will be used where two sensors will be individually connected for each pressure measurement, rather than using one Pitot-static pressure sensor. This was decided because if only one pressure sensor measures the difference between the two, sometimes a huge error can be induced into the measurement. To prevent this, two individual absolute pressure sensors will be used to measure each port of the Pitot-static probe, individually. The pressure sensors chosen for this measurement was a 480-5551-ND and a 480-3797-ND Absolute Pressure Sensors, 60 PSI and a 100 PSI respectively. The 100 PSI sensor was chosen for the tip of the nose because it sees the highest pressure, and the 60 PSI sensor was chosen for the side of the nose cone because it sees a lower pressure. The reason the high pressure sensors were chosen was due to the rocket traveling at supersonic speeds.

The last measurement needed to fulfill the Nanolaunch 1200 requirements was to be able to determine the base drag of the rocket. The base drag of the rocket can be determined by calculating the pressure at the base of the rocket in several different locations to provide a better pressure estimate. 4 pressure sensors will be used to measure this pressure change. The 30 PSI 480-5550-ND Absolute Pressure Sensor was chosen for this pressure measurement because it was from the same manufacturer as the other pressure sensors used. This would provide a similar interface to the Beaglebone and the code will be able to be almost identical. A smaller magnitude sensor was chosen because the pressure at the base of the rocket sees a decrease in pressure from the nose. A 30 PSI sensor was chosen to fulfill this requirement.

All telemetry capabilities will be handled by an embedded wireless radio frequency (RF) module that will be used to send all necessary data to the ground station in real-time. The module that has been selected is an XBee-PRO XSC S3B; Digi Part Number XBP9B-XSCT-001. This 900 MHz spread spectrum RF module has a selectable channel mask for interference immunity, has a RF data rate of up to 20 Kbps, and has an outdoor/LoS range of up to 9 miles with the included Omni-directional dipole antenna. This module has a transmit power of 250 mW and a supply voltage requirement of 3.0 to 3.6 VDC. The XBee is a universal asynchronous receiver/transmitter (UART). It functions as a wireless serial port: whatever is pushed to the data radio module gets broadcast through the omni-directional antenna and picked up by the ground station.

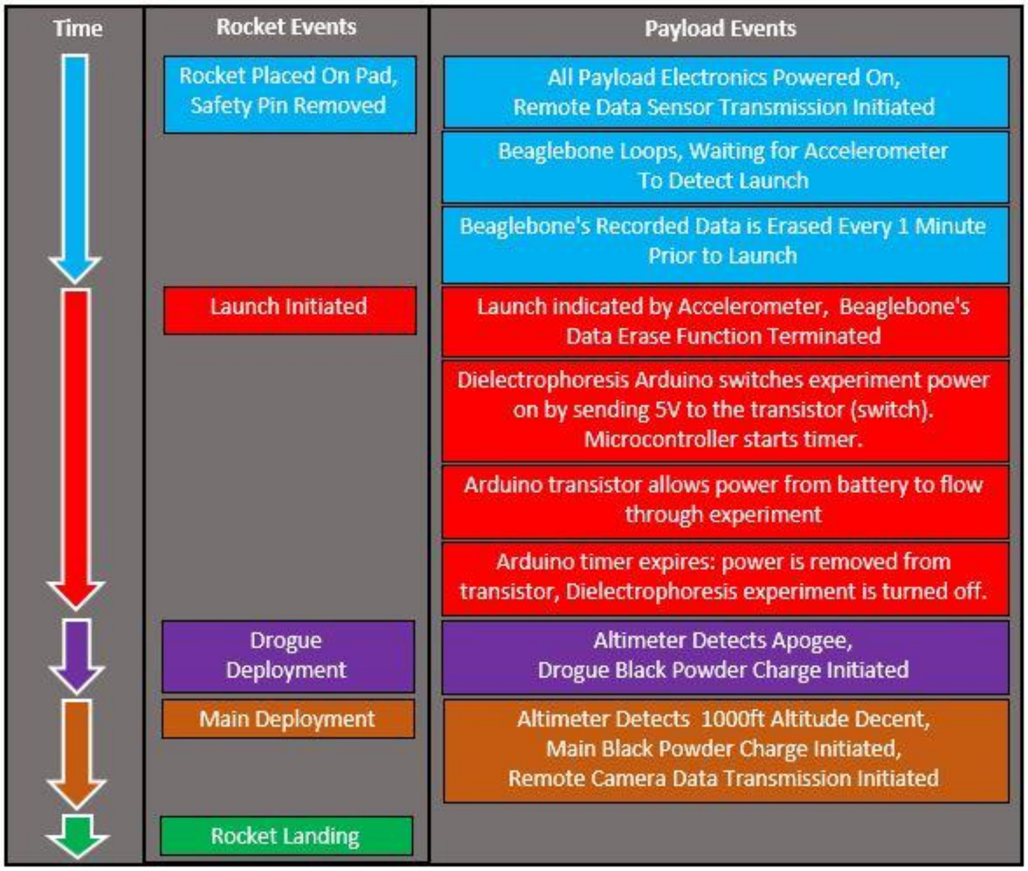
The ground station used to receive the RF data is a Sparkfun XBee Explorer USB which connects a second of the above XBee transmitters to the USB port on a laptop. A custom MATLab program will interpret and display the received serial data packet stream.

The wireless real-time GPS tracking uses a custom-built GPS module connected directly to the wireless transmitter described above. The GPS module is built around an Antenova M10382-Al UB GPS sensor mounted on a circuit board. A prototype has been field tested and flown successfully on multiple occasions, and the design is at version two. The prototype GPS module has an approximate battery life in excess of 24 hours, has a power requirement of 3V and 1500 mA, and runs on primary batteries (not disposables).

The GPS transmissions are expected to drop out when the GPS loses lock at speed during maximum velocities. The prototype module has been observed to reliably regain GPS lock and resume transmissions upon returning to lower velocities. At the velocities expected during launch, this temporary loss of tracking data is expected and unavoidable with this setup. Loads generated by the acceleration of the rocket are cause for concern with the soldering/structural and mounting of the electrical components. The RF and GPS modules will be mounted vertically in the nosecone along with the forward sensors. In the event of RF module or ground station failure, data will still be recovered from onboard memory after recovery. The rocket will be tracked and recovered visually even if live GPS data is not successfully received.

## 4.5. System and Subsystem Performance and Verification Metrics

The performance and verification metrics for the system and subsystems were modeled after the NASA's SLI competition requirements, the Nanolaunch 1200 customer requirements, and the internal Charger Rocket Works in-house requirements. These performance and verification metrics can be identified in the system requirements/verification plan found in Section 4.6. An overview of the main chronological events of the launch is shown in Figure 4-11.



| Time | Rocket Events | Payload Events |
|---|---|---|
| | Rocket Placed On Pad, Safety Pin Removed | All Payload Electronics Powered On, Remote Data Sensor Transmission Initiated |
| | | Beaglebone Loops, Waiting for Accelerometer To Detect Launch |
| | | Beaglebone's Recorded Data is Erased Every 1 Minute Prior to Launch |
| | Launch Initiated | Launch indicated by Accelerometer, Beaglebone's Data Erase Function Terminated |
| | | Dielectrophoresis Arduino switches experiment power on by sending 5V to the transistor (switch). Microcontroller starts timer. |
| | | Arduino transistor allows power from battery to flow through experiment |
| | | Arduino timer expires: power is removed from transistor, Dielectrophoresis experiment is turned off. |
| | Drogue Deployment | Altimeter Detects Apogee, Drogue Black Powder Charge Initiated |
| | Main Deployment | Altimeter Detects 1000ft Altitude Decent, Main Black Powder Charge Initiated, Remote Camera Data Transmission Initiated |
| | Rocket Landing | |

**Figure 4-11: Chronologic Overview**

The chronologic overview provides a general flow chart correlating the main rocket events to the payload events. The data processed by the Beaglebone will be stored on the on-board SD card. To avoid massive build-up of useless data from the rocket sitting on the pad and sampling at 200Hz while waiting on launch, the Beaglebone will be programmed with a loop that erases the data written to the SD card every 1 minute. When the accelerometer detects a launch, the loop in the Beaglebone code will terminate keeping all data after the last erase and will continue to record the data until the rocket's safety pin is inserted after landing.

## 4.6. System Requirements/Verification Plan

The following table presents each of the general requirements for the rocket and the individual requirement for each of the payloads. It also discusses the how each of the requirement is expected to work and risks associated with it. Finally it sets the criteria as for the requirements were successfully met.

**Table 4-3: Payload Requirement Verification**

| Payload Requirement | Design Capability | Risk | Metric/Verification |
|---|---|---|---|
| Administer High Voltage Dielectric Test | Provide same voltage as previous experiments | Electric shock or dielectric failure | Post flight video inspection and buzzer sounding to indicate voltage is on. |
| Microgravity | Experience a second of low g to run experiment | Not enough time to see clear results | Post-flight video inspection |
| Coatings and Paint | Two different coatings/ paints for analysis | Rocket appearance could change depending on the paint's reaction to the heat. | Visual inspection of surface roughness changes, most heat resistant, and durability of coating |
| Preflight Post flight surface analysis | Optical microscope analysis of the surface before and after flight | Deterioration of initial paint/coating due to high heat | Pre-flight vs Post-flight inspection/analysis comparison at microscopic level |
| Hazard detection camera | Hang a camera below the rocket on descent | Camera tangles up with the shock cord or parachute, and/or blocks the camera view | Camera deploys safely and analyzes the landing zone |
| Live Data Feed | Recording data if the ground below is clear of hazards | Camera results could be inconclusive due to swaying motion of parachute | Ground station receives live conclusive evidence of landing hazards |
| Recoverable and Reusable | Capable of being launched again on the same day without repairs or modifications | All or some of the systems/subsystems destroyed due to recovery failure | All payload components recovered, and in working condition |

## 4.7. Preliminary Integration Plan

The plan to integrate the dielectrophoresis and Aerodynamic Coefficients payloads into the rocket body structure will be accommodated by a sled housing. The sled housing will be inserted into the rocket through one of the multi-stage carbon fiber body tubes indicated in Section 0. The connections and interface to the rocket body tube will be enclosed in a payload sled as shown in Figure 4-12.

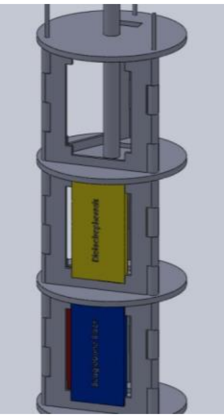


Figure 4-12: Payload Bay

Each payload has the ability to be segregated into its own container using the sled, which would be extremely useful for separating the high voltage dielectrophoresis payload from the rest of the electronics. The sled design provides a robust and compact design that will be ideal for interfacing with the multiple payloads required for the mission. To mount the sled to the rocket, the center rod will be mounted to a bulkhead at the top of the payload.

To provide easy install and perform maintenance to the payload, the sled was equipped with three removable all-thread rods used at hinge pins. By removing one of the all-thread rods from the payload sled all the electronics will be able to be easily accessed. Figure 4-13 below illustrates the easily accessible operation of the sled. The figure also denotes the preliminary example locations of the electronics. For example, the Beaglebone Black will be mounted on the blue panel below, the accelerometer and gyroscopes will be mounted on the red panel, and the power supply will be mounted on the green panel. Additional panels/levels will be added if more compartments are required.

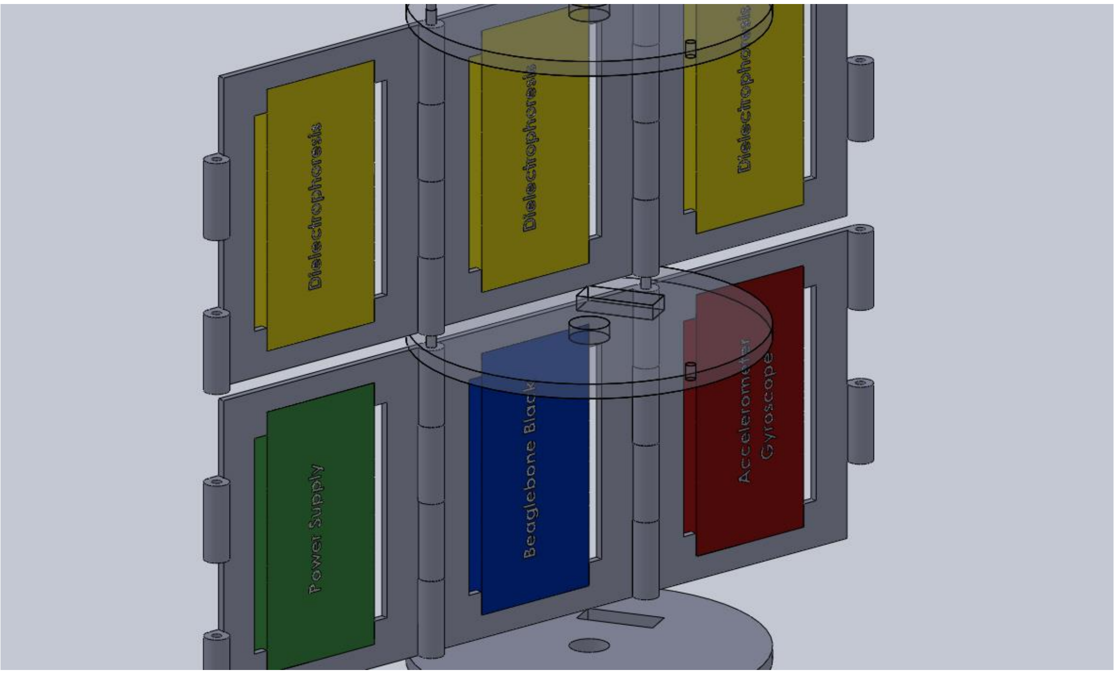


Figure 4-13: Payload Bay Unfolded

## 4.8. Precision and Repeatability

The experimental result is only as precise as the least precise data used in the calculation of that result. The sensors being used are well documented with known precision. It is challenging to say how precise this result will be as there are multiple sensors that could be used in the calculation of the aerodynamic coefficients.

To ensure that the results of the experiment were reliable, commercial sensors were purchased. These sensors have been tested and verified to be accurate for a given range. The sensors were well documented and enough sensors were purchased to perform the experiment multiple times in case of vehicle loss.

## 4.9. Electrical Schematics

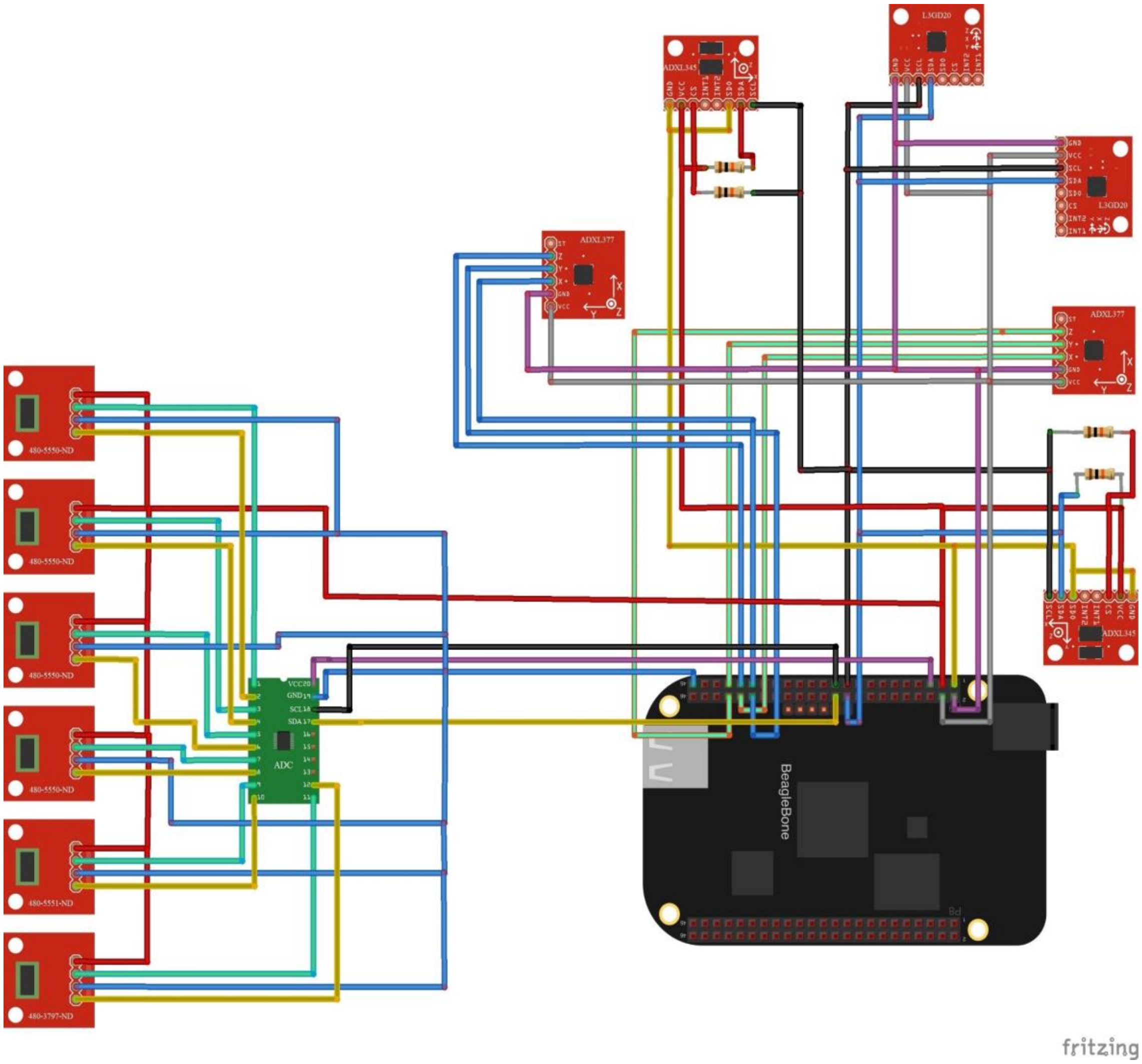


Figure 4-14: Electrical Schematic for Nanolaunch 1200 Payload

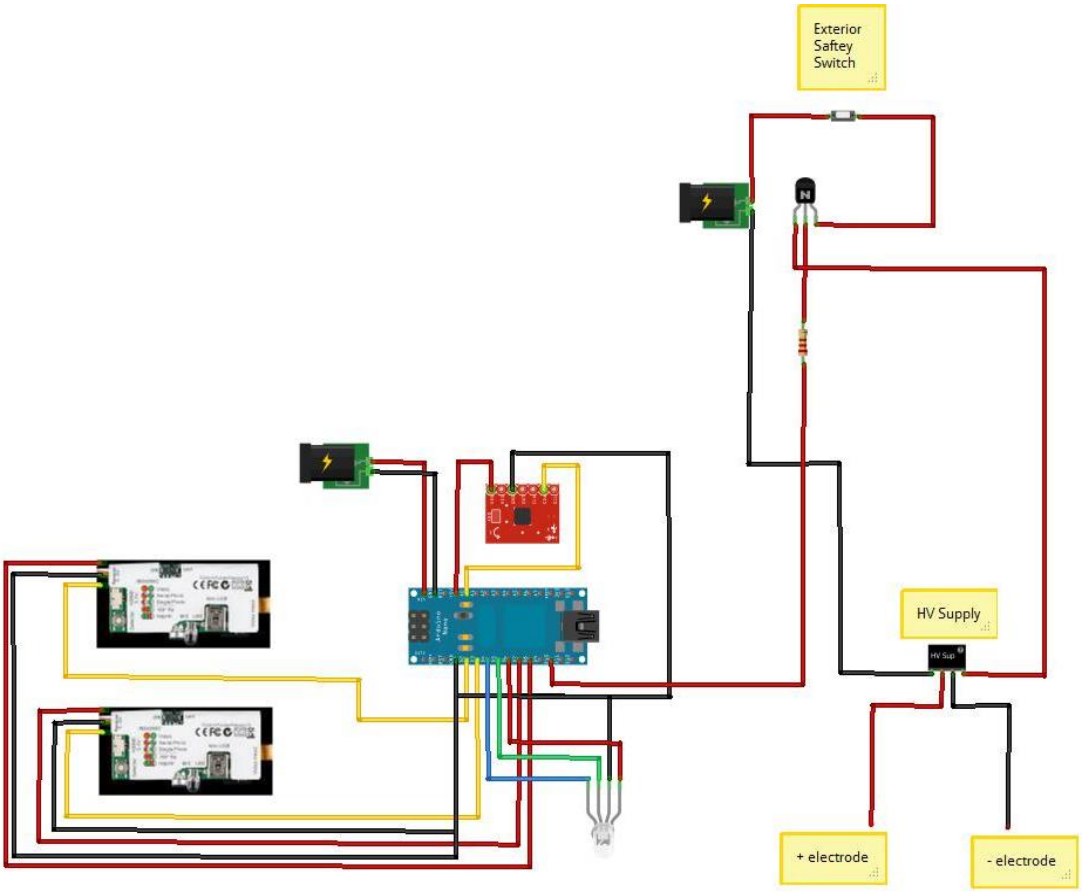


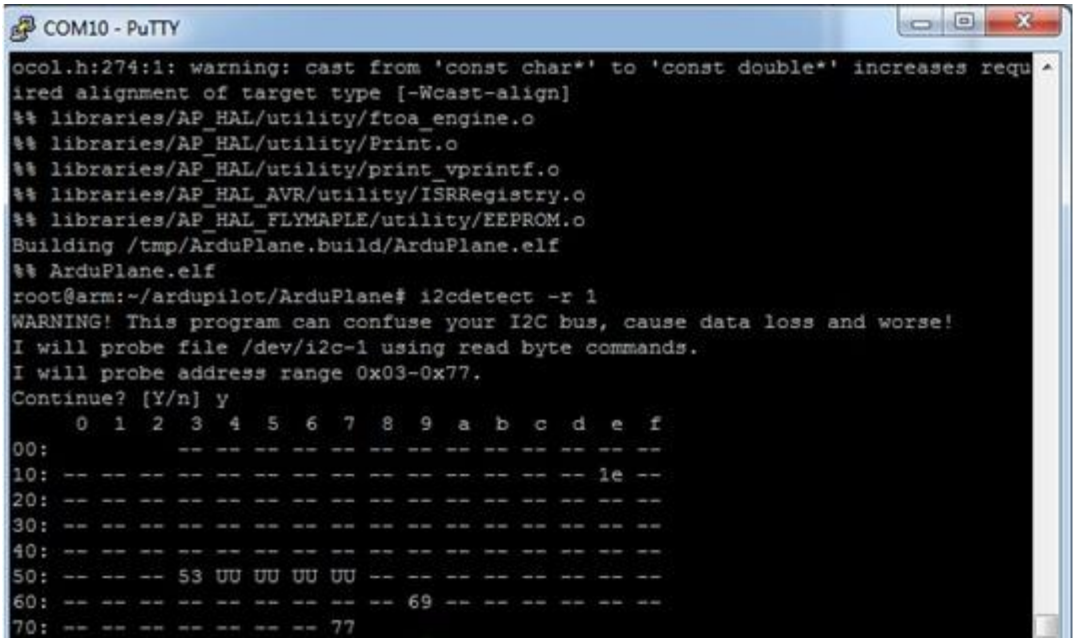
Figure 4-15: Electrical Schematic for Dielectrophoresis Experiment

## 4.10. Interfacing Payload Components

The key components of the payload outlined below interface together with the microprocessors to achieve the desired results for the experiment. The components are as follows: pitching moment trigger interface, accelerometer and gyroscope communication, pressure sensor communication, and the remote data transmission system.

The pitching moment trigger system will send a voltage through a GPIO port on the Beaglebone to a voltage actuated solenoid that will trigger the release of the compressed gas. The event will be triggered when the acceleration of the rocket reaches an optimum value. The mechanism and triggering of the event has not been finalized.

The interface between the digital accelerometers and gyroscopes to the Beaglebone will be the I2C port. The first I2C bus on the Beaglebone will have the 2 ADXL377 accelerometers and the 2 L3GD20 gyroscopes all communicating via the example addresses shown in Figure 4-16 below.



```
ocol.h:274:1: warning: cast from 'const char*' to 'const double*' increases requ
ired alignment of target type [-Wcast-align]
%% libraries/AP_HAL/utility/ftoa_engine.o
%% libraries/AP_HAL/utility/Print.o
%% libraries/AP_HAL/utility/print_vprintf.o
%% libraries/AP_HAL_AVR/utility/ISRRegistry.o
%% libraries/AP_HAL_FLYMAPLE/utility/EEPROM.o
Building /tmp/ArduPlane.build/ArduPlane.elf
%% ArduPlane.elf
root@arm:~/ardupilot/ArduPlane# i2cdetect -r 1
WARNING! This program can confuse your I2C bus, cause data loss and worse!
I will probe file /dev/i2c-1 using read byte commands.
I will probe address range 0x03-0x77.
Continue? [Y/n] y
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- 1e --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- 53 UU UU UU UU -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- 69 -- -- -- -- -- --
70: -- -- -- -- -- -- -- 77
```

Figure 4-16: PuTTY Connection to Beaglebone

The “- -“represents available I2C addresses that could be accessed through the same port limited by the capacitance. The “UU” represents ports that are being used by the Beaglebone. The example above currently has 4 devices connected through the I2C1 bus on the Beaglebone. This will be essentially the same setup that the 2 accelerometers and the 2 gyroscopes will have since it also has 4 devices similar to the I2C1 connection above. The Beaglebone black will support up to three I2C busses I2C1, I2C2, and I2C3 where the last bus would have to be reconfigured from being used for capes. Currently, the ADXL345 has been tested and the I2C method works as expected.

The NBP series pressure sensors interface to the Beaglebone will also be accessed through an Analog-to-Digital Converter (ADC) and afterwards traveling through the I2C2 bus. Since the pressure sensors are analog components and the Beaglebone only has 7 analog input ports, the NBP pressure sensor’s output will have to travel through an ADC to be converted to a digital signal that the I2C bus will be able to handle.

The live remote data transmission system will interface with the Beaglebone through either the SPI or a series of GPIO ports. Because the remote data transmission system design is not finalized, it is uncertain to exactly how the system will be connected.

## 4.11. Payload Concepts Features and Definition

*Prometheus*’s aerodynamic coefficients for the Nanolaunch 1200 payload is original and unique in that it will measure an array of 12 sensors to measure acceleration, yaw, pitch, roll, nose pressure, base pressure. It will provide data within the transonic region as well as discharge a compressed gas with a known exit force to be able to be able to extrapolate a pitching moment from the recorded data. The significance of extrapolating the aerodynamic coefficients is to provide data to simulate flight data for the Nanolaunch 1200 launch because without experimental testing several coefficient would be just a “best guess” and almost impossible to calculate without actual data.

The Supersonic Flight Vehicle Paint/Coatings Payload is original and unique in that it will provide useful data to further research in rocket coatings for better heat resistance and to further research in expanding the life of reusable rockets. The payload will also incorporate a unique heat tape that will provide temperature data on the max temperature seen by the rocket. This data would be extremely useful for verification of the rocket's thermal analysis.

The dielectrophoresis payload was unique and original in that was based on Dr. James Blackmon's research on the collection of liquid propellants in zero gravity with electric fields. The payload utilizes extremely high voltage to provide for improvement of fuel collection, preventing heat transfer to the fuel from the walls, and to reduce the amount of boil-off of cryogenic fuels for long missions. The payload is significant in that the research also could reduce the need for bulky insulation by using the gas already in the tank. The payload requires low power to generate the high voltage electric field.

The Hazard Detection Camera Payload's originality and creativity is that it will be designed by computer programmers or electrical engineers. A unique feature that the LHDS payload offers is that it will deploy with the main parachute rather than deploying at apogee, providing useful video processing for the entire decent time. If the LHDS was deployed at apogee, then the camera would not provide any useful meaningful data for a few seconds. The significance in the payload is to provide NASA with example code and video processing techniques to provide the SLS Rockets with the ability to detect whether or not it is safe to land for far away mission such as Mars.

Given the number of payloads being flown on the rocket and meeting a substantial number of requirements from both NASA (SLI) and for the Nanolaunch 1200 requirements, the payload's challenge level will be challenging to say the least. Charger Rocket Works' "suitable" level of challenge will be tested to its limits with the payloads for *Prometheus*. The payload will incorporate programming the Beaglebone microprocessor in a C/C++ environment directly accessed through a Linux based operating system, Ubuntu, to provide for ease of access to the Beaglebone's Linux based operating system. The Beaglebone's "sketches" will be coded in the integrated development environment Eclipse, where the code will be written in C/C++. The reason C/C++ was chosen for the language was because in order to be able to satisfy a 200Hz sample rate for extrapolating the aerodynamic coefficients, delays from an external cross compiling between languages were not feasible, thus C/C++ was chosen.

The Beaglebone programming will provide an unparalleled higher difficulty in comparison to an Arduino based payload system in that the Beaglebone will not have any example codes provided by the supplier/vendor. The Arduino on the other hand has thousands of example code existing online in every shape form and fashion. The Beaglebone will be a steep learning curve, but in the end the Charger Rocket Works team will become more practical and experienced engineers ready to serve the world, the nation, and employers such as NASA in support of the SLS program.

The Hazard Detection Camera System will be challenging to provide meaningful live data through programming an Arduino or Beaglebone to instantaneously process the video feed. The programming for the HDCS, if done correctly, will require heavy programming to be able to analyze hazards such as shape patterns, color detection, and kinetic energy consideration.

## 4.12. Science Value

The science value of the payloads in the *Prometheus* rocket varies in complexity from administering high voltage of upward of 20,000 volts to processing live video feed to detect a safe landing zone. The payloads involve heavy programming in C/C++ and provide a huge educational foundation for future endeavors as an engineer. The payload also touches on the application and analysis of paint/heat sensor tape to improve heat transfer traveling through the external body structure to the internal components.

### 4.12.1. **Effects of Supersonic Flight on Paint and Coatings**

The importance of finding durable paints and coatings for supersonic flight is multifold. Weight is often a major factor in space flight and minimizing weight by finding lighter coatings that can withstand the rigors of supersonic flight is important. Cost is another driving factor and should be minimized. By testing different paints with subscale rockets that still travel supersonic, reliable and accurate data can be gathered on a variety of paints and coatings cheaply. The importance of testing the reliability of the thermo changing tape lies in the cost. Typically to gain accurate temperature data at various location on the craft would require sophisticated temperature sensors and data acquisition. If the tape can be found to withstand the stresses of supersonic flight a cheap alternative will have been found.

### 4.12.2. **Landing Hazard Detection System**

The Landing Hazard Detection System is designed to detect landing hazards by a completely onboard system. The importance of this is the onboard system. A system that is capable of autonomously detecting landing hazards could redirect itself to a safe landing zone. Such a system could be used for future landing attempts where having data analyzed by an outside source couldn’t work. A system such as this would be perfect for a remote landing on other planets or distant bodies where the communication delay doesn’t allow human interaction in real time and all decisions must be made by onboard controllers.

### 4.12.3. **Dielectrophoresis:**

The purpose of the dielectrophoresis experiment is to simulate the collection of liquid propellant within fuel tanks in microgravity applications. Dielectrophoresis is the use of electric fields to move fluids. The power required to establish a high voltage electric field is low, and it can be triggered at any time. Various fluids such as corn oil, silicone oil, and peanut oil will be evaluated as the fluid to be flown in the experiment because their dielectric constants are similar to those of several liquid propellants. The use of dielectrophoresis to collect fuels for engine restart would be an excellent alternative to current systems involving inertial rockets. The same dielectrophoresis system could also aid in preventing heat transfer to the fuel from the walls of the container, reducing boil-off of cryogenic fuels on long missions such as one to Mars.

### 4.12.4. **Nanolaunch:**

The Nanolaunch experiment was designed to act as an inexpensive replacement for subscale wind tunnel tests to determine the pitching moment, total drag coefficient, and base pressure. The aerodynamic coefficients will be backed out from accelerometer, gyroscopic, and pressure data collected at the center of gravity and the nose of the vehicle. The Nanolaunch 1200 system is designed to provide a low-cost alternative for launching small experimental payloads approximately 2 to 20 pounds into low earth orbit. Providing a reliable method for determining these coefficients would support the Nanolaunch 1200 system and benefit future research possibilities requiring low gravity conditions.

The success criteria for each payload is outlined in Table 4-4. The table identifies the major flight events that would dictate success or failure of the payload objectives.

**Table 4-4: Payloads' Success Criteria**

| System | Failure Criteria | Success Criteria |
|---|---|---|
| *Prometheus* Rocket | Loss of vehicle and payloads | Recovery of rocket, payloads, and experimental data |
| Nanolaunch Experiment | Loss of data, either in part or in total, that would prevent extrapolating the aerodynamic coefficients | Recovery of data and extrapolation of aerodynamic coefficients |
| Supersonic Paints and Coatings | Inability to reach supersonic speeds. | Supersonic Flight, and measureable differences between control and experiment samples. |
| Dielectrophoresis | Inability to create an electromagnetic field to induce dielectrophoretic effects | Noticeable collection of dielectric fluid around the electrodes |
| LHDS | Inability to deploy, recognize potential landing hazards, or transmit to ground station | Full deployment and data transmission of image analysis |

The flow chart in Figure 4-17 describes the basic logic used to launch, initiate data acquisition system, perturb and deploy recovery system. The approach used to formulate this procedure was the Scientific method where each component was observed, measured, and experimented, and the formulation, testing, and modification of hypotheses is conducted when needed.

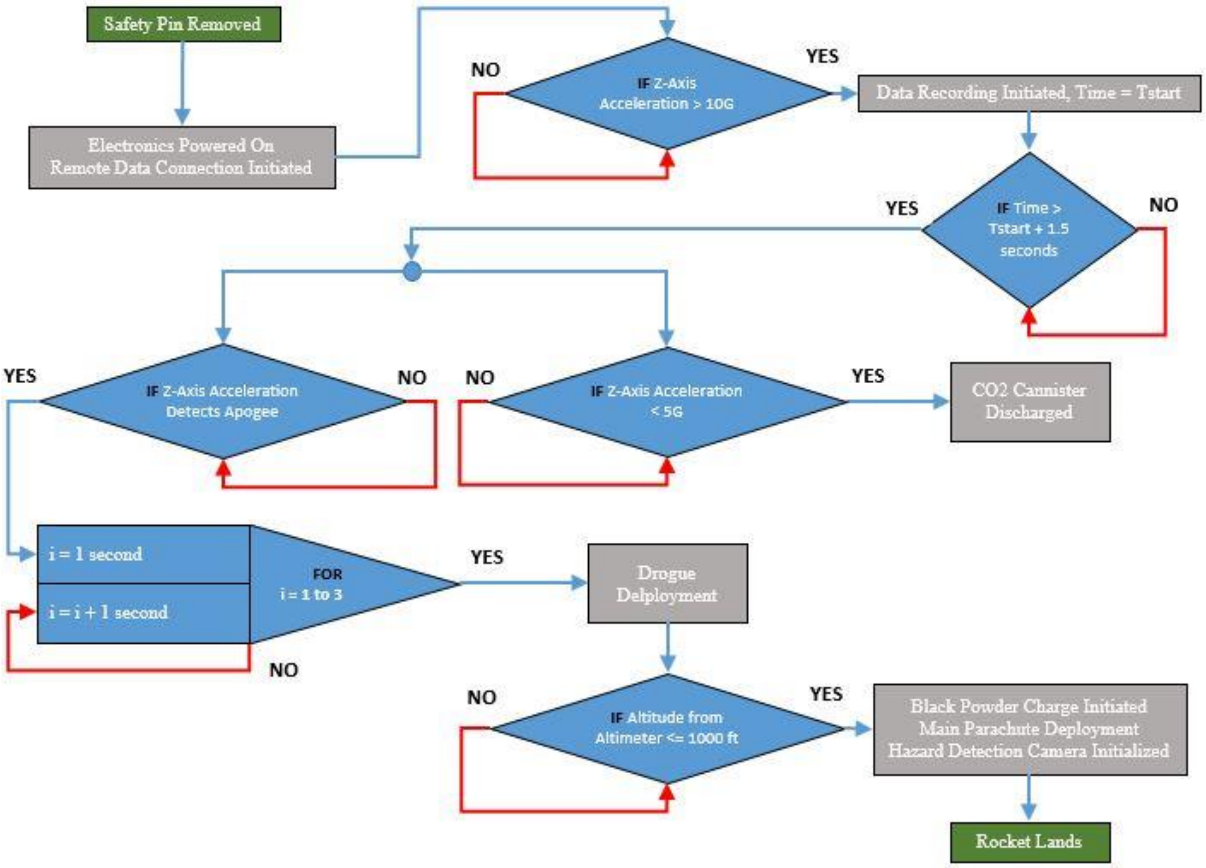


**Figure 4-17: Code Flowchart**

Many steps are being made to ensure that the experiment will be ready for launch and that it is capable of pulling accurate and reliable data. The dielectrophoresis payload, along with the sensors and paint coating experiment, are having tests ran in order to give the team comparable ground data for the data taken during flight. The Analysis team is also running programs in order to simulate the flight data. This will give the team more data to compare the flight information to. In order to get the experiment prepared for launch, first all of the payloads must be placed into the rocket around the parachutes. The rocket's external structure must then be reassembled and examined to make sure it was put together correctly.

The Nanolaunch 1200 experiment's payload accelerometer data will be expected to match the G loading profile shown in Figure 4-18 for the 1.53 seconds shown. The expected data will have significant G changes at the following events during flight: motor burnout, gas perturbation, apogee, drogue parachute deployment, and the main parachute deployment. The gas perturbation was not shown in the OpenRocket image because the gas discharge mechanism and quantity of gas being expelled has not been finalized.

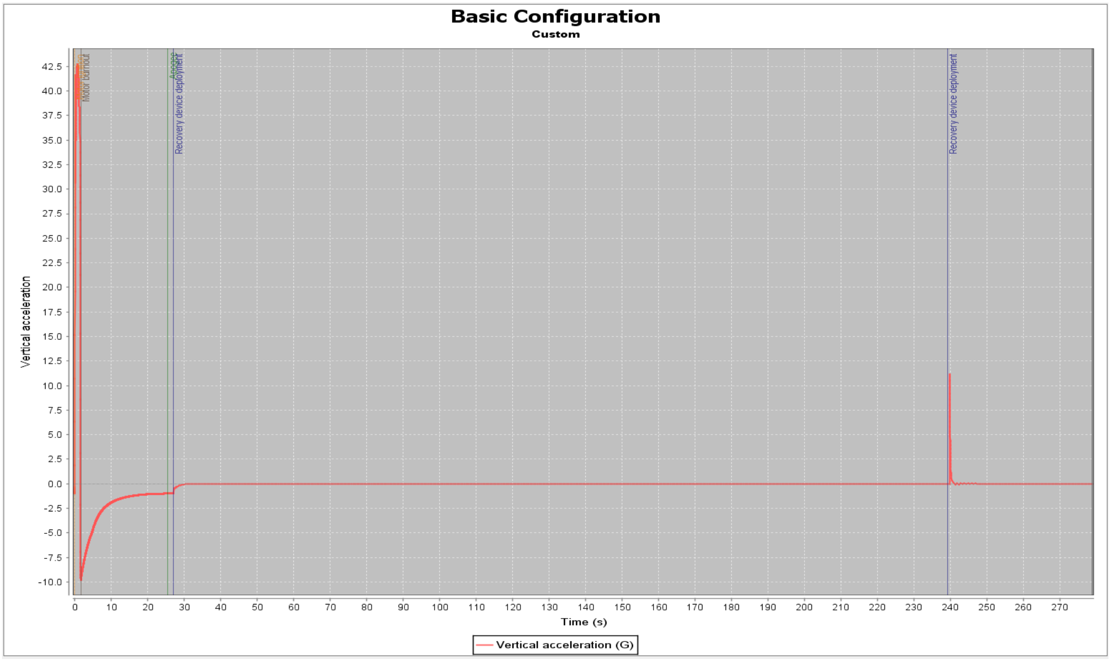


**Figure 4-18: OpenRocket Acceleration Vs Time**

The expected gyroscope data for the Yaw, Pitch, and Roll angles cannot be calculated or simulated which was why NASA had such a high push to make the angle measurements a requirement. This would then be used to provide NASA's Nanolaunch 1200 rocket with "expected data" for the gyroscope data. The expected absolute pressure readings at the rocket's nose using a Pitot static probe was calculated to be 82 psi at the tip and 56 psi on the side based on the Mach number using a compressible flow calculator. The sensors were purchased to be sure to cover the expected range of pressure with sensors of 100 and 60 psi, respectively. The base drag absolute pressure was estimated to be no greater than 25 psi, so a 30 psi sensor was chosen.

The accuracy and error analysis of all the measurements recorded will be calculated using the Kline-McClintock propagated uncertainty equation below

$$\delta R = \left[\left(\frac{\delta R}{\delta x_1}\delta x_1\right)^2 + \left(\frac{\delta R}{\delta x_2}\delta x_2\right)^2 + \cdots + \left(\frac{\delta R}{\delta x_N}\delta x_N\right)^2\right]^{\frac{1}{2}}$$

The uncertainty will include the resolution of the sensors, the resolution of the microprocessor, uncertainty of the calibration, and the precision error due to the sensor. The uncertainty will be propagated into the uncertainty of the aerodynamic coefficients when applicable. Example: If two "uncertain" measurements were multiplied together, then the resulting uncertainty would then be propagated with error from both uncertain measurements. The predicted uncertainty of the accelerometer that will be set at the 2G level will produce an uncertainty of +-0.1 G. The high G accelerometer was predicted to have an uncertainty of +- 10G. (Note: The purpose of the high G accelerometer was to provide data to fully define the acceleration throughout the flight. If the uncertainty of the 200G accelerometer was too high to extrapolate the aerodynamic coefficients, the 16G accelerometer from the dielectrophoresis experiment can be used with a predicted uncertainty of only +- 0.8G. )

## 4.13. Safety and Environment (Payload)

### 4.13.1. Safety Officer

The CRW has identified Brian Roy as the Safety Officer and Test Engineer, who will be responsible for keeping an updated account of all SOPs, MSDSs, and all state and federal regulations governing high powered rocketry. He will also be responsible for scheduling all ground tests to take place before any test launches and reviewing the procedures for those tests and launches with all CRW members who will be present.

### 4.13.2. Dielectrophoresis Risk and Failure analysis

There are two main categories of risk involved in this system: risk to the flight of the rocket, and risk of shock while handling the rocket. The risk to the flight of the rocket is the potential for electromagnetic interference to prevent proper operation of the recovery electronics. The risk of shock stems from the payload being active unexpectedly when being handled.

Risk to the flight of the rocket will be mitigated by conducting Electromagnetic interference testing in order to:

- Attempt to induce and subsequently understand failure in other components in a controlled scenario
- Measure effectiveness of mitigation techniques, primarily a faraday cage but including shielded coaxial wires

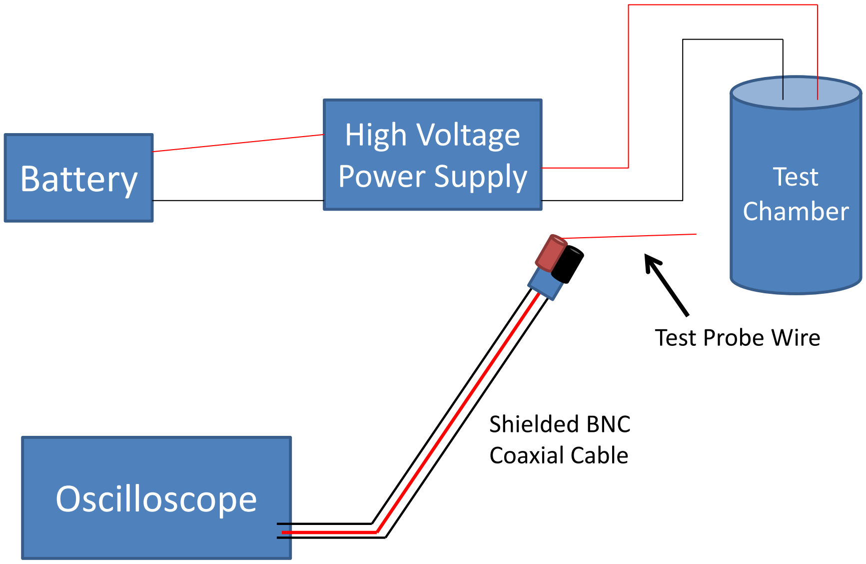


Figure 4-19: Block Diagram of Proposed EMI Test

A testing plan which includes a goal and basic high level procedure for a number of tests is included in Appendix H. The first such test has the goal of determining which part of the system presents the most electrically induced noise. EMI Test 1's block diagram is presented in Figure 4-19 below.

The open circuit signal induced on the test probe wire is measured by the oscilloscope. Measurements are taken at various locations to determine the location where the greatest signal is induced. This information is used in other tests to attempt to provoke controlled failure in other electrical systems. Similar methodology is used to measure the effectiveness of a faraday cage and wire shielding mechanisms. After this campaign of testing we should be able to quantify how much power it takes to cause a failure and quantify how much power is being developed in the final design to quote a factor of safety.

Due to the relative imprecision of these testing methods no factor of safety under 10 will be deemed acceptable without further analysis.

The risk of shock to an operator who is interacting with the experiment is greatest when they do not know that the experiment is on. We are using two separate methods to prevent this.

- A buzzer in line with the power that drives the HV supply
- A transistor acting as a switch which requires a signal from the microcontroller to maintain power to the HV supply
- Mechanical safety switch/remove before flight pin to physically disconnect the power circuit.

For auditory indication that the HV supply is on, a buzzer will be placed along the same line from the battery for the HV supply. This way if the supply is receiving power so will the buzzer, and the noise the buzzer makes will indicate this.

The transistor, in this application, acts as a dead-man's switch. It requires that a small current be maintained into one of its three terminals (base) to allow current to pass between the other two. (collector and emitter) The end result of this is that unless the microcontroller system is actively telling the HV system to go, the high voltage will default to off.

There is also a mechanical safety switch which physically disconnects the power from the HV supply. Whenever handling the payload when it is not intended to be in operation this switch should be active. This will be the first interaction with the payload upon a successful recovery.

Worst case scenario: The rocket has crashed, the buzzer was damaged, the transistor lead has somehow come into contact with a power source, the remove before flight pin access hole has been crushed but the high voltage circuit remains intact. In the case of a crash where there is not safe access to the safety switch all persons interacting with the rocket must wear insulating gloves until the high voltage has been verified off.

### 4.13.3. **Li-Poly safety plan**

Another risk involved in a crash scenario is a compromised Lithium-Polymer Battery. While verifying that the high voltage system is off, the person interacting with the payload should check for signs of distress in the batteries. If they are visibly swelling then they should be immediately removed to a safe location. If they are leaking or smoking all people near the rocket should immediately retreat to a safe distance and wait at least 20 minutes to make sure that it has reached a stable equilibrium before re-approaching with safety glasses and gloves to remove the batteries to a safe location.

### 4.13.4. **Thermal Analysis Consideration**

Detailed thermal analysis has not yet been a high priority. The largest contribution to heating is the high voltage supply because it consumes the most power. This component will be activated for only 30 seconds during flight. In preliminary ground testing, the high voltage supply only became slightly warm to the touch after several minutes.

### 4.13.5. **Hazard Detection Camera Risk Analysis**

The primary risk associated with the LHDC is a loss of functionality due to signal loss during flight. If a suitable software package cannot be developed to accurately identify on the ground hazards during the vehicle's descent, the LHDC will also be rendered useless. If a failure of the harness affixing the LHDC system to the parachute occurs, the camera and other hardware could either detach from the vehicle or prevent the main parachute from opening properly, posing a hazard for personnel on the ground.

### 4.13.6. **Supersonic Skin Friction Coating Risk Analysis**

The primary risk associated with the skin coatings is the exposure of CRW personnel to hazardous chemicals. In order to minimize this risk, all CRW members coming in contact with the coatings will follow the designated SOPs and wear the proper PPEs as specified by the MSDSs for the respective coatings. Aside from the personnel risks, the coatings must be evenly applied in order to prevent any unbalancing of the launch vehicle.

### 4.13.7. **Nanolaunch Payload Risk Analysis**

All reasonable risks for Nanolaunch payload will be accommodated by other payload analyses.

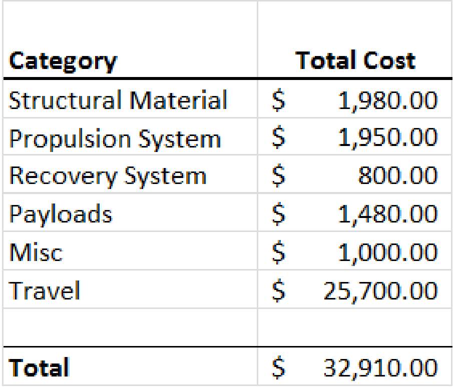
# 5. Project Plan

## 5.1. Budget and Funding

### 5.1.1. Budget

Table 5-1 shows a summary project budget with total estimated cost for each category. Descriptions for each category as well as more detailed cost breakdowns can be seen below.

**Table 5-1: Budget**

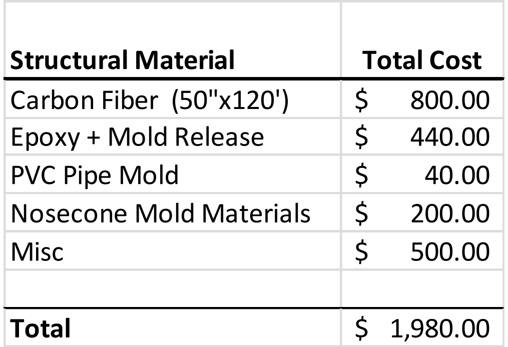


| Category | Total Cost |
|---|---|
| Structural Material | $ 1,980.00 |
| Propulsion System | $ 1,950.00 |
| Recovery System | $ 800.00 |
| Payloads | $ 1,480.00 |
| Misc | $ 1,000.00 |
| Travel | $ 25,700.00 |
| | |
| **Total** | $ 32,910.00 |

**Structural Material**

This category represents anything which is used to construct the rocket. This includes raw materials used for the rocket or associated materials such as material to produce molds to shape a nosecone. Materials used to support the rocket for traveling, display, or launching are also considered in this category.

**Table 5-2: Structure Budget**

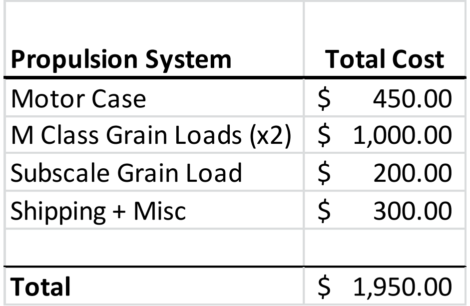


| Structural Material | Total Cost |
|---|---|
| Carbon Fiber (50"x120') | $ 800.00 |
| Epoxy + Mold Release | $ 440.00 |
| PVC Pipe Mold | $ 40.00 |
| Nosecone Mold Materials | $ 200.00 |
| Misc | $ 500.00 |
| | |
| **Total** | $ 1,980.00 |

**Propulsion System**

Anything related to powering the rocket in flight is in this category. This includes the fuel, motor case, and associated hardware required to connect the motor case to the rocket structure itself. Different motor cases or fuel sizes for subscale launches are also considered in the category. Any tools related to installing or changing delay timings for rocket motors are also considered as well as any additional costs related to shipping or obtaining motors at the launch locations.

Table 5-3: Propulsion Budget

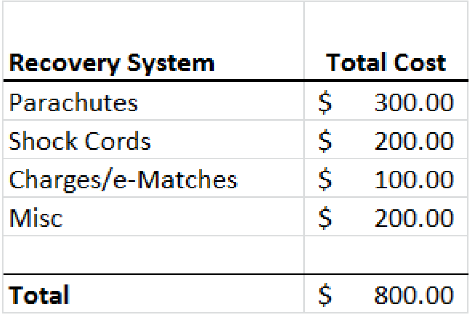


| **Propulsion System** | **Total Cost** |
|---|---|
| Motor Case | $ 450.00 |
| M Class Grain Loads (x2) | $ 1,000.00 |
| Subscale Grain Load | $ 200.00 |
| Shipping + Misc | $ 300.00 |
| | |
| **Total** | $ 1,950.00 |

### Recovery System

All parts related to the recovery system such as black powder, e-matches, parachutes, shock cords, altimeters, and the hardware required to connect the recovery system to the rocket are grouped together. The hazard detection system payload is also considered to be part of the recovery system and associated costs such as cameras, microcontrollers, radios, and hardware required to mount the system in the rocket is grouped in this category.

Table 5-4: Recovery System

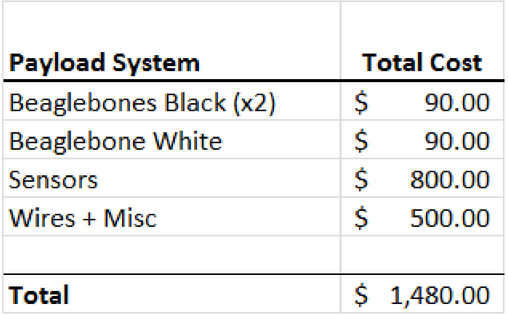


| **Recovery System** | **Total Cost** |
|---|---|
| Parachutes | $ 300.00 |
| Shock Cords | $ 200.00 |
| Charges/e-Matches | $ 100.00 |
| Misc | $ 200.00 |
| | |
| **Total** | $ 800.00 |

### Payloads

The payload cost covers the hardware, both the electronic components and the supporting structure, and any costs incurred while testing the payloads. Testing cost could be travel to special test sites, fees for performing drop test from a helicopter, wind tunnel testing, etc.

Table 5-5: Payload Budget



| Payload System | Total Cost |
|---|---|
| Beaglebones Black (x2) | $ 90.00 |
| Beaglebone White | $ 90.00 |
| Sensors | $ 800.00 |
| Wires + Misc | $ 500.00 |
| | |
| **Total** | $ 1,480.00 |

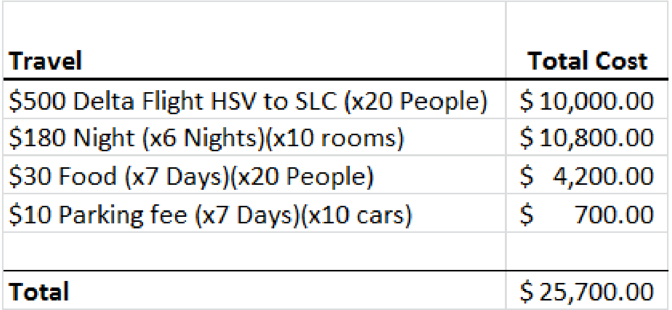
### Misc.

The $1000 miscellaneous category is to handle anything else that might be unaccounted for in any of the other categories. This is also a buffer to catch any overrun from the other categories.

### Travel

Travel is the cost for flying the team out to the launch site, the hotel reservations, and the cost of food. Additional cost such as parking fees at the airport and luggage fees are also considered and factored into the cost estimate.

Table 5-6: Travel Budget



| Travel | Total Cost |
|---|---|
| $500 Delta Flight HSV to SLC (x20 People) | $ 10,000.00 |
| $180 Night (x6 Nights)(x10 rooms) | $ 10,800.00 |
| $30 Food (x7 Days)(x20 People) | $ 4,200.00 |
| $10 Parking fee (x7 Days)(x10 cars) | $ 700.00 |
| | |
| **Total** | $ 25,700.00 |

### 5.1.2. **Funding**

The primary cost driver of the budget is the travel cost as can be seen in Figure 5-1. This is the result of budgeting to send the entire team to the launch.

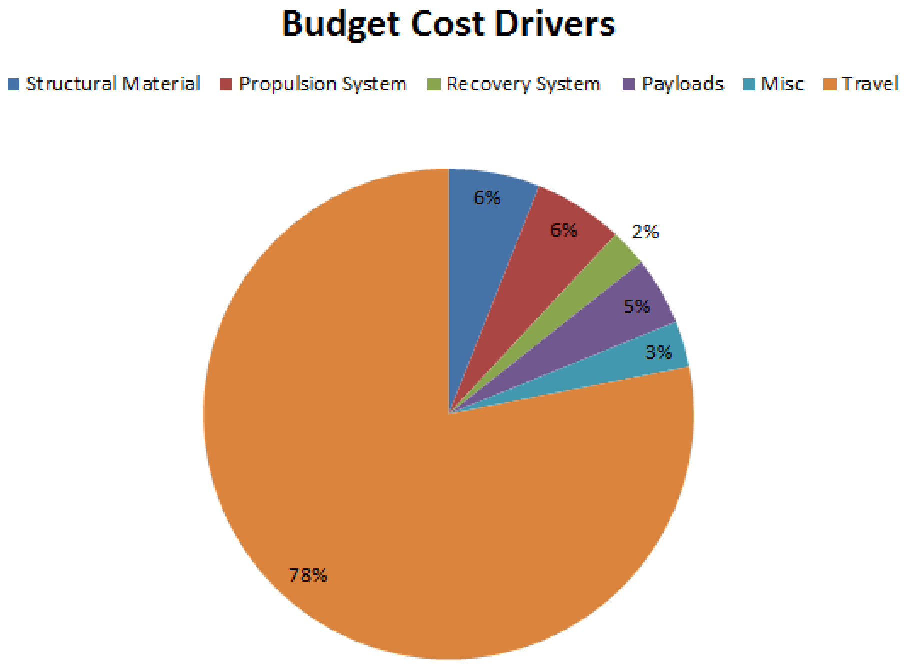
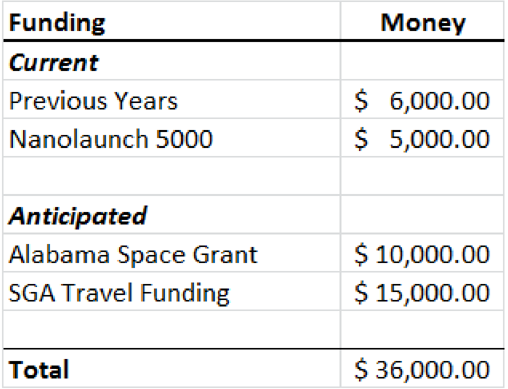


**Figure 5-1: Budget Cost Drivers**

As can be seen in the figure current travel funding takes up approximately 78% of the planned budget and is the major cost driver. This is for travel for the entire team. If funding proposals are not met it is possible to scale back the size of the team to a select few which would drop the cost of travel. A limited travel plan with only 6 participants would drive the travel budget down to approximately 50%. This option would only be used if the anticipated funding fails to come through. The current and anticipated sources of funding can be seen in Table 5-7.

**Table 5-7: Funding**

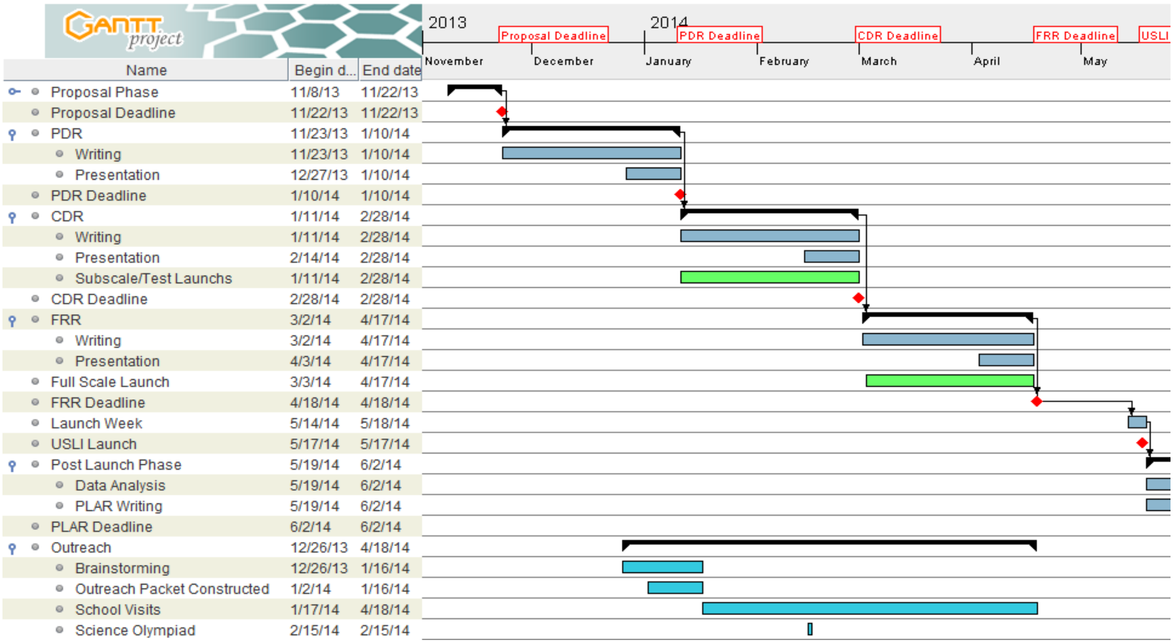


| Funding | Money |
|---|---|
| ***Current*** | |
| Previous Years | $ 6,000.00 |
| Nanolaunch 5000 | $ 5,000.00 |
| | |
| ***Anticipated*** | |
| Alabama Space Grant | $ 10,000.00 |
| SGA Travel Funding | $ 15,000.00 |
| | |
| **Total** | $ 36,000.00 |

Proposals are planned to the Alabama Space Grant Consortium for $10,000 and the UAH Student Government Association (SGA) for an additional $15,000. The funding from Alabama Space Grant Consortium would be half for construction of the rocket and half for the travel cost. The funding from the SGA would be used for travel. This anticipated funding along with the current existing funding will allow the rocket to be built and the entire time to travel out to the launch.

## 5.2. Timeline

A high level Gantt chart was developed to give a guideline of when major milestones will be met. Launch test are given as a range to accommodate weather delays in launches and other unexpected schedule delays.



| Name | Begin d... | End date |
|---|---|---|
| Proposal Phase | 11/8/13 | 11/22/13 |
| Proposal Deadline | 11/22/13 | 11/22/13 |
| PDR | 11/23/13 | 1/10/14 |
| Writing | 11/23/13 | 1/10/14 |
| Presentation | 12/27/13 | 1/10/14 |
| PDR Deadline | 1/10/14 | 1/10/14 |
| CDR | 1/11/14 | 2/28/14 |
| Writing | 1/11/14 | 2/28/14 |
| Presentation | 2/14/14 | 2/28/14 |
| Subscale/Test Launchs | 1/11/14 | 2/28/14 |
| CDR Deadline | 2/28/14 | 2/28/14 |
| FRR | 3/2/14 | 4/17/14 |
| Writing | 3/2/14 | 4/17/14 |
| Presentation | 4/3/14 | 4/17/14 |
| Full Scale Launch | 3/3/14 | 4/17/14 |
| FRR Deadline | 4/18/14 | 4/18/14 |
| Launch Week | 5/14/14 | 5/18/14 |
| USLI Launch | 5/17/14 | 5/17/14 |
| Post Launch Phase | 5/19/14 | 6/2/14 |
| Data Analysis | 5/19/14 | 6/2/14 |
| PLAR Writing | 5/19/14 | 6/2/14 |
| PLAR Deadline | 6/2/14 | 6/2/14 |
| Outreach | 12/26/13 | 4/18/14 |
| Brainstorming | 12/26/13 | 1/16/14 |
| Outreach Packet Constructed | 1/2/14 | 1/16/14 |
| School Visits | 1/17/14 | 4/18/14 |
| Science Olympiad | 2/15/14 | 2/15/14 |

**Figure 5-2: Schedule Gantt Chart**

### 5.2.1. Critical Path

The critical path for the project flows through the Proposal, Preliminary Design Review, Critical Design Review, Flight Readiness Review, Launch, and Post Launch Assessment Review. Several other critical events such as subscale launch and full-scale preliminary launch are contained within the other critical path events. A brief description of the critical path events is provided below.

**Proposal (11/22/2013) (Completed)**

Submit a proposal for the NASA Student Launch competition proposing a dual focus. Cover the details of the Nanolaunch 1200 subscale project and propose the three payloads for the NASA Student Launch. The project should be in the Technology Ready Level (TRL) 1 stage. [Appendix ] No presentation is required for the Proposal.

**Preliminary Design Review (PDR) (1/10/14) (Completed)**

Primary design work should be completed and a path forward should be known. Model design work should be mostly completed but full analysis is not required. The project should be in the TRL 4-5 stage. A presentation will be developed at the same time to accompany the PDR.

**Critical Design Review (CDR) (2/28/14)**

The design should be fully complete with full analysis of the design as well as discussion on the predicted data. A subscale launch to test airframe design will be flown. Subscale payloads if feasible will be flown as well. The project should be in the TRL 6-7 stage. A presentation will be developed at the same time to accompany the CDR.

**Flight Readiness Review (FRR) (4/18/14)**

The design should be tested and documented to show that the design functions. All of the sub projects should be shown to be functioning together. A full-scale full weight launch will be flown to prove that the design is functioning as expected. A presentation will be developed at the same time to accompany the FRR.

**Launch (5/17/14)**

The Competition launch will take place in the Bonneville Salt Flats, UT. Nothing should change between the FRR and the final launch. Launch week leading up to the launch day will include a Launch Readiness Review.

**Post Launch Assessment Review (PLAR) (6/2/14)**

An assessment of the launch with the results of the launch compared to prelaunch predictions will be written. An analysis of any significant deviation from the predictions will be analyzed and discussed. An overall summary of the project such as budget, outreach, lessoned learned, and others will be included.

### 5.2.2. **Outreach**

Although outreach is a required part of the competition its timeline is not tied to the launch of the rocket and is outside of the critical path.

**Brainstorming (1/16/14)**

Various ideas for an informational and engaging experience will be considered. A modular package that can be adjusted to fill different timeslots and grade levels will be strongly considered. This way the outreach program can be pitched to various classroom settings and Science, Technology, Engineering, and Math (STEM) events.

**Outreach Packet Construction (1/16/14)**

A set of slides will be developed based upon the ideas generated from the Brainstorming session. An outline of the information covered in the slides and the activities will be made. These outlines and slides will be given to teachers and coordinators to allow them to know what to expect and allow them to work in the teams outreach program.

**School Visits (4/18/14)**

Because the Outreach Packet allows the instructors to clearly see what is in the outreach event and because its length can be adjusted the outreach can easily be worked into their existing classes. Visits will be made to schools in the North Alabama area. This outreach can also be pitched to any STEM event.

## 5.3. Educational Outreach

**Figure 5-3: Girls in Science and Engineering Day**

Prior to the start of the NASA Student Launch competition CRW participated in several outreach events. The Mechanical and Aerospace engineering open house event was target at college age students and CRW members supported a booth to get potential engineering students interested in the program here at UAH. The Girls in Science and Engineering Day was targeted at girls from 3rd to 6th grade and had CRW team members present with several of the previous year’s rockets which the girls were able to hold and ask questions about. CRW also participated in a joint outreach effort at the Propulsion Research Center for homeschoolers where the students were given a tour of the PRC. Several key lessons were learned from these events that will help guide the outreach effort of the CRW team moving forward on the outreach program. Having a structured event with an end goal is critical for a good outreach plan. Having an activity that supports the concepts learned during an information stage in the event is critical for engaging the students and enforcing the concepts learned.

Charger Rocket Works is working on an outreach packet that can be pitched to various schools and STEM events to cover the basics of rockets and the work done by CRW and UAH. This packet will be modular in nature and allow it to be easily adjusted to match different grade levels and fill different time slots. This will be done by separating the information in the outreach packet into categories that correspond to different difficulties. More complex concepts such as drag or how thrust curves are used to predict apogee could be placed in slides reserved for more advanced classes or when more time can be devoted to their explanation. Current progress on the outreach packet construction is limited to brainstorming for engaging activities to accompany the outreach packet and categorizing topics as approachable for all grades or more advanced concepts.

Scheduling for the outreach events has not yet started because local schools are not fully back from end of year break. Plans exist to pitch the outreach packet to schools in the North Alabama area as an opportunity to get students engaged and excited about rockets and space exploration.

## 6. Conclusion

The Charger Rocket Works team is at a TRL level of 4. This means the project is running on schedule. The four sub-teams have all contributed to the design of the Rocket Body and Payload in accordance with all of the design, mission, and safety parameters required by NASA Student Launch. Preliminary analysis has shown that the rocket *Prometheus* is capable of transporting payloads at supersonic speeds with the structures and motors selected. Designs for payload circuitry and airframe structure are progressing well, and more and more people and organizations are becoming involved in Charger Rocket Works' design as outreach and collaboration takes place.

As the project moves forward, the four sub-teams each have tasks to overcome.

The Analysis team will be preparing post flight algorithms to provide an in-depth analysis of pressure, accelerometer, and gyroscope data. The sub-team is involved in research to determine analytical approximations for aerodynamic coefficients, axial precession during flight, and methods to predict these characteristics. Currently, a model is being developed to use CFD-ACE+ fluid modeling for drag coefficient predictions and various other aerodynamic coefficients.

The Avionics and Payload team will be fabricating the first batch of parts for the payload sled and begin the strength analysis. Appropriate design changes will be made to accommodate the unique subsystems and components. The radio system and the Nanolaunch and Dielectrophoresis components will be calibrated and tested individually. The LHDS will begin development under supervision of the Avionics and Payload team. The program code for the Nanolaunch experiment will be augmented and refined as component testing progresses.

The Hardware team will begin testing a fabrication and continue refining the design. The actual materials and several of the critical composite structures to be used will be laid up, and testing will be performed to prove that the strength and temperature characteristics are suitable for use in this application. FEA and calculations will be used to refine the dimensions of structural components throughout the vehicle with the objective of reducing weight, and confirming strength requirements. As designs are finalized, fabrication of subscale launch components and final launch components will begin.

# 7. Appendix A: CRW Safety Program

The CRW safety plan is the method by which the Safety Officer, Project Manager, and Team Leads can ensure that all members are conducting all tests and experiments safely. If any type of mishap occurs, all CRW team members follow the proper procedures to ensure the well-being of all affected members and ensure that proper measures are taken to reduce any future risks.

## 7.1. Management, Leadership, and Employee Participation Policy

Of vital importance to the CRW team are the safety of all personnel, property, test facilities, the environment, airspace, and the general public. This policy shall be the foundation upon which participation in the SLP competition will be based.

## 7.2. Goals and Objectives

The CRW team will implement all safety policies and procedures to meet the goals and objectives spelled out in Table 7-1.

**Table 7-1:** Safety Plan Goals and Objectives

Goals and Objectives of the CRW Safety Plan

| Goal | Objectives |
|---|---|
| Demonstrate a complete team commitment to safety and health. | • Definition and implementation of proper hazard control procedures by all leadership personnel.<br>• All CRW team members assist with the creation and proper implementation of the health and safety program. |
| Identify all hazards associated with CRW operations and facilities. | • CRW team leadership will conduct an initial risk assessment and hazard analysis to be updated as necessary by workplace changes.<br>• All CRW team members will review the initial assessments and propose recommendations on any revisions. |
| Prevent or control CRW team member exposure to identified hazards. | • CRW team leadership will designate, implement, and ensure compliance with all necessary hazard mitigation.<br>• All CRW team members will review the hazard mitigation and propose necessary revisions. |
| Train all CRW team members in safe work and manufacturing processes, hazard recognition, and emergency response. | • CRW team leadership will specify and document all appropriate work practices and emergency response procedures for hazardous situations.<br>• All CRW team members will be familiar with all plans, emergency procedures, and working documents. |

## 7.3. Team Leadership Roles

The CRW personnel who shall maintain an active role in the team safety plan include: the Program Manager, Safety Officer, Team Leads, and all involved UAH and PRC faculty members. This group's expertise will be used for all risk assessment, hazard analysis, and for the definition and documentation of all hazard mitigation procedures. The Safety Officer has the ultimate responsibility for the safety of all members throughout the duration of the project, and is responsible for the implementation of all aspects of the CRW safety plan. All other CRW leadership shall demonstrate their commitment to the health and safety plan through the conduction of any necessary inspections and through the verification of proper hazard mitigation by all team members.

## 7.4. Team Member Involvement

The goal of CRW is to foster cooperation and collaboration between all members, regardless of whether or not they hold management positions within the team. Ensuring the safety and well-being of all CRW members during all testing and experimentation requires a team effort, as does the completion of all necessary documentation. The Project Proposal, Preliminary Design Review (PDR), Critical Design Review (CDR), Flight Readiness Review (FRR), and all other milestone documents will be divided up amongst all team members whenever it is practical or feasible to do so. Any design or safety concerns of the team members will be referred to their respective Team Lead, who will bring said issue to the Systems Integration team if it is deemed necessary. Team Leaders and the Systems Integration Team are expected to see that closure of each issue is obtained in a manner consistent with all design and safety parameters set forth. Recommendations will be requested from team members to resolve any issues at hand, and any feedback regarding the decisions made is desired. The safety responsibilities of all team members are shown below in .

Table 7-2.

**Table 7-2: Safety Responsibilities**

| Personnel | Safety Program Responsibilities |
|---|---|
| Program Manager | • Ensure that any and all safety documents are available to all team members.<br>• Work with Team Safety Officer to ensure that all team members are following their safety plans. |
| Team Safety Officer | • Work with Team Leads to develop and implement Safety Plan.<br>• Review and approve all Standard Operating Procedures.<br>• Facilitate training for Team Leads on safe procedures for all design, testing, manufacturing, and launching activities. |
| | • Develop Standard Operating Procedures for all testing and launch operations pertaining to their subsystem. |

| | |
|---|---|
| Team Leads | • Facilitate training for team members on proper equipment and power tool operation before their use. |
| Team Members | • Follow all safety plans, procedures, and regulations.<br>• Identify any hazardous work conditions and file appropriate documentation.<br>• Ensure that fellow team members are following all safety protocols.<br>• Offer recommendations for improving safety protocols. |

### 7.5. Training

A CPR/AED and First Aid training is made available for members of the CRW to encourage and properly educate about safety. These tests will be encouraged for all members and mandatory for Red Team (see below) members. A White/Blue/Red card system is in place for the MAE workshop. To enter the shop requires a basic safety class which earns the White card. The Red card requires more advanced training and grants the holder the ability to operate a number of the machines in the shop with supervision from a Blue Card holder. A Blue card requires a comprehensive course that covers how to safely operate the machines in the workshop and grants the user the access to the machine shop and to act as supervisor to those operating under a Red card.

### 7.6. Material Hazard Communication Program

The Hazard Communication Program will identify all stored hazardous materials and those used in all project facilities and operations. The Safety Officer shall collect Material Safety Data Sheets (MSDSs) for these products and ensure that they have been correctly labeled. The Safety Officer shall also provide all CRW team members with the proper information and training to effectively mitigate any hazards present. This program shall serve to ensure compliance with the Occupational Safety and Health Administration (OSHA) regulation, 29 CFR Part 1910.1200, Hazard Communication. Hazardous materials shall be defined as any chemical which is classified as a physical hazard, health hazard, simple asphyxiant, combustible dust, pyrophoric gas, or any other hazard defined as such.

The product identifiers listed on any MSDSs must match those kept in the CRW Inventory of Hazardous Materials (see Appendix D) and the identifier displayed on the container labels. All CRW team members are responsible for ensuring that these labels are displayed in accordance with the appropriate OSHA regulations. Any chemicals transferred to containers for storage or transportation must also be labeled in this manner. A printed copy of each MSDS shall be kept in the Propulsion Research Center (PRC) by the Safety Officer. These MSDSs must be easily accessible by all CRW team members for reference, and for any emergency response purposes.

For hazardous chemicals present at the beginning of a work assignment, and any that are subsequently introduced into the work area, it shall be the duty of the Safety Officer to provide all CRW team members with the appropriate information and training in order for their safe use. This information and training shall comply with the requirements given in 29 CFR Part 1910.1200(h). Methods to mitigate chemical exposure shall also be incorporated into written standard operating procedures, hazardous operations procedures, and emergency procedures whenever possible.

### 7.7. Hazardous Materials Inventory

The Safety Officer shall maintain an inventory of all the hazardous materials stored and used in the CRW facilities and operations. All materials will be identified in the same manner as the MSDS. The inventory will be updated at the onset of each semester. Appendix D lists all of the current hazardous materials expected to be used throughout the project.

### 7.8. Purchasing and Procurement

All motors and energetic materials will only be purchased from licensed vendors by NAR or TRA certified members within CRW. Those motors and energetic materials will be stored in the propellant bunker.

### 7.9. Workplace Analysis

The CRW team will work to identify all hazards within the workplace for the duration of the project. This information will come from a combination of surveys, analyses, workplace inspections, mishap investigations, and collection of all health and safety data reports. These reports will include: reports of spills and releases of chemicals to the environment, facilities-related incidents related to partial or complete loss of a system function, and any reports of hazards by CRW members.

All hazards identified that pose an immediate threat to the life or health of any CRW members will be immediately brought to the attention of the Safety Officer, the Program Manager, and PRC faculty members to ensure that proper action to correct the hazard is taken. All of the current safety plans and any other working documents or procedures will immediately be reviewed by PRC faculty members.

### 7.10. Inspections

Inspections of work areas will be performed and documented each semester by the CRW team leadership. Any discrepancies between the safety requirements and the observed conditions will be recorded along with the personnel tasked for implementing the corrective measures. All corrective measures will be tracked to closure by the Safety Officer. Scheduled inspections for fire and other explosive hazards will be conducted in accordance with UAH policies and procedures.

### 7.11. Employee Reports of Hazards

All members of the CRW team are encouraged to report any hazardous conditions and analyze and prevent any apparent hazards. All CRW team leadership will ensure that reprisal-free reporting occurs, and will use safety training and all project life cycle reviews to incorporate all CRW team members into hazard prevention activities.

### 7.12. Mishap Reporting and Investigation

If any mishap occurs, it shall be promptly reported to the affected team lead and the Safety Officer, who will ensure the required procedures are carried out for any fire, hazardous material release, or other emergency. All of the CRW team leadership will be immediately notified of the incident by the Safety Officer, who will also submit all subsequently required documentation.

The Safety Officer shall then conduct an investigation into the cause(s) of the mishap and what actions must be taken to rectify the situation and ensure no future incidents occur. A safety meeting will then be conducted with all CRW team members to ensure they are aware of any and all potential safety problems and hazards.

## 7.13. Hazard Prevention and Control

### 7.13.1. **Appropriate Controls**

In order to mitigate or eliminate any potential hazards, the CRW team will use a multi-level hazard reduction sequence comprised of engineering controls, administrative controls, and personal protective equipment. Engineering controls involve designing the facility, equipment, or process in a way to reduce or eliminate any potential hazards. Administrative controls include: standard operating procedures (SOPs), work permits, training and safe work practices, exposure limits, alarms, signs and other warnings, and the use of a buddy system. Personal protective equipment will never be used as the sole avenue for mitigating risk and preventing hazards. It is to be used in conjunction with the engineering and administrative controls if they alone do not eliminate any possible hazards, or during emergencies when the aforementioned engineering controls would no longer be feasible.

Any risk remaining after all mitigation and controls is designated as residual risk. The CRW team leadership may, as a group, accept this risk based on risk assessment results and other factors pertaining to the SLP competition. However, residual risk that violates basic health and safety standards may not be acceptable. Any accepted risk will be communicated to the rest of the CRW team.

### 7.13.2. **Hazardous Operations**

Hazardous operations involve materials or equipment that, if used or handled improperly, pose a high risk of resulting in loss of life, serious injury or illness to personnel, or damage to systems, equipment, and facilities. All CRW personnel will be notified before the conduction of any hazardous operations is to take place and will be notified of any hazards which present themselves. This notification shall come from both procedural documentation, and from real-time communication, if necessary. Written procedures with emphasis on the safety steps will be developed before any hazardous operations commence to ensure that all regulatory requirements have been met.

General workshop safety rules are posted in all workshops and each tool or machine will display the proper operating procedures. It is required that more than one person be in the workshop to offer assistance if something does go wrong. First aid kits are also present in each of the work area AED locations.

### 7.13.3. **Protective Equipment**

The Occupational Safety & Health Administration (OSHA) requires the use of the personal protective equipment (PPE) at the workplace. The use of PPE is meant to reduce employee exposure to hazards when engineering and administrative controls are not effective in reducing these exposures to acceptable levels. Employers are required to determine if PPE should be used to protect their workers. The Safety Officer for CRW will be responsible for educating team members on the proper implementation for protective gear. CRW team members are required to wear appropriate PPE to perform hazardous activities. The requirements for PPEs will be based on the MSDS of the materials required to complete a task and the assessment of hazards that exist in the work environment. PPEs will be provided and maintained in the laboratory and all USLI related work spaces and will be taken to all field activities. The Safety Officer as well as Propulsion Research staff will monitor the proper use of the PPE. The expected PPE for the project includes but is not limited to:

1. Safety Glasses
2. Face Shields
3. Lab Coats
4. Hearing Protection
5. Work Gloves
6. Welding Protective Equipment (sleeves, face shield, etc.

## 7.14. Propulsion Research Center Procedures

The Propulsion Research Center affords the members of CRW the ability to perform numerous types of ground tests for propulsion, recovery, and other critical rocket subsystems. The facility is available for various research purposes including: externally sponsored research projects, Propulsion Research Center staff and Graduate Student research projects, and selected Undergraduate projects. Below is a list of safety protocols that all users of the PRC facilities must follow:

**UAH Propulsion Research Center- Facility Usage Policy**

1. All PRC Test operations are under the authority of the PRC Director and UAH campus safety practices.
2. All personnel involved in testing are UAH employees, UAH students under PRC supervision, customers with an active contract with UAH, or those with other formal arrangements agreed to in writing by the University.
3. All tests involving pressures over 100 psi, high voltage, combustion, or other sources of possibly injury require a Standard Operating Procedure (SOP), reviewed and signed by the test Red Team (see below), and approved by the PRC Director.
4. The tests are conducted by a designated Red Team who has at least one UAH staff member and has at least two members who are Red Cross Safety and CPR/AED Certified.
5. After any major test anomaly, all PRC test operations are automatically suspended until a determination of the basic cause of the incident is determined and all active SOPs are reviewed in light of the findings of the incident before resuming testing. A verbal report of the incident will be given to the V.P. of Research and a representative of Campus Safety within 24 hours of the incident.
6. If the need to evacuate the Johnson Research Center becomes apparent due to inclement weather, fire, or any other hazards, all CRW members will follow the evacuation plan provided in Appendix A.

All pertinent procedures from the UAH Emergency Procedures Handbook will be followed in the event of any mishap or injury. Any mishap or injury will be reported to the Safety Officer and the affected Team Lead as per UAH's Non-Employee Accident Report Form. Any other affected CRW Team Members and University staff will be notified to ensure that all required documentation is completed. The Safety Officer will then work to determine the cause(s) of the mishap and ensure that the proper corrective action is taken. A debrief of the incident will be provided to all CRW members in order to prevent any further mishaps from occurring.

## 7.15. Supervision

For tests, PRC and MAE staff will be present to supervise to ensure all safety measures are followed. A NAR/TRA mentor will help ensure rocket launches are safe and offer pointers to take safety beyond what is in the regulations. No test or launch will be performed without consultation and supervision from experienced staff or mentor.

## 7.16. Buddy System

No test will be undertaken by a single individual. All tests must not only have supervision but more than one person working on the test. A safety review will be conducted prior to any test. The safety officer will ensure that every member is aware of the appropriate information pertaining to any tests.

## 7.17. Accountability

All CRW team members will be held accountable to perform all assigned tasks in a safe and healthful manner, for identifying and reporting any apparent safety issues or non-compliances, and following all other provisions of the CRW safety plan. As stated earlier, any apparent safety issues shall be brought to the attention of the affected team lead(s), who will report the issues to the safety officer and the project manager if deemed necessary. Any issues that cannot be resolved by the CRW team will be brought to the appropriate faculty members. If disciplinary action is required, it may only be administered by faculty members.

## 7.18. Emergency Response

If cardiopulmonary resuscitation is required, certified personnel will administer the required aid using the AED machines located in each of the facility used by CRW. Any first aid certified CRW team member may also administer general first aid if it is required. If this basic first aid is not sufficient, the appropriate emergency procedures shall be followed to notify emergency responders. All CRW team members will be aware of the proper fire and tornado evacuation routes as depicted on the Johnson Research Center Emergency Evacuation in Appendix B.

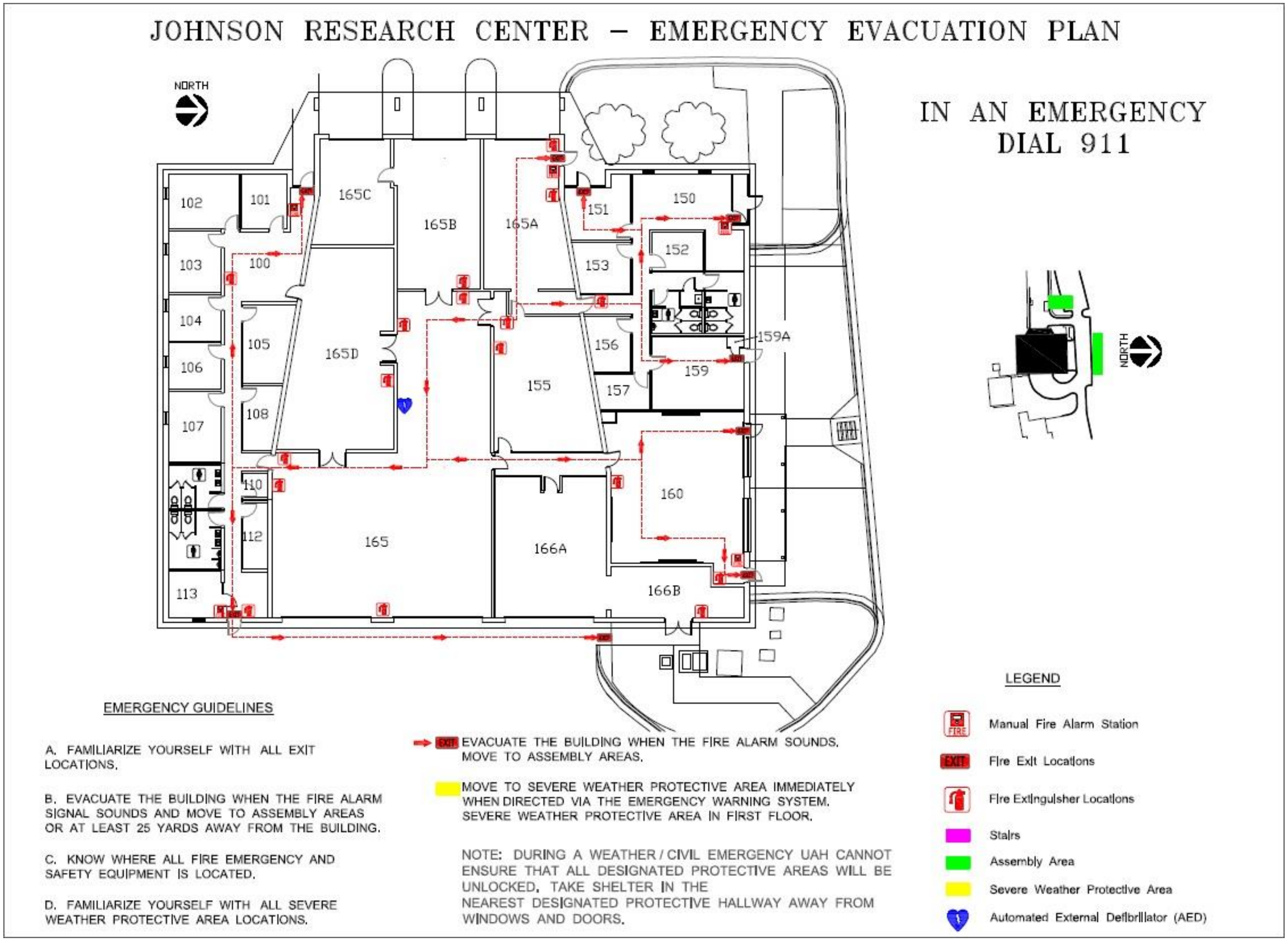
## 7.19. Periodic Safety Meetings

The Safety Officer will provide a safety briefing to the whole CRW team on a biweekly basis with information on any mishaps that may have occurred, any upcoming safety hazards that will affect the majority of the team, and safety information on any upcoming tests or launches.

## 7.20. State and Federal Regulations

The CRW team will agree adhere to all pertinent state and federal regulations throughout the duration of the project. The Federal Aviation Association (FAA), National Association of Rocketry (NAR), Department of Transportation (DOT), and Tripoli Rocketry Association (TRA) are the primary creators of regulation pertaining to amateur rocketry. All regulations can be found in Appendix C.

## 8. Appendix B: Johnson Research Center Evacuation Plan



JOHNSON RESEARCH CENTER – EMERGENCY EVACUATION PLAN

IN AN EMERGENCY
DIAL 911

EMERGENCY GUIDELINES

A. FAMILIARIZE YOURSELF WITH ALL EXIT LOCATIONS.

B. EVACUATE THE BUILDING WHEN THE FIRE ALARM SIGNAL SOUNDS AND MOVE TO ASSEMBLY AREAS OR AT LEAST 25 YARDS AWAY FROM THE BUILDING.

C. KNOW WHERE ALL FIRE EMERGENCY AND SAFETY EQUIPMENT IS LOCATED.

D. FAMILIARIZE YOURSELF WITH ALL SEVERE WEATHER PROTECTIVE AREA LOCATIONS.

→ EXIT EVACUATE THE BUILDING WHEN THE FIRE ALARM SOUNDS. MOVE TO ASSEMBLY AREAS.

🟨 MOVE TO SEVERE WEATHER PROTECTIVE AREA IMMEDIATELY WHEN DIRECTED VIA THE EMERGENCY WARNING SYSTEM. SEVERE WEATHER PROTECTIVE AREA IN FIRST FLOOR.

NOTE: DURING A WEATHER / CIVIL EMERGENCY UAH CANNOT ENSURE THAT ALL DESIGNATED PROTECTIVE AREAS WILL BE UNLOCKED. TAKE SHELTER IN THE NEAREST DESIGNATED PROTECTIVE HALLWAY AWAY FROM WINDOWS AND DOORS.

LEGEND

| | |
|---|---|
| FIRE | Manual Fire Alarm Station |
| EXIT | Fire Exit Locations |
| 🧯 | Fire Extinguisher Locations |
| 🟪 | Stairs |
| 🟩 | Assembly Area |
| 🟨 | Severe Weather Protective Area |
| ♥ | Automated External Defibrillator (AED) |

# 9. Appendix C: State and Federal Regulations

### 6.1.6a FAA Regulations, CFR, Title 14, Part 101, Subpart C, Amateur Rockets

### 101.21 Applicability.

(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with §101.25(b) (7) (ii) and with any additional limitations imposed by the using or controlling agency.

(b) A person operating an unmanned rocket other than an amateur rocket as defined in §1.1 of this chapter must comply with 14 CFR Chapter III.

### 101.22 Definitions.

The following definitions apply to this subpart:

(a) Class 1—Model Rocket means an amateur rocket that:

(1) Uses no more than 125 grams (4.4 ounces) of propellant;

(2) Uses a slow-burning propellant;

(3) Is made of paper, wood, or breakable plastic;

(4) Contains no substantial metal parts; and

(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.

(b) Class 2—High-Power Rocket means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.

(c) Class 3—Advanced High-Power Rocket means an amateur rocket other than a model rocket or high-power rocket.

### 101.23 General operating limitations.

(a) You must operate an amateur rocket in such a manner that it:

(1) Is launched on a suborbital trajectory;

(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;

(3) Is unmanned; and

(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

### 101.25 Operating limitations for Class 2-High Power Rockets and Class 3-Advanced High Power Rockets.

When operating Class 2-High Power Rockets or Class 3-Advanced High Power Rockets, you must comply with the General Operating Limitations of §101.23. In addition, you must not operate Class 2-High Power Rockets or Class 3-Advanced High Power Rockets—

(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(b) At any altitude where the horizontal visibility is less than five miles;

(c) Into any cloud;

(d) Between sunset and sunrise without prior authorization from the FAA;

(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;

(f) In controlled airspace without prior authorization from the FAA;

(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:

(1) Not less than one-quarter the maximum expected altitude;

(2) 457 meters (1,500 ft.);

(h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and

(i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

**101.27 ATC notification for all launches**.

No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation:

(a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;

(b) Date and time the activity will begin;

(c) Radius of the affected area on the ground in nautical miles;

(d) Location of the center of the affected area in latitude and longitude coordinates;

(e) Highest affected altitude;

(f) Duration of the activity;

(g) Any other pertinent information requested by the ATC facility.

### 6.1.6b NAR High Power Rocket Safety Code

1. **Certification**. I will only fly high power rockets or possess high power rocket motors that are within the scope of my user certification and required licensing.

2. **Materials**. I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.

3. **Motors**. I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

4. **Ignition System**. I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. The function of onboard energetics and firing circuits will be inhibited except when my rocket is in the launching position.

5. **Misfires**. If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

6. **Launch Safety**. I will use a 5-second countdown before launch. I will ensure that a means is available to warn participants and spectators in the event of a problem. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table. When arming onboard energetics and firing circuits I will ensure that no person is at the pad except safety personnel and those required for arming and disarming operations. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable. When conducting a simultaneous launch of more than one high power rocket I will observe the additional requirements of NFPA 1127.

7. **Launcher**. I will launch my rocket from a stable device that provides rigid guidance until the rocket has attained a speed that ensures a stable flight, and that is pointed to within 20 degrees of vertical. If the wind speed exceeds 5 miles per hour I will use a launcher length that permits the rocket to attain a safe velocity before separation from the launcher. I will use a blast deflector to prevent the motor's exhaust from hitting the ground. I will ensure that dry grass is cleared around each launch pad in accordance with the accompanying Minimum Distance table, and will increase this distance by a factor of 1.5 and clear that area of all combustible material if the rocket motor being launched uses titanium sponge in the propellant.

8. **Size**. My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third

of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.

9. **Flight Safety**. I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. **Launch Site**. I will launch my rocket outdoors, in an open area where trees, power lines, occupied buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater, or 1000 feet for rockets with a combined total impulse of less than 160 N-sec, a total liftoff weight of less than 1500 grams, and a maximum expected altitude of less than 610 meters (2000 feet).

11. **Launcher Location**. My launcher will be 1500 feet from any occupied building or from any public highway on which traffic flow exceeds 10 vehicles per hour, not including traffic flow related to the launch. It will also be no closer than the appropriate Minimum Personnel Distance from the accompanying table from any boundary of the launch site.

12. **Recovery System**. I will use a recovery system such as a parachute in my rocket so that all parts of my rocket return safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

13. **Recovery Safety**. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places, fly it under conditions where it is likely to recover in spectator areas or outside the launch site, nor attempt to catch it as it approaches the ground.

### 6.1.6c National Fire Protection Association Regulations

#### NFPA 1122: Code for Model Rocketry

'Model rockets' are rockets that conform to the guidelines and restrictions defined in the NFPA 1122 document. These rockets weigh less than 1500 grams, contain less than 125 grams of total fuel, have no motor with more than 62.5 grams of fuel or more than 160 NS of total impulse, use only pre-manufactured, solid propellant motors, and do not use metal body tubes, nose cones or fins. One inconsistency with this is the CPSC definition of a model rocket motor, which by their definition must contain no more than 80NS total impulse. NFPA 1122 contains the most complete definition of a model rocket and the model rocket safety code. This is the same safety code as adopted by NAR. 'Large Model

Rockets' is a term used in the FAA FAR 101 regulations. It refers to NAR/NFPA model rockets that are between 454 and 1500 grams (1 to 3.3 pounds) total liftoff weight and contain more than 113 grams but less than 125 grams of total fuel.

### NFPA 1127: Code for High Powered Rocketry

'High power rockets' are rockets that exceed the total weight, total propellant or single motor total impulse restrictions of model rockets, but otherwise conform to the same guidelines for construction materials and pre-manufactured, commercially made rocket motors. High power rockets also allow the use of metal structural components where such a material is necessary to insure structural integrity of the rocket. High power rockets have no total weight limits, but do have a single motor limit of no more than O power (40,960NS maximum total impulse) and have a total power limitation of 81,920NS total impulse. NFPA document 1127-1985 contains the most complete definition of a high power rocket and also the high power rocketry safety code. This safety code has been adopted by both the NAR and TRA. Metal bodied rockets are allowed by NFPA 1127 where metal is required to insure structural integrity of the rocket over all of its anticipated flight.

### 6.1.6d State of Alabama Regulations

### 11-47-12. Gunpowder and explosives storage

It is the duty of the corporate authorities of every city or town to provide a suitable fireproof building without the limits of the town or city for the storage of gunpowder or other explosive material on such terms as the corporate authorities my prescribe.

### 13A-11-224. Keeping gunpowder or explosives in city or town

Any person who keeps on hand, at any one time, within the limits of any incorporated city or town, for sale or for use, more than 50 pounds of gunpowder or other explosives shall, on conviction, be fined not less than $100.00. The explosive material on such terms as the corporate authorities may prescribe.

### 6.1.6e Tripoli Rocketry Association Requirements for High Power Rocket Operation

1 Operating Clearances: A person shall fly a high power rocket only in compliance with:

a. This code;

b. Federal Aviation Administration Regulations, Part 101 (Section 307, 72 Statute 749, Title 49 United States Code, Section 1348, “Airspace Control and Facilities,” Federal Aviation Act of 1958); and

c. Other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.

d. Landowner permission.

**2 Participation, Participation and Access at Tripoli Launches shall be limited to the following:**

2-1 HPR Fliers may access and conduct flights from the High Power Launch Area and/or Model Rocket Launch Area.

2-2 Non-Tripoli Members age 18 and over that are students of an accredited educational institution may participate in joint projects with Tripoli members. These individuals are allowed in the High Power Launch Area and/or Model Rocket Launch Area if escorted by a Tripoli member. The maximum number of non-member participants shall not exceed five (5) per Tripoli Member.

2-3 Non-Tripoli Members that are members of a Named Insured Group may participate in joint projects with Tripoli members. These individuals are allowed in the High Power Launch Area and/or Model Rocket Launch Area if escorted by a Tripoli member. The maximum number of non-member participants shall not exceed five (5) per Tripoli Member.

2-4 Tripoli Junior Members that have successfully completed the Tripoli Mentoring Program Training may access and conduct flights from the High Power Launch Area while under the direct supervision of a Tripoli Senior member in accordance with the rules of the Tripoli Mentored Flying program. The Tripoli Senior member may provide supervision for up to five (5) individuals that have successfully completed the Tripoli Mentoring Program Training at a time in the High Power Launch Area.

2-5 Children younger than 18 years of age may conduct flights from the Model Rocket Launch Area under the direction of a HPR Flier.

2-6 Attendance by Invited Guests and Spectators

2-6.1 An invited guest may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO.

2-6.2 An invited guest may be allowed in the High Power Launch Area if escorted by a HPR Flier. A HPR Flier may escort and be accompanied by not more than five (5) non-HPR fliers in the High Power Launch Area. The HPR flier escort is required to monitor the actions of the escorted non-HPR fliers, and the escort is fully responsible for those actions and for the safety of those escorted.

2-6.3 Spectators, who are not invited guests, shall confine themselves to the spectator areas as designated by the RSO and shall not be present in the High Power Launch Area or Model Rocket Launch Area.

**Referenced Publications**

The following documents or portions thereof are referenced within this code. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

3-1 NFPA Publications. National Fire Protection Association, I Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101

NFPA 1122, Code for Model Rocketry.

NFPA 1125, Code for the Manufacture of Model Rocket Motors.

NFPA 1127, Code for High Power Rocketry

3-2 Government Publications. Superintendent of Documents, U.S. Government Printing Office, Washington DC 20402.

Federal Aviation Administration Regulations, from the Code of Federal Regulations. Federal 7/31/2012

*Hazardous Substances Act, from the United States Code (re. Airspace Control)*

3-3 TRA Publications. Tripoli Rocketry Association, Inc., P. O. Box 87, Bellevue NE 68005.

Articles of Incorporation and Bylaws

High Power Rocketry Safety Code

Tripoli Motor Testing Committee (TMT), Testing Policies

Appendix A - Additional Tripoli Rulings

A-1 NFPA 1127 was adopted by the Tripoli Board of Directors as the Tripoli Safety Code. (Tripoli Report, April 1994, Tripoli Board Minutes, New Orleans, 21 January 1994, Motion 13.) Since this adoption, the code has gone through some revisions. Such is the way with codes – they are constantly undergoing change to improve and update them when safety prompts, or when the federal regulations change or are reinterpreted

A-2 All Tripoli members who participate in Association activities shall follow the Tripoli Certification Standards.

A-3 Any Board action(s), with regard to safety, made previous to or after publication of this document shall be a part of the Tripoli Safety Code.

A-4 Increased descent rates for rocket activities conducted at the Black Rock Desert venue are acceptable if needed to insure a controlled descent to remain inside the FAA approved Dispersion Area.

A-5 A rocket motor shall not be ignited by using:

a. A switch that uses mercury.

b. “Pressure roller” switches

## 10.Appendix D: Hazardous Materials Inventory

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Handling: 3M Scotch-Weld Structural Plastic Adhesive, DP-8005, Black, Part A (Epoxy) | • Corrosive eye burns in direct contact<br>• Moderate eye irritation from exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining<br>• Severe skin and<br>• Respiratory irritation. Gastrointestinal irritation from ingestion<br>• Combustible liquid and vapor<br>• Vapor may travel long distance along ground or floor to source of ignition and flash back<br>• Hazardous in contact with strong acids, strong oxidizing agents, heat, sparks and/or flames<br>• Fire | • Rating: Potentially Hazardous Operation<br>• Probability: Low<br>• Severity: Moderate to Severe | • Engineering: local exhaust ventilation for machining processes<br>• Administrative: MSDS; SOP; safe work practices; exposure time limitations; training<br>• PPE: safety glasses with side shields or indirect vented goggles; gloves; protective clothing to prevent skin contact if appropriate<br>• Respiratory Protection: not usually required; Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Handling: 3M Scotch-Weld Structural Plastic Adhesive, DP-8005, Black, Part B (Epoxy) | • Moderate eye irritation from exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining<br>• Moderate skin irritation<br>• Respiratory irritation from inhaling vapor or dust<br>• Gastrointestinal irritation from ingestion<br>• Contains a carcinogenic chemical<br>• Hazardous in contact with strong acids, strong oxidizing agents<br>• Fire | • Rating: Potentially Hazardous Operation<br>• Probability: Low<br>• Severity: Mild to Severe | • Engineering: local exhaust ventilation for cutting, grinding, sanding, or machining; shop exhaust ventilation<br>• Administrative: MSDS; SOP; safe work practices; exposure time limitations; training<br>• PPE: safety glasses with side shields; gloves (butyl rubber, nitrile rubber, polyethylene, or polyvinyl alcohol); protective clothing to prevent skin contact, if appropriate to task<br>• Respiratory Protection: not usually required; NIOSH approved air-purifying respirator with organic vapor cartridge and particulate prefilter, when ventilation is inadequate<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Handling: Black Powder, Loose | • Division 1.1 Explosive<br>• Sources of friction, impact, heat, low level electrical current, and electrostatic or RF energy may detonate<br>• Improper clothing may generate static, resulting in detonation<br>• Detonation may cause severe physical injury, even death<br>• Fire<br>• Facility/equipment damage (unlikely due to small quantities in use) | • Rating: Hazardous Operation<br>• Probability: Low<br>• Severity: Moderate to Severe | • Engineering: ventilation; storage<br>• Administrative: MSDS; HOP; safe work practices; training; personnel certification; access control; only non-sparking tools<br>• PPE: impervious rubber gloves; clothing must be metal-free AND non-static producing<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Use:<br>UNO HD SC bases & colors without lead | • Contains carcinogenic chemicals<br>• Skin and/ or respiratory tract irritation from inhalation/exposure<br>• CNS depression from inhalation<br>• Fire | • Rating: Hazardous Operation<br>• Probability: High<br>• Severity: Mild to Severe | • Engineering: proper ventilation; storage<br>• Administrative: SOP; MSDS; safe work practices; training; segregated from strong oxidizing agents, bases, and/ or acids<br>• PPE: safety glasses with side shields; gloves (butyl rubber, nitrile rubber, polyethylene, or polyvinyl alcohol); protective clothing to prevent skin contact, if appropriate to task; NIOSH approved air-purifying respirator with organic vapor cartridge and particulate prefilter, when ventilation is inadequate; tight fitting safety goggles (chemical goggles)<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Use:<br>White Epoxy Primer | • Skin and/ or respiratory tract irritation from inhalation/exposure<br>• CNS depression from inhalation<br>• Chemical asthma from long-term exposure<br>• Neurological system damage from long-term exposure<br>• Fire | • Rating: Hazardous Operation<br>• Probability: High<br>• Severity: Mild to Severe | • Engineering: proper ventilation; storage<br>• Administrative: SOP; MSDS; safe work practices; training; segregated from strong oxidizing agents, bases, and/ or acids<br>• PPE: solvent resistant gloves (nitrile rubber); isocyanate approved respirator; chemical splash goggles<br>• Residual risk: Accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical CRW Handling: Carbon Fabric, Sized or Unsized | • Temporary mechanical irritation of eyes, skin (primarily at pressure points such as neck, wrist, waist, between fingers), upper respiratory tract<br>• Eye and respiratory tract irritation from fumes or vapor generated by heating or curing sized product<br>• Electrically conductive carbon fibers and dust may cause electrical short-circuits, resulting in damage to and malfunction of electrical equipment and/or personnel injury<br>• Product or dust may aggravate pre-existing eye, skin, or respiratory disorders | • Rating: Potentially Hazardous Operation<br>• Probability: Low<br>• Severity: Mild to moderate | • Engineering: shop and/or local exhaust ventilation<br>• Administrative: MSDS; SOP; safe work practices; exposure time limitations; training<br>• PPE: safety glasses with side shields for product use or machining, grinding, or sawing cured product; loose-fitting long sleeved shirt that covers to base of neck; long pants; gloves<br>• Respiratory Protection: not usually required; use NIOSH approved organic vapor respirator if needed for heating or curing sized product; use NIOSH approved dust respirator if needed for machining, grinding, or sawing cured product<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Chemical Handling: Fiberglass Fabric | • Mechanical skin irritant (primarily at pressure points such as neck, wrist, waist, between fingers)<br>• Mechanical eye irritant<br>• Mouth, nose, and throat irritation if inhaled<br>• Mechanical stomach and intestine irritant if ingested<br>• Fiber release during cutting or sanding | • Rating: Potentially Hazardous Operation<br>• Probability: Moderate<br>• Severity: Mild | • Engineering: shop exhaust ventilation and/or local exhaust ventilation<br>• Administrative: MSDS; SOP; safe work practices; exposure time limitations; training<br>• PPE: safety goggles or safety glasses with side shields; loose-fitting long sleeved shirt that covers to base of neck; long pants; gloves<br>• Respiratory Protection: not usually required; NIOSH/MSHA approved disposable dust respirator, when ventilation is inadequate or irritation occurs<br>• Residual Risk: accepted |
| Ejection Charge Handling:<br>Assembly | • Accidental ignition<br>• Skin burn<br>• Impact injury<br>• Chemical exposure to black powder<br>• Bystander injury<br>• Facility/equipment damage | • Rating: Hazardous Operation<br>• Probability: Moderate<br>• Severity: Moderate to Severe | • Engineering: isolate ejection charge from strong electric fields and heat sources<br>• Administrative: HOP; safe work practices; training; personnel certification<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Ejection Charge Handling:<br>Testing | • Failure of ejection charge retention system releases projectile<br>• Premature combustion<br>• Injury to personnel<br>• Facility/equipment damage<br>• Unauthorized entry of test cell | • Rating: Hazardous Operation<br>• Probability: High<br>• Severity: Moderate to Severe | • Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system<br>• Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification<br>• Residual Risk: accepted |
| Machine Use: Lathe | • Injury to or loss of hand, limb<br>• Laceration by shrapnel<br>• Eye injury by shrapnel<br>• Bystander injury<br>• Facility/equipment damage | • Rating: Hazardous Operation<br>• Probability: Moderate<br>• Severity: Mild to Severe | • Engineering: machine selection; shop design<br>• Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access<br>• PPE: eye protection<br>• Residual Risk: accepted |
| Machine Use: Milling Machine | • Injury to or loss of hand, limb<br>• Laceration by shrapnel<br>• Eye injury by shrapnel<br>• Bystander injury<br>• Facility/equipment damage | • Rating: Hazardous Operation<br>• Probability: Moderate<br>• Severity: Mild to Severe | • Engineering: machine selection; shop design<br>• Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access<br>• PPE: eye protection<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Motor Handling: Installation | • Accidental ignition<br>• Skin burn<br>• Impact injury<br>• Bystander injury<br>• Facility/equipment damage | • Rating: Hazardous Operation<br>• Probability: Moderate<br>• Severity: Moderate to Severe | • Engineering: isolate ejection charge from strong electric fields and heat sources<br>• Administrative: HOP; safe work practices; training; personnel certification; performed only by Level 2 certified NAR Mentor<br>• Residual Risk: accepted |
| Motor Handling: Testing | • Motor retention system failure resulting in uncontrolled motor movement<br>• Premature combustion<br>• Injury to personnel<br>• Chemical exposure to ammonium perchlorate<br>• Facility/equipment damage<br>• Unauthorized entry of test cell | • Rating: Hazardous Operation<br>• Probability: High<br>• Severity: Moderate to Severe | • Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system<br>• Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification<br>• Residual Risk: accepted |
| Tool Use: Sanding/Grinding | • Skin abrasion<br>• Laceration by shrapnel<br>• Eye injury by shrapnel or dust<br>• Respiratory irritation<br>• Bystander injury<br>• Facility/equipment damage<br>• Chemical exposure if material being worked is hazardous | • Rating: Potentially Hazardous Operation<br>• Probability: Low<br>• Severity: Mild to Severe | • Engineering: machine selection; shop design; shop exhaust ventilation<br>• Administrative: SOP; safe work practices; exposure time limitations; training; supervision by experienced personnel<br>• PPE: eye protection<br>• Residual Risk: accepted |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| | • Catastrophic failure of grinding wheel resulting in high velocity | | |

| Work Task | Potential Hazard | Hazard Ranking | Hazard Controls |
|---|---|---|---|
| Tool Use:<br>Soldering, Electrical | • Skin burn<br>• Damage to components<br>• Fire | • Rating: Hazardous Operation<br>• Probability: High<br>• Severity: Mild to Severe | • Engineering: tool selection<br>• Administrative: SOP; safe work practices; training<br>• Residual Risk: accepted |

# 11. Appendix E: Technology Readiness Level

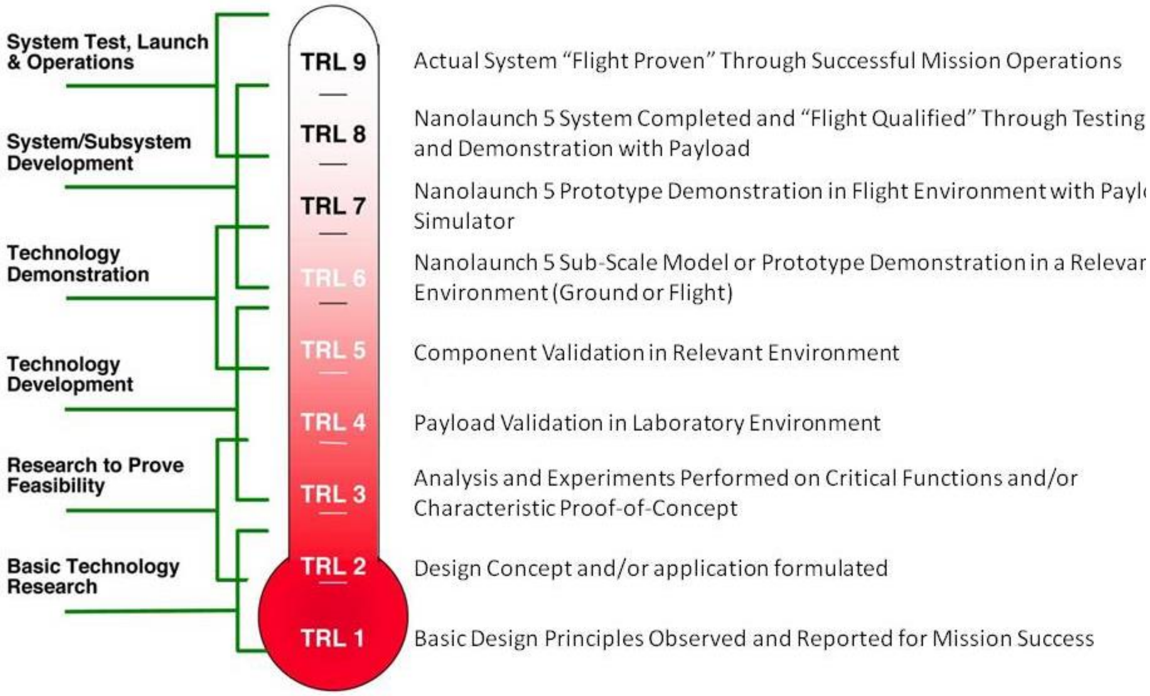


Figure 11-1: Technology Readiness Level

# 12.Appendix F: Landing Hazard Detection System (LHDS)

Introduction

The Charger Rocket Works (CRW) is a collection of faculty, staff and senior level students at the University of Alabama in Huntsville participating in the NASA Student Launch. The purpose of the NASA Student Launch is to design, build, and fly a high power rocket with experimental payloads in support of the NASA Space Launch System. CRW has been accepted into the competition along with 33 other teams both domestic and abroad. One of the four payloads that CRW will be flying is the LHDS. It is a required payload that will deploy on decent and scan the ground for potential landing hazards. The official launch will be held in Utah on the Bonneville Salt Flats.

1. System Requirements

1.1 The team will design and test a payload package to support CRW NASA Student Launch Team which meets the following minimum requirements.

1.1.1 The payload shall incorporate a camera system that deploys with the main parachute on decent and scans the surface in order to detect potential landing hazards.

1.1.2 The data from the hazard detection camera shall be analyzed in real time by a custom designed on-board software package that shall determine if landing hazards are present.

1.1.3 Data from the LHDS shall be transmitted in real time to a ground station.

1.1.4 The Payload shall be recoverable and reusable.

1.1.5 The LHDS shall have the ability to be assembled and within 10 minutes at the launch site.

1.1.6 The LHDS shall be capable of remaining launch ready at the pad for a minimum of one hour without losing functionality.

1.2 The team will have the option to choose its own components not provided by CRW.

1.2.1 The team must build a structural harness that will attach securely to a length of chord and be suspended beneath the rocket during decent.

1.2.2 The design must fit easily into a cylinder 4.5 inches (11.43 cm) in diameter and 2.5 inches (5.08 cm) in length and be easily deployed with the main parachute on decent.

1.2.3 The design must not exceed .5 lbm (226 g).

1.2.4 The team will have a budget up to but not exceeding $500.

1.3 The team will have the option of having the components provided by the University of Alabama in Huntsville 2013-2014 SLP Team. The components are listed below, in Table 12-1.

**Table 12-1: LHDS Components**

| Quantity | Component |
|---|---|
| 1 | Beaglebone Black |
| 1 | 5V Power Supply |
| 1 | HD Camera Cape |
| 1 | XBEE Transmitter |

2. General Requirements

2.1 The team will officially be under the supervision of the Avionics and Payload team from CRW.

2.1.1The team must provide a list of all team members with respective assignments by the date outlined in the Project Timeline.

2.1.2 The Team Lead will be the official point of contact for all communication between CRW and the team and must provide an email address and phone number with a voicemail option.

2.1.3 The team will submit all questions and reports by email to Wesley Cobb (Avionics and Payload Lead) but will copy all Systems Integration Team members on the email.

# Project Timeline for University of Alabama in Huntsville Senior Design

**January 2014:**

24 List of Team members and assignments due

31 Preliminary Design Review (PDR) reports due to CRW

**February 2014:**

21 Critical Design Review reports due

**March 2014:**

28 Prototype Due for full scale test launch

**April 2014:**

11 Final Design report due

**May 2014:**

14 Launch Week in Utah

The team must conform to the detailed schedule outlined in this document. Failure to do so will result in an inability to complete the minimum requirements for the NASA Student launch and the disqualification of CRW from the competition.

# 13.Appendix G: CRW Preliminary Testing and Verification Schedule

| Test Date(s) | Component/Material | Type of Test |
|---|---|---|
| Feb 3-7 | Carbon Fiber | • Tension test of dogbone samples (heated/room temp).<br>• Compression test of body tube sample (heated/room temp). |
| Feb 10-14 | Bulkheads/ Centering Rod | • Tension/compression tests of airframe support structure. |
| Feb 17-21 | Black Powder Charge | • Test of ejection charge for sub-scale launch. |
| Feb 22-23 | Subscale Rocket | • Sub-scale launch from Childersburg, AL.<br>• Functionality of major payload components. |
| March 10-14 | Black Powder Charge | • Test of ejection charge for full/sub-scale launch. |
| March 15-16 | Full-Scale Rocket/ Subscale (Backup) | • Full/sub-scale launch from Childersburg, AL.<br>• Functionality of major payload components. |
| March 31- April 4 | Black Powder Charge | • Test of ejection charge for full-scale launch. |
| March 31- April 4 | EMF Testing | • Test to ensure proper shielding of dielectrophoresis payload. |
| April 5-6 | Full-Scale Rocket | • Full-scale launch from Childersburg, AL.<br>• Test of competition payload. |

## 14. Appendix H: EMI Test Plan

EM Interference Testing Rationale:

1. Attempt to induce failure in other components in a controlled worst case design scenario
    a. Long, unshielded wires, close proximity
    b. Measure threshold for failure
2. Measure effectiveness of mitigation techniques
    a. Hold all other variables constant and add shielded wire etc.

**Test 1**

Goal: Determine what component of the system induces the highest signal on a test wire.

High level procedure:

1. Set up payload with approximate 6 inches each between the battery, transformer, and test chamber.
2. Attach a shielded coaxial wire to an oscilloscope; at the end of this attach a short (approximately 3 in) wire to act as a test probe.
3. Turn the payload on. measure the peak to peak open circuit voltage induced on the test probe (with the oscilloscope) at approximately 1 in away from the:
    a. Battery
    b. Wire from battery to transformer
    c. Transformer
    d. Wire from transformer to test chamber
    e. Test chamber
4. Note any observations about where the induced signal is greatest

**Test 2**

Goal: Determine response to probe wire length and gage

High level Procedure

1. Set up payload as in test 1
2. At location determined to induce the highest signal test a range of lengths of probe wire
    a. 1 in to 6 in in .5 inch increments
    b. Record Open Circuit voltage induced
3. At most responsive length test three different gages of wire the same way

**Test 3**

Goal: determine the power developed in a worst case scenario

1. Set up payload as in 1
2. At location determined to induce highest signal, using the worst case length and gage, measure The open circuit voltage
3. Attach different resistors from the open end of the test probe back to the ground of the oscilloscope until a range is found which reduces the voltage by an amount measureable in the range of the oscilloscope.
4. Measure the closed circuit voltage at three different resistances
5. Use these measurements to determine power developed using Power=Voltage^2/resistance

**Test 4**

Goal: attempt to provoke altimeter failure

High level procedure:

1. Set up payload as in Test 1
2. Place altimeter within 1 inch of the area which was identified in test 1 as inducing the greatest signal
3. Test altimeter with hand-held vacuum pump
4. Turn payload on
5. Measure induced voltage in manner
6. Repeat step 3
7. Compare results and note any observations

**Test 5**

Goal: attempt to provoke E-match Failure

High Level Procedure:

1. Set up payload as described in test 1
2. Set up simulated recovery system with the wire that we will have running through the payload area at the worst case scenario location.
3. Use the handheld vacuum pump to simulate operation at altitude
4. Reset recovery system with new match
5. Turn payload on
6. Repeat step 3
7. Compare results

**Test 6**

Goal: test shielded wire effectiveness

High Level Procedure

1. Set up payload as described in test 1
2. Measure at highest induced signal location
3. Replace unshielded test probe wire with shielded test probe wire
4. Repeat measurement
5. If worst case location is, as predicted, the wire from the transformer to the test chamber, then replace that wire with a shielded one
6. Repeat measurement (this time with both shielded)
7. Re-install the un-shielded test probe wire
8. Repeat measurement

**Test 7**

Goal: determine faraday cage effectiveness

1. Assemble payload as it would be in the rocket but without a faraday cage
2. Take measurements similar to test 1 using unshielded test probe
3. Add faraday cage, repeat measurements.

# 15. Appendix I: Flight Sheet

| Milestone Review Flysheet | | | |
|---|---|---|---|
| Institution | University of Alabama In Huntsville | Milestone | Preliminary Design Review |

| First Stage (Both Stages Together or Single Stage) | | Second Stage (If Applicable) | |
|---|---|---|---|
| Vehicle Properties | | Vehicle Properties | |
| Total Length (in) | 122 in | Total Length (in) | |
| Diameter (in) | 4.7 in | Diameter (in) | |
| Gross Lift Off Weight (lb) | 29 lb | Gross Weight (lb) | |
| Airframe Material | Carbon Fiber | Airframe Material | |
| Fin Material | Carbon Fiber | Fin Material | |
| Motor Properties | | Motor Properties | |
| Motor Manufacturer(s) | CTI | Motor Manufacturer(s) | |
| Motor Designation(s) | 7312M4770-P VMAX | Motor Designation(s) | |
| Max/Average Thrust (lb) | 1362/1073 | Max/Average Thrust (lb) | |
| Total Impulse (lbf-sec) | 1645 | Total Impulse (lbf-sec) | |
| Stability Analysis | | Ignition Altitude (ft) | |
| Center of Pressure (in from nose) | 90.5 in | Ignition Timing (From 1st Stage Burnout) | |
| Center of Gravity (in from nose) | 83.5in | Igniter Location | |
| Static Stability Margin | 1.5 | Stability Analysis | |
| Thrust-to-Weight Ratio | 35.6 | Center of Pressure (in from nose) | |
| Rail Size (in) | 1.0 in unistrut | Center of Gravity (in from nose) | |
| Rail Length (in) | 8 ft launch tower | Static Stability Margin | |
| Rail Exit Velocity (ft/s) | 130 ft/s | Thrust-to-Weight Ratio | |
| Ascent Analysis | | Ascent Analysis | |
| Maximum Velocity (ft/s) | 1960 ft/s | Maximum Velocity (ft/s) | |
| Maximum Mach Number | 1.7 | Maximum Mach Number | |
| Maximum Acceleration (ft/s^2) | 1383 ft/s^2 | Maximum Acceleration (ft/s) | |
| arget Apogee (1st Stage if Multiple Stages | 14,800 ft | Target Apogee (ft) | |

| Recovery System Properties | | Recovery System Properties | |
|---|---|---|---|
| Drogue Parachute | | Drogue Parachute | |
| Configuration | Round, Semi-Hemispherical | Configuration | |
| Size | 12 inch diameter | Size | |
| Deployment Velocity (ft/s) | < 20 ft/s | Deployment Velocity (ft/s) | |
| Terminal Velocity (ft/s) | 100 ft/s | Terminal Velocity (ft/s) | |
| Fabric Type | Ripstop Nylon | Fabric Type | |
| Shroud Line Material | Nylon Paratrooper Chord 500lb | Shroud Line Material | |
| Shroud Line Length (in) | 36 in | Shroud Line Length (in) | |
| Thread Type | Not Determined | Thread Type | |
| Seam Type | Not Determined | Seam Type | |
| Recovery Harness Type | Not Determined | Recovery Harness Type | |
| Recovery Harness Length (ft | Not Determined | ecovery Harness Length (ft | |
| Harness/Airframe Interface | Not Determined | Harness/Airframe Interface | |
| Main Parachute | | Main Parachute | |
| Configuration | Round, Semi-Hemispherical | Configuration | |
| Size | 220 inch diameter | Size | |
| Deployment Velocity (ft/s) | 100 ft/s | Deployment Velocity (ft/s) | |
| Terminal Velocity (ft/s) | 7 ft/s | Terminal Velocity (ft/s) | |
| Fabric Type | Ripstop Nylon | Fabric Type | |
| Shroud Line Material | Nylon Paratrooper Chord 500lb | Shroud Line Material | |
| Shroud Line Length (in) | 144 in | Shroud Line Length (in) | |
| Thread Type | Not Determined | Thread Type | |
| Seam Type | Not Determined | Seam Type | |
| Recovery Harness Type | Not Determined | Recovery Harness Type | |
| Recovery Harness Length (ft | Not Determined | ecovery Harness Length (ft | |
| Harness/Airframe Interface | Not Determined | Harness/Airframe Interface | |

| Kinetic Energy of Each Section (ft-lbs) | Section 1 | Section 2 | Section 3 | Section 4 | Kinetic Energy of Each Section (ft-lbs) | Section 1 | Section 2 | Section 3 | Section 4 |
|---|---|---|---|---|---|---|---|---|---|
| | Booster/ Body Tube | Nose Cone | | | | Fin Can | Avionics Bay | Nose Cone | |
| | 15.9 | 0.83 | | | | | | | |

# Milestone Review Flysheet

| | | | | |
|---|---|---|---|---|
| **Institution** | University of Alabama in Huntsville | | **Milestone** | Preliminary Design Review |

| **First Stage (or Single Stage)** | | **Second Stage (If Applicable)** | |
|---|---|---|---|
| **Recovery System Properties** | | **Recovery System Properties** | |
| Altimeter(s)/Timer(s) (Make/Model) | PerfectFlite SL-100 | Altimeter(s)/Timer(s) Make/Model | |
| | PerfectFlight miniTimer4 | | |
| | | | |
| | | | |
| Locators/Frequencies (Model-Frequency-Power) | GPS Antenova M10382-AIUB (Locator) | Locators/Frequencies (Model-Frequency-Power) | |
| | Xbee PRO XSC-S3B 900MHz | | |
| | | | |
| | | | |
| Black Powder Charge Size Drogue Parachute (grams) | Not Determined | Black Powder Charge Size Drogue Parachute (grams) | |
| | Not Determined | | |
| Black Powder Charge Size Main Parachute (grams) | Not Determined | Black Powder Charge Size Main Parachute (grams) | |
| | Not Determined | | |

| **Payloads** | |
|---|---|
| Mandatory Payload | Overview |
| | Landing Hazard Detection System - A Video system with object detection algorithms to identify possible hazards in the landing area. |
| 3.1 | |
| Optional Payload 1 | Overview |
| | Dielectrophoresis in Micro Gravity - Study of using Electric Fields to manipulate liquid fuels in micro gravity. |
| 3.3.1.1 | |
| Optional Payload 2 | Overview |
| | Supersonic Effects on Vehicle Coatings - Apply different surface products to the vehicle airframe and to observe the effects of supersonic flight in a post flight analysis. |
| 3.3.2.1 | |

| **Test Plans, Status, and Results** | |
|---|---|
| Ejection Charge Tests | Not Determined |
| Sub-scale Test Flights | Not Determined |
| Full-scale Test Flights | Not Determined |

## Additional Comments

Prometheus will feature a 4th payload in support of the NanoLaunch Project which includes a variety of gyroscopes, accelerometers, and pressure sensors to provide meaningful data in an attempt to characterize vehicle aerodynamic coefficients during transonic flight. The vehicle will have an induced pitched to determine pitching moment coefficient.