NASA University Student Launch

University of Alabama in Huntsville 2013-2014

Critical Design Review

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THE UNIVERSITY OF
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Propulsion Research Center, Huntsville, AL 35805, 256.701.4665

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1. Summary of CDR Report

1.1. Team Summary

Charger Rocket Works University of Alabama in Huntsville 301 Sparkman Drive Huntsville, AL 35899	NAR-TRA Mentor: Mr. Jason Winningham, Comp. Sys. Engineer (Level 2 NAR: 89526/TRA: 13669) Engineering Dept., UAH Jason.Winningham@uah.edu (Currently Level 2, Level 3 planned before full scale)

1.2. Launch Vehicle Summary

The Length of the *Prometheus* Rocket will be 121 inches and the outer diameter will be 4.59 inches. Calculations were performed using a target mass of 34 pounds. The Motor that will propel *Prometheus* is a M4770-Vmax by Cesaroni Technology Inc. This motor provides 1645.29 pound force-seconds of Total Impulse and a maximum thrust of 1362 pound force. *Prometheus'* nosecone is a 40.16 inch LV-HAACK Series Nose Cone. It uses four trapezoidal fins and a dual-deployment recovery system that utilizes a drogue chute and a main chute deployed by black powder charges.

Prometheus will leave the specially constructed launch rail at roughly 120 feet-per-second and reaches a maximum velocity of 1960 feet-per-second. The rocket will experience a maximum G loading of 40 G's. The rocket will coast to an apogee of about 15,800 feet, after a 1.53 second burn.

Milestone Review Flysheet

See Appendix L: Milestone Review Flysheet

Payload Summary

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 PDR

2.1. Vehicle Changes

2.1.1. Fins

The fins have been significantly redesigned since PDR due to two separate issues. First, the fin geometry for Nanolaunch was clarified after PDR. Initially a flush mounting was specified for Prometheus based on the models available for Nanolaunch. New information became available after PDR showing the Nanolaunch to use a bolted fin bracket, and Prometheus was modified to replicate this. Also, due to scaling issues the actual size of the fins must be modified from the Nanolaunch 1200 profile to allow for an appropriate stability margin. This has been determined to be an acceptable change in geometric similarity from the Nanolaunch 1200.

2.1.2. Nosecone

The nosecone for Prometheus was also redesigned since PDR. The nosecone for Nanolaunch is not specified at a final level. As such, following engineering intuition and with the Nanolaunch team's approval it was chosen to modify the nose cone from their original specification. The tip radius was reduced to provide a more aerodynamically efficient profile. After flight testing this change may be incorporated into Nanolaunch's final design.

2.2. Payload Changes

2.2.1. Live Data Removal

Live data from the Nanolaunch 1200 has been removed from the project as a requirement. A single antenna attached to the Landing Hazard Detection System will provide the live data for the LHDS and a GPS stream.

2.2.2. Attitude Disturbance System Removed

The Attitude Disturbance System (ADS) has been removed from the project as a requirement for the Nanolaunch 1200. Design will continue and the space in the rocket will remain. This will not be flown during the 2013-2014 competition but will continue to be designed for use on future launches.

2.3. Project Plan Changes

2.3.1. Landing Hazard Detection System

After an inability to get further help for the Landing Hazard Detection System (LHDS) it was brought back on as a payload to be handled by the original team with no extra members. This will make the LHDS run slightly behind schedule in comparison to the rest of the rocket design.

2.4. PDR Feedback

1. **98mm motor on 4.5" body frame leaves little room for fin through the wall construction.**
    a. The team received new fin can design concerning the Nanolaunch 1200 which allows the team to create brackets.
2. **How will you specifically test the fin system to match the aerodynamic loads to ensure the bond will hold?**

    a. Aerodynamic analysis shows fin flutter not to be a problem so far. Drag force on the fins is a concern which can be easily be tested.
3. **Threaded rod is a part of the motor retention system? How far up does it go?**
    a. The threaded rod goes less than half the length of the rocket with numerous bulkheads along its length. The rod will be preloaded in tension.
4. **Descent rate is really low, why?**
    a. Due to fins that stick below the fin can and the former method of attached the fins the descent rate was kept low to minimize the chance of damage. The new fin design allows the descent rate to be faster.
5. **Good work doing your own analysis and calculations, especially Monte Carlo analysis.**
    a. Further Monte Carlo analysis has been performed for the CDR
6. **Reason for scaling the fins up is the stability margin. How do the aerodynamic loads compare to the previous design?**
    a. Fin design does not have to be the same geometry and new fin designs have smaller size to keep static stability at a reasonable level
7. **What portion of the rocket do you expect to see mass growth in? Will it help or hurt the static stability margin?**
    a. The rocket was expected to have no mass growth due to intentional underestimates on several components. Any mass growth that may happen is expected in the payloads and would make the rocket more stable.
8. **Payload looks similar to last year's boosted dart. What is different between this year and last?**

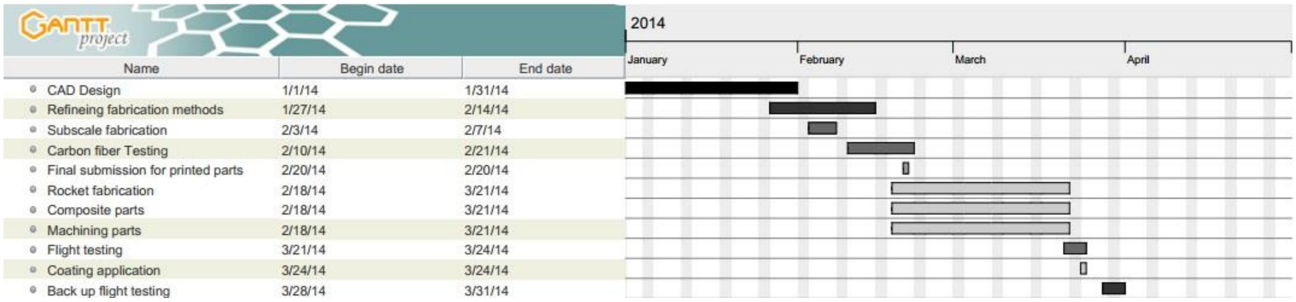
    a. Higher voltages to increase effect, new electrode design, and a new design to insure the sun doesn't affect the camera
9. **How much voltage is expected in the system?**
    a. Was 7kV at near zero amperage, will now be 12kV at near zero amperage
10. **Working fluid is?**
    a. Peanut Oil
11. **What would happen if the system was turned on and someone touched it?**
    a. Under normal operation nothing, if a failure occurred electric shock is possible through the carbon fiber body frame. Warning signs will be placed on the outside.
12. **Switch is robust enough to sustain these power levels?**
    a. Yes
13. **How much black powder is going to be used?**
    a. Ground tests were planned to be used. Use the ideal gas law to get a good starting point. Estimated at 6 grams.
14. **Parachute material, thread, and seam types, have they been examined?**
    a. Yes
15. **Will the parachutes fit in the body frame? Would it be possible to move the payloads back to get more space for the parachutes, and how will that affect the stability margin?**
    a. Will make the margin worse, but depends on fin design.
16. **Outreach, which schools will you be in touch with?**
    a. Challenger Elementary, Cullman Christian, Discovery Middle, and Challenger Middle

17. **Faraday cage with aluminum shaft going through the middle, how will that affect it?**
    a. This will be tested.
18. **Is there any chance of an arc happening to that shaft?**
    a. EMF testing plan in place to ensure the electronic components are not affected.
19. **For the threaded rod it has near zero strength in compression, the rod will not provide much loading capability to transfer energy from the motor to the bulkheads. Need to ensure minimum thrust load is transferred to the threaded rod, or use bulkheads down the length of the rod to minimize it likelihood of bending and to increase its stiffness.**
    a. Rod is present for motor retention and to secure the payloads. It is not a force path for the motor. The rod will also be preloaded in tension.
20. **Have you determined the level of heating that is going to be generated for the thermal experiment? Difference in temperature and if measurement device is sensitive enough to distinguish between the two zones.**
    a. CFD analysis as well as hand calculations have given an idea for the temperature at the surface. A known delay of 3-5 seconds is present in the temperature changing tape. Part of this experiment will be to see if the tape can even stay on the rocket at supersonic speeds.
21. **Why did you choose to do a 3D printed titanium bow tail with carbon fiber frame?**
    a. Goal is to use printed titanium wherever possible due to a Nanolaunch desire to test 3D printed titanium in rockets. Will not be used excessively and never used in an unsafe manner.
22. **Good job with identifying hazards, causes and mitigations. Would be a lot easier to read in table form.**
    a. The hazards, causes, and mitigations are now presented in table form.
23. **Severity probability risk matrix is kind of there, needs a pictorial form, and then you can plot on a matrix and get a better feel for the risks.**
    a. This was a mistake; the tables were created and didn't make it into the document. This was corrected for the CDR.
24. **Safety plan is good, for CDR you will have a better defined design, continue to update the hazard analysis, and anywhere you mention testing include the results. Reference results in the hazard analysis.**
    a. More detailed safety plans exist.
25. **Much of current material is shop/material safety. Start a failure modes and effect analysis for the major components. If part fails, what is outcome and what can you do to mitigate the failure.**
    a. Failure modes and effect analysis has been include for many of the components.
26. **Needs more design detail, analysis, and testing plans/results on the parachutes**
    a. Further Design of the parachute and testing plans/results for the parachutes have been included in the CDR
27. **Open Rocket looks to be more accurate than RockSIM for supersonic flight.**
    a. This may have been misstated. RockSIM is more accurate at Supersonic flight than Open Rocket.

3. Vehicle Criteria

3.1. Design and Verification of Launch Vehicle

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.



Name	Begin date	End date
CAD Design	1/1/14	1/31/14
Refineing fabrication methods	1/27/14	2/14/14
Subscale fabrication	2/3/14	2/7/14
Carbon fiber Testing	2/10/14	2/21/14
Final submission for printed parts	2/20/14	2/20/14
Rocket fabrication	2/18/14	3/21/14
Composite parts	2/18/14	3/21/14
Machining parts	2/18/14	3/21/14
Flight testing	3/21/14	3/24/14
Coating application	3/24/14	3/24/14
Back up flight testing	3/28/14	3/31/14

3.1.1. Review the design at a system level

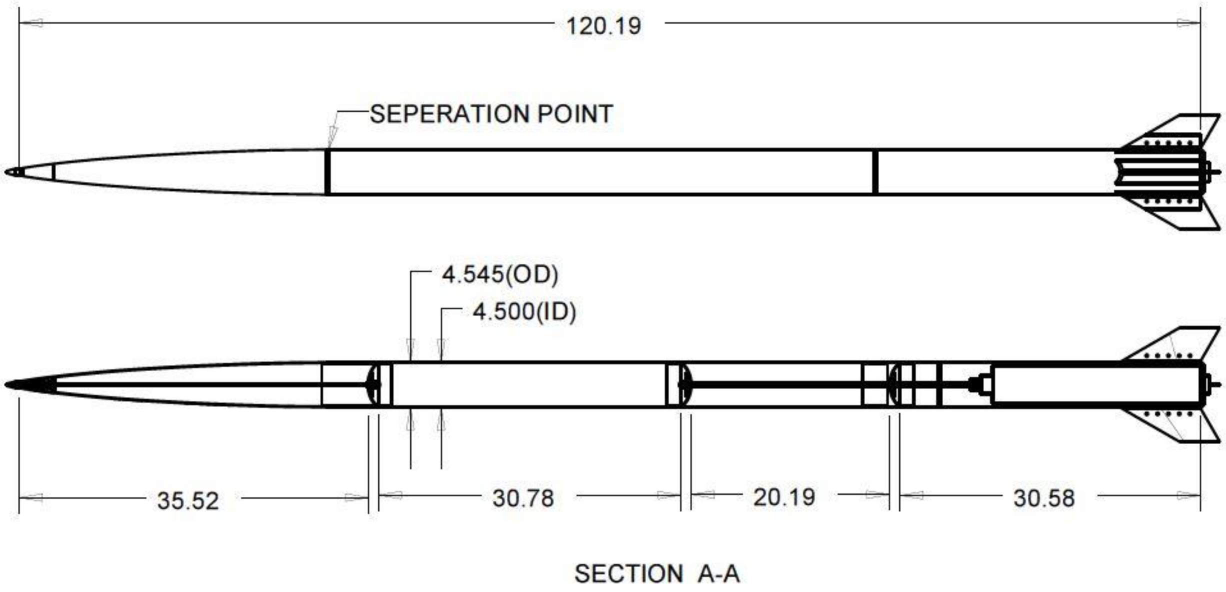


Figure 3-1: Vehicle Overview

Carbon fiber has been selected for the structure of the rocket based by its strength to weight ratio, ease of production, and availability. Test samples of the carbon fiber were made for lab testing the tensile and compressive strength. Dog bones were created from 5 flat sheets of carbon fiber with a 0-90 fiber degree to test the tensile strength. Test samples of the body tubes were made to test the releasing agents from the mold, 45-45 degree fiber sleeve, 0-90 degree wrapped fibers. The tube samples were used for compressive testing. From the testing we expect to find the compressive strength of our material in its configuration and determine the actual body tube thickness based on the data and factor of safety. These tests were completed on campus by the team using campus facilities.

Tubes were manufactured from carbon fiber sleeve, and wrapped sheet. The sleeve was applied in 2 layers with the wrapped 3 layers were applied. Wrapped tube gave the best compressive results with a failing load of 8093.5 lbf, seen in Figure 3-2: Tube Compressive Test. Fractures in the wrapped tube, seen in Figure 3-2: Tube Compressive Test, were uniform through the fiber. This shows that the fracture was due to shearing along the fibers. The sleeve failed earlier than the wrapped due to inconsistencies in the fiber. Frayed ends on the sleeve caused the ends of the tube to fracture before a significant load was applied. This was a fabrication failure due to the fibers being frayed.

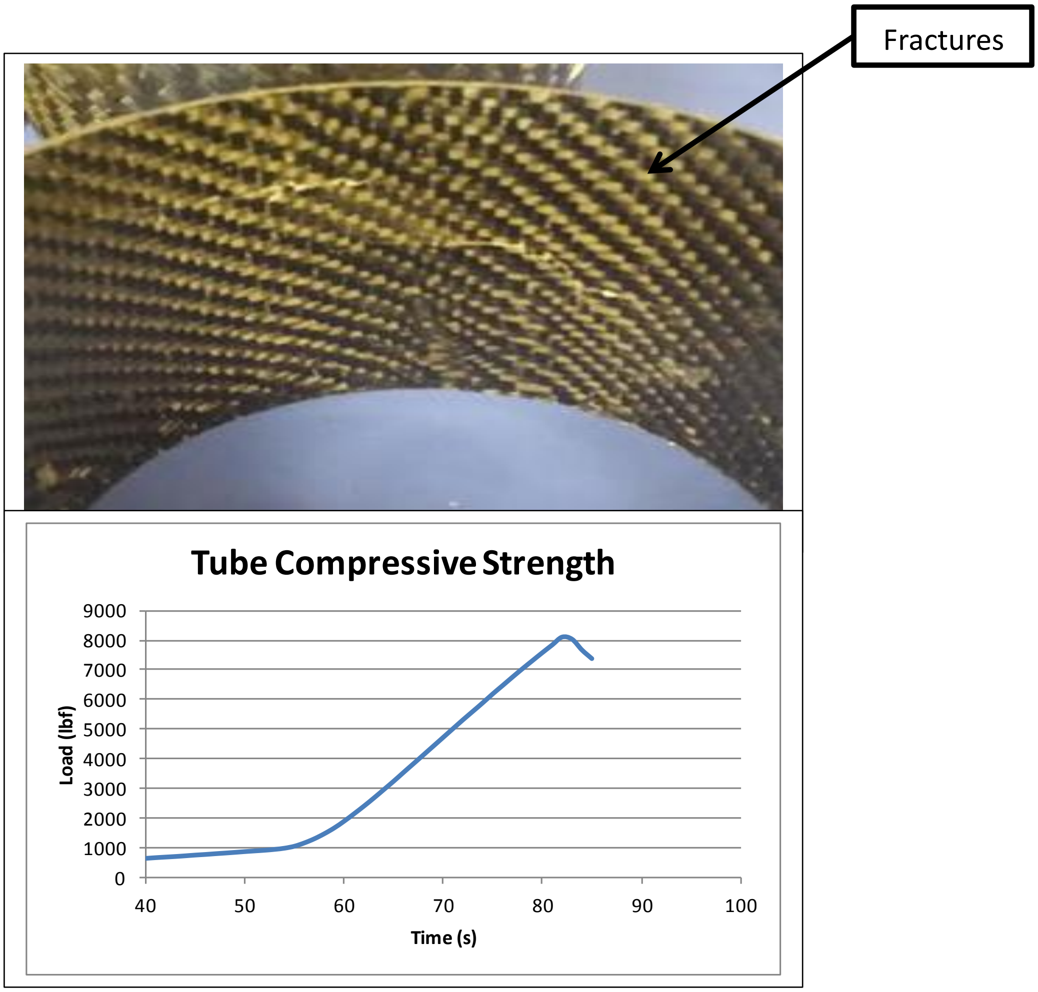


Figure 3-2: Tube Compressive Test

The compression of the wrapped tube was .070 inches, seen in Table 3-1: Tubes Tested. This was caused when the tube buckled under load of the compression. Testing the tubes showed that the material requirements far exceed the loads the body tubes will see during flight. While the sleeve, when fabricated correctly, can have a desirable strength the wrapped gives desirable results.

Table 3-1: Tubes Tested

Tubes		
Test Sample	**Failure Load (lbf)**	**Max Compression (in)**
Sleeve	6226.1	0.139
Wrapped	8093.5	0.070

Tensile dog bone samples were fabricated from 5 layer carbon fiber sheets with a thickness of .045 inch. Failures of the fibers were uniform for every tensile test which shows the consistency of the fiber placement angles when fabricated, and verifies the strength of the carbon fiber. Fibers that broke before total failure were graphed and appear as divots in Figure 3-3: Dog Bone Samples. The average extension for the samples was .075 inches, seen in Table 3-2: Tensile Test Results, with an average failure load of 1814.3 lbf. The forces seen in testing far exceed the forces that are expected during flight.

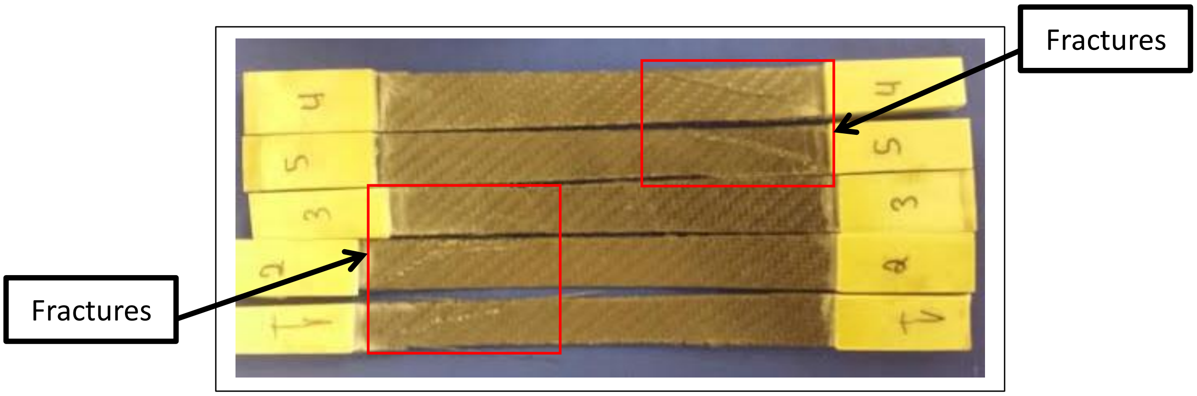


Figure 3-3: Dog Bone Samples

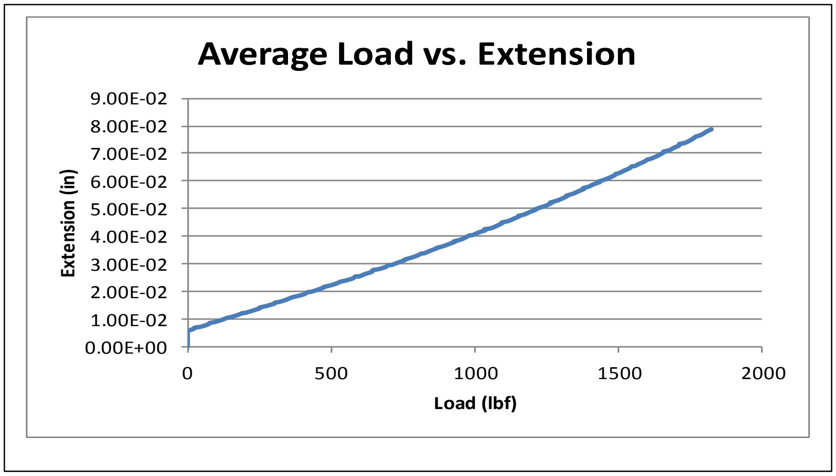


Figure 3-4: Avg. Load vs Extension

Table 3-2: Tensile Test Results

Dog Bones		
Test Sample	Failure Load (lbf)	Max Extension (in)
1	1951.4	0.086
2	1785.3	0.074
3	1781.8	0.068
4	1732.8	0.064
5	1820.3	0.084
Average	1814.3	0.075

The parachute test samples were fabricated to test which would fail first, the fabric or the seam. Tests showed that the seam failed well before the material would tear. This could have been due to the cuts made on the seams to make the test samples. The seam started to fail on the ends where the seams were frayed due to fabrication. As seen in Figure 3-5: Parachute Seam Test, the fabric is very elastic and can extend to 1.87 inches before seam failure.

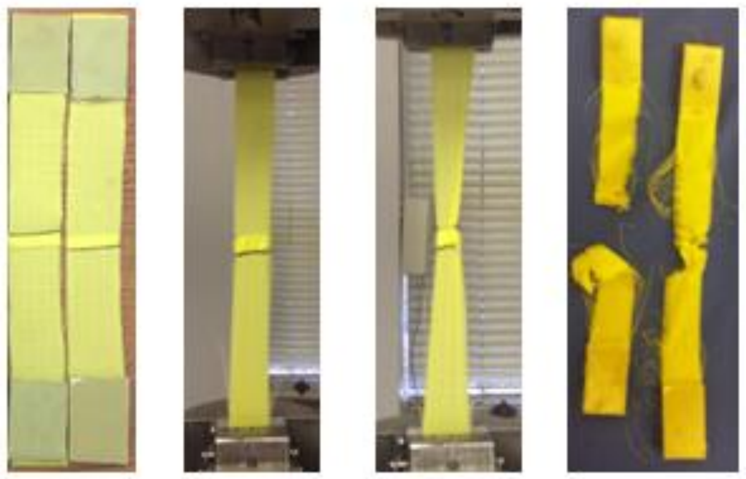


Figure 3-5: Parachute Seam Test

In Figure 3-6: Seam and Material Strength, the force shows fibers failing throughout the entire test before total seam failure. Fibers that tore before failure were due to frayed fabric on the edges.

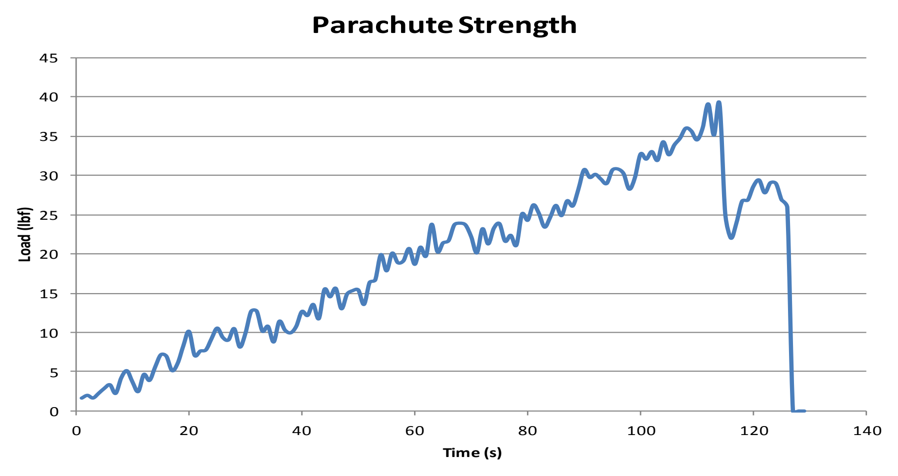


Figure 3-6: Seam and Material Strength

Table 3-3: Parachute Test Results

Parachute		
Test Sample	Failure load (lbf)	Max Extension (in)
1	35.71812	1.79

The testing of the structure material verified the team’s requirements for strength, thickness, and fabrication. The goal of the carbon fiber samples was to test materials constructed by the team and determine their strengths and failure loads. The testing’s intent was to prevent structure failing and maximize safety. The test determined that the body tubes will be wrapped due to their uniform strength and ease of fabrication. Testing verified that the material far exceeds the forces the rocket will receive during flight and been deemed sufficient by the team.

3.1.2. **Vehicle Success Criteria**

Vehicle Success Criteria

Requirement	Success Criteria	Verification
Safe launch	No harm to anyone or the rocket	Safety analysis before launch. No harm to anyone or the rocket
Recoverable and Reusable	No damage to the rocket or payloads	Check for structure damage and ensure the rocket can be reflow without part replacement
Geometrical similarity to the Nanolaunch 1200 prototype	Geometry scaled properly	Fabrication of rocket matches scaled design of Nanolaunch
Supersonic flight	Reach Mach .7-1.4	Review data from accelerometers and pitot pressure sensors
Vehicle must be assembled and ready to fly in reasonable time	Vehicle must be assembled in less than 3 hours from arrival at launch field	Ground testing assembly instructions
Vehicle must be aerodynamically stable before rail exit	Vehicle must exceed minimum stable speed for flight	Flight testing and analysis
Payloads must be integrated into vehicle design	Payloads must be able to retrieve data and return it to ground	Payloads will be integrated to vehicle via payload shaft , and nose cone will be built to accommodate supersonic pitot probe

3.1.3. **Workmanship**

Workmanship is important to every part of a project of this scale, and team leadership has encouraged an attitude that every detail is important to the final product with the team as a whole, and especially with the Hardware team. This has led to a tremendous amount of time spent on small details, but the team believes that this work being put in now will save time over the course of the project. To insure this attitude is followed, several steps have been taken. Team leadership meets once a week in addition to the two normal team meetings to discuss the status of the design, and interfacing between sub teams. Additionally, all designs are reviewed by each sub team lead prior to flight approval. Lastly, the team instructor and mentor are consulted regularly, and have final veto authority for all design details.

3.1.4. **Design Detail Discussion**

Prior to the release of the 2014 Student Launch rules, the Charger Rocket Works Team sought and was given a project to support NASA's Nanolaunch development program. Specifically, CRW was to build an aerodynamic test bed to emulate the profile of the proposed Nanolaunch vehicle, and fly it through the transonic region while collecting data with the objective of extrapolating aerodynamic coefficients and base drag to correlate with the Nanolaunch team's simulated values. While *Prometheus's* exterior profile and many related decisions were determined by the mold line that the Nanolaunch project required, when Student Launch was announced it was decided that CRW would fit Prometheus and the Nanolaunch project into the Student Launch mission. This held many challenges.

CRW initially specified a long burn motor to achieve the velocities required for completion of the Nanolaunch objectives, without exceeding traditionally 'reasonable' acceleration values. CRW's initial series of motor simulations would have pushed the rocket to between 20,000 and 40,000ft AGL at 20-35Gs acceleration with a realistic weight goal of 15lbs wet. However, after the release of the NSL rules, the flight ceiling at Bonneville Salt Flats and the drastic additional weight required to fly all of the payloads required meant that a much more powerful motor would be necessary. The resulting motor choice was a CTI M4770 Pro98 Vmax motor. With this motor, Prometheus in NSL trim will weigh 34lbs, and will experience 1361lb of max thrust force and approximately 40Gs of acceleration.

This high performance motor choice predicated a series of unusual design decisions that will be described below, but the most significant of these is the use of a shaft both to pass thrust forces to the payloads that would have otherwise been passed through the body tube, and to hold the rocket together as seen in Figure 3-7: Prometheus Internal Structure. This shaft allows a secure and convenient method to attach payloads to the rocket, and passes recovery forces back through the rocket components. The stress analysis for these components will be discussed below.

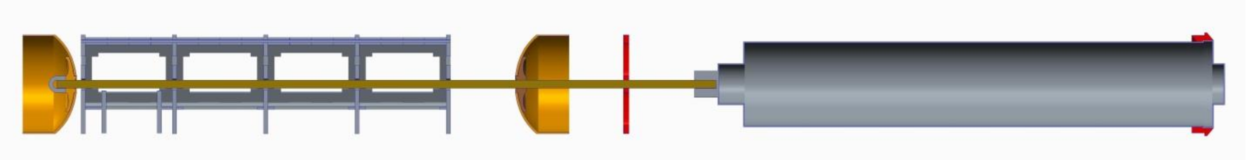


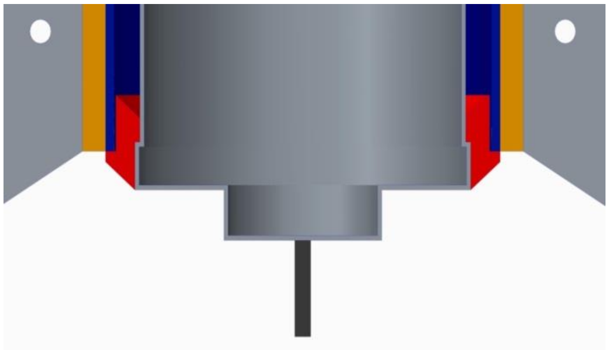
Figure 3-7: Prometheus Internal Structure

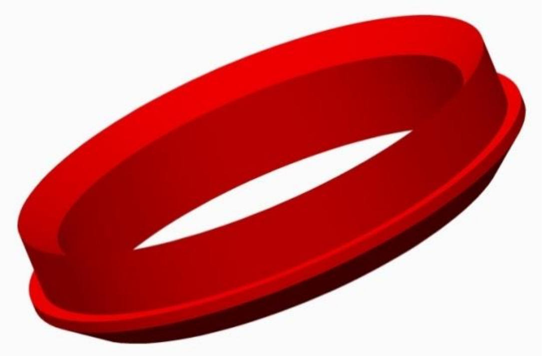
It should be noted that part of the guidelines for Nanolaunch was a suggestion to use as much Selective Laser Sintering printed titanium as possible. As such, many of the components will be printed by the Nanolaunch team for CRW. SLS can be used to produce very complex components with cross sections and density changes that wouldn't be possible with machining or casting. Some of the components specified for Prometheus won't take advantage of this, but others (the pitot probe in particular) wouldn't be possible, or wouldn't be labor effective to produce with any technique other than SLS.

3.1.5. **Component Details**

In this section the individual components under the responsibility of the Hardware Team will be discussed in their approximate order from base to nose cone, along with the significant design considerations, mass, materials, loads, analysis and testing involved in each component.

3.1.6. **Thrust Ring**





The Prometheus thrust ring for NSL will be printed in titanium. It will be a simple component which will take little advantage of the capabilities of SLS, but future thrust rings will incorporate aerodynamic shrouds intended to replicate the tail cone of the Nanolaunch vehicle which will allow for valid base drag measurements. For NSL the sensors for these measurements will be flown and the data logged, but because of the need for a 98mm motor to meet NSL's flight ceiling there won't be room in *Prometheus's* lower body tube for pressure tubes, so the measurements will simply be to prove that the data can be collected.

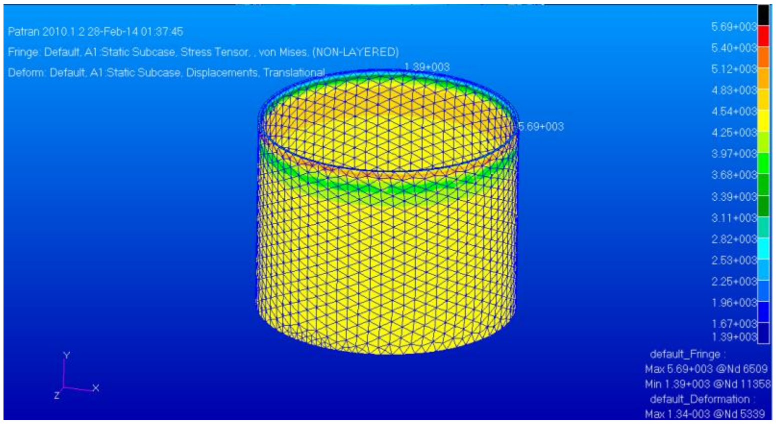
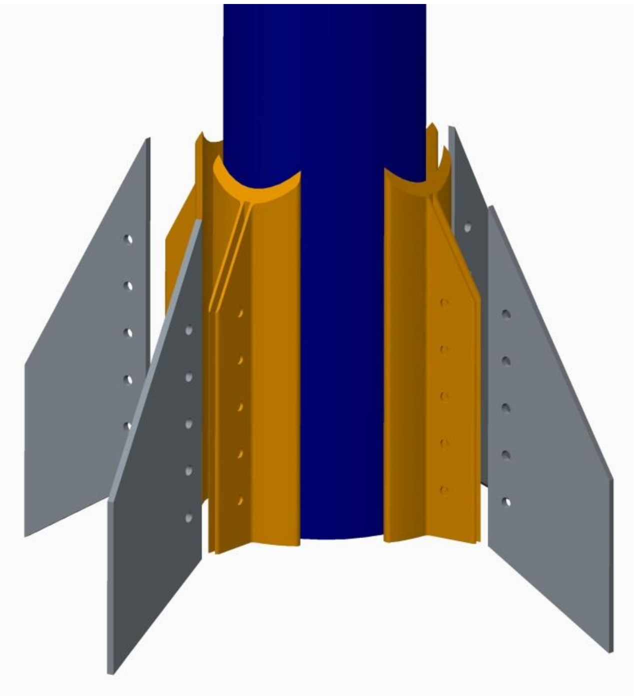


Figure 3-8: Tube Sample FEA

The NSL transition will simply pass a portion of the thrust force from the motor case to the body tube. Because of its profile, hand calculations would be difficult, but FEA indicates that it will be massively overbuilt.

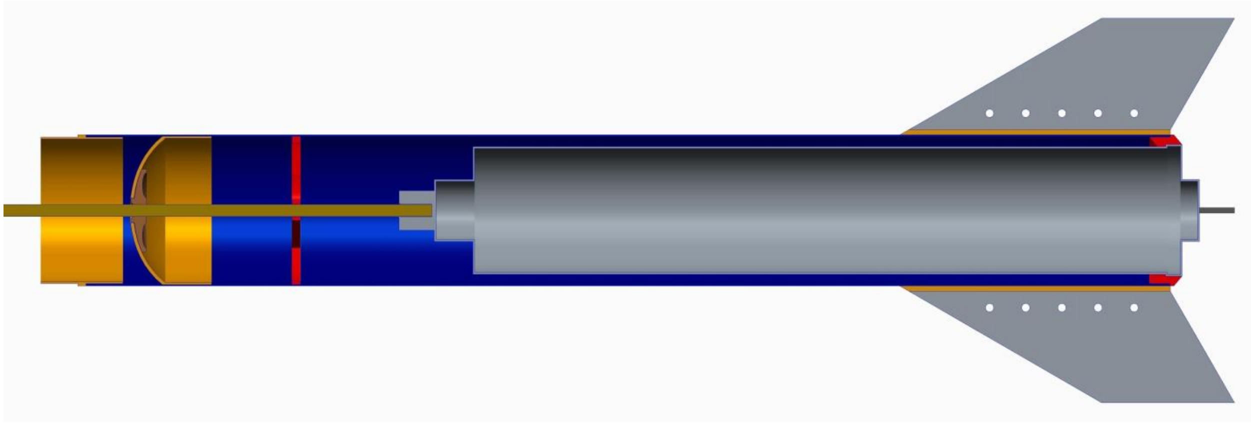
3.1.7. **Fins and Fin flanges**



The fin profile is defined by Nanolaunch. CRW will replicate the shape of Nanolaunch's fins and fin attachment method as closely as possible using titanium flanges bolted to the body tube. Unfortunately, due to scaling issues the actual size of the fins must be modified from the Nanolaunch profile to allow for an appropriate stability margin. This has been determined to be an acceptable change in geometric similarity from Nanolaunch.

The fins will be made form .17” thick carbon fiber sheet. Their loads are aerodynamic and acceleration of their own mass only. FEA and calculations have been performed to show that both the fins and their brackets are safe. They also have been analyzed for flutter using formulas published by Apogee Rocketry, and determined to be safe. Refer to the analysis section.

3.1.8. **Aft body tube and aft bulkhead**

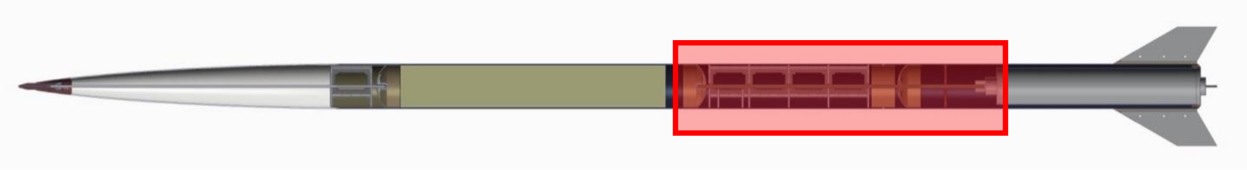


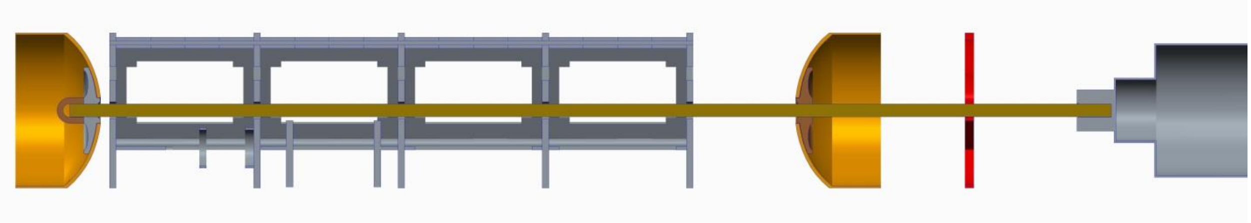
The thrust loads from the motor will pass through the lower body tube or the lower body tube bulkhead. As such, CRW will make them out of carbon fiber, and their thicknesses have been carefully chosen for strength and light weight. The body tube will be rolled from five plies of 640ksi “aerospace grade” Soller Composites 3k twill weave carbon cloth laid up 'wet' using off the shelf Adtech 820 laminating epoxy. This has been determined to be well over the strength requirements of the application using FEA analysis and destructive testing of dog bone type tension samples and representative tube samples. These tests were discussed above.

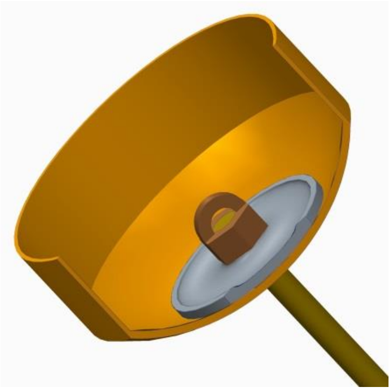
The bulkhead will be .1” thick and made form the same material as the body tube. It was analyzed for strength using FEA and correlated to the destructive testing discussed above. It will be epoxied into the lower body tube using structural adhesive. This joint will be impossible to inspect using the equipment available to CRW, so it will be proof loaded after construction to ensure that it is safe for flight.

A printed titanium threaded puck will be epoxied to the bulkhead that will pass forced from the payload shaft into the body tube. This will be discussed below.

3.1.9. **Payload shaft and ring nuts**







The payload shaft is a unique design consideration for *Prometheus's* unusual design requirements. It is a 3/8-16 7075-T6 threaded aluminum rod that threads into the mounting boss on the end of the CTI Pro98 motor case, passes through the center of the payload bay, and terminates at a bulkhead forming the bottom of the recovery bay in the center body tube. It was implemented to both allow a portion of the thrust force from the very powerful motor required to meet both the Nanolaunch and NSL requirements to be transferred through a path other than the body tube, and to secure the motor case into the lower body tube. It also provided a secure and convenient method to attach payloads to the rocket and to pass the recovery loads back to the payloads and the motor case. Payloads can simply be slipped over the shaft and nuts tightened above and below them to lock them in place. The modular payload bays discussed in the Payload section below take advantage of this ease of assembly to make maintainability and experiment adjustment or replacement between flights very easy.

Calculations have been done treating the payload shaft as a preloaded bolt made of 7075-T6. They have determined that the yield force would be over 5500 lbs of tensile load, as shown in Appendix M: Payload Shaft Pre-Load Calculations. The shaft can be safely preloaded over the maximum thrust force that the motor can produce, which means that the shaft will be loaded in tension throughout the flight. This means that there is no risk of separation of the mid body tube from the lower body tube, and that the loads experienced by the shaft and body tube in flight will be well within traditional preloaded bolt type strength values for the shaft.

A printed titanium threaded puck will be used to pass forces from the payload shaft into the

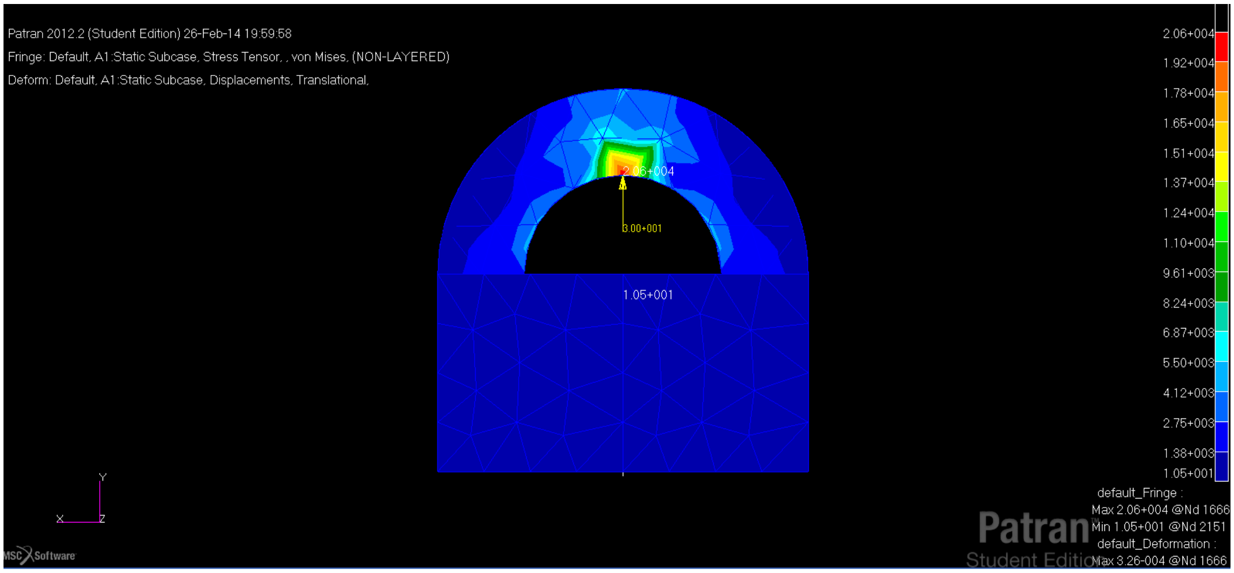
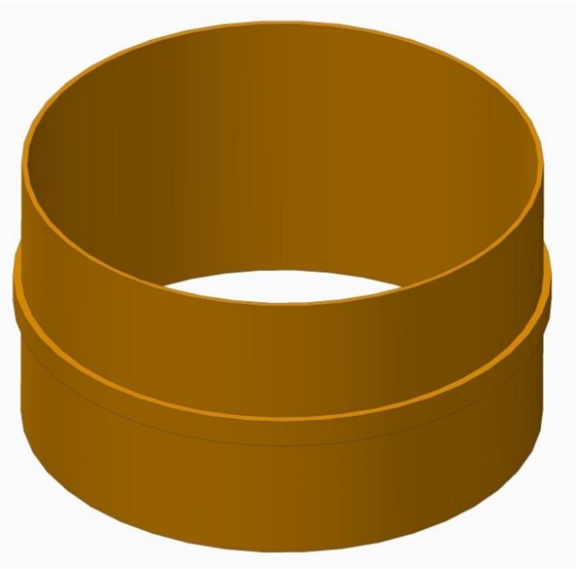


Figure 3-9: Titanium Nut FEA

lower body tube bulkhead. This puck will be printed in a complex profile to pass force over as much are as possible, while remaining as light as possible. It will be threaded after printing to ensure accuracy of the threads.

Securing the shaft to the recovery bay bulkhead will be a 7075-T6 ring nut. This will combine the functions of an anchor point for the recovery system and the fastener for the payload shaft. The whole assembly will be pre-loaded in order to be kept in tension. An overview of the calculations used to arrive at this conclusion can be found in Appendix M: Payload Shaft Pre-Load Calculations

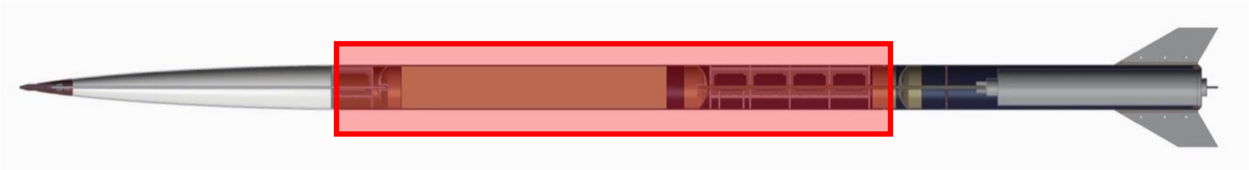
3.1.10. **Coupler Rings**



Machined aluminum slip rings will be used to secure the rocket together. The lower slip ring will be epoxied into the lower body tube for ease of use. The interface between the lower body tube and mid body tube will be retained by payload shaft tension. Therefore the slip joint section can be unusually short. It has been analyzed through FEA to ensure that it will meet the necessary structural requirements.

The slip ring between the nose cone and the mid body tube will be epoxied into the nose cone for ease of use. It must slip from the mid body tube during recovery separation and be safe for flight so it will be one body diameter long, which is a convention for hobby rocket slip joints. Shear pins will be used to ensure its security in flight, while still allowing the recovery charges to operate correctly.

3.1.11. Mid body tube and recovery bay bulkhead



The mid body tube is the most highly stressed portion of the rocket due to the preload forces from the payload shaft being additive with the motor thrust forces. They have been FEA analyzed as seen in Figure 3-10: Body Tube FEA, and the results anchored to the same destructive testing as the rest of the carbon fiber components use on Prometheus. This stress load actually drove the thickness decision for all of Prometheus's body tubes and nose cone. An unthreaded puck similar to the threaded puck used in the lower body tube bulkhead will be used to transmit force from the payload shaft into the bulkhead and body tube.

A payload bay will be located near the top of the payload shaft which will contain the Perfectflite altimeters for the recovery system. Wiring for the recovery charges will pass through small ports in the bulkhead.

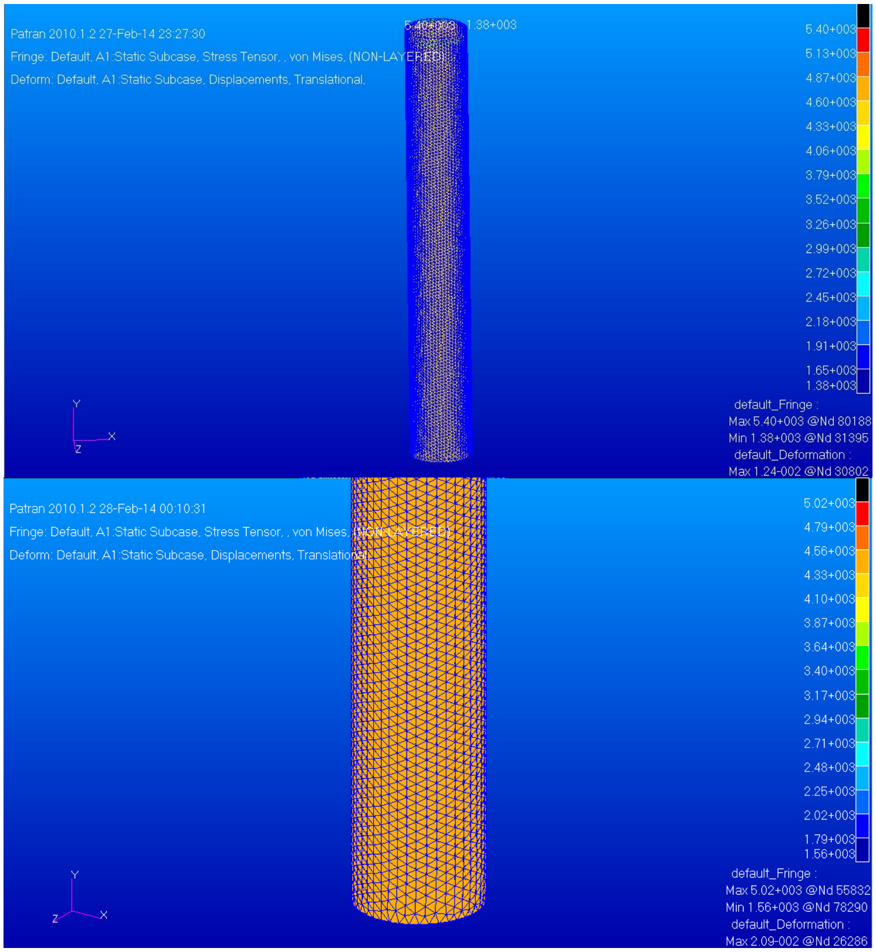
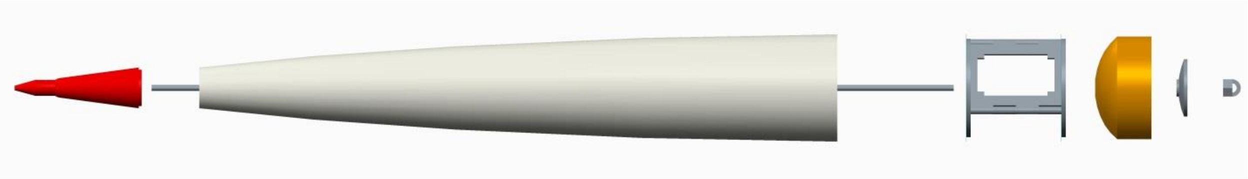


Figure 3-10: Body Tube FEA

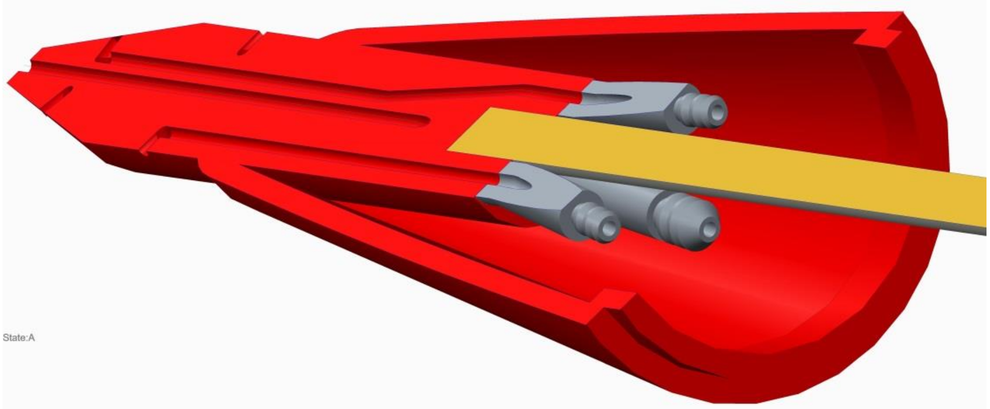
3.1.12. Nose cone and nose cone bulkhead



The nose cone will be assembled similarly to the upper and lower body tube sections with an aluminum shaft similar to the payload shaft. As shown it will pass through a radiused bulkhead similar to the others used on Prometheus, then through a payload bay section containing redundant accelerometers and gyros, a series of pressure sensors, and the pressure destabilization portion of the Nanolaunch payload and terminate in a printed titanium pitot tube assembly.

The nose cone itself will see only pressure forces in flight and acceleration forces from its own mass and the mass of its contents. It will use the same material thickness as the rest of the body tubes to ease difficulty with profile consistency due to juggling varying mold sizes and material thicknesses. It will be drastically over built.

3.1.13. **Pitot tube**



This pitot tube assembly is a unique CRW design that will allow us to measure both subsonic and supersonic velocity similar to a standard subsonic pitot probe. Printing it from titanium allows it to be lighter and more compact than any traditionally manufactured pitot probe of similar design.

3.2. Subscale Flight Results

Sub-scale flight #1 was conducted on February 8th, 2014. The CRW team successfully launched and recovered a modified ARCAS rocket kit which had been scaled to maintain the geometric profile of Prometheus, in order to fulfil the requirement for a sub-scale launch by CDR. A small portion of the raw data from the two recovery system altimeters has been included in Appendix D: Sample Altimeter Data. The launch vehicle featured an overall length of 65.8 inches, an outer diameter of 2.6 inches, a launch mass of 5.86 pounds, and was flown with a CTI I-205 motor. The vehicle reached apogee at 1,573 feet AGL approximate 10.5 seconds after motor ignition as can be seen in Figure 3-11 and Figure 3-12 : Sub-Scale Flight Data #2, below. The recovery system used for this launch was a very simple single-deploy with a 30 inch diameter main chute deployed 1 second after apogee.

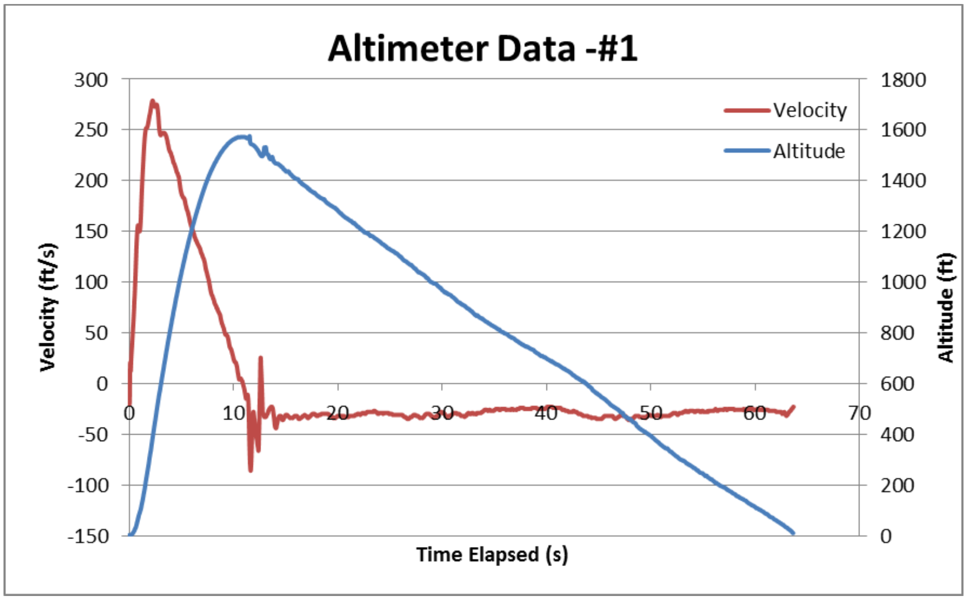


Figure 3-11 : Sub-Scale Flight Data #1

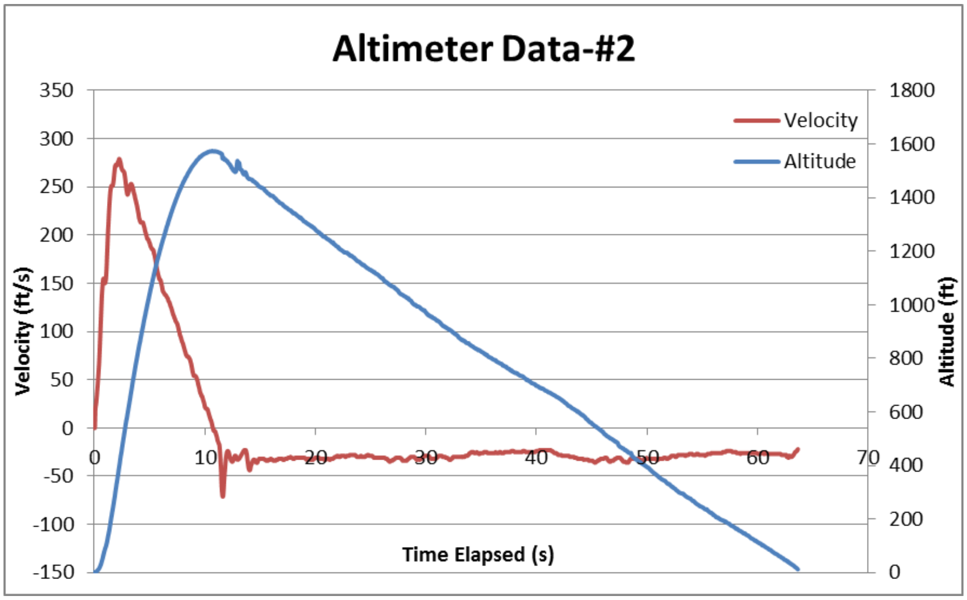


Figure 3-12 : Sub-Scale Flight Data #2

Flight simulations performed in RockSim initially indicated that the vehicle would reach a maximum altitude of 2,460 feet AGL, approximately 900 feet more than what was actually achieved.

Some last second modifications to the launch vehicle may have been the culprit behind this disparity. When the vehicle's center of gravity (CG) was measured before launch, it had shifted forward more so than anticipated in the simulations. The static stability margin reached a value of approximately 5.3 due to this shift in the CG. This would have rendered the vehicle grossly over-stable during flight, which required the team to add ballast to the base of the vehicle in order to lower the stability margin. This led to a final static stability margin of 3.2 which, while still over-stable, was deemed acceptable by the RSO. This additional vehicle mass decreased the thrust to weight ratio of the vehicle, which pitched approximately 15 degrees off vertical as it left the launch rail. If the vehicle did not have sufficient rail exit velocity, it may have been hung-up on the launch rail which reduced the maximum altitude attained.

Sub-scale launch #2 was conducted on February 22nd, 2014. This launch utilized the same vehicle as the previous, albeit with a larger motor and revised recovery system configuration. The vehicle was flown using an Aerotech I-600 and reached apogee at 4,156 feet AGL as can be seen below in Figure 3-13: Subscale #2 Flight Data.

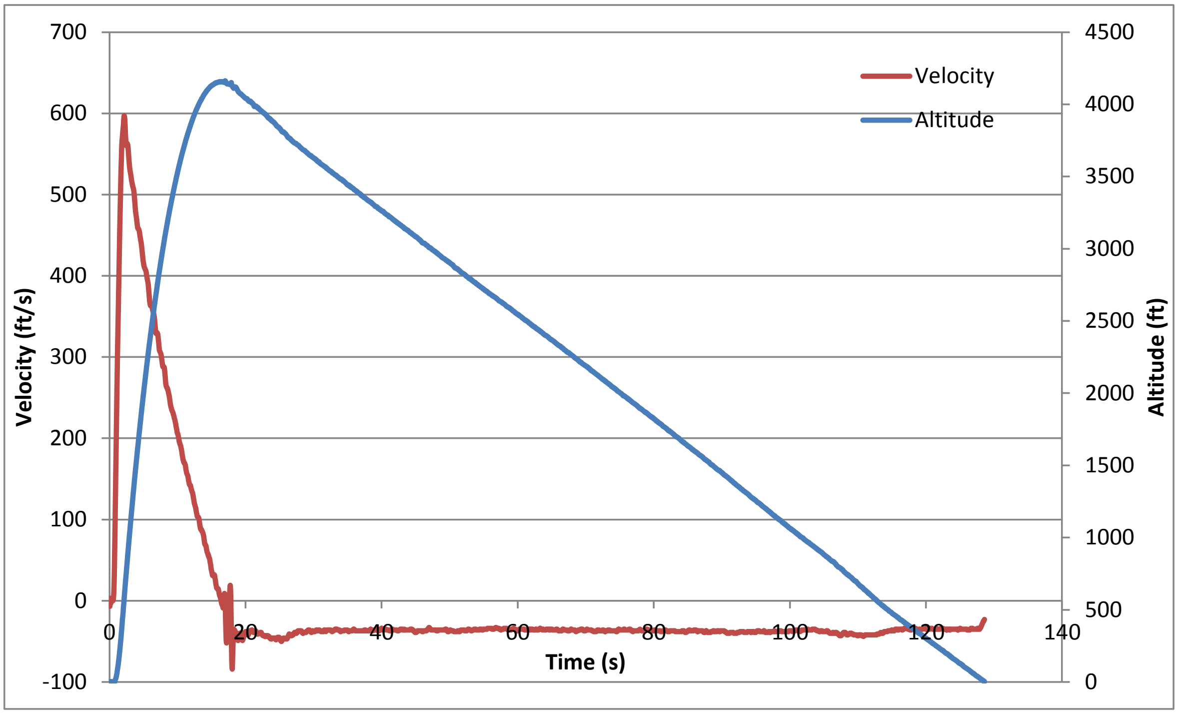


Figure 3-13: Subscale #2 Flight Data

One goal of this subscale flight was to test a parachute constructed by the CRW team and determine its effective drag coefficient from flight data collected. A 30 inch diameter in-house constructed parachute was used as the drogue for this flight, with two additional 30 inch diameter parachutes contained in a deployment bag to serve as the main parachute. The deployment bag failed to open properly at the prescribed time during the descent and the vehicle landed with a fair amount of kinetic energy. This caused the failure of an epoxy joint on one of the fins.

The results of the subscale launches have led to a redesign of the fins for Prometheus. In order to lower the predicted static stability margin, the size of the fins has been decreased to move the center of pressure forward and decrease its distance from the CG. This is intended to prevent the use of ballast in the full-scale vehicle.

3.3. Recovery Subsystem

The recovery subsystem section discusses the electrical components and analyzes how each component will work together to recover the launch vehicle. The section discusses the electrical connections, and the kinetic energy at the significant events, including the landing of the rocket. The results from testing were also discussed below.

3.3.1. Recovery System Deployment

The recovery system will use a single separation point. Using a single separation point allows for the rocket to be constructed out of longer lengths of tubing, this avoids the need for body couplers and will help reduce the risk of the body buckling or flexing during launch.

Figure 3-14 shows how the recovery section of the rocket will be packed before flight. The drogue, landing hazard detection system and the main chute will be attached to a common Kevlar suspension line. A black powder charge will set on the lower bulk head and will be used to separate the nose cone from the airframe. The main parachute will set directly above the black powder charge in a Nomex deployment bag. The landing hazard detection system will be tied to the main Kevlar shock below the main parachute, but will ride on top of the deployment bag to protect it from the black power charge. Finally the drogue will be attached to the bulkhead located in the nose cone.

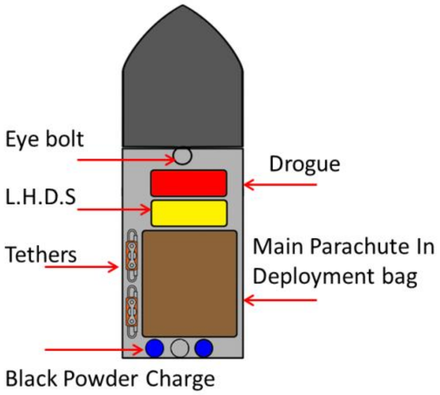


Figure 3-14 : Recovery Packing Diagram

The first event occurs two seconds after the rocket achieves apogee. The two second window is needed to simulate the zero gravity condition needed to observe dielectrophoresis. The first event in the recovery system is separation of the nose cone from the body tube. The nose cone will be separated by a black powder charge that will push the contents of the recovery bay out of the body tube. After this event occurs the rocket will use the drogue to fall at a rate of approximately 100 feet per second. This event is illustrated in Figure 3-15.

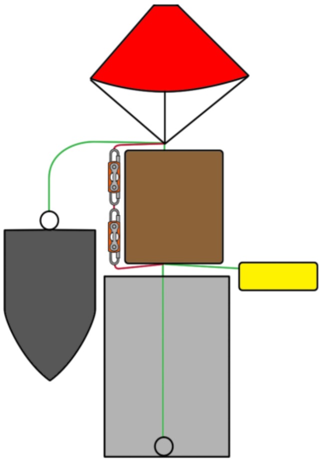


Figure 3-15 : Drogue Deployment Diagram

The rocket will fall to an altitude of 1000 feet before the second event is triggered. The second event is detonating the tethers that keep the main parachute packed into the deployment bag. The tether separation will cause the load path to be shifted, thus pulling the deployment bag free. This event is shown in Figure 3-16 and Figure 3-17.

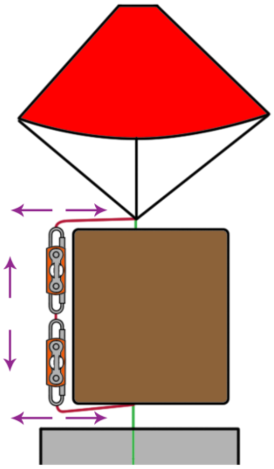


Figure 3-16 : Tether Tension Before Separation

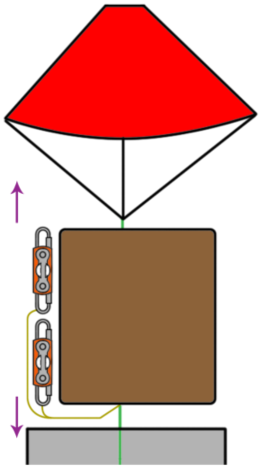


Figure 3-17 : Tension After Separation

The final stage of the recovery system is for the rocket to safely descent under the main parachute. Figure 3-18 shows how the rockets recovery system will look during this stage of recovery.

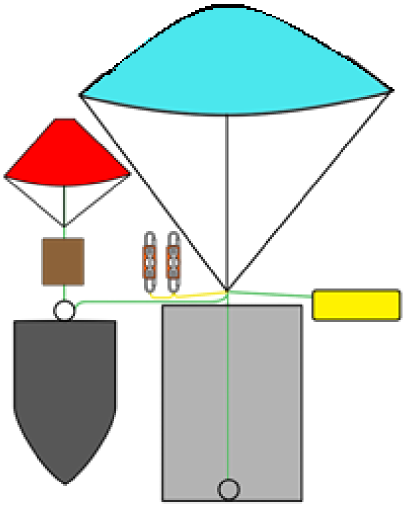


Figure 3-18 : Final Stage Deployment

Table 3-4 shows the altitude, velocity and energy of the rocket at the different stages of the deployment process

Table 3-4 : Recovery System Events

Stage of Recovery	Altitude (Ft)	Velocity (Ft/S)	Energy (ft*lb)
2 seconds after Apogee	15190.2	50.18	878.50
Theaters Separate	1000	98.58	3391.23
Landing	0	14.77	70.00

Table 3-5 shows the estimated recovery distance for varying wind speeds

Table 3-5 : Estimated Drift

Wind Speed (MPH)	Average Distance (Ft)
3 - 4	1388
8 - 14	3358
15 - 25	5692

For the recovery system deployment, the team will use a black powder charge. Assuming that the entire mass of the ejection charge will burn and be converted to gas, we can use the ideal gas law equation:

$$PV = NRT$$ Equation 3-1

Assuming the constants for 4F black powder:

$$R = 266\ in - lbf/lbm$$

$$T = 3307\ R\ (combustion\ temperature)$$

$$P = pressure\ in\ psi$$

$$V = volume\ in\ cubic\ inches$$

$$N = mass\ in\ pounds$$

Using the black powder test for the subscale launch as an example:

$$P = 20\ psi\ (to\ break\ shear\ pins)$$

$$d = 2.5\ in,\ L = 11.5\ in$$

$$V = 56.45\ in^3$$

$$N = \frac{PV}{RT} \Rightarrow N = \frac{20\times 56.45}{266\times 3307} \times 454g/lbm \Rightarrow N = 0.58g \qquad \text{Equation 3-2}$$

In the first test 0.60g of black powder was used, but the deployment was unsuccessful. The black powder charge was increased to 0.80g and the test resulted in a successful deployment.

The difference between the calculated charge and the charge necessary to result in a successful deployment could be associated with the “leaks” around the fitment of the nosecone with the rocket body. Another reason could be the friction between the parachute and the inside of the body tube, and its additional weight. For a preliminary analysis, these calculations are a good first step to begin testing on.

Using similar calculations for Prometheus:

$$P = 20\ psi\ (to\ break\ shear\ pins)$$

$$d = 4.5\ in,\ L = 27.5\ in$$

$$V = 437.4\ in^3$$

$$N = \frac{PV}{RT} \Rightarrow N = \frac{20\times 437.4}{266\times 3307} \times 454g/lbm \Rightarrow N = 4.52g \Rightarrow N' = 6.1g \qquad \text{Equation 3-3}$$

Using the black powder test as a reference, we have to increase the black powder charge close to 30% from the calculated value. This gives a charge of 6.1g of black powder for the ejection charge.

The recovery system, will use two altimeters will be used to deploy the system. It will use a pair of altimeters for redundancy, if one fails or a wire break up during the ejection the other one will be set up for back up. The drogue parachute will deploy at the apogee and the main parachute will deploy at 1000ft to avoid drifting too far away from the launch site.

The drogue will be a conical circular parachute. The conical circular parachute design was chosen because it is simple to design, proven reliable (this design is often used for personnel and cargo), easy to maintain, and easy to build. The drogue will have a canopy cone angle of 20^o and effective diameter of 30” as shown in Figure 3-19. Once the drogue is packed into the rocket it will require approximately 8.66” in length and have a packing volume of 150.7 in^3.

The main parachute will use a semi-hemispherical design. The semi-hemispherical design was chosen because it will use less material than a full hemisphere thus reducing the amount of material needed and decreasing the weight. The main parachute will have an effective diameter of 144”. The main parachute will have a packing volume of 257.4 in^3 packing volume and will need to occupy 17” in length of the body tube.

Table 3-6 shows what materials will be used in the recovery system and where.

Table 3-6 : Materials List

Part	Material
Main Canopy	Rip-stop Nylon
Thread	Polyester
Bias Tape	Polyester
Line Anchor Points	Nylon Strips (0.019” thick)
Swivels	316 SS (660lb rating)
Quick links	316 SS (950lb rating)
Chute lines	Technora (0.11” D 950lb test)
Main Shock Chord	Kevlar (1/4” D 1200 lb test)
Eyebolts	Steel (500lb rating)
Blast cloth and Deployment Bag	Nomex

The drogue gore calculations were indicated in Table 3-7 below. The table shows the canopy surface area (S_0), number of gores (N_0), gore area (S_g), flat canopy gore angle (γ), canopy cone angle (μ), conical gore area (β), width of gore (e_s), height of gore (h_s), length of vent (e_v^*), length of suspension lines (L_e).

Table 3-7 : Drogue Gore Parameters

Parameter	Drogue
S_0 (inches squared)	706.858
N_0 (Non-dimensional)	10
S_g (inches)	23.562
γ (degrees)	36
μ (degrees)	20
β (degrees)	35.99
e_s (inches)	9.887
h_s (inches)	15.215
e_v^* (inches)	0.109
L_e (inches)	28.5

The canopy surface area was found using the equation

$$S_0 = \frac{\pi D_0^2}{4} \qquad \text{Equation 3-4}$$

Where D_0 is the final constructed diameter of the parachute. The gore area was determined by the equation

$$S_g = \frac{S_0}{N_0} \qquad \text{Equation 3-5}$$

Where N_0 is the number of gores used to construct the parachute's canopy. The flat canopy gore angle was computed from the following equation

$$\gamma = \frac{360}{N_0} \qquad \text{Equation 3-6}$$

The conical gore angle is determined by the equation

$$\beta = 2sin^{-1}\left[cos\mu\left(sin\frac{180}{N_0}\right)\right] \qquad \text{Equation 3-7}$$

Where μ is the canopy cone angle, if the canopy is going to be a flat plate a cone angle of zero degrees is assumed. After finding the flat canopy gore angle, and conical gore angle the height, width, and size of the vent hole can be determined. The height of the gore is expressed as the equation

$$h_s = \sqrt{\frac{S_0}{\tan\left(\frac{\gamma}{2}\right) cos(\mu)\, N_0}} \qquad \text{Equation 3-8}$$

The width of the gore is expressed as

$$e_s = 2h_s * tan\left(\frac{\beta}{2}\right) \qquad \text{Equation 3-9}$$

The vent hole size can be found by the equation

$$e_v^* = 1.1e_v \qquad \text{Equation 3-10}$$

Where e_v is represented by the equation

$$e_v = D_0 * 0.01 \qquad \text{Equation 3-11}$$

The final component needed to finish the mathematical models of the gore's design is the length of the suspension lines. The length of the suspension lines can be found from the equation

$$L_e = 0.85\ to\ 1.5 * D_0 \qquad \text{Equation 3-12}$$

For the gore design for Prometheus a scalar of 0.95 was used to calculate the size of the suspension lines. 0.95 was selected because it is the scalar used for extended skirt designs. This allows us to easily add a skirt to the parachute if it is determined to be needed after test launches.

Figure 3-19 shows what the gores will look like for the 12" drogue (shown in blue) and 144" main chute (shown in red).

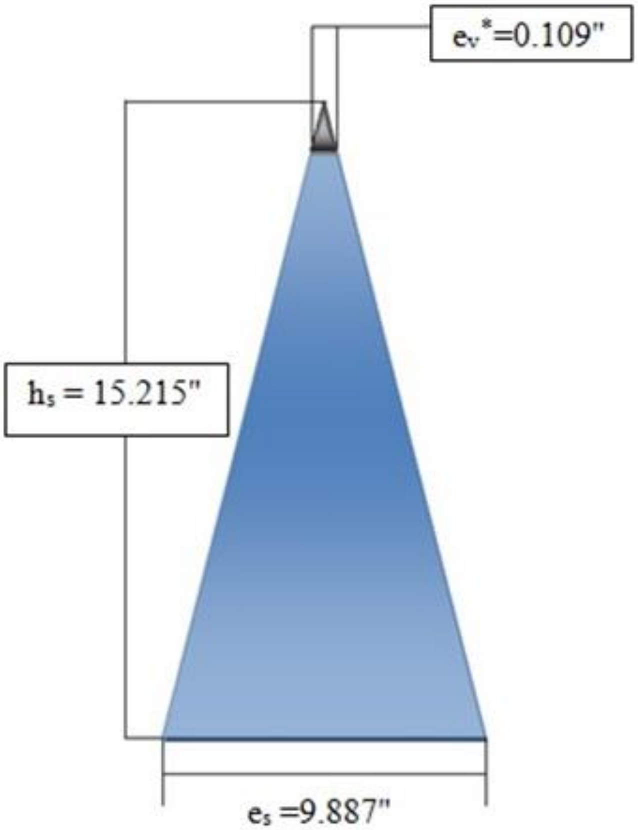


Figure 3-19 : Drogue Gore

The main parachute gore calculations will be based on a 12’ diameter. The gore sizes were calculated using the following equations.

$$R' = \frac{d}{2}$$ Equation 3-13

Where d is the parachutes diameter. From R$'$ the circumferences of the final parachute is calculated using the equation

$$C = 2 * \pi * R'^2$$ Equation 3-14

Knowing the circumference allows the length of the gores to be calculated by the following equation

$$L = \frac{\pi}{3} * R$$ Equation 3-15

Where R is

$$R = \frac{2}{\sqrt{3}} * R'$$ Equation 3-16

The width of the gore is calculated by the equation

$$W = \frac{C}{N}$$ Equation 3-17

where N is the number of gores. The final perimeter that is needed to model the gore is theta

$$\theta = \frac{360}{N}$$ Equation 3-18

These equations give a gore pattern shown in Figure 3-20.

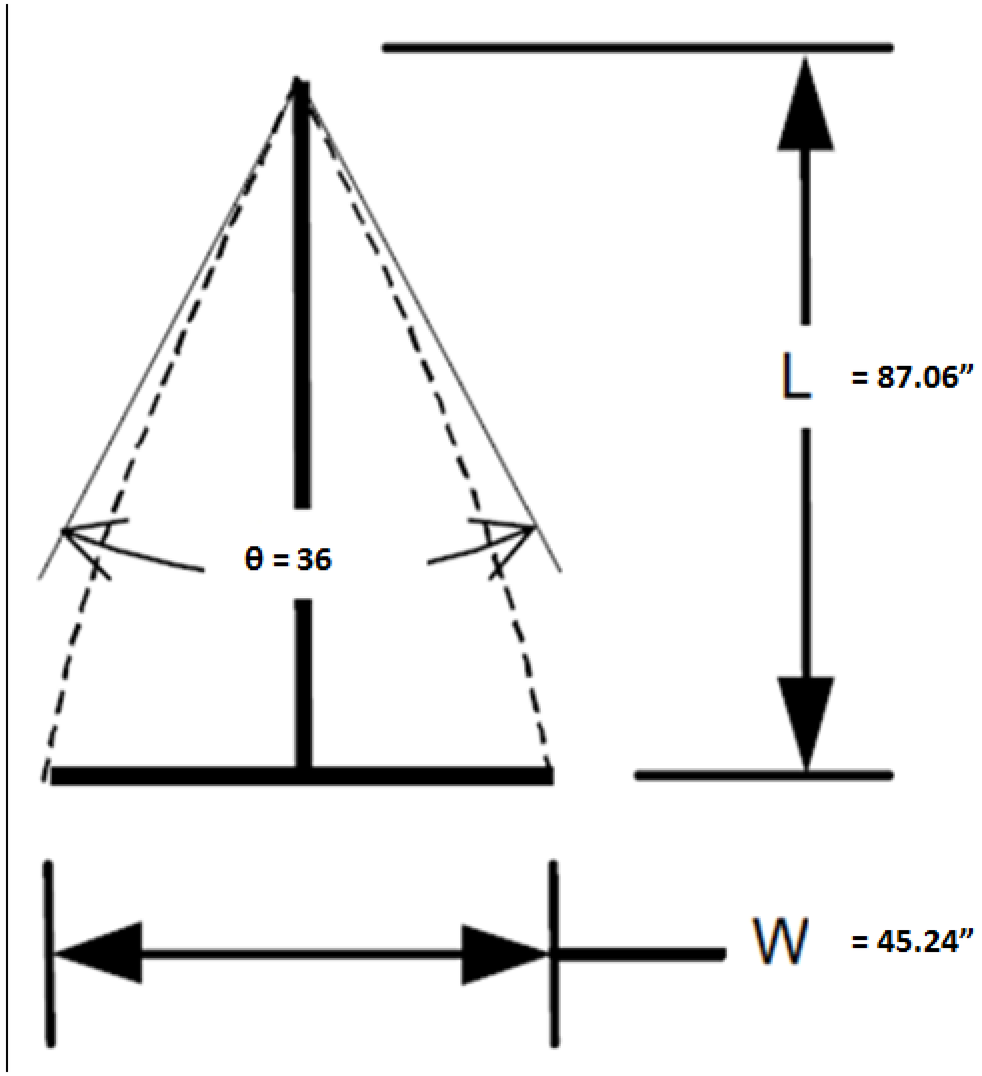
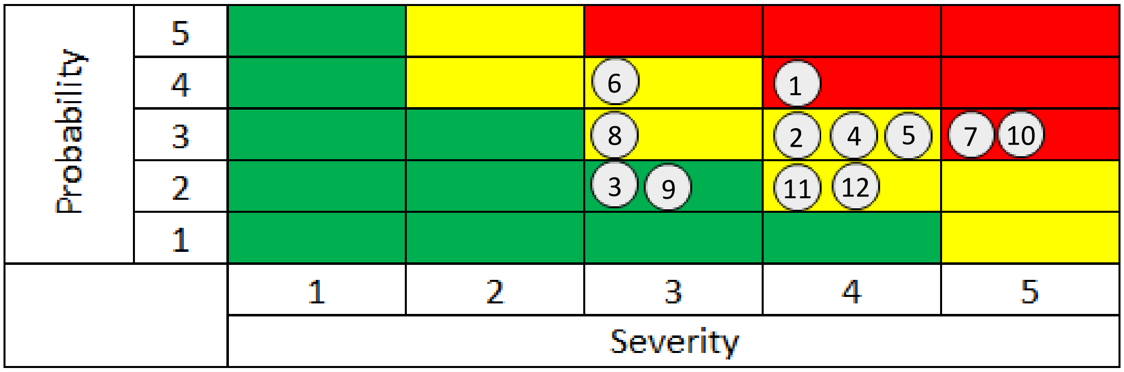


Figure 3-20 : Main Parachute Gore

The manufacturing of the chutes will be performed in-house by CRW team members. Each gore will be made of rip-stop nylon. Rip-stop nylon was chosen over silk and standard nylon, because rip-stop nylon will stop tears from growing in the parachute if a powder burn occurs. Rip-stop nylon achieves this property by using a special weave when it is manufactured. The gores will be connected to one another using a two-needle, 3/8" French fell seam. A 1/4" needle gauge will be used with nylon tread. The gores will be double seamed together in order to help distribute the loading on the fabric. Using a double seam will also provide some safety, because if one seam fails there will be a second seam stopping the gores from separating and causing the parachute from falling apart. The vent hole will polyester bias tape sewn around its diameter, so that the loading will be evenly distributed and stop the gores stitching from falling apart at the crown of the chute. Further reinforcement will be added at the base of the overlapping sections of the gores. This reinforcement will be a strip of 0.019" thick nylon. This nylon strip will also be an anchoring point for the suspension line. The suspension line will be 0.11" diameter Technora with failure strength of 950 lbs. Technora was selected because it is produced from aramid fibers. Aramid fibers are temperature resistant and strong under axial loading, and these two properties make aramid an ideal fiber for suspension lines. The suspension lines will be sewn directly into the nylon strip using a fell radial seam to ensure that they do not break free during landing.

Table 3-8 : Risk Probability



Probability	5	🟩	🟨	🟥	🟥	🟥
	4	🟩	🟨	🟨 ⑥	🟥 ①	🟥
	3	🟩	🟩	🟨 ⑧	🟨 ② ④ ⑤	🟥 ⑦ ⑩
	2	🟩	🟩	🟩 ③ ⑨	🟨 ⑪ ⑫	🟨
	1	🟩	🟩	🟩	🟩	🟨
		1	2	3	4	5
		Severity				

Table 3-9 : Potential Hazards

Ref #	Potential Hazard	Probability	Severity	Impact	Mitigation
1	Altimeter wire breaks	4	4	Black powder charge may not discharge, and lack of recorded data	Check wires for possible breaks/fatigue prior to launch
2	Shock chord breaks	3	4	Rocket reenters with high landing velocity	Purchase strong shock cord, and test methodically
3	Deployment bag failure	2	3	Parachute will not deploy, rocket reenters with high landing velocity	Test bag deployment bag technique prior to launch
4	e-match breaks free from powder charge	3	4	Parachute will not deploy, rocket reenters with high landing velocity	Test e-match connection to ensure solid interface
5	e-match breaks free from altimeter	3	4	Parachute will not deploy, rocket reenters with high landing velocity	Test e-match connection to ensure solid interface
6	Zippering	4	3	Severed Body Tube	Test shock cord deployment avoid zippering
7	Sharp edges around body tube	5	3	Damage to shock chord or altimeter wires.	Use Nomex sleeves to protect wires and shock chord.
8	Parachute bag fails to deploy	3	4	Vehicle undergoes a high energy impact.	Ground testing of all recovery system components.
9	Tension break	2	3	Recovery system detaches from rocket. Parts land ballistically.	Proof loading of all recovery system components.
10	Separation failure	3	5	Ballistic landing/ total vehicle loss.	Ejection charge testing with full-scale vehicle.
11	Stitching failure	2	4	Vehicle undergoes high energy impact due to parachute failure.	Ground and flight testing of parachute design.
12	Parachute/parachute bag fire	2	5	Vehicle undergoes high energy impact due to parachute failure.	Use of Nomex blast cloth to prevent burns to parachutes.

As shown in Table 3-8 and Table 3-9 : Potential Hazards, a high risk of failure originates from the wiring of the altimeter and e-matches. If a wire or e-match is pulled free the black powder will not have a source of ignition, and will result in the rocket's recovery system failing to deploy safely. If the rocket's recovery system does not deploy the rocket will free fall and potentially cause physical damage to personnel and views as well as property damage. In order to reduce the risk of the wires failing they will be ran through the center of a shock chord, and this will prevent the wires from rubbing and breaking due to sharp edges on the body tube. To prevent the wires from being pulled free from the altimeters or tethers a strip of electrical tape will be placed over the points that the wires go into. This will provide additional security by preventing the wires from coming loose during the deployment process. Finally, the wires will be left intentionally to long. Leaving the wires long will allow them to move slightly so that they are not pulled from any connection point.

Table 3-9 : Potential Hazards also shows that shock cord failure is a strong concern. If the shock cord fails the rocket will fall in an unpredictable manner in multiple pieces. The first action in avoiding the shock chord from failing is using an oversized main shock chord. The main shock chord will be made of one quarter inch diameter Kevlar rope rated to carry a load of 1200 lb. Kevlar was selected because it will resist zippering. A final spot that could cause the shock chord to fail is the sharp edges around the carbon fiber body. When a rocket falls it has a tendency to rotate. The shock cord will be cut if the rocket rotates and rubs the shock cord with the sharp edges of the body tube. In order to reduce this risk an insert will be placed along the leading edge of the body tube. This insert will have a smooth rounded edge, so if the shock cord rotates no damage will happen to it.

Another concern is that the rocket will fail to separate. If the rocket does not separate it will return in a ballistic manner. This is unacceptable because the rocket will have potential to cause great harm to anybody attending the launch. In order to reduce this risk extensive black powder testing will be conducted. The black powder test will occur under the supervision of trained personnel.

A final place that failure could occur is in the construction and materials used in the recovery system. If the materials fail the parachute will be unsafe and possibly become ineffective. If the parachute becomes ineffective during flight the rocket has the potential to return with a higher than desired amount of kinetic energy. This could result in harm to people, personal property, and destroy the rocket. In order to reduce damage caused by the black powered the deployment bag will be made of Nomex. Nomex is flame retardant and will protect the main chute from powder burns. The main chute will be made of rip-stop nylon. Rip-stop nylon will stop burns from causing large rips in the fabric if the Nomex doesn't fully protect the main chute. The parachute could potentially fail due to a bad stitching. In order to reduce the risk of failure due to stitching each seam will be double stitched providing redundancy to the seams.

Sub Scale Results

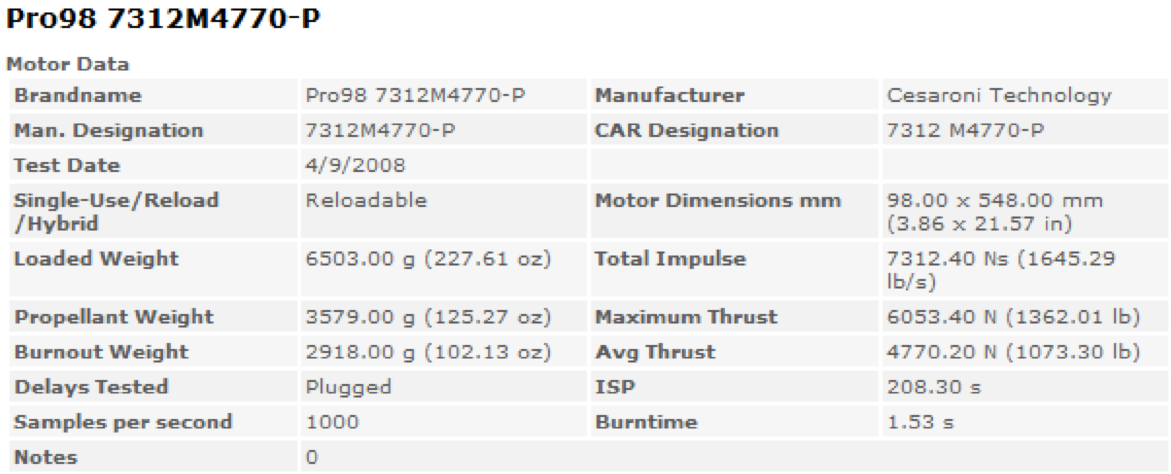
A drogue with an effective diameter of 27.5" was produced by the team for the February 22nd launch. The equations stated above were used to construct the gores. The drogue was supposed to be 30" however the equations do not allow for seam allowance and resulted in the drogue being slightly undersized. For future gore patterns an additional 5/8" will be added to each section that will be attached together. The drogue successfully deployed, and data from a perfect fight altimeter collected data during the landing. The perfect flight data showed that the in house made parachute had a C_d of 0.71.

3.4. Mission Performance Predictions

Performance Criteria	Relation to Competition/Payload Requirements
Achieve Supersonic Speeds (M > 1.2)	1. Supersonic Sensors for NanaLaunch1200 2. Supersonic Effects on Coatings
Maintain 20,000 ft. AGL Ceiling	Mission Requirement set forth by competition parameters.
Landing Impact Energy ≤ 75 ft-lbf	Safety Requirement per NAR Regulations of High Powered Rocketry
Minimal Vehicle Repair and Reset between Flights	Regulation per NASA Competition for theoretical quick turnaround time.
Delayed Drogue Deployment (Apogee + 1sec)	Required for dielectrophoresis micro-gravity experiment
Impact Speed Less than 8 ft/s	Requirement of a custom built recovery system with Prometheus's requirement of a softer landing in salt flats to prevent vehicle damage.

3.5. Propulsion System

Prometheus is a slender rocket with a length of 121.5 inch (~10 feet) and 4.59 inch outer diameter. The motor case is a three grain Pro98 designed for VMAX propellant mixture. Figure 3-21 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 3-21: Motor Statistics

This level 3 NAR certified motor features a large maximum thrust and a short burn time. This will induce a large acceleration during powered flight of approximately 40Gs for a pre-launch weight of 34 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 34 pounds, the thrust to weight ratio is 33.

Figure 3-22 is the characteristic thrust curve provided by the manufacturer, Cesaroni Technology Incorporated.

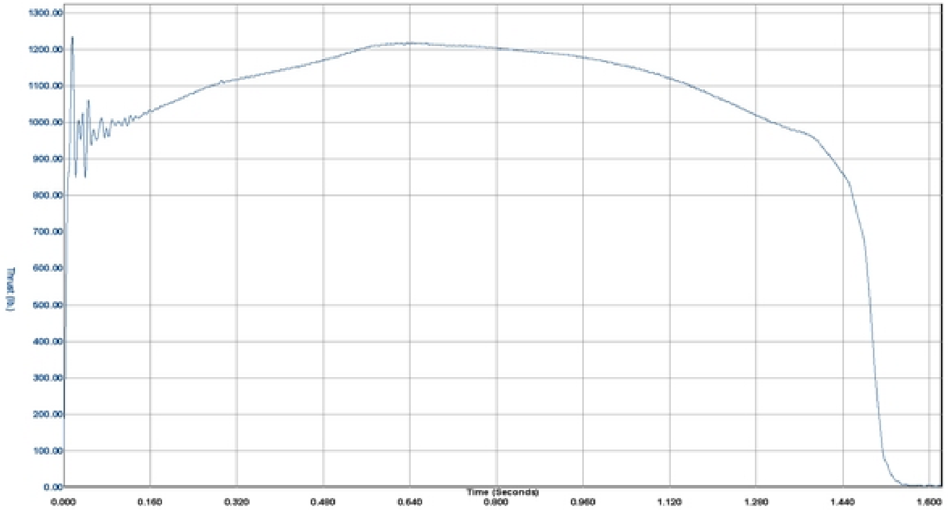


Figure 3-22: Thrust Curve

3.6. Flight Prediction

Figure 3-23 shows a predicted flight path for *Prometheus*.

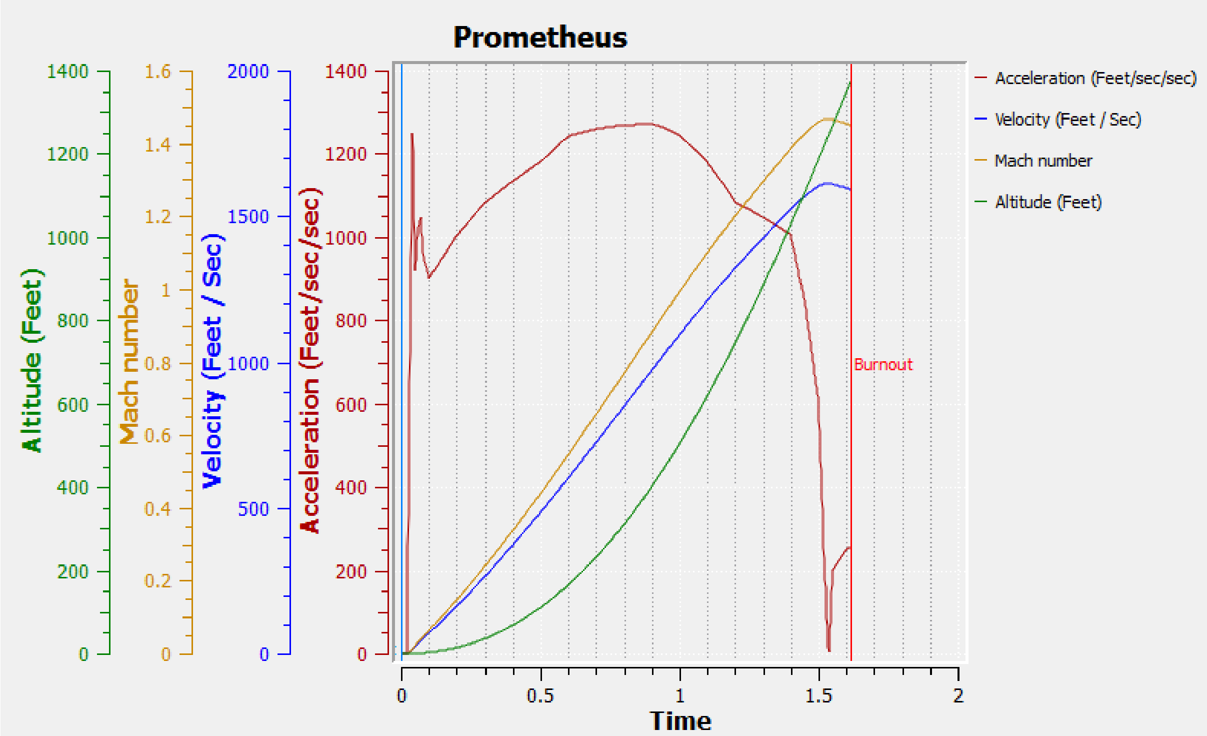


Figure 3-23: Trajectory Through Burnout

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 3-24 shows the vehicle's flight path before apogee. The target burnout mass of 26 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 3-24 details the flight pattern up to apogee.

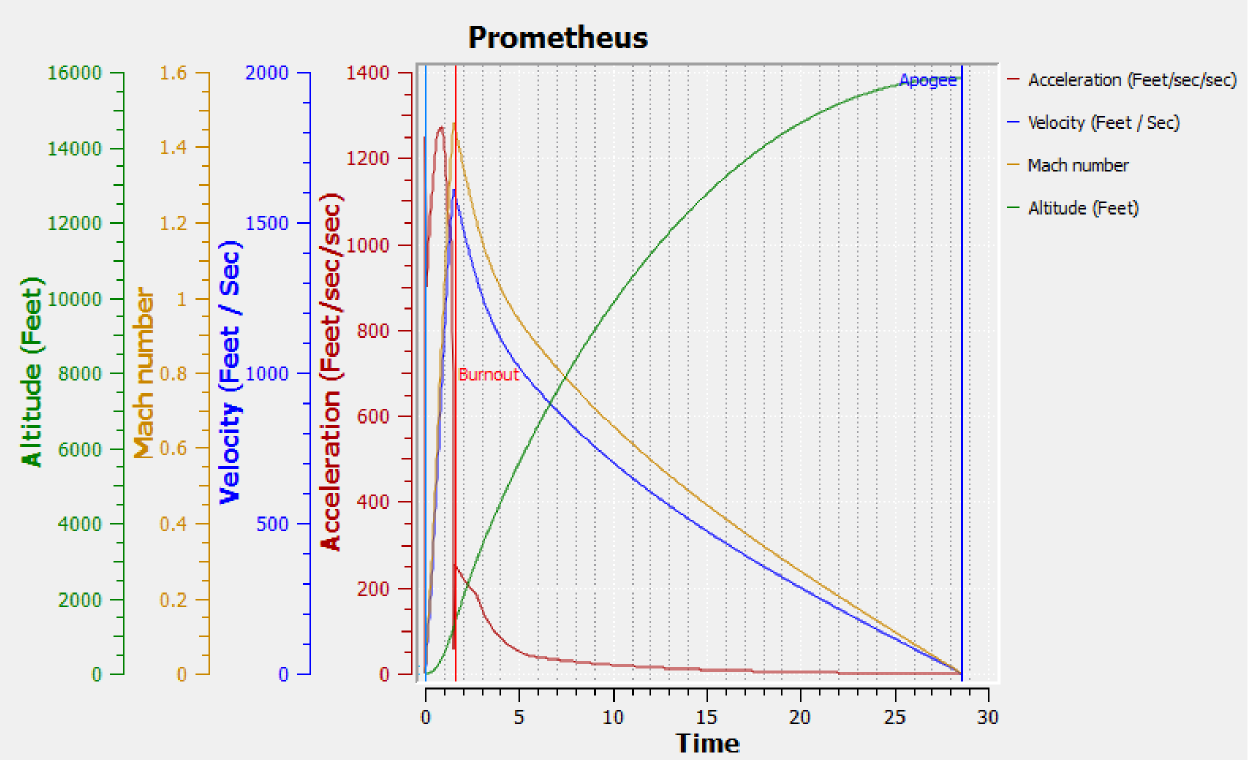


Figure 3-24: Vehicle Trajectory Through Apogee

Figure 3-25 details the powered flight which induces the acceleration in the vehicle.

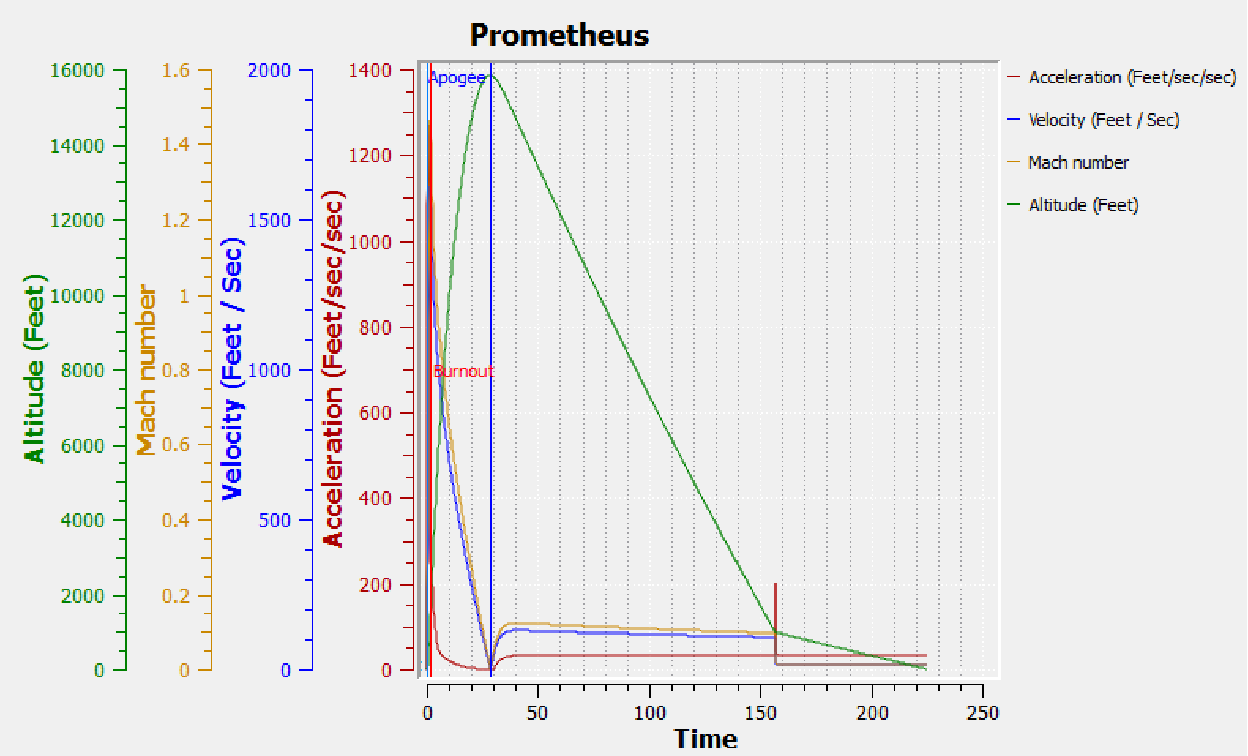


Figure 3-25: Vehicle Trajectory Through Landing

Figure 3-25 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 3-22. There is a small startup burn time in the motor during which the thrust produced isn't large enough to live the rocket.

3.6.1. **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	120	ft/s
Max Speed	1960	ft/s
Max Kinetic Energy	1.275E6	ft-lbf
Time To Apogee	28.61	seconds
Apogee	15841	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	14	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 Patran will confirm whether the design will be able to withstand the predicted loads.

3.6.2. **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.

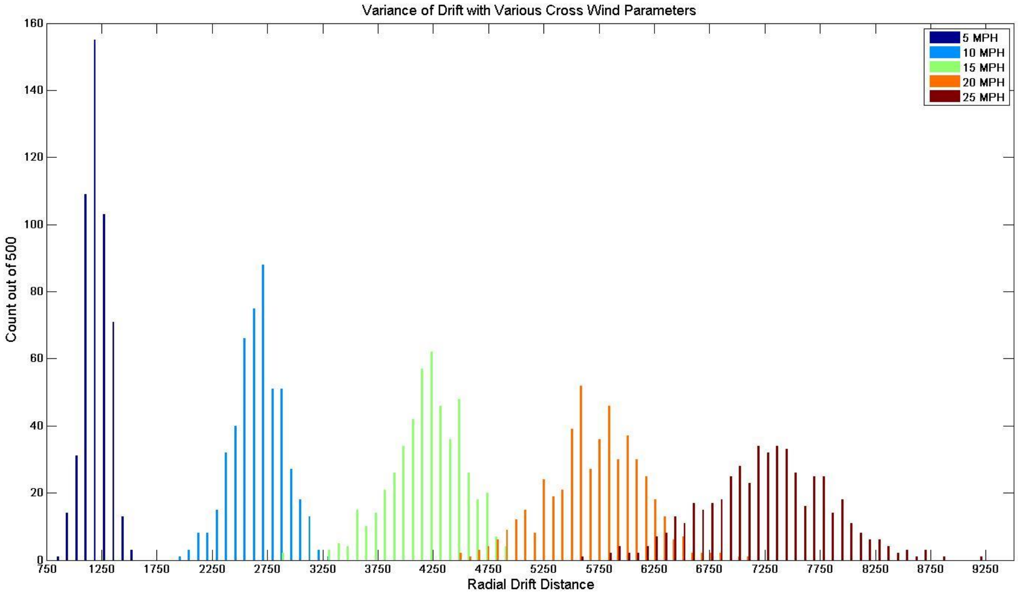


Figure 3-26: Radial Translation Vs Time

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.

3.6.3. Monte Carlo Simulations

MATLAB scripts were developed to obtain a multivariate input to a complex, non-linear, 5th order system for two dimensional motion that defines the trajectory of *Prometheus*. Key input variables selected were drag coefficient variables, launch pad mass and decent-triggered events at which the main and drogue parachutes were programmed to deploy. Table 3-10: Monte Carlo Variables details the selected variables of variance.

Table 3-10: Monte Carlo Variables

Variable	Definition	μ	σ
Cd	The estimated drag curve based on Mach number estimated from RockSim® V9 simulations.	Tabular Input	2.5%
dCd	The estimated coefficient of drag for the 24 inch conic drogue chute. This chute is designed in the idea for a fast high altitude descent for a reduced flight time.	0.71	2.5%
dCm	The estimated coefficient of drag for the 15 foot hemispherical main chute.	1.2	2.5%
Thrustm	A multiplier applied to the defined thrust curve for the motor to either increase or decrease thrust magnitude.	1.0	1%
WM	The wet mass of the vehicle sitting on the launch pad. This	30.8 lb	2%

	will affect the total trajectory.		
dTime	Time after launch at which the recovery system deploys the main.	27 sec	0.5 sec
dAlt	The Altitude at which the drogue deploys. This acts as a failsafe in the event apogee is achieved much faster than predicted.	15,000 ft	50 ft
dMain	The Altitude at which the recovery system deploys the Main Parachute. This will engage to provide a soft landing.	750 ft	50 ft

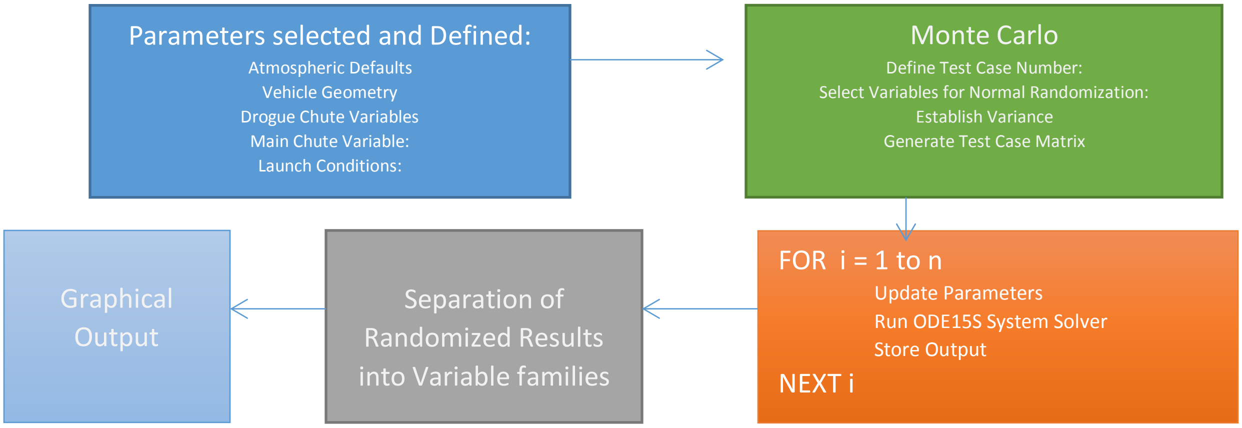
The values chosen for both the mean value and standard deviation were chosen arbitrarily as estimates. However, it allows for an in depth look at the possibilities regarding the unknown variance on launch day and in the design system.

Charger Rocket Works applied a through routine to observe system variance. After observing little change between 500 and 1000 cases in the average output, the team decided to optimize the time of simulation and run 500 test cases. Originally, 1000 cases were to be randomly generated using MATLAB's built in, multivariable randomization function called "mvnrnd". It takes an input of a vector of averages and a vector of corresponding standard deviations to generate a normally distributed table that has dimensions in rows of the number of cases and columns in the number of input variables. Each case running in serial took approximately 450 seconds to run.

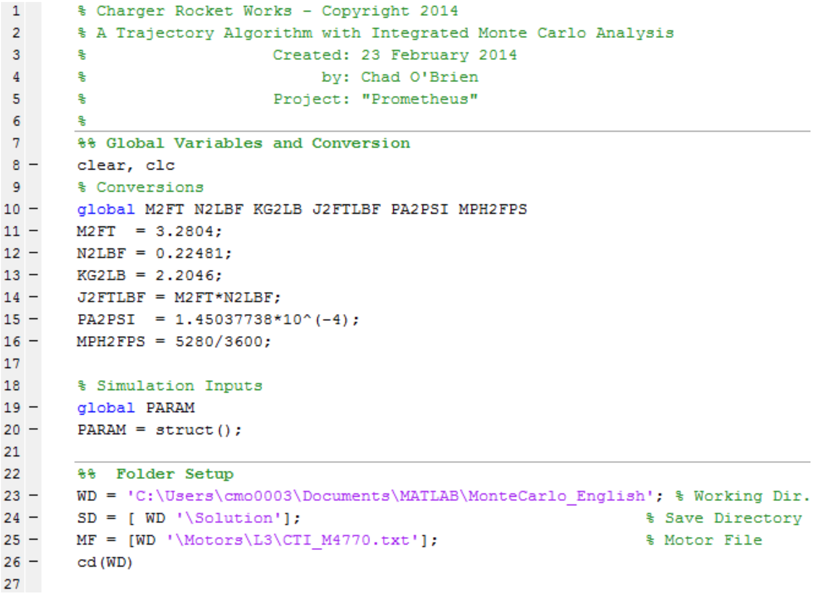
MATLAB Code Architecture

MATLAB is a powerful tool capable of cross discipline numerical analysis that the Charger Rocket Works team uses for predictions. Below is a flow diagram simplification of the code, including the primary section groups of the process.

Table 3-11: Monte Carlo Flow Diagram



Selected Parameters and Definitions:



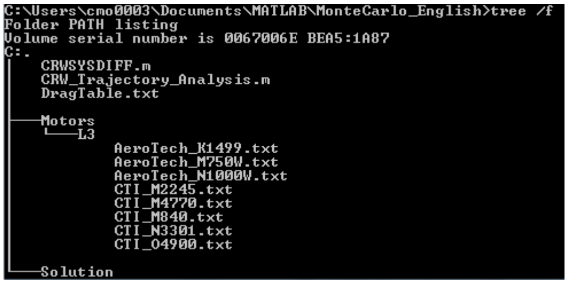
```matlab
% Charger Rocket Works - Copyright 2014
% A Trajectory Algorithm with Integrated Monte Carlo Analysis
%                   Created: 23 February 2014
%                        by: Chad O'Brien
%                   Project: "Prometheus"
%
%% Global Variables and Conversion
clear, clc
% Conversions
global M2FT N2LBF KG2LB J2FTLBF PA2PSI MPH2FPS
M2FT  = 3.2804;
N2LBF = 0.22481;
KG2LB = 2.2046;
J2FTLBF = M2FT*N2LBF;
PA2PSI  = 1.45037738*10^(-4);
MPH2FPS = 5280/3600;

% Simulation Inputs
global PARAM
PARAM = struct();

%%  Folder Setup
WD = 'C:\Users\cmo0003\Documents\MATLAB\MonteCarlo_English'; % Working Dir.
SD = [ WD '\Solution'];                                    % Save Directory
MF = [WD '\Motors\L3\CTI_M4770.txt'];                      % Motor File
cd(WD)
```

Figure 3-27: Example Code for Setup

Figure 3-27 shows the header information for the latest code developed to provide the optimized solver inputs and definitions. This section contains global parameters which are used in conversion and directory tree setup. When handling the volume of data that could be generated from a Monte Carlo simulation, it is important to have a well-structured file system as shown in Figure 3-28. The directories have been set up to provide rapid iteration with custom folder designations as well as a library of Thrust Curves for Various Motors.



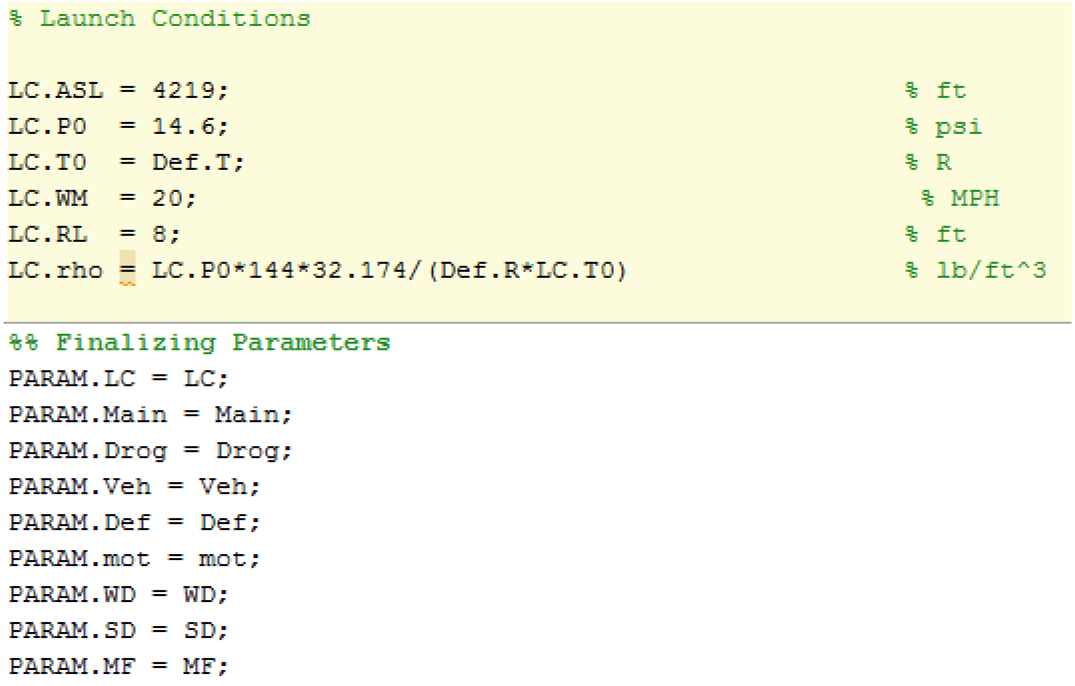
```
C:\Users\cmo0003\Documents\MATLAB\MonteCarlo_English>tree /f
Folder PATH listing
Volume serial number is 0067006E BEA5:1A87
C:.
│   CRWSYSDIFF.m
│   CRW_Trajectory_Analysis.m
│   DragTable.txt
│
├───Motors
│   └───L3
│           AeroTech_K1499.txt
│           AeroTech_M750W.txt
│           AeroTech_N1000W.txt
│           CTI_M2245.txt
│           CTI_M4770.txt
│           CTI_M840.txt
│           CTI_N3301.txt
│           CTI_O4900.txt
│
└───Solution
```

Figure 3-28: Directory Tree

In order to properly maintain a large number of variables while not hindering any possibilities in using a large subset of variables for the Monte Carlo simulation, MATLAB's convenient structure system was used to provide a characteristically grouped, single input, dynamic variable.

Input Parameters

Figure 3-29 is example code that details how structure variable system works. Under "Launch Conditions" think of the "LC" as the parent object and the "ASL", "P0", T0", "WM", "RL", and "rho" as children or objects in the container "LC". This allows for variable name reuse without change the value.



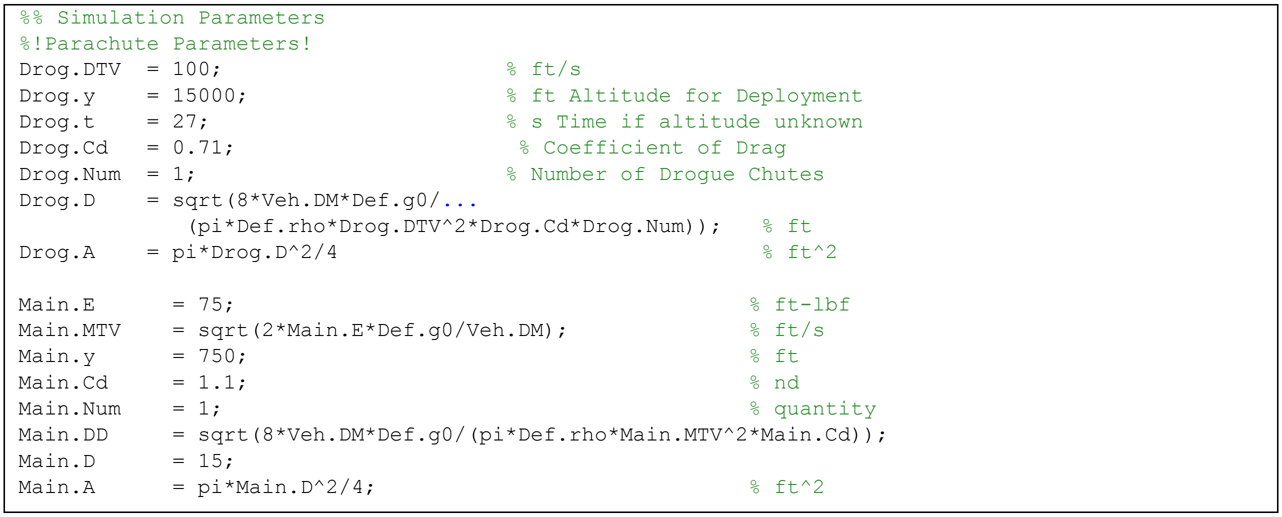
```
% Launch Conditions

LC.ASL = 4219;                                                  % ft
LC.P0  = 14.6;                                                  % psi
LC.T0  = Def.T;                                                 % R
LC.WM  = 20;                                                     % MPH
LC.RL  = 8;                                                     % ft
LC.rho = LC.P0*144*32.174/(Def.R*LC.T0)                         % lb/ft^3

%% Finalizing Parameters
PARAM.LC = LC;
PARAM.Main = Main;
PARAM.Drog = Drog;
PARAM.Veh = Veh;
PARAM.Def = Def;
PARAM.mot = mot;
PARAM.WD = WD;
PARAM.SD = SD;
PARAM.MF = MF;
```

Figure 3-29: Example Code for Setup

Not only does it permit common relative naming scheme for variables, but it gives greater control over which variables are used in the Monte Carlo simulations. Looking at “Finalizing Parameters”, all the main structure parents are loaded into a single structure called “PARAM” which will be passed as the input variable container.



```
%% Simulation Parameters
%!Parachute Parameters!
Drog.DTV   = 100;                      % ft/s
Drog.y     = 15000;                    % ft Altitude for Deployment
Drog.t     = 27;                       % s Time if altitude unknown
Drog.Cd    = 0.71;                      % Coefficient of Drag
Drog.Num   = 1;                        % Number of Drogue Chutes
Drog.D     = sqrt(8*Veh.DM*Def.g0/...
             (pi*Def.rho*Drog.DTV^2*Drog.Cd*Drog.Num));    % ft
Drog.A     = pi*Drog.D^2/4                                 % ft^2

Main.E       = 75;                                        % ft-lbf
Main.MTV     = sqrt(2*Main.E*Def.g0/Veh.DM);              % ft/s
Main.y       = 750;                                       % ft
Main.Cd      = 1.1;                                       % nd
Main.Num     = 1;                                         % quantity
Main.DD      = sqrt(8*Veh.DM*Def.g0/(pi*Def.rho*Main.MTV^2*Main.Cd));
Main.D       = 15;
Main.A       = pi*Main.D^2/4;                             % ft^2
```

Figure 3-30: Variable Storage Structure

Figure 3-30 separates out the 6 main variable families; Defaults (“Def”), Motor (“mot”), Vehicle (“Veh”), Drogue Chute (“Drog”), Main Chute (“Main”), and Launch Conditions (“LC”).

Monte Carlo Simulation Setup

The next item is to identify key variables which have a large effect in the simulation. Those variables are items that directly affect high order term in the system such as drag forces. Figure 3-31:

Monte Carlo Simulation Variables identifies the selected variables and assumes the input values are the system averages.

```
function mcrun = mc_run(Cdt, runname)
global PARAM
MCPARAM = PARAM;
mu_Cdm          = PARAM.Def.Cdm;
mu_Thrustm      = PARAM.mot.Thrustm;
mu_WM           = PARAM.Veh.WM;
mu_dCd          = PARAM.Drog.Cd;
mu_mCd          = PARAM.Main.Cd;
mu_dTime        = PARAM.Drog.t;
mu_dAlt         = PARAM.Drog.y;
mu_mAlt         = PARAM.Main.y;
sig_dTime       = 0.5;
sig_dCd         = 0.025*mu_dCd;
sig_mCd         = 0.025*mu_mCd;
sig_dAlt        = 50;
sig_mAlt        = 50;
sig_Cdm         = 0.025*mu_Cdm;
sig_Thrustm     = 0.01*mu_Thrustm;
sig_WM          = 0.02*mu_WM;
num = 500;
TC = mvnrnd([mu_Cdm mu_Thrustm mu_WM mu_dCd mu_mCd mu_dTime 
mu_dAlt mu_mAlt],...
    [sig_Cdm sig_Thrustm sig_WM sig_dCd sig_mCd sig_dTime 
sig_dAlt sig_mAlt],num);
```

Figure 3-31: Monte Carlo Simulation Variables

The averages (mu_<variable>) are redefined into local variables and a relative standard deviation(sig_<variable>) is either generated from a percent error of the average variable or an estimated input. Once the number of cases is defined, the standard deviations and averages are loaded into MATLAB’s multivariate random (mvnrnd) function which creates a matrix of cases that has dimensions of rows the number of cases by columns in quantity of variables selected. For the case shown in Figure 3-30, the matrix “TC” is size 500 by 8.

The Monte Carlo Simulation

```
for i = 1:num
    waitbar(i/num,h)
    MCPARAM.Def.Cdm      = TC(i,1);
    MCPARAM.mot.Thrustm = TC(i,2);
    MCPARAM.Veh.WM       = TC(i,3);
    MCPARAM.Drog.Cd      = TC(i,4);
    MCPARAM.Main.Cd      = TC(i,5);
    MCPARAM.Drog.t       = TC(i,6);
    MCPARAM.Drog.y       = TC(i,7);
    MCPARAM.Main.y       = TC(i,8);
    y0 = zeros(5,1);
    y0(1)  = MCPARAM.Veh.WM;
    y0(2)  = MCPARAM.LC.ASL;
    options = odeset('MaxStep',2,...
        'NormControl','On',...
        'RelTol',1e-6,...
        'AbsTol',1e-6,...
        'Events',@(t,y)CRWEvents(t,y,MCPARAM));
    mid_mcrun = ode15s(@(t,y)CRWDIFF(t,y,Cdt, MCPARAM),[0
300],y0,options);
```

Figure 3-32: Iterative Variable Setup

Figure 3-32 shows the process which during which the iterative data set is updated from the test case matrix (“TC”) mentioned previously. The local structure MCPARAM is loaded into the solver with the updated variables. The process updates the selected variable every iteration therefore providing the variance in inputs to the system.

The Physics Solver

Over the course of the project, various methods to analyze trajectory have been employed. The simplest models predicted only altitude with a 3rd order system while the most complicated system predicted 2-D trajectory with atmospheric temperature and pressure data included in a 7th order system. The model employed here is a simpler 5th order system where the atmospheric data has been curve fit as a function of altitude.

Motion is defined by Newton’s mechanical motion laws where the sum of all forces acting on the body is equivalent to the product of object’s mass and acceleration. However, for a rocket this problem becomes very coupled to the mass of the vehicle as the mass is rapidly changing during burn. In the following sequence of equations, all items are a function of time or a function of another variable which is also time driven. In the case of rockets, there are three primary sources of external forces; drag force, thrust, and gravity.

$$ma = \sum F$$

Equation 3-19

$$ma = F_{thrust} + F_{drag} + F_{weight}$$

Equation 3-20

$$ma = F_{thrust} - sign(V)0.5\rho V^2 CdA - mg$$

Equation 3-21

$$a = \frac{F_{thrust} - sign(V)0.5\rho V^2 CdA}{m} - g$$

Equation 3-22

MATLAB solvers require a system to be first order, therefore the common “x” design. Time derivatives will be signified by a dot for the order.

$$a = \ddot{x}, v = \dot{x}, and\ y = x \tag{Equation 3-23}$$

$$\ddot{x} = \frac{F_{thrust} - sign(V)0.5\rho(\dot{x})^2 CdA}{m} - g \tag{Equation 3-24}$$

However, this is still a non-linear 2nd order equation. A new set of variables denoted by subscript numbers will represent the order however it will reference the first order correlation.

$$x_1 = x = y; \dot{x}_1 = \dot{x};\ \ddot{x} = \dot{x}_2 = a \tag{Equation 3-25}$$

$$\dot{x}_1 = x_2 \tag{Equation 3-26}$$

$$\dot{x}_2 = \frac{F_{thrust} - sign(V)0.5\rho(x_2)^2 CdA}{m} - g \tag{Equation 3-27}$$

$$\dot{z} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} x_2 \\ \frac{F_{thrust} - sign(V)0.5\rho(x_2)^2 CdA}{m} - g \end{bmatrix} \tag{Equation 3-28}$$

This $\dot{z}$ matrix forms a system of non-linear first order equations. However, as mentioned before, mass is changing as well. In Equation 3-29, a third element is added to increase the system to a 3rd order state. This accounts for the system change in mass as the propellant is burned.

$$\dot{m} = -\frac{F_{thrust}}{I_{SP}g0} \tag{Equation 3-29}$$

$$\dot{z} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -\frac{F_{thrust}}{I_{SP}g0} \\ x_2 \\ \frac{F_{thrust} - sign(V)0.5\rho(x_2)^2 CdA}{m} - g \end{bmatrix} \tag{Equation 3-30}$$

Now, we have general equations of motion defined. It is relatively simple to define an acceleration function in the transverse or radial direction to find drift. A pressure difference between the dynamic pressure on the downwind side vs the dynamic pressure of the air on the up wind side of the rocket causes a net force in the direction of the cross wind.

$$\Delta P(A) = ma \tag{Equation 3-31}$$

$$ma = A\left(P_{upwind} - P_{downwind}\right) \tag{Equation 3-32}$$

$$ma = 0.5A\rho Cd\left(V_{wind}^2 - V_{\hat{r}}^2\right) \tag{Equation 3-33}$$

$$a = \frac{0.5ACd\rho\left(V_{wind}^2 - V_{\hat{r}}^2\right)}{m} \tag{Equation 3-34}$$

So as in Equation 3-27, the system must be reduced to a system of two first order equations. For purposes of simplicity, the numbering will follow the current derivative index.

$$\dot{x_4} = x_5 = V_{\hat{r}} \qquad \text{Equation 3-35}$$

$$\dot{x}_5 = a = \frac{0.5ACd\rho\left(V_{wind}^2 - V_{\hat{r}}^2\right)}{m} \qquad \text{Equation 3-36}$$

$$\dot{z} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \end{bmatrix} = \begin{bmatrix} -\dfrac{F_{thrust}}{I_{SP}g0} \\ x_2 \\ \dfrac{F_{thrust} - sign(V)0.5\rho(x_2)^2CdA}{m} - g \\ x_5 \\ \dfrac{0.5ACd\rho\left(V_{wind}^2 - V_{\hat{r}}^2\right)}{m} \end{bmatrix} \qquad \text{Equation 3-37}$$

Equation 3-37 is the final coupled 5th order system of equations that will be run through MATLAB's ODE15S solver and will numerically simultaneously solve this system. By establishing trigger events during the flight, it is straight forward to edit drag variables and areas based on which stage the vehicle is in. The code applies these events to form a piecewise continuous function which after being integrated will determine the total system.

Differential Piecewise System

Figure 3-33 details the same equations listed above however they are broken down into segments of the trajectory. The ignition state refers to a point in the trajectory that the motor is burning however the thrust produced is not enough to lift the mass of Prometheus. During this state, the only component in flux is the mass. During the "Powered" state, the motor is still burning and *Prometheus* is in motion which forces all other components into motion.

```
% Differntial Finder based on State
switch state
    case 'Ignition'
        mdot = -Ft/(ISP*g0);
        vel  = 0;
        acc  = 0;
        dr   = 0;
        ddr  = 0;
    case 'Powered'
        mdot = -Ft/(ISP*g0);
        vel  = y(3);
        acc  = (Ft - sign(y(3))*0.5*rho*y(3)^2*Cd*vCA)/y(1) - g0;
        dr   = y(5);
        ddr  = (windmag^2 -  y(5)^2)*0.5*rho*Cd*vLA/y(1);
    case 'Coast'
        % post burnout
        mdot = 0;
        vel  = y(3);
        acc  =  -sign(y(3))*0.5*rho*y(3)^2*Cd*vCA/y(1) - g0;
        dr   = y(5);
        ddr  = (windmag^2 -  y(5)^2)*0.5*rho*Cd*vLA/y(1);
    case 'FreeFall'
        % Cd and Area will change based on above if statement
        mdot = 0;
        vel  = y(3);
        acc  = -sign(y(3))*0.5*rho*y(3)^2*Cd*vCA/y(1) - g0;
```

```
        dr   = y(5);
        ddr  = (windmag^2 -  y(5)^2)*0.5*rho*Cd*vLA/y(1);
    case 'DrogueDescent'
       % Cd and Area will change based on above if statement
        mdot = 0;
        vel  = y(3);
        acc  = -sign(y(3))*0.5*rho*y(3)^2*Cd*vCA/y(1) - g0;
        dr   = y(5);
        ddr  = (windmag^2 -  y(5)^2)*0.5*rho*Cd*vLA/y(1);
    case 'MainDescent'
        % Cd and Area will change based on above if statement
        mdot = 0;
        vel  = y(3);
        acc  = - sign(y(3))*0.5*rho*y(3)^2*Cd*vCA/y(1) - g0;
        dr   = y(5);
        ddr  = (windmag^2 -  y(5)^2)*0.5*rho*Cd*vLA/y(1);
end
dy = [ mdot; vel; acc; dr; ddr];
```

Figure 3-33: Trajectory Event Changes

After the "Powered" state, the other states are relatively the same. The only items that change in the equation are the Drag Coefficient and relative cross sectional analysis whose values are controlled by the state check sequence not shown.

Critical Point Determination

In order to determine key points, a set of trajectory events are set to raise a flag and output certain values during the flight. The Charger Rocket Works team is most concerned with the flight time during transonic and supersonic MACH regimes.

```
global gamma R k T0
T = T0 + k*y(2);
a=sqrt(R*gamma*T);
M1=0.7;
M2=1.4;
value=[y(2)-PIN.LC.RL-PIN.LC.ASL;
        y(3);
        abs(y(3))-a*M1;
        abs(y(3))-a*M2;
        y(2)-PIN.LC.ASL];
direction=[1; -1; 0; 0; -1]; % [ dec, both, dec]
isterminal=[0; 0; 0; 0; 1]; % Stop if Altiude <=0
```

The key idea with this separate function is to identify when the values in "value" vector are zero and what the solver is supposed to do when the event occurs. The "Direction" vector defines whether or not the event occurs as the value is increasing, decreasing, or both (options: [1, -1, 0] respectively) and if the event occurs, the "isterminal" vector determines how the solver responds. For the purposes of land based free flight rockets, when the altitude component passes through 0, the solver needs to stop computing as ground defines the end of trajectory for a rocket.

Uncertainty in Trajectory Predictions – Max Altitude, Max Speed, and Max Acceleration

Figure 3-34: Max Trajectory Values

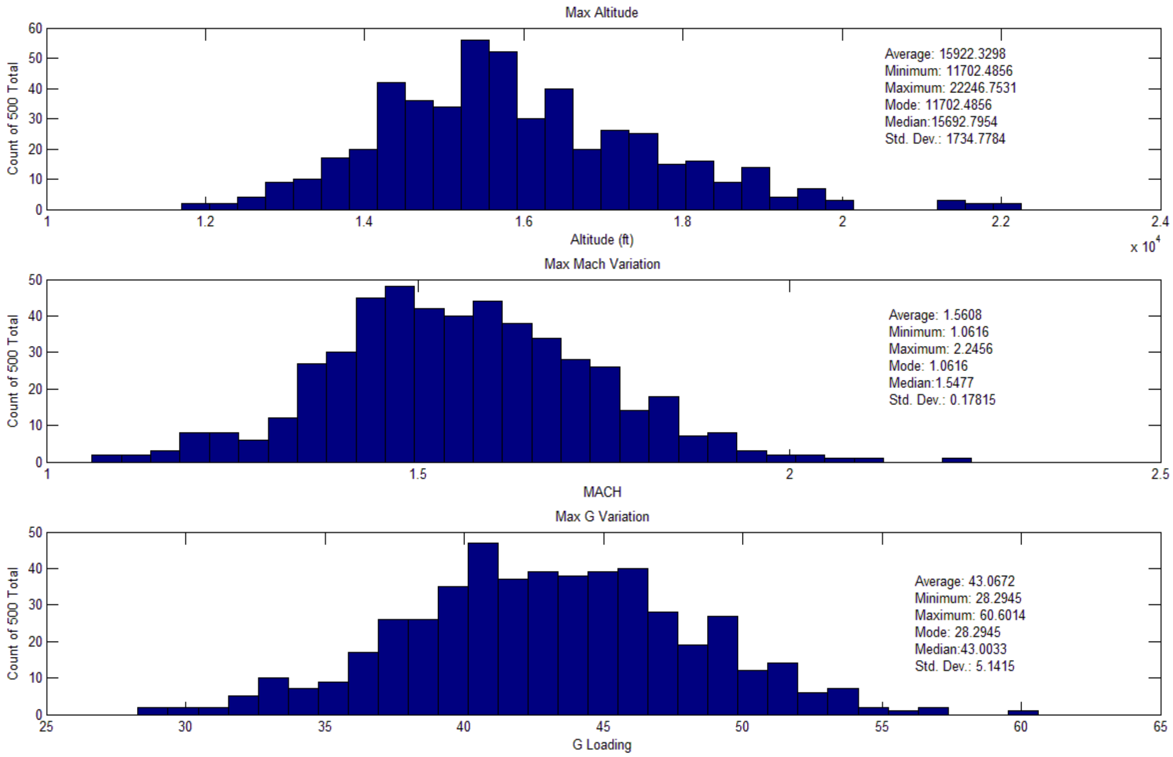


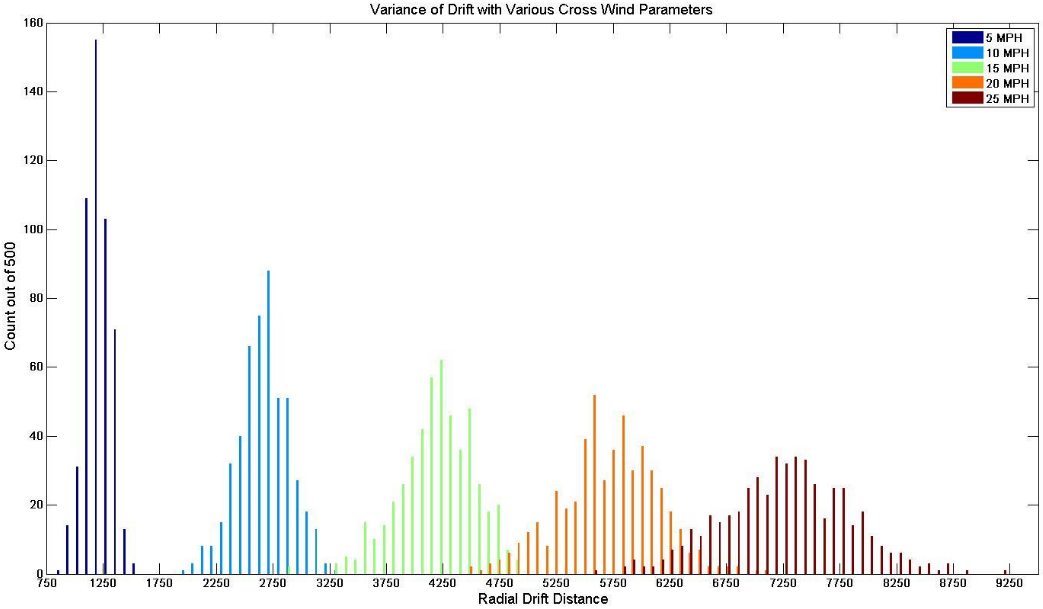
Figure 3-34 depicts a possible outcome in the max altitude, max speed, and max G loading *Prometheus* could experience under unknown conditions. According to the prescribed model, *Prometheus* has a high probability to obtain up to a max altitude of 17,500 feet, a max speed of Mach 1.7, and a max G of 40. This is calculated by summing the mean and 1st standard deviation as a high probability region with a ceiling obtained near the first standard deviation.

This provides an excellent basis for continuing design work on *Prometheus* as the team has numerically predicted that *Prometheus* has a high probability of achieving the ceiling and speed requirements of the project.

Uncertainty in Drift Predictions

Figure 3-35: Radial Drift with Cross Wind Variance depicts the possible Drift Range expected for stead cross winds of 5 mph to 25 mph with increments of 5 mph.

Figure 3-35: Radial Drift with Cross Wind Variance



Uncertainty in Predicted Flight Time

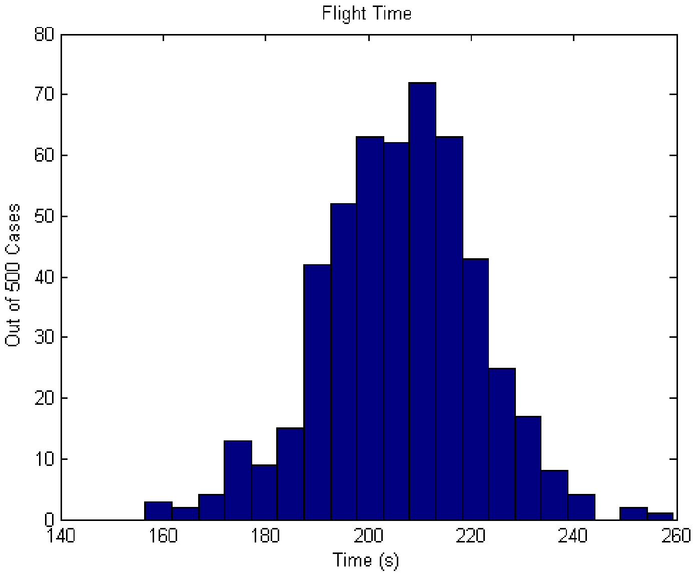


Figure 3-36: Uncertainty in Time of Flight

3.6.4. **Stress Analysis**

An important element of vehicle safety and survivability is stress analysis, and ensuring the selected materials can survive the applied stresses and strains produced by the acceleration forces required for supersonic flight. The basic equation employed for this analysis is as follows:

$$\sigma = E\varepsilon$$ **Equation 3-38**

Here σ is stress, E is the Modulus of Elasticity, and ε is the strain. Further, the basic equation for the components of stress is as follows:

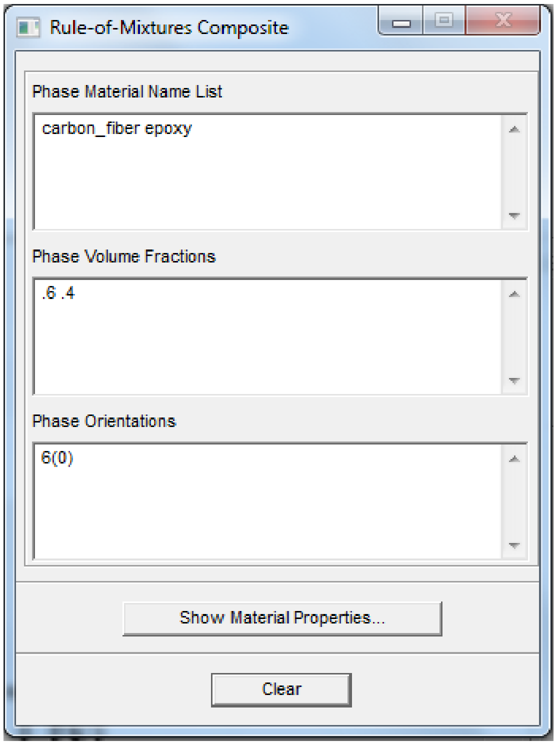
$$\sigma = \frac{F}{A}$$ **Equation 3-39**

Here F is the force, and A is the area over which the force is applied. For design purposes, the approximations of forces working on the rocket are known. Further, through material properties and assumptions, values for the Modulus of Elasticity of the various materials used are known.

For the analysis the Patran/Nastran package was used. CAD models were imported into Patran and 3-D meshes were created around the solids. Individual materials were defined, as well as composite materials when necessary. After defining the models in Patran, values for stress and deflection were obtained through analysis in Nastran, and then returned for Patran to provide a visual representation of the analysis.

Some of the most challenging analysis involved modeling the carbon fiber/epoxy composite materials. Each ply of the carbon fiber used was a 2x2 weave. In order to model this, the team had to employ the use of two different built in composite functions in Patran. The first was the Rule-of-Mixtures Composite function. This allows for a composite material to be defined based on isentropic inputs of the carbon fiber and epoxy based on an assumed mass ratio of 60%/40%. This is shown below in Figure 3-32.

The single composite ply was then layered to mimic the ply layup for each part. To account for the weave, the ply thickness was halved, and the plys were oriented at alternating angles of 0°/90°. An example of the entire layup is shown below in Figure 3-33.

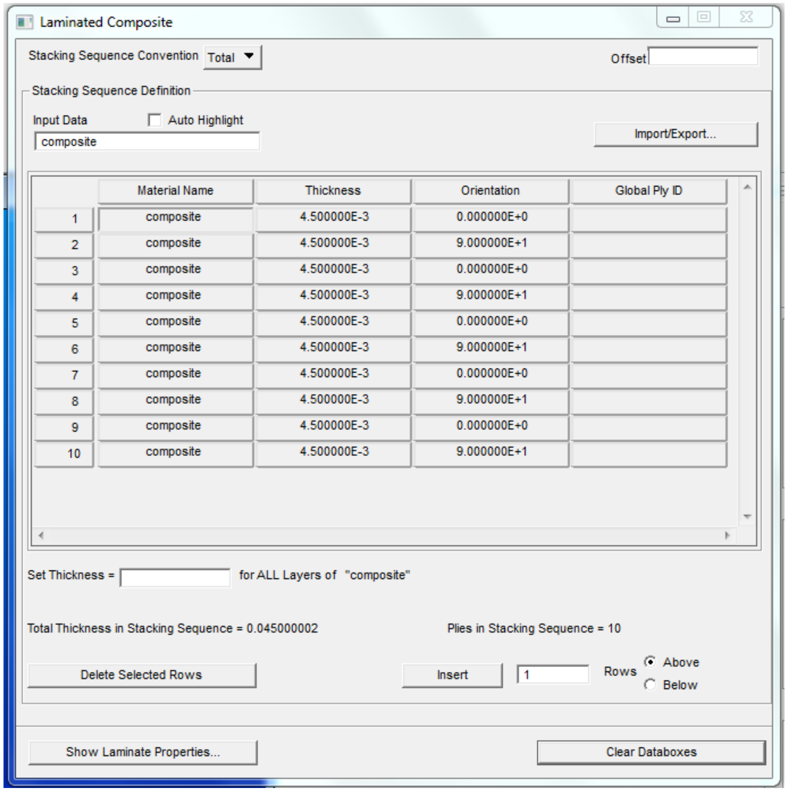


Phase Material Name List: carbon_fiber epoxy

Phase Volume Fractions: .6 .4

Phase Orientations: 6(0)

Figure 3-37: Rule of Mixtures Composite



Stacking Sequence Convention: Total

Offset:

Input Data: composite

☐ Auto Highlight

	Material Name	Thickness	Orientation	Global Ply ID
1	composite	4.500000E-3	0.000000E+0	
2	composite	4.500000E-3	9.000000E+1	
3	composite	4.500000E-3	0.000000E+0	
4	composite	4.500000E-3	9.000000E+1	
5	composite	4.500000E-3	0.000000E+0	
6	composite	4.500000E-3	9.000000E+1	
7	composite	4.500000E-3	0.000000E+0	
8	composite	4.500000E-3	9.000000E+1	
9	composite	4.500000E-3	0.000000E+0	
10	composite	4.500000E-3	9.000000E+1	

Set Thickness = for ALL Layers of "composite"

Total Thickness in Stacking Sequence = 0.045000002

Plies in Stacking Sequence = 10

Insert 1 Rows ● Above ○ Below

Figure 3-38: Composite Layup

3.6.5. **Fin Flutter Analysis**

A primary concern of supersonic flight is the dynamic loading on flexible and pliable fin components of *Prometheus*. A simple flutter analysis algorithm was used estimate the shear modulus of the fin composition material such that flutter conditions were mitigated. Fin flutter is a phenomenon which is characterized as an oscillation that occurs due to wind shear producing a lift and coupled moment. Unchecked, this oscillation will diverge as a resonant frequency with amplitude magnification until the fin fatigues. The primary factors in fin flutter calculations are the shear modulus of the material, shape of the fin, temperature of the air, and density of the air.

The velocity at which a fin will flutter is characterized in Table 3-12: Fin Flutter Variables

Table 3-12: Fin Flutter Variables

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

$$P = \frac{2116}{144}\left(\frac{T+459.7}{518}\right)^{5.356}\ psi$$

$$T = 59 - 0.00356h\ ^\circ\mathrm{F}$$

$$a = \sqrt{\gamma RT}$$

R	$1716.59\frac{ft^2}{s^2}\left(\frac{1}{^\circ R}\right)$
AR	Aspect Ratio
G	Shear Modulus
t	Fin Thickness
c	root chord
c_t	tip chord
c_r	root chord
S	Plan Form Area
b	semi span
P	Atmospheric Pressure as a Function of Temperature
T	Atmospheric Temperature as a Function of Altitude

For *Prometheus’* fins, special attention to fin flutter is applied to ensure a safe flight during which the fin flutter is mitigated. Below is an example calculation for these specific calculations.

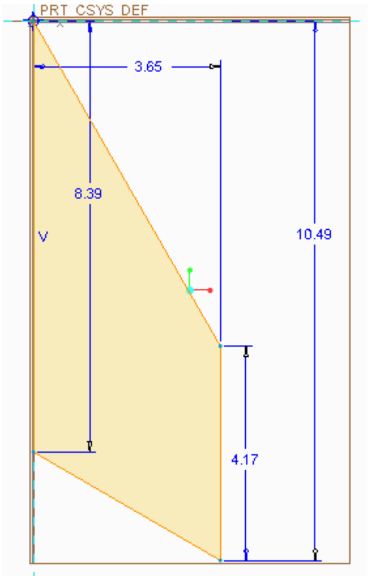


Figure 3-39: Fin Geometry

3.6.6. **CFD Analysis**

Through sponsorship of ESI-CFD, a multi-physics software developer, the UAH team was able to generate a mesh using CFD-VisCART™

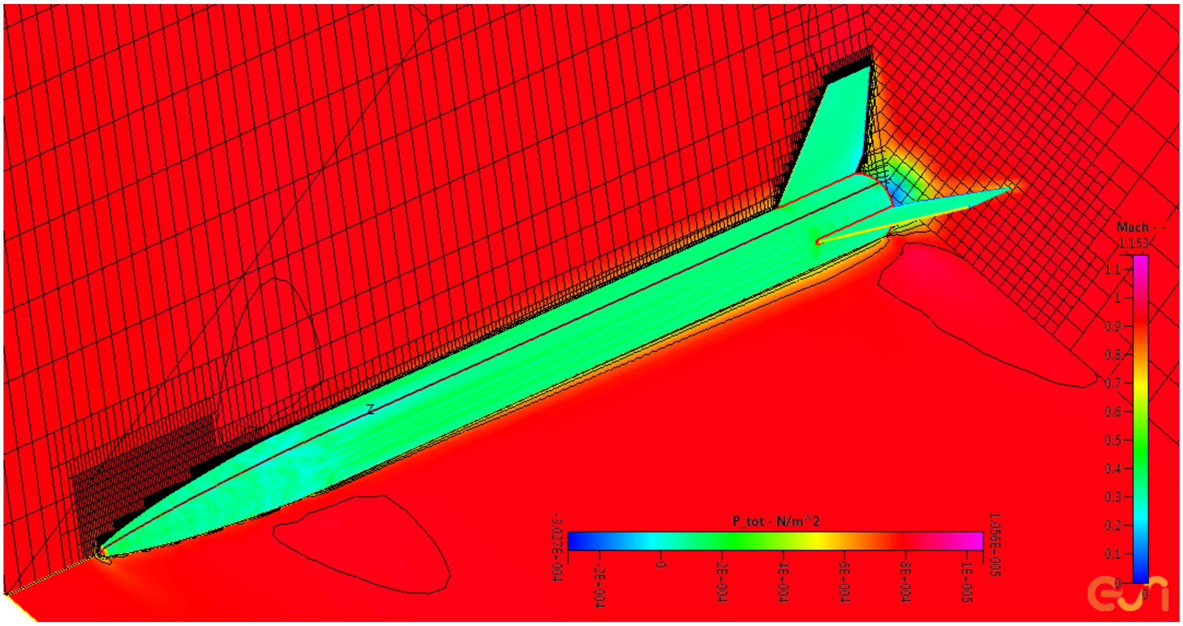


Figure 3-40: CFD Pressure and Fluid Flow

Thanks to ESI-CFD, a division of ESI-GROUP R&D Inc., the UAH team was given the opportunity to run CFD analysis on the airframe of *Prometheus*. Results helped predict the type of dynamic pressure loads seen during flight on the vehicle along with predicting thermal heat build-up on the skin. Figure 3-40 shows a fluid flow at Mach 0.9 and a surface pressure acting above a reference pressure. CFD Analysis helped identify locations of concern for high pressure loading and temperature due to supersonic loading.

3.6.7. Plan B Motor

Due to possible weather and environmental concerns of flooding in the salt flats, a secondary launch site was chosen. The ceiling requirement restricts flight to a max ceiling of 10,000 feet. Charger Rocket Works is pursuing a CTI-L890 as a backup motor. In certain cases of high cross wind, it may be advisable to change the main chute deployment to 500 feet to maintain a max radius of 5000 feet.

Table 3-13: Plan B Drift Estimates

Cross Wind	5 MPH	10 MPH	15 MPH	20 MPH	25 MPH
Drift Radius	900 ft	1950 ft	3050 ft	4250 ft	4200 ft
Main Chute Deployment	750 ft	750 ft	750 ft	750 ft	300 ft

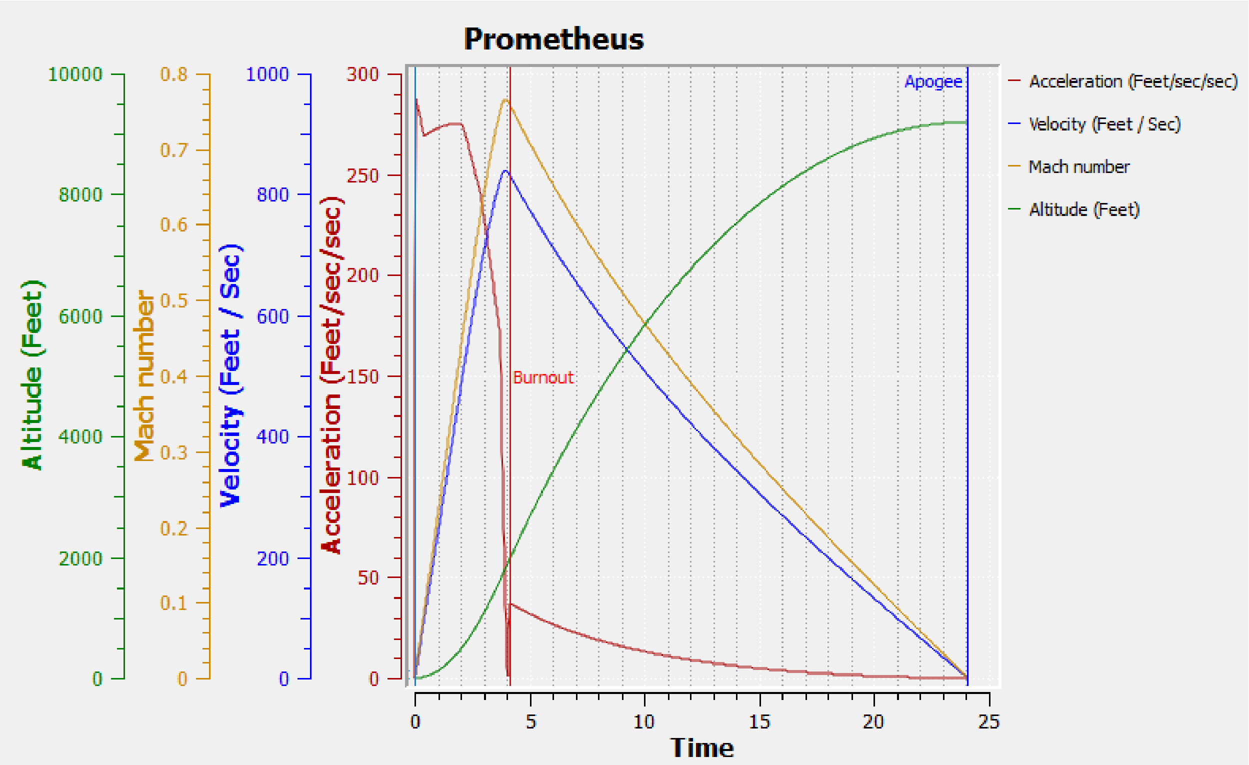


Figure 3-41: Apogee Predictions for Plan B

3.7. Launch Operation Procedures

3.7.1. Launch Procedures

All launch operations will be conducted by a designated Launch Team comprised of the following: the Safety Officer, Payloads Team Lead, and one member each from the Analysis and Hardware Teams who have received CPR/AED training. In order to ensure proper pre-launch vehicle assembly, the Launch Team shall follow a specific set of procedures that are drafted and reviewed by the entire team no more than 3 days prior to a launch at a meeting organized by the Safety Officer. These launch procedures shall contain descriptions of all pertinent steps in the vehicle assembly. Separate procedures shall be in place for any portions of the assembly dealing with propellant, E-matches, or explosives. A sample launch checklist from the most recent sub-scale launch can be found in Appendix E: Launch Operations Checklist

3.7.2. Recovery System Preparation

To ensure proper function of the recovery system and the survivability of the vehicle, numerous ground tests are performed in the weeks leading up to the launch. These tests may only be performed by Red Team members who have been authorized by the staff at the PRC. Numerous Black Powder Ejection System tests are performed in order to determine the amount of black powder required to achieve the desired vehicle separation for drogue and main parachute deployments. In order to obtain an initial estimate for the required amount black powder, Equation 3-40 is used.

$$PV = mRT \qquad \text{Equation 3-40}$$

In this equation, P is the pressure required to break the shear pins being used to hold the body pieces together. V is the volume of the recovery system bay containing the parachutes that must be deployed. M is the calculated mass of black powder required for deployment. R is the gas constant for air in the appropriate system of measurements. T is the approximate burn temperature for black powder. Though some adjustment and additional black powder is generally required, these calculations provide an acceptable starting point for the purposes of the test. A more detailed description of the Black Powder Ejection System test can be found in Appendix J: Black Powder Ejection System Standard Operating Procedure. An additional test of a proposed parachute release mechanism was conducted in a similar manner. A successful ground test of all deployment systems is required before moving forward with any launch.

3.7.3. Motor Preparation

All motor preparation and installation is handled by the CRW team's NAR/TRA mentor. For some larger motors, including the M-4770 that will be used in Prometheus, a cure time of 24 hours is required after the motor grains are epoxied together, which must be taken into account. If using a motor smaller than a motor tube is designed for, an approved motor tube adapter must be used to carry out the launch safely.

3.7.4. Igniter Installation

As with the motor preparation, installation of the igniter is the responsibility of the NAR/ TRA mentor. Regardless of the type of igniter used, either an e-match or an igniter provided by the manufacturer, care must be taken to follow the instructions of the manufacturer and ensure that no frayed wires are present. Additionally, care should be taken to ensure that the igniter is fully inserted into the motor to minimize the risk of an ignition failure.

3.7.5. Launch Rail Setup

When the vehicle is ready to be launched, the members of the Launch Team will carry the rocket out to the launch rail. The rail buttons on the rocket will be lined up with the slot in the launch rail and slid into place. The launch rail will then be locked into its final orientation and angled to compensate for wind if necessary. An appropriate blast shield will be placed at the base of the rocket to deflect the hot exhaust gasses away from the ignition circuit wires. Final activation of all payload electronics will take place once the rocket and igniter are in place.

3.7.6. Troubleshooting During Launch

If the motor fails to ignite, the members of the Launch Team will accompany the RSO and NAR/TRA mentor out to the launch rail once 60 seconds have passed and the vehicle has been deemed safe to approach. All recovery system electronics will be deactivated once the team reaches the launch rail to prevent accidental deployment of the ejection charges. The ignition circuit will then be disconnected so that the igniter can be removed and inspected to determine the cause of the ignition failure. If the igniter is deemed to be the source of the problem, it will be replaced. Otherwise, a check of the ignition circuit will be performed to ensure there is no break in continuity. Once any issues have been corrected, another launch will be attempted.

3.7.7. Post Flight Inspection

Once the vehicle has landed, pictures will be taken to document its status upon landing. A check of the ejection charges will be performed to ensure there is no unburned black powder still present in the vehicle. The maximum altitudes recorded by the altimeters will be noted and all payload electronics will then be shut down. If any parts of the vehicle have broken or dislodged, they should be collected and carried back to the staging area to determine if any repairs must be undertaken. A check of the structural integrity of the body tube and all internal hardware will be performed to ensure that the vehicle is suitable for additional flights.

3.8. Vehicle Safety and Environment

Hazards are an unavoidable part of any engineering design project and, as such, great care must be taken to minimize them. The CRW Safety Plan works to mitigate these hazards and maintain compliance with all pertinent state and federal laws regulating high powered rocketry and all Propulsion Research Center rules. A more detailed copy of the Safety Plan can be found in Appendix A: CRW Safety Plan.

3.8.1. Safety Officer

The Team Safety Officer is responsible for ensuring that all CRW team activities and procedures comply with any regulations set forth. They are also responsible for briefing CRW team members on any hazards they are likely to encounter during any manufacturing or testing to ensure that any potential hazards can be mitigated appropriately.

3.8.2. Failure Modes and Mitigations

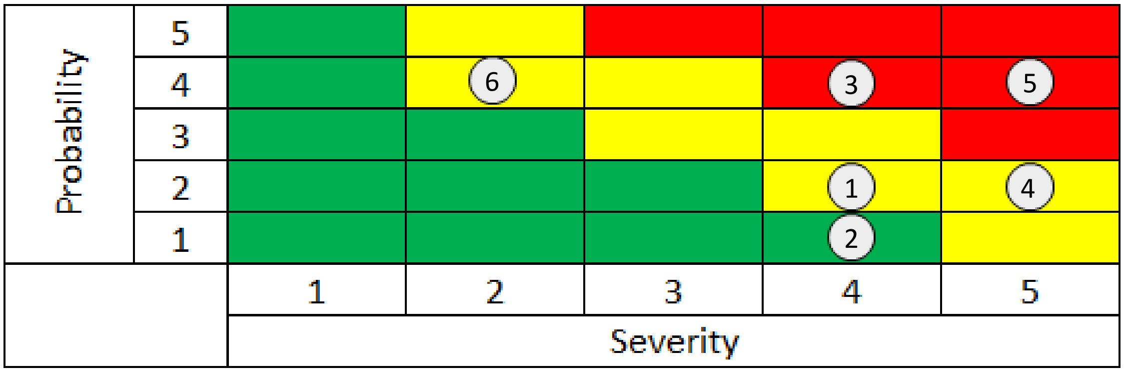
The rocket could fail if the materials selected for construction are not robust enough to withstand the 44 G’s of acceleration that the rocket is predicted to experience at launch. If the rocket is not constructed to handle 44 G’s of acceleration, the body tube could delaminate at a low altitude or be 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 and Categorization



Probability	5	🟩	🟨	🟥	🟥	🟥
	4	🟩	🟨 ⑥	🟨	🟥 ③	🟥 ⑤
	3	🟩	🟩	🟨	🟨	🟥
	2	🟩	🟩	🟩	🟨 ①	🟨 ④
	1	🟩	🟩	🟩	🟩 ②	🟨
		1	2	3	4	5
		Severity				

Table 3-14 : Hazard Determination

Ref #	Potential Hazard	Probability	Severity	Impact	Mitigation
1	Material Failure on Launch	2	4	Rocket destroyed	Reinforce bulkhead
2	Fin Delamination During Flight	1	4	Fin fracture, rocket instability	Reinforce composite fin layup method
3	Fin Delamination During Landing	4	4	Fin fracture, not reusable	Reinforce composite fin layup method
4	Motor Failure on Launch	2	5	Launch delayed	Meticulous SOP
5	Recovery System Failure	4	5	Rocket not reusable	Recovery system design and testing prior launch
6	Damage from Shipping	4	2	Delayed/Canceled flight	Proper packing

3.8.3. Personnel Hazards

In order to mitigate the hazards associated with the manufacturing and testing of Prometheus, the Safety Officer maintains a record of all MSDS, Standard Operating Procedures, and manufacturing hazard analyses. A current listing of all MSDS and manufacturing hazard analyses can be found in Appendix H: Hazardous Materials Inventory. All regulations pertaining to high powered rocketry and allowable materials for construction can be found in Appendix G: State and Federal Regulations

3.8.4. Environmental Concerns

The high powered rockets and their respective payloads, which have been designed for the purposes of this research project, due pose some threats to the environment. Chiefly among these, are the exhaust gasses expelled by the motors during flight. While this is an unavoidable part of high powered rocketry, selecting the smallest motor possible to meet the desired performance requirements of the team can help to limit this impact. The high capacity Li-Po batteries used frequently for payload electronics can also pose an environmental threat if not disposed of properly. The CRW team maintains an open relationship with the Office of Environmental Health and Safety at UAH in order to ensure proper disposal of any materials.

4. Payload Criteria

4.1. Testing and Design of Payload Experiment

4.1.1. Review the design at a system level

The Dielectrophoresis experimental payload consists of a dielectric fluid stored in plastic bottles, a high voltage power supply, video cameras, and various other electronics necessary for experiment control and data collection. The structure of the payload assembly will be built from 3-D printed ABS or polycarbonate plastic. 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 dielectrophoretic force.
- Electrode geometry – The gradient of the electric field is dependent on the geometry of the electrodes.

The structural design for this experiment can be found in Figure 4-1 below. The upper outside panels with the rings is where the containers will be placed. They will be inserted from the bottom and the circular plate will be used to hold them up once the panels are folded in. The notch in the center of the container panel is to allow room for the electrodes to stick out of the top of the containers. The upper middle panel is where the camera will be mounted and directed at the containers. The bottom right panel is where the HV supply will be mounted, and the remaining two bottom panels will be used for sensor mounting.

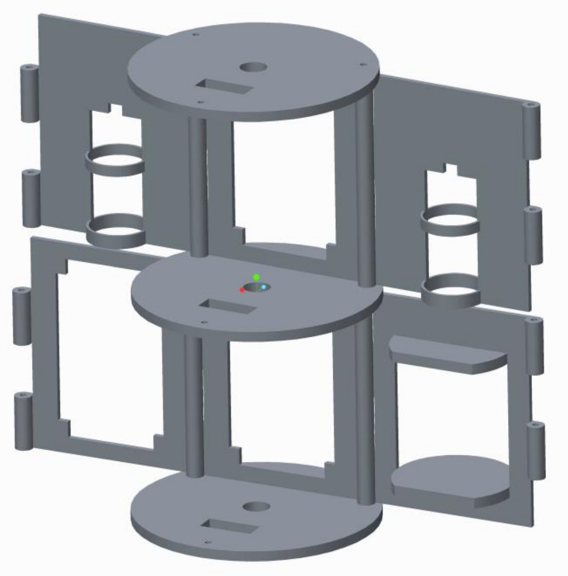


Figure 4-1: Dielectrophoresis Structure

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

For the Dielectrophoresis Payload previously there were two electrode configurations of different geometries being considered for use on the Prometheus. The first case under consideration was that of a cylindrical wall that surrounds a rod which is aligned axially with the cylinder as shown in Figure 4-2. The cylinder and the rod connected to the circuit in such a way that they are the anode and cathode, respectively.

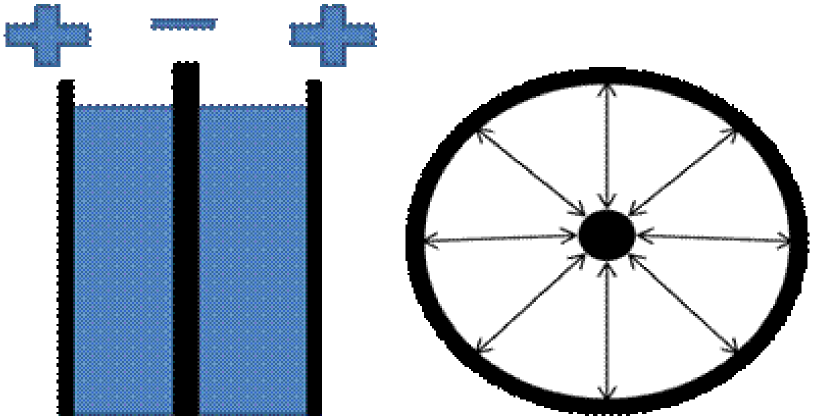


Figure 4-2 : Cylindrical Electrode Configuration

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, 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 affixing a strip of copper mesh to the outer surface of a plastic jar containing the dielectric fluid. A small copper tube will be used as the center rod electrode and will be affixed to the removable cap of the container. The outside copper mesh electrode establishes an electric field with the center rod. The cylindrical configuration 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 that was under consideration can be seen in Figure 4-3 below. This case is that of a jar that contains two parallel electrodes of opposite charge.

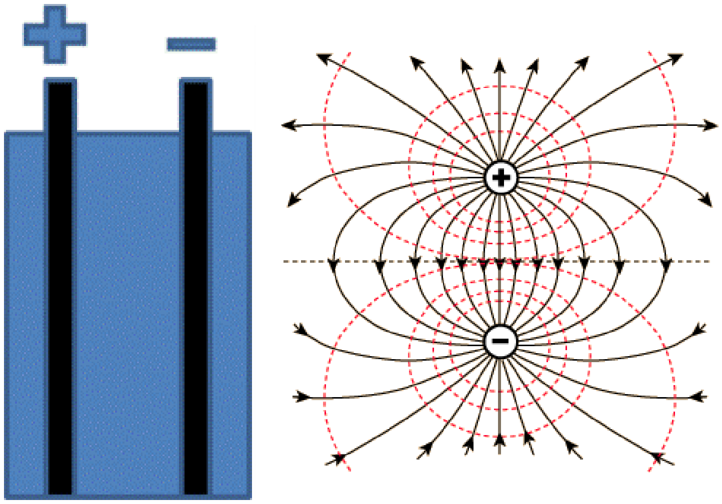


Figure 4-3: Parallel Electrode Configuration

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 4-3. Once the concentration has developed, the fluid will be attracted to the concentration and will be pulled up and isolated between the rods. The 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. However, this year it has been determined that the coaxial cylindrical electrode configuration will be more effective for demonstrating the dielectrophoretic effect because the consistent electric field will pull the fluid into a more focused region. Also, no fluid will get trapped outside of the electric field's concentration points.

The components that will be used in the payload are listed in Table 4-1 and described in further detail below.

Table 4-1: Dielectrophoresis Components

Item Name	Total Weight (lbs)	Total Cost ($)	QTY	Vendor	mass (g)
Transistor PN2222ATF	0	0.2	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	6.6	2	SKS-Bottle	20
Electrodes (total)	0.022	0.55	2	MSC	5
MINIMAX7 (HV Supply)	0.198	34.95	1	Info Unlim.	90
LED (blacklight)	0	0.95	1	Sparkfun	0.1
Small LiPo Batery	0.073	11.95	2	Sparkfun	16.5
Big LiPo Battery	0.304	12.95	1	Sparkfun	138
Penut oil (2 ttbsp) (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	233.02			356.11

Camera

The camera that has been chosen to record video of the liquid containers in-flight is the FlyCamOne eco V2, available from Sparkfun, and can be seen in Figure 4-4 to the right. 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.

Figure 4-4: Fly Cam One

HV Power Supply

Figure 4-5 below shows the high voltage power supply chosen to conduct the payload experiment. The high voltage supply is a fly back transformer and can operate at 12 kV at 1000 mA. The HV supply is the driving force behind the payload. It generates the electric field necessary for dielectrophoresis.

Figure 4-5: HV Power Supply

Fluid container selection

The containers selected to contain the liquid during flight are clear plastic jars seen below in Figure 4-6. It has a base diameter of 2” and a height of 3 5/8”. They will have to be aligned side by side with the cameras looking in through the sides.

Figure 4-6: DEP Fluid Containers and Mounting Structure

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 rotary 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 I: 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 pin switch with a "remove-before-flight" tag. 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.

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.

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.

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.

Accelerometer

The accelerometer being used in the payload is the Triple Axis ADXL377 and can be found in Figure 4-7 to the right. It is a triple axis accelerometer that can detect +-200 g. This is a better fit than the ADXL 345 since the rocket may experience more than 16 g during the boost phase. The increased resolution is useful during the coast phase to determine the quality microgravity achieved.

The accelerometer will be interfacing with the microcontroller at all times during the flight. In order to provide a visual feedback for the cameras, an LED will be used with the microcontroller and accelerometer. It will be placed in clear view of the cameras.

Figure 4-7: ADXL377 200-G Accelerometer

Power line buzzer

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

Accelerometer data storage

In order for data from the accelerometer to be stored, a micro SD card slot is necessary in order 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.

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 representation of cryogenic fuels that would be used in a real world application.

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.

Microcontroller selection

The microcontroller that will be used in the payload is the Arduino Pro 328 and can be seen in Figure 4-8 below. It is attached to the bottom portion of the payload and will be powered by the 7.4V battery. The Arduino will control two cameras, a transistor switch for the high voltage supply, an accelerometer, and a microSD card writer. It will activate the transistor and activate the cameras when launch is detected by the accelerometer. It will then interface with the accelerometer and SD card writer to store flight data.

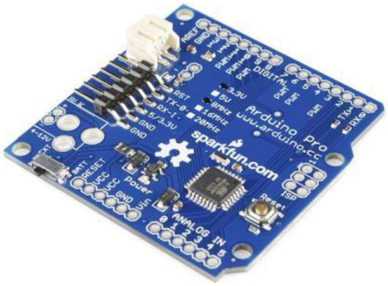


Figure 4-8: Arduino Pro 328

One minor drawback of the Arduino Pro 328 is the lack of an onboard USB port. In order to talk to the Pro 328, an intermediate chip is required: the FTDI Basic Breakout 3.3V from Sparkfun Electronics. Fortunately, this chip is very easy to use. Its 6 pin header connects directly to the horizontal pins on the Pro 328, and the USB connects to the computer. Once plugged in this way, the Arduino Pro 328 operates as if it was directly connected to the computer via USB. The FTDI breakout board requires no additional interaction from the user. This component will not be present in flight as it is only used to upload and debug code on the Arduino microcontroller.

The design of the Aerodynamic Coefficients Payload for the Nanolaunch 1200 at a system level 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 4-9 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*.

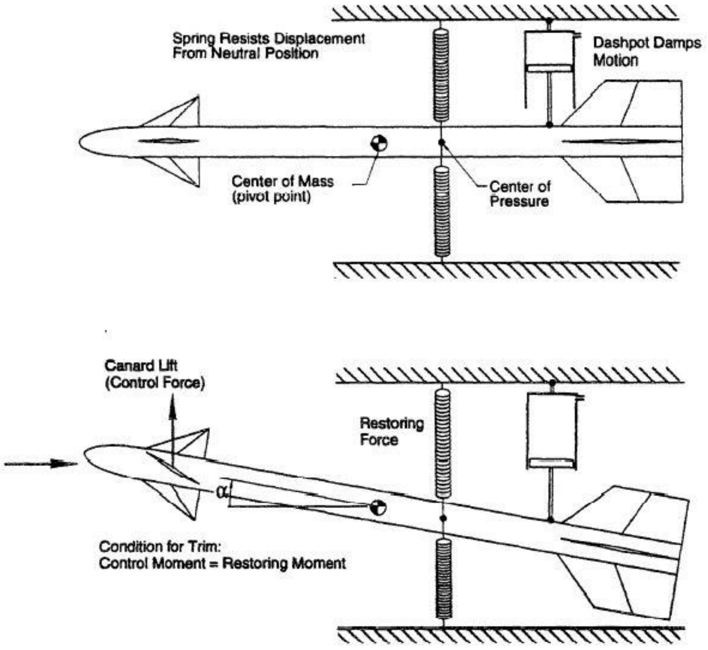


Figure 4-9 : Simulated Wind Tunnel Pitching/Restoring Moment

To monitor this, two accelerometers will be used in conjunction with each other, one at a 16 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 4-10 demonstrates the relationship between the gyroscope angles Yaw, Pitch, and Roll and the angle of attack.

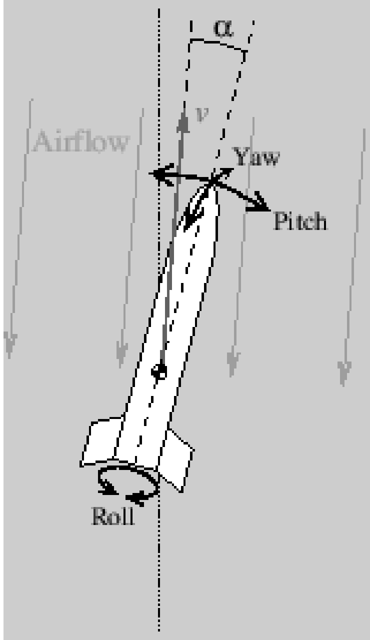


Figure 4-10 : Angle of Attack

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 4-11 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.

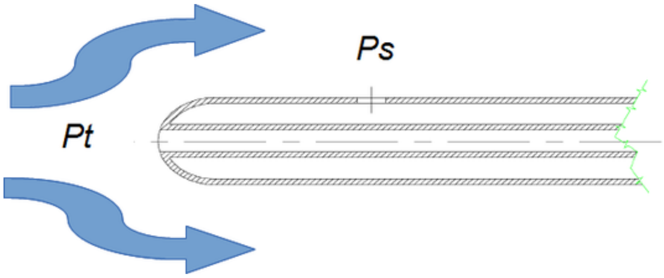
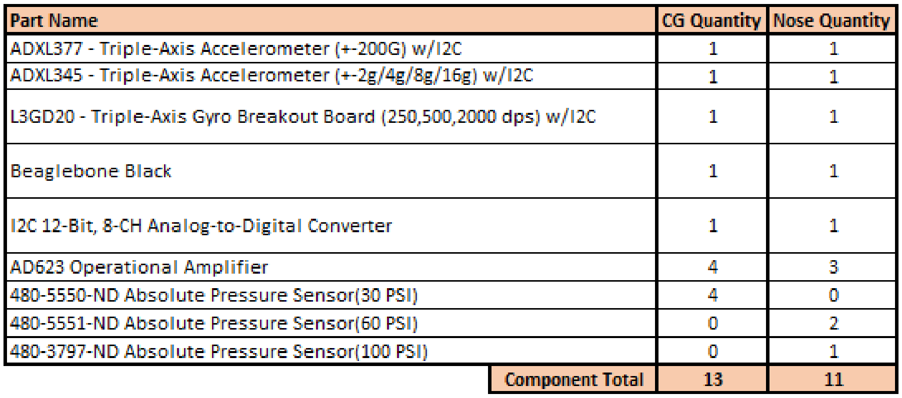


Figure 4-11 : Pitot-static Probe Example

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

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 with each component's corresponding location in the rocket. 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. The parts list for the payload will consist of all the parts for the two configurations combined into one. In total, the CG configuration will consist of 13 components, and the nose configuration will consist of 11 components. The main differences in the two payloads are the quantity and type of pressure sensor. The CG configuration will have 4 30psi pressure sensors, whereas the nose configuration will have 2 60psi pressure sensors and 1 100psi pressure sensor for the main Pitot-static pressure sensor at the nose for determining the velocity.

Table 4-2 : Nanolaunch 1200 Parts List



Part Name	CG Quantity	Nose Quantity
ADXL377 - Triple-Axis Accelerometer (+-200G) w/I2C	1	1
ADXL345 - Triple-Axis Accelerometer (+-2g/4g/8g/16g) w/I2C	1	1
L3GD20 - Triple-Axis Gyro Breakout Board (250,500,2000 dps) w/I2C	1	1
Beaglebone Black	1	1
I2C 12-Bit, 8-CH Analog-to-Digital Converter	1	1
AD623 Operational Amplifier	4	3
480-5550-ND Absolute Pressure Sensor(30 PSI)	4	0
480-5551-ND Absolute Pressure Sensor(60 PSI)	0	2
480-3797-ND Absolute Pressure Sensor(100 PSI)	0	1
Component Total	13	11

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 small disturbances in flight 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, three 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 two of the 60 PSI sensors were chosen for the side of the nose cone because it sees a lower pressure. The two 60 PSI sensors will provide a redundancy for possible differences in the measurement. 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.

Further definition of the design of the Nanolaunch 1200 payload at a system level can be found in Section 4.2.

Several tests have been conducted to validate the operation and the ability to successfully record data for the Nanolaunch 1200 payload. For the subscale launch the payload shown below was constructed and packaged tightly within a 2.6 in diameter modified Arcas Kit. The payload sled was launched as mass ballast for the first subscale. For the second subscale, the launch was successful in recording data using a launch detect of 10G measuring all six sensors at a rate of approximately 48 Hz throughout the flight.

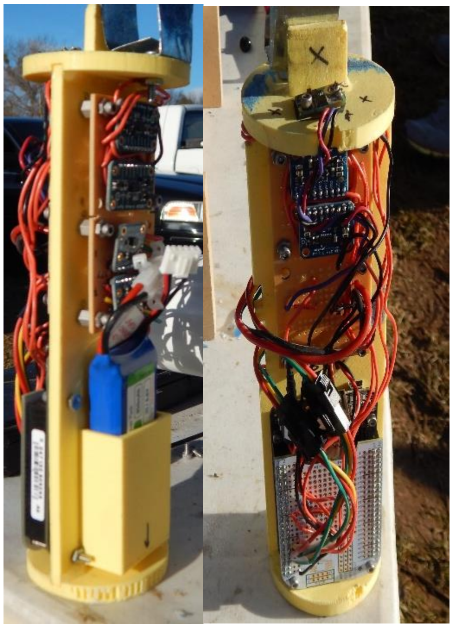


Figure 4-12 : Subscale Payload Views

Prior to the subscale launch the Nanolaunch payload was tested in an unloaded environment. Because the data sampled at 97 Hz and the program ran for 7 minutes, the entire output would be much too large to show in this document. After extracting the data from the Beaglebone, the Output.txt file was imported into Excel, where a custom "in-house" code was developed to sort the data into each sensor's respective worksheets. For display purposes, the sample data from the sensors were compiled onto one sheet, and an excerpt can be seen in Appendix C, Sample Sensor Array Data Extraction Format.

The altimeter data from the subscale launch was conclusive in that it provided the trajectory path of the rocket. From the altimeter software, the velocity profiles were also calculated. The trajectory can be seen in the 3.2 Section Subscale Flight Results.

4.1.2. **Demonstrate that the design can meet all system-level functional requirements**

The system level requirements are outlined below in Table 4-3. With the requirements are the success criteria for each, along with the method of verification.

Table 4-3: Payload System Level Requirements

Requirement	Success Criteria	Verification
Microgravity Environment	Reach apogee to experience microgravity.	Retrieve accelerometer data to calculate duration of microgravity environment.
Manipulate a fluid with an electric field	Noticeable collection of fluid around central electrode.	Retrieve camera and accelerometer data to view fluid during microgravity.
Perform experiment without interfering with other payloads	Reliable data collection from all experiments.	Rigorous preflight testing and post flight analysis of data.
Velocity Verification	Measure pitot static pressure at the nose to calculate Mach number.	Recover pressure data from nose cone sensor package. Post flight analysis.
Determine Axial Force	Collect reliable data from all four accelerometers on board.	Recover both sensor packages. Post flight analysis.
Determine angle of attack	Collect reliable gyroscopic data from both sensor packages.	Recover both sensor packages. Post flight analysis.
Transmit data in real time to a ground station	Data is sent from LHDS to ground station without data loss or corruption.	Receive transmitted data. Verified with check sum and post flight data comparison.
Transmit live GPS data	RF module transmits accurate GPS data to ground station	Successful location and recovery of vehicle.
Even film thickness	Coverage of the coatings is even and adheres correctly	Check for any defects post flight
Low coating weight	Adds minimal weight to the rocket	Weighing the rocket before and after application
High heat resistant	Coating unscathed from thermal loads	No discoloring of the coatings post flight
Recoverable and Reusable	Recover all payloads and be able to return them to a launch ready state at the launch site.	Recover the payloads. Inspect for catastrophic and unrepairable damage.

4.1.3. **Specify approach to workmanship as it relates to mission success**

Workmanship for the payload containers and support will be vital to the success of the multiple payloads in Prometheus. If parts do not assemble correctly then the sensors in the Nanolaunch payloads will not record consistent data from launch to launch and the results would not be accurate. In the

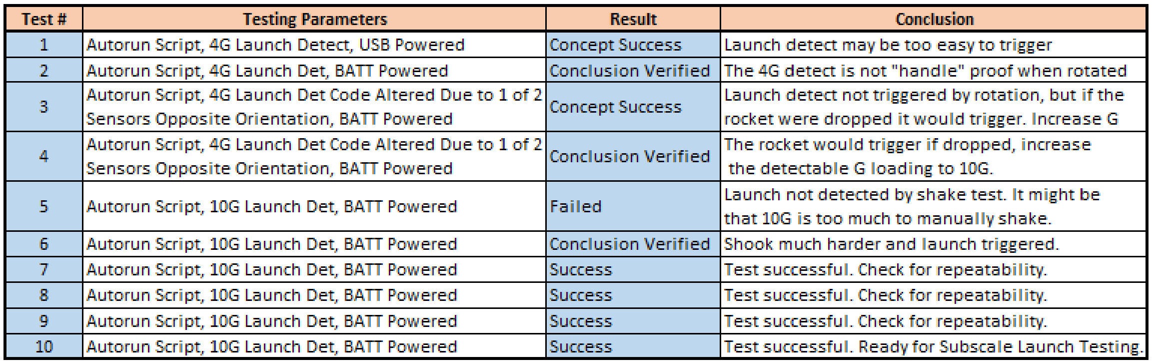
Dielectrophoresis payload, the hazards of high voltage and liquids will need to be properly contained by the payload sled so there is minimal risk of failure. To assure these needs are met, most of the payload housing will be made from rapid prototyped polycarbonate to ensure that the parts can be easily replaced if one breaks during testing.

Custom Printed circuit boards will be used to mount and connect all sensors to produce a compact and efficient payload. The PCB designs will be submitted to OHSPark for manufacturing. This method has been used on several vehicles by our Level 3 mentor and has a very record for quality and reliability. Using manufactured circuit boards will reduce the number of failure points in the payload and thus reduce the chance of failure during the aggressive launch of Prometheus.

4.1.4. **Discuss planned component testing, functional testing, or static testing**

The testing of the Nanolaunch 1200 payload was completed in a meticulous manner to investigate and prevent any possible programming issues. The payload was tested over 30 times to validate several of the programming features such as the following: auto-run script for executing the txtwrite.cpp file when the Beaglebone is connected to power, output.txt file rename if the file is already created, and the 10G launch detect. The 10G launch detect was the last test that was executed prior to the last subscale launch. The test matrix shown in Table 4-4 below, describes the testing parameters and the conclusion for each result.

Table 4-4 : Test Matrix



Test #	Testing Parameters	Result	Conclusion
1	Autorun Script, 4G Launch Detect, USB Powered	Concept Success	Launch detect may be too easy to trigger
2	Autorun Script, 4G Launch Det, BATT Powered	Conclusion Verified	The 4G detect is not "handle" proof when rotated
3	Autorun Script, 4G Launch Det Code Altered Due to 1 of 2 Sensors Opposite Orientation, BATT Powered	Concept Success	Launch detect not triggered by rotation, but if the rocket were dropped it would trigger. Increase G
4	Autorun Script, 4G Launch Det Code Altered Due to 1 of 2 Sensors Opposite Orientation, BATT Powered	Conclusion Verified	The rocket would trigger if dropped, increase the detectable G loading to 10G.
5	Autorun Script, 10G Launch Det, BATT Powered	Failed	Launch not detected by shake test. It might be that 10G is too much to manually shake.
6	Autorun Script, 10G Launch Det, BATT Powered	Conclusion Verified	Shook much harder and launch triggered.
7	Autorun Script, 10G Launch Det, BATT Powered	Success	Test successful. Check for repeatability.
8	Autorun Script, 10G Launch Det, BATT Powered	Success	Test successful. Check for repeatability.
9	Autorun Script, 10G Launch Det, BATT Powered	Success	Test successful. Check for repeatability.
10	Autorun Script, 10G Launch Det, BATT Powered	Success	Test successful. Ready for Subscale Launch Testing.

To test the RCS system, we will suspend the nosecone from its base and trigger the system. We should be able to extrapolate the force output by the system by recording how high the nosecone travelled. This will establish a baseline for the force put out and also ensure the system works together.

4.1.5. **Status and plans of remaining manufacturing and assembly**

The experimental payloads will use custom printed circuit boards (PCB’s) to efficiently use the available space inside the rocket. The schematics from the experimental payloads will be manually converted to a digital CAD file using the free software Eagle (v6.5). Eagle has two environments to aid in the design of a printed circuit board. The logic environment, seen in Figure 4-13, is used to specify the proper connections between two or more points on the board. The board physical environment, seen in Figure 4-14, shows the actual outline of the board along with all of the traces between pins.

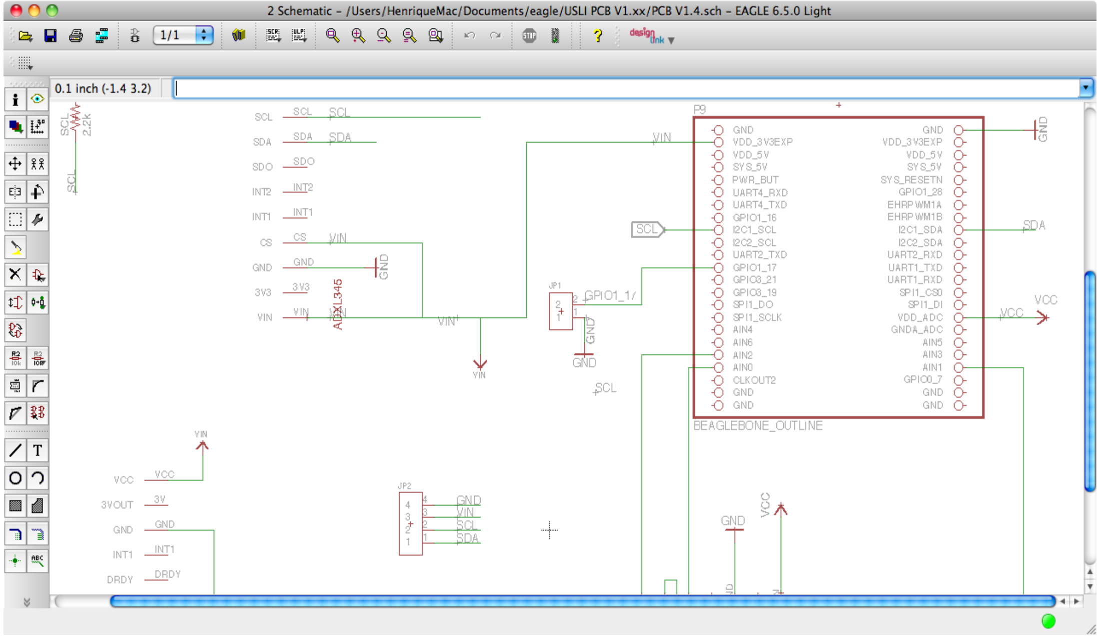


Figure 4-13: CAD Soft EAGLE Logic Environment

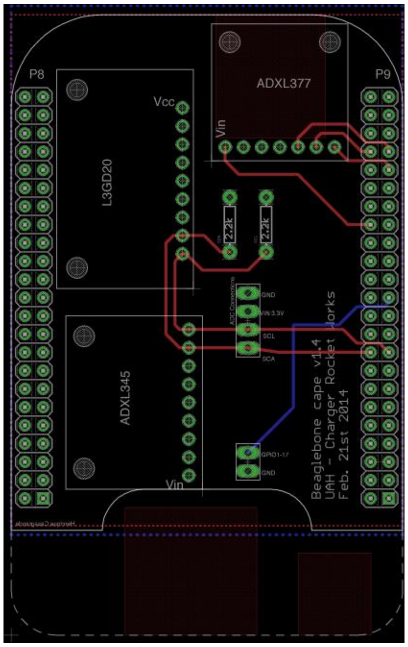


Figure 4-14: CAD Soft EAGLE Physical Environment

To allow enough time for the custom PCB's to be manufactured, a standard procedure has been created and attached to a time line. This schedule has been organized to give team members clearly defined steps to follow and to reduce the amount of error in designing the PCB's. The time line can be seen in Figure 4-15: Time Line for PCB's. The lead time on PCB's is quite substantial so the time line allows approximately 40 days from the time the circuit design is submitted to the full scale test launch on March 29. Before the PCB's are ordered, the designs will be reviewed by the experiment lead, the Avionics team lead, and the team mentor, Jason Winningham, to confirm that the design is feasible. From the time the PCB's are received to the time of launch, the boards will go through a battery of tests to ensure they perform as expected.

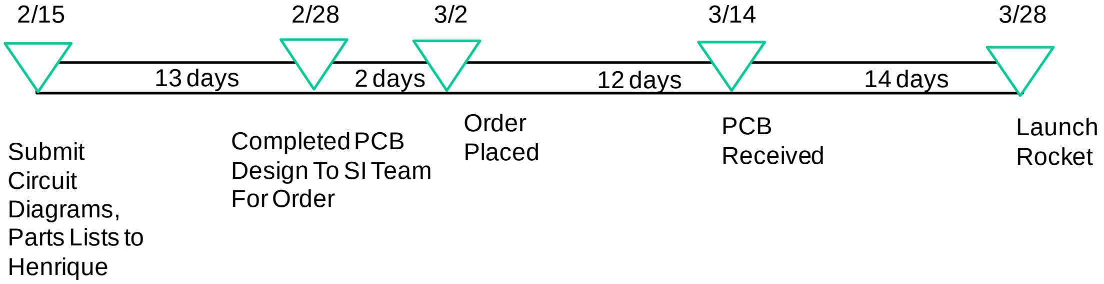


Figure 4-15: Time Line for PCB's

The benefits of using PCB's include reliability, weight savings, and volume reduction. PCB's limit the number of wired connection made between the sensors and the controller. When the PCB designs are fully implemented in the case of the Nanolaunch experiment, approximately four wires will run from the Beaglebone black to sensors on another board. Limiting the number of connections that must be soldered by hand will decrease the points of failure and increase the reliability. The amount of weight that will be saved is directly correlated to the number of wires and soldered connections that will be eliminated by using PCB's. Volume reduction is again connected to reducing the number of wires and soldered connections in the payload. Attention needed to be paid to the wires on the first subscale payload in order to insert the payload into the vehicle.

Tests performed on the PCB's will begin upon delivery. A simple inspection will take place to ensure no portions of the board have delaminated or damaged during shipment. Next a multimeter will be used to test the connections on the board. The continuity setting on the multimeter will be used to verify the different traces are properly connected or isolated as needed. After the board passes the multimeter test, the sensors will be added to the PCB. A bench test will be performed to verify the sensors perform as expected. The final test of the payload will occur with the subscale launch. The subscale vehicle will be subjected to the expected conditions of the full scale. The survival of the PCB's through those tests will signify a successful design.

The use of 3-D printed parts will be standard throughout the payload. Printed parts allow for a level of customization that is required for unique parts used in many of the experiments. This method of manufacturing also has a very short lead time, often same day or overnight. UAH has two 3-D printers that use ABS and Polycarbonate plastic, that are available for use by CRW. We will also be taking advantage of the resources provided by the Nanolaunch Team at NASA to print a titanium pitot static probe, seen in Figure 4-16, for use with the Nanolaunch and Supersonic Coatings experiments.

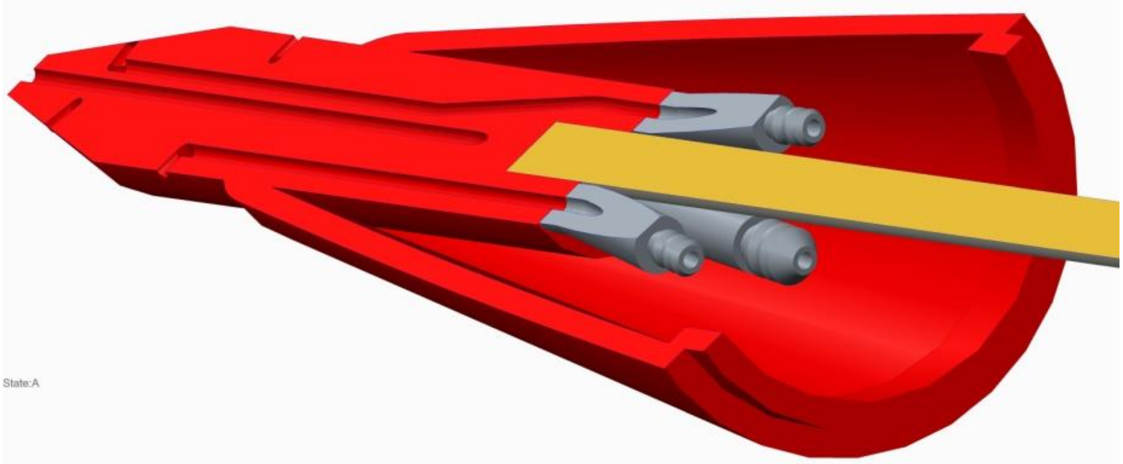


Figure 4-16: 3-D Printed Pitot Probe

The FEA analysis has been completed for select 3-D printed parts of the payload using Patran. One example of color map deformation results for one of the PCB support panels can be seen below in Figure 4-17. This simulation run uses the material specs for ABS plastic. This panel was loaded with expected launch forces that will equal the weight of one Beaglebone Black and a cape.

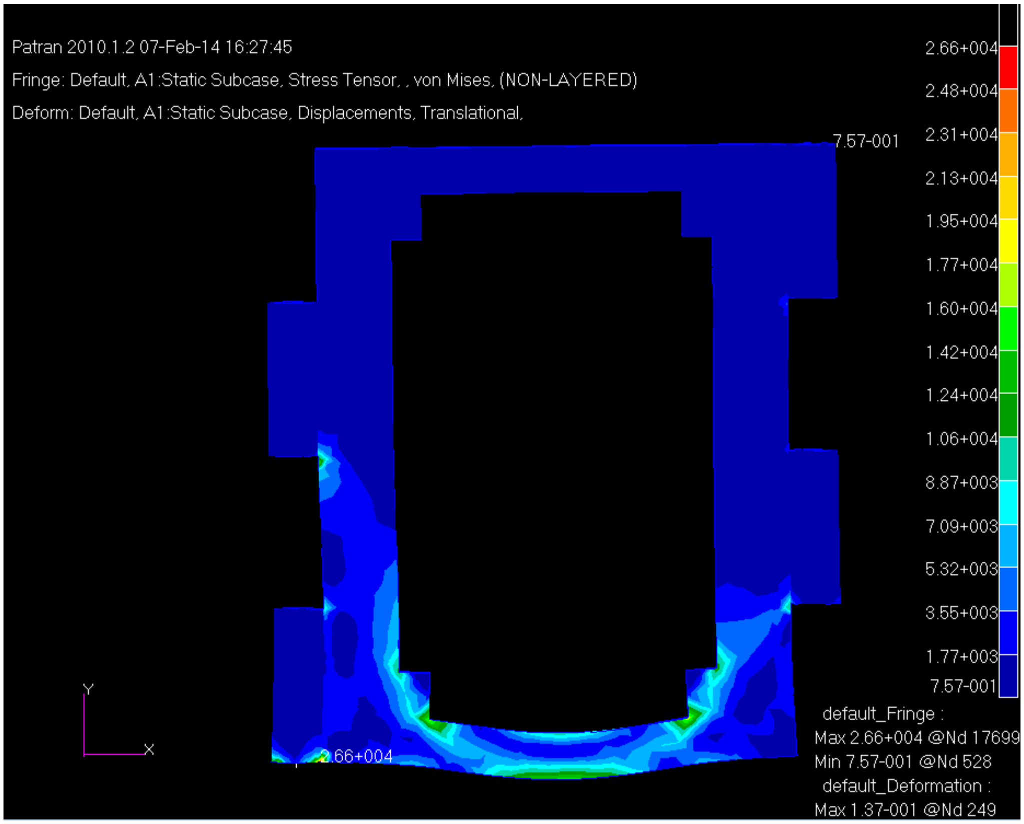


Figure 4-17: Deformation Color Map for PCB Mounting Panel

4.1.6. **Describe integration plan**

The Dielectrophoresis and Nanolaunch payloads are accommodated by a sled made primarily of 3-D printed plastic material, either ABS or polycarbonate. The sled is comprised of modular levels, each with 3 panels connected like hinges and a .190” thick circular baffle between each level. Several levels can be added to accommodate extra space for the experimental payloads as needed. The sled is attached to the payload shaft which is a 3 ft. section of 3/8 – 16 all thread rod. The sled is slid on to the rod and then secured in place by nuts and locking washers at specified points on the payload shaft. Two circular 7075 – T6 aluminum baffles will be used at both ends of the fully assembled payload sled. They will provide the support required at the interface point between the payload sled, the nuts, and the payload shaft. The FEA analysis for one of these payload baffles can be seen below in Figure 4-19. Once the payload sled is secured to the payload shaft, as in Figure 4-18, the body tube of the rocket will slide over the completed payload assembly and be held in place by the payload shaft.

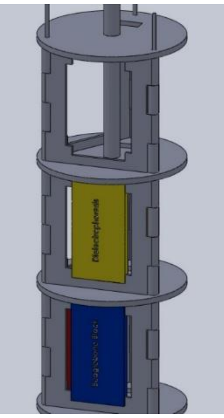


Figure 4-18: Payload Bay

Each level has the ability to be separated from the others, which would be extremely useful for separating the high voltage dielectrophoresis payload from the rest of the electronics using a faraday cage. The sled provides a robust and compact design that will be ideal for interfacing with the multiple

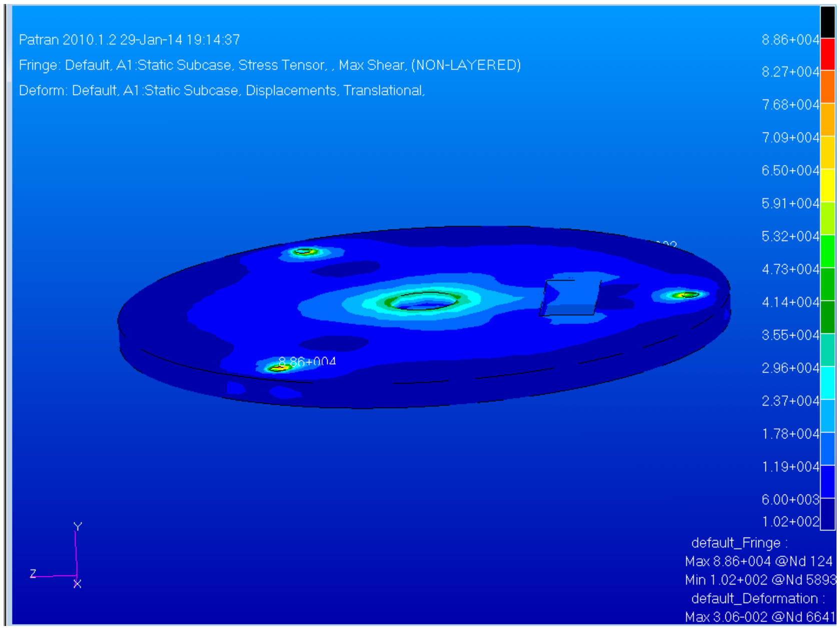


Figure 4-19: Aluminum Payload Baffle

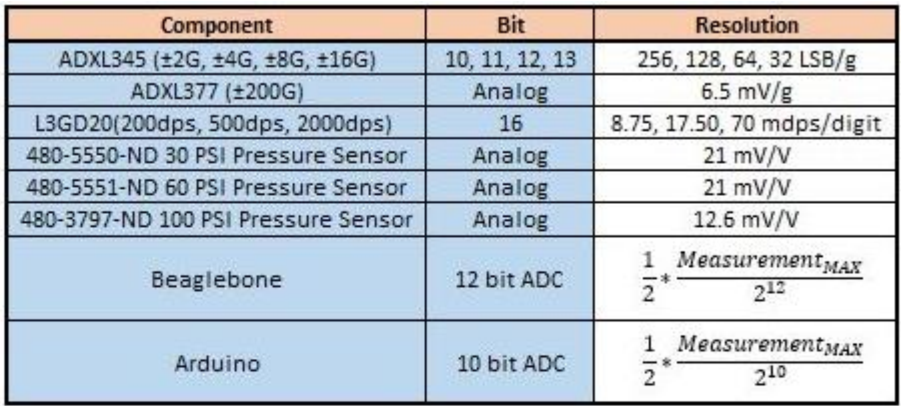
payloads required for the mission. The Panels will be manufactured using one of two 3-D printers available in the UAH MAE Machine Shop. Unique parts are being manufactured to house different and often awkwardly shaped components.

To provide easy install and perform maintenance to the payload, the sled was equipped with three removable all-thread rods used as 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 4-1 illustrates how the sled will be opened for maintenance. Because each level of the sled can be separated into its own compartment, the payloads can be separated and spaced out inside the rocket body. This allows the dielectrophoresis payload which contains high voltages to be moved away from the aerodynamic coefficient payload in case the high voltage would affect the reading of the accelerometers and gyroscopes. The multilevel sled provides the ideal compact design that will be used to mount the multiple payloads required by the mission and can be customized to fit the needs of each launch.

4.1.7. Discuss the precision of instrumentation and repeatability of measurement

A determination of each sensor's precision of instrumentation was shown in Table 4-5 below denoting the resolution of each sensor, Beaglebone, and Arduino as indicated by each component's respective datasheet. The Beaglebone and the Arduino's 10 and 12 bit ADC resolution is a function of the max measurement made divided by the number of bits as indicated below.

Table 4-5 : Component Resolution



Component	Bit	Resolution
ADXL345 (±2G, ±4G, ±8G, ±16G)	10, 11, 12, 13	256, 128, 64, 32 LSB/g
ADXL377 (±200G)	Analog	6.5 mV/g
L3GD20(200dps, 500dps, 2000dps)	16	8.75, 17.50, 70 mdps/digit
480-5550-ND 30 PSI Pressure Sensor	Analog	21 mV/V
480-5551-ND 60 PSI Pressure Sensor	Analog	21 mV/V
480-3797-ND 100 PSI Pressure Sensor	Analog	12.6 mV/V
Beaglebone	12 bit ADC	$\frac{1}{2} * \frac{Measurement_{MAX}}{2^{12}}$
Arduino	10 bit ADC	$\frac{1}{2} * \frac{Measurement_{MAX}}{2^{10}}$

The repeatability of measurement was preliminary tested in the subscale preliminary launch testing matrix in Table 4-4.

4.1.8. Discuss the payload electronics with special attention given to transmitters

For the two subscale launches, one Beaglebone was used to process 6 of the total 13 sensors to test the measurement concepts that will be utilized for the full scale launch. In the first subscale launch, the payload was flown as ballast, but on the second launch the entire flight was recorded at roughly 48 Hz for each sensor. The six sensors consisted of 2 ADXL345 accelerometers, 2 L3GD20 Gyroscopes, and 2 ADXL377 High G accelerometers. The schematic that models the payload that was launched on February 8th was shown in Figure 4-20 below. The sensors communicate through the I2C pins 19 and 20 on the Beaglebone. All of the sensors except the ADXL377 analog accelerometer run off the 3.3V supply in pin 3. The analog accelerometers run off of the unique 1.8V source specifically designed for the use of analog devices on pin 32 of the Beaglebone.

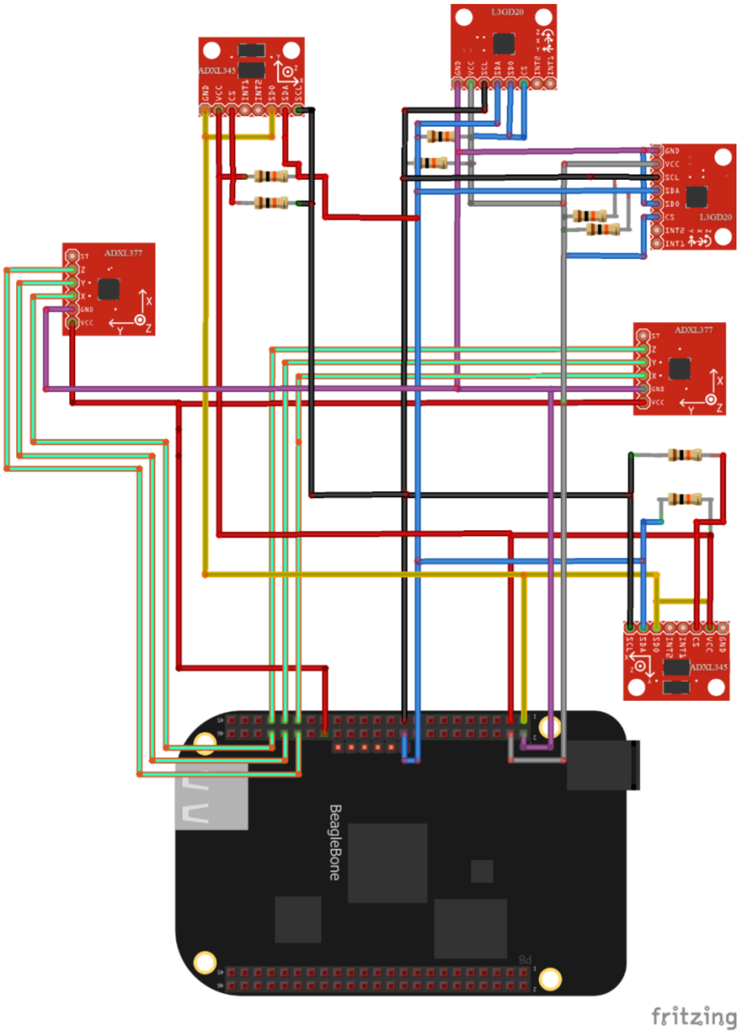


Figure 4-20 : Nanolaunch Subscale Configuration

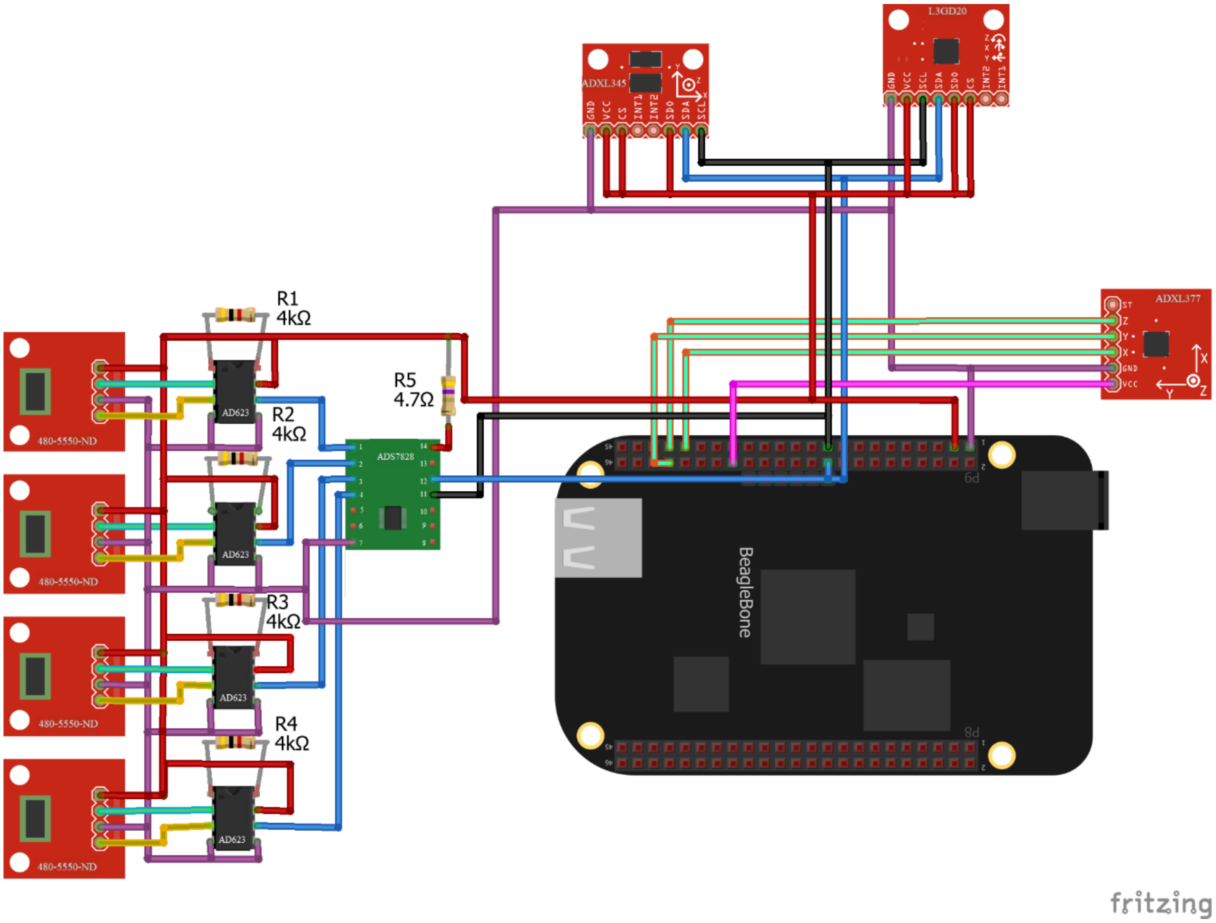


Figure 4-21 : Nanolaunch Payload, CG Configuration

The full scale launch's electronics will be split in two main locations, at the center of gravity and at the nose of the rocket. The Nanolaunch payload at the CG will consist of a low G (ADXL345) and a high 200G accelerometer (ADXL377), a gyroscope (L3GD20), and 4 pressure sensors that will be used to simulate base drag. The base drag sensors will be placed in the center of the rocket to provide proof of concept. The center of gravity configuration will also contain an analog to digital converter (ADC) used to convert the pressure sensors' analog output to an I2C based digital signal. The I2C pull-up resistors were already packaged in the ADC, which is why there are not any 2.2kohm resistors shown in the circuit. In order for the pressure sensor's data to be readable, the differential voltage will have to be amplified with a gain of 26 for the 30 and 60 psi pressure sensors and a gain of 43 for the 100 psi sensor. The gain was dictated by the resistance that runs from pin 1 to pin 8 in the AD623 through the use of a 2.4k ohm for the 100 psi sensor and 4k ohm resistors for the 30 and 60 psi sensors. The schematic that shows the circuitry for the CG configuration can be seen below in Figure 4-21.

The wiring diagram schematic for the nose configuration consists of the 3 Pitot-static pressure sensors that will travel through the nose of the rocket. The nose configuration will also consist of a low G accelerometer (ADXL345), a high 200G accelerometer (ADXL377), and a gyroscope (L3GD20). The accelerometers in the nose will be useful in providing meaningful data from small disturbances during flight. The low G accelerometer will be able to detect more precise measurements than the 200G accelerometer because of the 200G accelerometer has to cover a much wider range with only 12 bits. The schematic for the nose of the rocket was shown in Figure 4-22 below. The pressure sensors were also amplified similarly to the CG configuration.

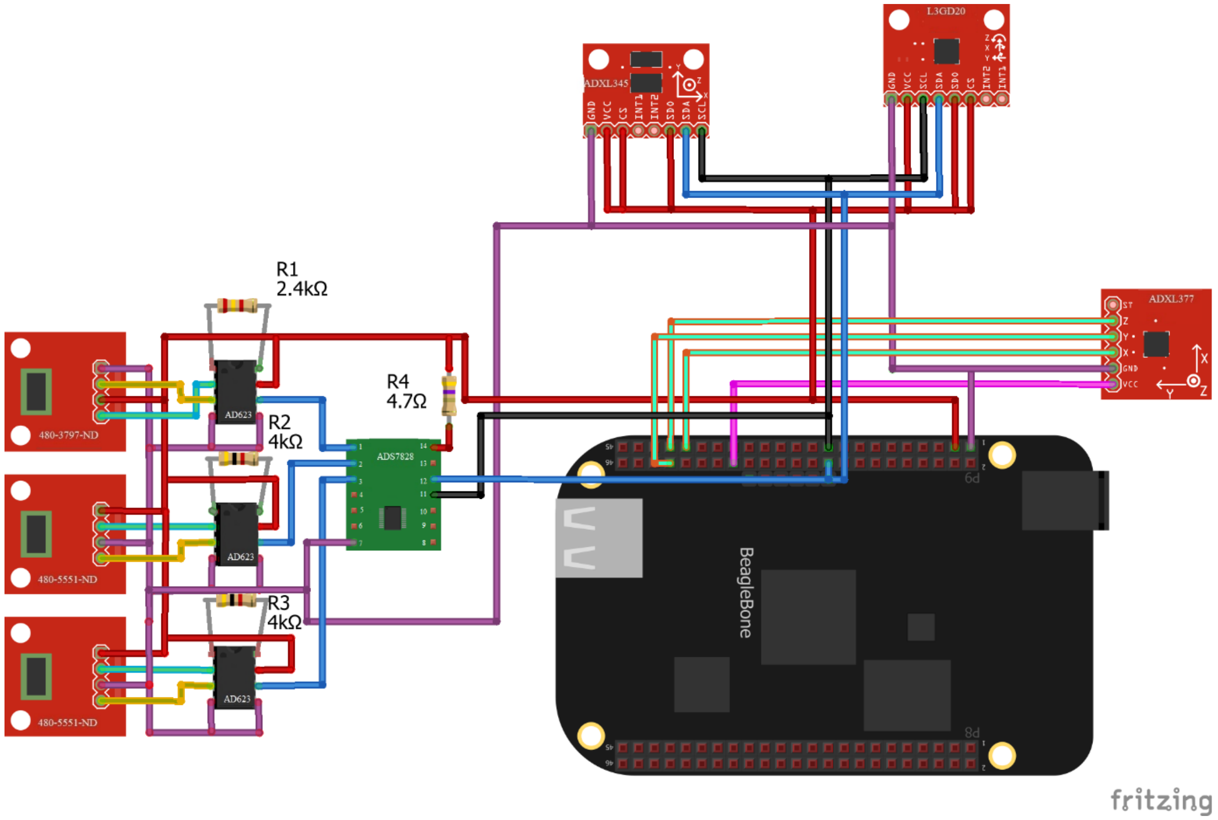


Figure 4-22 : Nanolaunch Payload, Nose Configuration

The Nanolaunch payload will consist of the two configurations, CG and Nose, as identified above. The payload electrical schematic is presented below in Figure 4-23. All electrical components can be seen in the schematic. Nothing can happen in the circuit if the switch is not turned on. This is one of the safety elements that has been incorporated into the design and will be switched once the rocket is on the pad. The HV supply is independent from the other electronics. It has its own current running through it along with its own PCB. The transistor will be the component that activates the HV supply during flight and is wired to the Arduino, battery, and HV supply. The accelerometer will be used to detect launch and also the measure acceleration levels after burnout. The information from this will be stored onto the SD Card Writer which is also wired to the microcontroller.

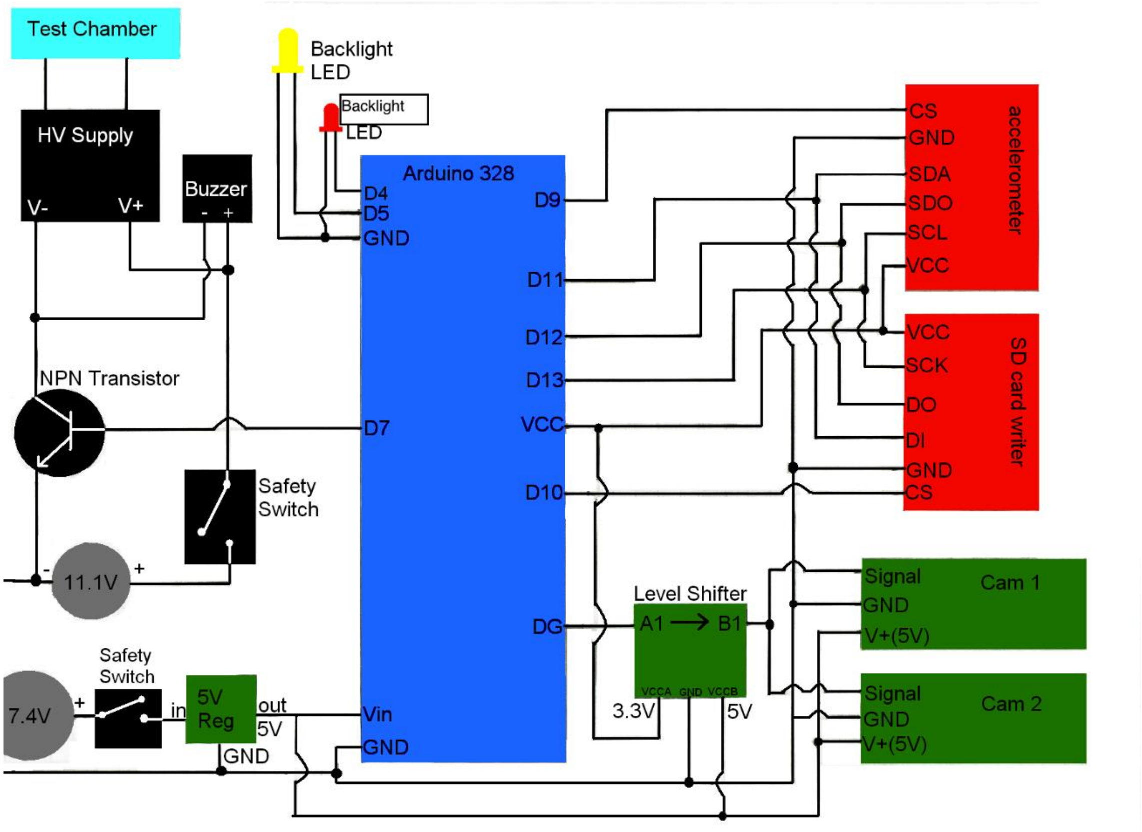


Figure 4-23 : Dielectrophoresis Electrical Schematic

As stated above, the HV supply works independently from the rest of the payload. The schematic show Figure 4-24 below is the wiring for the HV supply and has been incorporated into a single PCB design.

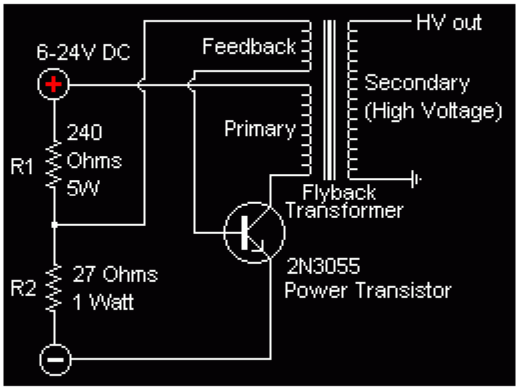
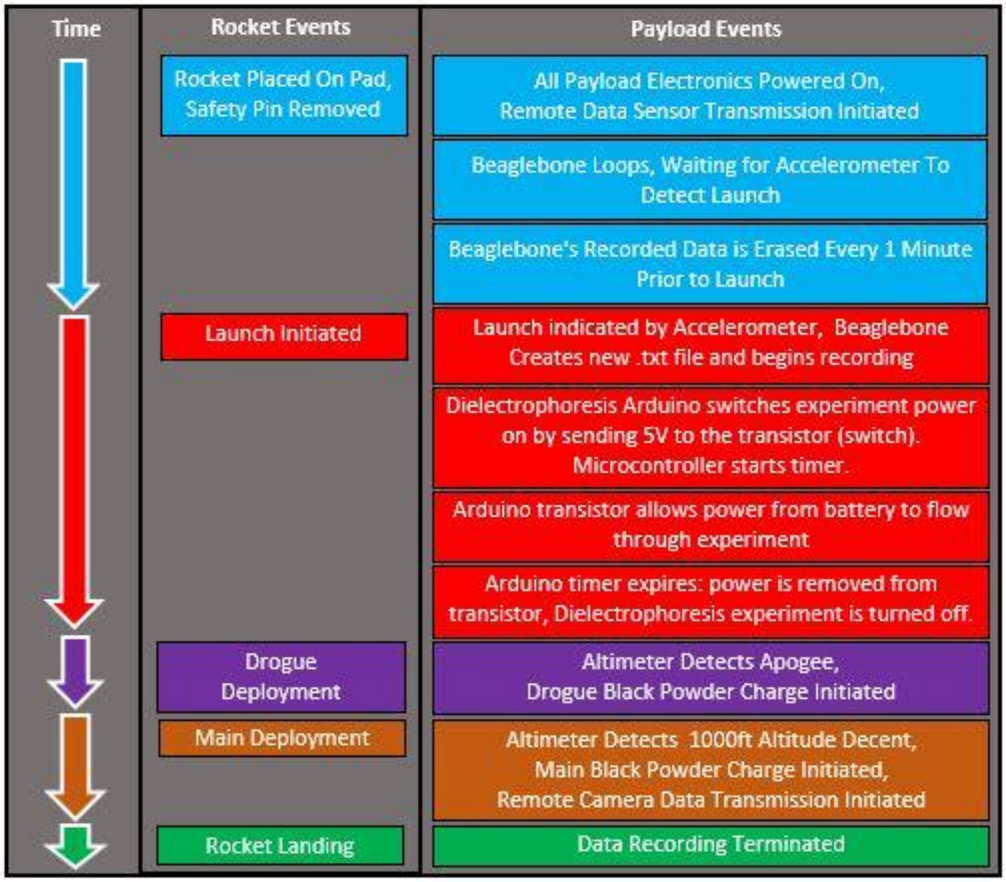


Figure 4-24 : Dielectrophoresis Payload, High Voltage (HV) Schematic

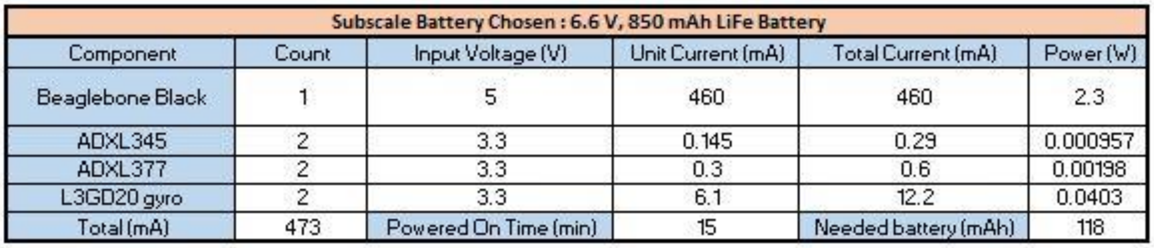


Time	Rocket Events	Payload Events
	Rocket Placed On Pad, Safety Pin Removed	All Payload Electronics Powered On, Remote Data Sensor Transmission Initiated
		Beaglebone Loops, Waiting for Accelerometer To Detect Launch
		Beaglebone's Recorded Data is Erased Every 1 Minute Prior to Launch
	Launch Initiated	Launch indicated by Accelerometer, Beaglebone Creates new .txt file and begins recording
		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	Data Recording Terminated

Figure 4-25 : Chronological Flow Diagram

For the subscale launch, the battery budget shown in Table 4-6 was used to size the appropriate battery necessary for the launch providing the electronics would be powered on for 15 minutes. The calculated battery capacity was 118 mAh, well under the capacity of the chosen 6.6V 850 mAh battery. The battery would have powered the electronics at a full current load for 107 minutes.

Table 4-6 : Subscale Payload Power Budget



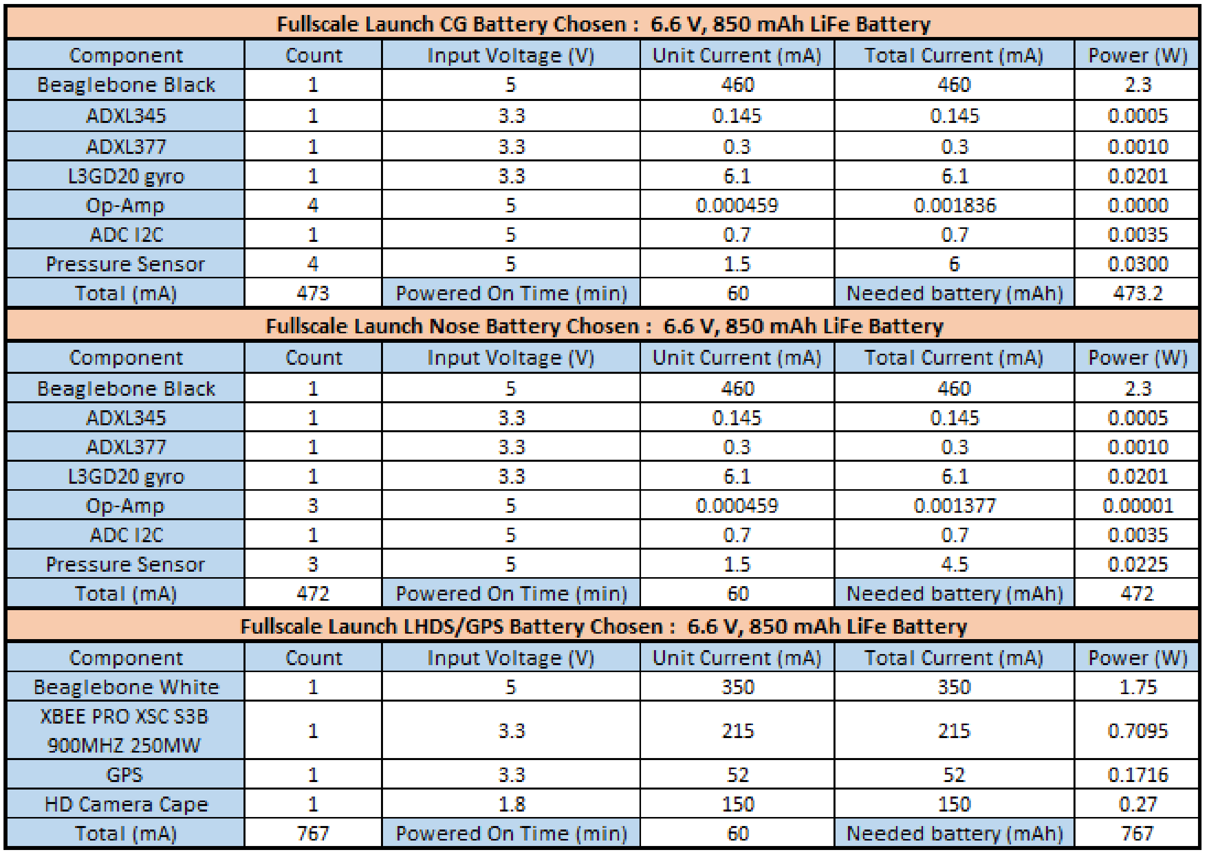
Subscale Battery Chosen : 6.6 V, 850 mAh LiFe Battery					
Component	Count	Input Voltage (V)	Unit Current (mA)	Total Current (mA)	Power (W)
Beaglebone Black	1	5	460	460	2.3
ADXL345	2	3.3	0.145	0.29	0.000957
ADXL377	2	3.3	0.3	0.6	0.00198
L3GD20 gyro	2	3.3	6.1	12.2	0.0403
Total (mA)	473	Powered On Time (min)	15	Needed battery (mAh)	118

The battery requirements for *Prometheus* were analyzed to ensure that a battery of sufficient size was chosen to power the rocket for the hour that it could possibly sit on the launch pad under maximum current draw. Each Beaglebone will be powered by an individual battery to ensure each microprocessor will operate independently. In the case of a malfunction with one system the other systems will not be jeopardized. The driving factor for utilizing multiple battery sources for the

Nanolaunch Payload was to accommodate for the components located in the nose. Without separate battery sources, when the rocket separates for drogue deployment a battery wire running from the CG to the nose would have to break/detach from a power clip which is not feasible because the LHDS and the Nanolaunch Payloads need to have power after chute deployment.

The full scale launch power budget was analyzed by documenting the full load current and voltage source located in each component's datasheet. The payload budget was shown in Table 4-7 below. The GPS and the Xbee transmitter will be powered by the LHDS power supply as indicated by the battery choices for each section below. Each battery will supply more than the needed power for each microprocessor.

Table 4-7 : Full Scale Payload Power Budget



Fullscale Launch CG Battery Chosen : 6.6 V, 850 mAh LiFe Battery					
Component	Count	Input Voltage (V)	Unit Current (mA)	Total Current (mA)	Power (W)
Beaglebone Black	1	5	460	460	2.3
ADXL345	1	3.3	0.145	0.145	0.0005
ADXL377	1	3.3	0.3	0.3	0.0010
L3GD20 gyro	1	3.3	6.1	6.1	0.0201
Op-Amp	4	5	0.000459	0.001836	0.0000
ADC I2C	1	5	0.7	0.7	0.0035
Pressure Sensor	4	5	1.5	6	0.0300
Total (mA)	473	Powered On Time (min)	60	Needed battery (mAh)	473.2
Fullscale Launch Nose Battery Chosen : 6.6 V, 850 mAh LiFe Battery					
Component	Count	Input Voltage (V)	Unit Current (mA)	Total Current (mA)	Power (W)
Beaglebone Black	1	5	460	460	2.3
ADXL345	1	3.3	0.145	0.145	0.0005
ADXL377	1	3.3	0.3	0.3	0.0010
L3GD20 gyro	1	3.3	6.1	6.1	0.0201
Op-Amp	3	5	0.000459	0.001377	0.00001
ADC I2C	1	5	0.7	0.7	0.0035
Pressure Sensor	3	5	1.5	4.5	0.0225
Total (mA)	472	Powered On Time (min)	60	Needed battery (mAh)	472
Fullscale Launch LHDS/GPS Battery Chosen : 6.6 V, 850 mAh LiFe Battery					
Component	Count	Input Voltage (V)	Unit Current (mA)	Total Current (mA)	Power (W)
Beaglebone White	1	5	350	350	1.75
XBEE PRO XSC S3B 900MHZ 250MW	1	3.3	215	215	0.7095
GPS	1	3.3	52	52	0.1716
HD Camera Cape	1	1.8	150	150	0.27
Total (mA)	767	Powered On Time (min)	60	Needed battery (mAh)	767

The dielectrophoresis payload power budget consisted of two unique budgets, one for the Arduino power supply and the other for the high voltage power supply. The Arduino power budget was shown in Table 4-8 below. The 7.4V battery supplies 555 mA of current. However, the total current draw is only 465 mA.

Table 4-8 : 7.4V Dielectrophoresis Payload Power Budget

7.4V Battery Total Current (mA) =			555.145		
Component	Count	Input Voltage (V)	Unit Current (mA)	Total Current (mA)	Power (W)
Arduino Pro	1	2.7 to 5.5	15	15	0.075
Accelerometer	1	3.3	0.3	0.3	0.001
LED white	2	3.0 to 3.4	20	40	0.128
To HV transistor	1	6	150	150	0.9
Camera Control	2	5	100	200	1
SD card	1	5	60	60	0.3
Total (mA)	465	Powered On Time (min)	15	Needed battery (mAh)	116.3

The power budget for the high voltage power source was independent.

Table 4-9 : 11.1V Dielectrophoresis Payload Power Budget

11.1V Battery Total Current (mA) =			1008	
Component	Count	Input Voltage (V)	Unit Current (mA)	Power (W)
HV Power Supply	1	12	1000	12
Buzzer	1	12	8	0.096

All data transmission capabilities are handled by an embedded wireless radio frequency (RF) module. The module is mounted in the body section of the rocket near the parachute and transmits all GPS and Landing Hazard Detection System (LHDS) data from a dedicated BeagleBone. The data will begin transmitting after deployment of the drogue parachute, which pulls the module from the body tube of the rocket as shown in Figure 4-26. 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 RF module will be powered by the BeagleBone which runs on a 6.6 V, 850 mAh LiFe Battery.

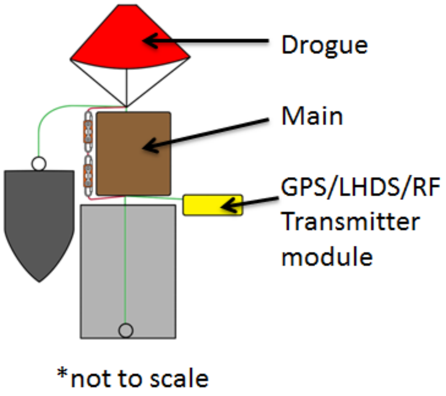


Figure 4-26 : Deployment Simulation

The XBee is a universal asynchronous receiver/transmitter (UART). It functions as a wireless serial port: whatever is pushed to the data radio module is 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 that connects a second of the above XBee transmitters to the USB port on a laptop. A custom program interprets and displays the received serial data packet stream, and the GPS information is used to recover the rocket.

The RF module and Beaglebone integration system will be extensively tested before final launch. Ground tests will be conducted to push data rate, LoS as well as partially obstructed range, and transmitted data integrity to their limits. Furthermore, the system will be used on subscale and full-scale test launches to evaluate any potential effects from external heating, high G loading, and other environmental factors. These results will be used to ensure optimal performance during the final launch. The minimum performance goals that must be achieved in order for the RF module to be deemed successful can be found in Section 4.5.2 Science Value.

Dynamic effects of vehicle flight, including vibration and high G loads, have a potential to damage the physical attachments between electrical components and the circuit board, between the GPS and LHDS and the Beaglebone, and between all of these components and the modular payload sled to which they are mounted in the rocket. The likelihood of this damage occurring is minimized through the use of PCBs which reduce the number of physical connections that need to be soldered, by designing component layout to ensure moment arms are as small as possible, and by fabricating support structures on the payload sled to brace components against movement cause by extreme accelerations. The range of the XBee RF transmitter is approximately 9 miles LOS and decreases with increasing obstructions due to terrain. To ensure the vehicle does not drift out of range of the ground station during descent, only a drogue chute is deployed at apogee. The main parachute is not deployed until the rocket is much closer to the ground, greatly decreasing the total descent time and thus the range over which it can drift. With the current parachute setup, the projected worst-case scenario for drift after drogue deployment is around 1.7 miles, far less that the projected 9 mile range. Furthermore, performing flights in large, open, flat areas (such as the salt flats) neglects the possibility of encountering interference from terrain. Radio Frequency interference (both external and internal) is also cause for design consideration. The XBee RF module has a power output of only 250 mW, making it very unlikely to interfere with other team's E-matches and ejection charges, as has been a concern with high power transmitters in the past. Additionally, the XBee and the "Tagg Pet Tracker" which is used as a backup, redundant system, transmit on widely different RF bands. This prevents interference between the two signals. Finally, if the RF module (including the XBee transmitter, GPS, and LHDS) is not successfully ejected from the main body tube of the rocket upon parachute deploy, the RF module will not be able to transmit through the carbon fiber of the body tube and no GPS or LHDS data can be received by the ground station, which would constitute a failure. Careful recovery system design, black powder testing, and deployment testing are the keys to mitigating the potential of this failure.

The GPS system used is built around an Antenova M10382-Al UB GPS Module (Digi Part Number 627-1030-ND) mounted on a PCB, as shown in Figure 4-27 and Figure 4-28. The GPS sensor requires an input of 3.3 VDC and has a dynamic current consumption that can peak at up to 100 mA but typically reaches its highest average (52 mA) while acquiring initial GPS lock and then averages between 22 and 45 mA depending on how frequently GPS fixes are being sampled. The Beaglebone will be used to power the GPS system. It connects to UART pins on the Beaglebone that in turn sends the GPS (and LHDS) data through the XBee RF module to the ground station. The GPS module will be mounted on the PCB as the XBee RF module in the main body tube of the rocket.

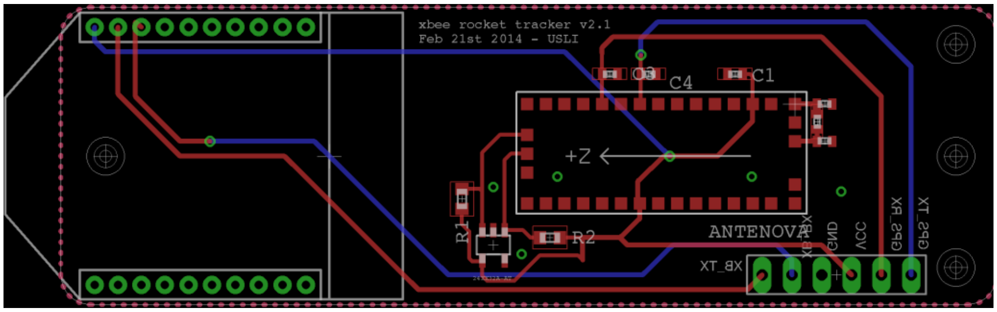


Figure 4-27 : GPS/XBee PCB Layout

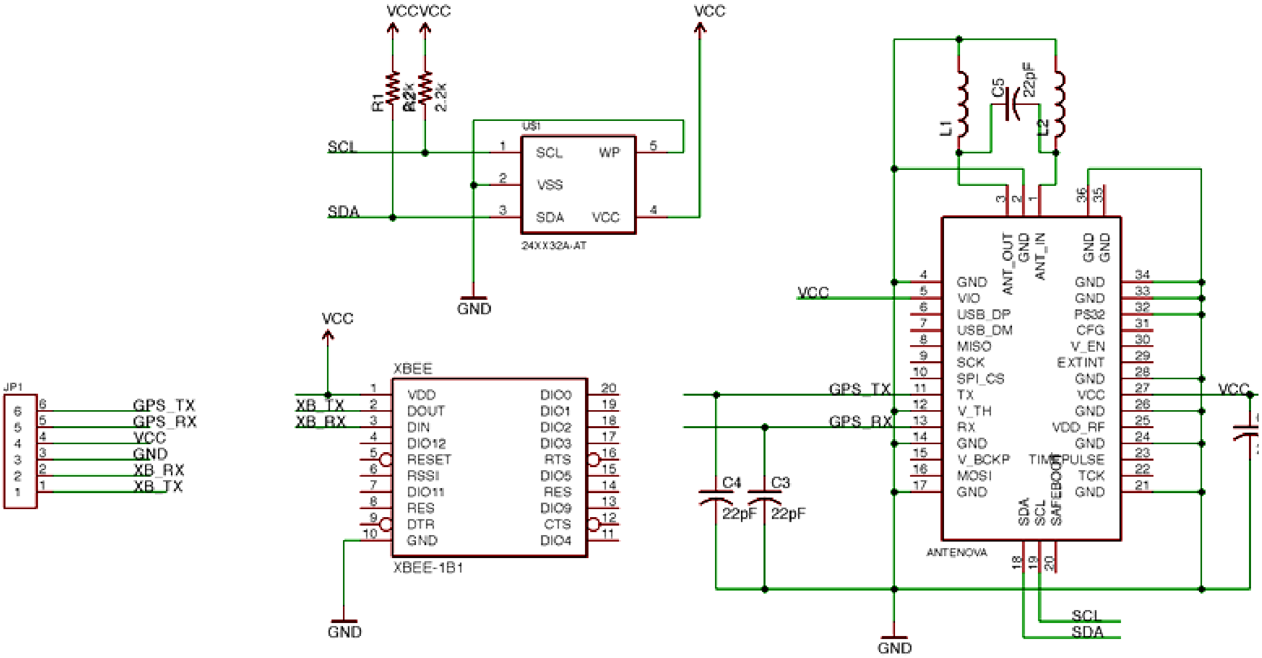


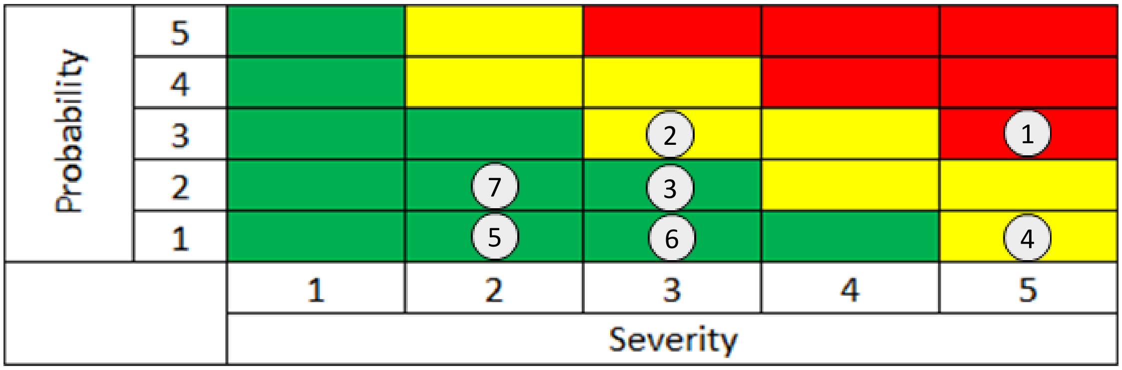
Figure 4-28 : Schematic of RF & GPS Module

The module will lose GPS lock during maximum accelerations/velocities, making transmission of GPS data during powered flight unreliable to impossible. It is for this reason that the RF module is not transmitting data until after the drogue parachute deploys. A redundant method of tracking the rocket is implemented in the form of a “Tagg Pet Tracker.” This independent on-board transmitter allows the unit to be tracked via the Verizon cell network using a Smartphone/mobile based application. If the redundancy also fails, the contingency is to track the rocket visually.

4.1.9. Provide a safety and failure analysis

The risk assessments for the payloads were evaluated in Table 4-10 and Table 4-11. The risk was evaluated using a probability and severity matrix that associates a number corresponding to the extremity of the risk’s occurrence on the outcome of the launch. The highest risk that was documented was the possibility of an incomplete deployment of the LHDS. The reason this risk was rated at a severity level of 5 was because it was a NASA requirement that it be deployed, and that it has a possibility of entangling with the parachute deployment, thus jeopardizing the launch. To prevent the parachute entanglement from occurring, Prometheus's deployment mechanism will be tested methodically before launch.

Table 4-10 : Risk Probability



Probability	5	🟩	🟨	🟥	🟥	🟥
	4	🟩	🟨	🟨	🟥	🟥
	3	🟩	🟩	🟨 ②	🟨	🟥 ①
	2	🟩	🟩 ⑦	🟩 ③	🟨	🟨
	1	🟩	🟩 ⑤	🟩 ⑥	🟩	🟨 ④
		1	2	3	4	5
		Severity				

Table 4-11 : Potential Hazards

Ref #	Potential Hazard	Probability	Severity	Impact	Mitigation
1	Incomplete Deployment	3	5	Loss of GPS signal, LHDS data, or vehicle.	Ground testing of recovery system
2	Vehicle Out of Range	3	3	Loss of LHDS/ GPS	Recovery system design to minimize drift
3	High Voltage	2	3	Electronics malfunction, sensor output manipulation due to gravitational field	Implement Faraday Cage
4	Launch Detect Not Triggered	1	5	No data recorded	Extensive program testing/verification
5	Environment	1	2	Payload stuck in a tree	Deploy main parachute at low altitude to reduce drift
6	Cold Solder Joints	1	3	Electronics malfunction	Methodical testing for verification
7	Broken Wire	2	2	Electronics malfunction	Subscale flight testing to simulate G loading

4.2. Payload NanoLaunch 1200

4.2.1. Payload Concept Features and Definition

The Nanolaunch 1200 payload was creative and original in that it uses a unique microprocessor that exposes the team to C/C++ coding which will be something that other teams will not be able to offer. The payload consists of two separate modules, one located at the CG and one located at the nose of the rocket. The two payloads will serve to record the in-flight data and will provide a substantial amount of data encompassing the entire flight. The significance of the payload is that it will be able to act as an inexpensive replacement for subscale wind tunnel tests to determine the pitching moment, total drag coefficient, and base pressure. The empirical data that will be recorded will be crucial to providing the background data to be able to extrapolate coefficients such as the ones that would be recorded in the wind tunnel as stated above.

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 platform 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.

Prometheus planned on using an Attitude Disturbance System (ADS) in order to test the aerodynamic effects of changing the rocket's trajectory, pitching moment in particular. The system's optimum primary is to temporarily tip the rocket's flight by 15 degrees and record the change in aerodynamics during its return to normal flight. In order to cause this tip, the system is designed to use pressurized carbon dioxide to pitch the rocket temporarily. The pressurized gas will be contained within a disposable cartridge. The gas will be released from the cartridge using a small electronic solenoid valve. The solenoid valve is designed to withhold pressures greater than 1000 psi, and has a high flow rate. It is vital that the valve's flow rate is very high so that the velocity of the gas can be high enough to cause the rocket to tip. When the rocket is ready to be tipped the solenoid valve will activate releasing the pressurized carbon dioxide into stainless steel tubing that will lead the gas to the exterior surface of the rocket. This small lightweight system should be easily contained within the nosecone of the rocket. By containing the system in the nosecone it will require less force to create the moment necessary to change trajectory.

The team decided that the Attitude Disturbance System's risks far outweigh the system's benefits at this time. Due to safety and flight risks the Attitude Disturbance System is being removed from Prometheus’s design in the competition. Even though the ADS is not being used in this year’s competition the project will continue with future teams to complete the research and fly a safe and valuable experiment.

4.2.2. Science Value

The Nanolaunch experiment’s objective was 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.

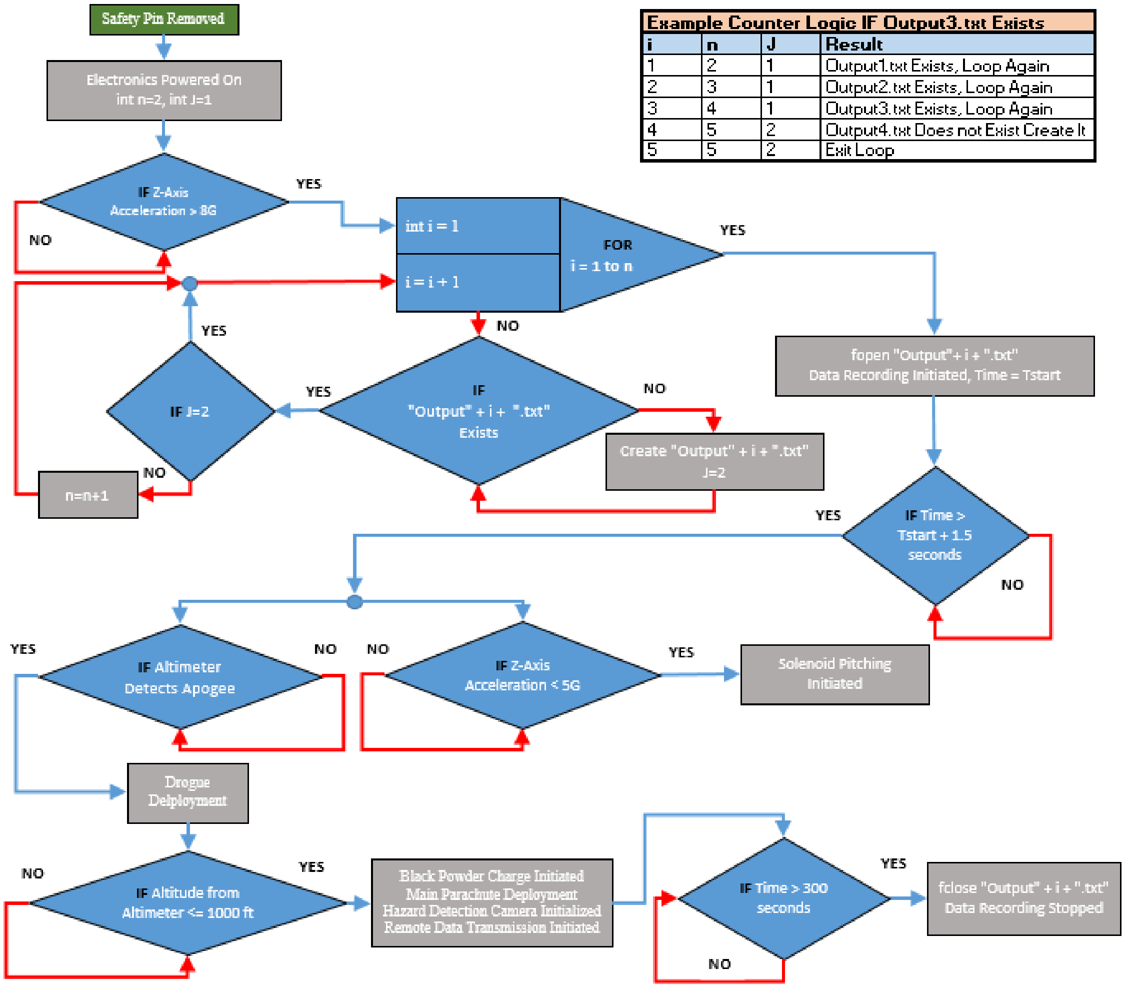
The success criterion for the Nanolaunch 1200 payload is outlined in Table 4-12. The table identifies the major requirements that would control the success or failure of meeting the payload’s objectives.

Table 4-12: Success Criteria

Requirement	Success Criteria	Verification
Velocity Verification	Measure Pitot static pressure at the Nose to Calculate Mach	Recover pressure data from the Pitot static probes
Determine Axial Force	Measure axial acceleration	Recover acceleration data in the axial direction
Determine Angle of Attack	Measure gyroscope data at CG and the nose to get Yaw, Pitch, and Roll	Recover gyroscope data from both Beaglebone modules
Recoverable and Reusable	Recover the payload and reuse it	Recover the payloads and be able to relaunch again in the same day

The flow chart in Figure 4-29 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.

The results of the Attitude Disturbance System experiment could be very significant, because the data recorded could provide us insight to the aerodynamic effect that Reaction Control Systems may have on rockets. Understanding these effects could be helpful in designing rockets to be more controllable in their flight's direction.



Example Counter Logic IF Output3.txt Exists			
i	n	J	Result
1	2	1	Output1.txt Exists, Loop Again
2	3	1	Output2.txt Exists, Loop Again
3	4	1	Output3.txt Exists, Loop Again
4	5	2	Output4.txt Does not Exist Create It
5	5	2	Exit Loop

Figure 4-29 : Code Flow Chart

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 Nanolaunch 1200 experiment's payload accelerometer data will be expected to match the G loading profile shown in Figure 4-30 for the 1.53 seconds shown. The expected data will have significant G changes at the following events during flight: motor burnout, apogee, drogue parachute deployment, and the main parachute deployment.

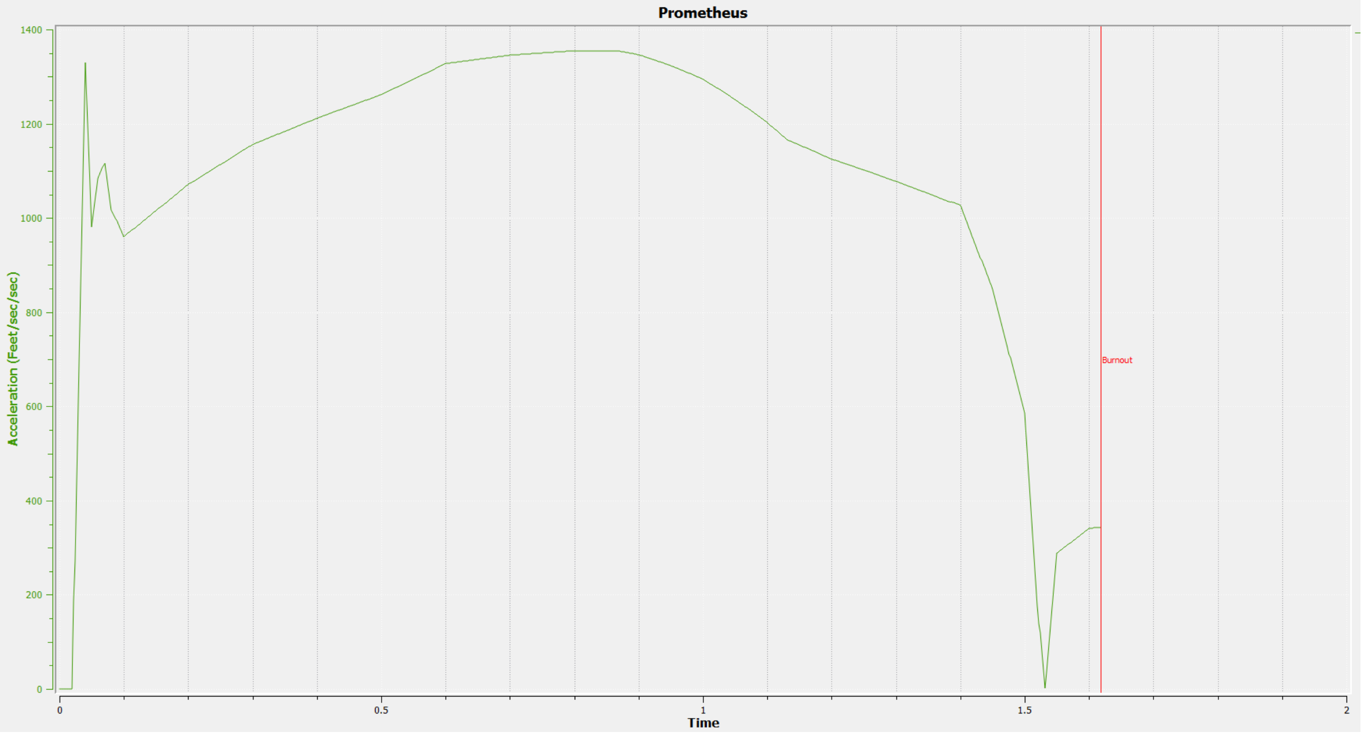


Figure 4-30 : OpenRocket Acceleration Vs Time

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 which was based on the textbook "Modern Compressible Flow" by John Anderson. The sensors were purchased to cover the expected range of pressure with 100 and 60 psi sensors, 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 when used to calculate the aerodynamic coefficients 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 is too high to extrapolate the aerodynamic coefficients, the 16G accelerometer from the dielectrophoresis experiment will be used with a predicted uncertainty of only +- 0.8G.)

The experimental procedure for using the Nanolaunch 1200 payload consists of three main components that will be broken down and analyzed below. The three main components that make up the procedure for using the payload are as follows: programming the Beaglebone, recording data in flight, and data extraction.

The programming of the Beaglebone microprocessor involved using the VI editor and/or the Eclipse environment as the graphical user interface for programming in C/C++. The Beaglebone's programming was difficult in that it required branching out finding examples of accelerometer and gyroscope code that was operating with the I2C communication bus similar to the Nanolaunch payload. The code was written to accommodate each sensor's unique registry map included in each sensor's datasheet. All the Nanolaunch sensors except for the analog ADXL377 accelerometers will communicate with the Beaglebone via the I2C bus, using a master/slave relationship to provide efficient data transmission between each individual device. Each device communicates to the Beaglebone with both a data and a clock wire which provides a way to accommodate sending data from several sensors back to the Beaglebone all on the same wire. The bus uses the unique clock measurement to identify each sensor's address that way the Beaglebone can identify which measurement belongs to which sensor. The I2C communication flow is shown in Figure 4-31 below.

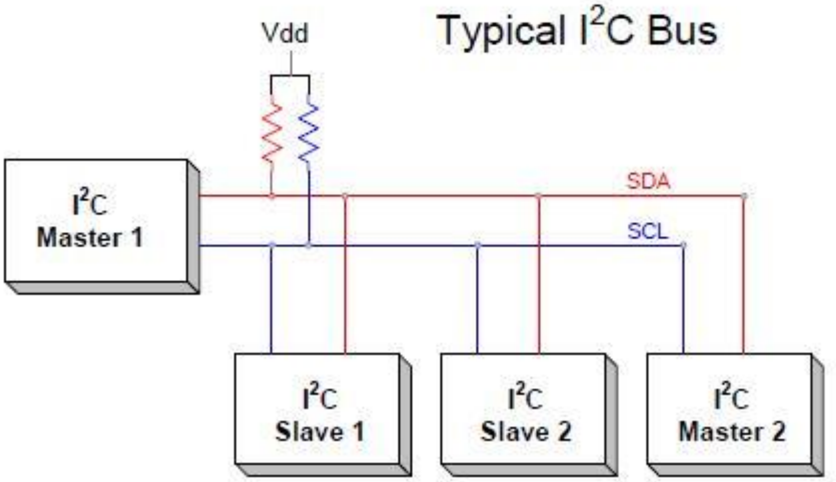


Figure 4-31 : Typical I2C Interface

After the I2C communication between the sensors was established, the process of reading and writing the sensor values to a text file was implemented. The Beaglebone code/library flow consists of a main () program that runs and references the header files for each sensor. Each sensor's C file such as ADXL345.C was used to define the functions used to establish communication between the sensor and the beaglebone to output the sensor's acceleration, degree per second, or pressure. As shown in the excerpt from the full txtwrite.cpp code in Figure 4-32 below, each sensor header was included within the extern "C" reference to enable the C code to be able to be compiled in a C++ environment. The getMilliCount function was used in conjunction with the getMilliSpan function to determine to be able to place a timestamp on each measurement in milliseconds.

```
#include<iostream>
#include<fstream>
#include<cstdlib>
#include<sstream>
#include<string>
#include<stdio.h>
#include<sys/timeb.h>
#include<stdlib.h>
#include<time.h>
#include<unistd.h>
#include<fcntl.h>
#include<sys/stat.h>
#include<sys/types.h>
#include<errno.h>
#include<linux/i2c-dev.h>
using namespace std;
extern "C" {
#include "ADXL345.h"
#include "demo.h"
#include "1dADXL345.h"
#include "1ddemo.h"
#include "Adafruit_L3GD20.h"
#include "demol.h"
#include "kAdafruit_L3GD20.h"
#include "demok.h"}
ofstream fileout;//declare variable of type "ofstream" to write test file
int getMilliCount(){
        timeb tb;
        ftime(&tb);
        int nCount = tb.millitm + (tb.time & 0xfffff) * 1000;
        return nCount;}
int getMilliSpan(int nTimeStart){
        int nSpan = getMilliCount() - nTimeStart;
        if(nSpan < 0)
        nSpan += 0x100000 * 1000;
        return nSpan;}
int main()
```

Figure 4-32 : Nanolaunch C/C++ Main Function Structure

Using the program structure, it created a strong foundation for the triggering of events during flight.

The recording of data during flight was a trivial procedure for the operation of the Nanolaunch 1200 payload. Before launch, the payload would need to be assembled into the rocket. Once the rocket is on the launch pad, the pin will be removed triggering the electronics to turn on. The electronics will then operate according to the Figure 4-29 code flow chart. After the rocket lands the electronics will turn off after an elapsed time expires, and then the data extraction will take place post launch.

The data extraction is not difficult in that it just requires hooking the Beaglebone up to a computer and copying the output0.txt file to a location on the PC hard drive. After the text file is copied to a location on the PC, a macro-enabled Excel Spreadsheet will take the data and sort it into respective worksheets/columns. An example of this data extraction can be seen in Appendix C, Sample Sensor Array Data Extraction Format.

The hierarchy of the program structure can also be seen more clearly in the VUE flow chart found in Figure 4-33 below. The flow chart does a good job demonstrating how the txtwrite.cpp file calls each other external file in the code. Through measuring the I2C bus and the analog pins, the “output” + i + ”.txt” file was created.

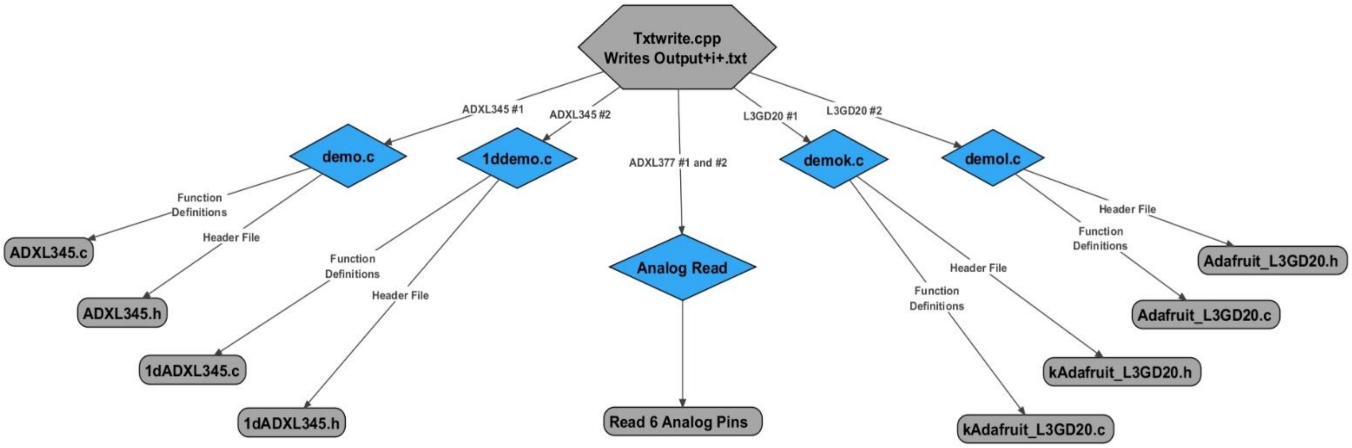


Figure 4-33 : Hierarchy Code Structure

4.3. Payload Dielectrophoresis

4.3.1. Payload Concept Features and Definition

Dielectrophoresis is the use of electric fields to move fluids. This is accomplished by subjecting a nonpolarized molecule with dielectric properties to an electric field. This separates the poles, which forces the molecule to be influenced in one direction or the other. 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. Another advantage of this system would be that if the fuel is more concentrated in one area, it would help act as an extra barrier from radiation from the sun. The power required to establish a high voltage electric field is low, and it is operable at any time.

This experiment is very creative and original in the sense that it is still a new concept with much of the serious work being done within the last century. This gives way to several different approaches that could be taken. Dr. James Blackmon, while at UAH, laid the foundation for this experiment with his research on the collection of liquid propellants in zero gravity with electric fields. This is only the second time this experiment has been conducted by a student team at UAH. The overall design is based off of the previous UAH CRW Student Launch Team’ ground work and setup. However, key variables of the experiment, electrode configuration in particular, have been altered in attempt to acquire better results.

The type of research that has been carried out gives this dielectrophoresis experiment its unique characteristics. 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.

This experiment was chosen for its applicability to microgravity and spacecraft applications. When conducting long term spaceflight, one of the most difficult problems that have 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.

The fact that the concept of using dielectrophoresis in aircraft is so new is the same thing that makes this experiment so difficult. Building off of previous errors and experiences has allowed this experiment to grow, overcoming previous challenges, and to begin working through new ones. One of the biggest challenges so far is how to make the dielectric forces have a greater effect on the fluid. Several experiments have been conducted such as increasing voltage and using different inner and outer electrode designs.

4.3.2. Science Value

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.

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. Various fluids such as corn oil, silicone oil, and peanut oil have been evaluated as the fluid to be flown in the experiment because their dielectric constants are similar to those of several liquid propellants.

The success of the payload experiment will be defined by the following three criteria that address both successful function of the payload and team safety. The three criteria are summarized in below.

Table 4-13 : Success Criteria

Requirement	Success Criteria	Verification
Overall Fluid Movement	Fluid behavior significantly influenced by dielectrophoresis versus the neutral control fluid	Recover camera data from FlyCamOne
Central Movement	Fluid retention away from container walls	Recover camera data from FlyCamOne
Team Safety	All members will be unharmed by the experiment	Check for any injuries
Recoverable and Reusable	Recover the payload and reuse it	Recover the payloads and be able to relaunch again the same day

Video will be captured showing the oil in the fluid containers collected between the two electrodes as a result of dielectrophoresis when the rocket reaches apogee. This will require all components of the payload to function as expected and safely. The video taken can then be analyzed to evaluate the fluid behavior against the three criteria listed above and determine if the experiment was successful. The final criteria will be met if all team members and observers are unharmed by the experiment. The team will incorporate redundant precautions to ensure this success criteria is met.

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 point of this whole experiment is to gain some kind of usable data in order to further progress the study of dielectrophoresis. If inaccurate analyses were conducted then the experiment would be of no use and could be termed unreliable. It is also good to have expectations of what the results should be. That way if the data obtained while running the experiment give results that differ from the expectations, one may be able to trace errors that were made.

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. 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. This is the idle mode of operation.

4.4. Payload Paints and Coatings

4.4.1. Payload Concept Features and Definition

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. These coatings could be seen as a more cost effective way to protect rockets bodies from wear. The payload will also incorporate a unique thermal 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 thermal tape changes color when it reaches a specific temperature as seen in Figure 4-34. The challenge of using this technique in collecting temperature reading is that the tape will be subjected to skin friction. Reaction time of the thermal tape is 3-5 seconds which could produce lost data, but alternative faster reacting tape could be an alternative. The adhesion of the tape is also significant so that the friction creates enough temperature for the tape to react, but not so much that it peals the tape off the body of the rocket.

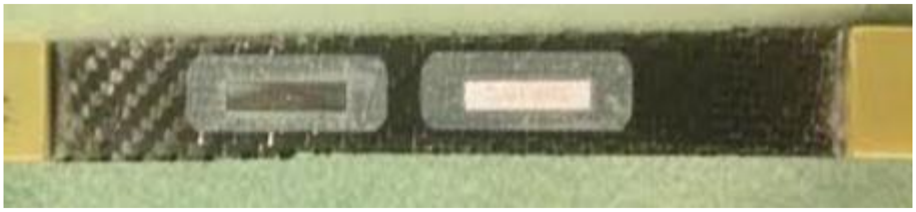


Figure 4-34: Temperature Tape Thermal Test

The coatings selected for Prometheus, epoxy primer and urethane, were selected on film thickness to weight ratio, adhesion, and heat resistance. Epoxy will be a two part system that is activated by mixing a catalyst with a reducing agent as seen in Figure 4-35. This allows for adjustment of the cure time for the coating to help speed up or slow down production time. Epoxy also offers high coverage properties with low film build allowing for a better coverage with less weight. It also has excellent adhesion and anti-corrosion properties allowing for application to multiple materials. Urethane, as seen in Figure 4-36, is a good alternative although it doesn’t have high adhesion when properly applied it still offers a high volume to film build ratio. It offers excellent retention along with abrasion resistance with a smooth finish. Urethanes heat capacity and curing times can also be altered to meet production needs. These coatings have the best durability qualities needed for a supersonic flight.

Figure 4-35: Two Part Epoxy

Figure 4-36 : Urethane

In order to test the coatings in supersonic flight each coating will cover half the rocket. Each coating will have different surface finishes with the epoxy having a rough surface and the urethane having a smooth finish. This will help show the differences between the two applications of the paintings post flight. The coatings will be analyzed post flight for any defects and compared with each other to determine their surface effectiveness. Along with the multiple coatings, a temperature tape will be applied to the rocket body. The tape will act as a visual reference to our thermal analysis to help verify the surface temperatures. The tapes being applied will be 300, 400, and 500F temperatures and were selected by a comparison of a heat and mass transfer analysis conducted by the team.

4.4.2. Science Value

The importance of finding durable paints and coatings for supersonic flight is multifold. Weight is always a major factor in space flight and minimizing weight by using lighter coatings that can withstand the rigors of supersonic flight is the objective. Cost is another driving factor and should be minimized. By testing different coatings with subscale rockets that still travel supersonic, reliable and accurate date can be gathered on a variety of paints and coatings cheaply. The importance of testing the reliability of thermal changing tape lies in the cost. Thermal tape is normally used for static temperature testing with this being the only time it’s ever been tested in supersonic flight. The thermal tape has a reaction time of 3-5 seconds with multiple temperature increments to choose from with the accuracy of 1 degree of the displayed temperature. Applying the thermal tape will be pertinent to its success. If the tape can be found to withstand the stresses of supersonic flight, and display a thermal reaction a cheap alternative will have been found. Preparing the surfaces for the coatings and thermal tape will be crucial to their success. The body of the rocket will be sanded and prepped for maximum adhesion of the coatings. Once the coatings have cured, their surface will be cleaned to ensure for greatest adhesion of the thermal tape.

The success criteria for the paint and coatings payload are outlined in Table 4-14 below. The table states the requirement, how the requirement will be rated as a success, and how the success criteria will be verified.

Table 4-14 : Success Criteria

Requirement	Success Criteria	Verification
Even film thickness	Coverage of the coatings is even and adheres correctly	Check for any defects post flight
Low coating weight	Adds minimal weight to the rocket	Weighing the rocket before and after application
High heat resistant	Coating unscathed from thermal loads	No discoloring of the coatings post flight
Recoverable and Reusable	Recover the payload and reuse it	Recover the payloads and be able to relaunch again in the same day

4.5. Payload LHDS

4.5.1. Payload Concept Features and Definition

The LHDS will be a self-contained system with independent power and data transmission capabilities, the structure for which can be seen in Figure 4-37. It will deploy with the drogue parachute approximately at apogee and scan the area beneath the vehicle for potential landing hazards. The system will use a Beaglebone white with a camera cape to scan the ground during decent. The system will be a pendulum hanging from the end of a tether below the rocket. A fast shutter speed is required to take images of the ground moving rapidly through the field of view of the camera. A custom software consisting of edge detection, color detection and shadow analysis will be coded using C++ and OpenCV in C++ as the primary language. The three detection methods were chosen because they each can help detect a different kind of threat and depending on the conditions edge detection will be difficult if pictures are too blurry. With all three methods, there is redundancy so that as long as one works, threats can be detected. A gyroscope will also be mounted to detect the orientation of the landing hazard detection system. This gyroscope will control when the camera takes the pictures so that the pictures will be of the ground below and not of the horizon.

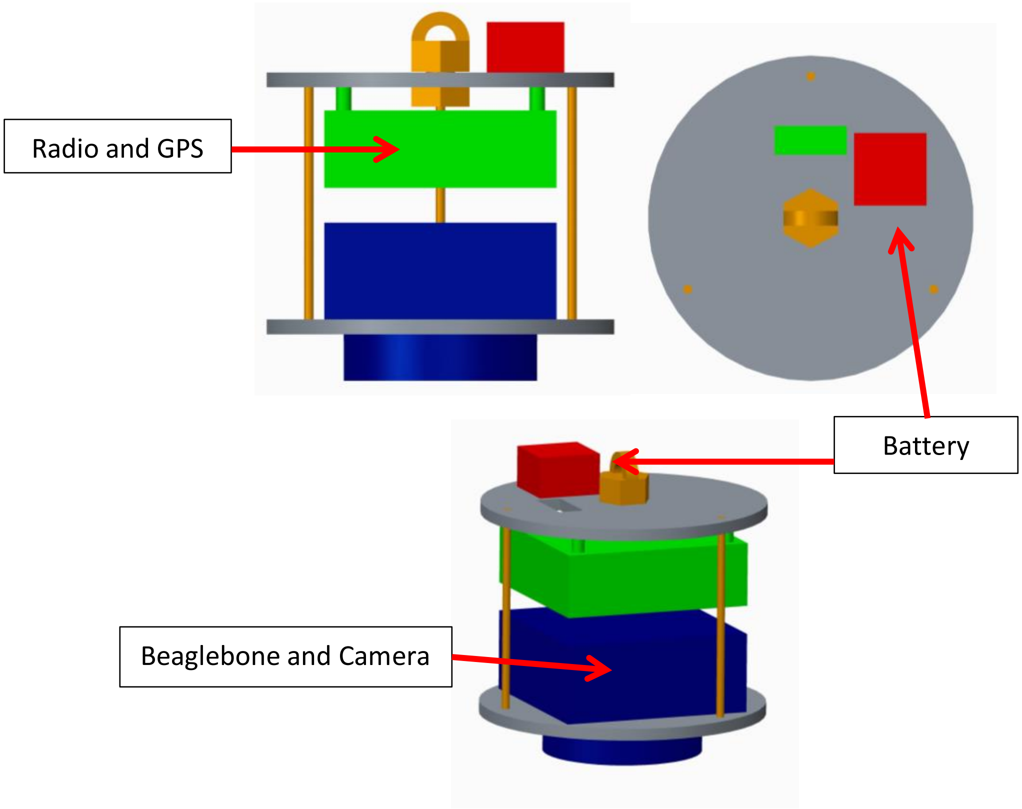


Figure 4-37: LHDS Structure and Layout

The purpose of the LHDS is to demonstrate a novel and unique approach to hazard detection during a vehicle decent. CRW's approach has to consider the deployment method, operating conditions, and test location to create a working code to analyze photographic data. Since the system will be suspended below the rocket on a long tether, constant and unavoidable motion exactly like a pendulum is expected. Because of the uncertainty of the image quality multiple methods were chosen to ensure that the threats of each launch site are taken into consideration. For the competition flight in Utah, edge detection will not be as useful as it would be during test launches in Manchester, Tennessee. Similarly, In Manchester, the color detection will not work as well because the grass and trees will be green. The LHDS will be challenging to the Prometheus team because as a team of Mechanical and Aerospace majors, Computer vision has never been touched on in any course. The team also was not taught C++ which most of the image processing operations will be performed in.

4.5.2. **Science Value**

The objective of the LHDS is to successfully detect threat areas on the ground and relay that data back to a ground station. The success criteria will be to capture images, analyze those images on the Beaglebone using at least one of the image processing methods, and relay that information back to the ground station. A partial success would be if the LHDS deployed, but failed to take pictures or relay them to the ground station.

The CRW definition of a landing hazard has applications in the exploration of the moon and other planets. For a manned mission, the landing sequence would most likely take place during the daytime hours on that planetary body. Assuming the atmosphere is sufficiently clear like the moon or

Mars, shadows will be cast by prominent features like mountains, canyons, and impact craters. Smaller features akin to large boulders would cast a shadow as well but would need to be grouped in large numbers or be of a certain size to be seen from high altitudes. Once the vehicle came sufficiently close to distinguish a boulder field, the system would recognize the shadows and register the feature as a hazard. The idea of avoiding shadows and aiming for an area that reflects sunlight is based on the assumption that the areas with no shadows are clear of objects that may cause damage during landing.

The LHDS poses a unique challenge for the CRW team as no team member has extensive knowledge of computer vision especially on a small system like a Beaglebone. The experimental method to develop the LHDS is to find a simple but effective method of analyzing images to decrease the load on the Beaglebone or its batteries. Through research, the OpenCV libraries in C++ were chosen for the image processing on the Beaglebone, because there is clear documentation and examples of Open CV on Beaglebone.

The data that will be retrieved from the LHDS will allow the recovery team to know if the rocket touched down safely. Depending on what we send back to the ground station, it can also help the recovery team locate Prometheus after touchdown. The pictures as well as the analysis will be kept on the Beaglebone so that any errors can be noted with post flight analysis so the design can be fine-tuned. The data also helps fulfill the requirements of the SLI competition.

The LHDS will consist of a Beaglebone white, the Beaglebone Camera Cape, a gyroscope, a battery and a frame. The Beaglebone white differs from the Beaglebone black used in the Nanolaunch payload. The Beaglebone white is less powerful with a 720 MHz ARM Processor, 256 megabytes of RAM, and lacks the HDMI output of the Beaglebone Black. The 3.2 megapixel Beaglebone camera cape, is used for the image capture. This camera has a max frame rate of 30 frames per second, but the LHDS will only take 1 frame every 5 seconds. The Beaglebone will take the image from the camera cape and run it through the different image processes before sending the end result of analysis through the RF module.

Table 4-15 Success Criteria for RF Module

Requirement	Success Criteria	Verification
Transmit LHDS data in real time to a ground station.	Data is sent from RF module aboard rocket to ground station without loss or corruption.	Transmitted data is received by ground station. Data is verified using either Checksums or post-flight data comparison.
The payload shall be recoverable and reusable.	Recover the RF module and reuse it.	The RF module is recovered and can be launched again on the same day.
Transmit live GPS Data	RF module transmits live GPS data from the GPS module to the ground station.	GPS location of the rocket is received by the ground station.
The electronic tracking device shall be fully functional during the official flight at the competition launch site.	GPS data is sent through RF module aboard the rocket to the ground station during the competition launch.	GPS location data from the rocket is received by the ground station during the official flight at the competition.

5. Project Plan

5.1. Budget

A budget is a crucial part of any project and must be planned with care to ensure that the required funding is maintained through till the project completion. This sometimes means making design decision based upon available funding. To minimize this risk a careful budget and funding plan will be kept.

5.1.1. Total Program Expense

Figure 5-1 shows the projected total cost for the Program. The travel expenses shown in the figure is the expense for the entire team to travel to Utah. An alternative travel expense for only a core group of team members will be covered below in the travel expense section. The cost is broken down into two major categories, rocket and travel, similar to the funding. The travel is broken down into its major components and the rocket expense is broken down into payload, propulsion, structure, and recovery.

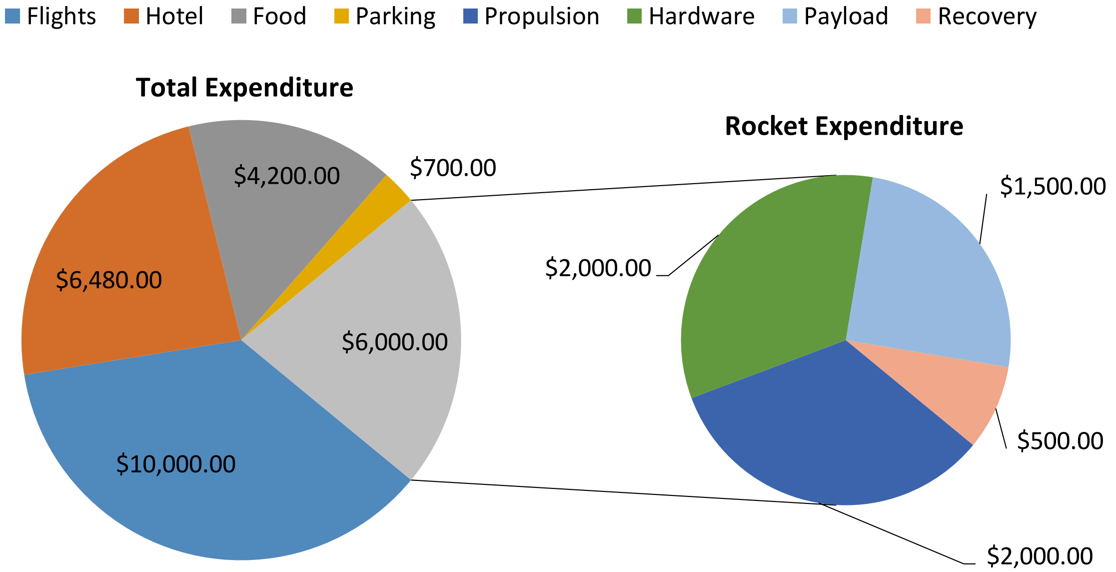


Figure 5-1: Program Expenditures

As can be seen in the figure travel drives the majority of the expense of the program due to all team members traveling out to the launch. The rocket portion of the project covers only $6,000 and the remaining $21,380 is due to travel. The travel and funding sections below will cover alternative travel plans and how the required amount of money for travel will be raised.

5.1.2. Core Program Expense

The core program expenditures covers all cost not associated with travel to the launch site. This covers any training, subscale components, full scale components, backup parts, and testing fees. Travel reimbursement to local launches are covered under funding for the class and do not come out of CRW funding. As can be seen in Figure 5-2, the total predicted cost of $6,000 for the rocket expense is given a linear growth over the approximately 190 days until the project ends on June 2nd. The actual cost quickly overtook the linear growth rate but settled down during Christmas break. The jump seen 70 days into the project represents the start of the new semester. Several large purchases such as motor case and motor fuel are still in line for purchasing and will raise the cost actual cost above the predicted current cost. This is negated by the fact that the predicted cost continues linearly past the FRR when actual core expenditures should be minimized.

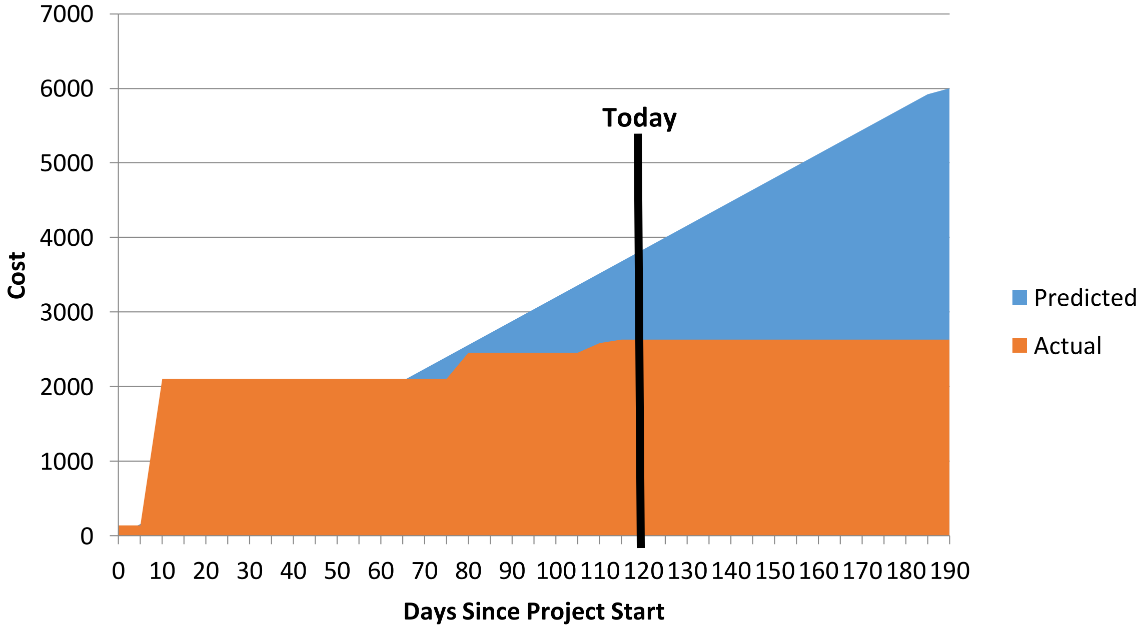


Figure 5-2: Core Program Expense

5.1.3. On the Pad Cost

The on the pad cost of the rocket is split into two different categories, actual and theoretical as seen in Figure 5-3. The actual on the pad cost is the current estimate of the cost as felt by CRW. The theoretical cost includes cost for parts that were available to CRW for free but their cost were estimated and included to simulate a “commercial” on the pad cost. The vast difference between the actual and theoretical cost is due to the use of 3D printed parts. Part of the Nanolaunch 1200 project was to also experiment with the use of 3D printed titanium parts. These parts as well as several payload pays printed out of ABS plastic that were obtained for free through the university drive up the theoretical cost of the rocket. Many of these 3D printed parts could be manufactured other ways which would drive down the on the pad theoretical cost.

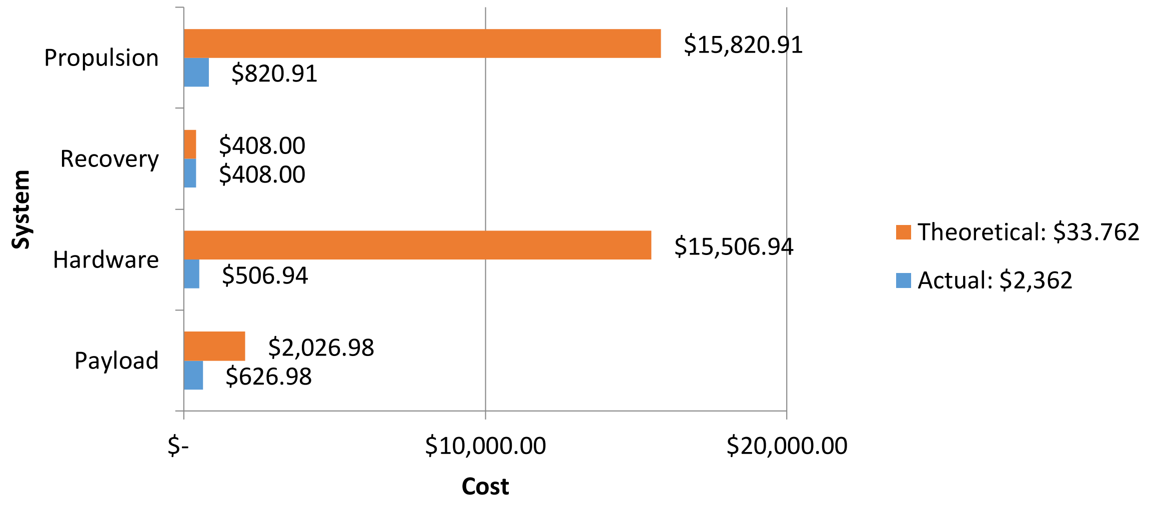


Figure 5-3: On Pad Cost

5.1.4. Travel Expense

As seen from the Figure 5-1 earlier the projected travel expense is the primary cost of the project. Two separate travel expense budgets exist. A budget for the entire team and a budget for only a subset of the team to travel out to the launch can be seen in Table 5-1 below.

Table 5-1: Two Travel Options

Travel	**Total Cost**
$500 Delta Flight HSV to SLC (x20 People)	$ 10,000.00
$180 Night (x6 Nights)(x10 rooms)	$ 6,480.00
$30 Food (x7 Days)(x20 People)	$ 4,200.00
$10 Parking fee (x7 Days)(x10 cars)	$ 700.00
Total	$ 21,380.00
Travel (Limited)	**Total Cost**
$500 Delta Flight HSV to SLC (x6 People)	$ 3,000.00
$150 Night (x6 Nights)(x3 rooms)	$ 2,160.00
$30 Food (x7 Days)(x6 People)	$ 1,260.00
$10 Parking fee (x7 Days)(x3 cars)	$ 210.00
Total	$ 6,630.00

If the SGA funding, Alabama Space Grant funding, and sponsorships come through the entire team will be able to travel to the launch. If only some of the funding comes through two options present themselves for travel. Either a small team can travel to the launch, a cost of which can be seen in the second part of the table, or students can partially fund their own trip to the launch. The second option will still allow the entire team to travel out and will lessen the cost to CRW. This second option will be the fall back option should the travel funding necessary to cover the full team not be acquired.

5.1.5. Funding

Funding for the rocket itself was provided primarily through the Nanolaunch 1200 funding. This was in addition to left over funding from the previous year's CRW funding. In addition to these two acquired sources additional funding will be sought from the Student Government for travel to the launch in Utah. Funding from Alabama Space Grant is being pursued to assist with funding the travel. A chart with funding broken down into two main categories, rocket and travel, can be seen in Table 5-2.

Table 5-2: Funding

Rocket Funding		
Source	**Amount**	**Status**
Previous Years	$ 1,000.00	Acquired
Nanolaunch 1200	$ 5,000.00	Acquired
Sponsorships	$ 1,000.00	Desired

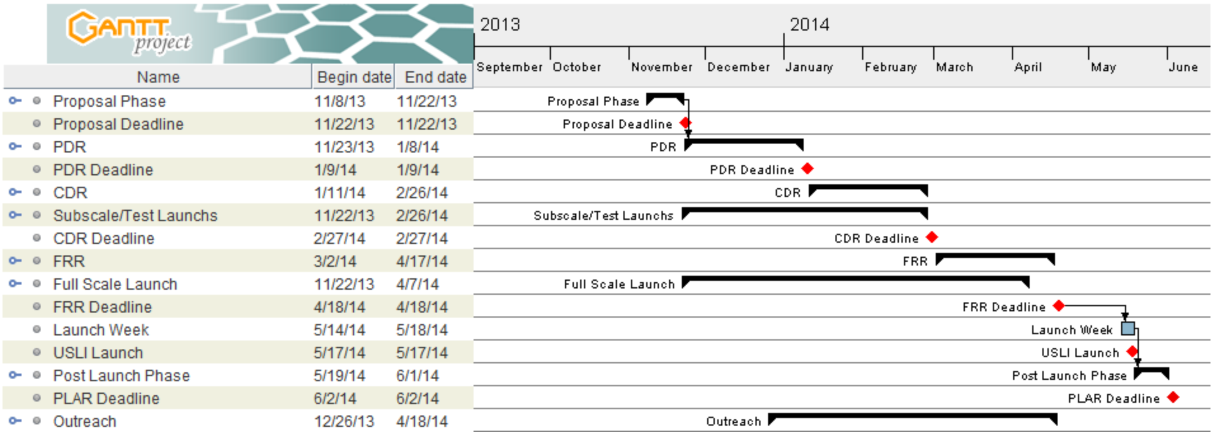
Travel Funding		
Source	**Amount**	**Status**
Student Government	$ 10,000.00	Pending
Alabama Space Grant	$ 5,000.00	Pending
Sponsorships	$ 8,000.00	Desired

Additional funding will need to be sought from outside sponsors. A sponsorship packet is being assembled to pitch to local companies to entice them to sponsor the team. Different levels of sponsorship will be provided based on the amount of money given with better rewards for more money. Items such as logos on the website or on the team shirts can be provided for smaller amounts of sponsorship. Larger sponsorships would put the company's logo on the rocket itself. The funding sought from company's would go to providing cushion funding for the rocket itself should it overrun as well as help fund the travel.

The values for the travel cost requested from the SGA match the predicted travel cost because the request for funding was based off of the team's analysis. This means that if the full funding comes through from the SGA the entire team will be able to travel to the launch.

5.2. Timeline

A high level Gantt chart was developed to give a guideline of when major milestones will be met. This shows the critical path of the project. The critical path, seen in Figure 5-4, 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 detailed description of the critical path events is provided below.



Name	Begin date	End date
Proposal Phase	11/8/13	11/22/13
Proposal Deadline	11/22/13	11/22/13
PDR	11/23/13	1/8/14
PDR Deadline	1/9/14	1/9/14
CDR	1/11/14	2/26/14
Subscale/Test Launchs	11/22/13	2/26/14
CDR Deadline	2/27/14	2/27/14
FRR	3/2/14	4/17/14
Full Scale Launch	11/22/13	4/7/14
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	6/1/14
PLAR Deadline	6/2/14	6/2/14
Outreach	12/26/13	4/18/14

Figure 5-4: Overview Schedule

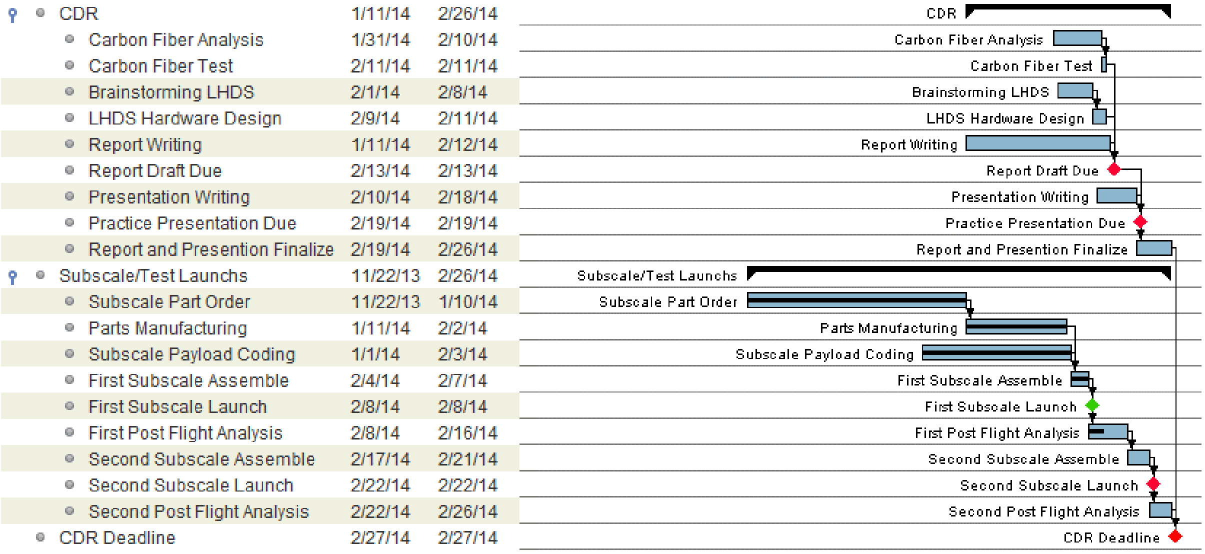
Proposal (11/22/2013) (Completed)

A proposal was submitted to NASA Student Launch competition proposing a rocket that fulfils both the Nanolaunch 1200 requirements as well as the requirements set by the competition. The details of the Nanolaunch 1200 project were covered and concepts were pitched to NASA in a proposal. The project was at a Technology Readiness Level (TRL) of 1. [Appendix 17]

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

Preliminary design work was completed and a path forward was proposed. Early modeling and simulation work had begun to verify the design. The design work and modeling were presented to both the Nanolaunch 1200 program as well as the NASA student launch competition in a Preliminary Design Review. This was accompanied by a presentation to further explain the design and allow any questions to be answered. The project was at a TRL stage 4 which is toward the lower end of stages considered to be in the PDR.

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



CDR	1/11/14	2/26/14
Carbon Fiber Analysis	1/31/14	2/10/14
Carbon Fiber Test	2/11/14	2/11/14
Brainstorming LHDS	2/1/14	2/8/14
LHDS Hardware Design	2/9/14	2/11/14
Report Writing	1/11/14	2/12/14
Report Draft Due	2/13/14	2/13/14
Presentation Writing	2/10/14	2/18/14
Practice Presentation Due	2/19/14	2/19/14
Report and Presention Finalize	2/19/14	2/26/14
Subscale/Test Launchs	11/22/13	2/26/14
Subscale Part Order	11/22/13	1/10/14
Parts Manufacturing	1/11/14	2/2/14
Subscale Payload Coding	1/1/14	2/3/14
First Subscale Assemble	2/4/14	2/7/14
First Subscale Launch	2/8/14	2/8/14
First Post Flight Analysis	2/8/14	2/16/14
Second Subscale Assemble	2/17/14	2/21/14
Second Subscale Launch	2/22/14	2/22/14
Second Post Flight Analysis	2/22/14	2/26/14
CDR Deadline	2/27/14	2/27/14

Figure 5-5: CDR Detailed Schedule

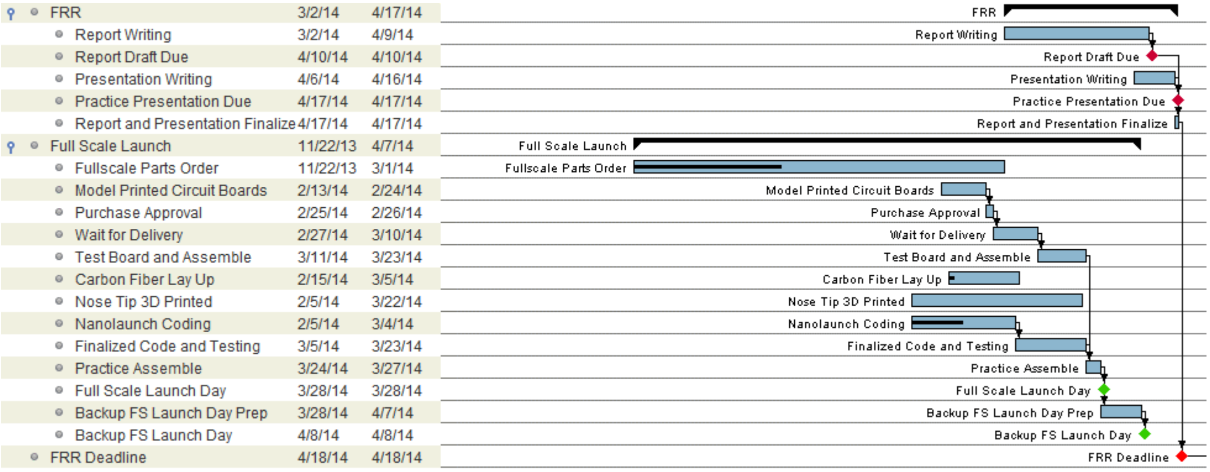
The critical design review represents the end of the major design phase. By this time the design is very mature and has begun to enter the testing phase. The design is at a TRL level of 6-7. The design work leading up to the report draft can be seen in the top portion of Figure 5-5. A rough draft of the CDR report was assembled on February 14. This gave two weeks between the CDR rough draft and the final report. This lead time drove the design of the project and forced the design to be primarily finished by this date. By doing this it allowed minor changes that always occur after the CDR to appear before the actual final CDR date. This will minimize changes after the CDR.

The subscale launch follows a separate timeline since it is not bound by the design of the payloads. It does however feed into the final report. The first subscale launch flew on February 8th to test the stability. Due to the fins not being sufficiently epoxied on, a second flight to test the dual deploy recovery system was not possible.

A second subscale launch was performed to test the payload and the dual recovery system on February 22nd. The results from both tests were analyzed and discussed earlier in the document.

The subscale launches and design come together as two separate critical paths and merge at the CDR report. This will set off the path forward through the FRR and begin the majority of the testing phase.

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



FRR	3/2/14	4/17/14
Report Writing	3/2/14	4/9/14
Report Draft Due	4/10/14	4/10/14
Presentation Writing	4/6/14	4/16/14
Practice Presentation Due	4/17/14	4/17/14
Report and Presentation Finalize	4/17/14	4/17/14
Full Scale Launch	11/22/13	4/7/14
Fullscale Parts Order	11/22/13	3/1/14
Model Printed Circuit Boards	2/13/14	2/24/14
Purchase Approval	2/25/14	2/26/14
Wait for Delivery	2/27/14	3/10/14
Test Board and Assemble	3/11/14	3/23/14
Carbon Fiber Lay Up	2/15/14	3/5/14
Nose Tip 3D Printed	2/5/14	3/22/14
Nanolaunch Coding	2/5/14	3/4/14
Finalized Code and Testing	3/5/14	3/23/14
Practice Assemble	3/24/14	3/27/14
Full Scale Launch Day	3/28/14	3/28/14
Backup FS Launch Day Prep	3/28/14	4/7/14
Backup FS Launch Day	4/8/14	4/8/14
FRR Deadline	4/18/14	4/18/14

Figure 5-6: FRR Detailed Schedule

The flight readiness review represents the end rocket project. By this time the design will be finished and flight tested. The design will be at a TRL level of 8-9. The detailed testing and flight schedule leading up to the report draft can be seen in the Figure 5-6. Similar to the CDR a draft of the FFR report will be due a week in advance. This drives an aggressive testing schedule and leads to and early launch day so that a backup launch day can also fit before this due date. The first launch day is March 29th from Manchester, TN. This early launch day allows the launch to slide to the backup full scale launch day of April 8th and still be before the FRR draft due date of April 10th.

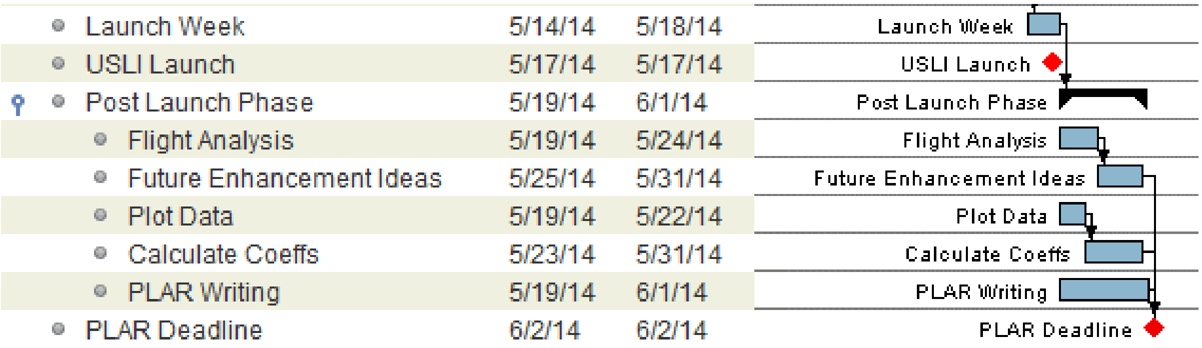
A series of construction steps lead up to the first full scale launch day. Custom print circuit boards have a long lead time and must be designed and order will in advance to avoid excessive cost increase for rush delivery. Carbon fiber layup for the rocket will take one to two weeks.

The FRR will be the last stage of the design and will contain the majority of the testing and verification of predictions. This will lead into the launches themselves where nothing should change between the FRR and the final launch day.

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. This launch readiness review is a final check to make sure that all of the systems proposed and tested in the FRR are present and ready to fly again in a safe manner. This gives the range safety officer a chance to see the rocket in person and verify it matches the proposed and tested design.

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



Launch Week	5/14/14	5/18/14
USLI Launch	5/17/14	5/17/14
Post Launch Phase	5/19/14	6/1/14
Flight Analysis	5/19/14	5/24/14
Future Enhancement Ideas	5/25/14	5/31/14
Plot Data	5/19/14	5/22/14
Calculate Coeffs	5/23/14	5/31/14
PLAR Writing	5/19/14	6/1/14
PLAR Deadline	6/2/14	6/2/14

Figure 5-7: Launch Week and Post Flight Launch Analysis

An assessment of the launch with the results of the launch compared to prelaunch predictions will be written as seen in Figure 5-7. An analysis of any significant deviation from the predictions will be analyzed and discussed. Ideas for future enhancements to the project or recommended changes to correct any failures will be included. An overall final summary of the project including budget, outreach, and lessoned learned will finalize the project and provide a look back. The website will be updated to include the final results of the launch and present the final data. This marks the final deliverable NASA Student Launch Competition part of the project and concludes the competition.

5.3. Outreach

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 as seen in Figure 5-8. 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.

Figure 5-8: Girls in Science and Engineering Day

Charger Rocket Works has constructed an outreach packet that can be pitched to various schools and STEM events to cover the basics of rockets. This packet is modular in nature and this allows 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. Slides have been constructed and plans are in place to consult an elementary school teacher and a middle school teacher to insure the slides are appropriate for their age groups.

The primary focus of the slides is based around soda bottle rockets. These allow the students to explore the concepts of rockets in a safe controlled environment in a hands on manner. Rather than just see a rocket launch demonstrated they get to see the results their decisions had on the flight of the rocket. This is a powerful tool that will leave a lasting impression on the students and inspire them to continue exploring.

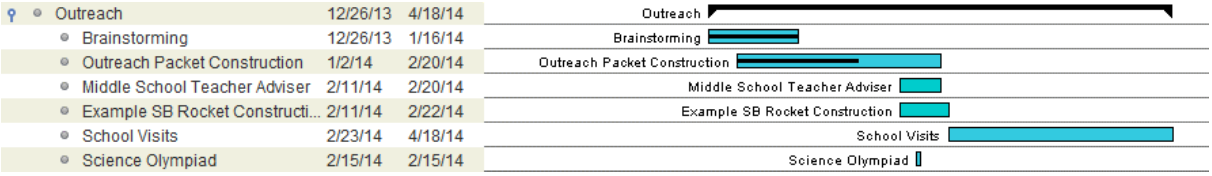
Outside of the dedicated outreach packet the team supported the Science Olympiad. The Science Olympiad is a national competition where middle and high school students compete in various competitions that are all based around concepts of science and engineer. Eight team members assisted the student's in four different competitions. The students were divided into teams and competed against each other under strict rules.

Table 5-3: Current Outreach Results

Participant's Grade Level	Education		Outreach	
	Direct Interactions	**Indirect** Interactions	**Direct** Interactions	**Indirect** Interactions
K-4				
5-9	102			
10-12	58			
12+				
Educators (5-9)				
Educators (other)				

5.3.1. Outreach Schedule

Although outreach is a required part of the competition its timeline, seen in Figure 5-9: Outreach Schedule is not tied to the launch of the rocket and is outside of the critical path.



Outreach	12/26/13	4/18/14
Brainstorming	12/26/13	1/16/14
Outreach Packet Construction	1/2/14	2/20/14
Middle School Teacher Adviser	2/11/14	2/20/14
Example SB Rocket Constructi...	2/11/14	2/22/14
School Visits	2/23/14	4/18/14
Science Olympiad	2/15/14	2/15/14

Figure 5-9: Outreach Schedule

Brainstorming (1/16/14) (Complete)

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 (2/20/14) (Complete)

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. The outreach packet will focus on using soda bottle rockets to back up basic science and allow the students to get hands one experience building their own soda bottle rockets.

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. This packet is currently being modified for outreach to elementary students for the planned outreach to Challenger Elementary. One of the Challenger Elementary teachers will be advising the rewriting of the outreach packet for elementary students. For the Challenger Elementary outreach an initial visit will be made on the week of March 10th. For this event the basic of rocketry will be explained and how this applies to water bottle rockets. The students will then be given approximately 2 weeks to construct water bottle rockets and will be launched during the second visit. Outreach attempts were made to three other schools seen in Table 5-4 below. CRW is still awaiting responses from the additional schools. Additional local schools are being sought to contact for the outreach effort.

Table 5-4: Future Outreach

School	Outreach
Challenger Elementary	Tentative: March 10th Tentative March 21st
Cullman Christian	Awaiting response
Discovery Middle	Awaiting response
Challenger Middle	Awaiting response

5.4. Programmatic Challenges

With any program there will be challenges that have to be faced and overcome for a successful project. Figure 5-10 and Table 5-5 identifies expected programmatic challenges, their risk level, program impact, and mitigation steps to be performed. Identifying potential challenges and taking steps to prevent them early on can greatly decrease their effect on the project. As with most projects externally funded several programmatic challenges will lie outside of the control of CRW and must be mitigated with careful budgeting.

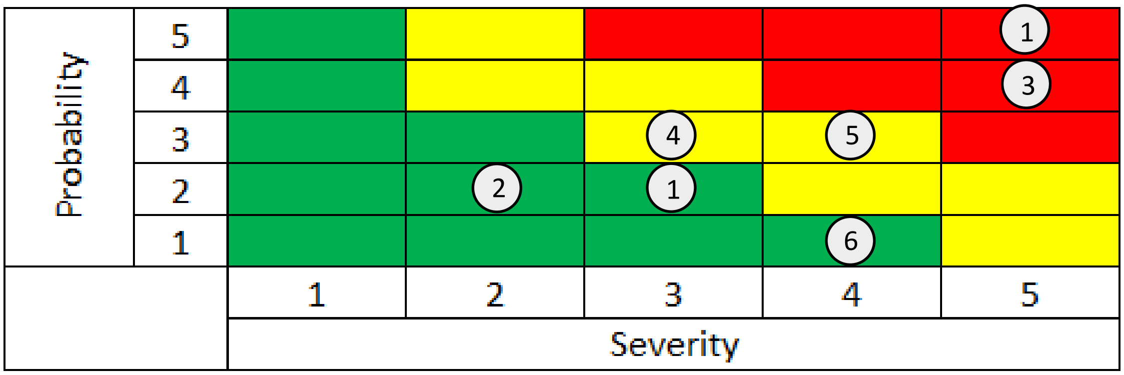


Figure 5-10: Program Risk Chart

Table 5-5: Programmatic Challenges

Ref #	Potential Hazard	Probability	Severity	Impact	Mitigation
1	Funding Loss	2	3	Reduced funding for the project and potential not enough funding to finish	Use financial reserves to finished project and develop backup plans should funding not be obtained
2	Overspending	2	2	Reduced funding for the project and potential not enough funding to finish	Closely monitor funding and ensure purchases are not wasted on hardware or test that are not used
3	Vehicle Failure	4	5	Significant cut into budget and major schedule delays	Carefully perform ground test and calculations to ensure no points of failure in primary vehicle load bearing members or recovery system
4	Purchase Orders Are Delayed	3	3	If parts are delayed in shipping the schedule could be delayed or rush order may be required	Orders will be placed well in advance of the time they are required and only order from reputable sources with known turnaround times
5	Team Falls Behind Schedule	3	5	Poorer quality work from rushed deadlines which further delay the project	Target dates will be placed ahead of actual due dates to drive the team and allow some slip
6	Team Conflicts	1	4	Reduced productivity and poorer design through poor communication	Strong leadership that addresses conflicts quickly and makes corrections to avoid further conflict and show solidarity between the team leads.

6. Conclusion

Prometheus is geometrically similar to the Nanolaunch 1200 to allow an advance avionics payload to back out several key aerodynamic coefficients. This is in addition to the three payloads entered into the NASA Student Launch competition. The Charger Rocket Works project is currently at a TRL level of 6. This is the lower end of TRL levels for the CDR. An aggressive testing and manufacturing schedule will get the project at the upper end of the FRR with several weeks planned between the first full-scale launch and the FRR due date. The Dielectrophoresis payload is running ahead of schedule and is ready for manufacture and testing. The Coatings and Paint payload is running on schedule with coatings already supplied and ground test planned. The Landing Hazard Detection System is running behind schedule due to an inability to bring on additional team members to handle this payload. This payload will be brought up to the correct TRL level from an aggressive development schedule. The Nanolaunch 1200 payload is on schedule and requires finished code and verification testing. With these steps finished the project can move on to the FRR.

The path forward for Charger Rocket Works consist of finalizing numbers based on results from tests performed early preparation for the FRR. With these steps done manufacturing can begin on all components leading up to the planned full-scale test launch on March 29th. This will enable the team to verify the design in an actual flight. This will prove the design and provide a set of test date to compare to the competition launch.

7. Appendix A: CRW Safety Plan

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

Goal	Objectives
Demonstrate a complete team commitment to safety and health.	• Definition and implementation of proper hazard control procedures by all leadership personnel. • 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. • 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. • 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. • 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. • 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. • Review and approve all Standard Operating Procedures. • Facilitate training for Team Leads on safe procedures for all design, testing, manufacturing, and launching activities.
Team Leads	• Develop Standard Operating Procedures for all testing and launch operations pertaining to their subsystem. • Facilitate training for team members on proper equipment and power tool operation before their use.

Team Members	• Follow all safety plans, procedures, and regulations. • Identify any hazardous work conditions and file appropriate documentation. • Ensure that fellow team members are following all safety protocols. • 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/Red/Blue 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.

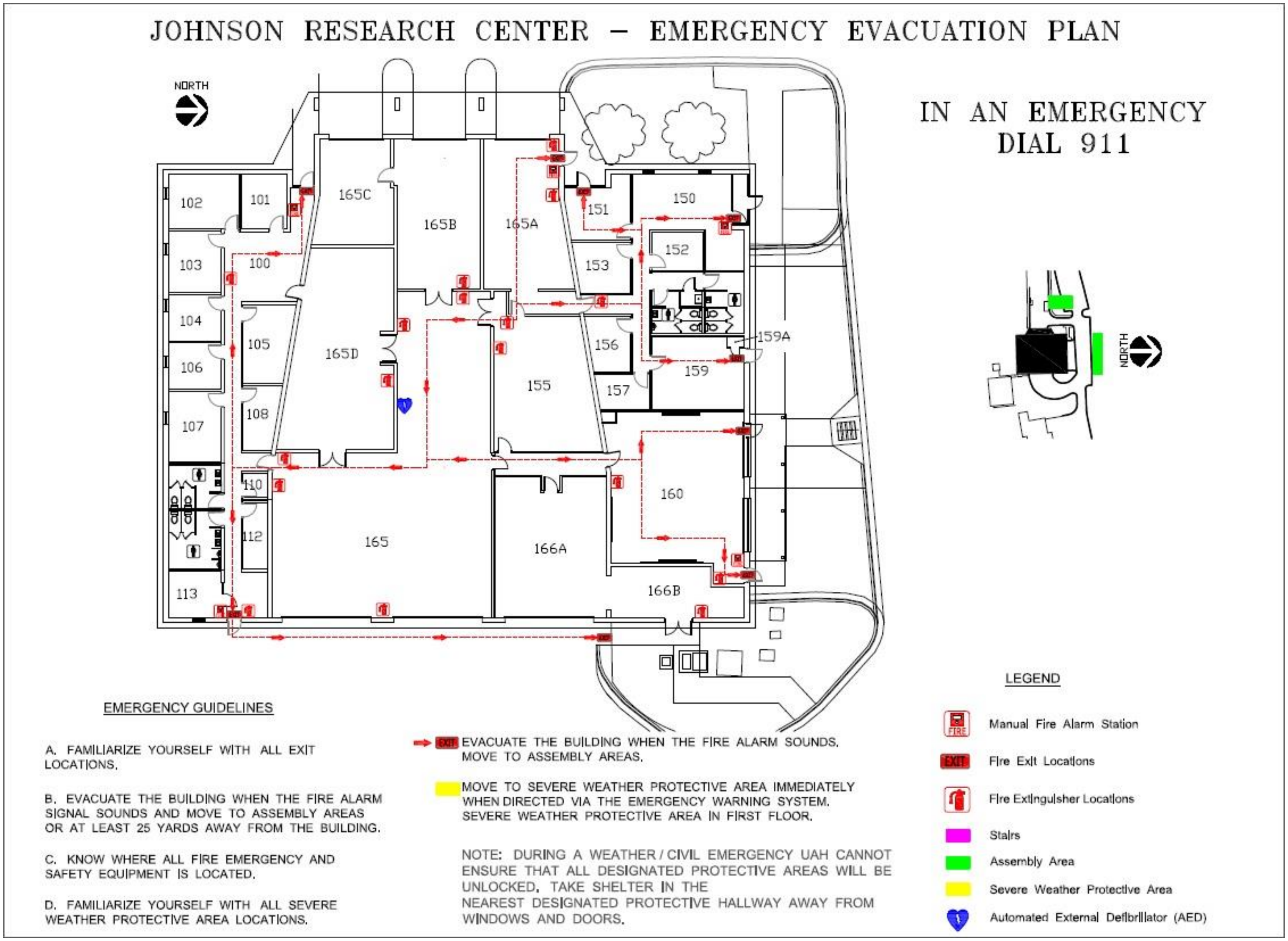
7.19. Periodic Safety Meetings

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.

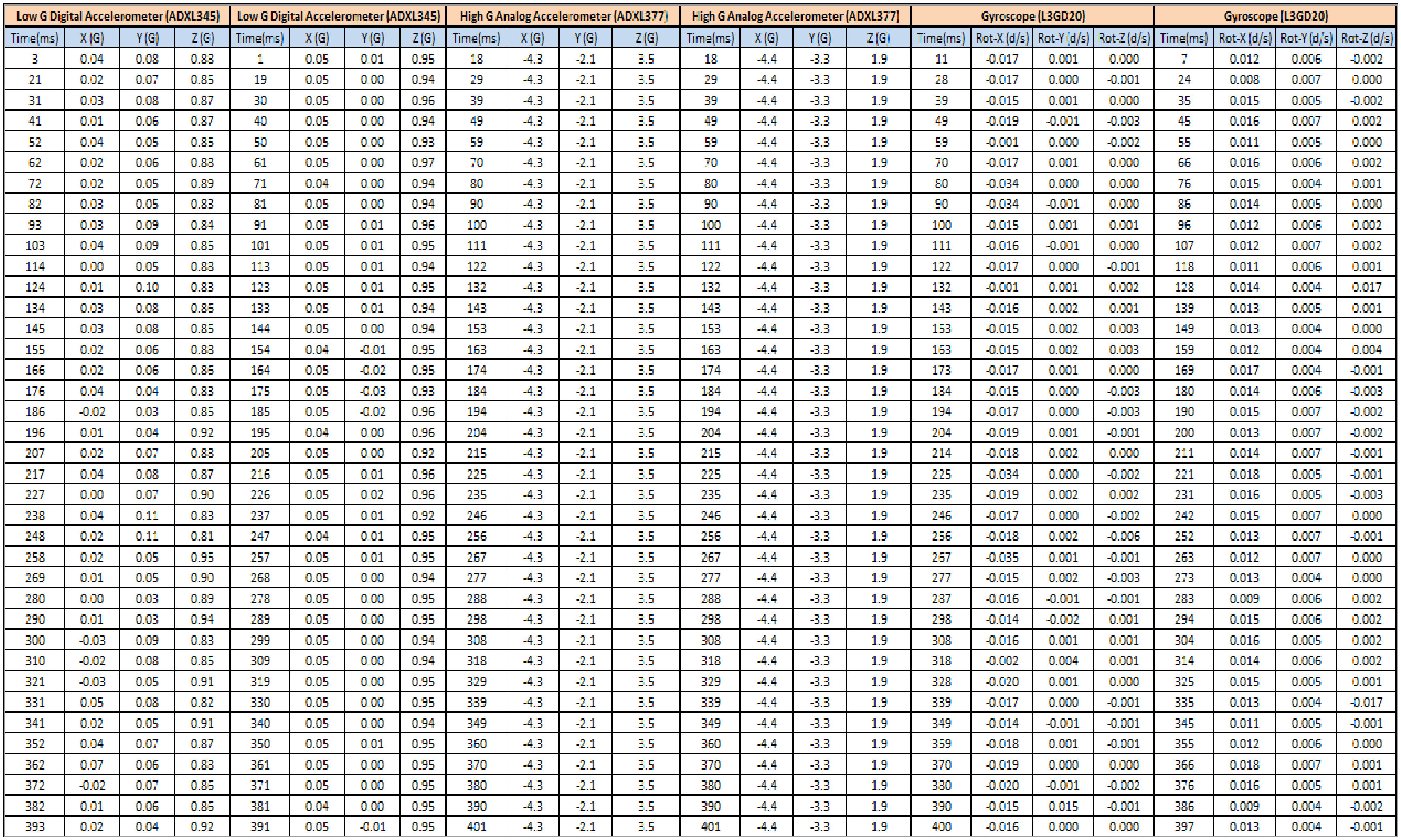
🟨 MOVE TO SEVERE WEATHER PROTECTIVE AREA IMMEDIATELY WHEN DIRECTED VIA THE EMERGENCY WARNING SYSTEM. SEVERE WEATHER PROTECTIVE AREA IN FIRST FLOOR.

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, Sample Sensor Array Data Extraction Format



Low G Digital Accelerometer (ADXL345)				Low G Digital Accelerometer (ADXL345)				High G Analog Accelerometer (ADXL377)				High G Analog Accelerometer (ADXL377)				Gyroscope (L3GD20)				Gyroscope (L3GD20)			
Time(ms)	X (G)	Y (G)	Z (G)	Time(ms)	X (G)	Y (G)	Z (G)	Time(ms)	X (G)	Y (G)	Z (G)	Time(ms)	X (G)	Y (G)	Z (G)	Time(ms)	Rot-X (d/s)	Rot-Y (d/s)	Rot-Z (d/s)	Time(ms)	Rot-X (d/s)	Rot-Y (d/s)	Rot-Z (d/s)
3	0.04	0.08	0.88	1	0.05	0.01	0.95	18	-4.3	-2.1	3.5	18	-4.4	-3.3	1.9	11	-0.017	0.001	0.000	7	0.012	0.006	-0.002
21	0.02	0.07	0.85	19	0.05	0.00	0.94	29	-4.3	-2.1	3.5	29	-4.4	-3.3	1.9	28	-0.017	0.000	-0.001	24	0.008	0.007	0.000
31	0.03	0.08	0.87	30	0.05	0.00	0.96	39	-4.3	-2.1	3.5	39	-4.4	-3.3	1.9	39	-0.015	0.001	0.000	35	0.015	0.005	-0.002
41	0.01	0.06	0.87	40	0.05	0.00	0.94	49	-4.3	-2.1	3.5	49	-4.4	-3.3	1.9	49	-0.019	-0.001	-0.003	45	0.016	0.007	0.002
52	0.04	0.05	0.85	50	0.05	0.00	0.93	59	-4.3	-2.1	3.5	59	-4.4	-3.3	1.9	59	-0.001	0.000	-0.002	55	0.011	0.005	0.000
62	0.02	0.06	0.88	61	0.05	0.00	0.97	70	-4.3	-2.1	3.5	70	-4.4	-3.3	1.9	70	-0.017	0.001	0.000	66	0.016	0.006	0.002
72	0.02	0.05	0.89	71	0.04	0.00	0.94	80	-4.3	-2.1	3.5	80	-4.4	-3.3	1.9	80	-0.034	0.000	0.000	76	0.015	0.004	0.001
82	0.03	0.05	0.83	81	0.05	0.00	0.94	90	-4.3	-2.1	3.5	90	-4.4	-3.3	1.9	90	-0.034	-0.001	0.000	86	0.014	0.005	0.000
93	0.03	0.09	0.84	91	0.05	0.01	0.96	100	-4.3	-2.1	3.5	100	-4.4	-3.3	1.9	100	-0.015	0.001	0.001	96	0.012	0.006	0.002
103	0.04	0.09	0.85	101	0.05	0.01	0.95	111	-4.3	-2.1	3.5	111	-4.4	-3.3	1.9	111	-0.016	-0.001	0.000	107	0.012	0.007	0.002
114	0.00	0.05	0.88	113	0.05	0.01	0.94	122	-4.3	-2.1	3.5	122	-4.4	-3.3	1.9	122	-0.017	0.000	-0.001	118	0.011	0.006	0.001
124	0.01	0.10	0.83	123	0.05	0.01	0.95	132	-4.3	-2.1	3.5	132	-4.4	-3.3	1.9	132	-0.001	0.001	0.002	128	0.014	0.004	0.017
134	0.03	0.08	0.86	133	0.05	0.01	0.94	143	-4.3	-2.1	3.5	143	-4.4	-3.3	1.9	143	-0.016	0.002	0.001	139	0.013	0.005	0.001
145	0.03	0.08	0.85	144	0.05	0.00	0.94	153	-4.3	-2.1	3.5	153	-4.4	-3.3	1.9	153	-0.015	0.002	0.003	149	0.013	0.004	0.000
155	0.02	0.06	0.88	154	0.04	-0.01	0.95	163	-4.3	-2.1	3.5	163	-4.4	-3.3	1.9	163	-0.015	0.002	0.003	159	0.012	0.004	0.004
166	0.02	0.06	0.86	164	0.05	-0.02	0.95	174	-4.3	-2.1	3.5	174	-4.4	-3.3	1.9	173	-0.017	0.001	0.000	169	0.017	0.004	-0.001
176	0.04	0.04	0.83	175	0.05	-0.03	0.93	184	-4.3	-2.1	3.5	184	-4.4	-3.3	1.9	184	-0.015	0.000	-0.003	180	0.014	0.006	-0.003
186	-0.02	0.03	0.85	185	0.05	-0.02	0.96	194	-4.3	-2.1	3.5	194	-4.4	-3.3	1.9	194	-0.017	0.000	-0.003	190	0.015	0.007	-0.002
196	0.01	0.04	0.92	195	0.04	0.00	0.96	204	-4.3	-2.1	3.5	204	-4.4	-3.3	1.9	204	-0.019	0.001	-0.001	200	0.013	0.007	-0.002
207	0.02	0.07	0.88	205	0.05	0.00	0.92	215	-4.3	-2.1	3.5	215	-4.4	-3.3	1.9	214	-0.018	0.002	0.000	211	0.014	0.007	-0.001
217	0.04	0.08	0.87	216	0.05	0.01	0.96	225	-4.3	-2.1	3.5	225	-4.4	-3.3	1.9	225	-0.034	0.000	-0.002	221	0.018	0.005	-0.001
227	0.00	0.07	0.90	226	0.05	0.02	0.96	235	-4.3	-2.1	3.5	235	-4.4	-3.3	1.9	235	-0.019	0.002	0.002	231	0.016	0.005	-0.003
238	0.04	0.11	0.83	237	0.05	0.01	0.92	246	-4.3	-2.1	3.5	246	-4.4	-3.3	1.9	246	-0.017	0.000	-0.002	242	0.015	0.007	0.000
248	0.02	0.11	0.81	247	0.04	0.01	0.95	256	-4.3	-2.1	3.5	256	-4.4	-3.3	1.9	256	-0.018	0.002	-0.006	252	0.013	0.007	-0.001
258	0.02	0.05	0.95	257	0.05	0.01	0.95	267	-4.3	-2.1	3.5	267	-4.4	-3.3	1.9	267	-0.035	0.001	-0.001	263	0.012	0.007	0.000
269	0.01	0.05	0.90	268	0.05	0.00	0.94	277	-4.3	-2.1	3.5	277	-4.4	-3.3	1.9	277	-0.015	0.002	-0.003	273	0.013	0.004	0.000
280	0.00	0.03	0.89	278	0.05	0.00	0.95	288	-4.3	-2.1	3.5	288	-4.4	-3.3	1.9	287	-0.016	-0.001	-0.001	283	0.009	0.006	0.002
290	0.01	0.03	0.94	289	0.05	0.00	0.95	298	-4.3	-2.1	3.5	298	-4.4	-3.3	1.9	298	-0.014	-0.002	0.001	294	0.015	0.006	0.002
300	-0.03	0.09	0.83	299	0.05	0.00	0.94	308	-4.3	-2.1	3.5	308	-4.4	-3.3	1.9	308	-0.016	0.001	0.001	304	0.016	0.005	0.002
310	-0.02	0.08	0.85	309	0.05	0.00	0.94	318	-4.3	-2.1	3.5	318	-4.4	-3.3	1.9	318	-0.002	0.004	0.001	314	0.014	0.006	0.002
321	-0.03	0.05	0.91	319	0.05	0.00	0.95	329	-4.3	-2.1	3.5	329	-4.4	-3.3	1.9	328	-0.020	0.001	0.000	325	0.015	0.005	0.001
331	0.05	0.08	0.82	330	0.05	0.00	0.95	339	-4.3	-2.1	3.5	339	-4.4	-3.3	1.9	339	-0.017	0.000	-0.001	335	0.013	0.004	-0.017
341	0.02	0.05	0.91	340	0.05	0.00	0.94	349	-4.3	-2.1	3.5	349	-4.4	-3.3	1.9	349	-0.014	-0.001	-0.001	345	0.011	0.005	-0.001
352	0.04	0.07	0.87	350	0.05	0.01	0.95	360	-4.3	-2.1	3.5	360	-4.4	-3.3	1.9	359	-0.018	0.001	-0.001	355	0.012	0.006	0.000
362	0.07	0.06	0.88	361	0.05	0.00	0.95	370	-4.3	-2.1	3.5	370	-4.4	-3.3	1.9	370	-0.019	0.000	0.000	366	0.018	0.007	0.001
372	-0.02	0.07	0.86	371	0.05	0.00	0.95	380	-4.3	-2.1	3.5	380	-4.4	-3.3	1.9	380	-0.020	-0.001	-0.002	376	0.016	0.005	0.001
382	0.01	0.06	0.86	381	0.04	0.00	0.95	390	-4.3	-2.1	3.5	390	-4.4	-3.3	1.9	390	-0.015	0.015	-0.001	386	0.009	0.004	-0.002
393	0.02	0.04	0.92	391	0.05	-0.01	0.95	401	-4.3	-2.1	3.5	401	-4.4	-3.3	1.9	400	-0.016	0.000	0.000	397	0.013	0.004	-0.001

10. Appendix D: Sample Altimeter Data

PerfectFlite SL100				
Firmware: 1.0				
Software: 1.0				
Serial Number: 1949				
Apogee: 1573' AGL				
Ground Elevation: 203' MSL				
NumSamps: 1416				
Flight Number: 8				
Main Setting: 700' AGL				
Apogee Delay: 1 Seconds				
Drogue At: 11.45 Seconds				
Main At: 39.95 Seconds				
Comments:				
Data: (Time	Altitude	Velocity	Temperature (F)	Voltage)
0	1	0	63.57	9.4
0.05	2	0	63.57	9.4
0.1	0	20	63.57	9.4
0.15	3	24	63.59	9.4
0.2	4	30	63.57	9.4
0.25	7	37	63.57	9.4
0.3	8	44	63.57	9.4
0.35	11	52	63.57	9.4
0.4	13	61	63.57	9.4
0.45	17	72	63.57	9.4
0.5	21	85	63.57	9.4
0.55	26	99	63.57	9.4
0.6	31	113	63.57	9.4
0.65	38	127	63.57	9.4
0.7	45	140	63.57	9.4
0.75	53	149	63.57	9.4
0.8	62	154	63.57	9.4
0.85	70	155	63.57	9.4
0.9	78	153	63.57	9.4
0.95	85	150	63.57	9.4
1	92	151	63.57	9.4
1.05	98	155	63.57	9.4
1.1	106	164	63.57	9.4
1.15	114	177	63.57	9.4
1.2	125	191	63.57	9.4
1.25	136	205	63.57	9.4
1.3	147	218	63.57	9.4
1.35	157	229	63.57	9.4
1.4	170	238	63.57	9.4
1.45	182	245	63.57	9.4
1.5	196	249	63.57	9.4
1.55	208	251	63.57	9.4

11. Appendix E: Launch Operations Checklist

T-48+ Hours

1. Vehicle Inspection –Components
    a. Recovery System
        i. Main Parachutes
            1. Visually inspect for holes, patches, and verify sizing.
            2. Double check descent rates as mass is added or subtracted.
            3. Verify equipment for dual deploy system.
        ii. Drogue's (if Applicable)
            1. If "yes", then visually inspect for holes or harness defects.
            2. Verify if ejection charge release system is being used.
        iii. Shock Cord
            1. Visual inspection for failure points.
            2. Check structural integrity of attachment points.
        iv. Black Powder Charge Capsules with E-matches
            1. Drill holes in bases of caps.
            2. If possible, attach e-match with epoxy or electrical tape.
        v. Trigger System (PerfectFlite StratoLogger)
            1. Ensure StratoLoggers are working properly.
            2. Check that fresh batteries are available (1 per altimeter).
        vi. Deployment System
            1. Perform successful tests of black powder ejection charge system with all flight hardware in vehicle.
            2. Perform successful tests of parachute release hardware.

    b. Airframe
        i. Consult with Analysis Team on proper vehicle geometry / configuration.
        ii. Estimate CG using finger/rope balance test.
        iii. Check separation points
            1. Verify holes for rivets are properly oriented and of the proper diameter.
            2. Verify shear pins are in stock and that the proper holes for them have been drilled.
            3. Verify that no-interference is present between internal components and fixtures.
            4. Check epoxy joints to ensure they are structurally sound.
            5. Paint vehicle if desired.

    c. Payloads
            1. Verify that payloads function through ground tests.
            2. Verify automation scripts run correctly.
            3. Verify that all sensors are working correctly.

        4. Verify location of CG within the rocket body.
        5. Verify that batteries for payloads are charged.
2. Stability Determination
    a. Fully assemble launch vehicle.
    b. Use a scale to weigh the vehicle.
    c. Determine CG location using rope/finger test
    d. Simulate CP location with RockSim and/or OpenRocket.
3. Prepare Team
    a. Submit travel authorization forms to PRC office for all team members driving to launch.
    b. Ensure that all team members attending launch have a means to get there.
    c. Arrange team meals for launch day (who will be purchasing meals, what will meals consist of).

T – 24+ hrs.

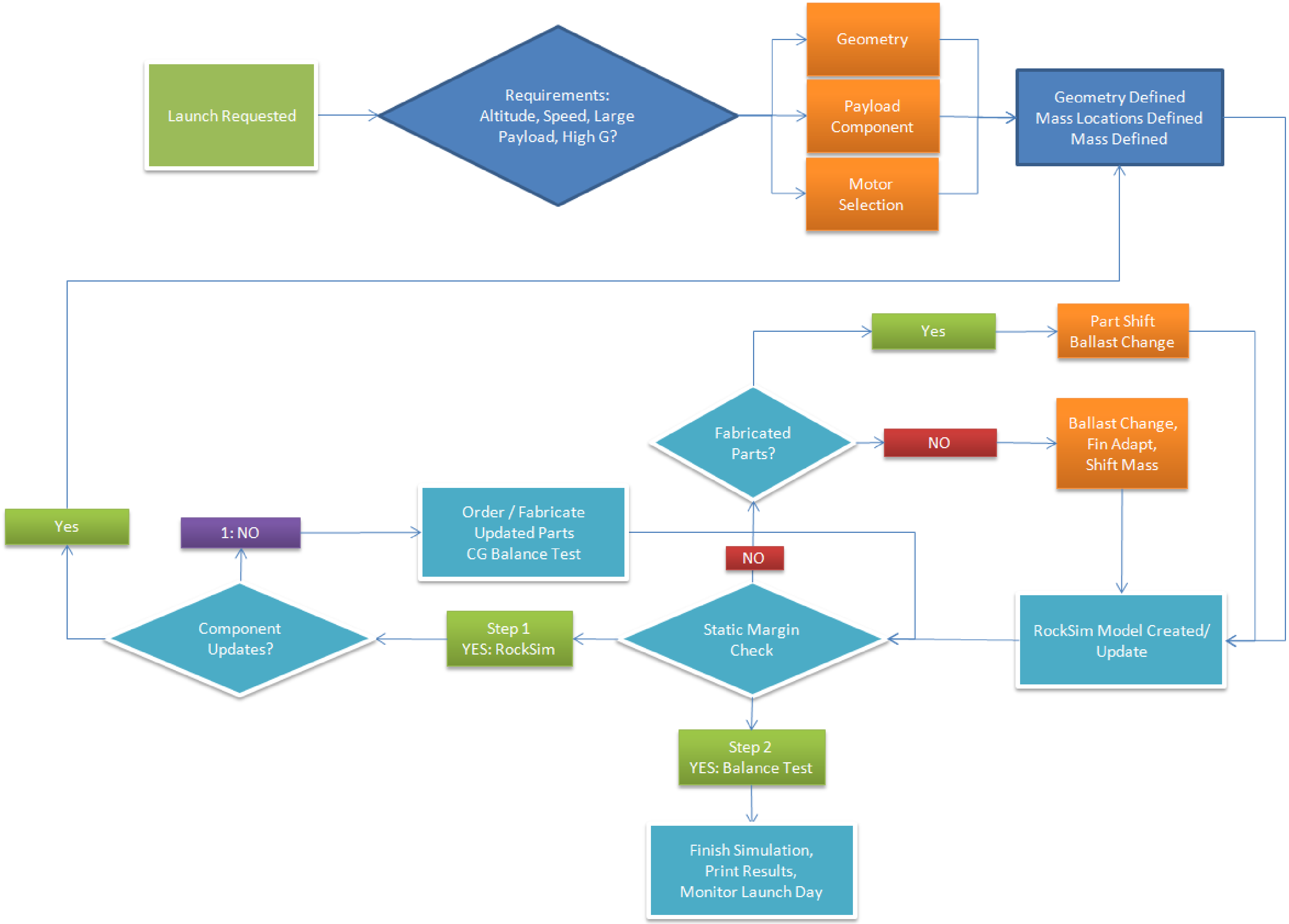
1. Verify any final changes made to vehicle geometry and payloads.
    a. Perform electronics check.
    b. Test fit all vehicle components once more.
2. Re-measure CG for any mass changes.
3. Re-validate CP location if geometry has changed.
4. Determine on-the-pad static stability margin.
5. Gather required flight equipment to be loaded for travel (See Launch Checklist).
6. Print flight cards or detailed flight plans.
    a. Vehicle weight.
    b. Motor selection.
    c. Stability margin.
    d. Predicted maximum altitude.
    e. Predicted rail exit velocity.
    f. Rocketeer with NAR/ TRA certification for motor selection.
        i. Amit Patel, NAR L2
        ii. David Lineberry, NAR L1
        iii. Jason Winningham, NAR/TRA L2
        iv. Chris Spalding, NAR L1
7. Check weather conditions
    a. Wind speed.
    b. Possibility of cloud cover.
    c. Expected temperature.
8. Verify launch is projected to continue and notify all team members traveling to launch of final go/no-go for launch.
9. Verify that equipment is packed or set aside for vehicle loading.

Launch Day – Pre Flight Setup

1. Verify All Components
    a. Double check interferences between vehicle airframe and payloads.
    b. Double check all rivet's interference with internal components.
2. Verify Electronic Components are Working
    a. Altimeters
        i. Ensure batteries and switches are connected and secured.
        ii. Ensure boards are secured to housing unit.
        iii. Listen for "Ready Status" chirp (3 short beeps every 2 seconds).
        iv. Connect wire leads for ejection charges and release hardware to altimeters.
    b. Check Payload Power System
        i. Use only freshly charged batteries.
        ii. Verify that start up program runs and boards reach "Ready" state.
        iii. Power off until launch.
3. Recovery System
    a. Fill ejection charges to prescribed mass of black powder determined from ground tests.
    b. Assemble recovery system components.
    c. Fill release mechanisms with manufacturer prescribed quantity of black powder.
    d. Install ejection charges in vehicle.
    e. Pack remainder of recovery system in the vehicle.
4. Just Prior to Launch
    a. Install motor (NAR/TRA mentor) and motor retention hardware.
    b. Weigh fully assembled rocket.
    c. Re-Verify stability margin.
    d. Re-Verify predicted flight trajectory values.
    e. Inform RSO of team status.
5. During Launch Setup
    a. Inform RSO that vehicle is ready for launch.
    b. RSO performs safety check and stability verification.
6. Launch Vehicle.

Post Flight

7. Recover Vehicle
    a. Take pictures of vehicle upon landing.
    b. Check recovery system status.
    c. Identify vehicle failure points.
    d. Record drift distance from launch stand.
    e. Record max altitude recorded by altimeters (from beeps).
    f. Weigh recovered rocket for descent mass.
    g. Recover data stored on perfect flights and onboard storage
8. Re Prep Rocket for Secondary Launch (if applicable)


Launch Requested
Requirements: Altitude, Speed, Large Payload, High G?
Geometry
Payload Component
Motor Selection
Geometry Defined Mass Locations Defined Mass Defined
Yes
Part Shift Ballast Change
Fabricated Parts?
NO
Ballast Change, Fin Adapt, Shift Mass
Yes
1: NO
Order / Fabricate Updated Parts CG Balance Test
NO
Component Updates?
Step 1 YES: RockSim
Static Margin Check
RockSim Model Created/ Update
Step 2 YES: Balance Test
Finish Simulation, Print Results, Monitor Launch Day

12. Appendix F: Launch Items Checklist

1) Rocket
2) Motors/ Motor Tubes/ Adapter Tubes
3) E-Matches
4) Black Powder
5) Dog Barf
6) Tool Box
7) Drill/Drill Bits/ Drill Batteries
8) Shear Pins
9) Rivets
10) Avionics Batteries (Li-Po, 9Vs)
11) Folding Table
12) Pop-Up Canopy
13) Parachutes/Recovery Hardware
14) Zip-Ties
15) Epoxy
16) Epoxy Mixing Tips
17) Extra Fasteners for Payload
18) Scale
19) Shovel
20) Extra Shock Chord
21) Chairs
22) Charge Caps
23) Sustenance (Food/Water)
24) Personal Protective Equipment
25) Launch Operations Checklist
26) Garbage Bags
27) Duct Tape/ Electrical Tape
28) Motor Tube Brushes
29) Paper Towels
30) Ballast/ Bags for Ballast
31) Tape Measure
32) Rocket Cradles
33) Isopropyl Alcohol
34) Q-Tips
35) Soldering Iron/ Tips/ Solder
36) Li-Po Battery Charger
37) Li-Po Charging Bag
38) GPS Trackers
39) Precision Screwdriver Set
40) Calipers
41) Sand Paper
42) Car Battery
43) Extension Wire
44) Ignition Circuitry

13.Appendix G: 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

14. Appendix H: 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 • Moderate eye irritation from exposure to vapor during curing, or to dust created by cutting, grinding, sanding, machining • Severe skin and • Respiratory irritation. Gastrointestinal irritation from ingestion • Combustible liquid and vapor • Vapor may travel long distance along ground or floor to source of ignition and flash back • Hazardous in contact with strong acids, strong oxidizing agents, heat, sparks and/or flames • Fire	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Moderate to Severe	• Engineering: local exhaust ventilation for machining processes • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety glasses with side shields or indirect vented goggles; gloves; protective clothing to prevent skin contact if appropriate • 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 • Moderate skin irritation • Respiratory irritation from inhaling vapor or dust • Gastrointestinal irritation from ingestion • Contains a carcinogenic chemical • Hazardous in contact with strong acids, strong oxidizing agents • Fire	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to Severe	• Engineering: local exhaust ventilation for cutting, grinding, sanding, or machining; shop exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • 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 • Respiratory Protection: not usually required; NIOSH approved air-purifying respirator with organic vapor cartridge and particulate prefilter, when ventilation is inadequate • Residual Risk: accepted

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

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Chemical Use: UNO HD SC bases & colors without lead	• Contains carcinogenic chemicals • Skin and/ or respiratory tract irritation from inhalation/exposure • CNS depression from inhalation • Fire	• Rating: Hazardous Operation • Probability: High • Severity: Mild to Severe	• Engineering: proper ventilation; storage • Administrative: SOP; MSDS; safe work practices; training; segregated from strong oxidizing agents, bases, and/ or acids • 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) • Residual Risk: accepted

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

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 • Eye and respiratory tract irritation from fumes or vapor generated by heating or curing sized product • Electrically conductive carbon fibers and dust may cause electrical short-circuits, resulting in damage to and malfunction of electrical equipment and/or personnel injury • Product or dust may aggravate pre-existing eye, skin, or respiratory disorders	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to moderate	• Engineering: shop and/or local exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • 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 • 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 • 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) • Mechanical eye irritant • Mouth, nose, and throat irritation if inhaled • Mechanical stomach and intestine irritant if ingested • Fiber release during cutting or sanding	• Rating: Potentially Hazardous Operation • Probability: Moderate • Severity: Mild	• Engineering: shop exhaust ventilation and/or local exhaust ventilation • Administrative: MSDS; SOP; safe work practices; exposure time limitations; training • PPE: safety goggles or safety glasses with side shields; loose-fitting long sleeved shirt that covers to base of neck; long pants; gloves • Respiratory Protection: not usually required; NIOSH/MSHA approved disposable dust respirator, when ventilation is inadequate or irritation occurs • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Ejection Charge Handling: Assembly	• Accidental ignition • Skin burn • Impact injury • Chemical exposure to black powder • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Moderate to Severe	• Engineering: isolate ejection charge from strong electric fields and heat sources • Administrative: HOP; safe work practices; training; personnel certification • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Ejection Charge Handling: Testing	• Failure of ejection charge retention system releases projectile • Premature combustion • Injury to personnel • Facility/equipment damage • Unauthorized entry of test cell	• Rating: Hazardous Operation • Probability: High • Severity: Moderate to Severe	• Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system • Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Machine Use: Lathe	• Injury to or loss of hand, limb • Laceration by shrapnel • Eye injury by shrapnel • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: machine selection; shop design • Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access • PPE: eye protection • Residual Risk: accepted
Machine Use: Milling Machine	• Injury to or loss of hand, limb • Laceration by shrapnel • Eye injury by shrapnel • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Mild to Severe	• Engineering: machine selection; shop design • Administrative: SOP; safe work practices; training and qualification; supervision by experienced personnel; controlled access • PPE: eye protection • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Motor Handling: Installation	• Accidental ignition • Skin burn • Impact injury • Bystander injury • Facility/equipment damage	• Rating: Hazardous Operation • Probability: Moderate • Severity: Moderate to Severe	• Engineering: isolate ejection charge from strong electric fields and heat sources • Administrative: HOP; safe work practices; training; personnel certification; performed only by Level 2 certified NAR Mentor • Residual Risk: accepted
Motor Handling: Testing	• Motor retention system failure resulting in uncontrolled motor movement • Premature combustion • Injury to personnel • Chemical exposure to ammonium perchlorate • Facility/equipment damage • Unauthorized entry of test cell	• Rating: Hazardous Operation • Probability: High • Severity: Moderate to Severe	• Engineering: conduct test in blast-proof test cell; large safety factor designed into retention system • Administrative: written test procedures; safe work practices; supervision by Level 2 certified NAR Mentor; controlled access; training; personnel certification • Residual Risk: accepted

Work Task	Potential Hazard	Hazard Ranking	Hazard Controls
Tool Use: Sanding/Grinding	• Skin abrasion • Laceration by shrapnel • Eye injury by shrapnel or dust • Respiratory irritation • Bystander injury • Facility/equipment damage • Chemical exposure if material being worked is hazardous • Catastrophic failure of grinding wheel resulting in high velocity	• Rating: Potentially Hazardous Operation • Probability: Low • Severity: Mild to Severe	• Engineering: machine selection; shop design; shop exhaust ventilation • Administrative: SOP; safe work practices; exposure time limitations; training; supervision by experienced personnel • PPE: eye protection • Residual Risk: accepted
Tool Use: Soldering, Electrical	• Skin burn • Damage to components • Fire	• Rating: Hazardous Operation • Probability: High • Severity: Mild to Severe	• Engineering: tool selection • Administrative: SOP; safe work practices; training • Residual Risk: accepted

15. Appendix I: 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.

16. Appendix J: Black Powder Ejection System Standard Operating Procedure

UAHuntsville Propulsion Research Center

STANDARD OPERATING PROCEDURE FOR:

Black Powder Ejection System

SOP #: USLI – SOP – TC - 003
Revision: 03
Operation: Black Powder Ejection System
Test Location: PRC Test Cell Facility and NAR/TRA approved test fields

Test Date: ____________________
Test Time Start: _______________ Finish: ________________

Test Team

NAME	ROLE

Notes: ____

____

____

☐ **Procedure Deviations Required (provide reasoning below)**

Revision Block

REVISION #	REASON FOR REVISION	DEVELOPMENT HOURS
3	**New SOP for New red team members and update to current procedure and ignition control circuit.** Based on USLI-Black_Powder_Ejection_System-SOP_Rev02 and PRC–SOP–JRC-001.	**18**

Active Waivers

The following waivers have been reviewed by the procedure approval team and are accepted based on assessment of additional mitigations put into effect for conducting the test.

#	DESCRIPTION	MITIGATION	EXPIRES	RESPONSIBILITY
1	No Active Waivers	None	N/A	N/A

Procedure Approval:

I have personally reviewed each of the operational steps of the SOP and have no questions that the operation can be performed safely and efficiently. I approve all red team personnel assigned in this document and verify that they have proper training to act in the prescribed test roles outlined in this procedure.

Amit Patel: ______________________________ **Date:** ____________

Author

Tony Hall: ______________________________ **Date:** ____________

Facility Engineer

Dr. David Lineberry: ______________________________ **Date:** ____________

Laboratory Supervisor

Dr. Robert Frederick: ______________________________ **Date:** ____________

PRC Director

Reviewed By:

Marcia Pendleton: ______________________________ **Date:** ____________

Director UAH OEHS

Authorized Red Team Members

Individuals identified below are authorized to participate in test operations as *Red Team Members* through the SOP approval signatures. By signing the document below, the individuals acknowledge that they have reviewed the procedure and understand the general and specific safety requirements, personnel limits, and work descriptions necessary to accomplish their part of the operation.

Additional Red Team Members may be added to this document without a procedure revision pending approval of the PRC Director or Laboratory Supervisor or Facility Engineer prior to participating in the experiment. Additional members require signatures of both the individual to be added and the approver.

Authorized test individuals agree to abide by and follow the procedure outlined in this document for conducting the described experiment. Any individual not following procedure during testing in a manner which jeopardizes other test members will be immediately removed from the red team and reported to the PRC director.

RED TEAM MEMBERS	AFFILIATION	FIRST AID/CPR-AED CERTIFICATION DATES	SIGNATURE
Amit Patel	PRC Staff	6/22/2012	
David Lineberry	PRC Staff	9/20/2013	
Tony Hall	PRC Staff	9/20/2013	
Robert Frederick	PRC Director	10/19/2012	
Jason Winningham	USLI L2 Mentor	2/12/2012	
Wesley Cobb	USLI Avionics Lead	9/20/2013	
Brian Roy	USLI Safety Officer	1/24/2014	

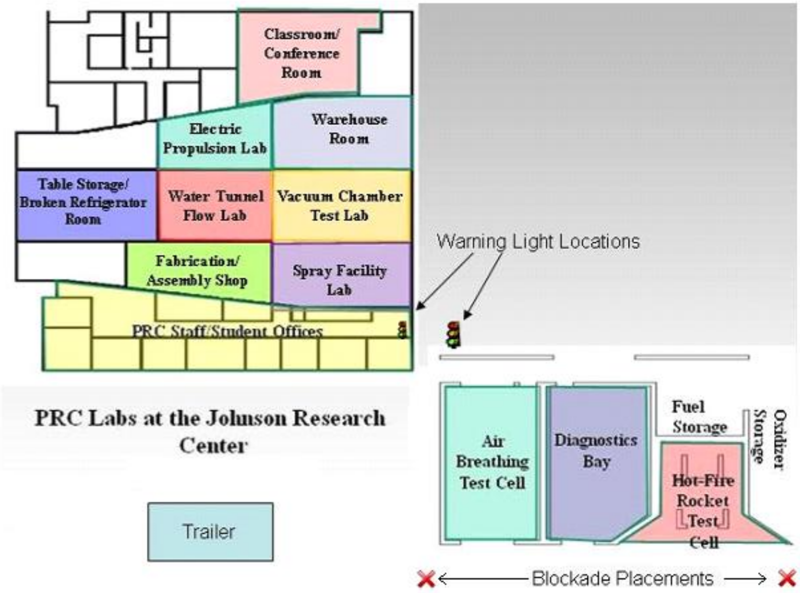
Section I. Declarations

Objective

This SOP establishes procedures and defines safety precautions that will be used to verify the amount of black powder needed to safely separate rocket body at break points in order to ensure proper deployment of recovery system as part of pre-flight testing.

Test Location

This procedure is open to testing in the PRC Test Cell Facility Laboratory and NAR/TRA approved test fields. Due to Fire Code Restrictions and exposure concerns, no more than 5 people are allowed in the test area at one time. All personnel will be at least 30 ft away.



Warning Barricade Placement

Roles and Responsibilities

This procedure requires a minimum of 2 test operators. No more than one (1) Test Conductor/Safety Monitor, one (1) Test Operator, one (1) person for Instrumentation and two (2) Test Observers at any time. At least one PRC Staff or USLI L2 Mentor must be present to perform test. Operator roles will be assigned on the day of testing. Each operator will be assigned a role and that role will be identified on the procedure cover sheet (pg 1). Test operator roles are identified below:

Test Conductor/Safety Monitor: Reads Procedure, Insures proper number of Red team members for test, Keeps test area isolated from guests, Makes sure all test materials are in place.

Test Operator: Handles loading of black powder and control of ignition circuit.

Instrumentation: Handles all other areas of instrumentation, camera, etc. If only two people are present for the test, this task may be handled by either the Test Operator of Test Conductor.

Test Observers (Optional): Observers are to remain in designated locations set forth by the Safety Monitor. They may be available to assist with test at request of the Test Conductor.

Observer Policy

Observers will be allowed under this test procedure pending approval of the PRC Staff. The occupation limitations of the test area apply to observers as well as test participants. Any observer must be briefed on the experiment hazards, emergency procedures prior to test operations, and listed on the title page of the procedure. An observer is required to remain behind remote physical caution boundaries at all times- during all operations.

Before operations commence, an observer must be briefed on the potential hazards of the facility, including:

- **Explosions**
- **Temperature Burns**
- **Debris**
- **Fires**

Additionally, an observer must be provided personal safety equipment and advised of its use as defined in Table 1.

Safety Policy

All PRC test operations require a minimum of two operators with First Aid, CPR, and AED training. Test operations are carried out according to the PRC Facility Usage Policy outlined in PRC-SOP-001-R01 and supplied in Appendix C. A copy of the facility usage policy will be provided upon request or may be found on the PRC website http://UAH.edu/prc. In addition to standard safety requirements the following special requirements apply for this procedure: All personnel involved with this operation have been empowered to stop any portion of this operation at any time if they feel it is not proceeding in a safe manner. The PRC Director, PRC Research Engineer/Laboratory Supervisor, PRC Facility Engineer, and other required personnel will be notified and a decision on whether to continue the operation will be made at that time. No safety interlock will be modified, bypassed, or defeated unless the test team has concurred and are aware of the inherent risks associated with the change. Otherwise, the offender will be permanently expelled from the PRC and all of its facilities.

Safety Requirements

- Only red team members are allowed to assist in loading and operating the triggering system in an environment clear of prohibited members.
- At least two red team members must be present at a test.
- Protective eyewear must be worn at all times during the test procedure.
- Canisters of black powder must be stored in approved a clearly-labeled containers. Bulk black powder must be contained and away from test operations during testing.

- In the event that the charge fails to trigger, a complete disarming of system must occur. Steps 67-75: Disarming/Failure Checklist must be followed to ensure involuntary ejection does not occur.
- Only proper installation tools should be used to load the Black Powder Ejection System. All tools should be verified to be in good working order before the test begins.

Personal Protective Equipment (PPE)

Test personnel must wear safety glasses at all times during test operations. Long pants and close toed shoes are required for testing. Cotton clothing is required. The following PPE are approved through the procedure and **Table 1** show when PPEs are necessary:

- Lab Glasses,
- Lab Goggles,
- Personal Spectacles with Side Shields
- Ear Plugs,
- Ear Muffs

Table 1 – Personal Safety Equipment

Equipment	Period
Approved eye protection	**All Times**
Closed-toed footwear	**All Times**
Approved hearing protection (Optional)	**Firing Procedures**

Weather/Emergency

Testing will not be conducted during unfavorable weather conditions. Additionally testing may not be conducted if lightning is expected in the area or if there is lightning in a 25 mile radius. Testing may be stopped if high or variable winds are present in the test area. In the event of non-weather related emergency test operations must be stood down so test personnel can evacuate test facility. If time does not permit safe mitigation of hazards, any immediate hazards should be identified to PRC Staff and emergency response personnel

Procedure Deviations

At any point during the execution of this SOP any team member may call for a stand down of test operations to discuss any concern related to safety. Additionally, during the execution of the SOP any deviation to the procedures outlined in this document must be noted on the procedure and it must be identified on the cover page that deviations were conducted. Revisions to the procedure may be required prior to the next test operation. Prior to each test, verify that the procedures do not require modification due to specific test plan requirements. In the event that redlines are required during execution, ensure that redlines present no safety, efficiency, or environmental concerns.

Materials Needed

Safety Glasses
Assembled Rocket Air Frame
Black Powder
E-Match
Black Powder Cap
Long wire
Fire Extinguisher (verify availability at site)
Wire cutters
Test stand
E-match Ignition Circuit
Volumetric measuring device
Electrical tape
Ear plugs
Battery
First Aid Kit (includes bottled water)
Parachute
Shock cord
D-Ring
Measuring tape
Multimeter

SECTION II. Test Procedures

Pretest Laboratory Preparation

Make sure you have a partner. You must observe the two-man rule. NO experiments shall be performed alone.

Ensure that every person involved in test is aware of all procedure.

Inform all guests of emergency exits and other pertinent safety information.

Identify nearest AED location to team and guests.

Place all jewelry and electronic devices, including cell phones, tablets, and radios in an approved location.

Make sure the two phones work in case an emergency occurs.

In case of an emergency, call campus police at: (256) 824-6911.

At any point during a test, any red team member can call for the test to be stopped at any point and for any reason.

Make sure all personnel are wearing the proper PPE, e.g., safety glasses, goggles, face shield, hearing protection (if needed).

Safety glasses are required when lines are pressurized (i.e. once warning light turned to Yellow).

If testing at the JRC, the 'Warning' barricades should be set up at each corner of the test area (see section 2 and Appendix F for barrier placement).

If testing at the JRC, warning light should be turned to RED during the set-up procedure and throughout the experiment.

New Red Team members must be certified in writing by Dr. Lineberry or Mr. Hall.

Observers must be approved by either Dr. Lineberry or Mr. Hall.

Preparing The Black Powder Charge

CAUTION

Failure to restrict access to the testing area could result in inadvertent personnel traffic which could lead to personnel injury.

Verify non Red Team members have vacated the testing area and PPEs are available.

Setup camera to record test (optional).

Inspect E-Match for frayed wires.

Cut a hole in the bottom of charge cap.

Secure E-Match into charge cap and seal with electrical tape.

Secure charge cap into position (i.e. bulkhead, nosecone, etc).

Twist e-match leads together to shunt circuit.

Remove black powder from designated container.

Measure specified amount of black powder to be tested in a volumetric measuring device.

Record the volume of the black powder: ________________.

NOTE: Start with half the amount needed and work up.

Insert specified amount of black powder into charge cap.

Pack charge cap with wadding material.

Close charge cap and ensure seal.

Return black powder to designated container and move container away from test area.

Assemble rocket components to be tested for separation.

If necessary, insert shear pins into rocket halves to be tested for proper shear.

Place rocket on designated test stand.

Ignition Circuit Setup

Verify Safety Monitor is in possession of arm key

Ensure ignition circuit is disconnected from battery

Shunt ends of wires.

Connect Igniter Cable into Ignition Circuit Extension Cord at rocket test stand.

Connect Ignition Box Cable Leads to Ignition Circuit Extension Cord at control station.

Connect battery leads to multimeter to perform continuity check on ignition circuit.

Hold control circuit arm key in ignition and press “fire” button to perform continuity check.

Remove control circuit arm key and hand to Safety Monitor

Disconnect battery leads from multimeter.

Connect E-Match leads to ignition circuit.

Remove all attending personnel at least thirty (30) feet radius from explosive zone.

Return to Operator Area

Person performing detonation should then take one last observation to ensure that no one is near explosive zone before detonation.

ONLY Red Team allowed in test cell area from this point forward.

Testing Procedure

Verify that the battery is disconnected from igniter circuit.

Verify that the Safety Monitor has possession of the control circuit arm key.

Announce "CLEAR AREA."

Confirm from Safety Monitor that test fire is a "GO."

Unshunt ends of wire.

Connect Battery to Ignition Circuit

Inform Safety Monitor that Rocket is ready for ignition

Insert control circuit arm key into control box and hold in to perform continuity check.

Perform a countdown of 5,4,3,2,1, FIRING CHARGE.

While holding in control circuit arm key, press and hold the fire button for 5 seconds.

If the charge fails to fire within 30 seconds,

First Failure: repeat steps 38 – 54.

Second Failure: Skip to Steps 67-75: Disarming/Failure Checklist.

Wait for charge to burn completely

Disconnect Battery

Remove control circuit arm key and hand to Safety Monitor

Wait 60 seconds.

All attendees should then remain in their safe zone until given the go ahead from test conductor.

Test operator should then approach the E-Match charges and ensure that all black powder was expelled from the E-Match charge and detonated.

In is now safe for all attendees to return to the test area to examine the results of the tests.

Record all results:

____

____

____

____

____
____
____
_____

All components should be inspected for damage.

If repeating test, return to step 15 and mark procedure with different check indicators.

Disarming/Failure Checklist

If the charge fails to fire a second time, remove power from the ignition circuit.

Remove key from box and hand to Safety Monitor.

Disconnect battery.

Shunt ends of wires.

Wait another 30 seconds, and then approach charges carefully.

Disconnect E-match leads from ignition cable.

Twist E-match leads together.

Remove rocket frame from test stand.

Ensure proper disposal of black powder and E-Match.

Administrative & Documentation Tasks

Update black powder inventory after a successful test or relocation of propellant.

Indicate on this SOP how data will be backed up.

Upon completion, the SOP needs to be signed by the participating Red Team members, scanned, and uploaded to the SOP database per direction of Dr. Lineberry.

APPENDIX A. Cross Referenced Procedures

The following procedures are referenced in this SOP and are required for verification purposes.

#	SOP Doc #	Description
		UAH PRC Safety Program, 22-Feb-2013.
	PRC-SOP-001	UAH Propulsion Research Center – Facility Usage Policy, 1-Apr-2012.
	PRC-SOP-HiPSF-003	General Spray Facility SOP
	PRC-SOP-JRC-001	Solid Rocket Motor Ground Testing
	USLI-Black_Powder_Ejection_System_Test SOP	Previous Black Powder SOP
	PRC-SOP-HPL-002 R00V01	ESP Ultrasonic Burn Rate SOP

APPENDIX B. STORAGE AND TRANSPORTATION OF BLACK POWDER

The following are instructions for the storage and transportation of black powder.

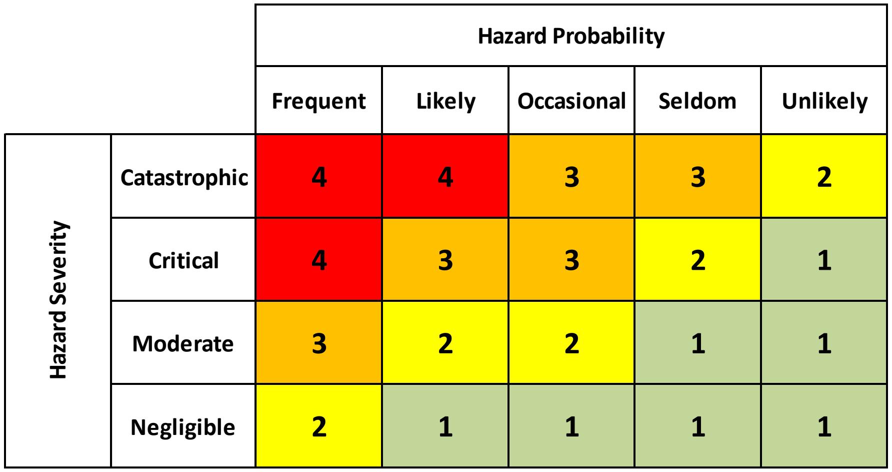
- The black powder will be stored in the PRC's Day Box. The Day Box will be locked.
- When transporting the black powder to launch sites, it will be stored in the locked Day Box.
- The Day Box will be transported in a non-confined space on a vehicle (i.e. the bed of a truck). It will not be transported inside any vehicle.

The following are instructions for the proper disposal of black powder.

- The black powder will be stored in a container separate from the unused powder.
- The black powder will be burned at the next available opportunity.

APPENDIX C. RISK ASSESSMENT

Hazard Ranking



		Hazard Probability				
		Frequent	Likely	Occasional	Seldom	Unlikely
Hazard Severity	Catastrophic	4	4	3	3	2
	Critical	4	3	3	2	1
	Moderate	3	2	2	1	1
	Negligible	2	1	1	1	1

Hazard	Rank	Effect	Reaction	Mitigation
Explosions	2	• Damage to facility • Injury from debris	• Assess situation before proceeding to test area • Stop test/disconnect circuit • Evacuate laboratory as necessary • Report incident	• Access to test area is restricted when testing • Start with smaller amount of black powder. • Inspect structure for points of failure.

HAZARD	RANK	EFFECT	REACTION	MITIGATION
High Temperature Burns	3	• Burns on Skin	• Alert on site personnel • Call emergency response	• Wait 60 seconds after test • Heat Gloves • Handle with helping hands.
Inadvertent firing of the Black Powder charge	2	• Laboratory Fire • Injury • Debris	• Get affected person out of hazard • Clear lab • Assess situation (do not try to fight any fire) • Report incident to Police as necessary • Report incident to PRC Director	• Igniter leads are shorted while personnel around rocket • Arm key provides physical break in igniter circuit • Work is conducted on a grounded work surface • Verify no voltage on igniter circuit before connecting it to the igniter • Always point rocket away from all personnel
Test stand structural failure	1	• Uncontrolled BP charge • Debris • Injury • Fire	• Assess Situation before proceeding to test stand • Stop test/disconnect circuit • Evacuate lab and report incident	• Assess Structure before returning to operating area
HAZARD	**RANK**	**EFFECT**	**REACTION**	**MITIGATION**
Inhalation of fumes from Black Powder products	2	• Long term health affects	• Exit laboratory • Report incident to OEHS	• Test areas are naturally vented

APPENDIX D. UAH PRC FACILITY USAGE POLICY

UAH Propulsion Research Center – Facility Usage Policy

The Propulsion Research Center (PRC) conducts research, produces publications, and mentors students in advanced propulsion technologies and their applications. The PRC connects the academic research community and propulsion community through interdisciplinary collaboration. Use of the facility requires prior written approval of the PRC Director.

The Propulsion Research Center laboratories were established to provide UAHuntsville faculty, staff, and students, state-of-the-art facilities for conducting basic and applied research on propulsion systems and related sciences. The PRC was established to provide students a “hands-on” education in propulsion. The facilities may be used for sponsored research projects, PRC staff and Graduate Student research projects, and approved UAHuntsville undergraduate research projects. The Propulsion Research Center acknowledges that hazards are inherent to the nature of the research conducted in the facilities that require strict adherence to facility rules and protocols for anyone engaged in research in the PRC laboratories. PRC facility protocol is as follows:

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.

Robert A Frederick

__________________________________ 4/1/2012_

Robert Frederick
Interim Director PRC

APPENDIX E. EMERGENCY CONTACT INFORMATION

In the event of an emergency, respond in accordance with off-nominal procedures defined in this SOP and in accordance with the appropriate section in the UAH PRC Safety Program dated 22-Feb-2013.

Emergency contact numbers are provided below.

Emergency Phone Numbers	
Police	911 (256) 824-6911 (6911 from campus phone)
Fire Department	
Hazardous Materials Incident	
Utility Failure	
PRC Contacts	
Tony Hall	Office : (256) 824-2887
David Lineberry	Office : (256) 824-2888 Cell: (256) 348-8978
Robert Frederick	Office : (256) 824-7200 Cell: (256) 503-4909
PRC Main Office	(256) 824-7209
High Pressure Lab Phone	(256) 824-6031
JRC Test Stand	(256) 824-2857
Marcia Pendleton/OEHS (Office of Environmental Health and Safety)	(256) 824-6053
Other Emergency Numbers of Interest	
UAH Campus Police Department	(256) 824-6911
Huntsville Police Department	(256) 722-7100
Madison County Sheriff’s Office	(256) 722-7181
Alabama State Troopers	(334) 242-4371
Huntsville Hospital	(256) 265-1000

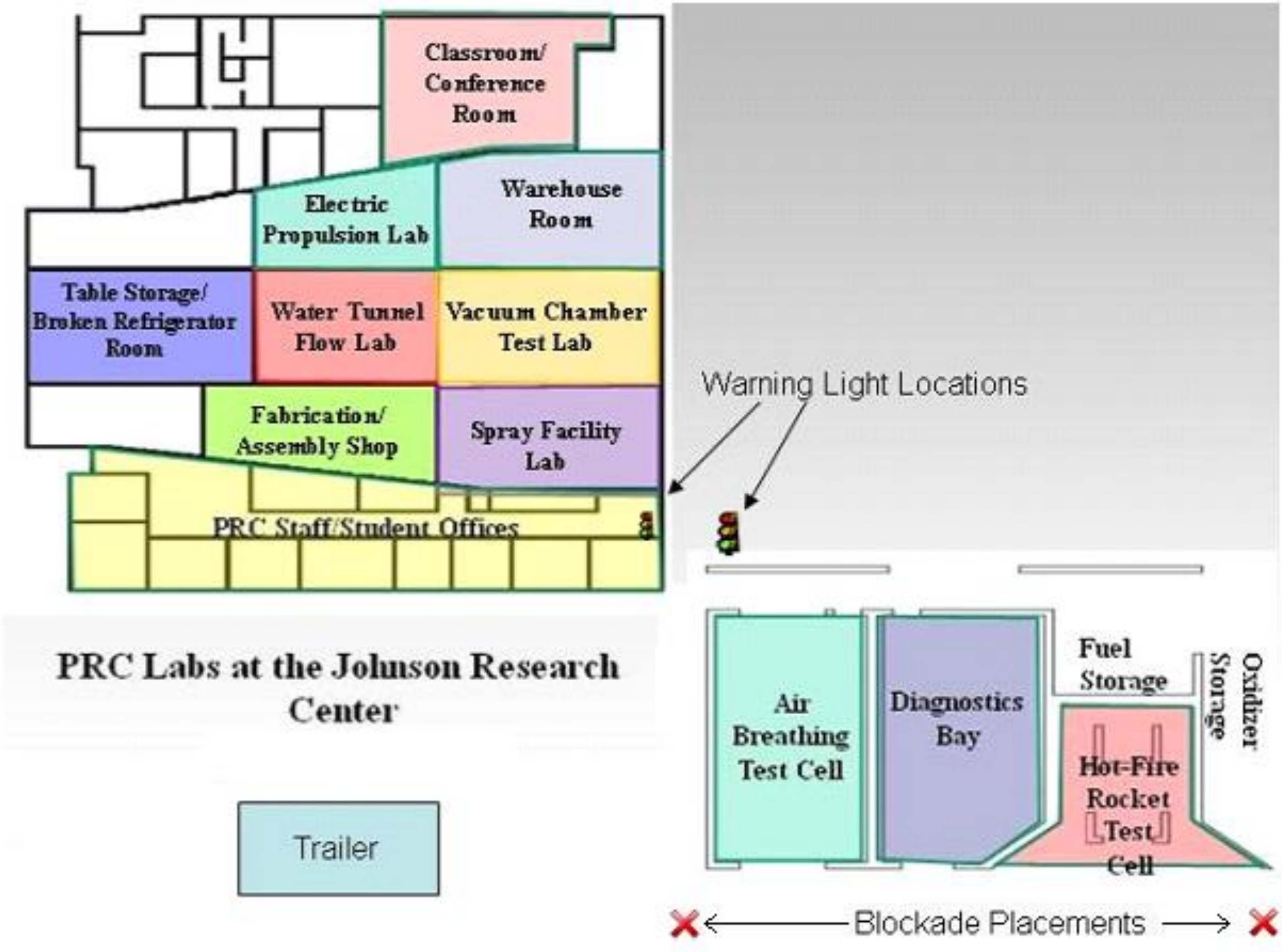
In the event of a non-emergency reportable incident call the numbers below in the following order.

1. **Dr. Robert Frederick (Dr. David Lineberry as an alternate)**
   Office: (256) 824-7200

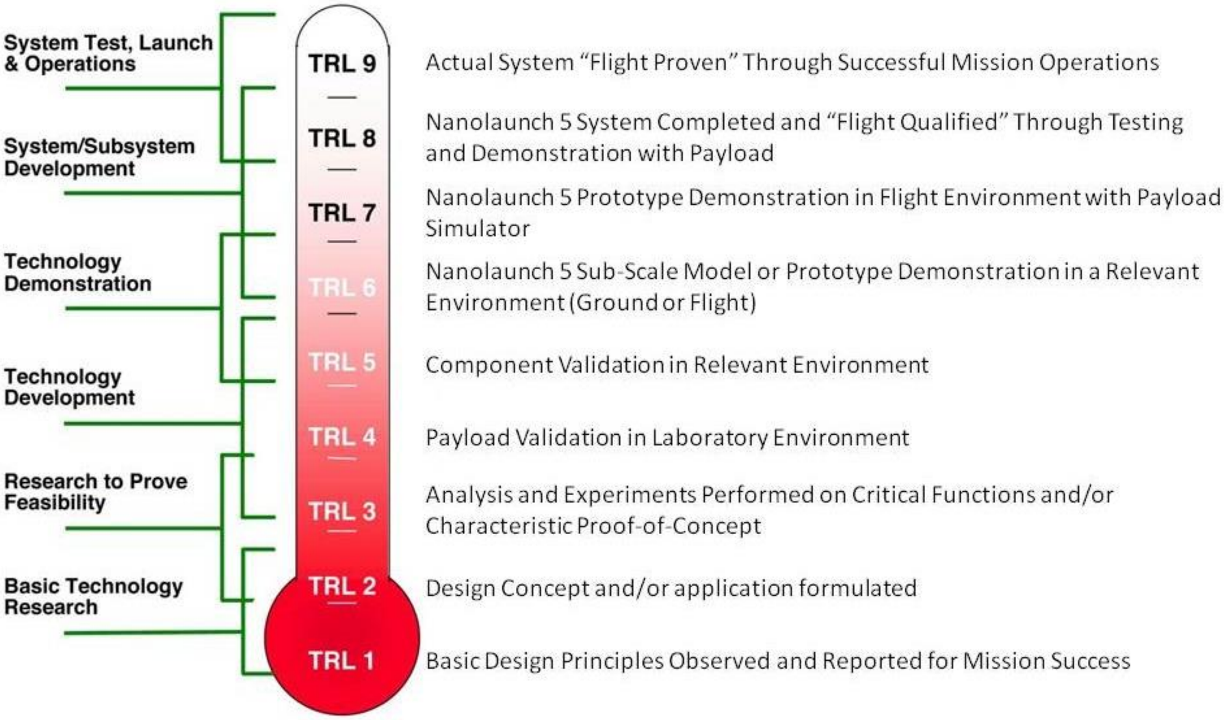
   Cell: (256) 503-4909
2. **UAHuntsville Police (Non-Emergency)**
   (256) 824-6596

   6596 (from campus phone)

Appendix F: Warning Barricade Placement



17. Appendix K: Technology Readiness Level



18. Appendix L: Milestone Review Flysheet

Milestone Review Flysheet			
Institution	University of Alabama in Huntsville	**Milestone**	Critical Design Review
First Stage (Both Stages Together or Single Stage)		**Second Stage (If Applicable)**	
Vehicle Properties		**Vehicle Properties**	
Total Length (in)	120.179"	Total Length (in)	
Diameter (in)	4.59"	Diameter (in)	
Gross Lift Off Weight (lb)	34.0 lbs	Gross Weight (lb)	
Airframe Material	Carbon Fiber	Airframe Material	
Fin Material	Carbon Fiber	Fin Material	
Motor Properties		**Motor Properties**	
Motor Manufacturer(s)	Cesaroni Technology Inc.	Motor Manufacturer(s)	
Motor Designation(s)	M-4770 (Vmax)	Motor Designation(s)	
Max/Average Thrust (lb)	1362.01/ 1073.3	Max/Average Thrust (lb)	
Total Impulse (lbf-sec)	1645.29	Total Impulse (lbf-sec)	
Stability Analysis		Ignition Altitude (ft)	
Center of Pressure (in from nose)	95.5	Ignition Timing (From 1st Stage Burnout)	
Center of Gravity (in from nose)	84.6	Igniter Location	
Static Stability Margin	2.37	**Stability Analysis**	
Thrust-to-Weight Ratio	38	Center of Pressure (in from nose)	
Rail Size (in)	1.5	Center of Gravity (in from nose)	
Rail Length (in)	120	Static Stability Margin	
Rail Exit Velocity (ft/s)	130	Thrust-to-Weight Ratio	
Ascent Analysis		**Ascent Analysis**	
Maximum Velocity (ft/s)	1960	Maximum Velocity (ft/s)	
Maximum Mach Number	1.7	Maximum Mach Number	
Maximum Acceleration (ft/s^2)	1416.8	Maximum Acceleration (ft/s)	
Target Apogee (1st Stage if Multiple Stages)	15,800 ft	Target Apogee (ft)	
Recovery System Properties		**Recovery System Properties**	
Drogue Parachute		**Drogue Parachute**	
Configuration	Conical	Configuration	
Size	24" Diameter	Size	
Deployment Velocity (ft/s)	50.18	Deployment Velocity (ft/s)	
Terminal Velocity (ft/s)	98.58	Terminal Velocity (ft/s)	
Fabric Type	Rip-Stop Nylon	Fabric Type	
Shroud Line Material	Polyester	Shroud Line Material	
Shroud Line Length (in)	28.5	Shroud Line Length (in)	
Thread Type	Polyester	Thread Type	
Seam Type	3/8" French Fell Seam	Seam Type	
Recovery Harness Type	1/4" Diameter Kevlar	Recovery Harness Type	
Recovery Harness Length (ft)	20	Recovery Harness Length (ft)	
Harness/Airframe Interface	Eyebolt/ Swivel/ Quick Links	Harness/Airframe Interface	
Main Parachute		**Main Parachute**	
Configuration	Semi-Hemispherical	Configuration	
Size	12 ft. Diameter	Size	
Deployment Velocity (ft/s)	98.58	Deployment Velocity (ft/s)	
Terminal Velocity (ft/s)	7	Terminal Velocity (ft/s)	
Fabric Type	Rip-Stop Nylon	Fabric Type	
Shroud Line Material	Polyester	Shroud Line Material	
Shroud Line Length (in)	87.06	Shroud Line Length (in)	
Thread Type	Polyester	Thread Type	
Seam Type	3/8" French Fell Seam	Seam Type	
Recovery Harness Type	1/4" Diameter Kevlar	Recovery Harness Type	
Recovery Harness Length (ft)	20	Recovery Harness Length (ft)	
Harness/Airframe Interface	Eyebolt/ Swivel/ Quick Links	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
	0.83	15.9							

Milestone Review Flysheet

Institution	University of Alabama in Huntsville	**Milestone**	Critical Design Review

First Stage (or Single Stage)		**Second Stage (If Applicable)**	
Recovery System Properties		**Recovery System Properties**	
Altimeter(s)/Timer(s) (Make/Model)	PerfectFlite Stratologger (SL100) (X2)	Altimeter(s)/Timer(s) Make/Model	
Transmitters (Model-Frequency-Power)	Xbee-PROXSC S3B-900 MHz-250 mW Antenova M10382-Al UB Tagg Tracker	Locators/Frequencies (Model-Frequency-Power)	
Black Powder Charge Size Drogue Parachute (grams)	6.1	Black Powder Charge Size Drogue Parachute (grams)	
Black Powder Charge Size Main Parachute (grams)	0.5	Black Powder Charge Size Main Parachute (grams)	

Payloads

Mandatory Payload 3.1	Overview Landing hazard detection system will deploy with the drogue chute and begin transmitting data to a ground station. This data will be processed at the ground station by a custom software package to determine if any hazards are present on the ground.
Optional Payload 1 3.2.1.2	Overview Dielectrophoresis payload to simulate liquid propellant management in a microgravity environment. This payload will utilize a high voltage power supply to deliver approximately 7 kV through an electrod in the liquid containers. The liquid should be drawn towards the electrode, and this effect will be captured on video.
Optional Payload 2 3.2.2.4	Overview Effects of supersonic flight on different vehicle coatings. The vehicle will be flown with both a urethane and an epoxy based paint to test whether any degredation of the surface coatings occurs due to the aerodynamic forces induced by supersonic flight. Several strips of temperature sensitive tape will also be flown on the vehicle to observe the maximum temperature that the vehicle's skin encounters.

Test Plans, Status, and Results

Ejection Charge Tests	Successful completion of ejection charge tests on Feb 8 & 21, 2014 before both sub-scale flights. Additional ejection charge tests will be performed prior to all subsequent flights to ensure proper deployment of all flight hardware.
Sub-scale Test Flights	Successful completion of subscale flight on Feb 8,2014 with geometrically scaled model of full-scale vehicle. Second flight completed on Feb 22,2014 with in-house made parachute design used as drogue and avionics package containing acceleraometers and gyroscopes to be used in the full-scale vehicle. Another flight is planned for March 8, 2014 to place the avionics and flight electronics under G-loading which will match that of the full-scale vehicle.
Full-scale Test Flights	First full-scale flight is tentatively planned for March 29, 2014.

Additional Comments

Our NAR/TRA mentor, Mr. Jason Winningham has not yet been able to obtain his Level 3 certification due to forces outside of his and the team's co

19. Appendix M: Payload Shaft Pre-Load Calculations

3/8 -- 16 $\text{Tensile\_area} := .0775\text{in}^2$

7075 $T6 := 73000 \frac{\text{lb}}{\text{in}^2}$

Yeild Strength $\text{Tensile\_area} \cdot T6 = 5.657 \times 10^3 \cdot \text{lb}$ 4.7 ets payload weight

$$\text{Payload\_weight} := \frac{4.7\text{lb}}{32.2 \frac{\text{lb}}{\text{slug}}} = 0.146 \cdot \text{slug}$$

1203 payloads tensile strength

44 projected G loading

27 Factor of safety

Ring Nuts/ Eye Nuts

$$\text{Proof\_Load} := 68,000 \frac{\text{lb}}{\text{in}^2}$$

$F_i := 4743\text{lb}$ F.i = .9 AtSp from tables

Tighting $T := 355\text{in} \cdot \text{lb}$ T = .2 Fid from tables

Torque $T_1 := 30\text{ft} \cdot \text{lb}$