ECLIPSE
University of California, Davis
http://mae.ucdavis.edu/~rocket

# Eclipse-I Flight Readiness Review

NASA University Student Launch Initiative Project

(2012-2013)

Submitted to

NASA Marshall Space Flight Center

By

University of California, Davis SpaceED_Rockets Team

18th March 2013

Contact email: nsarigulklijn@ucdavis.edu

# Table of Contents

# 1. Summary of FRR Report

## 1.1 Team Summary

**Name of School/Organization**

University of California, Davis – SpaceED Rockets Team

**Mailing Address:**

Attn: Nesrin Sarigul-Klijn

Professor and Director of SpaceED

Mechanical and Aerospace Engineering Department

2132 Bainer Drive

Davis, CA 95616-5294

**Reusable Rocket Vehicle Proposed:**

Eclipse-I

**Team Faculty Advisor:**

Dr. Nesrin Sarigul-Klijn

**Launch Assistance/Mentor:**

Steve Kendall (NAR 73704 L3 & TRA 10478 L3)

LUNAR #600

AeroPAC #445

## 1.2 Launch Vehicle Summary

The launch vehicle is designed to carry a payload and recovery system. The overall dimensions of the launch vehicle evolved through multiple iterations of design and testing cycles to accommodate all contract requirements as stated in the NASA USLI Handbook. The following sections describe the most updated specification of the launch vehicle:

**Final Launch Vehicle Dimensions**

The final dimensions of the launch vehicle as flown on March 2nd, 2013 and to be flown on launch day are presented in Figure 1 These dimensions are considered final. All dimensions are in inches.

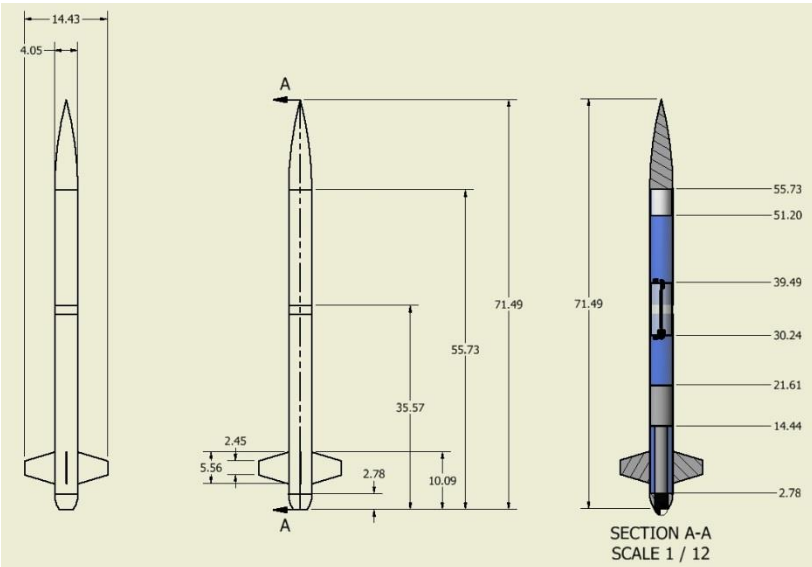


Figure 1, Vehicle Dimensions

**Weight Breakdown**

The current mass breakdown of the launch vehicle and payload is presented in Figure 2. These weight measurements represent the as-manufactured weight of the final launch vehicle that was flown in the March 2nd full scale test launch, and that will be used on launch day. Minor changes to these values are expected as part of the weight reduction strategy presented in Section 3.1.15 Mass Report and Deviations.

| Component | Weight (lbf) |
|---|---|
| **Nose Cone** | 1.20 |
| **Forward Body Tube** | 1.48 |
| **Aft Body Tube (with fins and boat-tail)** | 4.00 |
| **Motor Casing** | 0.97 |
| **Main Parachute and Drogue Parachute** | 3.19 |
| **Payload** | 2.02 |
| **E-bay** | 1.56 |
| **Motor** | 3.34 |
| **Total:** | 14.41 |

Figure 2, Weight Breakdown

**Final Motor Choice: Aerotech K550W**

| AeroTech K550W Specifications | | |
|---|---|---|
| **Diameter** | 54 | mm |
| **Length** | 41 | cm |
| **Total Weight** | 1487 | g |
| **Propellant Weight** | 889 | g |
| **Average Thrust** | 396.8 | N |
| **Maximum Thrust** | 655.3 | N |
| **Total Impulse** | 1539.1 | Ns |

Figure 3, Motor Specification

## Recovery System

| Primary Altimeter | **Featherweight Altimeters: Raven 3** |
|---|---|
| Redundant Altimeter | PerfectFlite: StratoLogger |
| Main deployment altitude (Primary) | 832 ft |
| Main deployment altitude (Redundant) | 750 ft |
| Drogue deployment altitude (Primary) | Apogee |
| Drogue deployment altitude (Redundant) | 2 seconds post apogee |
| Main chute dimensions | 72" Diameter |
| Drogue chute dimensions | 18" Diameter |
| Main chute model | Fruity Chutes: Iris Ultra |
| Drogue chute model | Fruity Chutes: Classic Elliptic |
| Black powder charge- main | 2 grams |
| Black powder charge- drogue | 2 grams |
| Recovery System Shielding | Metallic coating inside recovery bay |

Figure 4, Recovery Specifications

## Structural System

| Rail Size | **Standard - 1 “** |
|---|---|

Figure 5, Structural Specifications

## 1.3 Payload Summary

**Payload Title**

Rocket Performance and Atmospheric Evaluation Module (RPAEM)

**Experiment Summary**

Since the team did not receive funding from NASA to continue the SMD option 3 payload, the team has selected a modified version of the SMD payload. The modified payload follows the basic requirements of the SMD payload as defined by NASA, with the exception of ultraviolet radiation measurement. The solar irradiance pressure, temperature, and relative humidity will still be measured, logged, and transmitted to a ground station.

The experiment conducted in our payload it twofold: measuring atmospheric conditions and its change with respect to altitude, as well as measuring the rocket's dynamic behavior. Both parts of the experiment are conducted by the custom Arduino microcontroller (ArduPilot Mega 2.5). With respect to the atmospheric measurement, the measured data will be compared to predicted models for accuracy and trend assessment. Measurement of the rocket's dynamic behavior enables confirmation of the design, performance, and simulations of the launch vehicle.

# Milestone Review Flysheet

**CDR**

| | | | | |
|---|---|---|---|---|
| **Institution Name** | University of California, Davis | | **Milestone** | CDR Submission |

| **Vehicle Properties** | |
|---|---|
| Diameter (in) | 4" |
| Length (in) | 71.5" |
| Gross Liftoff Weight (lb) | 15.28 |
| Launch Lug/button Size | 1"/1.5" |
| Motor Retention | Slimline ogive boat-tail retainer |

| **Motor Properties** | |
|---|---|
| Motor Manufacturer | Aerotech |
| Motor Designation | K550W |
| Max/Average Thrust (N/lb) | 655.3/396.8 |
| Total Impulse (N-sec/lb-sec) | 1539.1 Ns |
| Mass pre/post Burn (lb) | 3.65/2.087 |

| **Stability Analysis** | |
|---|---|
| Center of Pressure (in from nose) | 56.2187 |
| Center of Gravity (in from nose) | 46.9731 |
| Static Stability Margin | 2.31 |
| Thrust-to-Weight Ratio | 8.19 |
| Rail Size (in) / Length (in) | 1"/96" |

| **Ascent Analysis** | |
|---|---|
| Rail Exit Velocity (ft/s) | 78 |
| Max Velocity (ft/s) | 538.63 |
| Max Mach Number | 0.47 |
| Max Acceleration (ft/s^2) | 249.3 |
| Peak Altitude (ft) | 4,225 |

| **Recovery System Properties** | |
|---|---|
| **Drogue Parachute** | |
| Manufacturer/Model | Fruity Chutes |
| Size | 18" |
| Altitude at Deployment (ft) | Apogee |
| Velocity at Deployment (ft/s) | 0 |
| Terminal Velocity (ft/s) | 74.06 |
| Recovery Harness Material | Kevlar |
| Harness Size/Thickness (in) | 0.5 |
| Recovery Harness Length (ft) | 30 |
| Harness/Airframe Interfaces | U-Bolt and quick-link connector |
| Kinetic Energy During Descent (ft-lb) | 824.02 |

| **Recovery System Properties** | |
|---|---|
| **Main Parachute** | |
| Manufacturer/Model | Fruity Chutes |
| Size | 72" |
| Altitude at Deployment (ft) | 832 |
| Velocity at Deployment (ft/s) | 74.06 |
| Landing Velocity (ft/s) | 14.69 |
| Recovery Harness Material | Kevlar |
| Harness Size/Thickness (in) | 0.5 |
| Recovery Harness Length (ft) | 30 |
| Harness/Airframe Interfaces | U-Bolt and quick-link connector |
| Kinetic Energy Upon Landing (ft-lb) | 47.79 |

| **Recovery System Properties** | |
|---|---|
| **Electronics/Ejection** | |
| Altimeter(s) Make/Model | Featherweight Raven3, |

| **Recovery System Properties** | |
|---|---|
| **Electronics/Ejection** | |
| Rocket Locators (Make, | GPS (ArduPilot |

| | | | |
|---|---|---|---|
| | Stratologger | Model) | 2.5) with 915Mhz transceiver |
| Redundancy Plan | Dual altimeters, each with primary and redundant charges (4 charges total) | Transmitting Frequencies | 915 MHz |
| | | Black Powder Mass Drogue Parachute (gram) | 2 |
| Pad Stay Time (Launch Configuration) | 0.174 seconds | Black Powder Mass Main Parachute (gram) | 2 |

# Milestone Review Flysheet

**PDR, CDR, FRR**

| | | | |
|---|---|---|---|
| **Institution Name** | University of California, Davis | **Milestone** | FRR |

| **Payload/Science** | |
|---|---|
| Succinct Overview of Payload/Science Experiment | The payload module will be measuring atmospheric conditions and rocket dyanmics through all stages of the rockets flight. |
| Identify Major Components | Airframe, Recovery System, Payload, Propulsive System |
| Mass of Payload/Science | 14.41 oz |

| **Test Plan Schedule/Status** | |
|---|---|
| Ejection Charge Test(s) | Completed 1/5/13 |
| Sub-scale Test Flights | Completed 1/5/13 |
| Full-scale Test Flights | Completed 3/2/13 |

| **Additional Comments** |
|---|
| |

# 2. Changes made since CDR

## 2.1 Changes made to vehicle criteria

**2.1.1 The attachment method for the altimeter bay was changed from screws to removable rivets.**

Reasoning: Removable rivets enable the team to more rapidly assembly and disassemble the launch vehicle. Field data, flight tests, and application research have indicated the removable rivets can sufficiently withstand all loads encountered during operation.

**2.1.2 The brand and type of epoxy to be used during assembly was exclusively specified to West Systems 105 Resin, 206 Hardener.**

Reasoning: To ensure reliability in manufacture, a single epoxy brand and type was specified. The West Systems 105/206 combination was evaluated to have sufficient material properties for the application while remaining cost effective. Manufacturer handling and use procedures were adhered to for all construction and assembly processes. For constructing fillet connections, the epoxy was thickened using West Systems 406 Colloidal Silica additive.

**2.1.3 The final motor choice was changed from Aerotech K513FJ-M to K550W**

Reasoning: Based on simulation the K550W motor provides an optimized flight trajectory when compared to the K513FJ-M, while maintaining the same dimensions, mounting configuration, and motor casing. The change was authorized by NASA’s Fred Kepner.

**2.1.4 An adjustable ballast system was added to the nosecone**

Reasoning: To allow precise adjustment of the rockets mass tapped holes were added within the interior of the nosecone to allow for the installation of ‘weightening bolts’

## 2.2 Changes made to payload criteria

### 2.2.1 The attachment method for the payload bay was changed from screws to removable rivets

Reasoning: Removable rivets enable the team to more rapidly remove and install the payload bay. Field data, application research, and flight tests have indicated the removable rivets can sufficiently withstand all loads encountered during operation.

### 2.2.2 The payload battery was changed from a Li-Ion 9V to a rechargeable USB Li-Ion battery pack

Reasoning: Replacement of the 9V battery with a Li-Ion battery pack simplifies and improves electrical efficiency of the payload electronics via the removal of external power regulation circuitry, and provides a greater usable charge density.

## 2.3 Changes made to project plan

### 2.3.1 A second full-scale test launch scheduled for March 30th has been added to the project plan.

# 3. Vehicle Criteria

## 3.1 Design and Construction of Vehicle

### 3.1.1 Structural Design of Rocket

Core structural components of the rocket were made out of fiberglass. Fiberglass is a polymer structure, thus its elasticity and toughness allow it to withstand impact forces or abrasion. On landing, the rocket may experience high impact loads, and a fiberglass structure has the ability to stretch and gradually absorb the large amount of change in energy. Fiberglass is a workable material and allows for easy tailoring and implementation of our design at a less costly expense.

| Mechanical Property | Value in ksi |
| --- | --- |
| **Young's Modulus** | 2600 |
| **Tensile Stress** | 30 |
| **Flexural Stress** | 30 |

**Figure 6, Mechanical properties of fiberglass**

The structural design of the launch vehicle was developed using prefabricated body tube components available from Apogee Rockets. The use of prefabricated components enabled easier assembly while still maintaining exceptional strength and weight characteristics.

After multiple design iterations a consistent body tube diameter of 4" was chosen to sufficiently accommodate the payload and recovery systems. The length of the vehicle was set at 71.5 inches in to allow enough room for all payload components, including the antenna, to be housed within a single bay.

### 3.1.2 Epoxy Selection

After considerable research West Systems model 105 epoxy resin and 206 hardener were chosen to be used for joining body tube components and affixing fins. The West Systems brand was chosen for its high strength characteristics, compatibility with G10 fiberglass, and cost effectiveness. When necessary, the epoxy was thickened using colloidal silica to fill seams and develop fillets. Colloidal silica was selected based on its all-around strength characteristics across a wide range of viscosities. All gluing operations were done in accordance with the manufacturer specified procedures for preparation, mixing, and application.

### Handling characteristics

| | |
|---|---|
| Mix ratio by volume (300 Mini Pump ratio) | 5 parts resin : 1 part hardener |
| by weight | 5.36 : 1 |
| Acceptable ratio range by weight | 4.83 : 1 to 6.01 :1 |
| Mix viscosity (at 72°F) ASTM D-2393 | 725 cps |
| Pot life (100g at 72°F) | 20 to 25 minutes |
| Working time, thin film* | 90 to 110 minutes |
| Cure to a solid, thin film* | 10 to 15 hours |
| Cure to working strength | 1 to 4 days |
| Minimum recommended temperature | 60°F (16°C) |

**Epoxy cures faster at higher temperatures and in thicker applications.*

### Physical properties of cured epoxy

| | |
|---|---|
| Specific gravity | 1.18 |
| Hardness (Shore D) ASTM D-2240 | 82 |
| Compression yield ASTM D-695 | 11,500 psi |
| Tensile strength ASTM D638 | 7,300 psi |
| Tensile elongation ASTM D-638 | 4.5% |
| Tensile modulus ASTM D-638 | 4.60E+05 |
| Flexural strength ASTM D-790 | 11,800 psi |
| Flexural modulus ASTM D-790 | 4.50E+05 |
| Heat deflection temperature ASTM D-648 | 123°F |
| Onset of Tg by DSC | 126°F |
| Ultimate Tg | 139°F |
| Annular shear fatigue @ 100,000 cycles | 10,100 lb |

Figure 7, Properties of West Systems 105/206 Epoxy

| Uses—Use description—desired characteristics (Resin/Hardener mixture thickened with a Filler) | ADHESIVE FILLERS (Highest density, Highest strength ←) | | | | FAIRING FILLERS (→ Lowest density, Easiest sanding) | |
|---|---|---|---|---|---|---|
| | 404 High Density | 406 Colloidal Silica | 403 Microfibers | 405 Filleting Blend | 407 Low-Density | 410 Microlight™ |
| Bonding Hardware—Increased fastener interface and hardware load capability—maximum strength | ★★★★ | ★★★ | ★★★ | ★★ | | |
| General Bonding—Join parts with epoxy thickened to create a structural gap filler—strength/gap filling | ★★★ | ★★★ | ★★★ | ★★ | ★ | |
| Bonding with Fillets—Increase joint bonding area and create a structural brace between parts—smoothness/strength | ★★ | ★★★★ | ★★ | ★★★ | ★★★ | |
| Laminating—Bond layers of wood strips, veneers, planks, sheets and cores—gap filling/strength | ★★ | ★★★ | ★★★★ | ★★ | ★★ | |
| Fairing—Fill low areas and voids with an easily sanded surface filler/fairing compound—sandability/gap filling | | | | | ★★★ | ★★★★ |

Figure 8, Comparison of epoxy filler options

### 3.1.3 Nosecone Shape and Style

Since Eclipse is not designed to exceed supersonic speeds, the drag of the nosecone and the fins is not incredibly significant. A nosecone with a sharper point provides better aerodynamic properties to the rocket, but is not necessary for subsonic velocities.

| Shape | Ogive (hollow) |
|---|---|
| Thickness | 0.1180 In. |
| Length | 15.76 In. |
| Diameter | 4 In. |
| Material | G-10 Fiberglass |

Figure 9, Nosecone Geometry

### 3.1.4 Fin Shape and Style

Because the rocket is not traveling at supersonic speeds, the fins were designed for structural integrity rather than aerodynamic efficiency. The primary goal of designing our rocket is to achieve the mission statement of reaching an altitude of 1 mile. As such, it is important that the rocket maintains and follows the appropriate orientation and flight path. To ensure this, the design and implementation of fins on the rocket is crucial. The stability of the rocket is affected mostly by the center of pressure (cp) and center of gravity (cg) and their relation to each other in terms of distance.

| | RockSim | Measured |
|---|---|---|
| CG | 46.9731 In. | 41.21875 In. |
| CP | 56.2187 In. | |
| Cd | 0.35 | |
| Static Margin | 2.31 calibers | 2.375 calibers |

Figure 10, Fin Parameters

A stable rocket has the cp aft of the cg. Since the cg is fixed by the weight of the entire rocket, it was easier to alter the cp via the fins to ensure stability. The location of the cg and cp along the rocket from its nose to attain stability was determined to be 46.9 in. and 56.2 in respectively.

In order to maintain a desirable static margin, a trapezoidal planform area was selected for the fins. Another advantage to using straight-taper fins is to avoid fractures of the fins on landing. The root of the fins along the rocket's airframe is highly sensitive to stress, thus it is suitable to have a fin-shape that will avoid high contact with the ground upon impact. Although fins that are swept back prove to have some aerodynamic advantages, they are not structurally ideal in that they would be the first to hit the ground on landing, increasing chances of a fin breaking off. G-10 fiberglass was selected for the fins' material to reduce the chances of fracture in case the rocket were to land improperly such that a fin hit the ground first.

| | |
|---|---|
| **Count** | **4** |
| **Shape** | Trapezoidal |
| **Material** | G10 Fiberglass |
| **Thickness** | 0.125 In. |
| **Root chord length** | 5.5 In. |
| **Tip chord length** | 2.5 In. |
| **Sweep length** | 1.5 In. |
| **Sweep angle** | 16.314 deg. |
| **Semi Span** | 5.125 In. |
| **Tab length** | 5.5 In. |
| **Tab depth** | 0.887 In. |

**Figure 11, Fin Design**

To properly attach the fins to the rocket, fin slots are cut into the rocket's airframe. The fins were designed to go through the airframe such that they intersect with the motor bay. All connections will be glued using West Systems epoxy. To align and secure the fins during the curing process a custom fin jig was developed. Prior to assembly of the final rocket the accuracy of the fin jig and strength characteristics of the West Systems epoxy was tested on the prototype rocket.

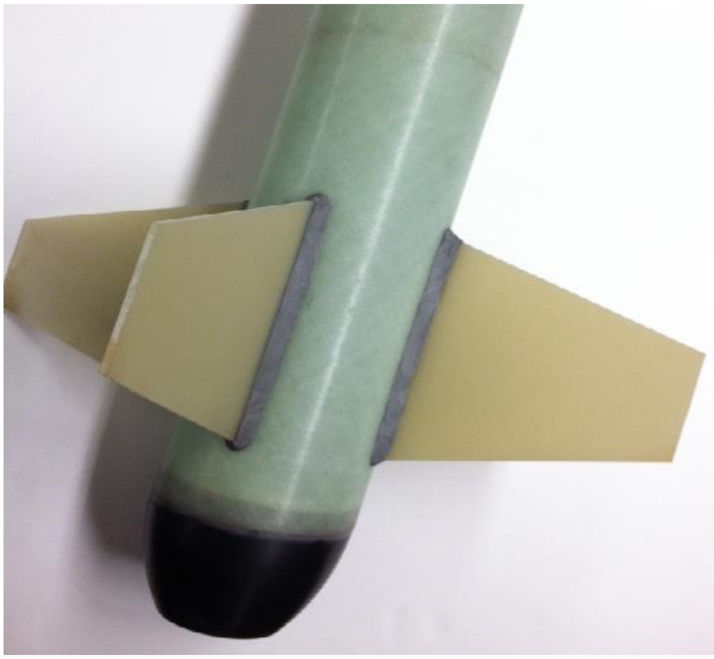

**Figure 12, Fin Attachment**

Figure 13, Fin Jig

### 3.1.5 Motor Mounting and Retention

To secure the motor and reduce form drag on the rocket an ogive tail cone was selected. The aluminum tail cone transmits the thrust of the motor directly to the outer body tube of the launch vehicle and thus prevents excessive loading of internal components. A fiberglass motor tube secured by centering rings surrounds the motor casing and restrains transverse movement or rotation.

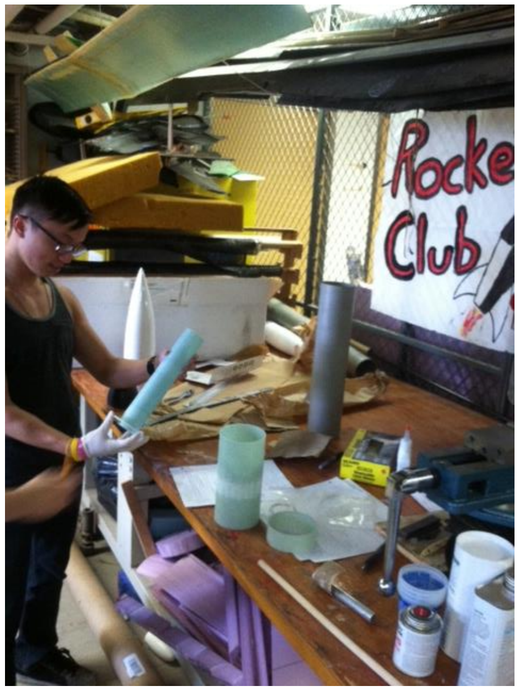


Figure 14, Motor Retainer Assembly

### 3.1.6 Mass Adjustment Capability

To accommodate for varying atmospheric conditions an adjustable ballast system was developed and installed within the nose cone. The system featured a steel plate attached to the nosecone bulkhead with two tapped holes to allow 5/8”-11 bolts to be inserted. The mounting location of the bulkhead within the nosecone was chosen to allow for bolts in excess of 8” in length to be inserted. This enabled a variable weight addition of up to 10% of the rockets launch weight. The exact weight added can be precisely controlled by selecting the length of the bolts to be inserted, with increments as low as 1.6 ounce to be achieved through the use of washers added beneath the bolt heads.

### 3.1.7 Assembly Considerations

To allow for rapid assembly and disassembly of the launch vehicle removable rivets were selected to secure the forward body tube and payload bay. The removable rivets provide sufficient shear strength characteristics to support structure and withstand pressure loading from ejection charges, while also exhibiting light weight and easy removal. Four ¼ inch removable rivets were used in both the attachment of the forward body tube and payload bay.

### 3.1.8 Electrical Design of Rocket

The rocket contains no electronic systems other than those incorporated in the recovery and payload systems. The details of these systems are presented in Section 3.2 Recovery Subsystem, and Section 4. Payload.

### 3.1.9 Construction and Assembly of the Rocket

Prior to assembly, all launch vehicle components needed to be cleared of any debris, such as fiberglass residue or dust. All joint locations were marked, such as location of centering rings inside the body tube and over the inner motor tube, and all bonding surfaces were roughened by sanding them with 60 grit sandpaper in a cross-hatch pattern. Prior to assembly a final cleaning was performed using denatured alcohol and the parts were allowed sufficient time to dryand cleaned. Samples from all epoxy mixtures used were kept and analyzed to ensure proper curing and strength.

#### Surface Preparation

Fiberglass surfaces to be epoxied were first prepared using 80 grit sandpaper in a +45º/-45º crosshatch pattern. After a consistent roughness was achieved across and surrounding the area to be epoxied, the surface was cleaned using a two stage process. In the first stage soapy water and a cotton cloth was used to remove all particulate debris from the surface that may remain after sanding. The surface was then dried with compressed air and allowed to sit at room temperature to ensure all moisture had evaporated. For the second stage the surface was wiped with denatured alcohol to remove all residue and oils. After a ten minute drying period epoxy was rubbed into the surface and the parts joined.

#### Airframe Assembly

First, the launch rail buttons were attached to the airframe. A straight line was drawn parallel to the body tube’s length such that it crossed the midpoint between two fin slots. Three holes were drilled: two 3/16 inch diameter holes for the rail buttons, and a single 1/8 inch hole for ventilation between the centering rings. The top launch rail button was placed 6 inches from the forward end of the body tube, and the bottom launch rail button was placed 2 inches from the aft end of the body tube, nearly aligned with the bottom of the fin slot. The launch rail buttons were then screwed onto weld nuts that were epoxied through the body tube

Locations on components to be joined to other surfaces were then prepared for epoxy to adhere to. Special care was taken with the assembly of the fins since they are at a location on the rocket most prone to large impact forces upon landing.

**Motor Retainer Assembly**

The centering rings were sanded as needed to ensure a tight fit in the body tube and to provide a rough surface for epoxy adhesion. Two centering rings were epoxied into the aft end of the outer body tube to support the motor casing. The top centering ring was epoxied 1.75 inches from the top of the inner motor tube; the bottom centering ring was epoxied 0.75 inches from the bottom of the inner motor tube. West Systems colloidal silica thickener was used with the epoxy mixture to produce fillets on the centering rings.

After all the internal connections supporting the inner motor tube had fully cured, the ogive tail cone was epoxied to the aft end of the body tube. Special care was taken in the preparation of the surface aluminum tail cone to ensure the surface was sufficiently rough to promote epoxy adhesion.

**Fins**

The fins purchased are made of G10 fiberglass. To properly install the fins onto the body tube, an alignment jig was made. The jig ensured that the four fins would be perpendicular to the rocket body surface and 90 degrees apart from each other. As with other rocket components, all bonding surfaces were roughened in a cross-hatched pattern using 60 grit sand paper. The fins were inserted through the body tube and glued onto the inner motor tube. Fillets were used to seal the bonds at the body tube and the inner motor tube. To ensure maximum bonding strength, the epoxy was left to cure for two days prior to additional construction on the rocket.

**Recovery Bay**

The recovery bay was assembled from a tube coupler that sits between the forward and aft body tubes. Bulkhead plates which seal the ends of the coupler were made from fiberglass and are restrained by 1/4"-20 all-thread rods which run the length of the recovery bay. The recovery electronics are mounted on a fiberglass sled which rides along the all-thread rods. Holes were drilled in the outside of the coupler to accommodate static ports and altimeter power switches. After completion of the recovery bay, holes were drilled through the body tube and recovery bay to support removable rivets used for quick assembly and disassembly of the structure.

**Payload Bay Construction**

The payload bay is the only structural component of the rocket not made from fiberglass. Although it supports some loading caused by the main parachute attachment, the loads are small enough to be safely carried by a standard cardboard electronics bay. The construction of the payload bay is similar to the electronics bay with bulkheads sealing both ends and being restrained by ¼”-20 all-thread rods. The electronics are mounted on a fiberglass sled within the bay which rides between the all-thread rods. Care is taken when assembling the rocket to ensure that the static ports drilled within the payload bay align with corresponding ports in the outer body tube.

### 3.1.10 Flight Reliability Confidence

Flight reliability is ensured through mission performance simulations, ground testing, and full scale flight tests conducted to date.

**Simulation**

Simulation results predict that the rocket will be able to achieve its mission requirements for all acceptable launch and weather conditions specified by the USLI handbook. Simulations were conducted across varying atmospheric conditions based on historical weather data for Huntsville Alabama. This tolerance study has led to the development of an adjustable ballasting system to fine tune the rockets performance to launch day conditions. Full scale flight testing has been used to optimize and confirm simulation results

### 3.1.11 Ground Test Results and Analysis

Ground testing has been conducted for the following systems:

1. Payload
2. Recovery
3. Structural

The procedures and results of the recovery system and payload system ground testing are presented in Section 3.2 Recovery Subsystem, and Section 4. Payload.

Structural testing was performed as part of the selection and verification process of the West Systems 105/206 epoxy specification and also to ensure the accuracy of the fin jig. Using the prototype rocket developed for the pre-CDR test flight, a non-destructive strength assessment was conducted on a fin prepared and epoxied in accordance with West Systems specification.

To test the epoxy and the application methods employed a fin from the prototype rocket was removed, prepared in accordance with West System's specifications, and then re-epoxied to the body tube while supported by the fin jig. After a cure period the rocket was removed from the jig and the fin was verified for straightness. It was determined that the fin jig performed exceptionally well. The fin was then subjected to both transverse and longitudinal loading and no observable defects or excessive deformation developed in the glued joints.

The process of applying the epoxy and producing smooth fillets on the fin was also evaluated and deemed a success, and therefore approved for the construction of the final launch vehicle.

### 3.1.12 Workmanship practices to enable mission success

To ensure precise and effective manufacture and assembly of the final launch vehicle and payload, vehicle and payload guidelines were developed. Proper assembly techniques mitigate risk due to unexpected component failures, thereby helping to ensure mission success. Guidelines regarding personnel safety and potential health hazards associated with the manufacturing and handling of rocket components are included in Section 5.2 Safety and Quality Assurance.

Structural Assembly

-Care will be taken to ensure no foreign contaminants such as oils or residues come into contact with any structural components, especially fiberglass, as it could result in modification of material properties and lead to material failure.

-All surfaces to be epoxied will be adequately prepared in accordance with manufactures instructions including but not limited to:

-Cleaning and drying of the surface with water, mild soap, and cotton cloth

-Roughing or scoring of the surface to promote adhesion using 60 grit sandpaper in a cross-hatch pattern

-Care will be taken to ensure that no sharp or foreign objects scratch, score, or otherwise modify any component of the structure during assembly or storage as this could create a fracture point leading to material failure

-Use of all epoxies will be in accordance with manufacturer's specification regarding ambient temperature, and humidity. Care will be taken to ensure no epoxied components are disturbed until after the specified cure time.

Aerodynamic Assembly

-Care will be taken to ensure that all external glue surfaces, such as fillets along fin connections, are made consistently and smoothly as to prevent the creation of excessive or unbalanced drag on the rocket. This may require sanding of fillet after the epoxy has fully cured.

Propulsive Assembly

-Care will be taken when assembling the motor and any other propulsive components to ensure conformance with all manufacturer instructions. Particular attention will be paid to the use of all O-rings and seals to ensure they are properly greased in accordance with specification.

-Care will be taken to ensure the ignition charge is correctly placed within the motor when installed on the launch stand. The ignition charge wires will be carefully connected to the launch system to ensure reliable electrical connection and prevent misfires or improper ignition. Furthermore a 'kink' will be placed in the wires shortly below the ignition charge to ensure the charge is pressed against the internal grain surface of the motor.

Recovery System Assembly

-Care is to be taken during the folding and insertion of the parachutes into the body tube to ensure reliable deployment. Parachute folding should always be performed under the supervision of the team's NAR level three certified mentor.

-Care is to be taken during the assembly of black powder ejection charges to ensure the correct quantity of black powder is included and minimize the chances of charges opening or falling apart due to vibrational or accelerative forces during launch. All ejection charge assembly should be performed under the supervision of or by the team's NAR level three certified mentor.

-Care will be taken in the assembly of all recovery system electronics to mitigate the risk of failure due to vibrational of accelerative forces encountered during launch. Furthermore, all static ports will be checked for correct sizing and adequate flow (no clogged ports) to ensure pressure based altitude measurements are performed correctly.

Payload and Electronics Assembly

-Care will be taken to ensure all functional components of the payload system are properly secured and assembled to prevent failure due to vibrational, accelerative, or impact forces encountered the vehicles flight.

-Care will be taken to prevent against any contamination of the sensors, (i.e. foreign substances obstructing the solar irradiance sensors lens) that could lead to incorrect or inaccurate measurements.

-Care will be taken in all electronics assembly to ensure proper wire connection and soldering procedures to reduce risk of failure due to corrosion, vibration, or thermal cycling.

-All payload readings and connectivity will be assessed for correctness while the rocket is in its final launch configuration on the pad before the launch is cleared to go.

Adherence to these guidelines is considered essential to prevent unexpected component failure and ensure all systems operate as designed.

**3.1.13 Safety and Failure Analysis**

Data showing risks are at acceptable levels:

1. Flights have been booked. Depart Sacramento at 6:00 AM on April $17^{th}$, 2013. Travel plans are set, risks of missing are low.
2. Data from last test launch shows a successful test with no failures. Nearly all of the same components and procedures will be used at competition.

**General Risks**

| Risk | Probability | Impact | Mitigation |
|---|---|---|---|
| **Travel Complications: Missed flights, Hotel Check ins** | Low | Delayed arrival to Huntsville, potential to miss competition entirely | Thorough planning and room for error (arriving 5 days before launch) |
| **Not receiving parts on time** | Low | Final design changes, affecting our projected altitudes | Verifying shipping times with distributor |
| **Final weight goal is not reached** | Medium | Lower than ideal altitude | 1. Keeping a conservative estimate for any potential weight savings<br>2. Checking all subteams for progress |

**Launch Operations Risk Assessment**

| Risk | Probability | Impact | Mitigation |
|---|---|---|---|
| **Black powder ignition prior to launch** | Medium | Large delay; disassemble rocket, reload charges and e-matches | Ensure both altimeters are OFF until the moments before launch |
| **Motor Ignition on launch pad** | Low | Fire on pad, launch before all systems are ready, possible injury to personnel | Proper inspection of motor, igniter; proper installation |
| **Fire on launch pad or on rocket** | Low | Damage to components, delay or cancellation of launch | Be meticulous in safety procedures with sensitive materials, have extinguisher ready. |
| **Fire in field underneath launch pad** | Low | Potential to become a serious fire, injuring people or damaging equipment | Ensure the metal shield on the launch pad is sufficiently large and well installed; have extinguishers on hand |
| **Launch components or tools are forgotten in CA** | Medium | Delays in rocket assembly or launch procedure | Create checklist of all parts, materials and tools needed. Organize all of these multiple days before departure |
| **Spectators are** | Low | Possible injury | Ensure all NAR safety |

| | | | |
|---|---|---|---|
| **too close to launch pad** | | | standards are known to spectators and are met |
| **Launch conditions are not ideal** | High | Altitude varying from projected 1 mile | Adjust ballast weight |

### 3.1.14 Full-scale testing and results

To date two full-scale launches have been performed.

| Launch Date | Launch Designation | Rocket Identifier | Structural Configuration | Recovery Hardware Configuration | Aerodynamic and Propulsive Hardware Configuration | Payload Hardware Configuration |
|---|---|---|---|---|---|---|
| **5-Jan-13** | Prototype Launch | Roxanne | Dimensionally identical to final configuration | No redundant altimeter. All else identical to final configuration | K513FJ-M Motor All else identical to final configuration | Mass Simulated |
| **2-Mar-13** | Full Scale Launch | Eclipse-1 | Final Configuration | Final Configuration | Final Configuration (K550W Motor) | External sensors excluded. All else identical to final configuration |

**Figure 15, Launch Configurations**

**Prototype Launch: January 5th, 2013**

The first launch was conducted on January 5th, 2013 in Farmington California in conjunction with the Livermore Unit of the National Association of Rocketry. The rocket used has been designated 'Roxanne'. The launch was conducted as a proof of concept of the design and to conduct a preliminary test of all launch vehicle systems in preparation for the Critical Design Review.

**Configuration**

*Structural Configuration*:

The structural configuration of the rocket was dimensionally equivalent to the final iteration of Eclipse-1 presented in Section 3.1.1 Structural Design of Rocket. The manufacture and assembly of Roxanne was less tightly controlled than for Eclipse-1. Use of epoxy clay and fast cure epoxies led to a minor structural failure of the altimeter bay bulkhead which was repaired onsite prior to launch using CA glue.

*Mass Configuration*:

The final launched mass of Roxanne was 15.28 lbf including a mass-simulated payload.

*Recovery Configuration*:

Altimeters

The prototype Flight test was conducted with only the Raven3 altimeter. The StratoLogger altimeter was unavailable at the time of the flight test. The Raven3 Altimeter was programmed for accelerometer apogee detection and main chute ejection at 832 ft, for an approximate main chute deployment altitude of 800 ft.

Recovery Harness

The configuration of the recovery harness was as follows:

The first section of harness consist of a pre-sewn 2ft long ½'' Kevlar harness that attaches to a u-bolt on the payload bay bulkhead (that's located in the aft body tube) via a quicklink connector. This section of Kevlar is connected to 15 ft of pre-sewn nylon harness via a quicklink connector. The 15 ft of nylon is attached to another segment of pre-sewn 2 ft long ½'' Kevlar via a quicklink connector. The final attachment point of the first section of harness is the Kevlar to the u-bolt on the altimeter bay bulkhead via a quicklink connector.

The second section of harness consist of a pre-sewn 2 ft long ½''Kevlar harness that attaches to a u-bolt on the altimeter bay bulkhead via a quicklink connector. This section of Kevlar is connected to 12 ft of pre-sewn nylon harness via a quicklink connector. The nylon harness terminates in the nosecone where it is attached to the u-bolt on the nosecone bulkhead via a quicklink connector.

Charge Placement

The drogue parachute ejection charge was placed between the altimeter bay and the drogue parachute to directly eject the parachute from the rocket

The main parachute ejection charge was placed between the parachute and nosecone to eject the nosecone from the rocket. The resulting momentum of the nosecone was intended to pull the main parachute from the rocket.

*Aerodynamic Configuration*:

All aerodynamic parameters were identical to the final launch vehicle. This includes placement, number, and sizing of all fins, nosecone, and tail cone.

*Propulsive Configuration*:

Based on initial simulations an Aerotech K513FJ-M motor was chosen for the prototype launch. Post launch assessment and review of the flight data indicated this motor selection to be undersized and has consequently been revised for the final launch configuration.

*Payload Configuration*:

The payload was simulated using a mass-equivalent payload bay model.

### Results

The launch was satisfactory with the exception of a main parachute deployment failure caused by incorrect ejection charge placement. Due to a minor structural failure of the altimeter bay bulkhead which was field repaired the main ejection charge was relocated beneath the nosecone in hopes of isolated the damaged bulkhead from ejection charge pressure and gasses. This unplanned change resulted in failure of the main parachute to deploy.

Results Summary:

| | | | |
|---|---|---|---|
| **Apogee Height** | | **4425** | **ft** |
| **Drift Radius** | | 3323.14 | ft |
| **Kinetic Energy** | | | |
| | Motor Burnout | 75120 | ft-lbf |
| | Drogue Descent (Average) | 676.7 | ft-lbf |
| | Landing | 588 | ft-lbf |

Figure 16, Prototype Flight Results

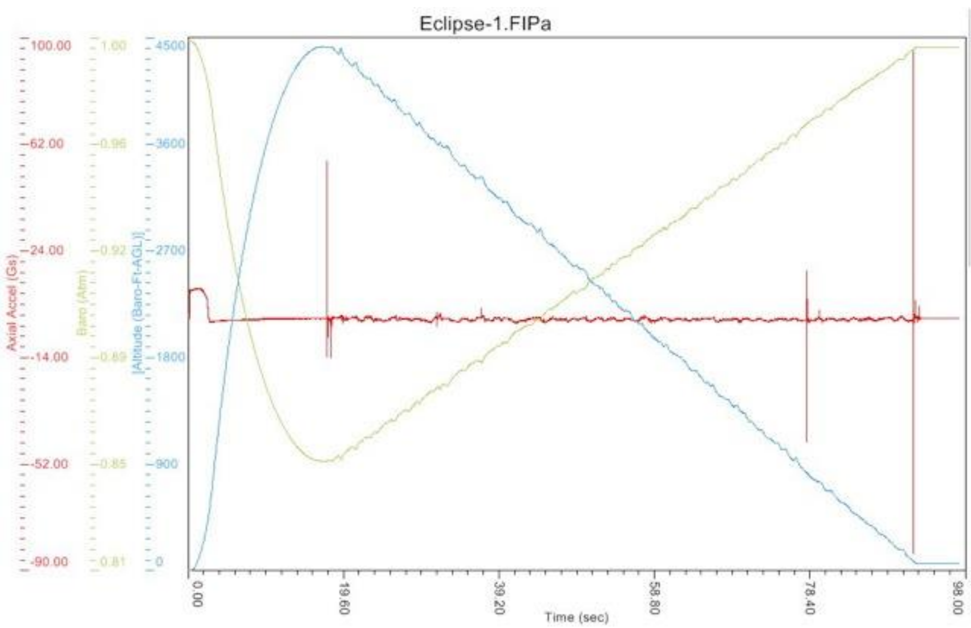


Figure 17, Flight Trajectory

| Parameter | Min | Max |
|---|---|---|
| Average PreLaunch Altitude (ft) | 32.00 | |
| Average PreLaunch Axial (Gs) | 0.98 | |
| Average PreLaunch Axial Offset | 0.96 | |
| Axial Accel (Gs) | -13.80 | 56.05 |
| Baro (Atm) | 0.8491 | 0.9988 |
| Current Draw (A) | 0.00 | 0.00 |
| Flight Count | 24.00 | |
| Lateral Accel (Gs) | -4.76 | 5.46 |
| Motor Ignition Time (sec) | 0.170 | |
| Temperature (F) | 68.30 | 68.78 |
| Time (sec) | 0.000 | 17.530 |
| Velocity (Accel-Ft/Sec) | -1 | 643 |
| Volts Battery (V) | 4.06 | 4.10 |
| Volts Pyro 3rd (V) | 4.06 | 4.08 |
| Volts Pyro 4th (V) | 4.10 | 4.12 |
| Volts Pyro Apogee (V) | -0.02 | 4.08 |
| Volts Pyro Main (V) | 4.04 | 4.06 |
| [Altitude (Accel-Ft)] | 0 | 5122 |
| [Altitude (Baro-Ft-AGL)] | 0 | 4425 |
| [Altitude (Baro-Ft-ASL)] | 32 | 4457 |
| [Velocity (Accel-Ft/Sec)] | 0 | 647 |
| [Velocity (Accel-MPH)] | 0 | 441 |

Figure 18, Flight Parameters

## Analysis

The launch results were considered satisfactory with a successful flight and recovery of the launch vehicle. The failure of the main parachute was easily identifiable and is easily correctable. More precise specification of correct manufacturing techniques, particularly in regards to epoxy use and surface preparation will help to prevent similar situations in the future.

Prelaunch:

At the time of the launch only preliminary launch procedures had been developed. Consequently the launch was performed under close guidance of the team's NAR mentor. Final preparation of the rocket including assembly of recovery system charges, parachute folding, and installation of shear pins was conducted on site prior to the launch. Hardware-In-Loop and parachute ejection testing which was performed on the recovery system to verify correct operation and charge sizing can be omitted or abbreviated in future launches now that the system has been verified. Throughout the prelaunch considerable time was spent learning the process and developing correct launch procedures for future use. Development of more complete procedures and specification of each team member’s role at launch will help to streamline the process.

Launch:

Since the prelaunch procedures ran longer than anticipated the rocket was launched approximately 10 minutes before the closure of the FAA sanctioned launch window. Due to time constraints the final launch angle of the rocket was not accurately set, and measurement of atmospheric conditions such as temperature, humidity, and wind speed were not determined. It is theorized that the excessive launch angle of the rocket contributed to the large drift radius measured. As a result these procedures have since been revised in the launch procedures to prevent oversight.

The ascent phase of the rocket operated as anticipated with the exception of an apogee altitude occurring at 4425 ft, 855 ft below the 1 mile prediction. The aerodynamic and mass models have subsequently been updated to accurately reflect the rockets behavior. As a result the motor selection was changed to the slightly higher impulse K550W model and an adjustable ballast system has been added to the nosecone of the launch vehicle.

Recovery:

The chain of events initiated by a minor structural failure that lead to failure of the main parachute deployment have been reviewed and will be avoided in future launches through tighter specification of manufacturing and launch operation procedures.

Post Launch:

Post launch procedures for the prototype flight test were not specified, and consequently resulted in incorrect data upload. Immediately following launch an attempt to upload the trajectory data measured by Raven3 altimeter was made. The data uploaded was in fact the results of hardware in loop simulations and consequently delayed the post launch analysis of the flight data until the error was identified and corrected. As a corrective measure more specific data upload procedures have been specified for future launches.

### Comparison to prediction

The results of the prototype flight test did not correlate well to the predicted altitude or drift radius determined through rocksim calculations. The source of this discrepancy was attributed primarily to weight and CAD model differences between the rocksim model and actual as-manufactured rocket. Since the launch condition data for the prototype rocket was lacking effort was instead redirected towards better preparation for the full scale launch.

## Full-Scale Launch: March 2$^{nd}$, 2013

The full-scale launch was conducted on March 2$^{nd}$, 2013 in Farmington California in conjunction with the Livermore Unit of the National Association of Rocketry. The rocket used has been designated 'Eclipse-1' and except for minor adjustments is the same vehicle that will be flown on launch day. The launch was conducted as a validation of design and manufacturing techniques and to test payload operation in flight.

### Configuration

*Structural Configuration*:

The structural configuration of the rocket was dimensionally equivalent to the final iteration of Eclipse-1 presented in Section 3.1.1 Structural Design of Rocket. The manufacture and assembly of Eclipse-1 was tightly controlled, specifically in regards to surface preparation and epoxy use.

*Mass Configuration*:

The final launched weight of Eclipse-1 was 17.56 lbf including the payload and motor.

*Recovery Configuration*:

Altimeters

The full-scale flight test was conducted with both Stratologger and Raven3 altimeters.  The Stratologger was configured as the primary and the Raven3 Altimeter was programmed for redundancy. This is the opposite configuration from what will be flown on launch day, but was chosen to simplify programming procedures. The parachute deployment settings were as follows.

| Altimeter | Designation | Parachute | Deployment Condition | Deployment Source |
|---|---|---|---|---|
| **Stratologger** | Primary | | | |
| | | Drogue | Apogee | Accelerometer |
| | | Main | 800 feet AGL | Barometric Pressure |
| **Raven3** | Redundant | | | |
| | | Drogue | 2 seconds post apogee | Accelerometer |
| | | Main | 775 feet AGL | Barometric Pressure |

**Figure 19, Recovery Configuration**

Recovery Harness

The configuration of the recovery harness was as follows:

Charge Placement

The drogue parachute ejection charge was placed between the altimeter bay and the drogue parachute to directly eject the parachute from the rocket

The main parachute ejection charge was placed between altimeter bay and main parachute.

*Aerodynamic Configuration*:

All aerodynamic parameters were identical to the final launch vehicle. This includes placement, number, and sizing of all fins, nosecone, and tail cone.

*Propulsive Configuration*:

Based on simulations and the results of the prototype test launch the Aerotech K550W motor was selected.

*Payload Configuration*:

The payload flown was the same configuration as will be flown on the final launch vehicle with the following exceptions.

-All sensors external to the ArduPilot Mega 2.5 were omitted (Solar Irradiance, Temperature, Relative Humidity).

-A 10.3 oz lithium-ion battery pack was used instead of the 4 oz one to be used in the final configuration.

## Results

The launch was considered a success with correct operation of all onboard systems and no damage sustained to the rocket. The source of discrepancy between the flight data and simulation predictions has been rectified, and it is expected that future launches should be able to reliably achieve our target altitude and drift radius.

Results Summary:

| | | | |
|---|---|---|---|
| **Apogee Height** | | **4765** | **ft** |
| **Drift Radius** | | 2501 | ft |
| **Kinetic Energy** | | | |
| | Motor Burnout | 103911 | ft-lbf |
| | Drogue Descent (Average) | 824.02 | ft-lbf |
| | Landing | 47.79 | ft-lbf |

Figure 20, Full Scale Launch Results

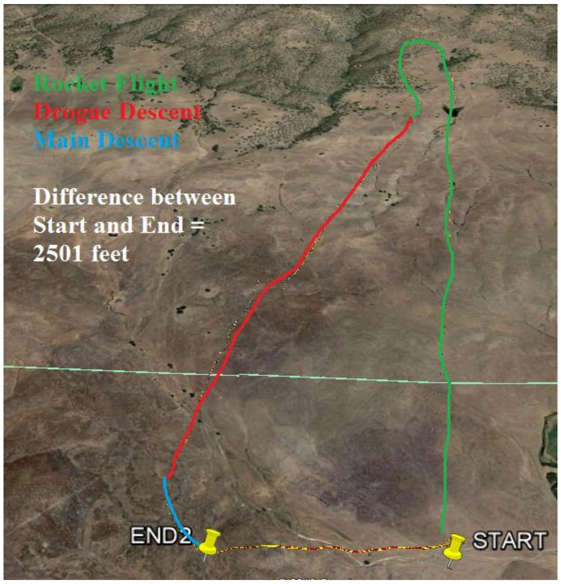


Figure 21, Rocket Trajectory

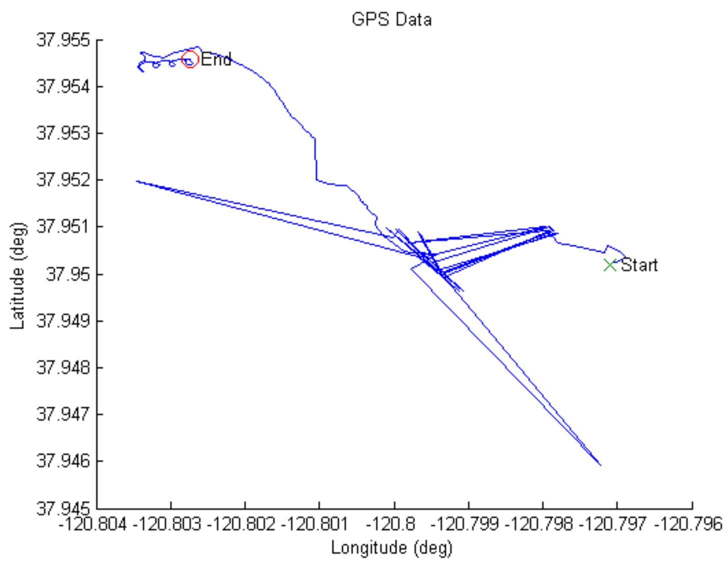


**Figure 22, GPS coordinates during flight**

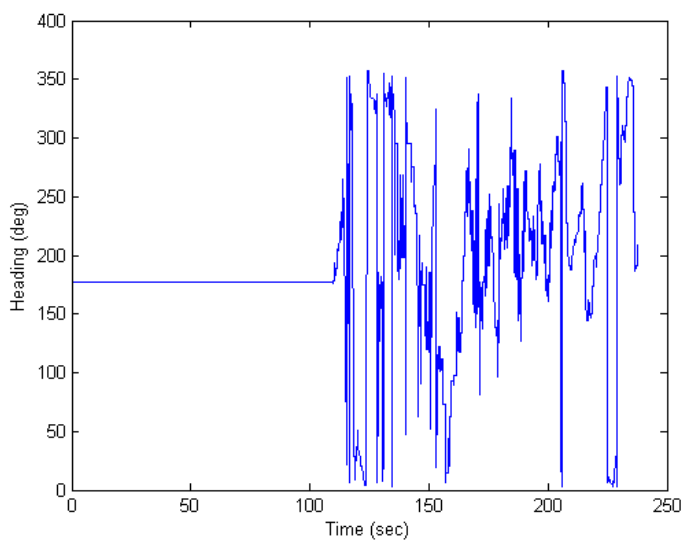


**Figure 23, Magnetic Heading**

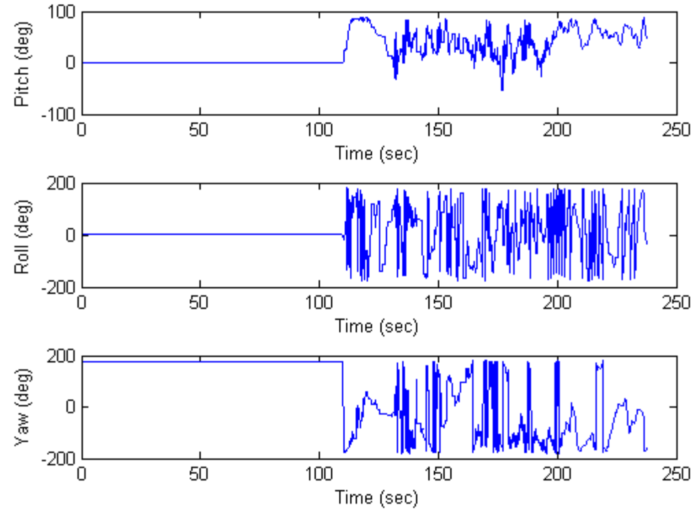


**Figure 24, Pitch, Roll, Yaw**

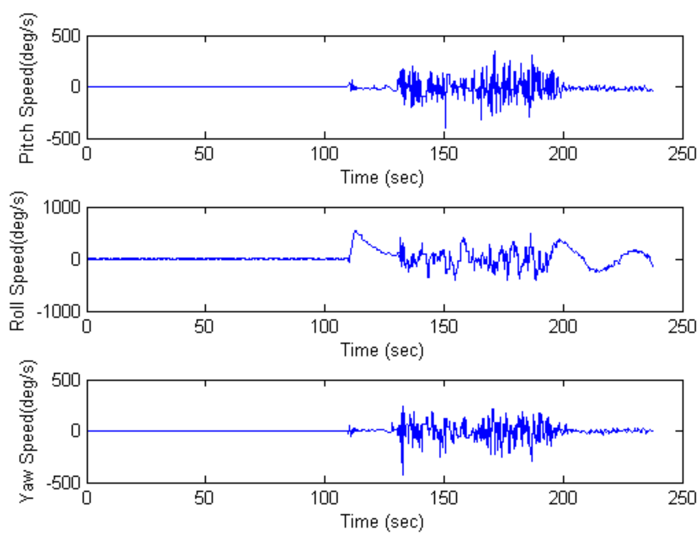


**Figure 25, Pitch Rate, Roll Rate, Yaw Rate**

## Analysis

The launch was considered successful with a successful flight and recovery of the launch vehicle. Incorrect mass predictions led to an excessively-ballasted launch configuration which resulted in a low apogee altitude. The mass accounting has since been updated and simulation results for the launch configuration now match the final altitude reached within a twenty-five foot tolerance.

Prelaunch:

Due to the development of prelaunch procedures from the prototype test launch the prelaunch phase of the full scale test launch was significantly expedited. The only concern was the difficulty in locating necessary components among all the tools and parts brought to launch. To remedy this specific organizers and tool sets devoted to each functional component of the rocket will be developed for subsequent launches.

Atmospheric conditions were recorded to a best approximation from nearby weather stations. The launch angle of the rocket was set using a two foot bubble level.

Launch:

The ascent phase of the launch performed satisfactorily with the rocket reaching an apogee height of 4765 feet AGL. The rocket had been excessively ballasted due to last minute changes to the payload configuration and incorrect measurement of component masses. As a corrective action the mass accounting of the launch vehicle has been revisited and the simulation models updated accordingly.

Despite concerns the payload system performed exceptionally with no interruption in GPS lock throughout the entire flight. Wireless data transmission from the payload to the ground station computer was maintained as long as the rocket remained in line-of-sight of the ground station. An interruption in data occurred immediately before landing as the rocket descended behind a hill. The use of higher gain antennas are currently being explored as a potential remedy for this.

Recovery:

The recovery system successfully verifed. It deployed all parachutes at the correct time. It was noted that the Raven3 altimeter ceased to log data following the activation of the redundant main parachute ejection is theorized that this is a result of a false triggering of the altimeters landing condition which stops data collection. The issue is currently being investigated further and a corrective action will be developed. It has been ruled out that the cessation of data logging was not due to a power failure or interruption.

Post Launch:

Using post launch procedures developed from the prototype launch the launch vehicle and specifically parachutes were properly dismantled and stored. Flight data from the Raven3 altimeter and payload systems were uploaded and analyzed. In addition to the trajectory data provided by the Raven3 altimeter, GPS coordinates and the three-axis dynamics of the rocket were available throughout the entire flight.

The Stratologger altimeter requires additional hardware to upload flight data. Since flight data between the payload and Raven3 altimeter is in agreement the additional data from the Stratologger is deemed unnecessary. Regardless, the data upload kit for the Stratologger has been placed on order and the Stratologger data will be used to further verify the flight data from the payload and Raven3 altimeter.

### Comparison to Predictions

Although the results of the full scale launch were closer to predicted results than those of the prototype launch, a significant altitude deviation still existed. Recent analysis has identified the source of the deviation to be a mass calculation error and the resulting simulations are now reaching within 25 feet of the actual apogee.

## 3.1.15 Mass Report and Deviations

### Weight Breakdown

The current mass breakdown of the launch vehicle and payload is presented in Figure 26, Weight Breakdown These weight measurements represent the as-manufactured weight of the final launch vehicle that was flown in the March 2$^{nd}$ full scale test launch, and that will be used on launch day. Minor changes to these values are expected as part of the weight reduction strategy presented below

| Component | Weight (lbf) |
|---|---|
| **Nose Cone** | 1.20 |
| **Forward Body Tube** | 1.48 |
| **Aft Body Tube (with fins and boat-tail)** | 4.00 |
| **Motor Casing** | 0.97 |
| **Main Parachute and Drogue Parachute** | 3.19 |
| **Payload** | 2.02 |
| **E-bay** | 1.56 |
| **Motor** | 3.34 |
| **Total:** | 14.41 |

Figure 26, Weight Breakdown

### Adjustable Ballast System

To accommodate for varying atmospheric conditions an adjustable ballast system was developed for the rocket. The ballast system allows for the rapid addition of ballast weight in 1.6 ounce increments from 0% to 10% of the rockets launch weight. Depending on the particular conditions present on launch day, the weight will be adjusted to optimize the performance of the rocket.

| | **Weight [oz (lbf)]** |
|---|---|
| **Worst conditions** | **253.0 (15.8125)** |
| **Best conditions** | **268.0 (16.75)** |

Figure 27, Ballast Range

### Weight Reduction Strategy

Based on the performance results of the March 2$^{nd}$ test launch, a minor weight reduction plan is currently being developed to optimize the vehicles performance. To achieve the target altitude under worst case scenario atmospheric conditions the plan has a targeted weight reduction of 25 ounces. Currently there appears to be strong potential for at least a 20 ounce reduction which will enable performance targets to be met for most atmospheric scenarios. The current weight reduction plan is as follows.

| **Component** | **Weight (lbf)** | **Est. Reduction (lbf)** |
|---|---|---|
| **Nose Cone** | 1.20 | -.188 |
| **Forward Body Tube** | 1.48 | 0 |
| **Aft Body Tube (with fins and boat-tail)** | 3.80 | 0 |
| **Motor Casing** | 0.97 | 0 |
| **Main Parachute and Drogue Parachute** | 3.19 | -.156 |
| **Payload** | 2.02 | -.500 |
| **E-bay** | 1.56 | -.375 |
| **Motor** | 3.34 | 0 |
| **Total:** | 17.56 | -1.219 |
| **Total after reduction:** | 16.33 | |

Figure 28, Weight Reduction Strategy

# 3.2 Recovery Subsystem

The Eclipse rocket will utilize a dual deployment recovery system with electronically activated ejection charges. The deployment process will consist of two stages. During stage 1, a drogue parachute is deployed at apogee. The main parachute is fully deployed at an altitude of 800 ft during stage 2. An advantage of dual deployment is that it minimizes drift by using a drogue chute that stabilizes the rocket and allows it to descend at a faster rate compared to the main chute.

### 3.2.1 Parachutes

The main parachute is the Iris Ultra 72'' made by Fruity Chutes. It is made out of rip stop nylon and has a rated descent rate of 20 fps for a 28 lb load. The Eclipse + casing weighs 12.63 lbf so we expect a slower decent rate. The shroud lines are 400 lb braided nylon and its connection point to the recovery harness is a 1500 lb swivel. The main parachute will be protected from the ejection charge gasses by a deployment sleeve and a nomex reusable fireproof parachute protector.

The drogue parachute is the Classic Elliptical 18’’ made by Fruity Chutes. Flight data from the Raven 3 altimeter test flight shows the drogue had a descent rate of 106 ft/s. The shroud lines are 330 lb braided nylon and its connection point to the recovery harness is a 1000 lb swivel. A nomex reusable fireproof parachute protector will protect the drogue parachute from the ejection charge gases.

### 3.2.2 Harness

The recovery harness tethers all of the rocket components together and helps absorb the energy of the components as they separate after chute deployment. The harness is split into two sections. The first section tethers the aft body tube + payload, the drogue chute + nomex chute protector and the altimeter bay coupler + forward body tube and nosecone. The second section tethers the altimeter bay coupler + forward body tube, the main parachute + deployment sleeve and nomex chute protector, and the nosecone.

The first section of harness consist of a pre-sewn 2ft long ½’’ Kevlar harness that attaches to a u-bolt on the payload bay bulkhead (that’s located in the aft body tube) via a quicklink connector. This section of Kevlar is connected to 15 ft of pre-sewn nylon harness via a quicklink connector. The 15 ft of nylon is attached to another segment of pre-sewn 2 ft long ½’’ Kevlar via a quicklink connector. The final attachment point of the first section of harness is the Kevlar to the u-bolt on the altimeter bay bulkhead via a quicklink connector.

The second section of harness consist of a pre-sewn 2 ft long ½’’Kevlar harness that attaches to a u-bolt on the altimeter bay bulkhead via a quicklink connector. This section of Kevlar is connected to 12 ft of pre-sewn nylon harness via a quicklink connector. The nylon harness terminates in the nosecone where it is attached to the u-bolt on the nosecone bulkhead via a quicklink connector.

Figure 29, Recovery Harness

All nylon segments are pre-sewn 11/16'' climbing grade, 3,000 lb, nylon.  All u-bolts are ¼'' zinc-plated steel that are attached to bulkheads by securing them with nuts and west systems epoxy with colloidal silica to ensure a permanent connection.  All quicklink connectors are 9/32'' zinc-plated 1,000 lb steel.

Instead of using Kevlar for the full length of the harness, it is used in 2 ft long segments in locations where the harness will be exposed to ejection charge gasses.  Climbing grade nylon is used for the remaining sections because its location allows it to be protected by either a nomex chute protector or a deployment sleeve and because nylon takes up less volume compared to Kevlar. Also, nylon is less expensive compared to Kevlar so it is more cost effective to only use Kevlar in segments that will be exposed to ejection charge gasses since Kevlar is heat resistant.  Another added benefit of using segments of nylon is that nylon is more shock absorbing compared to Kevlar so it will relieve some stress on our bulkhead attachment points.  Both segments of harness were designed to be as long as possible to allow the rocket components more time to decelerate after separation, thus reducing the force exerted on the bulkheads and points of attachment.

To prevent the recovery harness from tearing through the body tube in the event of a mistimed drogue deployment or during the main chute deployment, layers of guerilla tape are wrapped around the harness sections that will come into contact with body tube edges.  These layers of tape will help spread the load over a larger area and ensure that the harness will not tear.

### 3.2.3 Altimeters

The altimeters record flight data such as altitude, pressure, axial and lateral acceleration, flight duration time, velocity and temperature as well as ignite electrical matches that detonate ejection charges.  The main altimeter is the Raven 3 made by Featherweight Altimeters and the redundant altimeter is the StratoLogger made by PerfectFlite ( See Figure and Figure respectively).

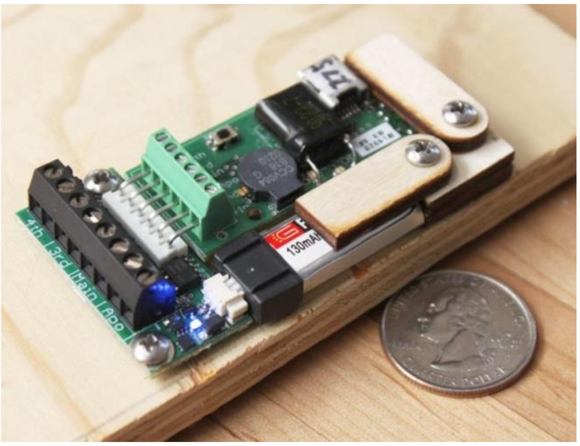

Figure 30, Raven3 Altimeter

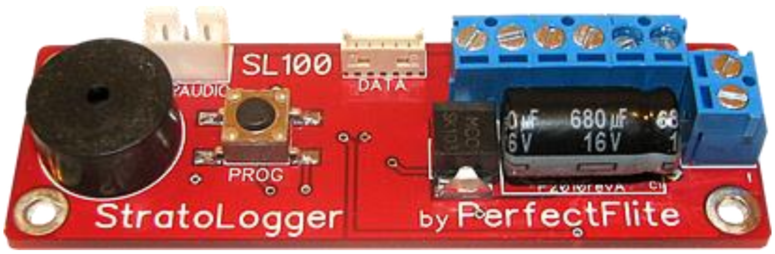


Figure 31, Stratologgger Altimeter

The Raven is programmed for accelerometer apogee detection and an apogee time delay will be set for the StratoLogger to avoid over pressurization and large loads on the recovery harness attachment points.

Main chute deployment is programmed for 832 ft for the Raven and the StratoLogger can be programmed in 1 ft increments to fire after the Raven to avoid over pressurization. The altimeters and the recovery system wiring diagram is shown in Figure 32.

The Raven is powered by one 3.7 V LiPo battery and is armed from the exterior of the body tube when the rocket is in the final launch configuration on the launch pad by a magnetic arming switch. The StratoLogger is armed from the exterior of by a physical switch and is powered by one 9 V battery. The Raven has a pad life of about 2.5 hours and the StratoLogger can stay powered for multiple days.

**Recovery System Wiring**

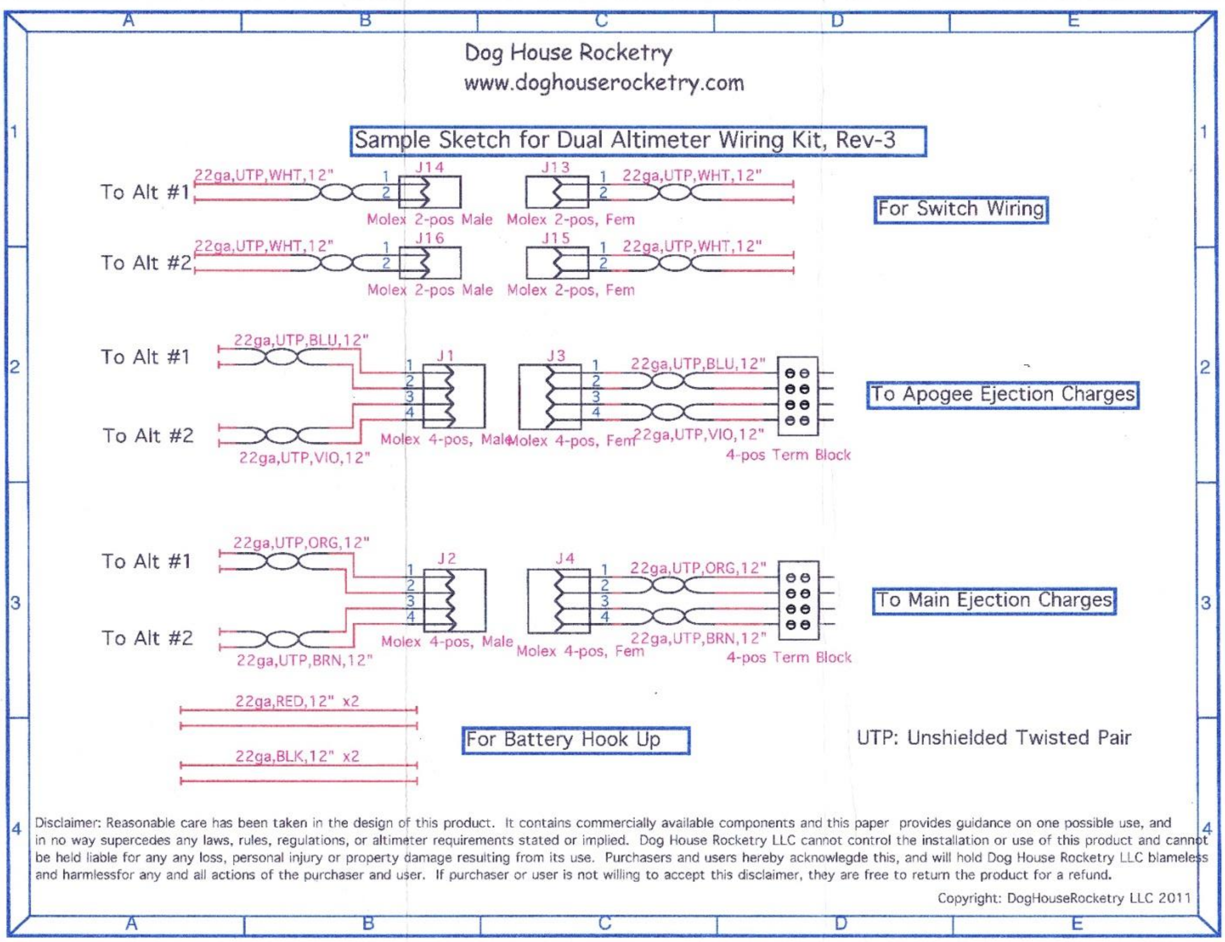


Figure 32, Recovery System Wiring

## Recovery System Failure Modes

| Function | Potential Failure Mode | Probability | Mitigation |
|---|---|---|---|
| **1** | Altimeter fails to ignite eject charge | Medium | Take care to wire altimeter bay correctly. Use fresh batteries. Add steps in pre-flight checklist to ensure we arm altimeters. Include a redundant altimeter and redundant ejection charges |
| **2** | Altimeter is not programmed correctly or is not calibrated. | Medium | Add steps to pre-flight checklist to ensure altimeter is calibrated and programmed correctly. To ensure altimeter is correctly programmed, run altimeter through test flight on computer and see if it powers the correct terminal connections at the correct time. |
| **3** | Ejection charges are not powerful enough to separate rocket. | Low | Perform ground testing to determine the amount of black powder necessary. |
| **4** | Failure of recovery harness attachment points | Medium | Test attachment points under a load to ensure they're strong enough. Apply epoxy to u-bolt threads. Use u-bolts and quick links to ensure a strong connection. |
| **5** | Power supply detaches and electronics fail | Low | Tightly secure batteries to electronics board. |
| **6** | Ejection charge fires too early or too late, potentially deploying the recovery harness while rocket is moving too fast, causing the harness to rip through the body tube | Medium | Take care in sizing static ports correctly to ensure pressure inside altimeter bay is equal to ambient pressure. Ensure altimeter bay isn't placed near fins or nosecone where turbulent air can cause unequal pressure between alt. bay and ambient air. Wind layers of guerilla tape around areas of harness that will come into contact with body tube edge. |
| **7** | Drogue ejection charge separates nosecone at apogee, deploying the main chute and potentially causing our rocket to drift too far | Low | Use plastic or nylon shear pins to keep nosecone attached until main ejection charge fires. Add step in pre-flight checklist to ensure shear pins are attached. |

| | | | |
|---|---|---|---|
| **8** | Booster section separates during upward ascent due to drag. | Low | Use plastic or nylon shear pins to keep booster section attached until drogue ejection charge fires. Add step in pre-flight checklist to ensure shear pins are attached. |
| **9** | Rocket drifts too far away or rocket drifts too far away and is lost. | High | Conduct detailed flight simulations using RockSim to accurately size parachutes, determine at which altitude to deploy the main, and predict drift for 15mph winds. Utilize a GPS transmitter. |
| **10** | Ejection charge gases damage terminal connections on altimeter bay bulkheads, any other part of bullheads or damage altimeters by entering altimeter bay. | High | Protect terminal connections by covering them with tape and fill all small openings leading into the altimeter bay with painter putty. |
| **11** | Ejection charge gases damage parachute or recovery harness | Medium | Carefully wrap drogue chute and nylon portion of harness in nomex chute protector. Carefully wrap main chute in deployment sleeve and in nomex chute protector. Use small sections of kevlar for the areas of the harness that are close to ejection charges. |

## 3.3 Mission Performance Predictions

Mission performance is predicted using RockSim simulation software to determine maximum altitude and drift radius for different atmospheric conditions. The development of an accurate model has been a challenging task but augmented with actual results from the full scale launch a fairly accurate model has been developed.

| | Distance from nose tip (inch) |
|---|---|
| RockSim CG (without ballast) | 43.3202 |
| CP | 56.2187 |
| Static Margin (without ballast) | 3.22 Caliber |

Figure 33, CG and CP

Wind Speed Simulations and ballast optimization

| | Launch conditions | | | | | | comments |
|---|---|---|---|---|---|---|---|
| **Ballast (lb)** | Launch angle (deg) | Temperature (deg. F) | Wind (mph) | Humidity | altitude (ft) | range (ft) | |
| **1.49615** | 0 | 62 | 0 | 66.5 | 5283.14607 | 0 | avg condition no wind |
| **1.49615** | 0 | 50 | 0 | 66.5 | 5247.02611 | 0 | low temp |
| **1.49615** | 0 | 74 | 0 | 66.5 | 5319.56594 | 0 | high temp |
| **1.49615** | 0 | 62 | 5 | 66.5 | 5258.28806 | 255.4363 | low wind |
| **1.49615** | 0 | 62 | 10 | 66.5 | 5182.92917 | 530.80216 | medium wind |
| **1.49615** | 0 | 62 | 15 | 66.5 | 5059.34036 | 833.78145 | medium-high wind |
| **1.49615** | 0 | 62 | 20 | 66.5 | 4893.8837 | 912.8995 | high wind |
| **1.25** | 0 | 62 | 10 | 66.5 | 5281.86847 | 518.33999 | optimal medium wind |
| **1** | 0 | 62 | 15 | 66.5 | 5258.63233 | 599.92591 | optimal medium-high wind |
| **0.6** | 0 | 62 | 20 | 66.5 | 5258.12428 | 1148.52295 | optimal high wind |

Figure 34, Ballast Adjustments

## 3.3 Vehicle Requirement Verification

| Launch Vehicle Requirements | Implementation | Verification |
|---|---|---|
| **Stability of rocket** | Ballast weight and appropriate fin size | RockSim & analytical calculations |
| **Reach altitude of 5280 ft AGL** | K550W motor | RockSim and test launches |
| **Barometric altimeter reports altitude by series of audible beeps** | Recovery Altimeters | Testing |
| **Recoverable and reusable** | Drogue and main parachute/robust airframe | RockSim calculations, precisely controlled manufacturing techniques, and testing |
| **Impact energy less than 75 lbf-ft** | Drogue and main parachute/main deployment altitude | RockSim & testing |
| **Drift range less than 2500 ft in a 15 mph wind** | Drogue and main parachute/main deployment altitude | RockSim & testing |
| **Solid motor** | K550W motor | Inspection |
| **Maximum impulse remains under 2560 Ns.** | K550W motor | Inspection |
| **No forward canards** | Structural and aerodynamic design | Inspection |
| **No forward firing motors** | Structural and propulsive design | Inspection |
| **No motors which expel titanium sponges** | Propulsive design and motor selection | Inspection |
| **No hybrid motors** | Propulsive design and motor selection | Inspection |
| **No cluster of motors** | Propulsive design and motor selection | Inspection |
| **Official altitude-determining altimeter shall be capable of being turned off** | Magnetic and external power switches | Inspection |
| **Launch vehicle shall remain subsonic from launch until landing** | K550W motor | Rocksim & testing |
| **Launch vehicle shall have a maximum of four independent sections** | Design | Construction |
| **Launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours** | Design | Test and Inspection |
| **The vehicle shall be compatible with either an 8 feet long 1 in rail, or an 8 feet long 1.5 in rail** | Design | Inspection |
| **Launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system** | Design | Test and Inspection |
| **Launch vehicle shall require no external** | Design | Inspection |

| | | |
|---|---|---|
| **circuitry or special ground support equipment to initiate launch** | | |
| **The amount of ballast, in the vehicle's final configuration, shall be no more than 10% of the unballasted vehicle mass** | Design and assembly | Inspection |

| Mission Success Requirement | Verification |
|---|---|
| **Reach altitude of 5280 ft AGL** | Altitude measurement from onboard barometric pressure and accelerometer sensors |
| **Must remain strictly under 5600 ft AGL** | Altitude measurement from onboard barometric pressure and accelormeter sensors |
| **Rocket recoverable with no sustained damaged, and capable of performing additional launches within the same day** | Visual and mechanical inspection |
| **The maximum amount teams may spend is $5000** | Expense accounting and bookkeeping |

## 3.4 Safety and Environment (Vehicle)

The team's safety officer Alejandro Pensado Valle will oversee all construction and launch operations of the vehicle. He is knowledgeable and prior experience with rocketry. He will provide oversight over the final construction of the rocket.

Safety precautions have been taken both with the rocket and with the project as a whole. All anticipated risks are accounted for and mitigations planned in order to help carry out the project efficiently and smoothly. Several failure modes for the payload and the propulsion system are also observed in detail, as seen in **Error! Reference source not found.** and **Error! Reference source not found.**.

The risks of delivering the Eclipse on time lie on the availability of materials and on the amount of time that team members can give to the project. The team currently has very dedicated members who manage to work on the "Eclipse" project as well as focus their attention to upper division engineering classes. The risks specifically lie in electronic malfunction; therefore we have planned out to test these components thoroughly before assembling the final rocket.

## 3.5 Payload Integration

The payload electronics is a completely self-contained and sealed unit. No external wiring is needed and a power supply was integrated into the design. The bay itself was designed to have a clearance fit with the rocket body of 1mm or less. This helps keep the payload snug, but still allows for easy removal and installation.

The payload is secured to the rocket body using 4 removable nylon rivets. The rivets have been tested and proven successful under the loads the payload will undergo due to drogue parachute deployment. The drogue parachute is attached to the payload bay via a quick link to U bolt connection in the forward bulk head. The hardware has been tested and was successful during a test flight on March 2nd. No sign of failure or problems occurred during the launch.

Finally, within the payload bay, all the ardupilot motherboard has been programmed to read all external analog and digital sensors, compile the data, and send it as a serial data stream to the ground station for further analysis. Protocols have been added to recognize possible loss of data due to the high g-force loading the rocket undergoes. Testing on March 2nd showed we received no dropped data bits and maintained signal lock while the rocket remained in line of sight (not behind any barriers).

# 4. Payload

## 4.1 Experiment and Concept

The experiment conducted in our payload it twofold: measuring atmospheric conditions and its changes with respect to altitude, as well as measuring the rocket's dynamic behavior. Both parts of the experiment are conducted by the custom Arduino microcontroller (the ArduPilot). This is rather creative in that we are using a microcontroller, which is manufactured to be used as an autopilot, as a data acquisition system instead, and are using its input/output capabilities to implement external sensors (e.g. temperature or solar irradiance) to conduct an experiment on the atmosphere, as well as using its integrated onboard sensors to conduct an experiment on our rocket's dynamic behavior. Furthermore, the significance of our experiment is also twofold. With respect to the atmospheric measurement, we can compare our data to predicted models for accuracy, as well as implement our rocket for long-term use in order to obtain atmospheric data over a large period of time to observe trends. Moreover, measuring our rocket's dynamic behavior allows us to confirm the design, performance, and simulations of our rocket, but also gives us insight into unforeseen perturbations and off-design conditions that we would not otherwise notice without the critical data from our payload.

## 4.2 Science Value

The objective of the payload is to collect atmospheric data, as well as the rockets dynamic behavior, as the rocket completes in trajectory. Atmospheric conditions need to be constantly monitored to predict short-term and long-term weather patterns, therefore, the ability to accurately measure atmospheric data is essential. Measuring a rocket's dynamic behavior is also important for improving our rocket's design, and well as verifying its predicted performance.

With respect to atmospheric data, the payload will be measuring pressure, temperature, relative humidity, and solar irradiance as a function of altitude. Even further, the rocket will also be measuring its own velocity and acceleration (linear and angular), as well as its position via GPS.

When collecting atmospheric data, we hypothesize that:

- Air density, pressure, and temperature will decrease linearly with altitude, in accordance with the U.S. standard atmosphere, as the rocket ascends and descends in the troposphere.
- As temperature decreases, water within the atmosphere will condense into liquid form, thus increasing the relative humidity.
- Since air has a non-zero absorptivity with respect to the solar wavelengths being measured, we expect that as the density decreases with altitude, solar irradiance will increase.

To test our hypothesis, we will be conducting numerous ground and air tests on our payload, and compare said data to our hypothesis, previously published data, and our own mathematical models. To ensure accuracy of our measurements, we will be using our own data, as well as experimental controls of known pressure, temperature, irradiance, and humidity, in order to calibrate our sensors and decrease experimental error. We also have other sensors onboard in recovery the system, which will allow us to compare certain measurements, such as pressure and acceleration, and therefore allow us to diagnose sources of error.

## 4.3 Payload Design

The payload has been designed with ease of access and efficiency in mind. The payload itself sits above the motor casing and below the drogue parachute in the rocket. Its overall length is the 8.12 inches, which is the minimum length needed to fit 3DR transmitter securely inside the bay. The shell of the payload bay is made strong spiral wound kraft tubing, with end caps machined from G-10 fiberglass. A U bolt is secured to the forward bulkhead of the payload bay which is used to connect the drogue parachute to the rocket body. The payload bay is then secured to the rocket body with removable nylon rivets. Testing confirmed both the kraft tubing, fiberglass end caps, and removable rivets can all safely handle the loads sustained during drogue parachute separation and decent of the rocket.

The payload bay itself is completely self-contained. Power is received from an aluminum encased 2600 mAh power supply that has been modified for high g-force loading. The modifications including re-soldering joints to eliminate solder joint cracking and separation as a possible mode of failure. The power supply sits directly below and mounts to the payload fiberglass sled. In addition, testing confirmed at maximum power the current draw from the payload is roughly 200mAh. Therefore, the battery chosen is more than sufficient to power the payload until it is launched.

The payload electronics sits elevated over the fiberglass sled on vibration reduction silicone mounts. The mounts help to alleviate the intense vibrations and possible shocks induced by the motor during accent. Additionally, a second level has been added to the fiberglass sled for the additional sensors that will be added.  The second level mounts directly to the original sled using aluminum risers and an additional fiberglass sled as a setting board.

The sled holding all of the electronics was constructed from of G-10 fiberglass. It includes brass rails secured using epoxy. Threaded rods pass through the brass rails to constrain the payload to moving in vertical directions. Furthermore, the threaded rods were machined and tapped to allow screws to pass through threaded and brass rods and into the bottom of the aluminum risers. This constrained to the board to allow for zero movement. The threaded rods are secured to the upper and lower fiberglass bulkhead of the payload bay and the unit is completely sealed from the rest of the rocket internals. Finally, two ¼” static port holes were drilled into the sides of the payload bay to allow for sensors to monitor temperature, humidity, and barometric changes.

The avionics payload will consist of the ArduPilot Mega 2.0 (APM 2.0) as a data acquisition system with the ATMega 2560 as the core processor. Its flexibility in programming combined with the built-in sensors make the APM 2.0 the best choice for the payload application. Within the APM 2.0 motherboard, sensors that will be utilized are the digital compass, 3 axis gyro, and daughterboard GPS unit. Additionally, the team will incorporate external sensors to measure solar irradiance, relative humidity and ambient temperature. Also, the team will couple the APM 2.0 with a 915 MHz transmitter that will provide a display of real time data to a laptop ground station.

As stated, the payload data acquisition system is the based around APM 2.0 embedded system. Included on the APM 2.0 board is a Honeywell HMC5883L-TR digital compass, a 6-axis MPU-6000 inertial measurement unit (3 axis gyroscope + 3 axis accelerometer), and MS5611barometric pressure sensor. An additional daughterboard which will be mechanically isolated from the airframe to reduce g-load exposure features a MediaTek MT3329 GPS module. All sensors will be sampled at a period of no more than 5 seconds. Analog sensors not mounted within the APM 2.0 board will also feature a hardware implemented low pass filter to reduce EMI interference caused by the wireless transceiver and other external noise sources. Custom firmware running on the APM 2.0 board will assemble measurements from all sensors into discrete packets which will be both wirelessly sent to a ground station, and logged in onboard non-volatile memory. Wireless transmission protocols will be developed to feature redundancy and error checking, with the ability to resend any dropped packets using those stored in memory. The firmware will optimize the sampling rate of each sensor to allow for sufficient averaging and signal processing to remove noise and increase measurement fidelity.

A ground station will be implemented via the modification of open source software (QGroundControl) to receive and parse the wireless data transmitted from the rocket. The communication protocol implemented between the ground station and the rocket will feature sufficient redundancy to allow the extraction of all measured data from the rockets onboard nonvolatile memory in the event a packet is dropped or communication is temporarily interrupted. Data will be displayed as graphs and will be exportable in the form of a comma separate value list which can be used for subsequent post-processing.

The team has selected to develop a modified version of -the SMD payload, titled the Rocket Performance and Atmospheric Evaluation Module (RPAEM). This module will perform the following tasks:

i. The RPAEM will measure atmospheric temperature, static pressure, relative humidity, solar irradiance, acceleration, angular velocity, and GPS location through all phases of operation (preflight, launch, ascent, descent, landing, and post-landing), with the following exception:

a. Due to high velocities and accelerations, the GPS may not be able to maintain a satellite lock throughout launch and ascent. If this occurs, it will relock at or before landing and return to normal position sampling.

ii. All measurements will be taken at least once every 5 seconds throughout all operation phases, unless the exception above holds true.

iii. The data from the RPAEM will be both continuously transmitted to a ground station and logged in onboard memory. If wireless communications are interrupted any lost data will be retransmitted from the data stored in memory.

iv. The RPAEM will remain enclosed within the main body tube of the rocket throughout all operation phases, which will remain tethered to all other structural sections before, throughout, and after parachute deployment.

v. The RPAEM will be configured in such a way to ensure data is recorded throughout all flight phases, and to ensure that data from all flight phases will not be lost or overwritten due to memory, power, or other electrical resource constraints.

## 4.4 Payload Verification

The payload design has been verified both through independent ground testing and flight testing. The ground testing has consisted of sensor calibrations, communications testing, and range testing. In the air communications testing has been frequently used to ensure the GPS does loose lock or exceed the radios usable radius.

.

## 4.5 Safety and Environment (Payload)

The integration of the payload into the launch vehicle has been designed to minimize the risks of physical damage to the payload electronics by exposure to extreme environments encountered in rocketry. Although physically located close to the motor, both the propulsive system and payload bay have been designed to physically and thermally isolate the payload electronics. Since all electronics are completely contained within the payload bay there are no opportunities for foreign contaminants to ingress, with the exception of through the static ports. Consequently, care will be taken to ensure the static ports are remain clear and are protected during handling and storage of the rocket. The electronics of the payload have been designed to maximize robustness through the use of the APM 2.0 which contains nearly all sensors on a single platform. Additionally, the APM 2.0 board has been mounted with vibration reduction silicone mounted to mitigate possible impact and vibration damage sustained during flight. The additional sensors will be mounted securely on a fiberglass board directly above the APM 2.0. The piggy back mounting style method is effective in decreasing weight and wiring length that could give signal instability due to vibration loading during flight. Longer wires would have a higher probability of noise interference during the flight of the rocket. Finally, the battery supply itself is a 2600mAh lithium polymer battery encased in an aluminum alloy. It is highly resistant to impact and vibrational loading; however, to ensure power loss is not an issue, solder joints in the main circuit were re-soldered and checked. Re-soldering helps to minimize the risk of solder joint cracking during the flight of the rocket, which could lead to power failure.

# 5. Launch Operations Procedures

## 5.1 Launch Checklist

The priority for launch operations is configuring all components and launch factors in a way to achieve maximum height. Our launch tests have gotten us within approximately 500 feet of a mile, and we are hoping to hit the mile mark in future tests. Achieving this will require changes to our rocket’s weight and aerodynamics, but also perfection in launch operations. For example, any small mistake in launch angle or blemishes in aerodynamic surfaces will lower apogee by some amount. So the Launch procedure must focus on maintaining condition conducive to the highest possible apogee.

1. Prior to  launch
    a. Ensure all components are ready for launch.
        i. Check with QC Lance to confirm all systems are adequately prepared.
        ii. Perform ground testing of ejection charges.
        iii. Organize supplies needed on launch day: Shear pins, removable rivets, e-matches, black powder charges and casings, motor casing and clip, motor (K550), *fully charged* altimeter batteries.
        iv. Tools needed on launch day: Level (to achieve vertical launch), two fully charged computers with BOTH altimeters software installed (Raven 3 FIP, and Stratologger Perfectflite) along with appropriate cables, rags and solution to clean exterior surfaces

1. Recovery
    a. Ensure both altimeters have been programmed by recovery team appropriately, and any necessary ground tests have been performed.
        i. Raven Three will serve as primary altimeter, set to deploy drogue at apogee and main at 700 feet. Programmed using the FIP interface. Stratologger will act as secondary altimeter, firing the backup drogue charge on a 2 second delay and the backup main charge at 650 feet.
        ii. Test both altimeters for proper functioning, substituting LED lights for black powder charges in terminals. Featherweight provides a program for this purpose; stratologger can be set to 6 feet above ground level in order to run a simulated flight.
    b. Ensure all connections have been properly made between altimeters and black powder charges, batteries and switch (stratologger only).
    c. Black powder charges must be oriented correctly relative to the packed drogue parachute. The altimeter bay (important to ensure there are no pathways for gas to enter) is then inserted on top of drogue chute with charges below the chute.
    d. The final pair of charges lies on top of the altimeter bay, with the packed main chute sleeve on top of this.
2. Motor preparation/Igniter Installation
    a. Insert motor into motor casing, and install igniter. Install assembly into motor tube.
    b. Secure retainer clip onto motor tube
    c. More to come, was doing something else on launch day.
3. Setup on Launcher
    a. Bend the 8ft, 1 Inch rail to near horizontal and insert the two launch lugs, sliding the rocket down to the base
    b. Once upright, take care to level the launch pad precisely. A 90-degree launch angle is essential to reaching 1 mile. This is done using an electronic level and adjustable platforms under each leg of launch pad.

4. Launch Procedure
    a. Verify that payload team is receiving data
    b. Switch both altimeters on, listen to beep responses to ensure they are functioning properly
    c. Final launch angle check and condition check
    d. Launch
5. Troubleshooting
    a. Discuss payload troubleshooting
    b. Altimeter problems will be identified before installation into rocket, and thus troubleshooting will happen through their respective softwares. IF STRATOLOGGER'S HARDWARE FAILS, Raven 3 can be set to deploy all 4 charges, with delays.
6. Postflight inspection
    a. Structural integrity of rocket: no breaks or damage
    b. Recovery deployment: All black powder charges fired, drogue and main chute deployed successfully, altimeters responding as expected through postflight beep reports
    c. Payload: Check for continuity of data throughout flight

## 5.2 Safety and Quality Assurance

**Mechanical Assembly**
Throughout the construction process care was taken to ensure all manufacturing and assembly was done in a safe and effective manner. Since the launch vehicle is based on a fiberglass airframe all cutting and sanding operations were performed with an exhaust hood and fume system to trap and remove hazardous debris and particulates. All individuals handling rocket components during assembly were required to wear latex gloves for both their own protection from fiberglass dust as well as to prevent oil and residue contamination of the rocket components. All epoxying operations were performed exactly as specified by the manufacturer under room temperature low humidity conditions. Samples from each epoxy batch were saved to evaluate strength properties and ensure a proper cure was attained.

**Electronic Assembly**
All electronic systems requiring soldering were assembled by experienced team members in a clean environment. All soldering operations were performed with 60/40 Lead-Tin rosin+flux core solder to ensure proper adhesion. After assembly all soldered connections were cleaned with denatured alcohol and insulated with heat shrink tubing where applicable.

Due to the corrosive nature of the gasses created by black powder ejection charges, all terminal blocks mounted externally to the altimeter bay are replaced or cleaned regularly to ensure reliable contact. Furthermore all interfaces on both the recovery and altimeter bays are sealed using moldable putty to ensure no ejection gasses enter the bay.

# 6. Project Plan

## 6.1 Activity and Schedule

**Major Challenges and Solutions**

Since this is the team's first year participating in the USLI competition, the main challenges the team will face are designing and handling the high power propulsion system and the payload avionics. Accurate calculation of the correct size and impulse of the motor is needed in order reach the one mile AGL altitude. Similarly, the avionics must be integrated properly in the payload bay to relay the altitude of the rocket to the ground crew at least once every 5 seconds. The team has paired with a local mentor from the Livermore Unit of the National Associate of Rocketry, who has provided an invaluable introduction and resources into the realm of high powered rocketry.

**Community Support and Team Sustainability**

The sustainability of the team can be ensured through the mutual learning process between the team and the community. Twice a quarter, the team hosts low power rocket launches on university campus to engage university students and K-12 students in the Davis community. To accommodate the multidisciplinary nature of designing rockets the team has recruited engineering students from a wide variety of backgrounds including electrical, mechanical, aerospace, material science, and civil.

**Budget Plan**

The teams accounting is handled by a dedicated treasurer, who is responsible for tabulating all purchases, invoices and accounts receivable. While not a primary design factor, effort was made throughout design phases to minimize costs and thus ensure a sufficient safety blanket within the budget for unexpected costs.

| Section | Material | Cost |
|---|---|---|
| **Payload** | Epoxy/Resin for FG | $10.00 |
| | Phenolic Avionics Bays: Electronics bay for 3.9" Airframe | $28.56 |
| | Analog Temperature Sensor | $0.86 |

| | | |
|---|---|---|
| | Analog Humidity Sensor | $7.89 |
| | Battery IND Alkaline 9 Volt | $1.98 |
| | Header Pins, 2 x 6, 0.050 pitch, male | $0.94 |
| | Conn Header .050” 12 PS D PCB Au | $1.52 |
| | Switch Push Button SPST 2A 14 V | $1.17 |
| | Holder Battery 9V Wire Leads | $1.51 |
| Propulsion | Aerotech K550 Motor | $98.30 |
| | Aerotech 1706 Motor Casing | $174.95 |
| | Aero Pack 54mm Motor Retainer | $34.00 |
| Structures | Fiber Glass Airframe | |
| | Fiber Glass Nosecone | |
| | Fiber Glass Motor Mount | |
| | Fiber Glass Centering Rings | |
| | Fiber Glass Altimeter Bay Coupler with Fiber Glass Bulkheads | |
| | Total Fiber Glass Material | $239.95 |
| | West Systems Epoxy Resin 105 | $43.34 |
| | West Systems Epoxy Hardener 206 | $22.40 |
| | West Systems 406 Collodial Silica | $29.20 |
| | Motor Retainer | $40.12 |
| Recovery System | StratoLogger Altimeter (Redundant) | $71.96 |
| | Raven 3 Altimeter (Main) | $131.75 |
| | Raven Power Perch | $35.00 |
| | L3 Dual Altimeter Av-Bay Wiring Kit | $17.00 |
| | 3.7V 120mAh 10C LiPo Battery (x3) | $22.95 |
| | Wall Charger for 3.7V LiPo Batteries | $21.25 |
| | 13’’ Nomex Blanket Parachute Protector (x2) | $25.50 |
| | For Drogue: 5 yards of Pre-sewn 11/16’’ Climbing Grade Nylon (3,000 lb test) | $12.75 |
| | For Main: 4 yards of Pre-sewn 11/16’’ Climbing Grade Nylon (3,000 lb test) | $11.57 |
| | 2 Feet of Pre-sewn 1/2'' Kevlar Harness (10,000 lb test) (x3) | $38.25 |
| | 9/32'' Diameter Oval Threaded Zinc-Plated Steel Quicklink Connector (1,000 lb test) (x7) | $8.47 |
| | 1/4'' Steel U-Bolts (x4) | $7.16 |
| | Other Hardware (Nuts, Bolts, Washers) | $5.00 |
| | Iris Ultra 72'' Main Parachute | $140.25 |
| | Classic Elliptical 18'' Drogue Parachute | $34.00 |
| Miscellaneous | Standard Rail Buttons(1”Rail) | $3.07 |
| | Large Rail Button (1.5” Rail) | $4.43 |

| | | |
|---|---|---|
| | Nylon Sheer Pins | $5.9 |
| | Fixit Epoxy Clay | $23.90 |
| | Small Removable Rivets | $3.56 |
| | Large Removable Rivets | $3.56 |
| | **Total Expenses of Rocket** | **$1,363.97** |

**Figure 35, Construction Costs for Eclipse-1**

| | | | | | |
|---|---|---|---|---|---|
| **Materials** | | | | | |
| | Type | | Cost | Quantity | Total |
| | Recovery System | | $635.56 | 1 | $635.56 |
| | Structure | | $761.28 | 1 | $761.28 |
| | Air brakes | | $21.56 | 1 | $21.56 |
| | Propulsion | | $467.33 | 1 | $467.33 |
| | Payload | | $480.51 | 1 | $480.51 |
| | Miscellaneous | | $47.97 | 1 | $47.97 |
| | | | | | |
| **Travel** | | | | | |
| | Type | | Cost | Quantity | Total |
| | Hotel | | $435.00 | 2 | 870 |
| | Airfare | | $350 | 14 | 4900 |
| | Car rental | | $343 | 2 | 686.1 |
| | | | | | |
| **Outreach** | | | | | |
| | Type | | Cost | Quantity | Total |
| | Materials | | $30 | 1 | $30 |
| | Gas | | 8.75 gal | $4.00/gal | $40.00 |
| | | | | | |
| **Total Expenses** | | | | | **$8,940.31** |

Figure 36, Overall Expenses for Space_ED Rockets

# 6.2 Funding Plan

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Funding** | | | | | | | |
| | Program | | | | Quantity | Restricted | Type |
| | MAE Department | | | | $1,000 | No | Materials |
| | College of Engineering | | | | $1,000 | No | Materials |
| | California Space Grant Consortium | | | | $10,000 | | Travel |
| | Club Finance Council | | | | $322.43 | Yes- CFC | Gas |
| | | | | | $1,403.13 | Yes- CFC | Rocket Kits |
| | | | | Total: | **$13,726** | | |

Figure 37, Funding plan of SpaceED_Rockets

## 6.3 Timeline

The primary milestones and their completion status for the team are listed as follows in table 5-2:

| | | |
|---|---|---|
| 10-22-12 | Web Presence Established | Completed |
| 10-29-12 | PDR Report Posted | Completed |
| 11-16-12 | PDR Presentation Completed | Completed |
| 1-5-13 | Prototype Launch | Completed |
| 1-14-13 | CDR Report Posted | Completed |
| 1-31-13 | CDR Presentation Complete | Completed |
| 3-3-13 | Initial Payload Testing | Completed |
| 3-9-13 | Full Scale launch with payload | Completed |
| 3-18-13 | FRR Posted | Completed |
| 4-3-13 | FRR Presentation Complete | In Progress |
| 4-17-13 | LRR Conducted | On Track |
| 4-20-13 | Launch Date | On Track |
| 5-6-13 | PLAR Posted | On Track |

**Figure 38, Primary Milestons and Status**

The team is currently on track to achieve all major milestones, with the largest uncertainty revolving weight reduction plan to improve altitude targets. At the current date it is believed sufficient weight reduction is achievable to enable attainment of the 1 mile altitude mark. The results of these efforts will be determined as part of the March 30th full scale launch.

To successfully design and build a rocket for the USLI competition, the team will follow the engineering design process: design, construction, test, and redesign. The primary design phase took place during between October and November, with refinement and preliminary testing occurring between December and January. Lessons learned from the December to January refinement and testing phase have been incorporated in the final design of the vehicle. At this point the final construction and assembly has been completed with the exception of minor adjustments being made to optimize flight trajectory.

## 6.4 Educational Engagement

Since the submission of the CDR, our team has presented to one school. California Middle School visited the U.C. Davis campus on February 21st, 2013. SpaceED Rockets hosted 35 middle school students, giving them a brief presentation on rocketry basics and the team's progress in the USLI competition. About fifteen model rockets were passed around during the presentation for students to take apart and observe a rocket's basic components. Following the presentation, students were given a hands-on project in which they build paper rockets either individually or in small groups. Each paper rocket was then launched off of a PVC pipe rocket launcher SpaceED Rockets had made specifically for their educational engagement programs.

With this presentation, SpaceED Rockets has successfully exceeded the Educational Engagement requirements of the USLI competition, with a total of 367 students engaged. Still, our team has continued to contact elementary, middle, and high schools throughout northern California, and we are planning to proceed with as many presentations as possible in the upcoming weeks. Furthermore, as it starts to get warmer outside, we are looking into the possibility of having a "field day" on our campus to which we could invite multiple schools for a large presentation, provide students with different projects, and host small competitions.

Lastly, our team has sought out a way to become more involved with the local community, so we have started to plan monthly model rocket launches at parks in Davis. Thus far, these monthly launches have not been formally planned, but every time we do launch we tend to draw attention and occasional curious children come look at the rockets. In the coming months, we hope to have a more formal way of advertising our rockets so that we can notify our community and invite all curious minds.

The following is a list of schools visited and students that attended the SpaceEd Rockets Seminars:

| Date | School | # of Students |
|---|---|---|
| 26 Aug. 2012 | Antelope Crossing M.S. | 64 |
| 9 Nov. 2012 | American Canyon M.S. | 42 |
| 16 Nov. 2012 | Elkorn Village Elementary | 35 |
| 29 & 30 Nov. 2012 | Riverbank Elementary | 40 |
| 3 Dec. 2012 | Sacramento's School of Engineering and Science | 150 |

Figure 39, Educational Engagement Status

# 7. Conclusion

The current status of the vehicle testing and integration is favorable and analysis strongly suggests that the minor adjustments being made to the airframe will enable the vehicle to reliably achieve its one mile target altitude for a variety of atmospheric conditions. The project plan is on track and financial support from a grant administered by the California Space Grant Consortium has enabled the team to reach its travel goals. With a second full scale test launch being conducted on March 30th the team hopes to fully verify the performance of the rocket and close out all manufacturing and adjustment operations. Moving forward, the team is pleased with its progress thus far and focusing on preparing all final logistical considerations for its travel to Huntsville.

# 8. References

Unless otherwise noted images from the following sources were used within the UC Davis Rocket Teams FRR report. Unless otherwise noted all sources used are suppliers of components included within the final vehicle design.

1. Motor Thrust Curve

**Aerotech Rocketry**. http://www.aerotech-rocketry.com. In partnership with Tripoli Rocket Association.
25 November, 2007. <http://www.aerotech-rocketry.com/customersite/resource_library/Certification_Documents/Tripoli/reloadable/rms-54_1706/k513fj_tra_cert.pdf>

2. PerfectFlite Stratologger Image

**PerfectFlite.** http://www.perfectflite.com/. Copyright PerfectFlite 2011.
<http://www.perfectflite.com/sl100.html>

3. DogHouse Rocketry recovery system wiring diagram

**DogHouse Rocketry.** www.doghouserocketry.com. Copyright Dog House Rocketry LLC 2012.
<http://doghouse.blastzone.org/DogHouseRocketry/Alt_Bay_Elect.html>

4. ArduPilot 2.5 Schematic

**DIY Drones.** http://diydrones.com/. Copyright DIY Drones 2013.
http://code.google.com/p/ardupilot-mega/wiki/HardwareDetails