2012 – 2013 University Student Launch Initiative
Preliminary Design Review

Department of Aerospace Engineering and Mechanics
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2012-2013 University of Minnesota USLI Team

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1 Summary of FRR Report

1.1 Team Summary

Team Name: ‘Gopher Throttle Up’ Rocketry
Mailing Address: University of Minnesota
            107 Akerman Hall
            110 Union St SE
Location: Minneapolis, MN 55455
Team Mentor: Gary Stroick
NAR/TRA Number: TRA 5440 – Level 3 Certified

1.2 Launch Vehicle Summary

Vehicle Diameter: 6 inches
Vehicle Length: 128 inches
Vehicle Weight (w/o Payload): 574 ounces
Motor: CTI Pro75 L1720-WT
Recovery System: Redundant Dual-Deploy w/ Black Powder Ejection
Rail Size: 10-10 Rail
Milestone Review Flysheet: Updated on team website

1.3 Payload Summary

Payload Title: Remote Controlled Exploration Rover *Inquisitivy*
The payload mission is to demonstrate that a small, remotely-controlled rover can complete a novel scientific mission. The rover will be equipped with a camera, to transmit a live video feed to the ground station. A team member will monitor the video feed and use a radio controller to input commands to the rover and navigate the landing site. The rover is to weigh no more than six pounds including all mechanical and electrical components. The current mission plan dictates that the rover will be deployed after the airframe has landed using a black powder-loaded piston.

In the big picture, the purpose of this project is to simulate and explore the possibility of deploying small, inexpensive probes to extraterrestrial bodies in order to scout potential landing zones for more complex, large-scale missions. In that respect, the vehicle’s descent from an altitude of one mile represents atmospheric entry of an extraterrestrial body and ground operation represents a full-scale data-acquisition mission.
2 Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

Anomalies in mass estimation have been removed, and the overall mass of the vehicle has been reduced since CDR. The team has discovered though that it is not possible to produce carbon fiber tubes that meet the rigorous tolerance demands for the rocket, and has decided to use fiber glassed reinforced phenolic as its main body tube material. The team has also decided to fix the motor mount directly to the airframe with epoxy in efforts to reduce the complexity of the design. A strength of materials analysis has determined that in high wind speeds the G10 fins come close to failure in bending, and to mitigate this, the team shall reinforce them with carbon fiber. The channels for the deployment charges have also been shortened and integrated with a removable canister for ease of access.

2.2 Changes Made to Payload Criteria

To accommodate the sabot deployment, the structure for Inquisitivity has been condensed. Smaller components have been implemented into the design. Additional changes include a reduction of redundant axle supports and the usage of composite legs to decrease mass. The payload shall also be jettisoned from a sabot, and the deployment scheme shall be triggered remotely through a secured channel and only after receiving RSO approval.

2.3 Changes Made To Project Plan

Critical testing deadlines have been solidified and the team has planned for more project time invested in verification of vehicle systems. The full scale launch is planned for late March. This is a little behind schedule, but should be completed with the full scale launch before the FRR presentation.
3 Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Structural and Electrical Elements

**Airframe**

Since CDR, the team has determined that the manufactured carbon fiber tubes cannot ensure function reliability within the recovery systems of the vehicle. Due to their tolerances and the complex configuration of the vehicle, these tubes may create fitting and separation issues within the vehicle.

Thus, the team has opted to purchase commercial phenolic tubing for the body of the airframe. The team intends to reinforce these tubes with fiber-glass to ensure that they will be reusable.

Although this will increase the overall mass of the vehicle, the mass increase is within the abilities of the selected motor to bring the vehicle to AGL.

*Figure 1: Coupler section with carbon fiber layup on the inside. The carbon fiber greatly increases the robustness of the coupler and will prevent the material from shattering during parachute deployment.*

**Coupler**

To join the body tubes together, the team has reinforced commercially bought coupler sections with carbon fiber. This increased the robustness of the material as well as its
bearing capabilities. This measure also prevents the phenolic from shattering during parachute deployment.

**Fins**

The fins have been constructed from a plate of 1/8\(^{th}\) inch thick G10 plating. The team determined that the G10 may fail in bending due to aerodynamic loading. These fins have been reinforced with carbon fiber to increase the ultimate strength of the fins.

The fins are mounted to the interior of the vehicle. The centering rings have been manufactured with slots and sinks to lock the fins in place. This method also ensures proper alignment and enables the team to replace or change the fins to match the vehicles needed performance.

The fins are held in place with a retaining plate that prevents the fins from becoming loose or falling free of the vehicle.

![Fin and centering ring mock up. The fins are made from G10 fiberglass and shall be laminated with carbon fiber to ensure they can handle the anticipated aerodynamic loads.](image)

**Motor Mount Tube**

The motor mount of the vehicle is integrated with the fin system of the vehicle. Phenolic was selected for the motor mount tube material for its favorable heat transfer properties.
It has been joined to the body of the vehicle through 1/8\textsuperscript{th} inch thick G10 centering rings. There are 3 of these rings total, and they shall be fixed to the body tube.

**Bulkheads**

To save on weight, the bulkheads are constructed with layers of carbon fiber and a ¼ inch honeycomb core material. These bulkheads have also been manufactured with wood hard points on the interior, for mounting U-bolts and the avionics bay sled.

*Figure 3: Bulkheads during the laminating process. These are composed of a composite honeycomb core with wood hard points to mount bolts and AV bay sled components.*
Figure 4: The fully laminated bulkheads. They are made from 2 layers of 11 oz Carbon fiber twill with a 45 degree bias.

**Attachment Hardware**

To enable the modular functionality of the vehicle, the interior and body tubes are joined together through the use of removable plastic rivets. The number of these rivets must be within the loading conditions of the vehicle during the mission. The strength of materials analysis and successful usage of these elements gives the team confidence that they will perform to meet the mission criteria.

**Harnesses**

See Recovery Section 3.2

**Nose Cone**

The nose cone is composed of 3 separate 3D printer parts joined and reinforced with carbon fiber twill. The plastic of the cone is 1/16 inch thick ABS plastic. The reinforcing within the cone increases the robustness of the shoulder of the nose cone, and allows for shear pins to be installed with confidence that the integrity of the cone shall not be compromised during deployment.

The profile of the full scale nose cone is derived from the Von Karmen nose cone formulation. Although this is optimized for regions of flight between 0.8 – 1 mach, the
high speed of the vehicle does approach this region, and nose cone that is optimized for this region can allow for future projects involving the same nose cone.

**Figure 5:** Fully assembled nose cone. The carbon fiber reinforcing has been laid up on the inside.

**Boat Tail**

The boat-tail is fastened to the aft body tube and is not load bearing. Its role in the vehicle system is to reduce the profile drag.
Figure 6: Boat tail of subscale. The results from the test launch have determined that the aft portion of the subscale shall be nearly identical to the full scale.

Rail Buttons

The team has still opted for use of retractable rail buttons to enable the team’s ability to make decisive choices for reaching the target altitude.

The 2, 1515 size, rail buttons shall be installed respectfully at the center of gravity and within the parachute tube section. This has been done to mitigate the severity of wind cock upon liftoff of the vehicle, and increases the confidence that the vehicle will be stable upon clearing the first rail button.

Wiring

There are no free wires within sections of the vehicle that incorporate moving parts, albeit the payload deployment scheme. This reduces the risk of continuity failure during the mission.

The wiring elements needed for payload deployment are minimal, and due to the vehicles configuration, can easily be accessed for installing black powder charges required for payload deployment.
The wires are all accessible through the use of terminals. This allows for an easier integration of the vehicles components, and a quicker assembly of all parts.

Switches

Electrical conduits for the arming switches have been imbedded into an epoxy fillet that runs along the length of the parachute tube. This ensures that the arming switch is 6 feet above the base of the rocket. The epoxy also ensures that the wire will be protected from the corrosive effects of the black powder blast.

Figure 7: Screw switch in place on the full scale vehicle. The full scale will feature the same style of switch and installation.

Battery Retention

All battery packs have been purchased from leading commercial suppliers and are installed with terminal heads pointing aft of the vehicle. This reduces the risk of power failure during the vehicle’s mission.

Retention and Avionics Board

All avionics elements are mounted with screws onto a 1/8th inch thick plywood board. This board is secured with carbon fiber tubes to the load bearing U-bolts of the avionics bay.
3.1.2 Schematic Depicting Assembly of Launch Vehicle

![Diagram of launch vehicle components]

*Figure 8: The picture above depicts the full assembly of the vehicle.*

3.1.3 Flight Reliability Confidence

**Mission Success Criteria**

In addition to meeting the USLI prescribed requirements, the team has defined its own success criteria with regard to mission events.

<table>
<thead>
<tr>
<th>Mission Event</th>
<th>Objective</th>
<th>Mission Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation</td>
<td>Vehicle, payload and motor are integrated</td>
<td>Launch readiness met, Phase I begins</td>
</tr>
<tr>
<td>RSO launch</td>
<td>All safety systems approved for flight</td>
<td>Safe mission outcome</td>
</tr>
<tr>
<td>approval</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch</td>
<td>Vehicle clears pad and is aerodynamically stable</td>
<td>Phase I completed</td>
</tr>
<tr>
<td>Drogue Deployment</td>
<td>Begin controlled descent of vehicle to safe main chute deployment</td>
<td>Primary vehicle mission objective</td>
</tr>
<tr>
<td>Main Deployment</td>
<td>Final descent stage of vehicle before landing</td>
<td>Primary vehicle mission objective</td>
</tr>
<tr>
<td>Landing</td>
<td>Vehicle does not damage property nor cause bodily harm</td>
<td>Primary vehicle mission complete, Phase II complete</td>
</tr>
<tr>
<td>Rover deployment</td>
<td>Deployment systems jettison rover from vehicle after RSO approval</td>
<td>Safe deployment, Phase III begins</td>
</tr>
</tbody>
</table>
## Analysis

Analysis was carried out in the domains of strength of materials, aerodynamics, and flight simulations. These often cross over with one another, and share common variables. The results from the various analyses are described in tabular form below.

### Strength of Materials

Fundamental strength of materials analysis was carried out for load bearing elements of the vehicle and aeroelastic elements. Each analysis focused on the elements respective high stress instance during the mission.

<table>
<thead>
<tr>
<th>Element</th>
<th>Assumptions</th>
<th>Equations used</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing/ Rivets</td>
<td>A = area of bearing</td>
<td>$\tau = \frac{P}{A}$</td>
<td>12 rivets are needed to hold coupler in place for entire mission. The maximum stress is $\sigma_{\text{max}} = 2000 \text{ psi}$</td>
</tr>
<tr>
<td></td>
<td>P = loading</td>
<td>$A = \pi dt$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>t = thickness of bearing (wall thickness)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Element</td>
<td>Assumptions</td>
<td>Equations used</td>
<td>Results</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Motor mount</td>
<td>A = total area of centering rings acting on</td>
<td>$\tau = \frac{T}{A}$</td>
<td>Epoxy fillet 3 times the thickness of the plate being attached. The maximum stress on the filet is $\sigma_{\text{max}} = 25$ psi</td>
</tr>
<tr>
<td></td>
<td>T = thrust of motor</td>
<td>$n = 3$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = number of centering rings fixed to tube</td>
<td>$A = n(6* t)2r\pi$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Assume uniformly distributed stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fin (Moment analysis)</td>
<td>Assuming rectangular planform, angle of attack = 10 degree, 0.7 mach, sea level</td>
<td>$M = \frac{wL^2}{2}$</td>
<td>Carbon fiber is needed to reinforce the G10 fins.</td>
</tr>
<tr>
<td></td>
<td>M = Maximum moment</td>
<td>$w = \frac{\partial Cl}{\partial \alpha} \frac{aqS}{L}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W = aerodynamic force acting on fin</td>
<td>$\sigma = \frac{Mc}{I}$</td>
<td>The maximum stress in bending is $\sigma_{\text{max}} = 58000$ psi</td>
</tr>
<tr>
<td></td>
<td>q = dynamic pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>c = distance from neutral surface to edge of fin</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2: Table of calculation variables and formulas.*

Further, the analysis of the fins accounted for the addition of carbon fiber to the surface of the G10 material. Divergence was eliminated as a possible failure mode due to the fins swept profile, and flutter has been eliminated as a potential failure mode our team mentor Gary Stroick’s flutter calculator.

**Static Tests**

The following tables outline various tests that must be completed before the full scale launch. These tests are primarily focused on functionality aspects of the vehicle.

<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose</th>
<th>Criteria</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drogue chute deployment</td>
<td>Determine if the drogue chute can deploy from vehicle</td>
<td>Vehicle must separate upon detonating black powder charges</td>
<td>Ground test with packed chutes</td>
</tr>
<tr>
<td>Tube friction for main chute release</td>
<td>Determine if the main chute can deploy after releasing from the ARRD</td>
<td>Chute must overcome friction within tube and fall freely from the body tube</td>
<td>Body tube is inverted with main chute bag already packed. The ease of the chutes motion shall be noted</td>
</tr>
<tr>
<td>Test</td>
<td>Purpose</td>
<td>Criteria</td>
<td>Procedure</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------------------------------------------</td>
<td>----------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rover deployment test Phase I</td>
<td>Verify that piston can pass though tube without jamming onto walls of body tube</td>
<td>Piston must exit main body tube</td>
<td>Load black powder in aft portion of a 1:1 scale tube. Fire the charge beneath the piston</td>
</tr>
<tr>
<td>Rover deployment test Phase II</td>
<td>Determine the mass and shear pin count for the deployment system</td>
<td>Simulated mass must exit vehicle</td>
<td>1:1 tube is prepared for ejecting a mass with a piston and black powder charge. Fire the charge beneath the piston</td>
</tr>
</tbody>
</table>

*Table 3: Proposed tests prior to full scale flight test.*

It must also be noted that many of the vehicle’s functional aspects have been verified through the two sub scale launches. These launches have verified that the configuration can meet the mission criteria and the modular aspects of the vehicle.

Since the sub scale aimed to incorporate nearly identical features and design elements as presented during critical design review, the team feels confident that the systems developed for full scale will function as intended and meet the USLI mission requirements.

**Static and Loading Tests**

Static tests were conducted for the primary structural elements of the vehicle. The results from these tests can be found in the table below with descriptions of the tests. Many of these tests were conducted using loading conditions that simulated the high accelerations that occur during the mission.
Figure 9: Static tests of main body tube. This tube was manufactured by the team and supported 300lb of static load. This is equivalent to the thrust of the motor

3.1.4 Test Data

Our second half-scale flight, while not completely successful, was nevertheless significantly more [successful] than our first half-scale flight. Since our first half-scale rocket was almost entirely destroyed as a result of its first and only test flight, we were forced to build an entirely new half-scale rocket in order to continue testing. This second half-scale was constructed primarily out of phenolic, with the exception of the nose cone which was plastic. Our second half-scale was also significantly thinner than our first half-scale with a diameter of only 3 inches, down from 3.5 inches. Since the primary source of our difficulties with the first half-scale was an insufficiently large parachute bay, this was somewhat alarming. However, we had redesigned the parachute bay to be somewhat longer than before, and had also selected a significantly smaller main parachute. We were hopeful that these changes would be sufficient to more than make
up for the reduction in diameter, but unfortunately we found that our hopes were largely unfounded.

Set-up went significantly more quickly for our second half-scale test flight than it did for our first, with one of the most noticeable improvements involving the activation of the avionics. The standard toggle switches we had used for the first half-scale had been replaced by screw switches. Furthermore, these screw switches had been moved from the sled in the middle of the avionics bay to the walls of the bay itself, allowing for far easier access. Finally, a deployment bag was used for the main parachute, allowing us to complete the majority of its packing before heading to the launch site.

The weather for our second half-scale flight was less than ideal, with winds in the 20 to 30 mile-per-hour range. The rocket windcocked immediately upon launch, which had the effect of reducing our final altitude considerably. Rocksim predictions had given us a maximum altitude of 2500 feet, while in reality neither of our altimeters recorded an altitude above 2000 feet. Instead they recorded maximum barometric altitudes of 1883 feet and 1885 feet. Upon reaching apogee, the drogue parachute successfully deployed and began its descent. Unfortunately, upon reaching the 800 foot target altitude the main parachute failed to deploy. Post-flight analysis revealed that the ARRD had, in fact, successfully fired, however the parachute had been so tightly packed that it had become stuck and the force of the drogue parachute pulling on it alone was not enough to dislodge it. Without the main parachute, the drogue was unable to reduce the rocket’s velocity enough to allow it to land safely. The position and acceleration data of the first accelerometer can be seen in Figure 10: Data from the first Raven3. Acceleration in G’s (red) and altitude above ground level in feet (blue) are plotted versus time. Below, while the position and acceleration data can be seen in Figure 11.

![Acceleration Data](image-url)
Figure 10: Data from the first Raven3. Acceleration in G’s (red) and altitude above ground level in feet (blue) are plotted versus time.
Figure 11: Data from the second Raven3. Acceleration in Gs (red) and altitude above ground level in feet (blue) are plotted versus time.

Fortunately there was a significant amount of snow on the ground at the impact site, and while it was not enough to completely prevent any and all damage to the rocket it did reduce it significantly. Instead of it being a total loss like the first half-scale, only the payload section experienced any noticeable damage. This section had contained a simple, non-functional mass simulator, as lacked the time, resources, or capability to create a working half-scale version of our rover payload. The mass simulator had broken completely through the side tube in which it was held, destroying it beyond repair. Fortunately, while it may have been beyond repair the tube is easily replaced. Our half-scale could conceivably be flown again in the near future, should we desire to do so.

Our full-scale rocket is still under construction and so we have not yet had the opportunity to conduct a full-scale test flight. However, we have conducted basic full-scale ground tests of both the parachute and the payload ejection systems, and both were completely successful. Unfortunately, significant changes have since been made to both systems, and so the tests will need to be redone using the updated designs and
configurations. For the parachute ejection, this will simply involve the inclusion of the ejection channels.

Detailed discussion of the payload testing, including electronic, structural, and the aforementioned ejection testing can be found in section 4.3.5

3.1.5 Workmanship

To ensure that the vehicle is properly assembled, the team members responsible for building the vehicle have reviewed many of the construction tutorials supplied by Apogee Components and Gary S., the team mentor. These skills are continuing to be cultivated through building test articles and prototype components.

For these vehicles, craftsmanship is critical to maximize aerodynamic efficiency and vehicle interface functionality. A poorly craft component is more prone to failure and the team will not install parts that do not meet their design standard.

Manufacturing

The team has determined the required manufacturing procedure for all of the vehicle components. These procedures are outlined in the table below.

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Tooling and Manufacturing Required</th>
</tr>
</thead>
</table>
| Tube            | ▪ Jig  
                  ▪ Vacuum  
                  ▪ Laminating Kit  
                  ▪ Chop Saw  
                  ▪ Band Saw |
| Bolt            | ▪ Hack saw  
                  ▪ File |
| Bulkhead, Annuls| ▪ Laser cutting (composite)  
                  ▪ Lathe  
                  ▪ Drill Press  
                  ▪ Filing |
<table>
<thead>
<tr>
<th>Part Type</th>
<th>Tooling and Manufacturing Required</th>
</tr>
</thead>
</table>
| Wire, Cable            | ▪ Solder  
                          ▪ Pliers  
                          ▪ Wire Striper |
| Fin                    | ▪ Dremmel  
                          ▪ Table Saw  
                          ▪ Drill Press  
                          ▪ Filing  
                          ▪ Router (edges) |
| Custom 3D part         | ▪ 3D printer  
                          ▪ ABS plastic |
| Planar Composite       | ▪ Laminating Kit  
                          ▪ Laser cutter  
                          ▪ Carbide saw  
                          ▪ Dremmel |

*Table 4: Summary of vehicle parts with manufacturing requirements.*

The team has already experienced manufacturing first hand during the half scaled build(s) and has determined the manufacturing requirements for the full scale, and is making efforts to maintain access to table saws, chop saws, and the lathes needed for fin slots, tube ends, and circular bulkheads respectfully.

Commercially purchased parts will be integrated into the vehicle while within their performance envelope. Modified parts from commercial supplies will go through a verification process to remove further hazards and risks. This would take on the form of adding fiberglass reinforcements or epoxy fillets.
Epoxy Bonding

The team has determined that fillets for reinforcing lap bonds of epoxy done over a sanded surface is required for ensuring the structural integrity of the vehicle. The radius of the fillet will be designed for redundancy of JB weld epoxy’s ultimate lap shear.

Fitting

To ensure structural integrity of the vehicle, fitted components must make snug fits within their respective parts to prevent aerodynamic divergence of parts.

Fitting is also crucial to ensuring that recovery system’s black powder charges can successfully separate vehicle components, without back blast damaging altimeters or other sensitive systems. The use of commercial tubes with highly accurate tolerances ensures this.

Precision

Precision is critical to ensure proper fin alignment and direction of thrust from the motor. Precision also allows for parts with tighter tolerances, uniform stress flow, and a vehicle that is converging to the mathematical models from Rocksim.

For final integration, all parts must pass through an iterative verification process that is outlined below.
Figure 13: The diagram represents a flow of operation per part of the vehicle from design to integration. No untested or unverified part shall be fully integrated into the vehicle.

See section 3.5 for failure analysis.

3.2 Recovery Subsystem

3.2.1 Robustness of Recovery System

Ground testing and half-scale flights were used to verify the robustness and overall functionality of the recovery subsystem. This testing revealed a number of issues that we have since worked to address. Many of these issues were due to the fact that we opted for a stacked deployment system instead of a more traditional system.

The first problem with our older designs was the difficulty in placing the drogue deployment charges behind the drogue parachute but in front of the main parachute. For the half-scale launch we simply created pouches out of coffee filters and tied them with Nylon string to the sides of the tube just behind the drogue parachute. The e-matches leading up to the pouches in question were pressed up against the sides of the bay, out of the way of the parachutes.
While ultimately successful in deploying the half-scale’s drogue parachute, this design was deemed to be unsuitable for our full-scale rocket. The placement of the pouches was imprecise and they were prone to being shifted or even completely detached from the wall during packing and/or deployment. Furthermore, the unsecured wiring can and possibly did get tangled with the main parachute and its shock cord, hampering or outright preventing its deployment.

In order to address these issues, we have created ejection channels which can be seen in Figure 14. The ejection channels are designed to direct the blast of the black powder charges to precisely where it is needed (i.e. right behind the drogue) while also removing the need for wiring along the length of the bay.

![Completed ejection channels prior to installation.](image)

The channels consist of a cardboard fiberglass composite tube, with 9/16 in PVC threads epoxied to one end. Two machined copper ejection canisters were epoxied to a female adapter for the 9/16 inch threads, as seen in Figure 15.
This allows them to be secured to the canisters as seen in Figure 16, which enables us to place the ejection canisters in close proximity to the avionics bay allowing for a shorter e-match wire to be used.

The second major problem we encountered involved the Advanced Retention Release Device (ARRD) that we are using to trigger the deployment of the main parachute. We discovered during our first test flight that the blast of the ARRD’s release charge may damage walls of the tube and/or components on the bulkhead the device is attached to. For our second half-scale launch, we dealt with this by making a ring of fiberglass to
reinforce the section of the tube exposed to the blast. For the full scale, the blast will instead be directed into the main parachute U-bolt, deflecting the force away from both the walls of the tube and the electrical connections on the surface of the bulkhead. The coupler has also been coated in carbon fiber to reduce the risk of burning the coupler when the ARRD fires. Ground testing will be conducted to ensure that these techniques will be sufficient to prevent the aforementioned damage.

The third major problem we encountered involved our avionics switches. We had underestimated how difficult it would be to access switches attached to the avionics sled, and so for our first half-scale rocket we simply drilled holes in the walls of the avionics bay and stuck a small screwdriver through them into the bay in order to flip the switches. This worked relatively well while in the lab, however it proved nearly impossible to successfully flip the switches while on the launch pad. Fortunately, we were able to solve this problem for our second half-scale, which we accomplished by switching to screw switches and epoxying those switches to the side of the avionics bay under access holes as seen in Figure 17. We are using a variant of this for our full scale, with the exception that our switches are mounted further down the rocket in order to comply with the restriction that they must be located less than six feet from the bottom of the rocket. The wiring from the bay to the switches runs along and is epoxied to the ejection channels down to just below the 6 foot mark in question.

![Figure 17: Screw switch epoxied to wall of half-scale avionics bay.](image)

The fourth and final problem we encountered was that our parachute bay simply was too small to contain the parachutes we had selected. This resulted in significant packing and preparation problems for our first half-scale launch which were directly responsible for that rocket's failure to deploy its parachutes. Analysis of the remains of our first half-scale indicated that the e-matches to our ejection canisters tore either during packing or when under acceleration, which would not have happened had everything not been so tight a fit. This issue was also responsible for the partial failure of our second half-scale
launch, since while our circuitry remained intact and the drogue parachute successfully deployed, our main parachute was packed in so tightly that the force of the drogue chute pulling on it was insufficient to remove it after the ARRD fired. Fortunately this should not be a problem with our full-scale, as we have significantly increased the size of our full-scale’s parachute bay. Even with the addition of the ejection channels described above, the parachute bays of our full-scale are proportionally larger than those of either half-scale. This was accomplished both by extending the length of the recovery tube as well as by recessing the avionics bay within its coupler as shown in Figure 18.

![Figure 18: Full-scale avionics bay recessed within coupler.](image)

Furthermore, in order to ensure the tightest possible packing of our main parachute, while simultaneously reducing the chances of tangling within the bay, as well as ensuring that the main parachute is protected from the ejection blast, we have decided to make use of a deployment bag for our main parachute, as noted in the CDR.

**Structural Elements**

Minor changes have been made to the structural elements of the recovery section since the CDR. The most significant of these changes is that the avionics coupler has been
modified so that the avionics bay itself now takes up less than half the total length of the coupler with the freed up space being added to the volume of the parachute bay. Another important change is in the composition of our bulkheads. While we are still using a honeycomb-carbon fiber composite, we have now embedded small plywood blocks into the bulkhead. These blocks enable us to drill through the bulkheads without reducing the overall structural integrity of the bulkhead itself. This also makes it so our U-Bolts are much more firmly attached to the bulkheads in question and minimizes the possibility they might tear free from the bulkheads when subjected to the expected loads.

The dimensions of the U-bolts for the full-scale are shown in the figure below.

![Figure 19: U-bolt CAD drawing.](image.png)

The workload limit for this U-bolt is 1090 pounds.
The parachute shock cords are attached to the U-bolts above using 2200 pounds workload limit quicklinks. The parachute bay shall be secured to the motor section using three 2-56 shear pins in order to hold the sections together until drogue parachute deployment. The 2-56 shear pins are rated for 34 pounds each. The avionics bay shall be secured to the payload bay using 10 quarter-inch rivets and to the parachute bay using 5 quarter-inch rivets.

The drogue parachute will be deployed using 4 grams of FFFFg black powder, while the main parachute will be deployed via ARRD release.

**Electrical Elements**

Recovery is making use of two Raven3 altimeters to trigger drogue and main parachute deployment. The altimeters are mounted on a plywood sled suspended on two bolts running through the avionics bay. Each altimeter is powered by its own 9V battery, and each is activated by turning independent screw switches. All of the necessary wiring connections are made through the use of screw terminals with the exception of the connections to the switches, which are soldered. Each side of the sled contains an entire independent set of deployment electronics and electrical connections, as seen in Figure 20. Furthermore, each deployment system is connected to its own independent ejection canister for drogue deployment. As a result, in the event that one of the electrical systems malfunctions or fails completely the other system can still trigger the necessary drogue deployment. Unfortunately, such a set-up cannot work with the main deployment, as adding a second ARRD would actually only serve to increase the likelihood of failure (since a failure of either system would prevent the main from deploying entirely). Instead, we are relying on only one ARRD but are splicing the main deployment wiring from both electrical systems together before connecting it to the ARRD. Thus, in the event that either electrical system fails the main parachute would still be released as planned.
Figure 20: Recovery avionics wiring diagram.

**RF Transmitter**

In order to facilitate the necessary tracking of our rocket, two low power PT-1B RF transmitters have been placed within our rocket. The first transmitter is located within the boat tail, while the second is located within the nose cone. Two RF transmitters are required because the nose cone is not tethered to the rest of the rocket in order to allow for the deployment of the payload. All other sections of the rocket are tethered together, and so can all be tracked using the transmitter in the boat tail. Both RF trackers are held in place via patches of 3M Dual Lock Velcro, which was successfully used for this purpose on the second half-scale flight.

The nose cone RF transmitter is situated as close to the top of the rocket as possible so as to maximize the distance between said transmitter and the payload electronics in order to minimize any possible interference. However, this distance alone may not be sufficient to completely remove any and all interference between the nose cone transmitter and the payload electronics, and so ground testing will be conducted in order to determine if additional shielding will be required between the two. Fortunately, the distance between the boat tail transmitter and any and all other electronics onboard the rocket is significantly larger than it is for the nose cone transmitter and so interference from that transmitter should largely be a non-issue. Once again, ground testing will still
be conducted to verify this assumption and additional shielding will be added if necessary. Placing the two transmitters as far away from each other as possible also reduces the possibility that they will interfere with each other and reduces the likelihood that both will be destroyed in the event of a crash.

The location, frequency, and range of the RF trackers are as follows:

<table>
<thead>
<tr>
<th>Tracker Location</th>
<th>Frequency</th>
<th>Wattage</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose cone</td>
<td>223.250 MHz</td>
<td>1 milliwatt</td>
<td>2 miles</td>
</tr>
<tr>
<td>Boat tail</td>
<td>223.270 MHz</td>
<td>1 milliwatt</td>
<td>2 miles</td>
</tr>
</tbody>
</table>

*Table 5: RF Tracker Specifications for PT-1B.*

For ease of use we chose sequential tracker frequencies. The range is more than sufficient given competition requirements, and will suffice in worst case scenario if our main parachute deploys at apogee.

The avionics bay electronics will be shielded from the RF trackers via our carbon fiber bulkheads, though additional materials and techniques may be added if ground testing indicates that such measures are necessary.

**Drogue Parachute Selection**

We are using a 36-inch diameter Rocketman Mach2 high-speed drogue parachute for our rocket. This is the same drogue parachute that we decided in the CDR. While the mass balance of the rocket differs slightly from the estimates made for the CDR, in the end the change in mass was found to be small enough that the drogue we selected should still perform within acceptable parameters. Based on RocksSim simulations, this drogue parachute should slow our rocket’s descent down to 85 ft/s, which is well below the general requirement for safe descent from apogee to main parachute deployment (800 feet) of 100 ft/s.

**Main Parachute Selection**

As noted in our CDR, we have decided to use the Fruity Chute Iris Ultra 84 as our main parachute. The specifications for this parachute are provided in the table below.

<table>
<thead>
<tr>
<th>Diameter (inches)</th>
<th>Chute Weight (ounces)</th>
<th>Packing Volume (cubic inches)</th>
<th>Coefficient of Drag</th>
<th>Shroud Lines (pounds)</th>
<th>Number of Gores</th>
</tr>
</thead>
</table>
Despite significant changes in the rocket’s overall design and weight, we have found that the Iris Ultra 84 will still allow us to meet our drift and kinetic energy requirements.

Currently, the heaviest single part of the rocket is the combined nose cone, payload, and recovery section, which we have calculated to weigh approximately 10.84lbs. According to our kinetic energy calculations the kinetic energy upon landing of this section will be approximately 71.25ft-lbf, below the 75ft-lbf kinetic energy limit. The kinetic energies of each individual section can be found in the table below.

<table>
<thead>
<tr>
<th>Section</th>
<th>Nose</th>
<th>Payload</th>
<th>Recovery</th>
<th>Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic Energy</td>
<td>6.11</td>
<td>50.08</td>
<td>15.0</td>
<td>25.72</td>
</tr>
<tr>
<td>(foot-pound force)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Iris Ultra 84 Specifications.

Table 7: Theoretical kinetic energies experienced by each section at impact.

3.2.2 Parachutes and Attachment Schemes

A stacked deployment system shall be used, with the drogue parachute being deployed at apogee and the main parachute being deployed at 800 feet. Two black powder ejection canisters, each containing 4 grams of FFFFg black powder, will be used to break the three 2-56 shear pins and deploy the drogue parachute.

Attachment Scheme

In order to protect the parachutes from being burned or otherwise damaged by the firing of the ejection charges, a chute protector will be used for the drogue parachute and a deployment bag will be used for the main parachute. The deployment bag also allows us to pack much more quickly and efficiently, saving a significant amount of time and space. Each parachute and protector combo will be connected to 30 feet segments of 9/16 inch tubular nylon shock cord via the quicklinks mentioned above. The same quicklinks will be used to connect the other ends of the shock cords to the U-bolts attached to the bulkheads at each end of the parachute bay.

3.3 Mission Performance Predictions

3.3.1 Mission Performance Criteria

The mission is to launch a high powered lift vehicle to a target altitude of 5280 feet and successfully deploy a science and engineering payload upon a safe landing. All mission
components must be recovered after launch and be reusable, and the payload must perform an engineering and exploration mission.

During the flight, the vehicle must lift off on an L-class commercial available solid propellant motor, remain subsonic, structurally sounds, and aerodynamically stable. Upon decent, the vehicle will detach into 2 tethered pieces within USLI kinetic energy requirements. The parts must be recovered and reusable after the mission. In addition, the vehicle will be designed and built by team members, ballasted within 10% of its empty mass and meet all NAR and FAA regulation. The launch vehicle will be easy to assemble, and use a light weight structure.

3.3.2 Comparison of Analysis and Simulations and Stability Relationships Between Aerodynamic Parameters

Through the application of Rocksim, the margin of stability was found to be 1.00 with motor unconsumed and 2.58 with the motor consumed. These values corresponded to a CG and CP at 68.0176 inches and 74.1032 Figure 21 from the tip of the nose cone respectively for the unconsumed motor case and 58.6155 inches and 74.1032 inches Figure 22 from the tip of the nose cone respectively for the consumed motor case.

As a validation, the CG and CP values were calculated independent of Rocksim. The CP was found through the canonical Barrowman equation given by,

\[ CP = \frac{(C_N)_N X_N + (C_N)_T X_T + (C_N)_F X_F}{(C_N)_R} \]
where \((C_N)_N\) and \(X_N\) are the nose cone terms, \((C_N)_T\) and \(X_T\) are the conical transition terms, \((C_N)_F\) and \(X_F\) are the fin terms and \((C_N)_R\) is the sum of the \(C_N\) coefficients. These terms are governed by the following equations:

\[
(C_N)_N = 2
\]

\[
X_N = 0.566 L_N
\]

\[
(C_N)_T = 2 \left[ \left( \frac{d_R}{d} \right)^2 - \left( \frac{d_F}{d} \right)^2 \right]
\]

\[
X_T = X_P + \frac{L_T}{3} \left[ 1 + \frac{1 - \frac{d_F}{d_R}}{1 - \left( \frac{d_F}{d_R} \right)^2} \right]
\]

\[
(C_N)_F = \left[ 1 + \frac{R}{S + R} \right] \left[ \frac{4N \left( \frac{S}{d} \right)^2}{1 + \sqrt{1 + \left( \frac{2L_F}{C_R + C_T} \right)^2}} \right]
\]

\[
X_F = X_B + \frac{X_R \left( C_R + 2C_T \right)}{3 \left( C_R + C_T \right)} + \frac{1}{6} \left[ \left( C_R + C_T \right) - \frac{C_RC_T}{C_R + C_T} \right]
\]

The parameters are depicted in Figure 23 below.
Figure 23: Parameters of rocket.

This provides a CP at 66.3242 inches from the tip of the nose cone. This corresponds to a percent difference of 10.50% when compared to the CP generated by Rocksim. This difference is accounted for by the fundamental assumptions required by the Barrowman equations:

- The angle of attack of the rocket is low
- The effects of compressibility can be neglected
Viscous forces are negligible
- Lift forces on the rocket body tube can be neglected
- The air flow over the rocket is smooth and does not change rapidly
- The rocket is thin compared to its length
- The nose of the rocket comes smoothly to a point
- The rocket is an axisymmetric rigid body
- The fins are thin flat plates

As noted by the developers of Rocksim, many of these assumptions were lifted and modifications were made to improve the accuracy of results generated. In particular, Rocksim better accounts for the geometry of the rocket which Barrowman restricted to simple generic shapes. Therefore, the team is confident in the CP produced by Rocksim.

Now, the CG was calculated through the following equation:

\[ CG = \frac{\sum_{i} X_i M_i}{\sum_{i} M_i} \]

where \( X_i \) and \( M_i \) are the CGs and masses of each individual component respectively. This provided a CG of 69.5100 inches and 59.8146 inches from the tip of the nose cone with the unconsumed motor and with the consumed motor respectively. With percent differences less than 3% in comparison to the Rocksim values, the validity of the Rocksim generated values are supported.

For reference, the margin of stability is defined as,

\[ Margin \ of \ Stability = \frac{|CP - CG|}{d} \]

where \( d \) is the outer diameter of the rocket body tube.

The management of kinetic energy can be found in Table 7: Theoretical kinetic energies experienced by each section at impact.

Altitude of the launch vehicle and the drift of each independent section of the launch vehicle for winds of 0, 5, 10, 15, and 20-mph tables from Rocksim shown below:
Figure 24: Zero miles per hour.

Figure 25: Five miles per hour.
Figure 26: Ten miles per hour.

Figure 27: Fifteen miles per hour.
Figure 28: Twenty miles per hour.

Rocksim Summary

Based on the simulation results, and as can be seen in the above graphs, the expected performance parameters are summarized below.

- Preburnout weight is 553.132oz
- Postburnout is 391.226oz or 34.571lbs and 24.452lbs respectively.
- Max vertical acceleration of 643.499ft/s (for the 0mph wind case)
- Max vertical Velocity of 709.69ft/s (0mph wind)
- Projected altitude of 5280.15536ft (0mph wind)

Specific drift rates for 0 to 20mph winds using the above specifications were calculated using Rocksim and are provided below.

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Drift Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0mph</td>
<td>0ft</td>
</tr>
<tr>
<td>5mph</td>
<td>311.46227ft</td>
</tr>
<tr>
<td>10mph</td>
<td>721.27953ft</td>
</tr>
<tr>
<td>15mph</td>
<td>1010.48885ft</td>
</tr>
<tr>
<td>20mph</td>
<td>1458.16601ft</td>
</tr>
</tbody>
</table>

Table 8: Drift Calculations
3.4 Verification (Vehicle)

From the NASA USLI Statement of Work, a list of requirements was given. We have addressed all of the requirements with the following Tables. We have listed if the requirement is currently satisfied, the verification method and a statement describing the results of verification or the reason the requirement has not yet been satisfied.

For reference, a list of all requirements from the SOW can be found in Appendix I.

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>No</td>
<td>Flight Test</td>
<td>We will verify this requirement upon completion of our full scale flight test.</td>
</tr>
<tr>
<td>1.2</td>
<td>Yes</td>
<td>Inspection</td>
<td>The vehicle will carry two Featherweight Raven barometric altimeters.</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Yes</td>
<td>Static Test</td>
<td>The Featherweight Raven reports altitude with audible beeps.</td>
</tr>
<tr>
<td>1.2.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.1</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.2.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.3.1</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.3.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.3.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>Yes</td>
<td>Analysis</td>
<td>Rocksim simulations confirm the vehicle will perform well under the supersonic range.</td>
</tr>
<tr>
<td>1.4</td>
<td>No</td>
<td>Flight Test</td>
<td>We will verify reusable launch vehicle after flight test.</td>
</tr>
<tr>
<td>1.5</td>
<td>Yes</td>
<td>Inspection</td>
<td>The launch vehicle consists of 3 tethered sections (and an ejectable nose cone)</td>
</tr>
<tr>
<td>1.6</td>
<td>No</td>
<td>Flight Test</td>
<td>We will verify at the full scale flight test whether the vehicle can be prepared for flight within 2 hours.</td>
</tr>
<tr>
<td>1.7</td>
<td>Yes</td>
<td>Static Test</td>
<td>All electronics have been tested for continued operation after a 1 hour standby.</td>
</tr>
<tr>
<td>1.8</td>
<td>Yes</td>
<td>Inspection</td>
<td>The rail buttons used allow the vehicle to fit on an 8 foot 1010 rail.</td>
</tr>
<tr>
<td>1.9</td>
<td>Yes</td>
<td>Analysis</td>
<td>The commercial motor used works with a 12-volt DC firing system.</td>
</tr>
<tr>
<td>1.10</td>
<td>Yes</td>
<td>Analysis</td>
<td>No external circuitry or ground support is required for launch of vehicle.</td>
</tr>
</tbody>
</table>
## 1. Vehicle Requirements

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.11</td>
<td>Yes</td>
<td>Analysis</td>
<td>All Cesaroni Motors are approved and certified by NAR/TRA and CAR.</td>
</tr>
<tr>
<td>1.12</td>
<td>Yes</td>
<td>Analysis</td>
<td>The CTI Pro75 L1720 has a rated total impulse of 3659 Newton-seconds.</td>
</tr>
<tr>
<td>1.13</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.14</td>
<td>No</td>
<td>Flight Test</td>
<td>Pending the results of flight test, it is not yet confirmed the amount of ballast required.</td>
</tr>
<tr>
<td>1.15</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.1</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.2</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.2.1</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.2.2</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.2.3</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.3</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.4</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.5</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.15.6</td>
<td>No</td>
<td>Flight Test</td>
<td>Our full scale flight test is pending.</td>
</tr>
<tr>
<td>1.16</td>
<td>Yes</td>
<td>Analysis</td>
<td>Upon summing the costs of all components, the vehicle and payload are less than $5000.</td>
</tr>
<tr>
<td>1.17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.17.1</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle does not have forward canards.</td>
</tr>
<tr>
<td>1.17.2</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle does not have forward firing motors.</td>
</tr>
<tr>
<td>1.17.3</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle does not utilize a motor which expels titanium sponges.</td>
</tr>
<tr>
<td>1.17.4</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle does not utilize a hybrid motor.</td>
</tr>
<tr>
<td>1.17.5</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle does not utilize a cluster motor.</td>
</tr>
</tbody>
</table>

*Table 9: Vehicle Requirement Verification Table*

## 2. Recovery Requirements

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Yes</td>
<td>Inspection</td>
<td>Our vehicle contains a dual deploy system, with one drogue and one main parachute.</td>
</tr>
<tr>
<td>2.2</td>
<td>Yes</td>
<td>Analysis</td>
<td>Simulations and calculations have determined our kinetic energy to be less than allowable.</td>
</tr>
<tr>
<td>2.3</td>
<td>Yes</td>
<td>Analysis</td>
<td>Simulations have determined all vehicle sections will land within 2500 ft of the pad with 15 mph wind.</td>
</tr>
</tbody>
</table>
### 2. Recovery Requirements

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>Yes</td>
<td>Inspection</td>
<td>The recovery system circuits are independent of payload circuits.</td>
</tr>
<tr>
<td>2.5</td>
<td>Yes</td>
<td>Inspection</td>
<td>The recovery system utilizes redundant commercially available Raven3 altimeters.</td>
</tr>
<tr>
<td>2.6</td>
<td>Yes</td>
<td>Inspection</td>
<td>Each altimeter is armed by a dedicated screw switch that is accessible from the exterior of the airframe when the rocket is in the launch configuration on the pad.</td>
</tr>
<tr>
<td>2.7</td>
<td>Yes</td>
<td>Inspection</td>
<td>Each altimeter has a dedicated 9-V power supply.</td>
</tr>
<tr>
<td>2.8</td>
<td>Yes</td>
<td>Static Test</td>
<td>The screw switches have been tested to ensure they can be locked in the ON (or closed) position.</td>
</tr>
<tr>
<td>2.9</td>
<td>Yes</td>
<td>Inspection</td>
<td>Each arming switch is located less than 6 feet from the base of the rocket.</td>
</tr>
<tr>
<td>2.10</td>
<td>Yes</td>
<td>Inspection</td>
<td>The tubes for the parachute compartment utilize removable shear pins.</td>
</tr>
<tr>
<td>2.11</td>
<td>Yes</td>
<td>Inspection</td>
<td>The vehicle contains two RF tracking devices.</td>
</tr>
<tr>
<td>2.11.1</td>
<td>Yes</td>
<td>Inspection</td>
<td>The nosecone will contain an RF tracker and the payload will contain a GPS tracker in case of early airborne deployment.</td>
</tr>
<tr>
<td>2.11.2</td>
<td>Yes</td>
<td>Static Test</td>
<td>All tracking devices have been confirmed fully functional and we do have spare trackers.</td>
</tr>
<tr>
<td>2.11.3</td>
<td>Yes</td>
<td>Inspection</td>
<td>There are no audible recovery beepers contained in our vehicle.</td>
</tr>
<tr>
<td>2.12</td>
<td>No</td>
<td>Flight Test</td>
<td>It remains to be seen if all electronic devices operating in test flight will cause interference.</td>
</tr>
<tr>
<td>2.12.1</td>
<td>Yes</td>
<td>Inspection</td>
<td>The recovery altimeters are located in a separate compartment than other electronics.</td>
</tr>
<tr>
<td>2.12.2</td>
<td>No</td>
<td>Static Test</td>
<td>A ground static test will confirm whether our carbon fiber bulkheads will shield the recovery electronics.</td>
</tr>
<tr>
<td>2.12.3</td>
<td>No</td>
<td>Inspection</td>
<td>There is no magnetic wave generation produced by our vehicle and/or payload.</td>
</tr>
<tr>
<td>2.12.4</td>
<td>No</td>
<td>Static Test</td>
<td>A ground static test will confirm whether our carbon fiber bulkheads will shield the recovery electronics.</td>
</tr>
<tr>
<td>2.13</td>
<td>Yes</td>
<td>Inspection</td>
<td>We have utilized commercially available low-current electric matches (J-TEK) for ignition of ejection charges.</td>
</tr>
<tr>
<td>2.14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Recovery Requirements

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.14.1</td>
<td>Yes</td>
<td>Inspection</td>
<td>Flashbulbs are not used for ignition of ejection charges.</td>
</tr>
<tr>
<td>2.14.2</td>
<td>Yes</td>
<td>Inspection</td>
<td>Rear ejection parachute is not utilized on our vehicle.</td>
</tr>
</tbody>
</table>

Table 10: Recovery Requirements Verification Table.

Completion of our full scale flight test should complete all requirement verifications.

3.5 Safety and Environment (Vehicle)

3.5.1 Safety and Mission Assurance Analysis

The failure modes, causes, effects and mitigation for the vehicle and recovery components are first discussed in the following Table. It is followed by a rating of likelihood and consequences for each failure mode. A risk severity matrix is also shown for quick reference.

<table>
<thead>
<tr>
<th>Vehicle Failure Modes and Effects Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1V</td>
</tr>
<tr>
<td>2V</td>
</tr>
<tr>
<td>3V</td>
</tr>
<tr>
<td>4V</td>
</tr>
<tr>
<td>5V</td>
</tr>
<tr>
<td>ID</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>6V</td>
</tr>
<tr>
<td>7V</td>
</tr>
<tr>
<td>8V</td>
</tr>
<tr>
<td>9V</td>
</tr>
<tr>
<td>10V</td>
</tr>
<tr>
<td>11V</td>
</tr>
<tr>
<td>12V</td>
</tr>
<tr>
<td>13V</td>
</tr>
<tr>
<td>14V</td>
</tr>
<tr>
<td>15V</td>
</tr>
</tbody>
</table>
Table 11: FMEA for Vehicle: Cause and Effect

The worst fault possible would be a complete failure of the fin assembly leading to a loss of stability leading to a highly erratic and unpredictable flight course. This risk is mitigated by maintaining a high level of precision in the manufacturing and assembly of the fins. The fins and the attachment scheme were tested on the half scale to assure the design was feasible for the full scale. The design also tested the motor retention device which worked flawlessly proving that the entire booster stage can be created to have flight capable specifications.

The most common failure which has been discovered in the half scale testing is the deployment of the main parachute. The black powder charges have been at fault in previous testing but utilizing ground testing has proved that the best possible ejection method is to line the parachute tube with baby powder to allow the parachute to be deployed easily by the drogue parachute. Along with testing, to make sure the main parachute can deploy under the weight of the forward section of the rocket, static load testing will be completed to confirm that the force of the drogue parachute is enough to deploy the main parachute.
### Vehicle Failure Modes and Effects Analysis

<table>
<thead>
<tr>
<th>ID</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>7V</td>
<td>2</td>
<td>4</td>
<td>The consequence is critical and would result in a large rocket landing ballistically.</td>
</tr>
<tr>
<td>8V</td>
<td>2</td>
<td>4</td>
<td>The consequence is critical since charges could either burn chutes, rupture tubes and/or cause unstable flight and no recovery.</td>
</tr>
<tr>
<td>9V</td>
<td>2</td>
<td>3</td>
<td>The consequence is moderate where either both chutes deploy increasing drift or tube ruptures.</td>
</tr>
<tr>
<td>10V</td>
<td>1</td>
<td>4</td>
<td>The consequence is critical and would result in a large rocket landing ballistically.</td>
</tr>
<tr>
<td>11V</td>
<td>1</td>
<td>4</td>
<td>The consequence is critical and the rocket would land ballistic.</td>
</tr>
<tr>
<td>12V</td>
<td>3</td>
<td>4</td>
<td>The consequence is critical and the rocket would land ballistic.</td>
</tr>
<tr>
<td>13V</td>
<td>2</td>
<td>4</td>
<td>The consequence is critical and the rocket would land ballistic.</td>
</tr>
<tr>
<td>14V</td>
<td>2</td>
<td>3</td>
<td>The consequence is moderate and the rocket would sustain damage.</td>
</tr>
<tr>
<td>15V</td>
<td>2</td>
<td>3</td>
<td>The consequence is moderate and the rocket would sustain damage.</td>
</tr>
<tr>
<td>16V</td>
<td>2</td>
<td>5</td>
<td>The consequence is catastrophic as the vehicle would be disintegrated.</td>
</tr>
<tr>
<td>17V</td>
<td>3</td>
<td>4</td>
<td>The consequence is critical and the rocket would fly unstable.</td>
</tr>
</tbody>
</table>

**Table 12: FMEA**

<table>
<thead>
<tr>
<th>Likelihood Rating and Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequence Rating and Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

**Table 13: The FMEA Key Descriptions**
3.5.2 Personnel Hazards and Control

Entering the operational phase of the project there will be new personnel hazards introduced in the final assembly, testing and operation of the vehicle and recovery system.

**Vehicle Final Assembly**

We will need to be in the work shop during the final stages of the construction of the payload still after the FRR in case a piece needs to be re-shopped. We will be using heavy and dangerous machinery. In order to reduce the risk of accidents happening we all remember from what we have learned from watching work shop safety videos, and previous experiences. We always make sure to wear goggles while in the shop, wear close toed shoes, and only work in the shop when the shop manager is present.

<table>
<thead>
<tr>
<th>Personnel Hazards and Controls - Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Epoxy inhalation</td>
</tr>
<tr>
<td>Machine Shop injury</td>
</tr>
<tr>
<td>Black Powder Explosions</td>
</tr>
</tbody>
</table>

*Table 14: Personnel hazards in vehicle assembly.*

**Vehicle Testing**

The testing of the vehicle once complete will involve hazards that must be planned for to minimize injury to personnel.
Personnel Hazards and Controls – Testing

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Effect</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection Testing</td>
<td>Black powder explosions can create debris</td>
<td>All black powder testing will be done on reinforced tubes with metal ejection canisters</td>
</tr>
<tr>
<td>Static load testing</td>
<td>Fins can shatter causing fragments to become airborne</td>
<td>The tester will wear goggles and long sleeve shirts</td>
</tr>
</tbody>
</table>

Table 15: Personnel hazards in vehicle testing.

Deployment of Parachutes

Probably the most hazardous part of the flight will be the deployment of the drogue parachute. The drogue parachute will be ejected from the rocket once it reaches apogee by black powder charges. In order to make this as safe as possible, the charges will not be live during the packing of the rocket. We will be implementing an on/off switch that controls the state of the black powder charges. Once we have clearance from the RSO, we can activate the charges on the pad with rocket in the vertical launch configuration.

Personnel Hazards and Controls - Flight

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Effect</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to eject parachute</td>
<td>The rocket will lawn dart</td>
<td>All ejection systems will confirmed as active before launch</td>
</tr>
<tr>
<td>Black powder damages tube</td>
<td>The rocket will not be reusable</td>
<td>The black powder charge will be measured to be below the breaking capacity of the tube</td>
</tr>
</tbody>
</table>

Table 16: Personnel hazards in vehicle flight.
Environmental Concerns

During the deployment of parachutes all sections must remained attached to the rocket. The impact on the ground has the potential to embed sections of the rocket into the ground which means that the shock cords must be able to remain attached to the sections even through a rough landing. In addition, the landing of the booster stage of a hard surface holds the potential to harm the fins. This is mitigated by the fins being wrapped in carbon fiber to ensure the structural integrity and the shock cord being secured into the U-bolts. With this plan, all pieces of the rocket will be connected regardless of the landing endured by the rocket.

3.6 Payload Integration

3.6.1 Integration into launch Vehicle

The payload will be integrated into the rocket in between the nose cone and the avionics bay. A sabot system will be used to fire the payload from the rocket and will be integrated with the rover into the payload bay. The sabot system consists of two sabot caps that will hold the payload in place. One sabot cap will be housed in a piston on the aft end of the payload while there will also be a forward sabot cap partially integrated into the nose cone.

Black powder will be placed in the piston at the aft end of the payload bay. A fixed bulkhead will separate the payload bay from the avionics bay. A shock chord will be connected between the fixed bulkhead and piston. Vent holes will be placed on the piston so that once the piston is fired out, it will stop due to the pressure being released once it is outside the payload bay. In case this relief in pressure does not stop the piston, a shock cord of 30 inches will be used so the piston is not lost.

The on/off trigger switch is a main part of the payload deployment and will be integrated from the rover to the piston housing the black powder charges. Deployment will be triggered by the ground controller after receiving permission from the RSO. After the RSO has given the ground controller the clearance, the controller will send the deployment signal to the electronic switch connected to the ArduIMU. This switch will ignite and Inquisitivity will be able to start its ground mission. It is important to have this part of the integration sound and reliable with the other components as this is one of the most vital parts of the integration. This will be made sure of when the rover is placed into the sabot cap-piston system.

Safety is also a concern when dealing with black powder and is addressed in section 4.5.
3.6.2 Compatibility of Elements

All the elements that are housed in the payload bay fit snugly and are made so there will be as little movement as possible throughout the flight and upon landing. A diagram is shown of the payload section in the rocket with its dimensions:

![Figure 29: Payload section in the rocket.](image)

Each element in the nose cone, the payload bay and the AV bay work together to be compatible with one another and to make a tight fit. The nose cone will go 5.5 inches into the payload bay while the AV bay will go 6.0 inches into the payload bay. While the forward sabot goes 1.0 inch into the nose cone with the forward end of the rover, there are 15.5 inches left for the rover and since it will partially be inside the piston with the aft sabot cap, there will be a 2.5 inches piston with the charges. There is 1.0 inch left for error as well as what the sabot caps will be taking up. It will be made that if there is slightly extra room, it will be filled so that everything is snug and ready for launch.

3.6.3 Payload Housing Integrity

A major concern with the integration of the rover into the payload bay is its durability during flight and upon landing as well as the issue of the rover moving around during flight. The rover, as it is being held in place by two sabot caps, is a solution to the issue of having the rover move around during flight. The sabot caps are made from a foam material, “Great Stuff Big Gap Filler”, which forms an expanding tight seal mold around the rover and once hardened, is a mold that is a perfect fit. This “cap” is then modified and cut so is fits inside the piston on the aft end of the rover as well as 1.0” inside the nose cone on the forward end. A prototype of these sabot caps is shown in Figure 30. The mold is made larger than it needs to be and then is cut down to fit inside the piston and around the rover. There is a bowl the diameter of the rover when closed inside the
piston on Figure 30 that once dry the sabot will have a mold for the rover. Once deployed, these caps will have slits in them so that they can open up when the rover moves out of them. A ground test has been completed with the piston design and it works effectively to blow the nose cone off.

Figure 30: Foam casing under construction

The payload bay itself is made out of carbon fiber and is a protective seal for the rover during flight and upon landing. This incorporated with the sabot molds protects the rover from any damage whether it is during flight, upon landing, or due to the black powder ejection charge. These components are a simplified way of maintaining the payload-housing integrity from any disturbances the payload may endure.
3.6.4 Demonstration of Payload Integration

The way that the payload will be integrated into the rocket to be flight ready will be:

First the payload is mounted with its aft sabot cap to protect the rover and to make a snug fit once implemented into the rocket. The aft sabot cap will also be housed inside of a piston shown in Figure 32 that will contain the black powder charges and will aid in the smooth deployment of the rover once these charges are fired. (Once the payload with the sabot cap is put into the piston, the on/off switch for the black powder charges will be connected at this time as well.)

The rover and its components will then be slid into the payload bay section of the rocket. The aft end of the payload section is held in with the avionics coupler 6.0” into the payload bay. This is also a way to remove the black powder if the charges do not fire. The black powder, once inside the rocket can be taken in and out by just unscrewing the AV bay and by going in the aft side of the payload bay. This is better instead of getting to the black powder by pulling out the rover, in case the charges do
fire. The last step is to put the nose cone on. The forward sabot cap will be placed one inch inside the nose cone and the nose cone will then be placed to connect with the payload bay. This will be a snug fit and the nose cone with the sabot cap will easily fit around the rover. Once this is all competed, the payload and nose cone portion will be ready for launch. A picture below is a larger depiction of the rover integration:

![payload inside payload tube](image)

*Figure 33: The payload inside the payload tube.*
4 Payload Criteria

4.1 Experiment Concept

Figure 34: A CAD Model of the rover.

4.1.1 Creativity and Originality

Space exploration is becoming more and more significant with each passing day. Robotic exploration vehicles such as the Mars Science Laboratory play a crucial role in exploring worlds unknown to us, and collecting necessary scientific information. Scientific information of this form is useful in determining how a particular planet could be put to good use, whether in the form of mining for rare minerals or even the possibility of developing space habitats.

Our scientific payload is a remote controlled rover *Inquisitively*, based on the concept of an extra-terrestrial space exploration vehicle and also on that of a rescue bot. For this purpose, we have included the primary functionality of being able to communicate and be controlled by a ground station into our rover.
While our concept is inspired by systems that are already in use, we have made the effort of integrating this into a rocket project, thereby getting as close to a simulated space mission as possible. The team has made use of advanced electronic systems available in the market such as the Xbee Pro wireless transmission device, and given considerable thought to the structural design and functioning of the payload through the design and construction process.

4.1.2 Uniqueness or Significance

This payload is extremely significant in today’s world, especially when it comes to planetary discoveries. On Earth, a rover can be able to explore places that may be difficult or even hazardous for humans. In space, it has the idea of exploring the surfaces of other planets, such as Mars. Whether it is on Mars or Earth, the rover will have an impact by encountering new things. Making such a system on a student level project poses a significant degree of challenge and allows students appreciate and understand the complexity of such systems by designing and constructing it themselves. Through the design and manufacturing process, the team members have already gained crucial insight into the aspect of systems engineering and learned about the challenges involved with any engineering project. Through our mission, we hope to form a test bed for future students to develop and advance such systems for the market.

4.2 Science Value

4.2.1 Payload Objectives

1. Stream Live Video Feed

The primary function of our exploration vehicle is to stream live video feed from its surroundings to the ground station. The live feed will allow the ground controller to see the surroundings from the rover’s perspective and accordingly control it. This functionality was chosen since for any exploration vehicle, it is of utmost importance to be able to relay back to mission control its perspective of the surrounding terrain, both for the purpose of scientific analysis and records and also for the purpose of control.

2. Record Inertial Measurement Unit Data

The rover has an Inertial Measurement Unit (IMU) on board that can accurately measure inertial data in the form of angular accelerations and forces in all directions. We plan to record this data on a data logger and from this data, get an estimate of the forces that the rover was subject to at different stages of the rocket flight.
3. Execute Autonomous functions

The team hopes that the rover will be able to execute a series of autonomous functions that will allow it to perform certain maneuvers after it is deployed. The autonomous functions will be executed after a single command is given by the ground controller, based on which the rovers on board microcontroller will execute the series of commands by driving the servos in the required manner.

4.2.2 Success Criteria

To be a successful payload, the rover must be able to

- Sustain the forces exerted on it during the flight time of the rocket and during landing.
- Successfully deploy from the rocket after landing.
- Receive control inputs from the ground input so as to maneuver in its terrain.
- Transmit live video feed from its CCD camera onto a ground station that will be monitored by the payload team.
- Execute a series of autonomous functions under the condition that it does not receive any input from the ground controller for a fixed period of time.

4.2.3 Experimental Approach

One of the main objectives of *Inquisitivity* is to prove itself as a test platform for rescue robots. The design itself and all its subsystems could be modified for future use and may prove beneficial for the growing field of distributed robotics, where several systems such as *Inquisitivity* communicate with each other to coordinate a common mission. That is, however, a future prospect of the project on which payload team members and other students in the Aerospace Engineering and Mechanics department at the University of Minnesota who are interested in autonomous systems and robotics may benefit from.

4.2.4 Experimental Test Measurement, Variables and Controls

Due to size and budget limitations, the team currently has no plans on adding any additional measurement sensors on the payload. However we plan on exploiting the full functionality of the ArduIMU and use the Inertial Measurement Unit sensor to record the magnitude of the forces experienced by the rover during the flight. This will have to be done with the support of an OpenLog Data logger that is compatible with the ArduIMU.
The entire rover is an engineering experiment in itself. It is a test of how the composite structures we have used in its construction perform on the final flight and how efficient the rover is in fulfilling its primary mission as an exploration vehicle.

### 4.2.5 Relevance of Expected Data and Accuracy/Uncertainty

*Inquisitivities*’ data collection system comprises the data logger that will be attached to the ArduIMU and shall record the three directional forces experienced by the payload during flight and deployment. This data will be relevant for future design modifications and will also be used to validate the theoretical calculations made by the payload team in determining the forces exerted on the rover. Uncertainty in data may be caused due to the sensor accuracy limitations or in the worst-case scenario, the sensor losing power or the data logger being cut off from the ArduIMU due to a loose electro-mechanical link.

The ArduIMU has been tested and it has been verified that it is compatible with all our other electronics and that the inertial measurements match the expected values.

### 4.2.6 Experiment Process Procedures

As stated, the rover is an engineering payload and the experiment consists of its efficiency and functionality as a system. Through the tests conducted so far, we are hopeful that the rover will be able to accomplish its mission and succeed. Further tests before flight will give us a better idea on what to expect as far as mission success goes. The procedure of the entire experiment is described in steps below.

1. **Integration and Launch**
   The rover will be integrated into the payload bay of the rocket with the accompanying sabot and ejection system. It will then be flown on the rocket as part of the competition.

2. **Landing and Deployment**
   Once the rocket has landed, and permission from the RSO has been received, the ground controller will trigger the e-matches for deploying the rover. This will cause the rover to shoot out of the payload bay by pushing out the nose cone.

3. **Mission initiation**
   Once deployed, the camera system will transmit a live video feed of the surrounding and allow the ground controller to drive the rover around near the landing site. Upon a certain command, the rover will execute its autonomous functions.
During the course of the rocket flight, deployment and its own mission, the IMU will record data related to inertial forces and store them on board a data logger. The team will study this data to reveal the magnitude of the forces that the rover was subject to after the rover has been recovered.

4.3 Payload Design

4.3.1 Structural Elements

Chassis

The Chassis of the payload has been built using 0.125 inch thick G10 fiberglass. Each individual wall of the chassis was cut to the required dimension and shape using a milling machine in the student machine shop. To improve structural integrity, especially due to the torsion caused by the servos, an inner wall was added to the chassis on each side to better support the servos. The individual components of the chassis have been reinforced together with 3M epoxy.

![Figure 35: The chassis.](image)

Wheel assembly

The Hubs for each individual wheel were 3D printed in the machine shop with Acrylonitrile butadiene styrene (ABS) plastic. The legs for the wheels were laser cut.
from 0.125 inch thick 3 ply balsa wood and then reinforced using carbon fiber and epoxy. This composite was cured overnight in a vacuum chamber to make a composite with high structural strength.

*Figure 36: Left: the wheel assembly. Right: the axle and servo.*

### 4.3.2 Electrical Elements

![Diagram of electrical elements](image)

*Figure 37: Wiring diagram of components on the rover.*
All electronic components are off the shelf components that are suited for our mission. The electrical components will be secured to the chassis using a combination of Velcro and zip ties, to ensure that they remain in place and are easily removable when needed. The wiring and soldering between the required electrical components has been done by the team members using conventional methods.

**Changes to Equipment since CDR**

Since the CDR, the team decided to abandon the idea of using the AR600 receiver and Spektrum DX5e transmitter to relay commands from the ground station to the rover for control purposes. This was done primarily due to the fact that the Xbee pro has a longer range which gives us a higher safety margin for our purpose. The replacement electrical components are described in more detail below.

1. **Xbee-Pro Wireless Transmission Module**

Two Xbee-Pro modules replace the AR600 receiver and Spektrum DX5e transmitter the team was initially planning on using to serve as a control link between the ground station and the rover. One of these devices will be attached to the ArduIMU on board the rover and the other device will be attached to the ground controller’s computer and have a Yagi high gain antenna attached to it. Commands sent from the ground station computer will be transmitted through this Xbee module and received and relayed to the ArduIMU on board the rover.

![Figure 38: The Xbee Pro Module](image)

<table>
<thead>
<tr>
<th>Model</th>
<th>Xbee-PRO XSC (S3B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>902MHz to 928 MHz</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>2.4 to 3.6 V DC</td>
</tr>
<tr>
<td>Transmit Current</td>
<td>215 mA</td>
</tr>
<tr>
<td>Receive Current</td>
<td>26 mA</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 9 miles with dipole antenna</td>
</tr>
<tr>
<td></td>
<td>Up to 28 miles with high-gain antenna</td>
</tr>
<tr>
<td>Cost</td>
<td>$42.00 per module</td>
</tr>
</tbody>
</table>

*Table 17: The Xbee specifications*
2. **Battery Pack**

The battery pack will be mounted on the top of the rover and will serve as a power supply for the RC receiver, the electronic switch and the drive servos. Given the configuration will need to be powered for at least half an hour; the largest possible battery life is desired. This battery was chosen because it has about twice the milliamp hours of the average RC battery pack. Part of the excess charge is to ensure the battery remains at 6V throughout the mission. The torque of the servos, and thus the performance of our rover, significantly drops with a decrease in voltage. The large capacity of this battery eliminates the risk of operating at low voltages.
3. Servos
Two high torque servos will be mounted on the rover to direct drive the wheels. Each servo will be operated independently, allowing the rover to turn without any additional steering system. High torque servos were chosen to give the rover enough power to drive across the rugged terrain experienced in a field. These servos were also chosen for their durability, their metal gear boxes providing more strength than the plastic gears of competing servos.

![Figure 41: Spektrum servos.](image)

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>Spektrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>S6030 Digital Surface Servo</td>
</tr>
<tr>
<td>Torque:</td>
<td>222 on-in</td>
</tr>
<tr>
<td>Gear Type/Material:</td>
<td>Metal</td>
</tr>
<tr>
<td>Motor Type:</td>
<td>Coreless</td>
</tr>
<tr>
<td>Speed:</td>
<td>0.15 sec/60 degrees @ 6V</td>
</tr>
<tr>
<td>Weight:</td>
<td>1.8 oz</td>
</tr>
<tr>
<td>Dimension:</td>
<td>1.6in x 0.8in x 1.5in</td>
</tr>
<tr>
<td>Unit Cost</td>
<td>$72.99</td>
</tr>
</tbody>
</table>

*Table 19: Spektrum servo specifications.*
Ground Station

The ground station will consist of one computer, one patch antenna, one radio antenna, and one of the two Xbee Pro modules connected to a Yagi Antenna. The purpose of the ground station is to interface the controllers with the sensors, camera, and rover controls. From this station the pilot will be able to retrieve all relevant information from the rover via radio waves. The patch antenna will act as a “booster” to receive the signal from the camera and transmit the signal to the computer. The pilot will monitor the live video feed and relay commands to control the rover.

![Diagram of Ground Station Setup]

*Figure 42: Ground Station Setup.*
4.3.3 Precision of Instrumentation and Repeatability of Measurements

The subsystems that will be integrated into the rover *Inquisitivity* will be compatible with the requirements for the rover upon landing such that they will still function properly within the range of 2,500 feet from the launch site.

- Xbee Pro wireless transmitter functions are required to serve as a relay between the ground station and the rover to transmit input commands. The device has a line of sight range of up to 9 miles with a dipole antenna and 28 miles with a high gain antenna. We are using a high gain antenna to have a higher safety margin and since the rover will be on the ground, the team has purchased a high gain Yagi antenna for the ground station that will be powerful enough to transmit the commands from the Xbee module on the ground station to the Xbee module on the rover.

- RMRC-600XV CCD Camera (NTSC) will use an Immersion RC 2.4GHz 500mW TX to transmit its video to the Airwave Receiver with a patch antenna. This system will have a range of ~6562 feet. This is within the range that the payload will land in making the system a dependable source for the rover to transmit live video feed to a team member’s computer.

- MediaTek MT3329 GPS tracking system has precision of within 9 feet, with a range of ~ 1 mile. It is important that this subsystem is reliable and this GPS tracking system is within the required range for the payload to land.

The measurements for all of the subsystems can be repeated by recharging the battery that it will be using to complete its mission. Testing will be accomplished to verify the ranges and precision of the instrumentation used. These tests will be repeated to make the conclusions more accurate.

4.3.4 Approach to Workmanship

The team has successfully manufactured and constructed the payload chassis. The chassis was built using 0.125 inch thick G10 fiberglass and glued together using 3M epoxy. Each individual wall of the chassis was cut out on a milling machine in the Mechanical Engineering Machine Shop to ensure precision. The team made use of the College of Design’s, Design and Fabrication lab to cut the leg pieces out of 0.125 inch thick balsa wood. Initially, the team made use of fiberglass to make a composite material and reinforce the legs. However, the team decided to add more structural strength to the legs by using carbon fiber to make the composite structure.

One of the most complex connections we encountered was that of connecting the axle from the wheel assembly to the servos. For this we are making use of a 0.375 inch
threaded steel rod cut to the right dimension to use as the axle. A washer assembly connects the servo to the axle and since the washer assembly has an inner threaded lining, it secures well with the axle. Thread locker glue was used to lock the threads so that the axle is free to turn in the opposite direction with the assembly without coming off.

The rover’s main electrical components are off the shelf. These include the servos, the ArduIMU, the GPS, Camera System and Xbee’s. The on/off switch for the ejection trigger is being constructed by the team members using a common drain amplifier. Some of the electrical connections and a common board for power supply has to be custom made by the team. We are ensurimg that all wire connections are held securely by coating them with a layer of hot glue.

4.3.5 Testing and Verification

**Structural testing**

It is integral to the success of our payload that its structural components can withstand the forces that they will experience. As mentioned, the team is extensively making use of a balsa wood-carbon fiber composite material to ensure the parts are strong and at the same time to reduce the overall mass of the rover to increase efficiency.

As of now the team has successfully manufactured and stress tested a leg of the rover, which is part of the wheel assembly and supports the weight of the rover. This was done by fixing one end of the leg and loading the other leg with a 3 pound mass. The stress test on this composite piece showed that it could alone support a 3 pound mass, which gives us a factor of safety of 4, since the estimated mass of the rover is a maximum of 6 pounds and at any instant of time, there will be four legs supporting the mass of the rover.

The chassis has been constructed and the team is currently working on finalizing the wheel assembly so that it can be connected to the chassis and then tested with the entire deployment system.

**Range Tests for the Control System and Camera System**

The team has conducted range tests for the control system using Xbee units similar in configuration to the ones we have but with a lower range. This was done since although the team possessed the necessary Xbee units required for our purpose, which have a listed line of sight range of up to 24 miles, we had a Yagi high gain antenna which was required at the ground station. The team however conducted a successful range test for
the control system and found that the ArduIMU is able to receive commands from the Xbee system from a ground controller’s computer and accordingly drive the servos.

The team tested the full functionality of the camera system to make sure it works inside a building. The camera unit was put at the end of a hallway inside the building while the receiver was kept inside a room on the other end. This way the signal needed to go through several walls to be able to show up on the TV screen connected to the receiver. We successfully received transmission from the camera.

**Propulsion System Testing**

The propulsion system will be tested once the entire rover has been constructed and all sub systems are integrated. This test is expected to demonstrate the ability of the servos to generate enough torque to drive the rover on a plain surface, as well as on rough and uneven terrain such as a cornfield. The team plans to perform this test in a corn field in North Branch, from where the team conducts its launch tests as well. Since the servos will use up a majority of the on-board power supply on the rover, this test will also give us an idea of how long we can sustain the batteries of the rover.

**Deployment System Testing**

The team first conducted a deployment tests for a prototype sabot by ejecting it from the payload tube of the rocket. This test was successful and we are now in the process of testing a dummy payload of identical mass as the actual rover with a sabot that has been made to tightly secure the rover in the payload tube.

*Figure 43: Some snow in Minnesota as well as deployment test.*
Further deployment testing will require the entire rover to be fitted into a tube with similar dimensions to the actual payload bay of the rocket and the test will contain a prototype of the proposed ejection system. A mockup nose cone will fit at the front end of the tube and the black powder charges will be fired via RC transmitter. The ejection test must demonstrate the ability of the rover to be pushed out of the payload bay without getting stuck to the nose cone of the rocket. It will also demonstrate the functionality of the RC on/off electronic switch that will connect to the ejection charges. If the ejection is successful at a short range, it will be tested at a long range to ensure that ejection is possible at a range of up to 2500 feet. Also to ensure the on-off switch can unarm the black powder charges in case of failure of deployment.

4.4 Verification (Payload)

From the NASA USLI Statement of Work, a list of requirements was given. We have addressed all of the requirements with the following Tables. We have listed if the requirement is currently satisfied, the verification method and a statement describing the results of verification or the reason the requirement has not yet been satisfied.

For reference, a list of all requirements from the SOW can be found in Appendix I.

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.1</td>
<td>Yes</td>
<td>Analysis</td>
<td>NASA has approved our rover payload over the course of the project.</td>
</tr>
<tr>
<td>3.1.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.1</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.4</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.5</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.7</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.8</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.2.9</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.1</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.2</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Payload Requirements

<table>
<thead>
<tr>
<th>Requirement Number</th>
<th>Satisfied</th>
<th>Verification Method</th>
<th>Verification Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.3.4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.5</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.6</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.7</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.8</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.9</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.10</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>No</td>
<td>Competition Flight</td>
<td>The data reported by the team will be collected during the competition flight.</td>
</tr>
<tr>
<td>3.3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>No</td>
<td>Competition Flight</td>
<td>The payload will not be jettisoned until the vehicle is on the ground and the RSO has given permission.</td>
</tr>
<tr>
<td>3.5</td>
<td>Yes</td>
<td>Testing</td>
<td>The rover payload is designed to be recoverable and reusable.</td>
</tr>
</tbody>
</table>

| Table 20: Payload requirements verification. |

4.5 Safety and Environment (Payload)

4.5.1 Safety and Mission Assurance Analysis

The failure modes, causes, effects and mitigation are first discussed in the following Table. It is followed by a rating of likelihood and consequences for each failure mode.

<table>
<thead>
<tr>
<th>Payload Failure Modes and Effects Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>1P</td>
</tr>
</tbody>
</table>
## Payload Failure Modes and Effects Analysis

<table>
<thead>
<tr>
<th>ID</th>
<th>Failure Mode</th>
<th>Cause</th>
<th>Effect</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2P</td>
<td>Rover fails to deploy</td>
<td>Black powder does not deploy or deploys ineffectively.</td>
<td>Rover will not be able to complete its mission. Unfired black powder may still be in rocket.</td>
<td>A lot of ground testing will be completed to make sure that the switch for the ejection charge is functional with what the rover will have to sustain. Off switch will not let the black powder fire.</td>
</tr>
<tr>
<td>3P</td>
<td>Rover out of range of RC controller/RC controller connection fails</td>
<td>Rover is out of range. Connection is lost due to damage of wires, disruption during flight.</td>
<td>The rover will not be able to be manually controlled to move around the terrain.</td>
<td>The ArduIMU will be programmed to be able to make the rover complete its mission autonomously. Testing of the autonomous programming function will be completed. Wires will be housed securely in rover chassis leading for little cause for damage during flight.</td>
</tr>
<tr>
<td>4P</td>
<td>Rover camera signal fails</td>
<td>Rover is out of range. Connection is lost due to damage of camera/its wires, disruption during flight.</td>
<td>The rover will not be able to be manually controlled as the team will not be able to see what the rover sees.</td>
<td>This will be completed autonomously to still complete its mission. Signal range testing will be completed. The camera is kept securely onto chassis for protection.</td>
</tr>
<tr>
<td>5P</td>
<td>Rover sustains damage</td>
<td>During flight there could be unexpected turbulence. Upon landing, it could be rough causing damage.</td>
<td>Rover may not be able to be driven, parts may be broken.</td>
<td>Strength tests will be completed so that the rover will be as strong as possible so as to not sustain damage. Electrical wiring will also be covered and protected in chassis to not break.</td>
</tr>
<tr>
<td>6P</td>
<td>Rover cannot navigate the terrain</td>
<td>The terrain could be more rough than expected.</td>
<td>The rover will not be able to complete its mission.</td>
<td>High torque servos are being implemented as well as its spring loaded wheels makes it able to navigate in rougher terrain with more ground clearance for the rover.</td>
</tr>
</tbody>
</table>

*Table 21: FMEA for payload: cause and effect.*
The likelihood and consequence of the risks are summarized in the following Tables. The values for rating are described in the key in Table 19. The feature of each risk that resulted in the value being selected are described in the notes.

<table>
<thead>
<tr>
<th>Payload Failure Modes and Effects Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>1P</td>
</tr>
<tr>
<td>2P</td>
</tr>
<tr>
<td>3P</td>
</tr>
<tr>
<td>4P</td>
</tr>
<tr>
<td>5P</td>
</tr>
<tr>
<td>6P</td>
</tr>
</tbody>
</table>

Table 22: FMEA for payload: risk ratings.

<table>
<thead>
<tr>
<th>Likelihood Rating and Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequence Rating and Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

Table 23: Ratings key definitions.
The worst consequence will be if the black powder goes off prematurely as this could pose a danger to all in the vicinity. This is the most important to test and we will make sure that the switch to arm and disarm the black powder functions perfectly. This switch acts as an extra precaution and works as well for the second worse consequence which would be if the black powder fails to deploy. This is dangerous as well since a team member will have to disassemble the rocket and it would be bad if the black powder accidentally went off since it did not before. This is mitigated by the switch as well as there being access to the black powder from the aft end of the payload bay. This was if the black powder goes off it will be directed outward and not at the person disassembling it. Both of these top two risks are not extremely likely to happen, but they could and if they do, it is best to take precautionary measures.

The third and fourth risks with the worst consequences would be if we lost communication the rover or lost camera feed. This is mitigated by our autonomous function. Although it would be unfortunate to be blind, the rover will still be able to accomplish its mission.

The last consequences are if the rover sustains damage or cannot navigate the terrain. Strength tests have been completed on the rover’s components and the rover will be able to withstand the flight and ejection. The structure was built in such a way as to be able to navigate rough terrain and testing is the mitigation for these issues.

4.5.2 Personnel Hazards and Controls

Entering the operational phase of the project there will be new personnel hazards introduced in the final assembly, testing and operation of the rover payload.

Final Assembly

We will need to be in the work shop during the final stages of the construction of the payload still after the FRR in case a piece needs to be re-shopped. We will be using heavy and dangerous machinery. In order to reduce the risk of accidents happening we all remember from what we have learned from watching work shop safety videos, and previous experiences. We always make sure to wear goggles while in the shop, wear close toed shoes, and only work in the shop when the shop manager is present.
Personnel Hazards and Controls – Assembly

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Effect</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy inhalation</td>
<td>Can cause irritation to the eyes, skin as well if inhaled.</td>
<td>Use precautionary measures when handling epoxy. Wear gloves be in well-ventilated area and wear ventilation mask. Consult MSDS sheet.</td>
</tr>
<tr>
<td>Machine Shop injury</td>
<td>Can cause bodily harm to oneself as well as to others.</td>
<td>Use measures learned in safety training, wear safety glasses, closed toe shoes and have machine shop manager present.</td>
</tr>
<tr>
<td>Battery Explosion</td>
<td>Cause irritation to the eyes, skin etc. if battery explodes or is not used properly.</td>
<td>Handle batteries only according to its operational use. Charge with its own charger and inspect before each use. See manual.</td>
</tr>
<tr>
<td>“Great Stuff” insulating foam</td>
<td>Can cause irritation to the eyes and skin as well if it is inhaled.</td>
<td>Work in properly ventilated area, wear gloves and ventilation mask. Handle according to operational directions and consult MSDS sheet.</td>
</tr>
</tbody>
</table>

Table 24: Personnel hazards payload assembly.

Testing of Rover

The testing of the rover once complete will involve hazards that must be planned for to minimize injury to personnel.

Personnel Hazards and Controls – Testing

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Effect</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ejection tests</td>
<td>Can cause bodily harm if proper precautions are not taken.</td>
<td>Have safety officer present and handle with care. Also ensure that our team mentor prepares the black powder charge and is present.</td>
</tr>
<tr>
<td>“Great Stuff” insulating foam</td>
<td>Can cause irritation to the eyes and skin as well if it is inhaled.</td>
<td>Making new sabot caps is necessary to perform separate tests. Work in properly ventilated area, wear gloves and ventilation mask. Handle according to operational directions and consult MSDS sheet.</td>
</tr>
</tbody>
</table>

Table 25: Personnel hazards payload testing.
Operation of Rover

Probably the most hazardous part of the payload will be the deployment of the rover. The rover will be ejected from the rocket once it lands by black powder charges. In order to make this as safe as possible, the charges will not be live during the flight of the rocket. We will be implementing an on/off switch that controls the state of the black powder charges. Once we have clearance from the RSO, we can activate the charges by using the transmitter to send a command to the switch and then deploy the rover after the charges are live. All of the testing hazards apply to the operation hazards as well.

<table>
<thead>
<tr>
<th>Personnel Hazards and Controls – Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Onboard battery failure.</td>
</tr>
</tbody>
</table>

Table 26: Personnel hazards payload operation.

Environmental concerns

During the deployment of the rover, we will need to make sure that the body of the rocket is not destroyed for two reasons. First the rocket needs to be reusable, and secondly no parts of the rocket or rover should be left behind because they are not biodegradable. We will ensure that we use the proper amount of black powder so that there is no trace that a rocket or rover was ever there. All of the parts will also be connected so nothing can fly off and not be recoverable.
5 Launch Operations Procedures

5.1 Checklist

This is provided in Appendix III.

5.2 Safety and Quality Assurance

Refer to Safety and Environment of Vehicle and Payload in sections 3.5 and 4.5 for detailed safety procedures, mitigation and environmental concerns for the Launch Operation Procedures.

The data demonstrates that the risks are at acceptable levels because the likelihood for even the worst case scenarios was very unlikely.

Greg Z. is responsible for maintaining safety, quality and procedures checklists as well as speaking and referring to our mentor Gary Stroick.
6 Project Plan

6.1 Budget Plan

Since the initial proposal, the estimated budget has been refined. At this stage, most items in the design have been finalized. The budget has been divided into Funding Summary and Budget Summary. The Budget Summary is divided into eight sections; Half Scales 1 and 2, Full Scale, Replacement Components, Manufactured Components, Safety Tools & Misc, and Travel.

The first half scale rocket we launched crashed catastrophically, causing us to lose everything in it other than the parachutes. Most of the components were either donated or scrap material from the previous year’s projects.

<table>
<thead>
<tr>
<th>Component</th>
<th>Unit Cost</th>
<th>Qty</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nosecone</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Bulkheads</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Raven</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>ARRD</td>
<td>$ 95.00</td>
<td>1</td>
<td>$ 95.00</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Co-Pilot v2.0</td>
<td>$ 129.95</td>
<td>1</td>
<td>$ 129.95</td>
<td>Anomaly</td>
</tr>
<tr>
<td>36” J-Tex E-Matches</td>
<td>$ 2.00</td>
<td>5</td>
<td>$ 10.00</td>
<td>Used</td>
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<tr>
<td>Body Tubes</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Couplers</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Motor Mount</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
</tr>
<tr>
<td>Fins</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Anomaly</td>
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<tr>
<td>Motor Retainer</td>
<td>$ -</td>
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<td>Anomaly</td>
</tr>
<tr>
<td>Parachutes</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>On Hand</td>
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</table>

**Half Scale Subtotal** $ 234.95

*Table 27: Half scale 1 budget summary (half scale 2 budget estimate $500).*

<table>
<thead>
<tr>
<th>System</th>
<th>Component</th>
<th>Unit Cost</th>
<th>Qty</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
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<tbody>
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<td>Nosecone</td>
<td>Nose Cone</td>
<td>$ 99.95</td>
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<td>$ 99.95</td>
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<td></td>
<td>Ballast Mass</td>
<td>$ 5.00</td>
<td>1</td>
<td>$ 5.00</td>
<td>Proposed</td>
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<tr>
<td>Tracker</td>
<td>RF Tracker</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>On Hand</td>
</tr>
<tr>
<td>PL Section</td>
<td>Payload Tube</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
</tr>
<tr>
<td></td>
<td>Piston (w/piston bulkhead)</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
</tr>
<tr>
<td></td>
<td>Front Permanent Bulkhead</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
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<tr>
<td></td>
<td>Coupler 1</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
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<tr>
<td>Recovery</td>
<td>Raven 3.0</td>
<td>$ 155.00</td>
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<td></td>
<td>Rocketman Deployment Bag</td>
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<td>$ 50.00</td>
<td>Proposed</td>
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<td>System</td>
<td>Component</td>
<td>Unit Cost</td>
<td>Qty</td>
<td>Total Cost</td>
<td>Status</td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------------------------</td>
<td>-----------</td>
<td>-----</td>
<td>------------</td>
<td>-------------</td>
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<td>Screw switches</td>
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<td>2</td>
<td>$ 8.00</td>
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<td>Iris Ultra 72” Parachute</td>
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<td>2200lb D-Clips</td>
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<tr>
<td>Rocketman Mach 2 3ft Drogue</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>On Hand</td>
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<td>16” Parachute Protector</td>
<td>$ -</td>
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<td>$ -</td>
<td>On Hand</td>
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<td>1/8”Threaded bolt-6”</td>
<td>$ -</td>
<td>2</td>
<td>$ -</td>
<td>On Hand</td>
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</tr>
<tr>
<td>ARRD</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>On Hand</td>
<td></td>
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<td>9/16” Shock Cord (per yd)</td>
<td>$ 0.60</td>
<td>20</td>
<td>$ 12.00</td>
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<td>2 inch U Blots</td>
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<td>$ -</td>
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<td>9v Batteries</td>
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<td>2</td>
<td>$ -</td>
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<tr>
<td>9V battery Holders</td>
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<td>$ 4.00</td>
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<td>Wire 10ft</td>
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<td>$ -</td>
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<td>Composite Sled Tubes</td>
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<td>$ -</td>
<td>On Hand</td>
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<tr>
<td>Booster</td>
<td>Booster Tube</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
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<tr>
<td>Coupler 2</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
<td></td>
</tr>
<tr>
<td>Back AV Bay Bulkhead Cap</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
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<td></td>
</tr>
<tr>
<td>Fins</td>
<td>Fins</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
</tr>
<tr>
<td>Fin Stabilizer</td>
<td>$ 30.00</td>
<td>1</td>
<td>$ 30.00</td>
<td>Manufactured</td>
<td></td>
</tr>
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<td>Motor</td>
<td>Front Centering Ring</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
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<tr>
<td>Motor Mount 75mm</td>
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<td>$ 31.00</td>
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<td>Motor Hardware Set</td>
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<td>Motor Casing</td>
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<td>$ 50.00</td>
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<td>L1720-WT</td>
<td>$ 190.00</td>
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<td>$ 190.00</td>
<td>Proposed</td>
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<tr>
<td>Aft Centering Ring</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>Manufactured</td>
<td></td>
</tr>
<tr>
<td>Aft Rail Button</td>
<td>$ 20.00</td>
<td>1</td>
<td>$ 20.00</td>
<td>Manufactured</td>
<td></td>
</tr>
<tr>
<td>Boat Tail</td>
<td>Transition</td>
<td>$ 109.00</td>
<td>1</td>
<td>$ 109.00</td>
<td>Proposed</td>
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<tr>
<td>Sabot Caps</td>
<td>$ 30.00</td>
<td>2</td>
<td>$ 60.00</td>
<td>Manufactured</td>
<td></td>
</tr>
<tr>
<td>Antigravity</td>
<td>Warp Coils w/ Antimatter</td>
<td>$ -</td>
<td>1</td>
<td>$ -</td>
<td>On Hand</td>
</tr>
<tr>
<td><strong>Full Scale Subtotal</strong></td>
<td><strong>$ 1,532.95</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 28: Full scale budget summary.*

The following table contains the items that will be used to manufacture other components, such as the bulkheads, for the full scale rocket.
<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Qty.</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT 6” phenolic Airframe Tubing</td>
<td>$39.50</td>
<td>2</td>
<td>$79.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>Fiberglass and Carbonfiber</td>
<td>$200.00</td>
<td>2</td>
<td>$400.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>Epoxy Pump</td>
<td>$25.00</td>
<td>1</td>
<td>$25.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>Flat Cable 0.1”</td>
<td>$30.00</td>
<td>1</td>
<td>$30.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>Cable Connector 20 AWG</td>
<td>$6.71</td>
<td>4</td>
<td>$26.84</td>
<td>Proposed</td>
</tr>
<tr>
<td>Screw Kit 1</td>
<td>$45.01</td>
<td>1</td>
<td>$45.01</td>
<td>Proposed</td>
</tr>
<tr>
<td>Screw Kit 2</td>
<td>$24.43</td>
<td>1</td>
<td>$24.43</td>
<td>Proposed</td>
</tr>
<tr>
<td>Quick Set Epoxy</td>
<td>$16.77</td>
<td>1</td>
<td>$16.77</td>
<td>On Hand</td>
</tr>
<tr>
<td>Marine-Grade Epoxy</td>
<td>$100.00</td>
<td>1</td>
<td>$100.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>Glue</td>
<td>$5.33</td>
<td>1</td>
<td>$5.33</td>
<td>On Hand</td>
</tr>
<tr>
<td>G10 3’x4’ sheet</td>
<td>$120.00</td>
<td>1</td>
<td>$120.00</td>
<td>On Hand</td>
</tr>
<tr>
<td>Balsa Wood 1/8”x6”x36”</td>
<td>$5.00</td>
<td>2</td>
<td>$10.00</td>
<td>Proposed</td>
</tr>
<tr>
<td>12” Tube</td>
<td>$13.36</td>
<td>3</td>
<td>$40.08</td>
<td>Proposed</td>
</tr>
<tr>
<td><strong>Manufacturing Subtotal</strong></td>
<td></td>
<td></td>
<td>$922.46</td>
<td></td>
</tr>
</tbody>
</table>

Table 29: Manufactured component budget summary.

<table>
<thead>
<tr>
<th>System</th>
<th>Component</th>
<th>Unit Cost</th>
<th>Qty.</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
<td>3D Printed Components</td>
<td>$32.00</td>
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<td>$32.00</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>G10 Components</td>
<td>$-</td>
<td>12</td>
<td>$-</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>Fiberglass Components</td>
<td>$-</td>
<td>12</td>
<td>$-</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>½”x1' Stainless Steel Axel</td>
<td>$5.00</td>
<td>1</td>
<td>$5.00</td>
<td>On Hand</td>
</tr>
<tr>
<td>Electronics</td>
<td>Advanced FPV StarterPackage</td>
<td>$289.99</td>
<td>1</td>
<td>$289.99</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>ArduIMU</td>
<td>$78.90</td>
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<td>$78.90</td>
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<td></td>
<td>Tenergy Li-ion 18650 Battery</td>
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<td>$57.00</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>Arduino GPS Shield</td>
<td>$37.95</td>
<td>1</td>
<td>$37.95</td>
<td>On Hand</td>
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<tr>
<td></td>
<td>High Torque Servos</td>
<td>$110.00</td>
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<td>$220.00</td>
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</tr>
<tr>
<td></td>
<td>RC receiver and transmitter</td>
<td>$-</td>
<td>1</td>
<td>$-</td>
<td>On Hand</td>
</tr>
<tr>
<td><strong>Payload Subtotal</strong></td>
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<td></td>
<td>$720.84</td>
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<td></td>
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</table>

Table 30: Payload budget summary.

<table>
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<tr>
<th>System</th>
<th>Item</th>
<th>Unit Cost</th>
<th>Qty.</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Foam Ear Plugs</td>
<td>$-</td>
<td>1</td>
<td>$-</td>
<td>On Hand</td>
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<tr>
<td>Supplies</td>
<td>Latex Gloves (per box)</td>
<td>$15.03</td>
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<td>$15.03</td>
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<tr>
<td></td>
<td>Safety Glasses</td>
<td>$-</td>
<td>4</td>
<td>$-</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>Respirator Masks (20-pack)</td>
<td>$19.97</td>
<td>1</td>
<td>$19.97</td>
<td>On Hand</td>
</tr>
<tr>
<td>Tools</td>
<td>Dremel Rotary Tool</td>
<td>$-</td>
<td>1</td>
<td>$-</td>
<td>On Hand</td>
</tr>
<tr>
<td></td>
<td>Pistol Grip Drill Kit</td>
<td>$76.83</td>
<td>1</td>
<td>$76.83</td>
<td>On Hand</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>System</th>
<th>Item</th>
<th>Unit Cost</th>
<th>Qty.</th>
<th>Total Cost</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drill Bit Set</td>
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<td>1</td>
<td>$ 21.37</td>
<td>On Hand</td>
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<td>Titanium Drill/Drive Set</td>
<td>$ 11.74</td>
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<td>On Hand</td>
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<tr>
<td></td>
<td>12&quot; Plastic Miter Box</td>
<td>$ 5.32</td>
<td>1</td>
<td>$ 5.32</td>
<td>On Hand</td>
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<tr>
<td></td>
<td>Fileset 8-piece Set/Host</td>
<td>$ 10.67</td>
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<td>On Hand</td>
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<td></td>
<td>Interlock Knife</td>
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<td>2</td>
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<td></td>
<td>10&quot;-12&quot; Hacksaw</td>
<td>$ 10.64</td>
<td>1</td>
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<tr>
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<td>Tungsten Rod Saw</td>
<td>$ 4.79</td>
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<tr>
<td></td>
<td>4.5&quot; Disc Saw 2 Pack</td>
<td>$ 4.04</td>
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<tr>
<td></td>
<td>Scotch Blue 1.88&quot; Painters</td>
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<td>On Hand</td>
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<td>6&quot; Crescent Wrench</td>
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<td>Power Strip</td>
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<td>1</td>
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<td>On Hand</td>
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<td>Calipers</td>
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<td>On Hand</td>
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<td>Heavy Duty 6&quot; Bar Clamp</td>
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<td>$ 1.20</td>
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<tr>
<td></td>
<td>1&quot; Spring Clamp</td>
<td>$ 2.23</td>
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<td></td>
<td>Multi-meter</td>
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<td>Angle Finder</td>
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<td>On Hand</td>
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<td>3</td>
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<td>Fastening</td>
<td>Shear Pins (per 100 pack)</td>
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<td></td>
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**Safety&Misc Subtotal** $ 927.39

*Table 31: Safety, tools and miscellaneous budget summary.*
### Gas Budget Summary

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas ~$4/gal</td>
<td>~15mpg truck/ ~30mpg car</td>
</tr>
<tr>
<td>Hotel</td>
<td>Comfort Inn</td>
</tr>
<tr>
<td><strong>Travel Subtotal</strong></td>
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</table>

*Table 32: Travel budget summary.*

### Total Cost of Project

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half Scale 1 Subtotal</td>
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<tr>
<td>Half Scale 2 Subtotal</td>
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<td>Full Scale Subtotal</td>
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<td>Replacement Components</td>
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<td>Manufacturing Subtotal</td>
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<td>Payload Subtotal</td>
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<tr>
<td>Safety, Tools &amp; Misc Subtotal</td>
<td>$927.39</td>
</tr>
<tr>
<td>Travel Subtotal</td>
<td>$1750.00</td>
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<tr>
<td><strong>TOTAL PROJECTED COSTS</strong></td>
<td><strong>$8,117.00</strong></td>
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</table>

*Table 33: Expense summary.*

### 6.2 Funding Source

At this point, the USLI rocket team has secured a total of $8750 for the project, which is sufficient to cover up the cost of the entire project.

<table>
<thead>
<tr>
<th>Funding Source</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Minnesota Space Grant</td>
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</tr>
<tr>
<td>UofM Aerospace Department</td>
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<tr>
<td>UofM Student Union Grant</td>
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<tr>
<td>Family Fun Fair</td>
<td>$200</td>
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<tr>
<td>ATK</td>
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<tr>
<td>UofM College of Science and Engineering</td>
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<td>UofM Electrical Engineering Department</td>
<td>$500</td>
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<tr>
<td>United technologies</td>
<td>$250</td>
</tr>
<tr>
<td>David Myren (individual donor)</td>
<td>$100</td>
</tr>
<tr>
<td>Other Sponsors</td>
<td>$100</td>
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<tr>
<td><strong>Total Current Funding</strong></td>
<td><strong>$8,750</strong></td>
</tr>
</tbody>
</table>

*Table 34: Funding summary.*
6.3 Educational Engagement

We have already begun creating new networks between the University and the local community. We plan on doing a variety of outreach projects at local area schools. We also plan on gaining additional community and University support through these outreach projects. We will be working with the Center for Compact and Efficient Fluid Power (CCEFP), North Star STEM Alliance, and the Minnesota Space Grant Consortium (MnSGC).
Events:
Hands on activities for our event either given to us or made include, but are not limited to:

- Straw rockets
- Plastic cup air cannons
- CD Mini Hovercrafts
- Water hydraulic pet racers
- Air pneumatic circuit kit
- Water hydraulic excavator demonstrator
- 1 foot tall rubber based, air propelled rocket
- Large Hovercraft demonstrations
- Angular Acceleration demonstrations
- Parachute launchers
- 4 inch water propelled plastic rockets

Figure 45: Pneumatics activity at the 2012 South East Minneapolis Learning Carnival

The event in Figure 45 was the 2012 South East Minneapolis Learning Carnival, which was on September 29th, 2012. This event attracted children of a variety of ages. The ages of children ranged from three years to 15 years. There were 60 children and adults that were present at this event. At this event, we set up three tables with different activities. We had one table for Straw Rockets, Air Pneumatic, and an Angular Acceleration activity. The Straw Rockets activity taught the students about fin design. The students were allowed to create different shapes for their fins, add as many fins as they desired, and chose the location of where the fins should be on their straw rocket.
The students had the opportunity to launch their straw rockets from a specially designed pressurized launcher. The students could change the angle of the launcher to determine a maximum height and distance their rocket could fly to. The students also experienced the Air Pneumatic activity, where they had to learn about pressure in order to successfully launch a tennis ball into a can a small distance away. The Angular Acceleration activity involved a stationary spinning chair and a spinning bicycle tire. The students sat on the chair and held the spinning bicycle tire. The students learned that if they changed the direction of the bicycle tire then they could control the direction the chair would rotate.

Contact Information for the 2012 South East Minneapolis Learning Carnival:
Matt Carlson
Learning Carnival Coordinator
Southeast Minneapolis Council on Learning
mcarlson@learningdreams.org

Figure 46: Electrical circuitry activity at the 2012 Family Fun Fair at Coffman Memorial Union
Since the PDR, we have participated in one event on November 17th, 2012. This was the Math & Science Family Fun Fair hosted by the University of Minnesota College of Science and Engineering. This event brought nearly 2,500 people to enjoy a wide range of learning activities presented by several organizations. The USLI team had three different activities. We showed off our current rocket design and displayed a range of different sized rockets. We also had straw rockets and electrical circuit activities. The straw rockets taught the students about fin design and aerodynamics. Students had the opportunity to let their rockets fly by a small pneumatic launching device. The students had a chance to change the angle of the launching device to aim better at the target. The electrical circuit sets had a variety of different mini activities that allowed the students to be creative. These activities included miniature radios and helicopter launching pads. The ages of the students ranged from kindergarten to eighth grade. In the same room, there was also the senior design rocket team that displayed their rocket video from the last launch. We all had a great time teaching the students about the current design of the rocket.

Figure 47: Display board for the project at the 2012 Family Fun Fair at Coffman Memorial Union
Contact Information for the Math & Science Family Fun Fair:

Dorothy Cheng
Outreach Coordinator
College of Science and Engineering
University of Minnesota - Twin Cities

Phone: 612-626-7566
Email: dcheng@umn.edu

Educational Engagement Timeline:

Minneapolis STEM Expo
February 12, 2013 from 2pm-7pm
Minneapolis Convention Center
7. Conclusion

The team is satisfied with its progress thus far, and are fortunate to have received the necessary funding from sources since CDR to proceed to the final stages of the project. We would like to thank NASA for giving us the opportunity to participate in this competition and for their valuable feedback over the course of our project.

To conclude, the University of Minnesota team is confident that we will be ready for the competition in Huntsville and are determined to succeed and do our best. Our team members have learned a multitude of engineering skills and have gained valuable insight in the field of aerospace systems, project planning and management and we continue to augment these skills and knowledge as we work on the final phase of our project.
Appendix I

USLI Statement of Work Requirements
1. Vehicle Requirements

1.1. The vehicle shall deliver the science or engineering payload to, but not exceeding, an apogee altitude of 5,280 feet above ground level (AGL).

1.2. (USLI Only) The vehicle shall carry one commercially available, barometric altimeter for recording of the official altitude used in the competition scoring.

1.2.1. The official scoring altimeter shall report the official competition altitude via a series of beeps to be checked after the competition flight in Huntsville.

1.2.2. Teams may have additional altimeters to control vehicle electronics and payload experiments.

1.2.2.1. At the Launch Readiness Review, a NASA official shall be able to mark the altimeter which will be used for the official scoring.

1.2.2.2. At the launch field, a NASA official shall be able to obtain the altitude by listening to the audible beeps reported by the altimeter.

1.2.2.3. At the launch field, to aid in determination of the vehicle’s apogee, all audible electronics, except for the official altitude-determining altimeter shall be capable of being turned off.

1.2.3. The following circumstances will warrant a score of zero for the altitude portion of the competition:

1.2.3.1. The official, marked altimeter is damaged and/or does not report an altitude via a series of beeps after the team’s competition flight.

1.2.3.2. The team does not report to the NASA official designated to record the altitude with their official marked altimeter on the day of the launch.

1.2.3.3. The altimeter reports an apogee altitude over 5,600 feet AGL.

1.3. The launch vehicle shall remain subsonic from launch until landing.

1.4. The launch vehicle shall be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.

1.5. The launch vehicle shall have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute.

1.6. The launch vehicle shall be capable of being prepared for flight at the launch site within 2 hours, from the time the Federal Aviation Administration flight waiver opens.

1.7. The launch vehicle shall be capable of remaining in launch-ready configuration at the pad for a minimum of 1 hour without losing the functionality of any critical on-board component.
1.8. The vehicle shall be compatible with either an 8 feet long 1 in. rail (1010), or an 8 feet long 1.5 in. rail (1515), provided by the range.

1.9. The launch vehicle shall be capable of being launched by a standard 12 volt direct current firing system. The firing system will be provided by the Range Services Provider.

1.10. The launch vehicle shall require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the range).

1.11. The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR).

1.12. **(USLI Only)** The total impulse provided by a USLI launch vehicle shall not exceed 5,120 Newton-seconds (L-class). This total impulse constraint is applicable to a single stage or multiple stages.

1.13. **(SLI Only)** The total impulse provided by a SLI launch vehicle shall not exceed 2,560 Newton-seconds (K-class). This total impulse constraint is applicable to a single stage or multiple stages.

1.14. The amount of ballast, in the vehicle’s final configuration that will be flown in Huntsville, shall be no more than 10% of the unballasted vehicle mass.

1.15. All teams shall successfully launch and recover their full scale rocket prior to FRR in its final flight configuration. However, the purpose of the full scale demonstration flight is to demonstrate the launch vehicle’s stability, structural integrity, recovery systems, and the team’s ability to prepare the launch vehicle for flight. The following criteria must be met during the full scale demonstration flight:

1.15.1. The vehicle and recovery system shall have functioned as designed.

1.15.2. The payload does not have to be flown during the full-scale test flight. The following requirements still apply:

1.15.2.1. If the payload is not flown, mass simulators shall be used to simulate the payload mass.

1.15.2.1.1. The mass simulators shall be located in the same approximate location on the rocket as the missing payload mass.

1.15.2.2. If the payload changes the external surfaces of the rocket (such as with camera housings or external probes) or manages the total energy of the vehicle, those systems shall be active during the full scale demonstration flight.
1.15.2.3. Unmanned aerial vehicles, and/or recovery systems that control the flight path of the vehicle, shall be flown as designed during the full scale demonstration flight.

1.15.3. The full scale motor does not have to be flown during the full scale test flight. However, it is recommended that the full scale motor be used to demonstrate full flight readiness and altitude verification. If the full scale motor is not flown during the full scale flight, it is desired that the motor simulate, as closely as possible, the predicted maximum velocity and maximum acceleration of the competition flight.

1.15.4. The vehicle shall be flown in its fully ballasted configuration during the full scale test flight. Fully ballasted refers to the same amount of ballast that will be flown during the official flight in Huntsville (Refer to requirement 1.14).

1.15.5. The success of the full scale demonstration flight shall be documented on the flight certification form, by a Level 2 or Level 3 NAR/TRA observer, and shall be documented in the FRR package.

1.15.6. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components shall not be modified without the concurrence of the NASA Range Safety Officer (RSO).

1.16. (USLI Only) The maximum amount teams may spend on the rocket and payload is $5000 total. The cost is for the competition rocket as it sits on the pad, including all purchased components. The fair market value of all donated items or materials shall be included in the cost analysis. The following items may be omitted from the total cost of the vehicle:
   - Shipping costs
   - Ground support equipment
   - Team labor costs

1.17. Vehicle Prohibitions
   1.17.1. The vehicle shall not utilize forward canards.
   1.17.2. The vehicle shall not utilize forward firing motors.
   1.17.3. The vehicle shall not utilize motors which expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)
   1.17.4. The vehicle shall not utilize hybrid motors.
   1.17.5. The vehicle shall not utilize a cluster of motors, either in a single stage or in multiple stages.

2. Recovery System Requirements
   2.1. The launch vehicle shall stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee and a main parachute is deployed at a
much lower altitude. Tumble recovery or streamer recovery from apogee to main parachute deployment is also permissible, provided that kinetic energy during drogue-stage descent is reasonable, as deemed by the Range Safety Officer.

2.2. At landing, each independent sections of the launch vehicle (as described in requirement 1.5) shall have a maximum kinetic energy of 75 ft-lbf.

2.3. All independent sections of the launch vehicle shall be designed to land within 2,500 ft. of the launch pad, assuming a 15 mph wind.

2.4. The recovery system electrical circuits shall be completely independent of any payload electrical circuits.

2.5. The recovery system shall contain redundant, commercially available altimeters. The term “altimeters” includes both simple altimeters and more sophisticated flight computers.

2.6. Each altimeter shall be armed by a dedicated arming switch which is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.

2.7. Each altimeter shall have a dedicated power supply.

2.8. Each arming switch shall be capable of being locked in the ON position for launch.

2.9. Each arming switch shall be a maximum of six (6) feet above the base of the launch vehicle.

2.10. Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.

2.11. An electronic tracking device shall be installed in the launch vehicle and shall transmit the position of the tethered vehicle or any independent section to a ground receiver.

2.11.1. Any rocket section, or payload component, which lands untethered to the launch vehicle shall also carry an active electronic tracking device.

2.11.2. The electronic tracking device shall be fully functional during the official flight in Huntsville.

2.11.3. Audible beepers may be used in conjunction with an electronic, transmitting device, but shall not replace the transmitting tracking device.

2.12. The recovery system electronics shall not be adversely affected by any other on-board electronic devices during flight (from launch until landing).

2.12.1. The recovery system altimeters shall be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device and/or magnetic wave producing device.

2.12.2. The recovery system electronics shall be shielded from all onboard transmitting devices, to avoid inadvertent excitation of the recovery system electronics.
2.12.3. The recovery system electronics shall be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.

2.12.4. The recovery system electronics shall be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.

2.13. The recovery system shall use commercially available low-current electric matches for ignition of ejection charges.

2.14. Recovery System Prohibitions

2.14.1. Flashbulbs shall not be used for ignition of ejection charges.

2.14.2. Rear ejection parachute designs shall not be utilized on the vehicle.

3. Payload Requirements

3.1. The launch vehicle shall carry a science or engineering payload following one of three options:

3.1.1. Option 1 (USLI and SLI): The engineering or science payload may be of the team’s discretion, but shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.

3.1.2. Option 2 (USLI only): NASA Student Launch Projects is partnering with the NASA Reduced Gravity Education Flight Program (RGEFP) to offer a chance for one team to fly a micro gravity payload on the reduced gravity aircraft. The team chosen to participate will be the team that has demonstrated the highest level of fidelity in meeting the following requirements:

3.1.2.1. The team participating in SLP may be of any size, but the team during the RGEFP event is limited to 6 flyers (5 prime, 1 alternate) and 2 ground crew personnel. Team members shall be 18 years or older and US Citizens. Each flight crew member shall fly once.

3.1.2.2. Student experiments shall be organized, designed, and operated by student team members alone.

3.1.2.3. The payload shall be designed to fly on an SLP rocket, yet be scalable to fly on the RGEFP aircraft.

3.1.2.4. Payloads shall not involve human test subjects or invertebrate animals.

3.1.2.5. The payload shall be designed to fly twice on the reduced gravity aircraft.
3.1.2.6. The payload on the RGEFP aircraft shall weigh no more than 300 pounds.

3.1.2.7. The payload size limit on the RGEFP aircraft shall be no more than 24 in. by 60 in. by 60 in.

3.1.2.8. Payload experiments that are free-floating (not secured to the aircraft) shall be no more than 50 pounds and 24 in. on any side.

3.1.2.9. The selected team shall complete a medical questionnaire, flight program paperwork, Test Equipment Data Package six weeks prior to the flight, complete the Test Readiness Review, and spend 8 business days in Houston, Texas for flight week activities.

3.1.3. Option 3 (USLI Only): The Science Mission Directorate (SMD) at NASA Headquarters will provide a $2,780 sponsorship for up to six teams that choose to design a payload that demonstrates the highest level of fidelity in meeting the following requirements:

3.1.3.1. The payload shall gather data for studying the atmosphere during descent and after landing, including measurements of pressure, temperature, relative humidity, solar irradiance and ultraviolet radiation.

3.1.3.2. Measurements shall be made at least every 5 seconds during descent.

3.1.3.3. Measurements shall be made every 60 seconds after landing.

3.1.3.4. Surface data collection operations shall terminate 10 minutes after landing.

3.1.3.5. The payload shall take at least 2 pictures during descent and 3 after landing.

3.1.3.6. The payload shall remain in an orientation during descent and after landing such that the pictures taken portray the sky toward the top of the frame and the ground toward the bottom of the frame.

3.1.3.7. The data from the payload shall be stored onboard and transmitted wirelessly to the team’s ground station at the time of completion of all surface operations.

3.1.3.8. Separation of payload components at apogee will be allowed, but not advised. Separating at apogee increases the risk of drifting outside the recovery area.

3.1.3.9. The payload shall carry a GPS tracking unit.

3.1.3.10. Minimum separation altitude shall be 2,500 feet AGL.

3.2. Data from the science or engineering payload shall be collected, analyzed, and reported by the team following the scientific method.
3.3. Unmanned aerial vehicle (UAV) payloads of any type shall be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given the authority to release the UAV.

3.4. Any payload element which is jettisoned during the recovery phase, or after the launch vehicle lands, shall receive real-time RSO permission prior to initiating the jettison event.

3.5. The science or engineering payload shall be designed to be recoverable and reusable. Reusable is defined as being able to be launched again on the same day without repairs or modifications.

4. General Requirements

4.1. Each team shall use a launch and safety checklist. The final checklist shall be included in the FRR report and used during the Launch Readiness Review and launch day operations.

4.2. Students on the team shall do 100% on the project, including design, construction, written reports, presentations, and flight preparation with the exception of assembling the motors and handling black powder charges (to be done by the team’s Level 2 or 3 mentor).

4.3. The team shall provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assigned, educational engagement events, and risks and mitigations.

4.4. Each team shall identify a “mentor” which is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year, and may or may not be affiliated with the school, institution, or organization. The mentor shall have been certified by the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle, and the rocketeer shall have flown and successfully recovered (using electronic, staged recovery) a minimum of 15 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to the launch in Huntsville, AL. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team attends launch week in April.

4.5. The team shall identify all team members (exception Foreign National team members — see item 4.6) attending launch week activities by the Critical Design Review (CDR). Team members shall include:
4.5.1. Students actively engaged in the project throughout the entire year (minimum 12 years of age).

4.5.2. One mentor (see requirement 4.4).

4.5.3. No more than two adult educators.

4.6. Foreign National (FN) team members shall be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during launch week due to security restrictions. In addition, FN’s may be separated from their team during these activities.

4.7. During test flights, teams shall abide by the rules and guidance of the local rocketry club’s RSO. The allowance of certain vehicle configurations and/or payloads at the NASA SLP launch does not give explicit or implicit authority for teams to fly those certain vehicle configurations and/or payloads at local club launches. Teams should communicate their intentions to the local club’s Prefect and RSO before attending any NAR or TRA launch.

4.8. The team shall engage a minimum of 100 middle school students or educators in educational, hands-on Science, Technology, Engineering, and Mathematics (STEM) projects by FRR.

4.8.1. Comprehensive feedback on the activities and an educational engagement form shall be completed and submitted within two weeks after completion of an event. A sample of the educational engagement form can be found on page 31.

4.9. The team shall develop and host a Web site for documentation of all project components.

4.9.1. Teams shall post, and make available for download, the required deliverables to the Web site by the due dates specified in the project timeline.
Appendix II

Failure Modes Verification Tracker
### Test FV-01-2013

**Test Description:** Static Loading Test

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
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<td>VF-2</td>
<td>Body Tube</td>
<td>Statically load body tube</td>
<td>Excellent</td>
<td>3/02/2013</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Feb-23</td>
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<tr>
<td>VF-17</td>
<td>Motor Retention</td>
<td>Static load motor retention structure</td>
<td>-</td>
<td>Feb-23</td>
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<tr>
<td>VF-18</td>
<td>Fins</td>
<td>Statically load fins</td>
<td>-</td>
<td>Feb-23</td>
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### Test FV-02-2013

**Test Description:** Rover & Parachute Deployment Mechanism Testing w/ Black Powder

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<th>Description</th>
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<tbody>
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<td>Nose cone</td>
<td>Test for nosecone deployment</td>
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<td>Feb-16</td>
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<tr>
<td>VF-5</td>
<td>Payload Piston</td>
<td>Test for piston mechanism</td>
<td>Good 3/08/2013</td>
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<tr>
<td>VF-6</td>
<td>Payload Piston</td>
<td>Test for piston mechanism</td>
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<td>Feb-16</td>
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<td>VF-11 &amp; VF-7</td>
<td>BP Charges</td>
<td>Test for parachute deployment using BP</td>
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### Test FV-03-2013

**Test Description:** Half Scale Test

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<th>Description</th>
<th>Test</th>
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<td>VF-8</td>
<td>BP Charges</td>
<td>Test for altimeter charge timing</td>
<td>Good-2/17/2013</td>
<td>Feb-16</td>
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<tr>
<td>VF-9</td>
<td>BP Charges</td>
<td>Test for programming code</td>
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<tr>
<td>VF-13</td>
<td>Avionics</td>
<td>Test for primary and secondary altimeters</td>
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<td>Feb-16</td>
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<tr>
<td>VF-14</td>
<td>Avionics</td>
<td>Test for altimeter readings</td>
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<td>Feb-16</td>
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<tr>
<td>VF-16</td>
<td>Shock Chord</td>
<td>Test shock cord swivel</td>
<td>Good-2/17/2013</td>
<td>Feb-16</td>
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<tr>
<td>Test</td>
<td>FV-04-2013</td>
<td>Test Description: Static &amp; Dynamic Test of Rover Structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>------------------------------------------------------------</td>
<td></td>
<td></td>
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<tr>
<td>Failure Item</td>
<td>Description</td>
<td>Test</td>
<td>Results</td>
<td>Date</td>
</tr>
<tr>
<td>PF-4</td>
<td>Control System</td>
<td>Test for hardware protective chassis for impact protection</td>
<td>-</td>
<td>Feb-16</td>
</tr>
<tr>
<td>PF-5</td>
<td>Camera System</td>
<td>Impact &amp; vibration test</td>
<td>-</td>
<td>Feb-16</td>
</tr>
<tr>
<td>PF-6</td>
<td>Orientation System</td>
<td>Impact test</td>
<td>-</td>
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<tr>
<td>PF-7</td>
<td>Power Sys.</td>
<td>Impact &amp; vibration test</td>
<td>-</td>
<td>Feb-16</td>
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<th>FV-05-2013</th>
<th>Test Description: Rover Field Test (must be one after rover Static &amp; Dynamic test)</th>
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<tr>
<td>Failure Item</td>
<td>Description</td>
<td>Test</td>
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<td>PF-1</td>
<td>Servos</td>
<td>Test for servos ability to maneuver</td>
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<tr>
<td>PF-2</td>
<td>GPS</td>
<td>Test for GPS range</td>
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<tr>
<td>PF-3</td>
<td>Control System</td>
<td>Test for software</td>
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Appendix III
Launch Operation Manual & Checklists
Foreword

This Launch Operations manual was produced by the 2012-2013 University of Minnesota USLI Team to be used for flight preparation on any and all flights occurring over the course of the project, be they test or competition. It entails the detailed procedures, component checklists and tool checklists to carry out a safe and successful flight.

The manual describes procedures in the general order of occurrence during a launch day (as seen in the Assembly Flow Chart). The checklists and procedures contained within are as follows:

- Assembly Flow Chart
- Launch Rail Preparation
- Payload Preparation
- Avionics Preparation
- Recovery Preparation
- Booster Preparation
- Motor Preparation
- Vehicle Integration
- Setup on Launcher
- Igniter Installation
- Launch Procedure
- Post-Flight Inspection

It must be noted that Launch Rail Preparation, Setup on Launcher and Launch Procedure will vary depending on whether it is a test launch at the local field or a competition launch at another field. All other procedures remain the same regardless of where the launch is performed.

When using a public rail, ensure to get assistance from local club members for proper setup. Follow local club rules at all times. Identify and obey the RSO at all times.
Assembly Flow Chart

Launch Rail Preparation

Avionics Preparation
Boosters Preparation

Payload Preparation

Recovery Preparation
Motor Preparation

Vehicle Integration

Setup On Launcher

Install Igniters

LAUNCH THE MAROON AND GOLD
Launch Rail Preparation

List of Components
- One (1) Steel Base
- Three (3) Legs with Jack Adjustments
- One (1) Predrilled 1515 8' 8020 Rail
- Two (2) ⅜” x 2” Bolts with matching nuts

List of Tools Needed
- Two (2) ½” wrenches
- Two (2) Levels

Procedure for Launch Rail Setup
1. Select Launch Pad location.
2. Bring Launch Pad components and tools to selected location.
3. Place Base at selected location with Jack Receptacles on the ground.
4. Insert Legs into Base Leg Receptacles (insuring that jacks open toward the ground).
5. Open each Jack and lock into position so that feet are resting on the ground.
6. Extract Levels from tool box.
7. Place one Level along the center of one side of the base and place the second Level along the center of an adjacent side of base.
8. Adjust the Jacks so that the base is level in both the x and y directions.
9. Remove levels from pad and place in tool box.
10. Insert the end of the Rail with the predrilled holes into the rail holder and align the hole nearest the end of the rail with the second hole from the bottom of the rail holder.
11. Insert Bolt into second hole from the bottom of the rail holder through the rail and out the opposite hole in the rail holder. Screw on nut and using both wrenches snug but not tighten nut.
12. Rail is now ready to receive rocket vehicle. See Setup On Launcher Section for further instructions.
Payload Preparation

List of Components

- Rover
  - Propulsion System
    - Spektrum S6030 Digital Surface Servos
    - Wheel Assembly
    - Carbon fiber composite legs
    - 3D printed hubs
    - Threaded steel axle and washer assembly
- Chassis
- Electrical system
  - Xbee Pro XSC (S3B) module with high gain antenna
  - ArduIMU microcontroller
  - OpenLog Data logger
  - Mediate GPS
  - ReadyMadeRC RMRC-600XV Camera
  - 400mW 1300MHz Transmitter
  - Spektrum SPMB4500 battery pack
- Ground Station
  - 8dbi patch Antenna
  - Xbee Pro XSC(S3B module with Yagi antenna)
  - Laptop Computer
  - 900MHz-1.3Ghz Receive

List of Tools Needed

- One (1) small flat-head screwdriver
- Electrical tape
- Shear Pins
- Black Powder
- Black Powder Canister
- Weigh Scale
- Wire Strippers
- Wire Cutters

Procedure for Payload Preparation

1. Connect batteries to each component inside the rover (after testing each one with the multimeter to make sure each has sufficient charge.)
2. Connect the ground station and make sure its functionality with the lap top is working correctly.
3. Inspect each component inside the rover and make sure that it is functioning correctly with the ground station.
4. Connect on/off switch from rover through sabot cap and piston to e-matches through screw connectors.
5. Put the rover with sabot system into payload bay.
6. Put top sabot cap in nose cone and put onto payload bay.

**Troubleshooting**

If the rover has a low battery, then remove the battery pack from the rover, and install a new battery.

If there are continuity problem with the e-matches to the on/off switch, check the e-match connections and the connections from the switch to the rover's system. If the e-match is faulty, replace with a new e-match. If there is still a problem, examine the wiring for any possible breaks or loose ends.

If the rocket does not deploy properly, then during the post-flight inspection check the connections from the charges to the rover to see if the ejection charges were connected correctly with the on/off switch. If the wiring checks out, perform ground testing to ensure that the system is functioning properly.

If there is loss of connection between the rover and the ground station, make sure that there was no loose wiring and all components were turned on properly. Post examination of the rover itself will be necessary if connections with the ground station check out and there is still a loss of connection.
Avionics Preparation

List of Components

- Two (2) Raven3 Altimeters
- Two (2) 9-volt battery holders
- Two (2) 9-volt batteries
- One (1) wooden sled with aluminum tubes epoxied to the sides (above components attached to the sled)
- Wiring for components on board
- Five (5) screw connectors (one three-piece, three two-piece, and one one-piece)
- Two (2) screw switches (attached to the inside wall of the avionics bay, under holes drilled to enable access to the switches)
- One (1) ARRD
- Three to four (3-4) E-matches
- Two (2) ejection canisters
- One (1) roll of duct tape
- One (1) avionics bay (coupler piece)
- Two (2) washers (currently attached to bay rods)
- Two (2) nuts (currently attached to bay rods)
- One (1) step-stool, step-ladder and/or ladder (recommend ladder or step-ladder)
- One (1) multimeter

List of Tools Needed

- One (1) small Phillips screwdriver
- One (1) small flat-head screwdriver
- One (1) set of small pliers (currently in avionics box)
- Black powder
- Weigh scale
- Wire cutters/wire strippers
- Zip ties

Procedure for Avionics Preparation

1. Inspect wiring of avionics sled to ensure proper connections
2. Connect altimeters to laptop and ensure that the programming is correct
3. Test batteries with multimeter to ensure they have sufficient charge remaining (use fresh batteries if at all possible, but still test to make sure)
4. Slide the avionics sled into the bay, connecting the switch wires to the proper screw connectors on said sled
5. Attach ARRD to avionics/payload bay bulkhead if not already done so
6. Attach trigger wires (epoxied to payload bay bulkhead) to the appropriate screw connectors on the sled
7. Test connections (tug on them)
8. Fit recovery bay bulkhead onto avionics bay. Secure with washers and bolts
9. Connect e-match leads to payload bay bulkhead screw connectors

**Functional Testing**
1. Both Raven3 altimeters need to be tested
   a) Must be programmed using a laptop with Featherweight software and a USB to mini-USB cable
   b) A pressure chamber would be ideal, but might not be necessary (change pressure with airflow?)
2. Both battery holders need to be tested
   a) Find some way to simulate expected forces
3. Screw connectors need to be tested
   a) Find some way to simulate expected forces (tug on the wires?)
4. The connection between the altimeters and the batteries needs to be tested
   a) Check by switching the altimeters on and seeing if they power up
5. The connection between the altimeters and the ARRD, ejection canisters needs to be tested
   a) Ground testing of the entire system should be conducted
6. Screw switches need to be tested
   a) Ensure that they are not only functional but can be easily accessed while the rocket is on the launch rail.

**Troubleshooting**

If the altimeters will not arm correctly, refer to the operation manual to try to diagnose the problem. If the altimeter has a low battery, then remove the altimeter sled, disconnect the old battery and install a new battery.

If there are continuity problem with the ematches, check the ematch connections and the altimeter connections. If the ematch is faulty, replace with a new ematch. If there is still a problem, examine the wiring for any possible breaks or loose ends.

If the rocket does not deploy improperly deploys either or both of the parachutes, then during the post-flight inspection check the connections to the altimeters to see if the ejection charges were connected correctly. If the wiring checks out, perform ground testing to ensure that the altimeters are functioning properly.
Recovery Preparation

List of Components
- Main Parachute (Iris Ultra 84)
- Rocketman 6 inch Deployment bag
- Drogue Parachute (Rocketman Mach 2 3ft)
- 24in Parachute Protector
- 30ft 9/16in tubular nylon shock cord with 3 loops
- 30ft 9/16in tubular nylon shock cord with 3 loops
- 2200lb Quick Links (x5)
- 550 Cord (2ft length and 6 inch length)
- RATT works Advance Retention Release Device (ARRD)
- Rivets
- 2-56 shear pins

List of Tools Needed
- Needle-nose pliers
- Small flathead screwdriver

Procedure for Recovery Preparation
1. Inspect the Main Parachute shock cord to be assured that all three loops are stable.
2. The shock cord then should be Daisy Chained for packing. Quick Links should be attached to the loops on the shock cord.
3. The Main parachute should be attached at the loop which is one third of the way from the end of the shock cord. The ends of the shock cord then are secured with Quick Links to the U-Bolt on the avionics bulkheads and the Drogue Parachute shock cord’s using a Quick link.
4. Inspect the Drogue parachute shock cord to be assured that all three loops are stable.
5. The shock cord then should be Daisy Chained for packing. Quick Links should be attached to the loops on the shock cord except where the Main Parachute joins.
6. The Drogue parachute and its parachute protector should be attached at the loop which is one third of the way from the end of the shock cord using a Quick Link. The parachute protector should be tied to the same loop as the Drogue chute using the 6 inch segment of the 550 Cord. The end of the Drogue Parachute shock cord then is secured with Quick Links to the U-Bolt on the payload bulkhead and to the Main parachute shock cord which is attached to the ARRD using the Main parachute Quick link.
7. Attach the Deployment bag to the Avionics bay U-Bolt using 550 Cord in the 2ft segment using two-half hitches at both ends to secure.
8. Insert the Main Parachute into the deployment bag and Velcro shut.
9. Insert the Drogue Parachute into the parachute bay with the parachute protector facing the black powder charges.
10. Insert the Deployment bag containing the Main parachute into the parachute tube.
11. Insert rivets into the predrilled holes on the recovery bay section of the parachute tube.
12. Insert 2-56 shear pins into the predrilled holes on the booster section of the parachute tube.

**Troubleshooting**

If the parachute will not slide smoothly out of the tube under only the weight of the forward section of the rocket then baby powder will be used to reduce the friction in the tube allowing the parachute to slide out smoothly.
Booster Assembly

List of Components

- Booster Tube
- Fin Components
  - (list all components)
- Motor Mount Tube Subassembly
- Boat tail
- Plastic Rivets
- Wood Screws

List of Tools

- Robertson Screwdriver
- (list other tools)

Procedure for Assembly

Note: The booster/fin section can be assembly prior to launch (previous night).

1. Position the fins on the mmt subassembly and secure.
2. Insert the fins/mmt subassembly in to the rear of the booster tube, aligning the fins in the half tang slots of the booster tube.
3. Secure it somehow.
4. Check proper alignment visually, making sure both tubes are concentric and rear centering ring is far enough in to booster tube.
5. Put some crap between the fins and tube to create an aerodynamic fillet. Ensure fins are snug and rigid.
6. Slide boat tail over extruding mmt subassembly and ensure boat tail shoulder is fully inserted in to remaining booster tube aft of the rear centering ring.
7. Align on holes (3) on booster with holes in boat tail and fully insert rivets to keep boat tail in place.
Motor Preparation

List of Components

- Cesaroni Pro75 4-Grain Reload Motor (L1720)
  - Forward Closure
  - Motor Grains
  - Rear Closure
  - Motor Igniter Wire
  - Nozzle Cap
- Cesaroni Pro75 4-Grain Motor Casing

List of Tools Needed

- Delay adjustment tool
- Grease
- Spacers (if needed)

Procedure for Assembly

Note: Motor reload shall remain intact in its original package until prepared at launch site.

Motor assembly requires Level-One certification. Refer to the following Cesaroni Technologies Motor Assembly Guide.
**Pro38® High-Power Reloadable Rocket Motor System**

*For use only by certified high-power rocketry users 18 years of age or older.*

Sale to persons under 18 years of age is prohibited by Federal law.

Flammable material – keep away from open flame, cigarettes or other heat sources at all times.

**Use within 1 year of manufacturing date**

**Temperature range:** -5 to 30°C

*Pro38® High-Power Reloadable Rocket Motors are professionally engineered propulsion systems designed for safe use, high performance, ease of assembly and high reliability. The Pro38® system also features a unique user-adjustable time delay. Reloading is a quick, easy, 3-step operation. Select and adjust the time delay, slide the forward closure into the inner sleeve, and thread the assembly into the motor case.*

![Graphs showing thrust curves for different grain configurations](image)

You will see that we've added a number to the front of the standard motor type code system. This number indicates the total impulse of the motor in Newton-seconds. For example, 800J366-15A is an 800N-s “J” motor, with 366N average thrust and a 15s adjustable delay.

**Assembly and Operating Instructions**

**WARNING**

Read and follow the Safety Code of the Tripoli Rocketry Association (TRA). Comply with all Federal, State and local laws in all activities with high-power rockets.

**Figure 1. Pro38 Components**

- Shunt Cap
- Motor Casing
- Nozzle Cap
- Igniter
- Reload Module
- Igniter Sleeve
- Delay/Eject Module

**Figure 2. Delay Adjustment**

- Delay/Eject Module
- Drill Guide
- Drill Holder

**Step 1 – Time Delay Adjustment**

Each motor is equipped with a full-length delay grain which provides the delay time shown in the motor designation. This delay may be reduced by 3, 5, or 9 seconds as required down to the minimum delay time allowed for the motor type. Refer to the following table to select the proper adjustment for your application:

<table>
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<th>Delay designation in motor type code:</th>
<th>Delay adjustment and resulting delay time:</th>
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<tr>
<td>-12A</td>
<td>None</td>
</tr>
<tr>
<td>-13A</td>
<td>12s</td>
</tr>
<tr>
<td>-15A</td>
<td>15s</td>
</tr>
</tbody>
</table>

**NOTE:** The ejection charge on all Pro38® motors is 1.3g of FFFF black powder. If additional ejection charge is required, do not remove white cap. Instead, add additional powder on top of white cap and seal cavity with tape.

**CAUTION**

Work in a tidy area, away from other rocket motors and materials, well away from any open flame or heat source. Perform delay adjustments in the field during rocket preparation. Delay adjustments are irreversible, and safer if done outside.

- Remove the delay/ejection module (Figure 1) from the reload kit liner. Return the reload kit to the package and store safely away during the delay adjustment operation. Check the drill guide and drill holder (Figure 2) for debris and clean if required before proceeding.
- Select the delay adjustment desired, rotate the drill holder to the appropriate notch in the drill guide and seat the drill holder tab into the drill guide notch.
- Hold the drill guide and drill holder together in one hand, insert the delay module into the drill guide cavity until the drill bit touches the delay material. Rotate the drill holder clockwise while applying light pressure. Drill into the delay material until the drill guide bottoms out against the delay material. Rotate the drill for several more revolutions in order to clear the delay material from the hole.
- Remove the delay module from the guide. Empty any residue from the module.
- For safety, we recommend that you dispose of the delay residue by soaking it in water for a minimum of 1 hour then discarding the residue. A small zip-lock bag can be used to hold the plastic container filled with water ideal and will safely dissolve the oxidizer from the delay material. This aqueous solution is not harmful to septic or sewage systems.

**NOTE:** If using an electronic recovery system, remove the white plastic disc from the end of the delay/ejection module and transfer the powder to your remote ejection charge holder and follow the recovery system instructions. Reinstall the module into the reload assembly.
Step 3 – Igniter Installation

**WARNING**

The yellow shunt cap must remain in place on the igniter leads until the rocket is placed on the pad and is ready for igniter hook-up. If the cap is lost or missing, twist the bare igniter leads together several times BEFORE proceeding with igniter installation. NEVER check continuity of an electric igniter after it has been installed in a rocket motor unless done remotely from launch control while all personnel are in the safe location for rocket launch.

![Figure 3. Reload Assembly](image)

![Figure 4. Igniter and Motor Assembly](image)

**Igniter specifications:**
- Bridgewire resistance: 1.2 – 1.8Ω
- Rated all-time current: 1.2 Amps for 10 milliseconds
- Typical response: 2.3ms @ 1.2 Amps

(*) These are manufacturer’s specs.

CTI assumes no responsibility for their use or misinterpretation.

Carefully uncoil the igniter leads. Remove any kinks or twists and straighten the wires for about 24" (60 cm) from the igniter head. Remove the yellow nozzle cap from the motor and feed the shunted ends of the igniter leads through the inside of the nozzle cap and out through the hole. Remove igniter sleeve.

Insert the igniter head into the nozzle and push until it stops against the top of the motor core. With the igniter in this position, bend a loop into the igniter leads one cap length from the nozzle exit (Figure 4).

Slice the nozzle cap up to the loop made in the previous step and firmly push the yellow nozzle cap over the nozzle to retain the igniter.

Remove the shunt and separate the wire leads ONLY while the rocket is installed on the pad and the launch control system is rendered safe (i.e. disarmed and shunted where applicable).

**WARNING**

Never store rocket motors with igniters installed. Do not install igniters until the rocket motor is installed in the rocket vehicle and the rocket vehicle is completely prepared and ready for launch. If weather, safety or other conditions result in a delay of the launch, disconnect all igniters from the launch system and replace the shunts. If the launch is aborted for any reasons, remove the igniters from the motors and install the shunts.

Step 4 – Post Firing

Unscrew the reload kit from the motor casing and discard - there are no reusable parts. If the delay module remains in the motor casing after removal of the reload assembly, push it out through the forward end of the motor case with a wooden or plastic tool. Be careful not to dent or scratch the motor casing in any way. The use of metal tools is NOT recommended.

Ordinarily, the motor casing will not require any post-flight cleanup. In the event that any combustion residue remains, the casing should be cleaned as soon as possible with hot soapy water and a non-abrasive cloth. When not in use, store the motor casing in its original package for protection. Care must be taken not to dent the motor casing or to damage the internal threads.

**MEANS OF DISPOSAL:** Remove forward closure and remove propellant grains from plastic liner. Discard plastic liner and nozzle assembly. Place forward closure and grains in a shallow hole in the ground, away from any combustibles. Install igniter in forward grain in contact with the igniter pellet, secure with tape if necessary. Ignite electrically from distance of 10 meters (min). Wait until flames cease. Remnants may be disposed of with household garbage.

First Aid: If ingested, induce vomiting. Burns from flames are to be treated as regular burns with normal first aid procedures. In either case, seek medical attention. Cesaroni Technology Incorporated (CTI) certifies that it has exercised reasonable care in the design and manufacture of its products. We do not assume any responsibility for product storage, transportation or usage. CTI shall not be held responsible for any personal injury or property damage resulting from the improper handling, storage or use of their products. The buyer assumes all risks and liabilities and accepts and uses CTI products on these conditions. No warranty, either expressed or implied is made regarding Pro38® products, except for replacement or repair at CTI’s option, of those products which are proven to be defective in manufacture within one (1) year from the date of original purchase. For repair or replacement under this warranty, please contact your point of purchase. Proof of purchase will be required. Your province may provide additional rights not covered by this warranty.

Check out our web site at http://www.Pro-X.co for tech tips, FAQ’s, user feedback and photos, or e-mail us at Pro38@cesaroni.net

For technical and warranty inquiries, please contact your Pro38® dealer.

Pro38® is a registered trademark of Cesaroni Technology Incorporated. Patent # US6079202. Other patents pending. Made in Canada.
Final Assembly

Procedure
Once all other subassemblies are completed the vehicle can be fully assembled. This will require a minimum of two personnel; one to assemble vehicle and one to verify task is completed properly.
1. Ensure nose cone is attached to payload bay tube with three 2-56 shear pins.
2. Insert avionics bay into rear of payload bay tube.
   a. Ensure avionics bay is flush with fixed internal bulkhead.
   b. Ensure switch band is flush with edge of payload tube.
   c. Secure with three plastic rivets.
   d. Ensure the arming switches are exposed and do not lie in line with rail buttons.
   e. Check vent holes for obstructions.
   a. Ensure the tube is flush with the switch band.
   b. Secure with three plastic rivets.
   c. Ensure rail button is not in line with avionics switches.
4. Join booster section (front coupler) with rear of parachute tube.
   a. Ensure the two tubes meet flush.
   b. Ensure the rail button on the booster tube is in line with the rail button on the parachute tube.
   c. Secure with three 2-56 shear pins.
5. Remove motor retainer cap, and insert motor assembly in to motor mount tube.
6. Replace motor retainer cap.
7. Verify fully loaded vehicle center of gravity (CG) by finding the fulcrum with one hand supporting the vehicle. Be careful not to drop the vehicle.
8. Proceed to RSO inspection on the flight line (ensure flight card is filled out properly and on hand).
Setup on Launcher

Procedure

Once RSO approval has been received and the range is open, a minimum of three personnel will proceed to deliver the vehicle to the launch rail.

1. Install Rocket on Rail
   a. Two team members supporting both front and rear of vehicle.
   b. With rocket practically horizontal to rail (which is in horizontal position on ground) slide rear rail button into rail.
   c. Slowly slide rocket onto rail making sure not to torque rail button.
   d. Slide front rail button into rail and slide rocket almost to the bottom of rail.
   e. One team member must support rocket against rail.

2. Raise rail until remaining hole is aligned with the fourth hole from bottom of the Rail holder (ensure rocket bottom does not interfere with raising of rail).

3. Insert bolt into fourth hole from the bottom of the rail holder through the rail and out the opposite hole in the rail holder. Screw on nut and using both wrenches tighten nut.

4. Using both wrenches tighten nut in second hole from bottom of rail.

5. Remove wrenches from pad and place in tool box.

Once the vehicle is vertical on the launch rail and verified secured, the recovery altimeters MUST be turned on prior to igniter insertion.

1. Place step stool next to launch rail.
2. Ensuring proper screwdriver in hand, stand on stool and tighten primary screw switch until primary altimeter powers up. (Do not bump or lean on vehicle!)
3. Listen for proper altimeter continuity beep sequence.
4. If proper beep sequence is identified, place step stool on opposite side of launch rail.
5. Stand on stool and tighten secondary screw switch until secondary altimeter powers up.
6. Stand on stool and tighten secondary screw switch until secondary altimeter powers up.
7. Listen for proper altimeter continuity beep sequence (be careful not to confuse with primary beep sequence).
8. If sequences are not confirmed, it is suggested to power off all altimeters and remove vehicle from rail.
Installing Igniters

Procedure
Once the altimeters are powered on correctly and verified the motor igniters may be installed.

1. Separate the ends of the leads of the igniter and strip 1 to 2 inches of insulation off the wires.
2. Verify the continuity of the igniter using a multi-meter.
3. Remove nozzle cap and insert igniter into motor opening (ensuring leads are not touching) until igniter reaches top of motor.
4. Mark bottom of igniter at this point (or hold with thumb), and kink igniter at 90 degrees at this point while removing from motor. Verify length of igniter from kink-to-tip is approximately the same length as the motor.
5. Slide igniter through hole in nozzle cap, and re-insert in to motor. Kink should sit inside nozzle cap. Replace nozzle cap on bottom of motor.
6. Clip the launch system leads to the igniter wires ensuring they cannot touch. Wrap igniter leads around alligator clips of launch system leads for good continuity.
7. Verify the continuity of the system.
Post-Flight Inspection

Procedure (in the field)
1. Locate the rocket and ensure it can be recovered safely.
2. Power down the altimeters by opening the screw switches (note the audible beeps and the altitude reached first).
3. Verify all ejection charges have fired by careful inspection (do not move the rocket).
4. If live charges are noticed, carefully open avionics bay and disconnect charges from altimeter. Cut the lead ends so they cannot make contact.
5. Inspect vehicle on the ground for any noticeable damage and/or missing parts. If parts are missing, search area around landing zone for missing parts.
6. Inspect parachutes for damage. If none found, disconnect from shock cords for transportation back to workstation.
7. Locate the payload and ensure it can be recovered safely.
8. If payload did not deploy from vehicle, ensure the ejection charge safety switch is in the off position.
9. Transport payload section (if payload still inside) in the vertical direction.
10. Return all vehicle sections to the workstation.

Procedure (at the bench)
1. If necessary, remove shear pins on nosecone and remove nosecone slowly.
2. Slide payload out of payload tube by tilting open end down.
3. Ensure payload ejection charge is fired, otherwise clip lead ends.
4. Inspect payload chassis and wheels for damage.
5. Inspect airframe in more detail for damage, including fin section.
6. Remove motor retainer and slowly remove motor casing (Caution: it may be hot!)
7. Inspect motor casing while removing the motor reload. Note any irregularities such as burned through liners, damage to casing, bulges in casing to damage to threaded closures.
8. Dispose of motor properly and clean the casing as soon as possible.
9. Remove boat tail, followed by motor mount tube and fin assembly. Inspect for damage.
10. Disassemble avionics bay while noting any damage or loose components. Clean bulkheads with cleaning wipes to remove ejection charge residue.
11. Clean the ejection charge residue from the inside of the parachute tube.