2012-2013 University of Minnesota Team

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1. Summary of PDR Report

1.1 Team Summary
Name: Gopher Throttle Up Rocketry
School: University of Minnesota
107 Akerman Hall
110 Union St SE
Minneapolis, MN 55455
Team Official: Dr. William Garrard
Team Mentor: Gary Stroick (TRA 5440 – Level 3 Certified)

1.2 Launch Vehicle Summary
Overall Length: 122.75 inches
Diameter: 6.160 inches
Span Diameter: 22.315 inches
Gross estimated weight: 49.00 lbs
Motor: Cessaroni Pro75 4-Grain L class (L2375P)
Total Impulse: 4687.94 N-s
Recovery (Dual Deploy): Main Parachute – Fruity Chute 120 Iris Ultra
Drogue Parachute- Rocketman Mach II 36"

The milestone review flysheet is available as a separate document on the team’s website.

1.3 Payload Summary
The payload objective is to deploy a small, remotely-controlled rover to collect atmospheric data. The rover will be equipped with a camera, to transmit a live video feed to the ground station, as well as a data logger that will collect and store temperature, relative humidity and solar radiation readings. 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’s maximum dimensions in flight configuration form a cylinder with a diameter of seven inches and a length of thirteen inches. The rover is to weigh no more than seven 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.

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 Proposal

2.1 Changes Made to Launch Vehicle
The over length of the vehicle has increased to 10', and center of gravity and center of pressure have moved. The positions of the main and drogue chutes have been reversed since proposal design. In addition, the vehicle has incorporated a removable fin and motor mount system. The body tubes will feature imbedded circuitry to allow the screw switches to be placed 6 feet from the bottom of the vehicle.

2.2 Changes Made to Payload Criteria
There are a few changes that were made to the rover “Inquisitivity” that will be the payload implemented into the rocket. The main change is that since the rover will have to be more condensed than previously thought, smaller components will have to be implemented into the changed design. First the design will not contain two inside walls to support the axle due to the decrease in required length for the payload. This will mean that the chassis will have to be made in such a way to reinforce the rover since there will be less support on the axle than previously designed. Due to this as well, its closed diameter will now be 5.5 inches with an open diameter of 10 inches, which is smaller than previously designed. Another change is that “Inquisitivity” will be using high torque servos instead of electric motors as these are more efficient in size and still will be able to accomplish what is required of the rover.

2.3 Changes Made to Activity Plan
Critical testing deadlines have been solidified and the team has planned for more project time invested in verification of vehicle systems. The half scale launch has been pushed back as well.
3. Vehicle Criteria

3.1 Selection, Design and Verification of Launch Vehicle

The vehicle is required to reach a target altitude of 5280 feet and successfully deploy a science and engineering payload.

During the flight, the vehicle must lift off on an L-class or lower commercial available solid propellant motor, remain subsonic, structurally sounds, and aerodynamically stable. Upon decent, the vehicle will detach into three 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 Vehicle will be easy to assemble, and light weight structure

Successful mission criteria includes Safely launching the vehicle, reaching the target altitude, and successfully deploying the rover, and safely recovering the rover and vehicle The vehicles components and systems are designed to enable a successful mission.

![Figure 1: Overview of major vehicle components and dimensions](image)

3.1.1 Success Criteria

Successful mission criteria includes:

- Safely launching the vehicle,
- reaching the target altitude, and
- successfully deploying the rover, and
- safely recovering the rover and vehicle The vehicles components and systems
Figure 2: Main mission overview with major flight events.
3.1.2 Systems Review

**Figure 3: Overview of major systems and components**
3.1.3 Booster Section Schematics

The booster section contains the fins, motor and houses the pressure cylinder for the air-brake system. Detailed description of these parts, their function performance characteristic will be discussed below.
3.1.4 Motor Mount

To reach the target altitude, the motor mount must secure the motor to the vehicle and allow for safe static force transmission along the airframe of the rocket. The motor must not jettison from the vehicle during launch nor allow the motor to become free of the motor mount.

Our sized rocket runs on the Cessaroni L2375 motor, and the vehicle configuration is built around its commercial 75mm diameter. For our selected motor, this force is anticipated to be $T = 625 \text{ lb}$

![Diagram of motor mount and dimensions](image)

Figure 6: Dimensions and configuration of the motor mount

3.1.5 Transition

Reaching the target altitude can also be accomplished through drag reduction of the exterior body. The bow tail transition accomplishes this while adding additional motor mount length to the vehicle. A bonus to the gives the vehicle a variety of motor options without the need to redesign body tubes and makes major component configurations.

To ensure the transition will not detach from the booster tube, it’s shoulder will be screwed into the wall of the body tube with 6 steel 2-56 screws.
Also, to avoid manufacturing challenges beyond the scope of the team, the transition will be purchased from Public Missile™.

3.1.6 Centering Rings

To keep the motor in line with the over center of mass of the vehicle, centering rings shall be implemented. The rings must not yield to lateral stress during launch, and must be manufactured within enough precision to ensure thrust vector of the motor is in line with the vehicle’s center of mass.

Most importantly, the rings must transmit the static loading of motor mount to the rest of the vehicle. The team intends to use epoxy and fillets to ensure a secure bond to the vehicle.

Schematics of Middle and Aft Centered Rings

Figure 7: Middle centering ring 2D. The slots stabilize the base of the fin.
Figure 8: Front and aft centering ring 2D made of G10 Fiberglass. The slots lock the fin tabs in place.
3.1.7 Fins

In order to provide a convenient means for testing a variety of fin plan-forms, tapering, airfoils and fin geometry in general, the team has designed a mechanism for removable fins. This functionality will allow for the ease of fin replacement and transportation. Below is the current fin design as well as the mechanism for removability integrated into the centering rings located in the rocket booster.

![Figure 9: Fin Parameters](image_url)

The team has decided to adopt the clipped-delta plan-form as their primary fin shape. This plan-form provides the greatest potential in fin drag optimization at subsonic speeds in comparison to the more basic parallelogram plan-forms. This is due to the difference in root and tip chord lengths which allow for purposeful radial tapering in the future. In general, research has indicated that the clipped-delta plan-form is ideal for subsonic flight.

Although research has shown that optimal tip chord to root chord ratio should be 0.5 and optimal wing span to root chord ratio is 1, initial projected parameters indicated an unexpectedly large mass contribution using G10 fiberglass. Since g10 fiberglass provides near isotropic shear modulus elasticity which is desired in flutter velocity calculations, the team decided to temporarily alter the fin parameters rather than
change fin material in order to resolve the design conflict whilst maintaining a margin of stability margin close to 2 (2.3) in aims of satisfying NASA ULSI requirements.

Figure 10: Fin planform

With these changes, fin thickness requires further adjustment to satisfy a safety margin of 15%-20% for fin flutter velocity considerations. For a fin of thickness t, root chord length Cr, tip chord length Ct and semi-span b, the flutter velocity boundary equation is given by,

\[
v_f = a \sqrt{\frac{G_E}{(1.337)(AR^2)(P)(\lambda + 1)}} \sqrt{\frac{2(AR + 2)(\frac{t}{Cr})^3}{2}}
\]

where,

- \( v_f \) = flutter velocity
- a = speed of sound = \( \sqrt{(1.4)(1716.59)(T + 460)} \) ft/s
- T = temperature at altitude = \( (59 - 0.00356h) \) °F
- h = altitude of maximum velocity (burnout)
- AR = panel aspect ratio = \( \frac{b^2}{S} \)
- S = \( \frac{1}{2}(Cr + Ct)b \)
\[ P = \text{air pressure at altitude} = \frac{2116(T + 459.7)}{518.6^{5.256}} \text{ psi} \]
\[ \lambda = \text{taper ratio} = \frac{C_t}{C_r} \]

### 3.1.8 Airbrakes System

#### Overview

The airbrake system is designed to increase the control of the vehicle between launch and apogee. The braking system would incorporate a pressurized tank that releases jets of air transverse to the direction of propagation of the rocket. The main mechanism by which the transverse jet induces drag is via inducing pressure drag. The transverse jet produces a region of high velocity flow perpendicular to the flow of air along the rocket. This forms a pressure boundary normal to the flow, with the highest pressure gradient occurring at the point of flow transverse on the surface of the rocket. As a result one experiences flow separation at the boundary layer on the rocket. This flow separation induces a significant pressure drag on the rocket. Additionally the flow behind the jet shall be highly turbulent with local vortices adding to the drag.

By putting such a system in place reduces the mechanical complexity of the rocket by removing mechanical systems associated with the retractable spoiler assembly, reducing the overall cost of the rocket. Additionally, such a set up can provide empirical data for the study of jets in cross-flow, which shall be useful in better understanding transverse jets, and vector thrust systems over the velocity ranges covered by the rocket.

It has been proven that the drag produced by the system is dependent on the ration of free stream velocity to the exit velocity of the jet, hence as the altitude of the rocket increases and the rocket slows down, our system will have greater sensitivity. Another important factor is the surface material used behind the jet, as the nature of the surface determines the distance after which
Implementation

Tank: Currently we have selected a carbon fiber high pressure tank manufactured by Ninja Paintball. The tank has a volume capacity of 90 in$^3$ and can store gasses at 4500psi. The tank can have output pressure up to 850psi. The tank is 12in long and has a diameter of 4.5in hence can fit into the 6in rocket diameter.

Figure 11: 2-D model of the expected disturbance Behind a Transverse jet (Muppidi and Mahesh, August 2012)

Figure 12: Ninja Paintball carbon fiber tank that is expected to be used in the rocket
**Fluid Used:** The system will be using nitrogen, as the gas for the transverse jets. Nitrogen was chosen between air and Carbon Dioxide. All three gases are readily available commercially. The rationale behind choosing nitrogen is tabulated below:

<table>
<thead>
<tr>
<th>Gas</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>• Very cheap</td>
<td>• Moisture produces uneven Pressure output • Moisture is less stable to maintain under pressure at varying temperatures.</td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>• Contains No moisture • Stable to store • Produces consistent output • Is a fire retardant and hence is safe to use in conjunction with the motor</td>
<td>• Relatively Expensive</td>
</tr>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>• Cheap • Stored as a liquid hence one can store more volume • Is a fire retardant and hence is safe to use in conjunction with the motor</td>
<td>• Can cause seals to freeze and fracture • Can cause frosting on rocket surface on a moist day • Produces uneven Pressure output at low temperatures</td>
</tr>
</tbody>
</table>

*Table 1: Comparison of commercially available gases for airbrake system*

**Dispensing Mechanism:** Nitrogen will be stored under high pressure in the above mentioned tank. The tank as shown has one outlet. There shall be a solenoid valve at this valve that releases the air that travels through the pipes to the system of four axis-symmetric dispensing nozzles.

These nozzles will be located 1 inch below the center of mass of the rocket. As the transverse jet would move the center of pressure towards the position of the jet, this setup is intended to maintain stability during braking by keeping the center of pressure beneath the center of mass.

The team is deciding between a conventional nozzle and an aerospike nozzle for the rocket. While a conventional nozzle may be bought commercially, the University of Minnesota has machining facilities capable enough to manufacture the spike and the cowl for the aerospike nozzle. The advantage of the aerospike nozzle is that it can provide constant pressure output at all altitudes.
Wind tunnel tests will be used to determine the effectiveness of the system to produce drag. The choice between the nozzles will be made on the basis of test flight performance of the system on the half scale rocket.

**Control Mechanism:** The airbrake system is controlled by an ArduMega Microcontroller and a dedicated AIM – XTRA altimeter and a gyroscope located in the rear avionics bay. The gyroscope would provide the microcontroller with the vertical speed of the rocket and the altimeter would give it, the current altitude of the rocket. The microcontroller will be programmed such that it will compare the vertical speed and altitude data and if corrective measures are required it shall open the solenoid valve to deploy the airbrakes. Upon correction the microcontroller shall close the valve.

**Pressure Tank and housing:** The volume space allocated for the tank is currently a conservative estimate. Flight testing will determine the final size of tank needed to guide the rocket to the target altitude. Currently we plan on using a 4.5” diameter and 12” long commercially available paint ball tank. The mount of this tank is required secure the tank during launch and deployment accelerations. The tank mount was also decided to offer affordance for tank size, and can be seen below.
**Figure 13:** Exploded view of pressure tank mounts. The mount is bolted to the aft bulkhead and fixed to the wall of the booster tube. The base plate is supported by the walls of the body tube and provides

**Figure 14:** Trimetric and close-up of mount. The Collar and Base Plate slide between the fixtures and are then rotated to align with the fixtures. A coder pin is used to prevent slipping during the flight, and the plates themselves offer a friction fit against the walls of the tube as well. The arrows indicate the direction of tension forces during launch, and will be the biases for future analysis of this system.
3.1.9 Avionics

There are two avionics bays in the rocket design shown in Figure 3.1.11.

![Forward and Aft Avionics Bays](image)

*Figure 15: Forward and Aft Avionics Bays (circled) shown on a Rocksims 2-D drawing.*

The front avionics bay will provide signals for main parachute deployment as well as payload deployment. The aft avionics bay will provide signals to deploy the drogue parachute and will house the microcontroller that will control the airbrake system. Each avionics bay will contain two altimeters, two power sources, and two on-off switches (Table 3.1.3) in compliance with the USLI guidelines for redundancy.

<table>
<thead>
<tr>
<th>Components</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raven3 Featherweight Altimeter</td>
<td>3</td>
</tr>
<tr>
<td>Redundant altimeter Entacore AIM USB (front avionics bay)</td>
<td>1</td>
</tr>
<tr>
<td>Redundant altimeter Entacore AIM XTRA. The AIM EXTRA also doubles as GPS tracker for Recovery (aft avionics bay)</td>
<td>1</td>
</tr>
<tr>
<td>9 Volt Battery</td>
<td>4</td>
</tr>
<tr>
<td>Screw Switch</td>
<td>4</td>
</tr>
</tbody>
</table>

*Table 2: Electrical components for avionics bays*

![Featherweight Raven3 Altimeter](image)

*Figure 16: Featherweight Raven3 Altimeter*
Table 3: Featherweight Raven2 Specifications

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Featherweight Altimeters LLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Accel range and frequency</td>
<td>70-g, 400 Hz</td>
</tr>
<tr>
<td>Lateral Accel frequency</td>
<td>35-g, 200 Hz</td>
</tr>
<tr>
<td>Download Interface</td>
<td>USB</td>
</tr>
<tr>
<td>Power Supply</td>
<td>9 volts DC</td>
</tr>
<tr>
<td>Max output</td>
<td>9 amps</td>
</tr>
<tr>
<td>Size</td>
<td>0.8” x 1.8” x 0.55”</td>
</tr>
</tbody>
</table>

Figure 17: Entacore AIM EXTRA

Table 4: Entacore AIM EXTRA specifications

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Entacore Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Acceleration Range</td>
<td>16-g</td>
</tr>
<tr>
<td>Linear Acceleration range</td>
<td>100-g</td>
</tr>
<tr>
<td>Download Interface</td>
<td>USB</td>
</tr>
<tr>
<td>Power Supply</td>
<td>9 volts DC</td>
</tr>
<tr>
<td>Max output</td>
<td>4 amps</td>
</tr>
<tr>
<td>Transmission Frequency</td>
<td>433.92 MHz</td>
</tr>
<tr>
<td>Antenna Power</td>
<td>100 mW</td>
</tr>
<tr>
<td>Tracking Range</td>
<td>10 km</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Memory</td>
<td>2 MB Flash Memory</td>
</tr>
</tbody>
</table>

2012 – 2013 USLi Preliminary Design Review
Figure 18: Entacore USB

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Entacore Electronics</td>
</tr>
<tr>
<td>Lateral Acceleration Range</td>
<td>16-g</td>
</tr>
<tr>
<td>Linear Acceleration range</td>
<td>100-g</td>
</tr>
<tr>
<td>Download Interface</td>
<td>USB</td>
</tr>
<tr>
<td>Power Supply</td>
<td>9 volts DC</td>
</tr>
<tr>
<td>Max output</td>
<td>4 amps</td>
</tr>
<tr>
<td>Sampling Frequency</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Memory</td>
<td>60 minutes of Flight Recording (Re-recordable)</td>
</tr>
</tbody>
</table>

Table 5: Entacore AIM USB specifications

Orientation and Wiring

The altimeters will be oriented axially to ensure accurate altitude results and the batteries will be oriented with the terminals facing the ground. Screw switches will be implemented to be turned on through a small hole in the airframe at launch. Due to symmetry from redundancy, the wiring schematics are shown in Figures 3.1.13 and 3.1.14 for only one half of each avionics bay.
Figure 19: Front avionics bay wiring schematic (shown without redundant system)

Figure 20: Aft avionics bay wiring schematic (shown without redundant system)
**Avionics Housing**

The avionics will be mounted onto a sled supported to 3/8” diameter stainless steel threaded bolts holding altimeters and batteries into position. The bolts also seal the house through the use of steel nuts. The tray will be made from G12 fiberglass.

The forward Avionics Bay is required to main parachute electronic hardware. The configuration is derivative of last year’s successful design, and has not greatly been altered for the current design.

The Aft Avionics Bay is required to house drogue and airbrake electronic hardware. The configuration is derivative of last year’s successful design, and has not greatly been altered for the current design.

Critical to the success of this system is the reliability of being armed by a screw switch situated in the Payload bay section of the vehicle. Wire must be trenched from the forward portion of the vehicle the aft most.

In order to accomplish this, the team has proposed embedding insulated copper wire into the composite layup of the carbon fiber tube and using a simple plug to bridge the connection to the couplers. Plug simply detach during Black powered detonation, at which point they will have fulfilled their purpose.

![Figure 21: Cross section of proposed airframe tube illustrating embedded copper in carbon fiber epoxy matrix. These wires are shielded from the blast of the black powder using this approach.](image)

**3.1.10 Aft Bulkhead**

To allow access to the avionics systems while the vehicle is disassembled, the Aft Bulkhead is removable, and mounted to the entire booster section though threaded bolts. Steel U-bolts are mounted on the end of the bulkhead to mount shock chords.

This bulkhead must be able to take the anticipated 10g loading of launch and drogue chute deployment. Child systems to the bulkhead affected by these stresses must also prove sufficient.
The Aft Bulkhead and Forward bulkhead will also experience the high shear stress during parachute chute deployment. It is anticipated that the parachute will impart 20 g's of shock acceleration to the U – bolts mounted to the bulkheads. To lower the stress intensity, washers shall be implemented to ensure safe deployment and avoid shear failure.

\[
\tau = \frac{P}{A}, \quad A = D\pi t
\]

Assuming chute may have to support a \(2P = 50 \text{ lb}\) load accelerated at 20 g's, the thickness of the g10 plate to be \(t = 0.25''\), and washer diameter of \(D = 1''\), it is found that \(\tau = 636 \text{ Psi}\). This is well within G10's \(\tau_{\text{ult}} = 22Ksi\), and the team will consider optimizing washer diameter in later designs to save mass.

### 3.1.11 Parachute Tube

**Separator Bulkhead**

To regulate the deployment of parachutes, the air tight bulkhead is placed between the main and drogue parachute. Steel U-bolts are mounted on either of the bulkhead to mount shock chords. This bulkhead is permanent, and must be designed to withstand shock force during deployment, and the weight of the vehicle during decent.

**Forward Bulkhead**
To allow access to the avionics systems while the vehicle is disassembled, the Forward Bulkhead is removable, and mounted to the entire booster section through threaded bolts. Steel U-bolts are mounted on the end of the bulkhead to mount shock chords.

This bulkhead must be able to take the anticipated 10g loading of launch and the 20g acceleration of main chute deployment. Child systems to the bulkhead affected by these stresses must also prove sufficient.

### 3.1.12 Nose Cone

Primary to the requirements of the nose cone are drag reduction. To avoid complex manufacturing demands, the team has opted to purchase a fiberglass 6” nosecone from Public Missiles™. Shear pins will keep the nosecone in place during the flight, and will shear during rover deployment.

### 3.1.13 Carbon Fiber Tubes

The state of the art for lightweight, reusability, and survivability of aerospace belong to carbon fiber structures. Creating the entire external airframe from carbon fiber as opposed to conventional phenolic can reduce its respective mass by 60% while at the same time creating a structure that is resistant to hazardous failure modes within high powered rocketry. It is thus advantageous to build our airframe from the carbon fiber.

However, given the cost to contract these custom tubes to a local manufacturer, the team will be required to manufacture them. Given the large cost and resource risk involved with the task, the team is currently running a low risk feasibility study with scaled down composite tubes made of fiberglass. This will assess our ability to manufacture full sized tubes (see section 3.3)

![Diagram of carbon fiber tube experiencing cross-sectional loading from the launch acceleration.](image-url)
The preliminary design for the tubes is aimed to satisfy the loading the vehicle experiences during launch and flight events. Since the primary loads are static, and 10 times the acceleration of gravity, the tube was designed to meet these specific quantities with a safety factor $SF = 2$.

These tubes can be modeled as free standing columns, with the governing equation as the design parameter.

$$\sigma_{cr} = \frac{F_{cr}}{A} = \frac{\pi^2 E}{\left(\frac{L}{k}\right)} , \quad k = \sqrt{\frac{J}{A}}$$

For a thin walled tube,

$$A = d\pi t , \quad J = \frac{d^3 \pi t}{4}$$

Assuming a $F = 50lb$ and 10 g acceleration, an effective tube length of $L = 2l$ and that the modulus of elasticity of carbon fiber-epoxy in compression is $E = 20 \text{ Msi}$, a matlab script was created the evaluated stress during launch against wall thickness for tubes with $d = 6"$

Similarly, the critical stress for buckling failure was plotted against tube length and found to be a negligible failure mode for the same rocket tubes.
Figure 24: Plots of predicted performance for 6.007” diameter carbon fiber tubes. In the top plot, the stress for even single layer of 3K weave is within limits, suggesting excellent performance of the material. The bottom plot show that the any of the tubes will not buckle under 10g loading.

Since all of these carbon fiber options meet the base stress performance requirements, selection of fiber material is shall be determined based on survivability requirements including “zippering” (shock cord shearing through tube) and high impacting with the ground.
<table>
<thead>
<tr>
<th>Tube Material</th>
<th>Fabric oz/yard^2</th>
<th>Tube Wall thickness (inch)</th>
<th>Mass / Length with Laminate (oz/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenolic</td>
<td>n/a</td>
<td>1/16</td>
<td>9.25</td>
</tr>
<tr>
<td>6K Harness Carbon Fiber</td>
<td>10.9</td>
<td>1/16</td>
<td>4.091</td>
</tr>
<tr>
<td>6K Plain Carbon Fiber</td>
<td>8.9</td>
<td>1/16</td>
<td>4.303</td>
</tr>
<tr>
<td>3K Plain Carbon Fiber</td>
<td>5.9</td>
<td>1/16</td>
<td>3.9179</td>
</tr>
</tbody>
</table>

Table 6: Tabulated data for common carbon fiber weaves against conventional Phenolic Tubing. The mass advantages are self-evident.

Research into composite material has revealed that these advantageous mass properties shown above can be easily achieved with carbon fiber. The table shows that if the tubes can be manufactured, they can be over half the weight of a conventional phonic tube and can withstand acceleration up to and beyond 20 g’s of static loading.

Since the desired tubes have simple geometries, the team has opted to use a 6K Plain Carbon Fiber weave. The weave is easier to sand without de-laminating the matrix, and is more cost effective than the other fibers. To laminate the fibers, the team has determined that the performance properties of marine grade epoxy from Adtech™ will allow the tubes to pass the verification requirements.

Given the complexities of manufacturing composite tubes, the team has begun a feasibility study to make scaled down tubes from scrap fiberglass and resin. If the manufacturing process is successful, these tubes shall meet the airframe requirements for the vehicle.

### 3.1.14 Shear Pins

During flight, the team shall utilize shear pins to avoid a premature deployment of recovery systems and payload. The pins must yield to black powder detonation.

For nylon 2-56 thread screws (McMaster-Carr 93135A017), the ultimate shear strength is assumed to be \( \tau_y = 11 \text{ K}si \). Assuming each pin shears across the diameter of its screw, the force to break each pin can be calculated with

\[
P = \tau_y A, \quad A = \frac{\pi d^2}{4}
\]
Choose the inner pitch diameter of \( d = 0.0717'' \), gives required force of \( P = 44.4 \text{ lb} \). Assuming a 10% margin for uncertainty, the minimum required force to remove the pin is \( P \approx 50 \text{ lb} \).

Adding more shear pins increase the required deployment force proportionally. For example, 2 pins will require \( P = 100 \text{ lb} \) for shearing. The table below relates decent accelerations to major vehicle connection and shear pin estimates. The weights are the gravitational weights after vehicle apogee and assuming a nose down trajectory.

<table>
<thead>
<tr>
<th>Connection</th>
<th>Loaded Weight post apogee lb</th>
<th>Maximum G factor</th>
<th>Shear pin count (1.25 safety factor and rounded up to nearest odd number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose Cone – Payload Tube</td>
<td>12</td>
<td>20.9 (main parachute deploy)</td>
<td>7</td>
</tr>
<tr>
<td>Payload tube – Parachute tube</td>
<td>22</td>
<td>3 (estimated airbrake deployment)</td>
<td>3</td>
</tr>
<tr>
<td>Parachute tube – Booster tube</td>
<td>34</td>
<td>3 (estimated airbrake deployment)</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 7: Performance table of 2 – 56 Nylon shear pins.*

These shear pin configuration represent the minimum required to avoid premature separation of vehicle components.

It must be noted that these shear pins have been known to fail at \( P = 35 \text{ lb} \). These leads to an uncertainty of +/- 1 pin count, and will be taken into consideration for ground test of the deployment.

### 3.1.15 Rail Buttons

The rail buttons shall be compatible for 10 – 10 rail. The profile of the 10-10 rail button is smaller ensuring that commercial rail buttons shall have the a smaller drag profile.

Presently, the team has only considered purchasing commercial rail buttons, but the altitude benefits of retractable or streamlined rail buttons has been noted by the team and will be evaluated in the future.

### 3.1.16 Bonding
Previous rocketry experience has shown that the best option for high strength and lightweight assembly of the vehicle is epoxy. Since the team is using fiber glasses and epoxy materials for most of its components, these adhesives will readily bond to parts with minimal need to key joining surfaces or fillet parts. It must be noted though that applying these adhesives is a permanent fixture, and has been chosen with care for the presented design.

For bonding technique, the team will practice fillet’s for reinforcing lap bonds of epoxy. The radius of the fillet $R$, will be designed for redundancy of JB weld Epoxy’s ultimate lap shear of $\tau_y = 1000 \text{ psi}$. For additional safety and avoidance of CATO, the centering rings and motor mounts shall have a bond radius of $R = 3t$, where $t =$ bond line $= 0.25"$. In practice, this produces an addition bonding strength of 9000 psi.

### 3.1.17 Manufacturing

The team currently possesses the facilities to fabricate all the vehicle’s primary composite parts using vacuum bagging techniques as well as any alloy or G10 fiberglass machining needs that the team will encounter.

However, special attention must be kept to details including jigs, fiber alignment, and tooling and gluing techniques to ensure that designed parts can be manufactured.

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 risk.
3.1.18 Composites

Given the inherit complexities in designing composite materials and the affects the manufacturing process can impart of material performance, all composite components will undergo static tests to ensure they meet the vehicles requirements. If static loadings are not applicable, tests article of the part will be manufactured to their predicted performance, and then flight tested for verification.

Further, given that the manufacturing process of these tubes can be time consuming, and expensive process, prototypes scaled down prototypes made with inexpensive fibers and resins (fiberglass and polyesters) will be made to verify the team’s ability to manufacture the full scale part to acceptable performance requirements. The team has already begun this feasibility study for the air frame’s carbon fiber tubes, and will conduct similar studies for additional composite parts.
Upon completion of a prototype part, the part must undergo functionality tests to validate further vehicle integration and static tests if the part is to experience loading during the mission. Successful parts will be considered for optimization if resources permit so.

As part of a contingency plan, the vehicle was designed using known commercial parts from Public Missiles™. In the event these tubes do not pass verification, commercial parts will be substituted and the rocket performance reevaluated.

### 3.1.19 Parts and Operations

Mission events shall be simulated preflight to team’s best abilities in the laboratory or appropriate testing facilities. All deployment systems shall be tests on the ground to ensure correct shear pin configurations before full vehicle integration Air breaking systems shall undergo test deployments prior to all launches

Designed parts that meet vehicle integration will be demonstrated during future flight test up until final verification test flight. Afterwards, no changes in part design the will affect mission performance or fail verification may be manufactured.

Further, the team intends to supply the necessary spare parts to ensure a successful mission in the event of unpredictable catastrophe to parts or components while traveling or on the flight line.

### 3.1.20 Verification Metrics
The table is a means to keep track of requirements and verification statuses

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Design feature satisfying requirement</th>
<th>How the requirement will be verified</th>
</tr>
</thead>
<tbody>
<tr>
<td>The launch vehicle shall carry a science or engineering payload</td>
<td>The vehicle has a payload bay defined in section III is capable of housing our designed rover payload in defined in section IV</td>
<td>Lift capability of vehicle shall be predicted with Rocksim and verified with full scale test launch</td>
</tr>
<tr>
<td>The launch vehicle shall deliver the science or engineering payload to, but not exceeding an altitude of 5,280 feet above ground level.</td>
<td>Performance of vehicle is predicted with Rocksim with proper mass allocation with respect to motor performance. Air braking system shall reduce trajectory speed to ensure reaching target altitude</td>
<td>The airbrake system shall be simulated using CFD techniques. The system will be priority during half scale testing</td>
</tr>
<tr>
<td>The vehicle shall carry one altimeter to be determined for recording the official altitude used in the competition.</td>
<td>Installation space included in avebay design</td>
<td>Our full scale test flight as well as material compression tests will be used to verify the strength of the avionics bay.</td>
</tr>
<tr>
<td>The recovery system shall be designed to be armed on the pad.</td>
<td>Body of tube will have hole to allow screw switch activation using screwdriver</td>
<td>Lab testing of hardware functionality</td>
</tr>
<tr>
<td>The recovery system electronics shall be completely independent of the payload electronics.</td>
<td>There is no electrical connection between the avionics bay and the payload.</td>
<td>N/A</td>
</tr>
<tr>
<td>The recovery system shall contain redundant altimeters.</td>
<td>There will be two sets of redundant altimeters for the drogue and main parachute events. Avionics systems are further defined in section 3.1.9</td>
<td>The redundancy of the altimeters and the electrical circuitry will be tested on the ground using a vacuum chamber to simulate changes in barometric pressure for the altimeters</td>
</tr>
<tr>
<td>Requirement</td>
<td>Design feature satisfying requirement</td>
<td>How the requirement will be verified</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Each altimeter shall be armed by a dedicated arming switch.</td>
<td>Four screw switches will be supplied for the four separate altimeters.</td>
<td>Ground testing of the avionics bay circuitry will be done to ensure each switch is connected to only one altimeter.</td>
</tr>
<tr>
<td>Each altimeter shall have a dedicated battery.</td>
<td>Four 9V batteries will be supplied for the four separate altimeters.</td>
<td>Ground testing of the avionics bay circuitry will be done to ensure each battery is supplying power to only one altimeter.</td>
</tr>
<tr>
<td>Each altimeter arming switch shall be accessible from the exterior of the rocket airframe.</td>
<td>Hole in body tube to allow screw switch arming</td>
<td>Each switch is grounded tested before launch</td>
</tr>
<tr>
<td>Each altimeter arming switch shall be capable of being locked in the ON position for launch.</td>
<td>Screw switch design locks upon activation</td>
<td>Switched shall be designed to ensure complete circuit during all mission events</td>
</tr>
<tr>
<td>Each altimeter arming switch shall be a maximum of six feet above the base of the launch vehicle.</td>
<td>arming switches shall be 6 feet above base of vehicle. Wires to respective AV bays will ensure arming of components</td>
<td>Tape measure shall be used to verify this distance</td>
</tr>
<tr>
<td>The recovery system electronics shall be shielded from all onboard transmitting devices.</td>
<td>The RF tracker is placed in the nose cone, while the payload's transmitter is separated from the tracker by over 2 ft. The GPS tracker is placed in the aft avionics bay and thus is more than 2 ft. from either of the other two transmitters.</td>
<td>We will have multiple tests at placing each of the transmitters at their planned distances apart. to check if any interference is observed between the electrical systems.</td>
</tr>
<tr>
<td>Requirement</td>
<td>Design feature satisfying requirement</td>
<td>How the requirement will be verified</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>The launch vehicle and science or engineering payload shall be designed to be recoverable and reusable.</td>
<td>All payload materials are made of metal or strong composites. The vehicle is made from carbon fiber tubes and G10 fiberglass. An RF tracker is placed in the nose cone for tracking purposes, and the material performance characteristics of the chosen composite material shall ensure reusability.</td>
<td>We will do tensile and compression test on the G10 fiberglass to ensure structural strength to absorb impact, and similar test for the carbon fiber tubes as well. We will also be using the same RF tracker in the ½ scale testing to make sure the tracker is working properly.</td>
</tr>
<tr>
<td>The launch vehicle shall stage the deployment of its recovery devices.</td>
<td>The rocket will have 4 altimeters. Two, for redundancy purposes, will be activated at apogee to release the drogue, and two will be activated at 800ft. altitude to release the main parachute.</td>
<td>We will test that the altimeters are working properly with ½ scale testing.</td>
</tr>
<tr>
<td>Removable shear pins shall be used for both the main parachute compartment and the drogue parachute compartment.</td>
<td>The current design of deployment for the main and drogue parachutes is by using black powder charges large enough to break the shear pins used to keep the airframe together during flight.</td>
<td>Shear pin calculations will be tested on the ground to ensure the charges are large enough to deploy each parachute. The shear pin strength will also be designed to withstand the forces from the deceleration of the airframe due to the parachutes and will be tested at the full scale test launch.</td>
</tr>
<tr>
<td>The launch vehicle shall have a maximum of four independent or tethered sections.</td>
<td>The airframe has four sections (nosecone, payload/main parachute tube, booster tube) which are all tethered together.</td>
<td>N/A</td>
</tr>
<tr>
<td>Requirement</td>
<td>Design feature satisfying requirement</td>
<td>How the requirement will be verified</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>At landing, each independent or tethered section of the launch vehicle shall have a maximum kinetic energy of 75 ft-lbf.</td>
<td>Our dual deploy parachutes will work in unison to guarantee that our kinetic energy upon landing is minimal.</td>
<td>Using simulations, such as Rocksim, and independent calculations, we will minimize kinetic energy as well as drift, by varying the area of our parachutes</td>
</tr>
<tr>
<td>The launch vehicle shall require no external circuitry or special ground support equipment to initiate the launch.</td>
<td>Our rocket only requires a standard firing system and requires no external circuitry or special ground support equipment to initiate launch.</td>
<td>N/A</td>
</tr>
<tr>
<td>Data from the science or engineering payload shall be collected, analyzed, and reported by the team following the scientific method.</td>
<td>The payload will transmit scientific data outlined in section 4 which will be analyzed and reported by our team following the scientific method.</td>
<td>The payload data transmission and collection will be tested on the ground at distances up to 2,500 feet prior to launch.</td>
</tr>
<tr>
<td>An electronic tracking device shall be installed in each independent section of the launch vehicle and shall transmit the position of that independent section to a ground receiver.</td>
<td>An RF tracker will be installed in the nosecone of the airframe as well as housed within the payload. A GPS tracker will be installed in the aft avionics bay.</td>
<td>Each transmitter/receiver will be tested prior to launch as well as at the half and full scale test launches to verify their capabilities.</td>
</tr>
<tr>
<td>The launch vehicle shall use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant which is approved and certified by the National Association of Rocketry, Tripoli Rocketry Association, and/or the Canadian Association of Rocketry.</td>
<td>We will be using a commercially available Cessaroni L2375 solid motor which is certified by the National Association of Rocketry, Tripoli Rocketry Association, and/or the Canadian Association of Rocketry.</td>
<td>N/A</td>
</tr>
<tr>
<td>Requirement</td>
<td>Design feature satisfying requirement</td>
<td>How the requirement will be verified</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>The total impulse provided by the launch vehicle shall not exceed 5,120 Newton-seconds (L-class)</td>
<td>The Cessaroni L2375 solid motor has an impulse of 4864 N-s.</td>
<td>N/A</td>
</tr>
<tr>
<td>All teams shall successfully launch and recover their full scale rocket prior to FRR in its final flight configuration.</td>
<td>We will test our design near the end of February with a mass matching that of the payload in the payload bay.</td>
<td>We have designated a strict schedule to ensure completion of the construction of our design by our preliminary test launch date.</td>
</tr>
<tr>
<td>Risk</td>
<td>Consequence</td>
<td>Mitigation</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>One or more systems fail on half scale flight test.</td>
<td>Must re-design systems.</td>
<td>Keep backup design of systems in mind, keep everyone informed of failed systems</td>
</tr>
<tr>
<td>Parts for half scale do not arrive on time.</td>
<td>Pushes schedule back, causes other delays.</td>
<td>Order parts early, contact distributors a head of time to make sure part is in stock</td>
</tr>
<tr>
<td>Parts for full scale do not arrive on time.</td>
<td>Pushes schedule back, causes other delays.</td>
<td>Order parts early, contact distributors a head of time to make sure part is in stock</td>
</tr>
<tr>
<td>Team under estimates costs</td>
<td>Project will be over budget.</td>
<td>Keep a constantly updated budget plan, and a contingency plan to secure additional funds</td>
</tr>
<tr>
<td>Team under estimates time to manufacture and assemble half scale.</td>
<td>Project will be behind schedule.</td>
<td>Plan to manufacture and assemble early</td>
</tr>
<tr>
<td>Rocket does not pass RSO inspection on competition launch day.</td>
<td>Team does not get to fly, losing major points.</td>
<td>Check constantly with NAR mentor to ensure all systems will pass safety inspection</td>
</tr>
<tr>
<td>Not enough team members to finish manufacturing and testing in time for flight tests.</td>
<td>Project seriously behind schedule</td>
<td>Abandon all non-essential systems and components in favour of on-time flight.</td>
</tr>
<tr>
<td>Team Member leaves</td>
<td>Project or Sub-system behind schedule</td>
<td>Disperse responsibilities among other people of the team</td>
</tr>
</tbody>
</table>

*Table 8: Project Risk Mitigation*
## 3.1.21 Mass Statement

<table>
<thead>
<tr>
<th>Part</th>
<th>Quantity</th>
<th>Mass (oz)</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose Cone</td>
<td>1</td>
<td>28</td>
<td>0.01</td>
</tr>
<tr>
<td>Ballast Mass</td>
<td>1</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Payload Tube</td>
<td>1</td>
<td>20.4</td>
<td>0.05</td>
</tr>
<tr>
<td>Payload</td>
<td>1</td>
<td>112</td>
<td>0.25</td>
</tr>
<tr>
<td>Piston (w/piston bulkhead)</td>
<td>1</td>
<td>7</td>
<td>0.25</td>
</tr>
<tr>
<td>Front Av bay Permanent Bulkhead</td>
<td>1</td>
<td>0</td>
<td>0.05</td>
</tr>
<tr>
<td>Front Avionics Bay Electronics</td>
<td>1</td>
<td>12</td>
<td>0.25</td>
</tr>
<tr>
<td>Front Av Bay Removable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulkhead Cap</td>
<td>1</td>
<td>3</td>
<td>0.05</td>
</tr>
<tr>
<td>Coupler 1</td>
<td>1</td>
<td>3.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Paint</td>
<td>1</td>
<td>8</td>
<td>0.25</td>
</tr>
<tr>
<td>Epoxy</td>
<td>1</td>
<td>10.66</td>
<td>0.25</td>
</tr>
<tr>
<td>Main Chute</td>
<td>1</td>
<td>49</td>
<td>0.01</td>
</tr>
<tr>
<td>Forward Rail Button</td>
<td>1</td>
<td>2.5</td>
<td>0.05</td>
</tr>
<tr>
<td>U Bolt</td>
<td>4</td>
<td>3</td>
<td>0.01</td>
</tr>
<tr>
<td>Parachute Tube</td>
<td>1</td>
<td>21.76</td>
<td>0.05</td>
</tr>
<tr>
<td>Main Shock Cord</td>
<td>1</td>
<td>21.6</td>
<td>0.05</td>
</tr>
<tr>
<td>Quick Link</td>
<td>4</td>
<td>2.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Swivel</td>
<td>1</td>
<td>1.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Chute separation bulkhead</td>
<td>1</td>
<td>2.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Drogue Parachute Shock Cord</td>
<td>1</td>
<td>12</td>
<td>0.01</td>
</tr>
<tr>
<td>Drogue Chute</td>
<td>1</td>
<td>12</td>
<td>0.01</td>
</tr>
<tr>
<td>Paint</td>
<td>1</td>
<td>8</td>
<td>0.25</td>
</tr>
<tr>
<td>Epoxy</td>
<td>1</td>
<td>10.66</td>
<td>0.25</td>
</tr>
<tr>
<td>Booster Tube</td>
<td>1</td>
<td>10.66</td>
<td>0.05</td>
</tr>
<tr>
<td>Coupler 2</td>
<td>1</td>
<td>14.96</td>
<td>0.01</td>
</tr>
<tr>
<td>Back Av Bay Removable Bulkhead Cap Head</td>
<td>1</td>
<td>3.6</td>
<td>0.05</td>
</tr>
<tr>
<td>Rear Avionics Bay</td>
<td>1</td>
<td>40</td>
<td>0.25</td>
</tr>
<tr>
<td>Pressure Tank</td>
<td>1</td>
<td>110</td>
<td>0.25</td>
</tr>
<tr>
<td>Front Centering Ring</td>
<td>1</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td>Motor mount 75mm</td>
<td>1</td>
<td>15</td>
<td>0.25</td>
</tr>
<tr>
<td>Fin mounts</td>
<td>1</td>
<td>7.6087</td>
<td>0.25</td>
</tr>
<tr>
<td>Fins</td>
<td>3</td>
<td>15</td>
<td>0.25</td>
</tr>
<tr>
<td>Transition</td>
<td>1</td>
<td>22</td>
<td>0.01</td>
</tr>
<tr>
<td>Aft Rail Button</td>
<td>1</td>
<td>2.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Aft Centering Ring</td>
<td>1</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>Motor Casing</td>
<td>1</td>
<td>64.89</td>
<td>0.05</td>
</tr>
<tr>
<td>Propellant Weight</td>
<td>1</td>
<td>81.89</td>
<td>0.1</td>
</tr>
<tr>
<td>Paint</td>
<td>1</td>
<td>8</td>
<td>0.25</td>
</tr>
<tr>
<td>Epoxy</td>
<td>1</td>
<td>10.66</td>
<td>0.25</td>
</tr>
</tbody>
</table>
For commercial supplied parts, the margin mass error is low, and these parts are considered to have highly accurate mass estimates. Care has gone into the estimates for manufactured part including conservative estimates of adhesives and paint, and is a measurement based on the paint and epoxy consumption form last year's vehicle build.

Still, it is anticipated that the mass of the vehicle will fluctuate over the course of the project. To account for this, the team has determined the margin of allowable mass for the selected motor to be $m = 821 \text{ oz}$, a margin of 7% against the calculated 13%. Although not above 25%, it should be noted that the preliminary design mass was derived from conservative estimates to begin with.

$$\text{Margin of Mass} = \frac{\text{Estimate}}{\text{Uncertainty} \times \text{Estimate}}$$

Thus, it is the team’s chief objective to observe mass changes and make appropriate changes in motor selection or component masses if needed. To afford a change in motor selection, the team’s vehicle design is able to accommodate larger motors simply by increasing the booster tube length. Increasing this length will not dramatically alter the rest of the vehicle systems or the manufacturing of the vehicle and systems.
3.2 Recovery Subsystem

3.2.1 Analysis

Main Parachute

Main parachute selection was based on four criteria: drift distance, kinetic energy at impact, force exerted at deployment, and the volume of the packed parachute. The USLI handbook specified that all independent sections of the launch vehicle must land within 2,500 ft. of the launch pad, assuming a 15 mph wind. The kinetic energy requirement, also specified by the handbook, stated that the maximum kinetic energy of an independent section upon landing must be 75 ft-lbf. The force exerted by parachute deployment was a significant consideration, since too severe of deceleration could result in severe damage to the rocket and possibly even tear the main parachute off entirely. Finally, the rocket’s parachute bay has a diameter of 6 in. and a length of 12.5 in., resulting in a total volume of 354.25 in³. Any parachute selected would need to fit within this volume, shock cord included.

Several different parachutes were investigated in order to find one that best fulfilled all of the above requirements. The three most promising parachutes were the SkyAngle Cert 3 XL, the Fruity Chutes Iris Ultra 144, and the Fruity Chutes Iris Ultra 120. RockSim simulations quickly revealed that while it met all of the other requirements, the Cert 3 XL did not reduce the descent velocity of the rocket enough to meet kinetic energy requirements. The Ultra 144 fulfilled the kinetic energy and drift rate requirements, but RockSim simulations indicated that the force exerted on the rocket at deployment was approximately 100 g’s. Furthermore, it was determined that the Iris Ultra 144 was too large to fit within the rocket without a significant redesign of the recovery section. Fortunately, the Iris Ultra 120 was found to fulfill all of the listed requirements, and so was chosen to be the main parachute.

The Iris Ultra 120 is composed of rip-stop nylon bringing the total weight of the chute to 36oz including a 6000 lb. max load rated swivel which is attached to the harness of the chute. The Fruity Chutes website provided detailed specifications for the parachute, listing its $C_D$ as 2.2 and its packing volume as 220.6 in³. Combing the listed packing volume with the 90.2in³ volume calculated for the shock cords below brings the total volume to 310.8 in³, which is significantly less than the 354.25 in³ of the main parachute bay. RockSim simulations indicated that the final descent rate of the rocket would be approximately 14.92 ft/s. The kinetic energies for each separate section of the rocket were calculated for this descent rate using the equation,

$$KE = \frac{1}{2}mv^2,$$
where $KE$ is the kinetic energy, $m$ is the mass of each section of the rocket (determined from the mass balance sheet), and $v$ is the velocity of the rocket immediately prior to impact. Kinetic energies at impact for each of the separate sections of the rocket can be seen in Table 9. The maximum amount of kinetic energy experienced by any single section of the rocket was found to be 68.83 ft-lbf, thus meeting the requirement of 75 ft-lbf or less.

<table>
<thead>
<tr>
<th>Sections</th>
<th>Kinetic Energy On Landing (ft-lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Section</td>
<td>40.44</td>
</tr>
<tr>
<td>Recovery</td>
<td>21.998</td>
</tr>
<tr>
<td>Booster</td>
<td>68.83</td>
</tr>
</tbody>
</table>

*Table 9*: Theoretical kinetic energies experienced by each section at impact

The Iris Ultra 120 did not initially meet the drift requirements, but this was easily rectified by lowering the deployment altitude from 1000 ft. to 800 ft. The total drift assuming a 15 mph wind was determined using RockSim and was found to be 1,682.9 ft., well below the limit of 2,500 ft. The drift distances for 5, 10, 15, and 20 mph winds were likewise calculated using RockSim and can be found in Table 10.

<table>
<thead>
<tr>
<th>Wind Speed (mph)</th>
<th>Drift Distance (ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>554.2</td>
</tr>
<tr>
<td>10</td>
<td>1120.5</td>
</tr>
<tr>
<td>15</td>
<td>1682.9</td>
</tr>
<tr>
<td>20</td>
<td>2234.7</td>
</tr>
</tbody>
</table>

*Table 10*: Theoretical drift distances under various wind conditions

RockSim simulations indicated that the main parachute deployment would exert approximately 20 g’s of force on the rocket, which was deemed to be within acceptable levels. It is important to note that RockSim’s predictions assume that the parachute deployment is instantaneous and thus the force predicted by RockSim are significantly higher than what will actually be exerted on the rocket at any given moment during parachute deployment. A more realistic way of modeling the force experienced during deployment is currently being investigated.

The Fruity Chutes Iris Ultra 120 chute has a spill hole at the center of the canopy, which helps to prevent Karman vortex trail. The vortex is created by the airflow blocked by the canopy and goes around and separates at the leading edge. The flow separation creates the uneven distribution of pressure in the canopy, and this produces the
oscillations. This type of parachute has the highest drag coefficient related to the canopy surface area and, due to its toroidal design, is lightweight and compact.

**Drogue Parachute**

Drogue chute selection was closely interlinked with main parachute selection. In order to minimize the force exerted at main parachute deployment, the drogue parachute needed to first slow the rocket down to a reasonable descent velocity. The drogue chute we have selected is a Rocketman Mach 2 with a diameter of 36 in. and a $C_D$ of 1.16. RockSim calculations showed that this drogue chute brings the rocket to a descent velocity of 65.97 ft/s which is well below the general requirement for safe descent from apogee to main parachute deployment (800 ft.) of 100 ft/s. The drogue bay has a diameter of 6 in. and a length of 6.5 in., resulting in a total drogue bay volume of 184.2 in$^3$. The estimated total packing volume of the drogue parachute was determined to be 50.3 in$^3$, which when combined with the shock cord's volume of 90.2 in$^3$ brings the total drogue parachute volume up to 140.5 in$^3$, well below the total volume of the drogue bay.

### 3.2.2 Major Components

**Shock Cords, Quick Links, U-Bolts**

The shock cord to be used for parachute attachments will most likely be a 9/16 in. tubular nylon type. We will be using standard length guides and half scale flight testing to determine the optimal length of shock cord to be used. All connection points for the shock cords will be quick links; each weighing 0.595 oz. Quick links provide ease of maintenance, and a quick and easy assembly, as well as providing some versatility to trade out damaged parts. The quick links from the shock cords will attach to U-bolts in bulkheads. The shock cords will have individual volumes of 90.2 in$^3$ resulting in a total combined volume of 180.4 in$^3$.

**Parachute Protectors**

Parachute protectors will most likely be used on both our main and drogue parachutes. The purpose of the parachute protectors is to wrap the chutes in a fireproof kevlar-nomex material and provide protection against the damaging effects of black powder charges and residue. Singeing parachutes could lead to a catastrophic failure of our parachutes, endangering personnel and damaging to our rocket.
Attachment Scheme

The payload section of the rocket will contain both parachutes and is shown in Figure 26. The main parachute is located within the main parachute bay, and will be protected by a parachute protector. The parachute will be connected to a shock cord, which in turn will be connected to the main parachute U-bolts (one end of the shock cord will connect to one of the U-bolts, and the other end will connect to the other). The main parachute will be deployed by firing a main ejection canister once the rocket descends to an altitude of 800 ft, as determined by the electronics in the fore avionics bay.

The drogue chute will be located within the drogue parachute bay, and will also be protected by a parachute protector. The drogue will be connected to a shock cord, which will be attached to the drogue U-Bolts in the same manner as the main parachute shock cord. The drogue parachute will be deployed by firing a drogue ejection canister at apogee, as determined by the electronics in the aft avionics bay. Both shock cords will be 30 ft. in length, or approximately three times the length of the rocket.

Black Powder Ejection Canisters

Black powder ejection canisters shall be used to deploy both the drogue and main parachutes. The ejection canister set-up will consist of Pratt Hobby SEC-5B Ejection Canisters mounted within custom-made aluminum cylindrical housings. These housings will be attached to the G10 fiberglass bulkheads of the parachute bays of the rocket. This shall be done cutting holes into the bulkheads of the same diameter as the housing cylinders and sliding the cylinders through said holes until the front of the cylinder is flush with the bulkhead and the rear end extends into the avionics bay. The front end of each cylinder shall be chamfered outward and a concave groove shall be cut into the corresponding bulkhead. This will be done so as to prevent the cylinder from sliding backward into the avionics bay due to the force of the black powder detonation. The rear half of the housing shall have a clip attached at the point of contact between the housing and the bulkhead in order to prevent it from sliding into the parachute bays during transport or rollover. The canisters shall be filled with the necessary masses of
black powder to ensure the timely and complete deployment of each parachute. These masses were determined to be 2.19 g for the main parachute and 1.14 g for the drogue parachute, as calculated in the next section. Though only a single ejection canister will be necessary to deploy each parachute, two ejection canisters shall be attached to the bulkheads of each of the parachute bays in order to fulfill redundancy requirements. The black powder canister set-up is shown in Figure 27.

![Figure 27: Black Powder Canister Set-Up](image)

**Figure 29: Removable bulkhead and mount for U – bolts, avionics sleds, and BP canisters.**

**Black Powder Required to Deploy Main and Drogue Parachute**

The mass of black powder necessary to ensure the proper deployment of each parachute was calculated using Chuck Pierce’s Black Powder Ejection Charge Calculator. This calculator was capable of determining the required mass of black powder for ejection based on several different criteria, including the volume of the parachute bay, the type of black powder used, and either the desired pressure or the desired ejection force. The basic formula used for the calculations was,

\[ N = \frac{VP}{RT} \times 454, \]
where \( N \) is the number of grams of black powder required, \( V \) is the volume of the payload bay, \( P \) is the pressure, \( R \) is the combustion gas constant and \( T \) is the burn temperature of the black powder used. The 454 is a constant used to convert the result from pounds to grams. This calculator was preconfigured to use required mass of black powder gas properties in its calculations, the same type of black powder that had been selected, and thus were left unchanged. This meant that \( R = 22.16 \text{ ft-lbf/lbm} \) and \( T = 3307 \text{ Rankine} \). The volume of the main parachute bay, based on a 6.007 inch diameter and a 12.5 inch length, was found to be \( V = 354.3 \text{ in}^3 \). Similarly, the volume of the drogue parachute bay, based on a 6.007 inch diameter and a 6.5 inch length, was found to be \( V = 184.2 \text{ in}^3 \). The mass of black powder required was calculated based on a desired pressure of 12 psi, and was determined to be 2.19 g for the main parachute and 1.14 g for the drogue parachute. The calculator also determined that this set up would produce an ejection force of 340.1 lbf for each parachute deployment. This has been deemed to be more than enough force to properly eject each parachute, though there is some concern that it may result in damage to the rocket or the chutes. Given that the maximum combined shear pin strength is merely 150 lbs., it seems quite possible that the mass of black powder used for parachute ejection may be reduced in the future. Ground-based ejection tests will be undertaken to determine the most appropriate level of force for parachute deployment and thus mass of black powder required.
3.3 Mission Performance Predictions

3.3.1 Mission Performance Criteria

In order for this mission to be considered as successful, the following events must occur:

- The vehicle shall deliver the science or engineering payload to an apogee altitude of 5,280 feet above ground level (AGL). Automatic disqualification if over 5,600 feet AGL.

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

- 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.)

- 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.

- 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).

- 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.

- 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.

Vehicle Prohibitions:

- The vehicle shall not utilize forward canards.

- The vehicle shall not utilize forward firing motors.

- The vehicle shall not utilize motors which expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)

- The vehicle shall not utilize hybrid motors.

- The vehicle shall not utilize a cluster of motors, either in a single stage or in multiple stages.
3.3.2 Flight Profile

The preliminary design review flight profile simulations were primarily performed with the assistance of Rocksim. For simulation, a model of the rocket was built and fitted with the Cesaroni L2375, which proved to be a more powerful motor than necessary in propelling the rocket to the target altitude of one mile. This motor was chosen for it provides the greatest altitude in Rocksim for an L-class, 75mm motor. It was known that this motor would exceed the acceptable altitude range for the altimeters of 5600 feet, taking into account no wind, so to compensate for the excess altitude a 15oz ballast mass component was placed in the nosecone. This addition resulted in a more acceptable value 232 feet above the target altitude. The predicted altitude can be shown in Figure 28.

![Figure 30: Altitude vs. Time prediction from Rocksim.](image)

The ballast mass is expected to increase as the design matures, but as it currently stands, it accounts for only 2.35% of the unballasted vehicle mass which meets USLI requirements. The design consists of four removable, tethered sections listed in order from the tip of the rocket: Nosecone, Payload Tube, Recovery Tube, and Booster Tube.
At $t = 0$, the Cesaroni L2375 is ignited. The velocity at launch guide departure is safe, given as 71.9076 feet/sec. tested on a 96” launch rail. Burnout occurs at 2.1 seconds, and apogee occurs at 18.4 seconds. At apogee, the first charge is ignited to separate the Nosecone/Payload Tube/Parachute Tube system from the Booster Tube section deploying the drogue chute. During decent at an altitude of 800 feet, the second charge is ignited separating the Nosecone/Payload Tube system from the Parachute Tube releasing the Main parachute.

The maximum speed occurs near burnout resulting in a simulated value of Mach 0.602 which meets USLI requirements with the design remaining subsonic throughout flight. The acceleration that occurs before burnout applies a compressive force of about 18.54g's onto the rocket. To compensate for this, the use of G10 or even the production of Carbon Fiber tubing has been proposed.

Future plans for stress testing will decide whether the lighter composite is practical enough for implementation. The use of multiple shear pins and rivets on the detachable sections will be used to keep the rocket as singular system until deployment. At apogee, the tensile force applied by the drogue parachute’s deployment is of less concern as the composition of the bulkheads and the shock cord characteristics should be able to withstand the force of an optimal deployment with the addition of expected but minimal external forces. The use of 0.25 inch G10 for all bulkheads with future shear stress
testing should be able to confirm this, otherwise the use of carbon fiber w/honeycomb is another option that will be discussed in more detail in the CDR.

The acceleration depicted at 86 seconds from the main parachute's deployment is estimated to apply 12.9 g's. During this deployment, the aft sections of the rocket, containing the Parachute Tube/Booster Tube system, are falling slower than the front section, the Nosecone/Payload Tube system, due to the drogue parachute's drag and the rocket's weight distribution from burnout. This will apply the deployment's force on the front section's removable bulkhead connection. Once the rocket returns safely to the ground, the nosecone will be blown off with ejection charges, breaking shear pins. The rover will be pushed out by a piston, then continue on to survey the terrain and take its necessary measurements.

![USLI Concept](image)

*Figure 32: L2375 Thrust Profile from Rocksim over 2.5 seconds*

The L2375 motor is made with the White Thunder pyrotechnic colorant. These characteristics are common with ammonium perchlorate composite propellant (APCP) suppliers and they often offer a variety of different propellant types. The propellant type doesn't necessarily affect the flight performance, but for safety reasons USLI prohibits vehicles that expel titanium sponges. The L2375 motor not only satisfies this, but it is also a commercially available solid motor propulsion system using APCP that is sold by Cesaroni Technology so it satisfies both criteria. Cesaroni Technology is approved and certified by the National Association of Rocketry (NAR) and Tripoli Rocketry Association (TRA).
Based on Figure 32, the L2375 has a manufactured impulse value of 4,864 newton-seconds, which meets the USLI criterion in not exceeding 5,120 Newton-seconds (L-class). When choosing the motor that would allow our team's design to reach the target altitude, we needed to be sure the motor existed and would be at least powerful enough to show that it could exceed the target altitude. A mass is currently located in the nosecone to compensate for the excess altitude, but depending on space, stability, and
future design constraints, the location and mass may change in future iterations. The L2375’s thrust to weight ratio, with respect to the design, results in a ratio of 11.247 which exceeds mission performance expectations with safety and is sufficient for our design. The motor is the closest to the Rocksim substitute in both physical and flight characteristics, with similar thrust curves shown in both Figure 30 and Figure 31, but there are minor discrepancies between Rocksim that may need to be taken into account such as the differences in burn time, that could potentially lead to small inaccuracies in simulations.

Future flight profile modeling will more accurately define the launch conditions, including launch pad altitude, predicted weather conditions (relative humidity, average wind speed, etc.), and competition settings. Immediately before the flight, these conditions will be taken into account to adjust the design accordingly, (ballast masses, air brake systems, etc.), to achieve the predicted altitude given the very best initial conditions simulations the team can generate.

3.3.3 Stability Predictions

![Figure 34: Full-Scale Concept 2-D Rocket Drawing from Rocksim before Ignition](image)

![Figure 35: Full Scale Concept 2-D Rocket Drawing from Rocksim after Burnout](image)
Initial modeling on Rocksim has shown that the Center of Pressure (CP), depicted as a red dot for the concept design at ignition shown in Figure 32 will be located 90.5862 inches from the nose tip. The Center of Gravity (CG), depicted as the blue and white dot, will be located 76.9739 inches from the nose tip before ignition as well, shifting to 73.0827 inches at burnout. Given these locations for the CG and CP, the static stability margin is hand calculated with the data shown to be 2.21 before ignition and 2.84 at burnout. The static stability margin’s change can be viewed in Figure 33. As the design continues mature, it is expected that the static stability margin will vary. The total mass will decrease with iteration and more concise measurements.

Figure 36: Longitudinal Moment of Inertia vs. Time from Rocksim.
Figure 37: Damping Coefficient vs. Time from Rocksim

Figure 38: Corrective Moment Coefficient vs. Time from Rocksim
Figure 35 shows that the longitudinal moment of inertia of the rocket before launch is 714,000 oz/in$^2$. The larger the longitudinal moment of inertia the less likely the rocket will be disturbed by large wind gusts. Primarily due to the forward movement of the CG from engine burn, after about 2 seconds the rocket’s longitudinal moment of inertia drops to 620,000 oz-in$^2$. Our corrective moment coefficient peaks at 4300 which occurs at burnout, since the moment is proportional to the velocity squared. Compared to the damping moment coefficient, the corrective moment coefficient is used to determine the corrective force that the rocket creates in response to a disturbance in flight. The larger the value, the more force the rocket creates and the quicker it will react to a disturbance. Figure 36 shows the damping moment coefficient with respect to time. This moment coefficient determines how fast the rocket will return to a stable state when disturbed. The damping moment peaks at 31.15, which also occurs at burnout.

References:


3.4 Interfaces and Integration

The payload has been sized to be compatible with the Public Missiles™ 6.007” tube. Because of the simple geometries of the tubes, the preliminary design affords easy size changes along the length of the rocket, if required for a successful mission. The deployment mechanism was also sized in a similar manner, and is compatible with the payload tube, and any Public Missiles™ 6.007” tube.

This tube selection is part of a larger contingency plan to make parts easy to replace in the event of damages during test flights. This means that the vehicles manufacture parts will be compatible with commercial parts if the vehicle design and testing suffers major pitfalls over the coming month.

Specifically, all tube size are the same 6.007” Inner diameter, and all couplers, shoulders, and bulkheads are built within this consistent design parameter. This approach will ensure a smoother integration process of the vehicle structure.

To interface with the ground, TX and RX (transmission and reception) functions are routed from an antenna to the ground station transmitter then to a ground station computer. This system affords all mission TX and RX needs, and is within the team members abilities to implement.

Prior to launch, the vehicle’s onboard altimeters shall be armed through screw switched placed 6’ form the base of the rocket. The switches are activated using a screwdriver, and are locked in place by tightening the screw. After this operation, the vehicles electronics are mission ready.

During decent, the launch vehicle shall transmit GPS data to a secondary ground station to aid in recovery of the vehicle. In addition, the vehicle shall power an onboard RF transmitter in the event GPS transmission is lost.
3.5 Launch Operations

Team Member Responsibly

To efficiently conduct the launch, tasks and responsibilities will be distributed amongst individual team members. Each team member will be responsible for verifying their individual subsystem checklist prior to launch. The safety officer along with the team lead will provide oversight and communication for launch preparation. High level descriptions of individual responsibilities are shown below. The full launch procedures checklist can be seen below.

*Project Lead & Safety Officer*

The two officers will ensure that proper compliance with Safety Codes set by NAR and other federal codes has been met. Ensure that leads are checking off launch procedures in a proper and timely manner. Communicate and trouble shoot problems with team members to resolve issues that may arise during launch.

*Structures Lead*

The Structures Lead is responsible for ensuring proper assembly of individual subsystems and components. The lead will also ensure that the vehicle is free of defects that could possibly hinder the launch. The structural lead will also be responsible for the assembly of the rocket’s propulsion system by properly mounting the motor and ignition charges.

*Recover Lead*

The Recovery Lead is responsible for ensuring the proper assembly of the recovery envelope for the rocket and its recovery payload. The recovery lead will work together with the team sponsor Gary Stroick who is a level 3 Tripoli Rocketry Association certified member to load and properly size the black power ejection charge.

*Avionics Lead*

The Avionics will ensure that the nitrogen tank is at the correct pressure, free of defects, and is in working order prior to launch. The Avionics lead will also ensure that all electronics are transmitting correctly.
Pre-Launch Checklist
Structures & Propulsion Preflight Checklist
People Responsible: Devin V, Maninder G

Fin Installation
1. Inspect fin surface for cracks or chips
2. Slide each fin into fin centering ring
3. Install locking centering ring
4. Inspect quality of lock for fins
5. Inspect fin alignment

Pressure Vessel Installation
1. Check pressure vessel for pressure
2. Check pressure vessel for cracks or chips
3. Mount vessel to pressure tank mount
4. Charge tank with compressed gas
5. Slide mount into booster tube
6. Apply pins with coder pins to secure tank
7. Install gas lines to pressure tank valve
8. Ensure no nozzle is blocked

Avionics – Vehicle Installation
1. Test Systems for functionality
2. Test Batteries
3. Test Altimeters
4. Slide avionics sled onto tressed bolts
5. Secure sled with lock 2 nuts
6. Ensure nuts are locked
7. Switch on main avionics board

Vehicle Assembly
1. Inspect tubes for potential snags or stops and make proper adjustments
2. Slide coupler into respective body tube
3. Inspect payload bay for hazardous obstructions or snags
4. Slide nose cone into Payload tube
5. Check for snug fit in all connections
6. Inspect body tube for cracks and chips
7. Inspect rail buttons for miss alignment
8. Inspect motor mount
9. Apply shear pins
Recovery Checklist
People Responsible: Nathan K

1. Inspect all shock cords for structural integrity, removing and replacing any frayed components
2. Inspect drogue and main parachute for defects
3. Attach each end of the drogue shock cord to one of the two drogue bay U-bolts
4. Hook on drogue parachute to the middle of the drogue shock cord
5. Fold and load drogue parachute into drogue bay
6. Connect recovery section to motor section
7. Attach each end of the main shock cord to one of the two main parachute bay U-bolts
8. Hook on main parachute to middle of the main shock cord
9. Fold and load main parachute into main parachute bay
10. Connect recovery section to payload section

Payload Checklist
People Responsible: Vishnuu M, Hannah W, Mathew D

1. Verify that the battery pack is connected
2. Verify that the RMRC-600XV Camera is oriented correctly and stable on the payload chassis
3. Verify that the camera’s Immersion RC transmitter is functioning with the Airwave Receiver and Patch antenna and its transmitting live video feed to the ground station.
4. Verify that the high torque continuous rotation servos are properly connected mechanically to the rover as well as electrically to the ArduIMU
5. Verify that the RC receiver is successfully connected to the ArduIMU and the RC Transmitter/Controller is able to transmit commands to the receiver.
6. Test the rover to make sure that it is functioning and can move forward and rotate 180°
7. Verify that the GPS is properly connected and is transmitting coordinated of the rover’s location
8. After all subsystems are properly functioning, wrap payload into its polyethylene foam case.
9. Inspect the black powder canister and make sure that the on/off switch is properly connected and functioning
10. Put the black powder and piston assembly into the payload bay before the rover is put in
11. Put the payload with its casing into the payload section of the rocket
12. Verify that the payload is secure and can be sealed into the rocket and place the nose cone into place along with the shear pins
Post-Launch Checklist

1. Locate the rocket and ensure that it can be recovered safely.
2. Verify that all four ejection charges fired. If any have not fired, carefully disconnect the ematches and twist the leads together. Consult the Safety Officer regarding the disassembly of the charge(s).
3. Power off the altimeters after recording the altitude readout.
4. Remove the camera section from the rocket, stop the recording, and power off the camera.
5. Remove the screws holding on the nosecone and then remove the nosecone from the payload section.
6. Unmount the thermocouples and then remove the payload electronics, powering them off once they have been removed from the rocket.
7. Inspect the main and drogue parachutes for any damage from the ejection charges or landing.
8. Inspect the fin fillets for any cracks or damage.
9. Inspect the motor retainer to ensure that there is no damage.
10. After the motor cools off some, remove the motor and clean the casing. Note any irregularities in the motor, such as burned through liners, damage to the casing, any bulges in the casing, or damage to the closure threads.
11. Remove any remaining tape on the ejection charge wells as well as fired ematches.
12. Clean the bulkheads with cleaning wipes to remove the ejection charge residue.
13. Inspect the bulkheads for any damage or loose components.
14. Remove the electronics bay bulkhead and the attached altimeters.
15. Disconnect the charge and switch wires from the altimeters.
16. Inspect the payload bulkhead for any damage and clean any charge residue from the bulkhead.
17. Clean out the charge residue from the main and drogue airframe sections.
3.6 Safety and Environment (Vehicle)

3.6.1 Safety Officer

The safety officer for the team is Binh Bui. The safety officer responsibilities include developing safety plans and procedures to ensure proper compliance with school, regional, and federal codes. In addition, the safety officer will provide oversight to ensure that safety procedures and best practices are met by team members.

3.6.2 Vehicle Failure Modes

To save time, cost, and increase the overall success of the design requirements, Table 3.11.1 summarizes the possible failure modes and their respective mitigation.
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Potential Failure Mode</th>
<th>Effects of Failure Mode</th>
<th>Potential causes</th>
<th>Severity Rating</th>
<th>Probability</th>
<th>Recommended Actions</th>
<th>Completed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF-1</td>
<td>Launch Rail Button</td>
<td>Launch rail shear off</td>
<td>Rocket launches at an angle</td>
<td>Manufacturing defect</td>
<td>3</td>
<td>Low</td>
<td>Test sliding action before each launch</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-2</td>
<td>Body Tube</td>
<td>Yields to compression</td>
<td>Rocket splits, structural failure</td>
<td>Manufacturing defect</td>
<td>3</td>
<td>Low</td>
<td>Static load test per FV-01-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-3</td>
<td>Nosecone</td>
<td>Separation in flight</td>
<td>Unstable flight dynamics</td>
<td>Not enough shear pins</td>
<td>2</td>
<td>Low</td>
<td>Detailed calculations will be done to confirm proper amount of shear pins in nosecone. Static load test per FV-01-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-4</td>
<td>Nosecone</td>
<td>Nosecone jams upon deployment</td>
<td>Rover will not deploy</td>
<td>Too little BP, or too many shear pins</td>
<td>2</td>
<td>Medium</td>
<td>Using the proper shoulder length, and guarantee that the load to separate is evenly distributed. Ground Rover Deployment test with BP charge test per FV-02-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-5</td>
<td>Payload Piston</td>
<td>Piston jams upon deployment</td>
<td>Rover will not deploy</td>
<td>Too little BP, or too many shear pins</td>
<td>2</td>
<td>Medium</td>
<td>Using the proper shoulder length, and guarantee that the load to separate is evenly distributed. Ground Rover Deployment test with BP charge test per FV-02-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-6</td>
<td>Payload Piston</td>
<td>Piston bulkhead fails</td>
<td>Nosecone will not deploy</td>
<td>Too much BP or improper manufacturing</td>
<td>2</td>
<td>Low</td>
<td>Use proper epoxy techniques to ensure a rigid bond, ground testing to find failure load limit. Ground Rover Deployment test with BP charge test per FV-02-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-7</td>
<td>BP Charges</td>
<td>Charges fail to ignite</td>
<td>Parachutes will not deploy</td>
<td>Igniter does not receive signal to ignite</td>
<td>3</td>
<td>Low</td>
<td>Proper wiring to avionics is important, will check power to leads prior to ejection canister being loaded, ematches will be centered in the canister. Parachute Deployment test with BP charge test per FV-02-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-8</td>
<td>BP Charges</td>
<td>Charges ignite prematurely</td>
<td>Parachute tears off rocket, structural breach</td>
<td>Altimeter malfunction</td>
<td>3</td>
<td>Low</td>
<td>Proper wiring to avionics, and programming of avionics is important. Half scale test per FV-03-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF-9</td>
<td>BP Charges</td>
<td>Charges ignite simultaneously</td>
<td>Larger drift distance</td>
<td>Programming code</td>
<td>2</td>
<td>Low</td>
<td>Proper wiring and programming. Half scale test per FV-03-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>VF</td>
<td>Component</td>
<td>Issue Description</td>
<td>Severity</td>
<td>Impact</td>
<td>Recommendation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------------</td>
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<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-10</td>
<td>BP Charges</td>
<td>BP residue contaminates avionics</td>
<td></td>
<td>Lose GPS tracking</td>
<td>Improper seal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 Low The avionics bays must be properly sealed to protect from BP residue, ejection canisters must fit properly and not move or fail. Perhaps incorporating a ground radio based tracker. Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-11</td>
<td>BP Charges</td>
<td>Not enough BP to deploy payload or parachutes</td>
<td></td>
<td>Parachute does not deploy</td>
<td>Insufficient BP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Low Calculations will be essential, and ground tests will be conducted. Parachute Deployment test with BP charge test per FV-02-2012 Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-12</td>
<td>Avionics</td>
<td>Power failure</td>
<td></td>
<td>Parachutes does not deploy</td>
<td>Connectors Severed, Short Circuits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Low Ensure correct orientation of battery terminals, fresh batteries every flight, and holder strength prevents movement under acceleration. Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-13</td>
<td>Avionics</td>
<td>Altimeter failure</td>
<td></td>
<td>Parachutes does not deploy or deploy late</td>
<td>Damaged Altimeter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 Low Primary and secondary systems are onboard to ensure ejection charges and electronics will function. Half scale test per FV-03-2012 Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-14</td>
<td>Avionics</td>
<td>Microcontroller Malfunctions</td>
<td></td>
<td>Rocket Overshoots</td>
<td>Poor coding, Circuit damaged due to vibrations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Low Half scale test per FV-03-2012 Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-15</td>
<td>Parachutes</td>
<td>Singed by BP charge</td>
<td></td>
<td>Descent rate will be higher, high kinetic impact</td>
<td>Parachute damaged</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Low Main and drogue will have a chute protector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-16</td>
<td>Shock Chord</td>
<td>Shock chord becomes tangled</td>
<td></td>
<td>High descent rate, high kinetic impact</td>
<td>Defective Swivel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Low Half scale test per FV-03-2012 Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-17</td>
<td>Airbrake</td>
<td>Pressure valve failure</td>
<td></td>
<td>Fails to eject gas</td>
<td>Manufacturing defect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Medium Testing valve on site before launch and having a backup valve</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-18</td>
<td>Airbrake</td>
<td>Gas tank failure</td>
<td></td>
<td>Loss of Pressure and decreased drag</td>
<td>Improper placing of valve, or fracture of tank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 Medium Tank will be coated with fiber glass and ensure proper valve assembly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF-19</td>
<td>Motor</td>
<td>Retention failure</td>
<td></td>
<td>Structure failure caused by motor</td>
<td>Manufacturing Process defect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 Low Proper epoxy attachment of CR’s and calculations of max structural loads on CR’s Static load test per FV-01-2012 Tentative</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>VF-20</th>
<th>Fins</th>
<th>Fins fail</th>
<th>Stability failure</th>
<th>Manufacturing process</th>
<th>Severity</th>
<th>Medium</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Medium</td>
<td>Ensure fins are properly and snugly attached to fin mount. Static load test per FV-01-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tentative</td>
</tr>
</tbody>
</table>

**Table 11: Vehicle Failure Modes [see Appendix II for failure verification plan]**

**Severity Rating:**

1 - Minor failure. Over all mission requirements are still attainable
2 - Moderate failure. One or two requirements is/are unattainable.
3 - Complete failure. Overall mission is unattainable, failure of most requirements.
Procedural Risk

There will also be procedural hazards to the team members as they prepare for flight and recover the vehicle and payload. Checklists for pre-flight procedures launch procedures and post-flight procedures as well as travel and shop checklists will be maintained and adhered to.

The following table lists some of the procedural hazards, and the proposed mitigations.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Hazard</th>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-flight</td>
<td>Black powder ignites on loading</td>
<td>Low</td>
<td>Mentor and safety officer will load black powder charges, and will be one of the last components to be loaded into rocket</td>
</tr>
<tr>
<td>Launch</td>
<td>Charges Ignite on pad</td>
<td>Low</td>
<td>Ensure avionics are powered off</td>
</tr>
<tr>
<td>Post-flight</td>
<td>Live charges still onboard</td>
<td>Low</td>
<td>Switch off electronics immediately upon recovery, and disassemble ejection canisters</td>
</tr>
</tbody>
</table>

Table 12: Procedures Risk and Mitigation Summary

Note, by the time the team attends the competition launch, we will have successfully launched a minimum of one half scale rocket and one full scale rocket. We will practice our flight operation procedures as a team at each of the test launches.

We will also practice successful assembly and disassembly of the entire rocket and all components prior to competition launch. Each team member will be expected to be familiar with all rocket systems to ensure safety. On launch day, each team member will be assigned specific tasks to be performed in preparation of launch. The team lead and the safety officer will supervise the preparation and maintain the checklists.

3.6.3 Personnel Hazards and Environmental Concerns

Personnel hazards will exist during the course of this project, and all steps will be taken to prevent any accidents from occurring. Construction, testing and assembly of our high powered rocket (consisting of various materials including fiberglass, aluminum and wood) will require the use of various specialty tools.

Many of the tools required are contained in the Mechanical Engineering machine shop. All team members who will be working on constructing the rocket have completed a shop safety course.
The team has put forth a general rule that will require any member working on any component to do so in pairs. This rule will be held in strict adherence especially when working in the machine shop. The purpose of the rule is to not only prevent accidents by providing assistance in proper shop techniques, but also so that each component that is fabricated will have more than one person who understands the fabrication process.

In addition on October 11th the Safety Officer put on a safety training session that was required for all team members. This included familiarizing with MSDSs, proper lab safety practices, safe design practices, and risk mitigation practices. This ensured that all team members have a high level of awareness for safety.

The following table summarizes the shop hazards that will be encountered during the manufacturing and assembly of our rocket.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Hazard</th>
<th>Mitigation</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band Saw</td>
<td>Rotating blade</td>
<td>Always wear safety equipment, and pay attention.</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Jig Saw</td>
<td>Reciprocating blade</td>
<td>Pay attention</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Milling Machine</td>
<td>Rotating bits</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Lathe</td>
<td>High speed rotation</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Drill Press</td>
<td>High speed rotation</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Miter Saw</td>
<td>Rotating blade</td>
<td>Pay attention</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Rotary Tool</td>
<td>Rotating bits</td>
<td>Pay attention</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
</tbody>
</table>

*Table 13: Machine Shop Hazards and Mitigation*
With regard to the various hazardous materials to be used during the testing and construction of our high powered rocket, we will keep all materials in a locked storage cabinet in our Aerospace workspace in Akerman Hall 130B.

Upon the purchase of any hazardous material, the team lead and the safety officer will present details of how to handle the material properly during the weekly meetings. All MSDS sheets will be kept in a binder located at the storage cabinet. All team leads will be required to know the high level overview of chemicals that they will be using extensively. Again, it will be a mandatory rule that all team members must work in pairs when handling any hazardous material.

The shop in Akerman Hall 130B will also contain all safety equipment that will be required for the safe construction of our rocket. It is the responsibility of the team lead and the safety officer to ensure that the first aid kit and the fire extinguishers located in the workspace are functioning properly at all times.

Other safety equipment to be purchased will include respirator masks to be used when cutting or sanding fiberglass, applying epoxy and applying paint or primer. Safety goggles will also be purchased to be used as needed. Ear plugs and latex gloves will also be purchased and placed by the storage cabinet to be used as needed.

The following table summarizes the hazards from the various working materials in the lab, and includes risk mitigation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Hazard</th>
<th>Safety Equipment</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>Noxious fumes</td>
<td>Respirator, safety glasses, latex gloves</td>
<td>Make sure well ventilated</td>
</tr>
<tr>
<td>Super Glue</td>
<td>Fumes, skin contact</td>
<td>Respirator, latex gloves</td>
<td>Use ventilation</td>
</tr>
<tr>
<td>Black Powder</td>
<td>Skin contact</td>
<td>Latex gloves</td>
<td>Always wear gloves</td>
</tr>
<tr>
<td>Pyrodex</td>
<td>Skin contact</td>
<td>Latex gloves</td>
<td>Always wear gloves</td>
</tr>
<tr>
<td>Spray Paint</td>
<td>Fumes</td>
<td>Respirator, gloves</td>
<td>Make sure well ventilated</td>
</tr>
</tbody>
</table>

Table 14 Chemical hazards
4. Payload Criteria

4.1 Design and Verification of Payload Experiment

4.1.1 Mission Statement

The payload consists of a remote controlled rover that is based on the concept of an extraterrestrial exploration vehicle. Our rover will primarily perform the function of a vehicle that streams live video of its surrounding onto a ground station. An ArduIMU microcontroller will be instrumental in allowing our rover to receive and control two continuous rotation servos to drives its wheels and also executes a series of autonomous functions. The autonomous functions will be executed under the condition that the rover receives no transmission from the ground controller through the remote control link for a certain period of time, say 5 minutes. If such a condition is satisfied, then the rover will execute a set of functions that will allow it to follow a certain trajectory based on commands that would make the servos rotate through a certain number of revolutions.

Figure 39: Solidworks sketch of Rover "Inquisitivity"
4.1.2 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.

4.1.3 Rover Design

A number of factors influenced the initial design plan for “Inquisitivity”. These include:

- Ability to fit and deploy smoothly from the payload bay of the rocket.
- Structural integrity to withstand the forces experienced during takeoff, flight, parachute deployment and landing.
- Ability to drive on uneven terrain
- Robust performances of on-board electronic systems
- Orientation correction

Dimensional analysis was one of the first things the payload team had to come to an agreement upon. Although the payload bay measures 30 inches in length and 6 inches in inner diameter, we had to take into consideration the space utilized by the avionics bay, the piston deployment system, and the coupler for the nose cone that extended into the payload bay. For the efficient functionality of all the systems, it was decided that the payload length will not exceed 15 inches and the inner diameter must be kept at 5.5 inches. However, a wheel diameter of 5.5 inches does not provide sufficient ground clearance for the rover to drive well. To deal with this, “Inquisitivity” will have a compressible wheel assembly that will consist of six drive legs connected to two hubs on an axle that connects each of these assemblies to the chassis. The outer hub of each wheel assembly is fixed to the end of the axle, while the inner hub is attached to the chassis by means of a spring. Each leg is connected to the outer hub and then linked to the inner hub. This way, when the inner hub is compressed, the legs collapse into the chassis of the rover. This gives “Inquisitivity” the flexibility of fitting inside the rocket payload bay, as the closed cross sectional diameter can be maintained at 5.5 inches, and also gives it the ability to have sufficient ground clearance, as the open wheel diameter is 10 inches.

The payload deployment system will consist of a piston that covers the wheel assembly of the rover one side. The piston will come into effect by the force generated by deploying black powder charges attached to the outer end of the piston.
Structural integrity is an essential parameter for the design of any system and its components. “Inquisitivity” will boast a fiberglass chassis and wheel assembly, coupled with a stainless steel axle. The 0.5 inches difference between the closed diameter of the rover and the inner diameter of the rocket gives us the ability to wrap the rover in a thin foam pad as it fits inside the payload bay. This will reduce any vibrations and shaking the rover experiences during the flight and will also avoid it from bumping into the walls of the payload bay by ensuring a tight but flexible fit, as the foam pad will be able to absorb reaction forces from the rocket.

The wheel design, which ensures a sufficient ground clearance and the propulsion system comprised of high torque servos enhances the rover’s ability to drive and maneuver itself on uneven terrain. The rover’s electronics have been carefully selected to ensure superb functionality, efficiency and system harmony. The team is certain that the operating frequency of the RC receiver will not interfere with the operating frequency of the camera transmitter system. However, we still plan to test all these systems together. Each servo and will run on a separate battery, and the ArduIMU and camera systems will run on different power sources as well. This will ensure the independence of all the subsystems, so in case one subsystem fails due to lack of power, the others will continue to operate under a different power supply.
4.1.4 Orientation Correction System

The high torque servos located on the chassis of the rover and responsible for driving the wheels create a reactive torque that tends to rotate the chassis of the rover. Correcting the orientation of the rover is important for continued proper transmission and for a continuous streaming of relevant video data.

To correct the orientation of the rover, the team will attach an outrigger arm to the underside of the rover, which will stick out at the back of the rover. This outrigger will serve to counteract the torque that is generated by the servos and act on the chassis of the rover so that it remains in the correct orientation. The correct orientation is defined as the orientation of the chassis such that the camera points straight ahead and the transmitter antenna points straight up.

![Solidworks sketch showing the orientation system and the forces that make it work](image)

If the rover does not land in the correct orientation, then its orientation will be corrected once the outrigger touches the surface of the terrain as it rotates with the chassis due to the reactive torque of the servos. It will then drag behind the rover and continuously exert a counter torque which will keep the chassis in the correct orientation.
4.1.5 Payload Subsystems

Figure 42: Solidworks sketch showing Inquisitivity’s subsystems

A. Hitec HSR-5980SG Digital HMI High Torque Robot Servo
Once it is deployed in the ground, “Inquisitivity” will have to be capable of functioning on terrain that will not be smooth or flat. There is a high possibility of obstacles such as small rocks and ground bumps and depressions. Apart from having a significant ground clearance, the wheels of the rover will have to rotate with enough torque to be able to get through such rough terrain. Taking these factors into consideration, the payload team has decided to use two high torque servos that will drive each wheel of the rover. Steering the rover will be dependent on varying the speed of each servo.

B. 2.4 GHZ First Person Camera System
- RMRC-600XV Camera
- ImmersionRC 500mW 2.4GHz TX
- Airwave Receiver
- Power Cable for Receiver (may vary from product photo)
- 460mAh Batteries (2)
- 8dBi Patch Antenna

One of the primary objectives of an exploration vehicle is to be able to transmit the view of its surrounding to its operating team. This feature enables the ground team to
maneuver the rover and also provides useful information in case the rover is being used for a rescue mission.

“Inquisitivity” will be loaded with a High definition CCD camera that will transmit live video feed through a small radio transmitter that will also be mounted on its avionics bay. A receiver and patch antenna combination on the ground station will display the video feed from the rover on a TV or computer screen. The system is compact and efficient and a similar system has been tested on a high-altitude balloon flight by one of the team members for a UAV project. The team still plans on doing further tests as to the robustness of this system on the ground and its ability to transmit high-definition video efficiently.

C. ArduIMU Microcontroller
The ArduIMU will serve as rovers control system unit. The team chose this microcontroller for its superb functionality coupled with its compact design so that it does not take up much space on the rover chassis. The unit will be connected to the RF transmitter for the purpose of controlling the servos. The autonomous control commands will also be executed through the ArduIMU, which will send the control output to the servos and hence autonomously maneuver the rover. As the name suggests, the microcontroller has an in built Inertial Measurement Unit (IMU) and we plan on exploiting this capability and recording the three-axis forces experienced by the rover during the takeoff, flight and landing.

D. MediaTek MT3329 GPS
Once the rocket has landed and the rover is deployed, it will be extremely important to determine the exact location of the rover for recovery purposes. The Mediatek GPS is compatible with the ArduIMU with a low power consumption, high sensitivity and has a built-in patch antenna. The GPS has a position accuracy of less than 3 meters, which is acceptable for our purpose.

E. RC Receiver and Transmitter
A Spectrum AR600 Receiver will be connected to the ArduIMU on the rover to receive and relay control inputs from the transmitter to the ArduIMU, which in turn will process the inputs and relay them to the servo’s that will drive the wheels of the rover.

4.1.6 Summary of changes made to rover design and systems since proposal

There are a few changes that were made to the rover “Inquisitivity” that will be the payload implemented into the rocket. The main change is that since the rover will have to be more condensed than previously thought, smaller components will have to be implemented into the changed design. First the design will not contain two inside walls to support the axle due to the decrease in required length for the payload. This will mean that the chassis will have to be made in such a way to reinforce the rover since there will be less support on the axle than previously designed. Due to this as well, its closed diameter will now be 5.5 inches with an open diameter of 10 inches, which is
smaller than previously designed. Another change is that “Inquisitivity” will be using high torque servos instead of electric motors as these are more efficient in size and still will be able to accomplish what is required of the rover.

4.1.7 Performance Characteristics

A. Exploration System
“Inquisitivity’s” video camera system must be capable of transmitting live video feed after deployment from the rocket to the ground station, which means it must have a range of up to 2640 feet. The team has selected a camera system, which will be capable of meeting this requirement. The verification plan for this system is discussed in 4.1.6.

B. Propulsion System
The rover’s propulsion system consists of the high torque servos that drive the wheel assembly. This system must be capable of generating enough torque to drive the rover and account for the rough and uneven terrain of a cornfield. The servos selected for the propulsion system will be able to meet this requirement and generate enough torque to drive and steer the 6-pound rover.

C. Control System
The ArduIMU is an extremely robust, compact and reliable microcontroller platform and is compatible with the spectrum receiver. These two components shall be the rovers on-board control system, while the transmitter remote controller that will be operated by the ground station operator will serve as the rovers manual control link. Since the Spectrum receiver and transmitter system is mainly used for model airplanes, they have a long range of up to 1.6 miles, which is more than sufficient for our purpose; however this is when the aircraft is flying at an altitude, and hence radio coverage is better. Testing will be done to verify that this system can function equally or sufficiently well on the ground at a range of up to 2640 feet.

4.1.8 Payload Verification

Verification of “Inquisitivity’s” systems and subsystems will take place through the phases that are described below:

A. Electronics Testing
This phase shall embody the testing of the rover’s electronic components that include the ArduIMU, RC receiver and transmitter, data logger and video camera system.

B. Ground Testing
Once the structural design is ready and the propulsion system is integrated, the rover will be tested on terrain similar to that of the landing site on the final launch day. Through this process it will be determined how well a manual operator is able to drive the rover and what range it can operate from.
C. Deployment testing

Deployment from the rocket after landing is of prime importance for the success of “Inquisitivity”. Without proper deployment, it would be impossible to determine the functionality and effectiveness of the payload and the exploration mission would be a complete failure.

The deployment system consists of black powder charges attached to a piston that cover one of the wheel assemblies of the rover. The black powder will be triggered by an on/off switch electronic connection that will run from the rover to the piston and will be under the control of the ground operator through the RC transmitter. The connection will be such that it will snap easily once the black powder ignites and pushes the piston into the rover and out through the nose cone.

![Figure 43: Rough Sketch of the deployment system, showing the on/off switch connection to the rover](image)

The reason for using an on/off switch is that in case the black powder does not ignite for some reason, the switch can be turned off to eliminate the live charge that may have travelled through the connection but due to some reason, could not ignite the charge at that moment. This makes the recovery of the rocket and the payload safe. To test this system, we shall be testing the piston and black powder system with a dummy payload through the development phase of the project, and through these tests, we will be able
to determine if our theoretical calculations for the amount of black powder we need to use to deploy the rover out of the nose cone under the worst case scenario conditions match with experimental results. If the results differ, then further tests will help us improve and make any necessary changes to our deployment system.

4.1.9 Verification Plan and its Status

The rover payload “Inquisitivity” will follow a verification plan so that it will be able to complete its tasks and let the team know if it has successfully completed its projected missions. There will be certain design features on the payload that will let the payload accomplish these requirements with the highest efficiency. There will be verification for the payload’s obligations in a variety of ways.

<table>
<thead>
<tr>
<th>Payload requirement</th>
<th>Design feature to verify requirement</th>
<th>Verification of completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload must not sustain any damage upon landing or deployment from the rocket itself.</td>
<td>The rover will have a casing around itself during flight and upon landing. The chassis will be built such that the rover will be able to experience up to 20 G in the rocket.</td>
<td>By inspection of the rover it will be clear whether the rover sustained any damage. Also if the rover is not performing certain functions in real time such as the live feed video to a computer, damage could be potentially verified.</td>
</tr>
<tr>
<td>Successful deployment from the rocket upon landing.</td>
<td>The casing will protect the rover until it is deployed out in which the casing will fall off helping in the successful deployment. Black power will be used to deploy the rover safely from the rocket.</td>
<td>The verification can be seen by inspection whether the rover was successfully deployed. As there will be an electronic switch to turn the black powder off in case of it not deploying, data will be sent back to see if was deployed or not.</td>
</tr>
<tr>
<td>The rover is required to perform certain maneuvers during its time on the surface of the earth. It will have to move 10 feet forward, rotate 180° and move forward 10 feet again.</td>
<td>Two high torque servos will be used independently on each wheel to maneuver the rover. A receiver will obtain the functions from the RC controller and the ArduIMU+V3 will interpret these maneuvers to make the rover move its servos to inevitably move the rover.</td>
<td>By inspection if the rover has moved in the desired path.</td>
</tr>
<tr>
<td>If no command is sent to rover upon deployment for five minutes move to autonomous functions of moving the rover 10 feet forward, rotating 180° and</td>
<td>The autonomous function will be programmed into the ArduIMU such that if a signal is not received from the RC controller, it will perform the autonomous functions.</td>
<td>If the rover has moved, by inspection it will be shown if it functioned autonomously.</td>
</tr>
</tbody>
</table>
moving forward 10 feet.

<table>
<thead>
<tr>
<th>There will be a live video feed from the rover to a team member’s computer</th>
<th>A CCD Camera will be mounted on the rover that is able to transmit its video to a team member’s computer via a receiver and patch antenna.</th>
<th>If there is camera visual on the team member’s computer, it will be known that the requirement was successfully accomplished.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A GPS unit will transmit the rover’s location back to a team member.</td>
<td>GPS ArduIMU shield.</td>
<td>If there are transmissions from the rover back to a team member’s computer, the requirement will be verified.</td>
</tr>
</tbody>
</table>

Table 15: Payload requirements and verification table

4.1.10 Preliminary Integration Plan

The payload will be located in between the nose cone and the aviation bay. The nose cone will be 24 inches with a shoulder of 6 inches. The payload bay will be 30 inches in length as shown in picture 5. The rover length with its casing will be 15 inches and the black powder canister will be 5.5 inches in length. There will be avionics utilizing 3 inches in the payload bay and separated from the black powder canister by a 0.5 inch fiberglass bulkhead.

The diameter of the rocket is 6 inches and the rover, when it is closed, has a diameter of 5.5 inches with a length of 14 inches. With the casing, the rover’s diameter will be 6 inches with a length of 15 inches. The black powder canister will be placed behind the
rover and fired to deploy the rover, the bulkhead will be the support for the canister to keep it in place. A shock chord will be connected between the bulkhead and the black powder canister to keep the canister from ejecting the payload once it is fired. The shock chord will be made to be 26 inches long so that it is easy to recover, but isn’t too short as to affect the rover’s deployment.

A coupler will be placed between the nose cone and the payload as well as a fiberglass plate so that upon deployment, the rover will not shoot into the nose cone. This will ensure that the payload will deploy from the nose cone and the rover will be able to move without restrictions.

The casing for the payload will be made out of a 0.5 inch polyethylene foam material to surround the rover. Since the diameter of the wheels for the rover is 5.5 inches, the foam material can be condensed slightly to fit exactly into the 6 inch diameter space available in the rocket. This will be useful so that the rover does not move at all during the flight so little damage will occur.

Nylon 2-56 thread screws will be connecting the nose cone to the payload bay and will be sheared off once the black powder is fired to propel the rover from the rocket.

It is essential to calculate the shear force required to shear the pins off to deploy the rover. From this, the amount of black powder charge required in the canister can be found. The ultimate shear strength of nylon 2-56 thread screws is \( \tau_y = 11 \text{ Ksi} \) and calculated previously in 3.2.5 the required force to shear one pin is \( P = 44.4 \text{ lb} \) and with 10% uncertainty, 50lbs.

Additional forces will have to be taken into account such as the frictional force of the payload against the rocket, especially with its casing, and the shoulder of the nose cone to the payload bay. The minimum force required to shear these pins will be more than 50.0 pounds for each pin and additional testing will be required to find a more accurate maximum shearing force.

Since the largest change in momentum for the rocket, and the payload inside, will be when the main parachute opens, the rocket and payload will experience up to 20 G. The force on the payload from this 20G will be calculated and therefore, the amount of shear pins needed to connect the nose cone to the payload bay can be found. The mass of the contents of the payload bay are found as the rover, the black powder canister, and the nose cone are 6.0 pounds, 1.35 pounds, and 1.75 pounds respectively. 0.75 pounds are added for excess material not taken into account such as epoxy.

\[
m * g * 20 = \frac{6.0 \text{ lbs} + 1.75 \text{ lbs} + 0.75 \text{ lbs} + 1.35 \text{ lbs}}{32.2 \frac{\text{ft}}{s^2}} * 32.2 \frac{\text{ft}}{s^2} * 20 \text{G}
\]
From the equation, 197 pounds was calculated for the force on the payload during 20 G. From section 3.2.5 it was found that 7 shear pins would be required to connect the nose cone to the payload section.

Upon landing, it is necessary to calculate the force needed to deploy the payload from the rocket. The maximum force needed is ideal and the maximum force will be when the rocket lands vertical with the nose cone in the ground. The payload will still have to eject itself out in this configuration. Initially the rover will have kinetic energy from the black powder charge given by the equation

$$K = \frac{1}{2}mv^2$$

and once out of the rocket it will have potential energy from the equation

$$P = mgh.$$  

The maximum height of the rover will be h and by putting these two equations together, a value for the velocity can be calculated using

$$v = \sqrt{2gh}.$$  

The height will be taken to be the 21 inches plus the length of the payload of 15 inches for a total of 36 inches. This will be a height that will make sure that the payload is completely out of the rocket. This velocity is found from the equation to be 13.90 feet/second.

The impulse-force equation can be used to calculate the force required for the ejection system to expel the payload:

$$m(\Delta v) = F(\Delta t)$$

thus,

$$F = \frac{m(\Delta v)}{(\Delta t)}.$$  

The estimation for $\Delta t$ is 0.1 seconds as this is the expected burn rate. This time may increase as finalization of the black powder charge is found. With the time of 0.1 seconds, the force needed to push out the payload is 42.52 pounds. This force added to the force required from the seven shear pins (350 pounds) gives a total of 392.5 pounds that the black powder will have to discharge. A 20% contingency is used due to pressure escaping around the black powder canister, the frictional forces from the payload and the nose cone as well as energy loss due to elastic collisions of the black powder canister with the bulkhead. With the 20% contingency, the force is approximately 471 pounds.
The mass of the black powder needed for the deployment of the rover is given by the equation:

\[ W = \frac{P \times V}{R \times T} \times 454. \]

Where \( W \) is the amount of black powder needed, \( P \) is the pressure assuming to be at sea level of 14.7psi, \( R \) is the gas constant of 266 in-lbf/lbm, and the temperature is given in Rankine for 3307 R. The pressure is assumed at sea level as it should only have a slight increase in the rocket. Further testing will be done to get a more accurate reading of the real pressure in the rocket for the final calculation for the amount of black powder needed. The volume is taken from the equation

\[ V = L \times \frac{\pi}{4} \times D^2 \]

where \( D \) is the diameter of the rocket, 6 inches, and the length is the length of the payload bay being 30 inches. With all of these values, the amount of black powder needed will be 6.437 grams.

4.1.11 Precision of instrumentation, repeatability of measurements, and recovery system

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.

- AR600 Receiver to receive transmissions from the DX5e controller has a range of ~ 2,600 feet. This will be well within the range 2,500 feet from the launch site making the receiver a reliable system for the rover payload.
- RMRC-600XV CCD Camera (NTSC) will use an ImmersionRC 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.
The recovery of the rover is an important part of the payload design. The MediaTek MT3329 GPS tracking system will be used to accurately obtain the payload once it has deployed and moved away from the rocket.

4.1.12 Tentative Schedule

A few of the key dates for the rover testing and assembly are listed in Table ?.

<table>
<thead>
<tr>
<th>Date</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 29th 2012</td>
<td>PDR report, presentation, and flysheet due</td>
</tr>
<tr>
<td>November 12th 2012</td>
<td>Order RC receiver and servos</td>
</tr>
<tr>
<td>November 19th 2012</td>
<td>Order CCD Camera system, ArduIMU, GPS</td>
</tr>
<tr>
<td>November 25th 2012</td>
<td>Test supplies (range) and functions</td>
</tr>
<tr>
<td>December 2nd 2012</td>
<td>Finalize rover design</td>
</tr>
<tr>
<td>December 16th 2012</td>
<td>Test supplies again with finalized rover design</td>
</tr>
<tr>
<td>January 7th 2012</td>
<td>Order materials to build rover</td>
</tr>
<tr>
<td>January 14th 2012</td>
<td>CDR report, presentation, and flysheet due</td>
</tr>
<tr>
<td>March 18th 2012</td>
<td>FRR report, presentation and flysheet due</td>
</tr>
<tr>
<td>April 20th 2012</td>
<td>Launch day</td>
</tr>
</tbody>
</table>

Table 16: Tentative Project Schedule

4.1.13 Rover Electronics

We will be purchasing the Advanced FPV Starter Package: 2.4GHz. We found that this package has a lot of the components we will need and is cheaper than buying all of the components separately. The package includes a camera, transmitter, power cables for the receiver, two batteries, and a patch antenna. The main components we will be using from this package are the camera, transmitter, receiver, and patch antenna. This package along with a patch antenna and computer is all we will need to transmit and receive the live video feed from the rover.
Figure 44: Camera System Package

<table>
<thead>
<tr>
<th>Camera:</th>
<th>RMRC-600XV Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter:</td>
<td>ImmersionRC 500mW 2.4GHz TX</td>
</tr>
<tr>
<td>Receiver:</td>
<td>Airwave 2.4GHz A/V Receiver</td>
</tr>
<tr>
<td>Patch Antenna:</td>
<td>2.4 GHz 8 dBi Flat Patch Antenna</td>
</tr>
<tr>
<td>Package Cost:</td>
<td>$289.99</td>
</tr>
</tbody>
</table>

Table 17: Advanced FPV Starter Package components

A. Camera
The camera will be mounted on the lower shelf of the rover and will be mounted forward facing i.e. towards the direction of travel. This camera will be connected to a wireless transmitter to send the live feed to the driver’s computer to assist the driver in navigation and obstacle avoidance. The camera will be the main tool used in the navigation of the rover.
Figure 45: ReadyMadeRC RMRC-600XV Camera

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>ReadyMadeRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>RMRC-600XV</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>5-15V</td>
</tr>
<tr>
<td>Field of View</td>
<td>35 degrees</td>
</tr>
<tr>
<td>Resolution</td>
<td>CMOS of 600 TV lines of resolution</td>
</tr>
<tr>
<td>Weight</td>
<td>1.3 oz</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1.2 x 1.2 x 0.5 in</td>
</tr>
<tr>
<td>Price</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
</tbody>
</table>

Table 18: ReadyMadeRC RMRC-600XVN Camera Specifications

B. Transmitter
The transmitter will be attached to the camera directly and will send the live video feed from the camera to the ground station. The receiver will then receive the transmissions from the transmitter and will then connect directly to the computer at the ground station. By itself, the transmitter will not have enough power to send the transmission all the way to the ground station, so the transmitter will be coupled with a patch antenna in order to achieve the distance required.
Figure 46: ImmersionRC IMRC24500TX wireless transmitter

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>ImmersionRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>IMRC24500TX</td>
</tr>
<tr>
<td>Transmitter Frequency:</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Range with patch antenna :</td>
<td>6562ft</td>
</tr>
<tr>
<td>Input Voltage Range:</td>
<td>6-16V</td>
</tr>
<tr>
<td>Dimensions:</td>
<td>2.36 x 1.26 x 0.55 in</td>
</tr>
<tr>
<td>Weight:</td>
<td>0.78 oz</td>
</tr>
<tr>
<td>Cost:</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
</tbody>
</table>

Table 19: ImmersionRC IMRC24500TX specifications
C. RC Receiver
The RC receiver will be mounted on the top surface or the rover and will act as an interface between the RC transmitter and microcontroller. The receiver will relay commands from the ground station to the microcontroller and then to the servos, giving the pilot complete control over the rover.

![Spektrum AR600 Receiver](image)

*Figure 47: Spektrum AR600*

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Spektrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>AR600</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>3.5-9.6V</td>
</tr>
<tr>
<td>Band</td>
<td>2.4GHz</td>
</tr>
<tr>
<td>Range</td>
<td>Full Range line of sight, 2640 ft. on</td>
</tr>
<tr>
<td>Weight</td>
<td>0.017lbs</td>
</tr>
<tr>
<td>Dimensions</td>
<td>1.18 x 0.85 x 0.49 in</td>
</tr>
<tr>
<td>Antenna Length</td>
<td>5.98 in</td>
</tr>
</tbody>
</table>

*Table 20: ImmersionRC IMRC24500TX specifications*
D. Microcontroller

The microcontroller will be mounted to the lower shelf of the rover. It will be used to relay commands from the RC receiver to the servos. In the event of the RC receiver not receiving any commands, the microcontroller will initialize a set of commands making the rover semi-autonomous. The microcontroller has a tri-axis accelerometer and tri-axis angular rate sensor onboard which can measure the accelerations and angular rates of the rover. This coupled with the live video feed will assist the driver in determining the terrain that the rover is encountering and how to pilot accordingly.

![Arduino arduIMU +v3 microcontroller](image)

*Figure 48: Arduino arduIMU +v3 microcontroller*

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>Arduino</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>ArduIMU + v3</td>
</tr>
<tr>
<td>Processor:</td>
<td>ATmega328</td>
</tr>
<tr>
<td>Frequency:</td>
<td>16MHz</td>
</tr>
<tr>
<td>Tri-axis accelerometer range:</td>
<td>16g</td>
</tr>
<tr>
<td>Tri-axis angular sensor range:</td>
<td>2000dps</td>
</tr>
<tr>
<td>Dimensions:</td>
<td>1.5 x 1.0 in</td>
</tr>
<tr>
<td>Cost:</td>
<td>$78.90</td>
</tr>
</tbody>
</table>

*Table 21: Arduino arduIMU +v3 microcontroller specifications*
E. High Torque Continuous Rotation Servos

Two high torque servos will be mounted in the rover in order to direct drive the rover. Each servo will be mounted and operated separately for optimal control of the rover without any additional steering system to be put in place. High torque servos were chosen so that the rover could drive across any terrain that the rover encountered. These servos were also chosen for their reliability and durability. The metal gearboxes within these servos provide extra durability that the plastic counterparts simply do not provide.

![Figure 49: Hitec HSR-5980SG](image)

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>Hitec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>HSR-5980SG</td>
</tr>
<tr>
<td>Torque:</td>
<td>333 oz-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>0.17 sec/60 degrees</td>
</tr>
<tr>
<td>Weight:</td>
<td>2.46 oz</td>
</tr>
<tr>
<td>Dimension:</td>
<td>1.57 x 0.78 x 1.45</td>
</tr>
<tr>
<td>Cost:</td>
<td>$110</td>
</tr>
</tbody>
</table>

Table 22: Hitec HSR-5980SG specifications
F. Power Supply
There will be one battery on the rover powering all the components on board. It will be mounted within the rover on the upper shelf. The arduIMU board will be connected to the battery and most of the components through the arduIMU board. This specific battery was chosen for its high mAh rating of 8800 which should be more than enough to power this rover for an extended period of time which is essential because the GPS in the rover will be powered by this battery.

Figure 50: Tenergy Li-ion 18650 Battery Pack

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>Tenergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>Li-Ion 18650</td>
</tr>
<tr>
<td>Battery Type:</td>
<td>Li-Ion</td>
</tr>
<tr>
<td>Number of Cells:</td>
<td>8</td>
</tr>
<tr>
<td>Voltage:</td>
<td>7.4V</td>
</tr>
<tr>
<td>Capacity:</td>
<td>8800 mAh</td>
</tr>
<tr>
<td>Dimensions:</td>
<td>2.56 x 2.87 x 1.46 in</td>
</tr>
<tr>
<td>Cost:</td>
<td>$57.00</td>
</tr>
</tbody>
</table>

Table 23: Tenergy Li-ion 18650 Battery Pack specifications
G. GPS
A GPS will be placed within the rover to aid in recovery. The rover will be separated from the rocket if the mission is a success, so it will be vital that we have a recovery system for the rover as well. The GPS will connect to the ArduIMU and transmit its position in real time.

![Mediatek MT3329 GPS](image)

**Figure 51: Mediatek MT3329 GPS**

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>MediaTek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>MT3329</td>
</tr>
<tr>
<td>Accuracy:</td>
<td>9 ft.</td>
</tr>
<tr>
<td>Sensitivity:</td>
<td>Up to -165 dBm</td>
</tr>
<tr>
<td>Dimensions:</td>
<td>0.63x0.63x0.24in</td>
</tr>
<tr>
<td>Patch Antenna Size:</td>
<td>0.59x0.59x0.16in</td>
</tr>
<tr>
<td>Weight:</td>
<td>0.21 oz</td>
</tr>
<tr>
<td>Cost:</td>
<td>$37.95</td>
</tr>
</tbody>
</table>

*Table 24: Mediatek MT3329 GPS specifications*
Ground Station
The ground station will consist of one computer, one patch antenna, one radio antenna, and one RC transmitter/controller. 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 it the signal to the computer. The pilot will monitor the live video feed and relay commands to control the rover. The components and their costs are summarized below.

<table>
<thead>
<tr>
<th>Component</th>
<th>Model</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>Unspecified</td>
<td>Provided by pilot</td>
</tr>
<tr>
<td>8 dbi Range Booster Patch Antenna</td>
<td>RE09P-SM</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
<tr>
<td>RC Transmitter/Controller</td>
<td>DX5e</td>
<td>Our team already owns this</td>
</tr>
<tr>
<td>Receiver</td>
<td>AWM634RX RF</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
</tbody>
</table>

Table 25: Ground station

Figure 52: Ground station diagram
A. RC Transmitter/Controller

The pilot will use the DX5e full range RC Transmitter to control the rover. Typically the controller and transmitter combination is used for aerospace vehicles, and has a large range due to the nature of the intended use; however this controller will easily fulfill all of the needs for our mission. Because the rover will be ground based, the range will be limited to line of sight, so roughly 2,640 ft on ground.

![DX5e RC Transmitter](image)

*Figure 53: DX5e RC Transmitter*

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>Spektrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>DX5e</td>
</tr>
<tr>
<td>Power Requirements:</td>
<td>4 Alkaline Batteries (included)</td>
</tr>
<tr>
<td>Frequency:</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Number of Channels:</td>
<td>5</td>
</tr>
<tr>
<td>Range:</td>
<td>Full line of sight, 2,640 ft. on ground</td>
</tr>
<tr>
<td>Key Features:</td>
<td>Two gimbals allow for independent wheel control</td>
</tr>
<tr>
<td></td>
<td>Servo Reversing</td>
</tr>
<tr>
<td></td>
<td>Includes AR600 RC Receiver</td>
</tr>
<tr>
<td>Cost:</td>
<td>Already Owned</td>
</tr>
</tbody>
</table>

*Table 26: RC Transmitter Specifications*
B. 8dbi Flat Patch Antenna
Under standard operating procedures the ReadyMadeRC camera used in rover navigation transmits roughly 300-450 ft. on the ground. Our mission requires that the test equipment will function properly a maximum of 2,500 ft. from the launch pad. In order to accomplish this task, the signal must be boosted. The 8dbi Flat Patch Antenna will allow for the live video feed to be received over 1 mile.

![Figure 54: 8dbi Flat Patch Antenna](image)

<table>
<thead>
<tr>
<th>Manufacturer:</th>
<th>L-com</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model:</td>
<td>RE09P-SM</td>
</tr>
<tr>
<td>Range:</td>
<td>5600+ ft.</td>
</tr>
<tr>
<td>Frequency:</td>
<td>2.4 - 2.5GHz</td>
</tr>
<tr>
<td>Polarization Type:</td>
<td>Vertical, Horizontal</td>
</tr>
<tr>
<td>Beam Width:</td>
<td>65° (Vertical), 75° (Horizontal)</td>
</tr>
<tr>
<td>Dimensions:</td>
<td>4.5 x 4.5 x 0.9 in</td>
</tr>
<tr>
<td>Cost:</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
</tbody>
</table>

*Table 27: 8dbi Patch Antenna Specifications*
C. A/V Receiver
The receiver receives the live video feed from the rover and sends it to the ground station computer. This receiver is capable of receiving both audio and video transmissions. However, the rover will not be transmitting any audio transmissions, so we will only need to worry about the video.

![Airwave 2.4GHz A/V Receiver](image)

*Figure 55: Airwave 2.4GHz A/V Receiver*

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Airwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>AWM634RX RF</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>9VDC – 12VDC</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4GHz</td>
</tr>
<tr>
<td>Dimensions</td>
<td>4.5 x 4.5 x 0.9 in</td>
</tr>
<tr>
<td>Cost</td>
<td>Included in Advanced FPV Starter Package</td>
</tr>
</tbody>
</table>

*Table 28: Airwave 2.4GHz A/V Receiver*
4.2 Payload Concept Features and Definition

The payload concept of a deployable and maneuverable rover was inspired by the recent mission to Mars with the rover Curiosity. The rover that the University of Minnesota is creating for the USLI named “Inquisitivety” is a unique and significant, yet challenging design for a rocket payload.

This payload is extremely significant in today’s society when it comes to planetary discoveries and uses. On Earth, a rover can be able to go to places that may be difficult or even hazardous for a human to go to. 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 impact in encountering new things.

“Inquisitivety” is a suitable level of challenge as no one at the University of Minnesota has successfully created an operational rover that will eject from a rocket payload. The design, components and experimentation of the rover are very complex and there are many tasks involved. It is unique in the fact that it will also be able to become autonomous if the manual controller and receiver fail. Therefore, it will still be able to accomplish its mission even without the help of its team members.

As the three team members are all juniors in Aerospace Engineering and Mechanics at the University of Minnesota, this also holds a challenge for them as some of the material may be new to them. This makes it slightly more challenging, but as working together as a team, they will be able to overcome any obstacles faced by “Inquisitivety”.

4.3 Science Value

4.3.1 Payload Objectives

As was stated in the payload criteria, “Inquisitivety” will be able to be deployed from the rocket payload bay after landing and will be able to be driven by a ground operator through remote control. The rover will stream live video back to the ground operator through its onboard camera system, which will assist the ground operator in driving it. Furthermore, the rover will be capable of executing a series of autonomous functions that will allow it to drive automatically by flowing a set of commands that vary the rotational velocity of each servo. We expect the rover to be operational for about 10 minutes on the ground.

4.3.2 Payload Success Criteria

The success of the payload depends on its ability to withstand structural damage while it is inside the rocket and after it is deployed. It will also be determined by its ability to perform the necessary functions outlined in 4.1.2 efficiently. The exploration system of the rover comprises the camera system, which will stream live video feed to the ground operator. The video streaming will not only be instrumental in determining how well the
rover executes the control inputs given by the ground operator but also in assessing to what extent it executes the autonomous commands programmed onto its control system, which is the ArduIMU.

Once recovered, the rover system and all its subsystems will be analyzed to investigate if they have sustained any damage and if they are reusable.

4.3.3 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 stems and robotics may benefit from.

4.3.4 Experimental Test Measurement, variables and controls

Due to size and budget limitations, the team currently has no plan on adding any additional measurement sensors on the payload. However we may exploit 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 additional data logger that is compatible with the ArduIMU and will be implemented if the ArduIMU has any spare pins to accommodate this secondary function apart from its primary functions.

4.3.5 Relevance of Expected Data and Accuracy/Uncertainty

Inquisitivity's 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 modification 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. Before the ArduIMU is put onto the rover, it will be tested on the ground and the data will be validated using a Vicon Motion Tracking Camera System. This resource is available in the Interactive Guidance and Control Lab at the University of Minnesota's Aerospace department. It will allow us to validate the IMU's data with similar data from the motion tracking system, and MATLAB graphs will be used to determine the accuracy of the sensor. Minor accuracies can be fixed by manipulating the raw data collection code on the IMU.
4.3.6 Preliminary Experiment Process Procedures

Inquisitivity is a systems engineering project, and involves the careful testing of the subsystem to determine their capability and enhance or modify them for the purpose of the project. One of the first things the team will test is the servo motor and wheel assembly to experimentally prove that the torque generated by the propulsion system is sufficient for the rovers operating conditions. The material used for the rover’s structure is primarily fiberglass, which is extremely durable. However, it will be essential to determine the thickness of the material used for each section of the payload, which can be found by calculating the stress exerted on the structure from the reaction forces on the rover that were calculated in 4.1.8 and confirming that they fall within the elastic limit of the material.

The exploration subsystem will be ground tested to check it and validate its range and the control system will be tested for precision and robustness after implementing it on the rover.

4.4 Safety and Environment (Payload)

4.4.1 Safety Officer

As stated in the Section 3.4.1 (Safety and Environment - Vehicle), the team safety officer will be Binh B.

4.4.2 Failure Modes (Payload)

Similar to the failure modes for the vehicle, failure modes of the payload are summarized on table Table 29.
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Potential Failure Mode</th>
<th>Effects of Failure Mode</th>
<th>Potential causes</th>
<th>Severity Rating</th>
<th>Probability</th>
<th>Recommended Actions</th>
<th>Completed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF-1</td>
<td>Servos</td>
<td>Failures to rotate</td>
<td>Rover can’t move</td>
<td>Broken link bw/ control sys. and servos</td>
<td>2</td>
<td>Medium</td>
<td>Field test per FV-05-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-2</td>
<td>GPS</td>
<td>Failure to give accurate coordinates</td>
<td>Can’t locate rover</td>
<td>Defective GPS, or out of range</td>
<td>2</td>
<td>Low</td>
<td>Test range on GPS. Field test per FV-05-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-3</td>
<td>Control system</td>
<td>Code malfunction</td>
<td>Manual control is lost</td>
<td>Buggy software</td>
<td>2</td>
<td>Medium</td>
<td>Rover will be field tested. Field test per FV-05-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-4</td>
<td>Control system</td>
<td>Code malfunction</td>
<td>Manual control is lost</td>
<td>Hardware damaged</td>
<td>2</td>
<td>Medium</td>
<td>Electronics will be protected by chassis and rover will be wrapped in protective coating during flight. Development of a suspension system to dampen forces in three directions of motion. Static &amp; Dynamic test per FV-04-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-5</td>
<td>Camera system</td>
<td>Failure to transmit</td>
<td>No video feed</td>
<td>Hardware damaged</td>
<td>2</td>
<td>High</td>
<td>Extensive ground testing will determine the exact range for which signal may be received. Antenna may be upgraded if needed to increase range. Field test per FV-05-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-6</td>
<td>Orientation system</td>
<td>Broken outrigger folding arms</td>
<td>Loss of transmission</td>
<td>Broken outrigger folding arms</td>
<td>2</td>
<td>High</td>
<td>Structural integrity testing. Static &amp; Dynamic test per FV-04-2012</td>
<td>Tentative</td>
</tr>
<tr>
<td>PF-7</td>
<td>Power System</td>
<td>Power Failure</td>
<td>No Power</td>
<td>Broken Wire or Connector.</td>
<td>2</td>
<td>Medium</td>
<td>Drop Test. Vibration Test. Static &amp; Dynamic test per FV-04-2012</td>
<td>Tentative</td>
</tr>
</tbody>
</table>

**Table 29: Summary of Payload Failure Modes**

**Severity Rating:**

1 - Minor failure. Over all mission requirements are still attainable
2 - Moderate failure. One or two requirements is/are unattainable.
3 - Complete failure. Overall mission is unattainable, failure of most requirements.
4.4.3 Personal Hazards and Mitigation

A. Battery Handling

The Nickel Metal Hydride battery must be handled with care to prevent damage to the battery and injury to those handling it. The battery will be stored in a dry location at room temperature. Additionally, the battery will be disconnected from rover for the purpose of storage. When charging the battery one team member will always be present to ensure no circuit malfunctions and to prevent overcharging. Taking these precautions will prevent damage to the battery and will prevent sudden failure of the battery, such as an explosion, that could cause severe bodily harm.

B. Chassis Construction and Assembly

All team members involved in the manufacturing process of the rover will follow the same rules and safety procedures as laid out by the Safety and Environment - Payload section. Most importantly, this included the safety review that all team members have already received in order to receive authorization to work in the Mechanical Engineering Student Shop which goes over safety procedures when operating large pieces of machinery necessary for the construction of the aluminum chassis, as well as general shop safety tips and procedures. Additionally, the MSDS forms for all potentially hazardous materials such as the epoxy we are planning to use will be available in the storage area of Akerman 103B and the team will be briefed on their content by a team safety officer.

The personal protective equipment recommended in these forms are readily available in both the Mechanical Engineering shop as well as in the Akerman workspace, including safety goggles, gloves and personal respirators, as well as first aid kits and fire extinguishers. As stated before, the team will recommend that team members manufacture components in pairs, to keep one another alert and focused while in the shop and alert each other of potential hazards and safety violations.

C. Rover Deployment

Because the deployment plan dictates that the airframe will land with active black powder charges, it is extremely important that the rover not be deployed in a way such that anyone could potentially be hit by the moving airframe components or the rover during deployment. This scenario is very unlikely since the landing zone will be kept clear of all persons, however if the airframe should somehow land near people, the rover cannot be deployed until they have moved sufficiently far away. This is ensured by the fact that there is a remote trigger from ground control determining whether the
rover may or may not be able to ignite its black powder charge. In addition the team will not ignite the charge until clearance from the Range Safety Officer.

### 4.4.4 Environmental Concerns

As per the given requirements, all separable sections of the airframe (including the rover) will be equipped with an RF tracker to ensure their recovery. Thus no part of the rocket can be left in the field assuming no structural failures.

A potential environmental concern associated with the payload is the proposed spacer put in between the rover and the inner wall of the airframe in order to ensure a tight fit and a successful deployment. The team has not yet determined the details of this system and as such do not have a material selection nor a definite plan to ensure that the material will not be discarded into the field, however the easiest and most likely solution will simply be to tie the ends of the spacers to the airframe so they will not blow away and become unrecoverable.
5. Project Plan

5.1 Budget Plan

Since the initial proposal, the estimated budget has been refined. At this stage, most items in the design have been finalized. We have yet to purchase any components, and will begin with half scale acquisition in the first week of December. We also plan to purchase some payload electronics to begin initial testing.

The following tables are detailed budget current as of PDR. As with most design projects however, we realize that the budget will evolve with time, following testing and half scale results.

For ease of readability, the budget has been divided into Airframe, Payload, Travel, and Testing and Supplies.

<table>
<thead>
<tr>
<th>System</th>
<th>Component</th>
<th>Unit Cost</th>
<th>Qty</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubes</td>
<td>Nose Cone</td>
<td>$90.00</td>
<td>1</td>
<td>$90.00</td>
</tr>
<tr>
<td></td>
<td>Payload Tube</td>
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<tr>
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<td>Parachute Tube</td>
<td>$105.00</td>
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<td>$105.00</td>
</tr>
<tr>
<td></td>
<td>Booster Tube</td>
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<td>Payload Piston</td>
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<td></td>
<td>Coupler Tube</td>
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<td></td>
<td>Motor Mount Tube</td>
<td>$70.00</td>
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<td>Bulkheads</td>
<td>Transition Centering Rings</td>
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<td>Fin Surface Mounts</td>
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<td>Fins</td>
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<td>3</td>
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<tr>
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<td>MMT CRs</td>
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<td>Avionics Sled</td>
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<td>Payload Ejection Plate</td>
<td>$25.00</td>
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<tr>
<td></td>
<td>Main Ejection Plate</td>
<td>$20.00</td>
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<td>$20.00</td>
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<tr>
<td></td>
<td>Drogue Ejection Plate</td>
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<td>$20.00</td>
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<td>Recovery</td>
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<td>Drogue Parachute</td>
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<td>System</td>
<td>Component</td>
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<td>----------------------------</td>
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<td>Main Shock Cord</td>
<td>$30.00</td>
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<td>Electronics</td>
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<td>Upper Secondary Switch</td>
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<td>Lower Primary Switch</td>
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<td>$4.00</td>
</tr>
<tr>
<td></td>
<td>Lower Secondary Switch</td>
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<td></td>
<td>RF Transmitter</td>
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<td>Altimeter Battery</td>
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<td>E-Matches</td>
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<td>Raven3</td>
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<td>Motor</td>
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<td>75mm 5-Grain Motor Casing</td>
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<td>75mm Motor Retainer</td>
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<td><strong>SUBTOTAL</strong></td>
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'Subtotal': 3018.00
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<tr>
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<tbody>
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<td>Suspension</td>
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<td>Wheels</td>
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<td>Outriggers</td>
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<td>Bushings</td>
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<td>Shocks</td>
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<tr>
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<td>High Torque Servos</td>
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<td>Power Supply</td>
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<tr>
<td></td>
<td>GPS</td>
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<td>RC Transmitter</td>
<td>On Hand</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RC Receiver</td>
<td>On Hand</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patch Antenna</td>
<td>On Hand</td>
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<td>Booster Tube</td>
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<td>Nosecone</td>
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<td>$32.00</td>
</tr>
<tr>
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<td>Motor Mount Tube (54mm)</td>
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<td>1</td>
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<tr>
<td></td>
<td>Coupler Tube</td>
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<td></td>
<td>Payload Piston</td>
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<td>1</td>
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<tr>
<td></td>
<td>Fins</td>
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<td>3</td>
<td>$30.00</td>
</tr>
<tr>
<td></td>
<td>Fin Mounts</td>
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<td>3</td>
<td>$30.00</td>
</tr>
<tr>
<td></td>
<td>Bulkheads</td>
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<td>4</td>
<td>$20.00</td>
</tr>
<tr>
<td></td>
<td>Centering Rings</td>
<td>$2.00</td>
<td>6</td>
<td>$12.00</td>
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<tr>
<td></td>
<td>Main Parachute Piston</td>
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<td></td>
<td>Drogue Parachute</td>
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<td>1</td>
<td>$30.00</td>
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<td></td>
<td>Transition Section</td>
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<tr>
<td></td>
<td>Motor (J1520 Vmax)</td>
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<td></td>
<td>Motor Retainer</td>
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<td>Latex Gloves (per box)</td>
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<td>Safety Glasses</td>
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<tr>
<td></td>
<td>Resipartor Masks (3-pack)</td>
<td>$7.00</td>
<td>2</td>
<td>$14.00</td>
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<tr>
<td></td>
<td>First Aid Kit</td>
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<td>$50.00</td>
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</tbody>
</table>
PVC Rocket Stand $50.00 1 $50.00
Cleaning Wipes $10.00 3 $30.00
Various Spray Paint $100.00 1 $100.00
Epoxy Resin $20.00 1 $20.00
Epoxy Hardener $40.00 1 $40.00
Epoxy Filler $20.00 1 $20.00
Shear Pins (per 100 pack) $6.50 3 $19.50
Plastic Rivets $0.40 40 $16.00

SUBTOTAL $957.50

<table>
<thead>
<tr>
<th>Travel Expenses</th>
<th>Per Day</th>
<th>Insurance</th>
<th># Days</th>
<th>Total</th>
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</thead>
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<td>$115.00</td>
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<td>$625.00</td>
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<tr>
<td>Miles</td>
<td>2300</td>
<td>Mileage ($/mile)</td>
<td>Total</td>
<td>$529.00</td>
</tr>
<tr>
<td>Fuel</td>
<td>529</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotel Cost</td>
<td>$90.00</td>
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<td>3</td>
<td>$810.00</td>
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</table>

SUBTOTAL $1,964.00

<table>
<thead>
<tr>
<th>TOTAL PROJECTED BUDGET</th>
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</thead>
<tbody>
<tr>
<td>Airframe Subtotal</td>
</tr>
<tr>
<td>Payload Subtotal</td>
</tr>
<tr>
<td>Travel Subtotal</td>
</tr>
<tr>
<td>Testing and Supplies Subtotal</td>
</tr>
<tr>
<td>TOTAL PROJECTED EXPENSES</td>
</tr>
</tbody>
</table>

5.2 Funding Source

At this point, the USLI rocket team has secured $600 from the Student Union Association at the University of Minnesota, $500 from the Minnesota Space Grant Consortium, and $500 from the University of Minnesota Department of Aerospace Engineering and Mechanics. This is enough to get us started with the half scale test launch as well as the educational outreach our group is doing.
Though there is a large gap with the amount of funds we currently have secured, our team has previous contacts as well as new ones such as ATK, Best Buy, Goodrich Sensors and Integrated Systems, and Boeing. These contacts as well as others will be able to donate similar sums to the other groups and we will meet the total projected expenses.
Educational Engagement Timeline

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 29th, 2012</td>
<td>2012 South East Minneapolis Learning Carnival</td>
</tr>
<tr>
<td>November 17th, 2012</td>
<td>Family Fun Fair</td>
</tr>
<tr>
<td>January-March, 2013</td>
<td>Outreach Events with local Middle School (tentative)</td>
</tr>
</tbody>
</table>

Table 30: Educational Engagement Timeline Summary

5.4 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
At this time, we have attended one event. This event was the 2012 South East Minneapolis Learning Carnival, which was on September 29\textsuperscript{th}, 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

The Family Fun Fair on November 19th, 2012, is a fun activities fair for all ages. There are many themes including the Mystery Science Lab and Fundamental Robotics. We will be having students build straw rockets, mini hovercrafts, and show off our flown rockets.

The timeline for all outreach events are showed in Table EO 1. Contact information for previous or future outreach coordinators that were named in our proposal are listed in the appendix.
Appendix I: License(s)
Appendix II: Safety Protocol

Launch Operations Procedures

Launch System

For the launch system, our rocket will have a launch lug compatible to the 8 feet long 1 in. rail provided by the range. The vehicle will be capable of being launched by a standard 12 volt direct current firing system provided by the Range Services Provider. The vehicle planned will not require any external circuitry or special ground support equipment to initiate the launch.

Launch Procedures

Team Member Responsibilities

To efficiently conduct the launch, tasks and responsibilities will be distributed amongst individual team members. Each team member will be responsible for verifying their individual subsystem checklist prior to launch. The safety officer along with the team lead will provide oversight and communication for launch preparation. High level descriptions of individual responsibilities are shown below.

Project Lead & Safety Officer

The two officers will ensure that proper compliance with Safety Codes set by NAR and other federal codes has been met. Ensure that leads are checking off launch procedures in a proper and timely manner. Communicate and trouble shoot problems with team members to resolve issues that may arise during launch.

Structures Lead

The Structures Lead is responsible for ensuring proper assembly of individual subsystems and components. The lead will also ensure that the vehicle is free of defects that could possibly hinder the launch. The structural lead will also be responsible for the assembly of the rocket’s propulsion system by properly mounting the motor and ignition charges.

Recover Lead

The Recovery Lead is responsible for ensuring the proper assembly of the recovery envelope for the rocket and its recovery payload. The recovery lead will work together with the team sponsor Gary Stroick who is a level 3 Tripoli Rocketry Association certified member to load and properly size the black power ejection charge.

Avionics Lead

The Avionics will ensure that the nitrogen tank is at the correct pressure, free of defects, and is in working order prior to launch. The Avionics lead will also ensure that all electronics are transmitting correctly.
Safety and Environment (Vehicle)

Safety Officer

The safety officer for the team is Binh B. The safety officer responsibilities include developing safety plans and procedures; ensure proper compliance with school, regional and federals codes. In addition the safety officer will provide oversight to ensure that safety procedures and best practices are met by team members.

Vehicle Failure Modes

To save time, cost, and increase the overall success of the design requirements possible failure modes and their respective mitigation have been considered and tabulated.

Procedural Risks

There will also be procedural hazards to the team members as they prepare for flight and recover the vehicle and payload. Checklists for pre-flight procedures launch procedures and post-flight procedures as well as travel and shop checklists will be maintained and adhered to.

The following table lists some of the procedural hazards, and the proposed mitigations.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Hazard</th>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-flight</td>
<td>Black powder ignites on loading</td>
<td>Low</td>
<td>Mentor and safety officer will load black powder charges, and will be one of the last components to be loaded into rocket</td>
</tr>
<tr>
<td>Launch</td>
<td>Charges Ignite on pad</td>
<td>Low</td>
<td>Ensure avionics are powered off</td>
</tr>
<tr>
<td>Post-flight</td>
<td>Live charges still onboard</td>
<td>Low</td>
<td>Switch off electronics immediately upon recovery, and disassemble ejection canisters</td>
</tr>
</tbody>
</table>

Procedures Risk and Mitigation Summary

Note, by the time the team attends the competition launch, we will have successfully launched a minimum of one half scale rocket and one full scale rocket. We will practice our flight operation procedures as a team at each of the test launches.

We will also practice successful assembly and disassembly of the entire rocket and all components prior to competition launch. Each team member will be expected to be familiar with all rocket systems to ensure safety. On launch day, each team member will be assigned specific tasks to be performed in preparation of launch. The team lead and the safety officer will supervise the preparation and maintain the checklists.
Personnel Hazards and Environmental Concerns

Personnel hazards will exist during the course of this project, and all steps will be taken to prevent any accidents from occurring. Construction, testing and assembly of our high powered rocket (consisting of various materials including fiberglass, aluminum and wood) will require the use of various specialty tools.

Many of the tools required are contained in the Mechanical Engineering machine shop. All team members who will be working on constructing the rocket have completed a shop safety course.

The team has put forth a general rule that will require any member working on any component to do so in pairs. This rule will be held in strict adherence especially when working in the machine shop. The purpose of the rule is to not only prevent accidents by providing assistance in proper shop techniques, but also so that each component that is fabricated will have more than one person who understands the fabrication process.

In addition on October 11th the Safety Officer put on a safety training session that was required for all team members. This included familiarizing with MSDSs, proper lab safety practices, safe design practices, and risk mitigation practices. This ensured that all team members have a high level of awareness for safety.

The following table summarizes the shop hazards that will be encountered during the manufacturing and assembly of our rocket.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Hazard</th>
<th>Mitigation</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band Saw</td>
<td>Rotating blade</td>
<td>Always wear safety equipment, and pay attention.</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Jig Saw</td>
<td>Reciprocating blade</td>
<td>Pay attention</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Milling Machine</td>
<td>Rotating bits</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Lathe</td>
<td>High speed rotation</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Drill Press</td>
<td>High speed rotation</td>
<td>No loose clothing</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety Training</td>
<td></td>
</tr>
<tr>
<td>Miter Saw</td>
<td>Rotating blade</td>
<td>Pay attention</td>
<td>Eye, ear protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Safety Training

Rotary Tool
Rotating bits
Pay attention
Safety Training
Eye, ear protection

Machine Shop Hazards and Mitigation

With regard to the various hazardous materials to be used during the testing and construction of our high powered rocket, we will keep all materials in a locked storage cabinet in our Aerospace workspace in Akerman Hall 130B.

Upon the purchase of any hazardous material, the team lead and the safety officer will present details of how to handle the material properly during the weekly meetings. All MSDS sheets will be kept in a binder located at the storage cabinet. All team leads will be required to know the high level overview of chemicals that they will be using extensively. Again, it will be a mandatory rule that all team members must work in pairs when handling any hazardous material.

The shop in Akerman Hall 130B will also contain all safety equipment that will be required for the safe construction of our rocket. It is the responsibility of the team lead and the safety officer to ensure that the first aid kit and the fire extinguishers located in the workspace are functioning properly at all times.

Other safety equipment to be purchased will include respirator masks to be used when cutting or sanding fiberglass, applying epoxy and applying paint or primer. Safety goggles will also be purchased to be used as needed. Ear plugs and latex gloves will also be purchased and placed by the storage cabinet to be used as needed.

The following table summarizes the hazards from the various working materials in the lab, and includes risk mitigation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Hazard</th>
<th>Safety Equipment</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>Noxious fumes</td>
<td>Respirator, safety glasses, latex gloves</td>
<td>Make sure well ventilated</td>
</tr>
<tr>
<td>Super Glue</td>
<td>Fumes, skin contact</td>
<td>Respirator, latex gloves</td>
<td>Use ventilation</td>
</tr>
<tr>
<td>Black Powder</td>
<td>Skin contact</td>
<td>Latex gloves</td>
<td>Always wear gloves</td>
</tr>
<tr>
<td>Pyrodex</td>
<td>Skin contact</td>
<td>Latex gloves</td>
<td>Always wear gloves</td>
</tr>
<tr>
<td>Spray Paint</td>
<td>Fumes</td>
<td>Respirator, gloves</td>
<td>Make sure well ventilated</td>
</tr>
</tbody>
</table>
Personal Hazards and Mitigation

A. Battery Handling

The Nickel Metal Hydride battery must be handled with care to prevent damage to the battery and injury to those handling it. The battery will be stored in a dry location at room temperature. Additionally, the battery will be disconnected from rover for the purpose of storage. When charging the battery one team member will always be present to ensure no circuit malfunctions and to prevent overcharging. Taking these precautions will prevent damage to the battery and will prevent sudden failure of the battery, such as an explosion, that could cause severe bodily harm.

B. Chassis Construction and Assembly

All team members involved in the manufacturing process of the rover will follow the same rules and safety procedures as laid out by the Safety and Environment - Payload section. Most importantly, this included the safety review that all team members have already received in order to receive authorization to work in the Mechanical Engineering Student Shop which goes over safety procedures when operating large pieces of machinery necessary for the construction of the aluminum chassis, as well as general shop safety tips and procedures. Additionally, the MSDS forms for all potentially hazardous materials such as the epoxy we are planning to use will be available in the storage area of Akerman 103B and the team will be briefed on their content by a team safety officer.

The personal protective equipment recommended in these forms are readily available in both the Mechanical Engineering shop as well as in the Akerman workspace, including safety goggles, gloves and personal respirators, as well as first aid kits and fire extinguishers. As stated before, the team will recommend that team members manufacture components in pairs, to keep one another alert and focused while in the shop and alert each other of potential hazards and safety violations.

C. Rover Deployment

Because the deployment plan dictates that the airframe will land with active black powder charges, it is extremely important that the rover not be deployed in a way such that anyone could potentially be hit by the moving airframe components or the rover during deployment. This scenario is very unlikely since the landing zone will be kept clear of all persons, however if the airframe should somehow land near people, the rover cannot be deployed until they have moved sufficiently far away. This is ensured by the fact that there is a remote trigger from ground control determining whether the rover may or may not be able to ignite its black powder charge. In addition the team will not ignite the charge until clearance from the Range Safety Officer.

SO 3.4 Environmental Concerns

As per the given requirements, all separable sections of the airframe (including the rover) will be equipped with an RF tracker to ensure their recovery. Thus no part of the rocket can be left in the field assuming no structural failures.

A potential environmental concern associated with the payload is the proposed spacer put in between the rover and the inner wall of the airframe in order to ensure a tight fit and a successful deployment. The team has not yet
determined the details of this system and as such do not have a material selection nor a definite plan to ensure that the material will not be discarded into the field, however the easiest and most likely solution will simply be to tie the ends of the spacers to the airframe so they will not blow away and become unrecoverable.
Launch Procedures

Structures & Propulsion Preflight Checklist

Structural Lead: Devin Vollmer

Date:

Fin Installation

6. _____Inspect fin surface for cracks or chips
7. _____Slide each fin into fin centering ring
8. _____Install locking centering ring
9. _____Inspect quality of lock for fins
10. _____Inspect fin alignment

Pressure Vessel Installation

9. _____Check pressure vessel for cracks or chips
10. _____Mount vessel to pressure tank mount
11. _____Charge tank with compressed gas
12. _____Slide mount into booster tube
13. _____Apply pins with coder pins to secure tank
14. _____Install gas lines to pressure tank valve

Avionics – Vehicle Installation

8. _____Slide avionics sled onto treaded bolts
9. _____Secure sled with lock 2 nuts
10. _____Ensure nuts are locked
Vehicle Assembly

10. _____ Inspect tubes for potential snags or stops and make proper adjustments
11. _____ Slide coupler into respective body tube
12. _____ Inspect payload bay for hazardous obstructions or snags
13. _____ Slide nose cone into Payload tube
14. _____ Check for snug fit in all connections
15. _____ Inspect body tube for cracks and chips
16. _____ Inspect rail buttons for miss alignment
17. _____ Inspect motor mount
18. _____ Apply shear pins
19.

Safety Officer (Binh Bui) __________________________

Team Lead (Mark Abotossaway)____________________
Recovery Preflight Checklist

Recover Lead: Nathan Kluegel

Date:

Recovery System Check/Installation

1. _____Inspect all shock cords for structural integrity, removing and replacing any frayed components
2. _____Inspect drogue and main parachute for defects
3. _____Attach each end of the drogue shock cord to one of the two drogue bay U-bolts
4. _____Hook on drogue parachute to the middle of the drogue shock cord
5. _____Fold and load drogue parachute into drogue bay
6. _____Connect recovery section to motor section
7. _____Attach each end of the main shock cord to one of the two main parachute bay U-bolts
8. _____Hook on main parachute to middle of the main shock cord
9. _____Fold and load main parachute into main parachute bay
10. _____Connect recovery section to payload section

Safety Officer (Binh Bui) ____________________________

Team Lead (Mark Abotosaway) ________________________
Payload Preflight Checklist

Payload Lead: Hannah Weihner  ____________________
Payload Lead: Vishnuu Mallik  ____________________
Date: ____________________

Rover payload check

13. _____ Verify that the battery pack is connected
14. _____ Verify that the RMRC-600XV Camera is oriented correctly and stable on the payload chassis
15. _____ Verify that the camera’s Immersion RC transmitter is functioning with the Airwave Receiver and Patch antenna and its transmitting live video feed to the ground station.
16. _____ Verify that the high torque continuous rotation servos are properly connected mechanically to the rover as well as electrically to the ArduIMU
17. _____ Verify that the RC receiver is successfully connected to the ArduIMU and the RC Transmitter/Controller is able to transmit commands to the receiver.
18. _____ Test the rover to make sure that it is functioning and can move forward and rotate 180°
19. _____ Verify that the GPS is properly connected and is transmitting coordinated of the rover’s location
20. _____ After all subsystems are properly functioning, wrap payload into its polyethylene foam case.
21. _____ Inspect the black powder canister and make sure that the on/off switch is properly connected and functioning
22. _____ Put the black powder and piston assembly into the payload bay before the rover is put in
23. _____ Put the payload with its casing into the payload section of the rocket
24. _____ Verify that the payload is secure and can be sealed into the rocket and place the nose cone into place along with the shear pins

__________________________
Safety Officer (Binh Bui)

__________________________
Team Lead (Mark Abotossaway)
## Failure Modes Verification Tracker

### Test: FV-01-2012

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test Description</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF-2</td>
<td>Body Tube</td>
<td>Statically load body tube</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-3</td>
<td>Nose Cone</td>
<td>Statically load nose cone</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-19</td>
<td>Motor Retention</td>
<td>Statically load motor retention structure</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-20</td>
<td>Fins</td>
<td>Statically load fins</td>
<td>-</td>
<td>Jan-13</td>
</tr>
</tbody>
</table>

### Test: FV-02-2012

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test Description</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF-4</td>
<td>Nose Cone</td>
<td>Test for nosecone deployment</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-5</td>
<td>Payload Piston</td>
<td>Test for piston mechanism</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-6</td>
<td>Payload Piston</td>
<td>Test for piston mechanism</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>VF-11 &amp;VF-7</td>
<td>BP Charges</td>
<td>Test for parachute deployment using BP</td>
<td>-</td>
<td>Jan-13</td>
</tr>
</tbody>
</table>

### Test: FV-03-2012

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test Description</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF-8</td>
<td>BP Charges</td>
<td>Test for altimeter charge timing</td>
<td>-</td>
<td>1-Nov-12</td>
</tr>
<tr>
<td>VF-9</td>
<td>BP Charges</td>
<td>Test for programming code</td>
<td>-</td>
<td>1-Nov-12</td>
</tr>
<tr>
<td>VF-13</td>
<td>Avionics</td>
<td>Test for primary and secondary altimeters</td>
<td>-</td>
<td>1-Nov-12</td>
</tr>
<tr>
<td>VF-14</td>
<td>Avionics</td>
<td>Test for altimeter readings</td>
<td>-</td>
<td>1-Nov-12</td>
</tr>
<tr>
<td>VF-16</td>
<td>Shock Chord</td>
<td>Test shock cord swivel</td>
<td>-</td>
<td>1-Nov-12</td>
</tr>
</tbody>
</table>
### FV-04-2012 Test

**Test Description:** Static & Dynamic Test of Rover Structure

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test Description</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF-4</td>
<td>Control System</td>
<td>Test for hardware protective chassis for impact protection</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>PF-5</td>
<td>Camera System</td>
<td>Impact &amp; vibration test</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>PF-6</td>
<td>Orientation System</td>
<td>Impact test</td>
<td>-</td>
<td>Jan-13</td>
</tr>
<tr>
<td>PF-7</td>
<td>Power Sys.</td>
<td>Impact &amp; vibration test</td>
<td>-</td>
<td>Jan-13</td>
</tr>
</tbody>
</table>

### FV-05-2012 Test

**Test Description:** Rover Field Test (must be done after rover Static & Dynamic test)

<table>
<thead>
<tr>
<th>Failure Item</th>
<th>Description</th>
<th>Test Description</th>
<th>Results</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF-1</td>
<td>Servos</td>
<td>Test for servos ability to maneuver</td>
<td>-</td>
<td>Feb-13</td>
</tr>
<tr>
<td>PF-2</td>
<td>GPS</td>
<td>Test for GPS range</td>
<td>-</td>
<td>Feb-13</td>
</tr>
<tr>
<td>PF-3</td>
<td>Control System</td>
<td>Test for software</td>
<td>-</td>
<td>Feb-13</td>
</tr>
</tbody>
</table>
Federal Aviation Regulations (as pertaining to HPR)

§ 101.21 Applicability.
(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with §101.25(b)(7)(ii) and with any additional limitations imposed by the using or controlling agency.
(b) A person operating an unmanned rocket other than an amateur rocket as defined in §1.1 of this chapter must comply with 14 CFR Chapter III.

§ 101.22 Definitions.
The following definitions apply to this subpart:
(a) Class 1—Model Rocket means an amateur rocket that:
(1) Uses no more than 125 grams (4.4 ounces) of propellant;
(2) Uses a slow-burning propellant;
(3) Is made of paper, wood, or breakable plastic;
(4) Contains no substantial metal parts; and
(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.
(b) Class 2—High-Power Rocket means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.
(c) Class 3—Advanced High-Power Rocket means an amateur rocket other than a model rocket or high-power rocket.

§ 101.23 General operating limitations.
(a) You must operate an amateur rocket in such a manner that it:
(1) Is launched on a suborbital trajectory;
(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;
(3) Is unmanned; and
(4) Does not create a hazard to persons, property, or other aircraft.
(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

§ 101.25 Operating limitations for Class 2-High Power Rockets and Class 3-Advanced High Power Rockets.
When operating Class 2-High Power Rockets or Class 3-Advanced High Power Rockets, you must comply with the General Operating Limitations of §101.23. In addition, you must not operate Class 2-High Power Rockets or Class 3-Advanced High Power Rockets—
(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;
(b) At any altitude where the horizontal visibility is less than five miles;
(c) Into any cloud;
(d) Between sunset and sunrise without prior authorization from the FAA;
(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;
(f) In controlled airspace without prior authorization from the FAA;
(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:
   (1) Not less than one-quarter the maximum expected altitude;
   (2) 457 meters (1,500 ft.);
(h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and
(i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

[74 FR 38092, July 31, 2009, as amended by Amdt. 101–8, 74 FR 47435, Sept. 16, 2009]

§ 101.27 ATC notification for all launches.
No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation:
(a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;
(b) Date and time the activity will begin;
(c) Radius of the affected area on the ground in nautical miles;
(d) Location of the center of the affected area in latitude and longitude coordinates;
(e) Highest affected altitude;
(f) Duration of the activity;
(g) Any other pertinent information requested by the ATC facility.

§ 101.29 Information requirements.
(a) Class 2—High-Power Rockets. When a Class 2—High-Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:
(1) Estimated number of rockets,
(2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),
(3) Description of the launcher(s) planned to be used, including any airborne platform(s),
(4) Description of recovery system,
(5) Highest altitude, above ground level, expected to be reached,
(6) Launch site latitude, longitude, and elevation, and
(7) Any additional safety procedures that will be followed.

(b) Class 3—Advanced High-Power Rockets. When a Class 3—Advanced High-Power Rocket requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 3 rocket expected to be flown:

(1) The information requirements of paragraph (a) of this section,
(2) Maximum possible range,
(3) The dynamic stability characteristics for the entire flight profile,
(4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight control, and tracking,
(5) A description of other support equipment necessary for a safe operation,
(6) The planned flight profile and sequence of events,
(7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point,
(8) Launch commit criteria,
(9) Countdown procedures, and
(10) Mishap procedures.

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

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

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

4. **Ignition System.** I will launch my rockets with an electrical launch system, and with electrical motor igniters that are installed in the motor only after my rocket is at the launch pad or in a designated prepping area. My launch system will have a safety interlock that is in series with the launch switch that is not installed until my rocket is ready for launch, and will use a launch switch that returns to the "off" position when released. If my rocket has onboard ignition systems for motors or recovery devices, these will have safety interlocks that interrupt the current path until the rocket is at the launch pad.

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

6. **Launch Safety.** I will use a 5-second countdown before launch. I will ensure that no person is closer to the launch pad than allowed by the accompanying Minimum Distance Table, and that a means is available to warn participants and spectators in the event of a problem. I will check the stability of my rocket before flight and will not fly it if it cannot be determined to be stable.

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

8. **Size.** My rocket will not contain any combination of motors that total more than 40,960 N-sec (9208 pound-seconds) of total impulse. My rocket will not weigh more at liftoff than one-third of the certified average thrust of the high power rocket motor(s) intended to be ignited at launch.
9. **Flight Safety.** I will not launch my rocket at targets, into clouds, near airplanes, nor on trajectories that take it directly over the heads of spectators or beyond the boundaries of the launch site, and will not put any flammable or explosive payload in my rocket. I will not launch my rockets if wind speeds exceed 20 miles per hour. I will comply with Federal Aviation Administration airspace regulations when flying, and will ensure that my rocket will not exceed any applicable altitude limit in effect at that launch site.

10. **Launch Site.** I will launch my rocket outdoors, in an open area where trees, power lines, buildings, and persons not involved in the launch do not present a hazard, and that is at least as large on its smallest dimension as one-half of the maximum altitude to which rockets are allowed to be flown at that site or 1500 feet, whichever is greater.

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

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

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

### MINIMUM DISTANCE TABLE

<table>
<thead>
<tr>
<th>Installed Total Impulse (Newton-Seconds)</th>
<th>Equivalent High Power Motor Type</th>
<th>Minimum Diameter of Cleared Area (ft.)</th>
<th>Minimum Personnel Distance (ft.)</th>
<th>Minimum Personnel Distance (Complex Rocket) (ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 -- 320.00</td>
<td>H or smaller</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>320.01 -- 640.00</td>
<td>I</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>640.01 -- 1,280.00</td>
<td>J</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>1,280.01 -- 2,560.00</td>
<td>K</td>
<td>75</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>2,560.01 -- 5,120.00</td>
<td>L</td>
<td>100</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Range</td>
<td>Letter</td>
<td>125</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>5,120.01 -- 10,240.00</td>
<td>M</td>
<td>125</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>10,240.01 -- 20,480.00</td>
<td>N</td>
<td>125</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>20,480.01 -- 40,960.00</td>
<td>O</td>
<td>125</td>
<td>1500</td>
<td>2000</td>
</tr>
</tbody>
</table>

*Note: A Complex rocket is one that is multi-staged or that is propelled by two or more rocket motors*

Revision of July 2008
Tripoli Research Safety Code

1. Administration

1.1. Scope

1.1.1. This code shall apply to all individuals who wish to participate in Tripoli Research Launches.

1.1.2. This code shall apply to the design, construction, limitations to the kinds of propellants, their mass and power as used at a Tripoli Research Launch.

1.1.3. This code shall apply to other activities explicitly described herein as permitted at Tripoli Research Launches that do not involve the use of research motors.

1.1.4. This code shall not apply to the self-manufacture or process of manufacture of rocket motors or propellants for an individual's own use.

1.1.5. This code only identifies the requirements that are unique for Tripoli Research Launches. In areas where this code is silent, the requirements defer back to the Tripoli High Power Rocketry Safety Code for commercial launches.

1.2. Purpose

1.2.1. The purpose of the Tripoli Research Program is to foster the research and development of propulsion, payloads, electronics, recovery devices, air frame design, and construction materials.

1.2.2. It is the purpose of Tripoli to sanction and insure legal Tripoli Research activities as set forth in the Articles of Incorporation, Article III (a), (b), and (f).

1.2.3. The purpose of this code is to provide reasonable safety guidelines for the use of members of the Tripoli Rocketry Association at Tripoli Research Launches.

1.2.4. It is the purpose of this code to provide a means to introduce new technology or to include currently prohibited technology into Tripoli Research activities as the ability and expertise of these technologies becomes available.

1.2.5. This code is an extension to the Tripoli High Power Rocketry Safety Code. It is to be used to clarify the additional rules that govern Tripoli Research Launches. Fliers and launch organizers that participate in Tripoli Research Launches are governed by both safety codes.

1.3. Enforcement

1.3.1. This code shall be enforced according to the provisions set forth in the Articles of Incorporation and Bylaws of the Tripoli Rocketry Association, Inc., and the operating rules approved by the Board of Directors (BOD).
Tripoli Research Safety Code

2. Referenced Publications

2.1. General

2.1.1. Some of the documents or portions thereof listed in this chapter are referenced within this code and shall be considered part of the requirements of this document except for such requirements modified or waived in this code.

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

   Articles of Incorporation and Bylaws

   High Power Rocketry Safety Code

   Tripoli Motor Testing Committee (TMT), Testing Policies

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

   NFPA 1122, Code for Model Rocketry

   NFPA 1127, Code for High Power Rocketry

3. Definitions

3.1. General

3.1.1. The definitions contained in this chapter shall apply to the terms used in this code. Where terms are not included, common usage of the terms shall apply.

3.2. Tripoli Research Definitions

3.2.1. BOD. Board of Directors of the Tripoli Rocketry Association, Inc.

3.2.2. Rocket Motor. As used in this code, Rocket Motor shall refer only to Composite Propellant, Sugar Propellant, commercial black powder, and Hybrid Rocket Motor.

   3.2.2.1. Certified Motor. Any commercial motor which has been certified by Tripoli Motor Testing (TMT) and/or NAR Standards and Testing (S&T) and/or CAR Motor Certification Committee, or at one time was certified and has expired, or has been decertified.

   3.2.2.2. Research Motor. Any non-certified motor made for personal use that may or may not contain commercially available components. Research motors shall not be sold or distributed for a profit.

   3.2.2.3. Commercial Motor Approved for Research Use Only. Any commercial motor that has been reviewed and approved by Tripoli Motor Testing (TMT) that exceeds the limits of total thrust limit identified in NFPA 1127.

   3.2.2.4. Composite Propellant Rocket Motor. Any device as defined under Rocket Motor that utilizes a propellant charge consisting primarily of an inorganic oxidizer dispersed in a carbonaceous polymeric binder.

   3.2.2.5. Hybrid Rocket Motor. A rocket motor in which the fuel exists in a different physical state (solid or gaseous) than the oxidizer and that derives its force or thrust from the combination thereof.

   3.2.2.6. Sugar Propellant Rocket Motor. A propellant charge containing potassium nitrate as the primary oxidizer, and containing either dextrose or sorbitol or erythritol as the primary fuel and binder.
Tripoli Research Safety Code

3.2.3. **Research Rocket.** Any rocket flown from the Research / High Power Launch Area during a Tripoli Research launch.

3.2.4. **Range Safety Officer (RSO).** A Tripoli Level 2 or Level 3 member who is responsible for the safety of the launch.

3.2.5. **Launch Director (LD).** A Tripoli Level 2 or Level 3 member who has overall administrative responsibility for the launch.

3.2.6. **Launch Site.** The primary parcel of land from which research activities are conducted and all adjacent parcels which are owned by the same property owner, or other property owners, and who have granted permission for Tripoli Research Launch activities to be conducted on their property. This includes the Research / High Power Launch Area, Model Rocket Launch Area and Preparation Area.

3.2.6.1. **Research / High Power Launch Area.** An area or areas designated by the Launch Director or Range Safety Officer from which research / high power rockets are launched or motors are static tested.

3.2.6.2. **Model Rocket Launch Area.** An area or areas designated by the Launch Director or Range Safety Officer from which model rockets are launched.

3.2.6.3. **Preparation Area.** An area designated by the Launch Director or Range Safety Officer in which rocket motors, research rockets, or electronic components for research rockets are prepared for launching or static testing.

3.2.7. **Named Insured.** Individuals that are not Tripoli Members but are members of groups that have been submitted to, and approved by the Tripoli Insurance Liaison.

3.2.8. **Tripoli Regular or Certified Launch.** Any Tripoli launch where only certified motors may be flown.

3.2.9. **Shall.** Indicates a mandatory requirement.

3.2.10. **Tripoli (TRA).** Tripoli Rocketry Association, Inc.

3.2.11. **TRC** Tripoli Research Committee

3.2.12. **Tripoli Research Launch.** Any Tripoli Research launch where research activities, as described in this code, may be conducted.

4. **Limits of Liability**

4.1. **Use**

4.1.1. The use of all motors at Tripoli Research Launches shall be conducted in accordance with this code.

4.2. **Disclaimer**

4.2.1. The Tripoli Rocketry Association does not in any way participate in the manufacturing or fabrication process of Research Rocket Motors or propellants.

4.2.2. The Tripoli Rocketry Association does not regulate, approve, or officially support or endorse any propellant manufacturing or fabrication process, or in any way imply such approval.
4.2.3. The Tripoli Rocketry Association does not endorse or provide any safety codes for the self-manufacture of any propellant.

4.2.4. The publishing or reporting of any research rocketry activity in any publication shall not imply TRA endorsement of any research activity or endorsement of any research manufacturing or fabrication procedure.

4.3. Legality

4.3.1. The Tripoli Rocketry Association does not claim Research Rocketry to be legal in every municipality or in every state.

4.3.2. Participants in the Tripoli Research program shall comply with all local, municipal, state, and federal regulations where said activities are conducted.

4.4. Insurance

4.4.1. The Tripoli Rocketry Association supports Tripoli Research activities where said activities are conducted legally.

4.4.2. Tripoli Research activities are only insured when the provisions of this code are followed.

4.4.3. No Tripoli member shall imply to any authority or landowner that Tripoli Research activities are insured when, due to not following the provisions of this code, they are not.

5. Exclusions

5.1. Black Powder Rocket Motors

5.1.1. Uncertified black powder-based research motors are prohibited. (including as a composite ingredient, regardless of binder and/or formulation modifications). Certified black powder motors are not excluded by this code.

5.2. Liquid Rocket Motors

5.2.1. With the exception of nitrous-oxide hybrid rocket motors, liquid rocket motors are prohibited at Tripoli Research Launches. BOD approval may be given for very well documented liquid motor projects.

5.3. Additional Prohibited Propellants

5.3.1. The following propellants shall also be excluded from Tripoli Research launches: So called double-based, triple-based, and micro-grain propellants (including zinc/sulfur propellants).

6. Process of Inclusion

6.1. General

6.1.1. A proposal for the introduction of new technologies and the inclusion of currently prohibited technologies into the Tripoli Research program shall be submitted, in writing, by one or more Tripoli Research members to the Tripoli Research Committee (TRC) for review, after which the proposal is forwarded to the BOD.

6.1.2. The originator(s) of the proposal shall provide any and all technical documents that may be requested by the TRC and/or the BOD.
Tripoli Research Safety Code

6.1.3. Following review, the TRC and BOD may set a time and location for a demonstration of the requested technology, as is deemed necessary by the TRC and BOD.

6.1.4. After demonstration and testing, the TRC and BOD shall determine whether or not to introduce the requested technology into the Tripoli Research program.

6.1.5. Acceptance of new technology shall be based on technical data, and/or on review of any federal regulations that may impact the association or the hobby with the inclusion of any new technology, and/or on the impact of said technology on TRA insurance coverage.

6.1.6. If the requested technology is introduced, the TRC shall recommend any necessary changes to this code to safely introduce said technology for Tripoli Research use.

6.1.7. Any new technology approved shall be used in accordance with this code and any future requirements that may be added to this code.

7. Tripoli Research Launches

7.1. Launch Scheduling

7.1.1. All Tripoli Research launches shall take place at a time which is to be separated from any other Tripoli Regular or Certified launch, or any other non-TRA launch, at that same site by no less than 8 hours and a change of calendar date.

7.1.2. Operating separate range heads at separate locations on the same or adjacent property shall not meet this requirement unless launch/firing times for Tripoli Regular or Certified flights (or any non-TRA flights), and Tripoli Research flights are separated by no less than 8 hours and a change of calendar date.

7.2. Participation

Note: The information provided below identifies the minimum requirements for individuals that participate / attend Tripoli Research Launches. A Launch Director has the discretion to increase these requirements through prior notice with a Launch Announcement and exclude some of the categories of individuals that would normally be allowed to participate/attend during Tripoli Research Activities.

Participation and Access at Tripoli Research Launches shall be limited to the following:

7.2.1. Members of Tripoli in good standing and 18 years of age or older may access and conduct flights from the Research / High Power Launch Area and/or Model Rocket Launch Area.

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

7.2.3. Tripoli Junior Members that have successfully completed the Tripoli Mentoring Program training may access and conduct flights from the Research / High Power Launch Area and/or Model Rocket Launch Area in accordance with the rules of the Tripoli Mentoring Program under the direct supervision of a Tripoli Senior Member. The Tripoli Senior member may provide supervision for up to five (5) individuals that have successfully completed the Tripoli Mentoring Program Training at a time.
7.2.4. Children younger than 18 years of age that have not completed the Tripoli Mentoring Program may access and conduct flights from the Model Rocket Launch Area under the direction of a Senior Tripoli Member. These individuals are not allowed in the Research / High Power Launch Areas except for recovery of rockets launched from the Model Rocket Launch Area and only then if the Research / High Power Launch Area is open and no rockets are being launched from there.

7.2.5. Named Insured individuals approved by Tripoli Insurance may access and conduct flights from the Model Rocket Launch Area under the direction of a Senior Tripoli Member. These individuals are not allowed in the Research / High Power Launch Areas except for recovery of rockets launched from the Model Rocket Launch Area and only then if the Research / High Power Launch Area is open and no rockets are being launched from there.

7.2.6. Access by Non-Tripoli Members (Invited Guests and Spectators)

7.2.6.1. An invited guest (including non-Tripoli members of a group project) may be permitted in the Model Rocket Launch Area and preparation areas upon approval of the RSO but shall not be present at the High Power / Research launch area (except as allowed in 7.2.2).

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

7.3. Tripoli Research Launch Operations

7.3.1. Rockets may be launched from the Research / High Power Launch Areas only after verification that Children and other Named Insured individuals are not in the Research / High Power Launch Areas.

7.3.2. All flights and static tests conducted by the member shall be within the member’s certification level, with the exception of permitted TRA flyer certification attempts, using certified rocket motors.

7.3.3. All flights and static tests that use research motors shall be conducted by Tripoli members who are Tripoli certified level 2 or higher.

7.3.4. The member shall provide proof of membership and certification status by presenting their membership card to the LD or RSO upon request.

7.3.5. A person who makes the research motor(s) for a Tripoli Research group project may do so only if he/she is an official member of said group, and may collect only the costs (without profit) for materials used to produce the motor(s) for use in the group project.

7.3.6. The person who makes the research motor(s) for a Tripoli Research group project shall be physically present at that Tripoli Research group project flight, and shall retain possession of the rocket motor(s) for the group project until such time as the motor(s) are installed.
7.4. Prohibitions

7.4.1. Research motors shall not be used for certification flights.

7.4.2. Research motors shall not be fabricated of steel or other frangible materials (e.g., PVC).

7.4.2.1. Cases (including hybrid cylinders), front and rear closures, and nozzles shall not be fabricated of steel.

7.4.2.2. Screws, washers, compression rings and related closures, and sealing devices shall be exempt from requirement 7.4.2.1

7.4.3. No range activity shall be conducted when a thunderstorm has been sighted within ten miles or less of the launch site or if audible thunder or lightning is present.

7.5. Distances

7.5.1. The maximum launch altitude for flights containing research motors shall be 90% of the waiver altitude established for the launch.

7.5.1.1. The BOD may waive this requirement when it can be demonstrated (by past performance, actual thrust curves, etc.) that the performance of the motor(s) to be used shall not exceed the limits of the waiver.

7.5.1.2. Computer simulations without actual thrust data derived from one or more actual test stand firings shall not satisfy the requirements of 7.5.1.1

7.5.2. The minimum safe standoff distance from the spectator area for the Model Rocket Launch Area shall be 50 feet (15 meters).

7.5.3. The minimum safe standoff distance from the spectator and Model Rocket Launch Area for any research / high power flight and/or static test shall be per the table below.

**Research / High Power Launch Area Safe Standoff Distances**

<table>
<thead>
<tr>
<th>Total Installed Impulse, N-s</th>
<th>Motor Type</th>
<th>Non-Complex</th>
<th>Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 to 1.280</td>
<td>A-J</td>
<td>200 feet</td>
<td>250 feet</td>
</tr>
<tr>
<td>1.280.01 to 2.560</td>
<td>K</td>
<td>250 feet</td>
<td>350 feet</td>
</tr>
<tr>
<td>2.560.01 to 5.120</td>
<td>L</td>
<td>300 feet</td>
<td>500 feet</td>
</tr>
<tr>
<td>5.120.01 to 10.240</td>
<td>M</td>
<td>500 feet</td>
<td>1,000 feet</td>
</tr>
<tr>
<td>10.240.01 to 20.480</td>
<td>N</td>
<td>1,000 feet</td>
<td>1,500 feet</td>
</tr>
<tr>
<td>20.480.01 to 40.960</td>
<td>O</td>
<td>1,500 feet</td>
<td>2,000 feet</td>
</tr>
<tr>
<td>40.960.01 to 890,000</td>
<td>P-T</td>
<td>2,000 feet</td>
<td>2,500 feet</td>
</tr>
</tbody>
</table>

7.5.3.1. The Launch Director or Range Safety Officer may, at their discretion, require greater standoff distances.
7.6. Tripoli Certifications

7.6.1. Tripoli certification flights shall be permitted at Tripoli Research launches only for fliers using certified motors.

7.7. Launch Director and Range Safety Officer

7.7.1. The LD/RSO may, for any reason, refuse to allow the launch or static testing of any rocket motor or rocket that he or she deems to be unsafe.

7.7.2. Decisions of the Launch Director and/or the Range Safety Officer shall, in every case, be final.

7.8. Approved Motors

7.8.1. Research Motors, Certified Motors, and Commercial Motors Approved for Research Use Only shall be allowed at a Tripoli Research Launches.

7.8.2. Rockets containing a total impulse of more than 40,960 N-s shall not be flown without prior review/approval of the Tripoli Class 3 committee.

7.9. Recovery

7.9.1. A rocket shall be launched only if it contains a recovery system that is designed to return all parts of the rocket to the ground intact and at a landing speed at which the rocket does not present a hazard.

7.9.1.1. Rockets that employ passive recovery (e.g. tumble recovery, aero-braking) need not employ an electronically actuated recovery system.

7.9.1.2. Increased descent rates for Class 3 Rocket activities conducted at the Black Rock Desert venue are acceptable if needed to insure a controlled descent to remain inside the FAA approved Dispersion Area.

8. Waived Rules and Exceptions

8.1. Application for Waiver or Exceptions

8.1.1. Any provision of this code waived or excluded by the BOD shall be on a case-by-case basis.

8.1.2. Application for exceptions to any provision of this code shall be submitted in writing to the BOD at least 30 days prior to the activity covered by the exception.

8.1.3. In the event that BOD approval for waiver or exclusion from any provision of this code is granted, said approval shall apply only to a single event, at a single location.
Tripoli Rocketry Association Safe Launch Practices

Note: The enclosed guidance is a condensed version of Tripoli Safety Codes and policies. The complete Tripoli policies are available at www.Tripoli.org

I. All Launches:
   B. A person shall fly a rocket only if it has been inspected and approved for flight by the RSO. The flier shall provide documentation of the location of the center of pressure and the center of gravity of the high power rocket to the RSO if the RSO requests same.
   C. The member shall provide proof of membership and certification status by presenting their membership card to the LD or RSO upon request.
   D. Recovery.
      1. Fly a rocket only if it contains a recovery system that will return all parts of it safely to the ground so that it may be flown again.
      2. Install only flame resistant recovery wadding if wadding is required by the design of the rocket.
      3. Do not attempt to catch a high power rocket as it approaches the ground.
      4. Do not attempt to retrieve a rocket from a power line or other place that is hazardous to people.
   E. Payloads
      1. Do not install or incorporate in a high power rocket a payload that is intended to be flammable, explosive, or cause harm.
      2. Do not fly a vertebrate animal in a high power rocket.
   F. Weight Limits
      1. The maximum lift-off weight of a rocket shall not exceed one-third (1/3) of the average thrust on the motor(s) intended to be ignited at launch.
   G. Launching Devices
      1. Launch from a stable device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path.
      2. Incorporate a jet/blast deflector device if necessary to prevent the rocket motor exhaust from impinging directly on flammable materials.
   H. Ignition Systems
      1. Use an ignition system that is remotely controlled, electrically operated, and contains a launching switch that will return to "off" when released.
      2. The ignition system shall contain a removable safety interlock device in series with the launch switch.
      3. The launch system and igniter combination shall be designed, installed, and operated so the liftoff of the rocket shall occur as quickly as possible after actuation of the launch system.
      4. A rocket motor shall not be ignited by a mercury switch or roller switch.
   I. Launch Operations
      1. Do not launch with surface winds greater than 20 mph (32 km/h) or launch a rocket at an angle more than 20 degrees from vertical.
      2. Do not ignite and launch a high power rocket horizontally, at a target, in a manner that is hazardous to aircraft, or so the rocket’s flight path goes into clouds or beyond the boundaries of the flying field (launch site).
      3. A rocket shall be pointed away from the spectator area and other groups of people during and after installation of the ignition device.
      4. Firing circuits shall not be aimed with the rocket in other than a launching position and after recovery electronics have been armed (if used).
      5. Do not approach a high power rocket that has misfired until the ROS/LCO has given permission.
      6. Conduct a five second countdown prior to launch that is audible throughout the launch site, spectator, and parking areas.
      7. All launches shall be within the Flyer’s certification level, except those for certification attempts.
      8. The LD/RSO may refuse to allow the launch or static testing of any rocket motor or rocket that he or she deems to be unsafe.
Tripoli Rocketry Association Safe Launch Practices

II. Commercial Launches
A. Use only certified rocket motors.
B. Do not dismantle, reload, or alter a disposable or expendable rocket motor, nor alter the components of a reloadable rocket motor reloading kit for a purpose other than that specified by the manufacturer in the rocket motor or reloading kit instructions.
C. Do not install a rocket motor or combination of rocket motors that will produce more than 40,960 N-s of total impulse.
D. Rockets with more than 2560 N-s of total impulse must use electronic recovery mechanisms.

III. Research Launches
A. Exclusions / Prohibitions (may be waived on a case by case basis by the BOD):
   1. Uncertified black powder-based research motors are prohibited, including as a composite ingredient, regardless of binder and/or formulation modifications.
   2. Uncertified liquid rocket motors, with the exception of nitrous-oxide hybrid rocket motors, are prohibited.
   3. So called double-based, triple-based, and micro-grain propellants (including zinc/sulfur propellants) are prohibited.
   4. Cases (including hybrid cylinders), front and rear closures, and nozzles shall not be fabricated of steel or other flammable materials (e.g. PVC).
   5. Research motors shall not be used for certification flights.
B. All flights and static tests that use research motors shall be conducted by Tripoli members who are Tripoli certified level 2 or higher.
C. A flyer with a rocket with more than 40,960 N-s of total impulse requires review and approval by the TRA Class 3 Committee.
D. Rockets that employ passive recovery (e.g. tumble recovery, aero-braking) need not employ an electronically actuated recovery system.
E. Launch Directors have the right to restrict participation and access at Research Launches in addition to the allowances below.

IV. Participation / Access

<table>
<thead>
<tr>
<th>Individual Description</th>
<th>Model Rocket Launch Areas</th>
<th>Commercial High Power Launch Areas</th>
<th>Research Motor Launch Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripoli Senior Member</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adult Members of other recognized National / International Rocketry Organizations</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Tripoli Junior members that have completed the Tripoli Mentoring Program training</td>
<td>Supervised</td>
<td>Supervised</td>
<td>Supervised</td>
</tr>
<tr>
<td>Non Tripoli members age 18 and over that are students of an accredited educational institution</td>
<td>Supervised</td>
<td>Supervised</td>
<td>Supervised</td>
</tr>
<tr>
<td>Children younger than 18 years of age</td>
<td>Supervised</td>
<td>Supervised</td>
<td>No</td>
</tr>
<tr>
<td>Named insured</td>
<td>Supervised</td>
<td>Supervised</td>
<td>No</td>
</tr>
<tr>
<td>Invited guest</td>
<td>RSO Permission</td>
<td>Supervised</td>
<td>No</td>
</tr>
<tr>
<td>Spectator (Non-invited guest)</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Note - Supervised access means a single Tripoli Senior Member can provide direct supervision of up to 5 of the identified individuals.

V. Distance Tables

<table>
<thead>
<tr>
<th>Rocket's Total Installed Impulse, N-s</th>
<th>Motor type</th>
<th>Minimum Clear Distance</th>
<th>Minimum Launch Site Dimensions (diameter or shortest dimension), feet (The larger of 1/2 of the waivered altitude or)</th>
<th>Minimum Safe Distance, Commercial Launch</th>
<th>Minimum Safe Distance, Research Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ft</td>
<td>m</td>
<td>ft</td>
<td>ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regular</td>
<td>Square</td>
<td>Non-Complex</td>
<td>Complex</td>
</tr>
<tr>
<td>0.01 to 160.00</td>
<td>A-G</td>
<td></td>
<td></td>
<td></td>
<td>ft</td>
</tr>
<tr>
<td>160.01 to 320.00</td>
<td>H</td>
<td>50</td>
<td>15</td>
<td>75</td>
<td>23</td>
</tr>
<tr>
<td>320.01 to 640.00</td>
<td>I</td>
<td>50</td>
<td>15</td>
<td>75</td>
<td>23</td>
</tr>
<tr>
<td>640.01 to 1280.00</td>
<td>J</td>
<td>50</td>
<td>15</td>
<td>75</td>
<td>23</td>
</tr>
<tr>
<td>1,280.01 to 2,560.00</td>
<td>K</td>
<td>75</td>
<td>23</td>
<td>113</td>
<td>36</td>
</tr>
<tr>
<td>2,560.01 to 5,120.00</td>
<td>L</td>
<td>100</td>
<td>30</td>
<td>130</td>
<td>45</td>
</tr>
<tr>
<td>5,120.01 to 10,240.00</td>
<td>M</td>
<td>125</td>
<td>38</td>
<td>230</td>
<td>61</td>
</tr>
<tr>
<td>10,240.01 to 20,480.00</td>
<td>N</td>
<td>125</td>
<td>38</td>
<td>230</td>
<td>61</td>
</tr>
<tr>
<td>20,480.01 to 40,960.00</td>
<td>O</td>
<td>125</td>
<td>38</td>
<td>230</td>
<td>61</td>
</tr>
<tr>
<td>40,960.01 to 850,000</td>
<td>P-T</td>
<td>125</td>
<td>38</td>
<td>230</td>
<td>61</td>
</tr>
</tbody>
</table>

* F and 'G Motors that are above the limits in the definition of Model Rocket Motor shall be flown at the 'H' distance.

7/31/2012
Appendix III: Rules

LAUNCH RULES & PROCEDURES
North Branch, MN Launch Site

Welcome to Tripoli Minnesota. If you like smoke, flame, and big rockets, you've come to the right place! Most of the rockets flown at our launches fall into the large or high power class, however smaller model rockets also make an appearance. To launch, you must either be a dues paying member of the club, or pay a $15 launch fee for the day.

Exception – Children under the age of 18 may fly model rockets (1/4A – E impulse) without paying dues.

You must be a current member of TRA (Tripoli Rocketry Association) or NAR (National Association of Rocketry) to fly rockets with an H impulse or above.

Whether you are a seasoned rocketeer, novice, or a spectator we are thrilled that you are here.

In order to provide a safe, educational, and enjoyable event we all have to work together to follow a few simple rules.

LAUNCH RULES

• The Tripoli Safety code applies to this event. No smoking on the range or within 25 feet of motor prep areas. Consumption of alcohol is not allowed on the range.

• TRA/NAR membership and high power certification will be verified. If you are launching an H impulse motor or higher, please have your ID card available. Your credentials will be checked appropriate to the motor impulse being used.
• There is a daily launch fee of $15 for non-Tripoli Minnesota members payable at the launch site. Tripoli Minnesota membership dues can be paid online, onsite, or at any of our winter meetings. Children under the age of 18 may fly model rockets (1/4A – E) for free at any commercial launch.

• Our launch site requires the use of biodegradable cellulose wadding. Tissue paper or toilet paper type wadding is not allowed. Cellulose wadding is available in the box on the front of the equipment trailer free of charge.

• A flight card must be filled out for each flight. Please fill in all known information.

• The Range Safety Officer (RSO) will perform a safety check prior to each flight of any rocket. You may be required to explain your rockets flight plan as part of this safety check.

• Launch rod/rail selection is up to you. Please select a rod of sufficient length and diameter to properly guide your rocket during initial boost. If you bring a different rod or rail to a pad, please bring back the one that was changed. Do not leave launch rods or rails lying on the ground at the pad.

• When installing your igniter(s) please bring back and discard any igniter found in the clips. This will help keep our launch site clean.

• Please track your rocket during its flight. You alone are responsible for recovery of your rocket. If in doubt Rocket Hunter tracking transmitters are typically available to borrow for a given flight. Ask a club member, RSO or LCO (Launch Control Officer) for assistance.

• If your rocket lands in a crop field, only one person at a time will be allowed in the field to locate the rocket. Please walk parallel to the rows and be careful to avoid damaging the crops during search and recovery operations.

• Clean up your materials. If you find trash on the field please pick it up and throw it away. A waste bin is provided near the launch control desk.

• Rockets fascinate children. Please keep track of yours during this event. High power rockets are not toys and should be handled by adults or under close adult supervision. Children must be closely supervised while at club launches.

**LAUNCH PROCEDURES**

1. Prep your rocket. Withhold installing igniter until the rocket is upright on the launch pad.
2. Obtain and fill out an appropriate flight card. Cards are available at the launch control desk. The cards are color coded by motor impulse. Please have your card filled out prior to the safety inspection.

3. Have your rocket inspected by the RSO at the launch control desk. After the inspection, you will be assigned a launch pad. Remember all rockets must be inspected prior to flight.

4. Load your rocket on the pad when the range has been opened by the LCO. (See rules section pertaining to launch rod/rail use).

5. Set your launch angle as required for safe flight and recovery. Should you have any questions or concerns please ask for help.

6. Install the igniter(s) and check continuity at the pad relay box. Cleaning of the igniter clips is recommended to ensure good electrical contact. Good continuity is key to successful ignition.

7. Do not forget to arm your electronics and verify operational status.

8. Once the range is clear, the LCO will close the range.

9. A description of the rocket, motor, ejection, and payload will be given via PA followed by a 5 count and launch.

10. Have fun and enjoy the launch.

Remember if you have any questions concerning any of these rules please consult with the club Prefect, RSO, or LCO. We want your launch and recovery to be a safe, successful, and enjoyable experience. Club officials will be onsite to help.

Thank you for your cooperation.

Steve Anderson
Prefect
Tripoli Minnesota
tripolimnprefect@me.com
Appendix IV: Motor Instructions

Pro75® High-Power Reloadable Rocket Motor Systems

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

Read this BEFORE you start assembly:

- If you have any questions or require assistance, please contact your dealer. If you are unable to resolve your questions or problems then please contact the manufacturer directly. Assistance is available Mon – Fri 9am – 4:30pm at (605) 887-2370. Ask for ProXX motor products technical support.
- Read all instructions carefully and be sure you fully understand each step before proceeding with motor assembly.
- Inspect the components of your reload kit carefully before you start assembly. DO NOT use any parts that appear damaged or faulty in any way.
- Do not tamper with or modify the hardware or reload kit components in any way. Not only will this void all product warranty, it could cause catastrophic failure of your motor system and result in damage to your rocket vehicle, launch equipment and create a hazard to persons or property.
- Reload kit components are designed for ONE USE ONLY, and may not be reused. Reuse of any of these components could result in motor failure and will void product warranty.
- Follow the safety code and all rules and regulations of your sport rocketry association. Also ensure that you are in compliance with all local, state/provincial, and Federal laws in all activities involving high power rockets and rocket motors.

Parts checklist:

Pro75® Instructions, March 2005 revision
Pro75® hardware components (if used):
✓ Appropriate size of motor case
✓ Forward closure
✓ Nozzle holder
✓ Threaded retaining rings (2)

Reload kit components:
✓ Case liner (phenolic tube)
✓ Nozzle
✓ Forward insulator disk
✓ P75-ORK (o-ring kit)
✓ P75-TSI-KIT (smoke tracking grain/insulator & igniter kit)
✓ Propellant grains (check reload kit package for number and type required for your motor)

Assembly instructions

• Be sure to follow the correct instructions for the brand of motor hardware you are using!

• Step 1 is the same for both brands of hardware.

• All o-rings are pre-lubricated at the factory where required.

• Three o-rings are supplied in the P75-ORK o-ring kits. The two larger o-rings are used with both Pro75® and RMS™ hardware. The smaller o-ring is only used with Pro75® hardware.

• Do not apply lubricant to the grain spacer o-rings, they are for spacing only.

• Phenolic and phenolic/paper components such as the nozzle and case liner tube are brittle and can be crooked, broken or otherwise damaged by excessive force or impact. Please be careful during handling and assembly. If you suspect a part has been damaged in any way, STOP and do not proceed with assembly and especially firing until inspected and replaced if necessary.

1. Forward Closure Assembly

1.1. Apply a light coating of o-ring lubricant or grease to the inside of the cavity in the forward closure. Insert the smoke tracking charge insulator into this cavity and ensure it is seated fully.

1.2. Apply a liberal layer of grease or o-ring lubricant to one end of the smoke tracking grain. Be sure the entire face is coated.

1.3. Insert the smoke tracking grain into the smoke tracking charge insulator, coated end first. Push the grain in with sufficient force to fully seat it and spread the lubricant as shown. The excess lubricant will help prevent gas leakage forward as well as protecting the forward closure from heat and combustion products from the smoke tracking charge.

You may now proceed to the remainder of the instructions for your brand of motor hardware.

Step 2 is for Pro75® hardware users.
Step 3 is for RMS™ hardware users.

Pro75® Instructions, March 2005 revision
2. Motor Assembly: Pro75® Hardware.

Before proceeding, inspect the external o-ring grooves on the forward closure and nozzle holder, as well as the internal groove on the nozzle holder. Clean thoroughly if necessary to remove ALL combustion residue and debris. Also ensure that the inside of the motor case has been thoroughly cleaned.

2.1. Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.

2.2. Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.

2.3. Locate the smaller o-ring in the P75-ORK o-ring kit. Fit the o-ring to the internal groove of the nozzle holder. Push the nozzle holder over the nozzle until fully seated. Apply additional lubricant to the nozzle exit section if necessary to facilitate assembly.

2.4. For steps 2.5 – 2.6 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

2.5. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.

2.5.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.

2.6. Carefully install the two larger o-rings into the external grooves of the nozzle holder and forward closure. Handle these components with care from this point on as to not damage or contaminate the o-rings.

2.7. Place the case liner/nozzle assembly on your work surface with the nozzle end down, and slide the motor case down rear end first (end with thrust ring) over the top of the liner towards the nozzle. Note: a light coat of grease on the liner exterior will aid assembly, disassembly and cleanup.

2.8. Lay the motor case assembly down horizontally, and push on the nozzle ring until the assembly is far enough inside the case that the threads are partly exposed and the screw ring can be threaded into the rear of the case. Don’t push on the nozzle itself as you will push it out of the nozzle holder.

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Pro75® Instructions, March 2005 revision
2.9 Screw in the nozzle retaining ring using the supplied wrench, pushing the nozzle/nozzle ring/case liner assembly forward as you proceed. Screw it in only until the retaining ring is exactly even with the end of the motor case - do not thread it in as far as it will go. Then, back the retaining ring out one half of a turn.

2.10 Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

2.11 Verify that the inside of the motor case is clean ahead of the liner assembly before proceeding. Wipe with a clean rag, tissue or wet-wipe if required. Apply a light coat of silicone o-ring lubricant onto this area after cleaning.

2.12 Insert the assembled forward closure into the top of the motor case, pushing it down carefully with your fingers until you can thread in the retaining ring. Thread in the forward retaining ring using the wrench, until you feel it take up a load against the top of the case liner. At this point the ring should be approximately flush with the end of the motor case, or slightly submerged. If it extends out the case at this point by more than about one half a turn, check the nozzle end to make sure the ring is not screwed in too far forward. If so, unscrew the nozzle retaining ring another half turn and screw the forward closure retaining in further.

**NOTE:** it is best to have the forward closure retaining ring flush or slightly submerged and the nozzle retaining ring protruding by a half turn or so, than vice versa. There is more tolerance for o-ring location at the nozzle end. There will always be some minor variation in the length of internal components due to manufacturing tolerances.

2.13 Skip ahead to Section 4, Preflight preparation.

3. Motor Assembly, RMS™ Hardware.

3.1 Check both ends of the phenolic case liner to ensure that the inside ends have been chamfered or deburred. If not, use a hobby knife or coarse sandpaper to remove the sharp inner edge to allow components to be inserted easily.

3.2 Fit the nozzle to one end of the paper/phenolic case liner tube. It may be a snug fit. Push it carefully but with sufficient force to seat the shoulder on the nozzle all the way into the insulator tube.

3.3 For steps 3.4 – 3.8 work with the nozzle/case liner assembly and motor case horizontally on your work surface.

---

Pro75® Instructions, March 2005 revision
3.4. Insert one propellant grain into the forward end of the case liner and push it a short way into the tube. Fit one grain spacer o-ring to the top face of the grain, ensuring it sits flat on the end of the grain. Insert the second grain, push it in a short ways, then add another grain spacer, and so on until you have loaded all propellant grains into the case liner.

3.4.1. There should be sufficient space after the last grain is inserted to fit the last spacer in place so that it is flush or extends only slightly from the end of the tube. If it extends out by more than 1/3 of its own thickness, remove it and do not use. Only this spacer may be omitted and only if necessary to fit.

3.5. Slide the completed liner/nozzle/grain assembly into the motor case until the nozzle protrudes about 1/8" from the end of the case. Note: A light coat of grease on the liner exterior will aid assembly, disassembly, and cleanup.

3.6. Fit the forward insulating disk to the top of the case liner, checking that the top grain spacer (if used) is still properly in place.

3.7. Place one of the larger pre-lubricated o-rings from the P75-ORK kit into the forward end of the case until it is seated against the forward insulator.

3.8. Thread the completed forward closure into the forward end of the motor case by hand until it is seated against the case. Note: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.

3.9. Hold the motor vertically on your work surface with the forward closure downwards, and push down on the nozzle to ensure the liner/nozzle assembly is seated fully forward.

3.10. Place the other identical o-ring into the groove in the nozzle.

3.11. Thread the aft closure into the motor case until it is seated. It is normal for a small gap (up to about 1/16") to remain between the closure and the end of the case, due to manufacturing tolerances on internal components. Note: There will be considerable resistance to threading in the closure in the last 1/8" to 3/16" of travel, due to compression of the o-ring.

3.12. Proceed to Section 4, Preflight preparation.

Pro75® Instructions, March 2005 revision
4. Preflight Preparation.
   4.1. Prepare the rocket’s recovery system, before motor installation if possible.
   4.2. Install the motor in your rocket, ensuring that it is securely mounted with a positive means of retention to prevent it from being ejected during any phase of the rocket’s flight.
   4.3. IMPORTANT: DO NOT INSTALL THE IGNITER IN THE MOTOR UNTIL YOU HAVE THE ROCKET ON THE LAUNCH PAD, OR IN A SAFE AREA DESIGNATED BY THE RANGE SAFETY OFFICER. Follow all rules and regulations of your rocketry association, and the National Fire Protection Association (NFPA) Code 1127 where applicable.
   4.4. Install the supplied igniter, ensuring that it travels forward until it is in contact with the forward closure. Securely retain the igniter to the motor nozzle with tape, or (if supplied) the plastic cap, routing the wires through one of the vent holes. Ensure that whatever means you use provides a vent for igniter gases to prevent premature igniter ejection.
   4.5. Launch the rocket in accordance with all Federal, State/Provincial, and municipal laws as well as the Safety Code of your rocketry association, as well as NFPA Code 1127 where applicable.

5. Post Flight Cleanup.
   Do not try to dismount or disassemble your motor until it has thoroughly cooled down after firing. Some components such as the nozzle may be extremely hot for some time after firing.
   Perform motor cleanup as soon as possible after firing, however, as combustion residues are corrosive to motor components, and become very difficult to remove after several hours.
   5.1. Unthread and remove the forward and rear closures. Remove the nozzle holder from the nozzle.
   5.2. Remove the phenolic tracking smoke charge insulator from the forward closure.
   5.3. Remove all o-rings.
   5.4. Discard all reload kit components with regular household waste, after they have completely cooled down.
   5.5. Use wet wipes, or paper towels or rags dampened with water or vinegar to thoroughly clean all residue, grease etc. off all hardware components. Pay close attention to internal and external o-ring grooves. A cotton swab or small stick of balsa is an excellent tool for cleaning these grooves.
   5.6. Apply a light coat of grease or o-ring lubricant to all threaded sections and reassemble threaded components for storage.

MEANS OF DISPOSAL: The propellant grains, smoke tracking charge, and the igniter are extremely flammable and burn with an intense, hot flame. The remainder of the components are inert and may be disposed of with household trash. To destroy the flammable components, dig a shallow hole in the ground in a remote area, away from any buildings, trees, people, or any other combustibles. Place the propellant grains and smoke tracking module in the hole. Install the igniter into the core of one of the propellant grains and secure with tape. Ignite electrically from a minimum distance of 15 meters. Douse any smoldering paper residue and discard. Ensure that you are not in violation of any local or state regulations for this procedure. If in doubt, contact your local fire department. Please direct any questions regarding safe disposal to our technical support number on page one of this document.

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’s products on these conditions. No warranty either expressed or implied is made regarding Pro75® 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 or state may provide additional rights not covered by this warranty.

= Check out our web site at http://www.Pro-X.ca for tech tips, FAQ’s, user feedback and photos, or e-mail us at ProX@cesaroni.net
= For technical and warranty inquiries, please contact your Pro75® dealer.

Pro75® is a registered trademark of Cesaroni Technology Incorporated. Patent# US06079202. Other patents pending. Made in Canada.

Pro75® Instructions, March 2005 revision
Appendix V: MSDS’s

i. Epoxy
ii. Filler
iii. Pyrodex
iv. Pyrodex 2
v. Resin 205
vi. Spray Paint
vii. Super Glue
viii. Jtek
ix. Goex Powder
x. ProX
1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: ............................................. WEST SYSTEM® 105 Epoxy Resin®.
PRODUCT CODE: ............................................. 105
CHEMICAL FAMILY: ............................................. Epoxy Resin.
CHEMICAL NAME: ............................................. Bisphenol A based epoxy resin.
FORMULA: ...................................................... Not applicable.

MANUFACTURER:
West System Inc.
102 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS:
Transportation
CHEMTREC: ...................... 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation
Poison Hotline: ...................... 800-222-1222

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

<table>
<thead>
<tr>
<th>HMIS Hazard Rating:</th>
<th>Health - 2</th>
<th>Flammability - 1</th>
<th>Physical Hazards - 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>WARNING! May cause allergic skin response in certain individuals. May cause moderate irritation to the skin. Clear to light yellow liquid with mild odor.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PRIMARIAL ROUTE(S) OF ENTRY: ............................................. Skin contact.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION: ............................................. Not likely to cause acute effects unless heated to high temperatures. If product is heated, vapors generated can cause headache, nausea, dizziness and possible respiratory irritation if inhaled in high concentrations.

CHRONIC INHALATION: ............................................. Not likely to cause chronic effects. Repeated exposure to high vapor concentrations may cause irritation of pre-existing lung allergies and increase the chance of developing allergy symptoms to this product.

ACUTE SKIN CONTACT: ............................................. May cause allergic skin response in certain individuals. May cause moderate irritation to the skin such as redness and itching.

CHRONIC SKIN CONTACT: ............................................. May cause sensitization in susceptible individuals. May cause moderate irritation to the skin.

EYE CONTACT: ...................................................... May cause irritation.

INGESTION: ...................................................... Low acute oral toxicity.

SYMPTOMS OF OVEREXPOSURE: ............................................. Possible sensitization and subsequent allergic reactions usually seen as redness and rashes. Repeated exposure is not likely to cause other adverse health effects.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: ............................................. Pre-existing skin and respiratory disorders may be aggravated by exposure to this product. Pre-existing lung and skin allergies may increase the chance of developing allergic symptoms to this product.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

<table>
<thead>
<tr>
<th>INGREDIENT NAME</th>
<th>CAS #</th>
<th>CONCENTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bisphenol-A type epoxy resin</td>
<td>25085-99-8</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>100-51-6</td>
<td>&lt; 20%</td>
</tr>
<tr>
<td>Bisphenol-F type epoxy resin</td>
<td>28064-14-4</td>
<td>&lt; 20%</td>
</tr>
</tbody>
</table>

4. FIRST AID MEASURES

FIRST AID FOR EYES: ............................................. Flush immediately with water for at least 15 minutes. Consult a physician.

FIRST AID FOR SKIN: ............................................. Remove contaminated clothing. Wipe excess from skin. Remove with waterless skin cleaner and then wash with soap and water. Consult a physician if effects occur.

FIRST AID FOR INHALATION: ............................................. Remove to fresh air if effects occur.
FIRST AID FOR INGESTION: No adverse health effects expected from amounts ingested under normal conditions of use. Seek medical attention if a significant amount is ingested.

5. FIRE FIGHTING MEASURES

FLASH POINT: >200°F (Tag Closed Cup)

EXTINGUISHING MEDIA: Foam, carbon dioxide (CO₂), dry chemical.

SPECIAL FIRE FIGHTING PROCEDURES: Wear a self-contained breathing apparatus and complete full-body personal protective equipment. Closed containers may rupture (due to buildup of pressure) when exposed to extreme heat.

FIRE AND EXPLOSION HAZARDS: During a fire, smoke may contain the original materials in addition to combustion products of varying composition which may be toxic and/or irritating. Combustion products may include, but are not limited to: phenolics, carbon monoxide, carbon dioxide.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: Stop leak without additional risk. Dike and absorb with inert material (e.g., sand) and collect in a suitable, closed container. Warm, soapy water or non-flammable, safe solvent may be used to clean residual.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): 40°F (4°C) / 120°F (49°C)

STORAGE: Store in cool, dry place. Store in tightly sealed containers to prevent moisture absorption and loss of volatiles. Excessive heat over long periods of time will degrade the resin.

HANDLING PRECAUTIONS: Avoid prolonged or repeated skin contact. Wash thoroughly after handling. Launder contaminated clothing before reuse. Avoid inhalation of vapors from heated product. Precautionary steps should be taken when curing product in large quantities. When mixed with epoxy curing agents this product causes an exothermic, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: Safety glasses with side shields or chemical splash goggles.

SKIN PROTECTION GUIDELINES: Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.

RESPIRATORY/VENTILATION GUIDELINES: Good room ventilation is usually adequate for most operations. Wear a NIOSH/MSHA approved respirator with an organic vapor cartridge whenever exposure to vapor in concentrations above applicable limits is likely.

Note: West System, Inc. has conducted an air sampling study using this product or similarly formulated products. The results indicate that the components sampled for (epichlorohydrin, benzyl alcohol) were either so low that they were not detected at all or they were significantly below OSHA’s permissible exposure levels.

ADDITIONAL PROTECTIVE MEASURES: Practice good caution and personal cleanliness to avoid skin and eye contact. Avoid skin contact when removing gloves and other protective equipment. Wash thoroughly after handling. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: Not established for product as whole. Refer to OSHA’s Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL FORM: Liquid.
COLOR: Clear to pale yellow.
ODOR: Mild.
BOILING POINT: > 400°F.
MELTING POINT/FREEZE POINT: No data.
VISCOSITY: 1,000 cPs.
PH: No data.
SOLUBILITY IN WATER: Slight.
SPECIFIC GRAVITY: 1.15
BULK DENSITY: 9.6 pounds/gallon.
VAPOR PRESSURE: < 1 mmHg @ 20°C.
VAPOR DENSITY: Heavier than air.
% VOLATILE BY WEIGHT: ASTM D 2369-07 was used to determine the Volatile Content of mixed epoxy resin and hardener. Refer to the hardener’s MSDS for information about the total volatile content of the resin/hardener system.

10. STABILITY AND REACTIVITY
STABILITY: Stable.

HAZARDOUS POLYMERIZATION: Will not occur by itself, but a mass of more than one pound of product plus an aliphatic amine will cause irreversible polymerization with significant heat buildup.

INCOMPATIBILITIES: Strong acids, bases, amines and mercaptans can cause polymerization.

DECOMPOSITION PRODUCTS: Carbon monoxide, carbon dioxide and phenolics may be produced during uncontrolled exothermic reactions or when otherwise heated to decomposition.

11. TOXICOLOGICAL INFORMATION

No specific oral, inhalation or dermal toxicology data is known for this product. Specific toxicology information for a bisphenol-A based epoxy resin present in this product is indicated below:

Oral: LD_{50} >5000 mg/kg (rats)
Inhalation: No Data
Dermal: LD_{50} = 20,000 mg/kg (skin absorption in rabbits)

TERATOLOGY: Diglycidyl ether bisphenol-A (DGEBA) did not cause birth defects or other adverse effects on the fetus when pregnant rabbits were exposed by skin contact, the most likely route of exposure, or when pregnant rats or rabbits were exposed orally.

REPRODUCTIVE EFFECTS: DGEBA, in animal studies, has been shown not to interfere with reproduction.

MUTAGENICITY: DGEBA in animal mutagenicity studies were negative. In vitro mutagenicity tests were negative in some cases and positive in others.

CARCINOGENICITY:
NTP: Product not listed.
IARC: Product not listed.
OSHA: Product not listed.

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

Ethylbenzene, present in this product < 0.1%, is not identified by OSHA or NTP as a carcinogen, but is identified by NTP as a Group 2B substance possibly carcinogenic to humans.

Many studies have been conducted to assess the potential carcinogenicity of diglycidyl ether of bisphenol-A. Although some weak evidence of carcinogenicity has been reported in animals, when all of the data are considered, the weight of evidence does not show that DGEBA is carcinogenic. Indeed, the most recent review of the available data by the International Agency for Research on Cancer (IARC) has concluded that DGEBA is not classified as a carcinogen.

Epichlorohydrin, an impurity in this product (<5 ppm) has been reported to produce cancer in laboratory animals and to produce mutagenic changes in bacteria and cultured human cells. It has been established by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (Group 2A) based on the following conclusions: human evidence – inadequate; animal evidence – sufficient. It has been classified as an anticipated human carcinogen by the National Toxicology Program (NTP). Note: It is unlikely that normal use of this product would result in measurable exposure concentrations to this substance.

12. ECOLOGICAL INFORMATION

Prevent entry into sewers and natural waters. May cause localized fish kill.

Movement and Partitioning:
Bioconcentration potential is moderate (BCF between 100 and 3000 or Log Kow between 3 and 5).

Degradation and Transformation:
Theoretical oxygen demand is calculated to be 2.35 p/p. 20-day biochemical oxygen demand is <2.5%.

Ecotoxicology:
Material is moderately toxic to aquatic organisms on an acute basis. LC50/EC50 between 1 and 10 mg/L in most sensitive species.

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: Evaluation of this product using RCRA criteria shows that it is not a hazardous waste, either by listing or characteristics, in its purchased form. It is the responsibility of the user to determine proper disposal methods.

Incinerate, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.
14. TRANSPORTATION INFORMATION

DOT
SHIPPING NAME: ............................................................ Not regulated.
TECHNICAL SHIPPING NAME: ........................................ Not applicable.
D.O.T. HAZARD CLASS: .................................................. Not applicable.
U.N./N.A. NUMBER: ...................................................... Not applicable.
PACKING GROUP: .......................................................... Not applicable.

IATA
SHIPPING NAME: ............................................................ Not regulated.
TECHNICAL SHIPPING NAME: ........................................ Not applicable.
HAZARD CLASS: .......................................................... Not applicable.
U.N. NUMBER: ............................................................. Not applicable.
PACKING GROUP: .......................................................... Not applicable.

15. REGULATORY INFORMATION

OSHA STATUS: ................................................................. Slight irritant; possible sensitizer.
TSCA STATUS: ................................................................. All components are listed on TSCA inventory or otherwise comply with TSCA requirements.

Canada WHIMIS Classification: ............................................. D2B

SARA TITLE III:
SECTION 313 TOXIC CHEMICALS ..................................... None (deminimus).

STATE REGULATORY INFORMATION:
The following chemicals are specifically listed or otherwise regulated by individual states. For details on your regulatory requirements you should contact the appropriate agency in your state.

<table>
<thead>
<tr>
<th>COMPONENT NAME</th>
<th>CAS NUMBER</th>
<th>CONCENTRATION</th>
<th>STATE CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epichlorohydrin</td>
<td>106-89-8</td>
<td>&lt; 5ppm</td>
<td>'CA</td>
</tr>
<tr>
<td>Phenyl glycidyl ether</td>
<td>122-60-1</td>
<td>&lt; 5ppm</td>
<td>'CA</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>100-41-4</td>
<td>&lt; 0.1%</td>
<td>'CA, NJ, PA</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>100-51-6</td>
<td>&lt; 20%</td>
<td>MA, PA, NJ</td>
</tr>
</tbody>
</table>

1. These substances are known to the state of California to cause cancer or reproductive harm, or both.

16. OTHER INFORMATION

REASON FOR ISSUE: ..................................................... Changes made in Sections 10, 11, 14 & 15.
PREPARED BY: ............................................................. G. M. House
APPROVED BY: ............................................................. G. M. House
TITLE: ................................................................. Health, Safety & Environmental Manager
APPROVAL DATE: ....................................................... June 22, 2011
SUPERSEDES DATE: ..................................................... February 6, 2011
MSDS NUMBER: .......................................................... 105-11b

Note: The Hazardous Material Indexing System (HMIS), cited in the Emergency Overview of Section 3, uses the following index to assess hazard rating: 0 = Minimal; 1 = Slight; 2 = Moderate; 3 = Serious; and 4 = Severe.

This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of West System Inc. The data on this sheet is related only to the specific material designated herein. West System Inc. assumes no legal responsibility for use or reliance upon these data.
1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: WEST SYSTEM® 406™ Colloidal Silica.
PRODUCT CODE: 406
CHEMICAL FAMILY: Silicon.
CHEMICAL NAME: Silicon dioxide (amorphous).
FORMULA: SiO₂

MANUFACTURER:
West System Inc.
102 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS:
Transportation CHEMTREC: 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation Poison Hotline: 800-222-1222

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW
HMIS Hazard Rating: Health - 1 Flammability - 0 Physical Hazards - 0

CAUTION! Static ignition hazard. Avoid excessive breathing of airborne dust. White, fluffy powder with no odor.

PRIMARY ROUTE(S) OF ENTRY: Inhalation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION: If exposure limits are exceeded, the respiratory tract may become irritated. May cause shortness of breath, coughing, and/or chest tightness due to temporarily physically overloading the lungs.

CHRONIC INHALATION: May aggravate existing respiratory conditions. May cause dryness of mucous membranes of the respiratory tract.

ACUTE SKIN CONTACT: May cause irritation and dryness.

CHRONIC SKIN CONTACT: Repeated exposure may cause dermatitis due to drying of the skin.

EYE CONTACT: May cause irritation, redness and tearing.

INGESTION: No known health effects.

SYMPTOMS OF OVEREXPOSURE: Coughing, shortness of breath or irritation of the respiratory tract. Dry, chapped or irritated skin. Irritated or tearing eyes.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: Skin and respiratory conditions, such as dermatitis and asthma.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

<table>
<thead>
<tr>
<th>INGREDIENT NAME</th>
<th>CAS#</th>
<th>CONCENTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fumed Amorphous Silica</td>
<td>112945-52-5</td>
<td>99%</td>
</tr>
</tbody>
</table>

4. FIRST AID MEASURES

FIRST AID FOR EYES: Flush adequately with water to remove particles. If discomfort persists, seek medical advice.

FIRST AID FOR SKIN: Wash with soap and water. Apply moisturizing cream to replenish moisture in the skin if necessary.

FIRST AID FOR INHALATION: Remove to fresh air if effects occur. If effects persist, seek medical advice.

FIRST AID FOR INGESTION: No specific information.
5. FIRE FIGHTING MEASURES

FLASH POINT: Greater than 535°F (COC, ASTM D-92).

EXTINGUISHING MEDIA: Water, dry chemical, halon or foam.

SPECIAL FIRE FIGHTING PROCEDURES: No specific information.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR LEAK PROCEDURES: Sweep and shovel or use properly grounded vacuum equipment. Do so in a manner that minimizes airborne dust.

7. HANDLING AND STORAGE

STORAGE TEMPERATURE (min./max.): 0°F (-17°C)/100°F (38°C)

STORAGE: Keep dry.

HANDLING PRECAUTIONS: Avoid handling that will unnecessarily generate airborne dust. Properly ground all material handling equipment to prevent static discharge.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

EYE PROTECTION GUIDELINES: Safety glasses or goggles are recommended, depending on the expected level of exposure.

SKIN PROTECTION GUIDELINES: Areas expected to have repeated exposure, such as hands, may need to be protected by an impervious material to prevent dryness. Barrier creams can be used effectively.

RESPIRATORY/VENTILATION GUIDELINES: Work environments should be maintained below applicable exposure level through the use of engineering controls, such as dilution and exhaust ventilation. If this is not feasible, use a NIOSH approved dust mask/respirator for nuisance dust.

ADDITIONAL PROTECTIVE MEASURES: Practice good industrial hygiene by washing with soap and water after each use. Apply moisturizing cream to replenish moisture if necessary. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.

OCCUPATIONAL EXPOSURE LIMITS: This product should be treated as a nuisance dust. Refer to OSHA’s Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL FORM: Powder.

COLOR: White.

ODOR: Odorless.

BOILING POINT: No data.

MELTING POINT/FREEZE POINT: No data.

pH: No data.

SOLUBILITY IN WATER: Insoluble.

SPECIFIC GRAVITY: 2.2

BULK DENSITY: 0.33 pounds/gallon.

VAPOR PRESSURE: Not Applicable.

VAPOR DENSITY: Not Applicable.

% VOLATILE BY WEIGHT: 0.0 (0.0 g/L)

10. STABILITY AND REACTIVITY

STABILITY: Stable.

HAZARDOUS POLYMERIZATION: Will not occur.

INCOMPATIBILITIES: A chemical reaction is possible with strong bases or hydrofluoric acid.

DECOMPOSITION PRODUCTS: Can include carbon monoxide (CO) and carbon dioxide (CO₂).

11. TOXICOLOGICAL INFORMATION

Oral: LD₅₀ >5000 mg/kg (rats)

Inhalation: LD₅₀ > 2.08 mg/L 4hr.

Dermal: LD₅₀ >5000 mg/kg (rabbits)
Data from chronic inhalation of treated and untreated silicas are currently under review.

**CARCINOGENICITY:**

- NTP: No.
- IARC: No.
- OSHA: No.

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

**12. ECOLOGICAL INFORMATION**

No information.

**13. DISPOSAL CONSIDERATIONS**

**WASTE DISPOSAL METHOD:** This material is determined not to be a hazardous waste as per RCRA standards, either by listing or characteristics. Disposer must comply with all federal, state and local laws. Waste product may be sent to a landfill.

**14. TRANSPORTATION INFORMATION**

**DOT**
- D.O.T. SHIPPING NAME: Not regulated by DOT.
- TECHNICAL SHIPPING NAME: Not applicable.
- D.O.T. HAZARD CLASS: Not applicable.
- U.N./N.A. NUMBER: Not applicable.
- PACKING GROUP: Not applicable.

**IATA**
- SHIPPING NAME: Not regulated.
- TECHNICAL SHIPPING NAME: Not applicable.
- HAZARD CLASS: Not applicable.
- U.N. NUMBER: Not applicable.
- PACKING GROUP: Not applicable.

**15. REGULATORY INFORMATION**

**OSHA STATUS:** Hazardous. Nuisance dust.

**TSCA STATUS:** All components are listed on TSCA inventory or otherwise comply with TSCA requirements.

**Canada WHIMIS Classification:** No data.

**SARA TITLE III:**
- SECTION 313 TOXIC CHEMICALS: None.

**STATE REGULATORY INFORMATION:**

The following chemicals are specifically listed or otherwise regulated by individual states. For details on your regulatory requirements you should contact the appropriate agency in your state.

<table>
<thead>
<tr>
<th>COMPONENT NAME</th>
<th>CAS NUMBER</th>
<th>CONCENTRATION</th>
<th>STATE CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amorphous Silica</td>
<td>112945-52-5</td>
<td>99%</td>
<td>MA, NJ, RI</td>
</tr>
</tbody>
</table>

**16. OTHER INFORMATION**

**REASON FOR ISSUE:** Changes made in Sections 3, 11, 14 & 15.
**PREPARED BY:** G. M. House
**APPROVED BY:** G. M. House
**TITLE:** Health, Safety & Environmental Manager
**APPROVAL DATE:** February 6, 2011
**SUPERSEDES DATE:** January 3, 2008
**MSDS NUMBER:** 406-11a

Note: The Hazardous Material Indexing System (HMIS), cited in the Emergency Overview of Section 3, uses the following index to assess hazard rating: 0 = Minimal; 1 = Slight; 2 = Moderate; 3 = Serious; and 4 = Severe.
This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of West System Inc. The data on this sheet is related only to the specific material designated herein. West System Inc. assumes no legal responsibility for use or reliance upon these data.
Pyrodex Family MSDS

MATERIAL SAFETY DATA SHEET

IDENTITY
Pyrodex, a pyrotechnic mixture

HMIS Rating
Health Hazard: 2 Flammability Hazard: 3 Reactivity Hazard: 4

Section I.

Hodgdon Powder Co., Inc.
6231 Robinson
Shawnee Mission, Ks. 66202, USA
Emergency Telephone: Chem-tel 800-255-3924
Telephone Number for Information: 913-362-9455
Date Prepared: 6/17/96

Section II. HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Components
(Chemical Identity: Common Name(s) OSHA PEL ACGIH TLV Other Limits %(optional)
Charcoal NA NA NA
Sulfur NA NA NA
Potassium Nitrate NA NA NA
Potassium Perchlorate NA NA NA
Graphite NA 2.5 mg/m3 Respirable Dust
Other: Other ingredients are trade secrets, but can be disclosed per 29 CFR 1910.1200(i)

Section III. PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point Not Applicable Specific Gravity (H2O =1): Bulk density is 0.75 (g/cc)
Vapor Pressure (mm HG): Not Applicable Melting Point: Not Applicable
Vapor Density (AIR = 1) Not Applicable Evaporation Rate: Not Applicable
Solubility in Water: Partially (Butyl Acetate = 1)
Appearance and Odor: Medium to dark pray granular solid. Slight odor when ignited.

Section IV. FIRE AND EXPLOSION HAZARD DATA

Auto-ignition Temperature: 740 (F) (Pellets: 500[f]) Flammable Limits: N/A LEL: N/A UEL: N/A
Extinguishing Media: For unattended fire prevention, water can be used to disburse burning Pyrodex. Pyrodex has its own oxygen supply, so flame smothering techniques are ineffective. Water may be used on unburnt Pyrodex to retard further spread of fire.
Special Fire Fighting Procedures: Pyrodex is extremely flammable and may deflagrate. Get away and evacuate the area.
Unusual Fire and Explosion Hazards: As with any pyrotechnic, if under confinement or piled in moderate quantities, Pyrodex can explode violently, toxic fumes such as sulfur dioxide are emitted while burning.

Section V. REACTIVITY DATA

Stability Unstable: X Conditions to Avoid: Avoid storage at temperatures above 150[F], impact, hot embers, sparks and static discharges.
Incompatibility (Materials to Avoid): Metal powders and acids
Hazardous Decomposition or Byproducts: CO, CO₂, SO₂, non-metallic oxides, and suspended particulate matter from burning.
Hazardous May Occur: Conditions to Avoid: Not known to occur.
Polymerization: Will Not Occur: X

Section VI. HEALTH HAZARD DATA

Route(s) of Entry: Inhalation?: Yes Skin?: Yes Ingestion?: Yes

Health Hazards (acute and Chronic): TLV unknown for ingestion of dust, Acute oral LD₅₀ in rats is calculated to be 4.0 [g/kg body weight].
Carcinogenicity: No NTP? No IARC? No OSHA regulated?: No
Signs and Symptoms of Exposure: Burning or itching of the eye, nose, or skin; shortness of breath.
Medical Conditions Generally Aggravated by Exposure: Some people may be unusually sensitive to the product.
Emergency and First Aid Procedures: Remove patient from exposure, and if skin contact, wash affected area with copious amounts of water.

Section VII. PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to Be Taken in Case Material is Released or Spilled: Do not smoke in the area. Powder should be scooped or swept up using non-sparking, conductive tools. This should be done in a manner so that no dusting occurs.
Waste Disposal Method: Wet thoroughly with water to dissolve the powder. Comply with all federal, state, and local laws.

Precautions to Be Taken in Handling and Storing: Pyrodex is a solid propellant which is designed to propell a mass. Thus appropriate care should be taken to avoid heavy confinement and ignition sources such as, but not limited to, heat, static discharge, embers, friction, and impact. Do not drop containers of powder. Store at temperatures of less than 150°F in approved magazines.

Other Precautions: In the area of use, avoid all possible sources of ignition and use explosion proof electrical equipment suitable for use with explosive dusts.

Section VIII. CONTROL MEASURES

Respiratory Protection (Specify Type): Disposable NIOSH approved dust masks may be used if desired.
Ventilation Local Exhaust: if used, should be equipped with well maintained, continuously active water washing system.
Mechanical (General): Use NEMA Class II, Division 1, Groups F&G motors or better.
Other Protective Clothing or Equipment: "100%" cotton clothing and grounded work station are recommended to minimize static electricity discharge.
Work/Hygienic Practices: Work with small quantities, keeping main supply in closed container. Shower after exposure, and wash clothing daily.

Please read container warning, and call 913-362-9455 for more information

Send mail to help@hodgdon.com with questions or comments.
Hodgdon Powder Co., Inc. Phone 913-362-9455 Fax 913-362-1307

Send mail to webmaster with questions or comments about this web site.
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This site maintained by 98.Net, Inc.

...get more power with the Muzzleloading Propellant!
Pyrodex® Propellants

MATERIAL SAFETY DATA SHEET

April 2009

The following Muzzleloading Propellants are manufactured and distributed by Hodgdon Powder Company.

**Granular**
- Pyrodex® RS
- Pyrodex® P
- Pyrodex® Select

**Pellets**
- Pyrodex® BP5030
- Pyrodex® BP5050
- Pyrodex® P5030
- Pyrodex® P5050
- Pyrodex® P5460
- Pyrodex® RP4430
PYRODEX®

Material Safety Data Sheet
May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

IDENTITY (as Used on Label and List)
Pyrodex®, a pyrotechnic mixture

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

Section I
Manufacturer's name
HODGDON POWDER COMPANY, INC
Address (Number, Street, City, State and ZIP Code)

Emergency Telephone Number
Chem-Tel (800) 255-3924

Telephone Number for Information
(913) 362-9455

Date Prepared
03/16/2009

Signature of Preparer (optional)
Mark Wendt

Section II—Hazardous Ingredients/Identity Information
Hazardous Components (Specific Chemical Identity, Common Name(s))

<table>
<thead>
<tr>
<th>Component</th>
<th>OSHA PEL</th>
<th>ACGIH TLV</th>
<th>Other Limits Recommended</th>
<th>% (optional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Nitrate</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Perchlorate</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td></td>
<td>2.5 mg/m³</td>
<td>Respirable Dust</td>
<td></td>
</tr>
</tbody>
</table>

Other: Other ingredients are trade secrets, but can be disclosed per 29CFR 1910.1200(i)

Section III—Physical/Chemical Characteristics

Boiling Point
N/A

Specific Gravity (H₂O = 1)

Bulk density is 0.75 (g/cc)

Vapor Pressure (mm Hg)
N/A

Melting Point
N/A

Vapor Density (AIR = 1)
N/A

Evaporation Rate (Styly Acetate = 1)
N/A

Solubility in Water
Partially

Appearance and Odor
Medium to dark gray granular solid. Slight odor when ignited.

Section IV—Fire and Explosion Hazard Data

Flash Point (Method Used)
Auto-Ignition temperature: 740°F [pellets]

Flammable Limits
N/A

UEL
N/A

UEL
N/A

Extinguishing Media
For unattended fire prevention, water can be used to disburse burning Pyrodex®. Pyrodex® has its own oxygen supply; flame smothering techniques are ineffective. Water may be used on unburnt Pyrodex® to retard further spread of fire.

Special Fire Fighting Procedures
Pyrodex® is extremely flammable and may deflagrate. Get away and evacuate the area.

Unusual Fire and Explosion Hazards
As with any pyrotechnic, if under confinement or piled in moderate quantities, Pyrodex® can explode. Toxic fumes such as sulfur dioxide are emitted while burning.

(Reproduce locally)
### Section V—Reactivity Data

<table>
<thead>
<tr>
<th>Stability</th>
<th>Unstable</th>
<th>Conditions to Avoid</th>
<th>XX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stable</td>
<td>Avoid storage at temperatures above 150°F, impact, hot embers, sparks, and static discharges.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Incompatibility (Materials to Avoid)</th>
<th>Metal powders and acids.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Hazardous Decomposition or byproducts</th>
<th>CO, CO₂, SO₂, non-metallic oxides and suspended particulate matter from burning.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Hazardous Polymerization</th>
<th>May Occur</th>
<th>Conditions to Avoid</th>
<th>Not known to occur.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will Not Occur</td>
<td>XX</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Section VI—Health Hazard Data

**Health Hazards (Acute and Chronic)** TLV unknown for ingestion of dust. Acute oral LD₅₀ in rats is calculated to be 4.0 [g/kg body weight]

<table>
<thead>
<tr>
<th>Route(s) of Entry</th>
<th>Inhalation?</th>
<th>Skin?</th>
<th>Ingestion?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Carcinogenicity** NO  NTP: NO  IARC Monographie: NO  OSHA Regulated: NO

**Signs and symptoms of Exposure** Burning or itching of the eyes, nose or skin; shortness of breath

**Medical Conditions Generally Aggravated by Exposure** Some people may be unusually sensitive to the product.

**Emergency and First Aid Procedures** Remove the patient from exposure, and if skin contact, wash the affected area with copious amounts of water.

### Section VII—Precautions for Safe Handling and Use

**Steps to Be Taken in Case Material Is Released or Spilled** Do not smoke in the area. Powder should be scooped or swept up using non-sparking, conductive tools. This should be done in a manner so that no dusting occurs.

**Waste Disposal Method** Wet thoroughly with water to dissolve the powder. Comply with all federal, state, and local laws.

**Precautions to Be Taken in Handling and Storage** Pyrodex® is a solid propellant which is designed to propel a mass, or in some cases, break open a container. Thus appropriate case should be taken to avoid heavy confinement and ignition sources such as, but not limited to, heat, static discharge, embers, friction, and impact.

**Other Precautions** in the area of use, avoid all possible sources of ignition and use explosion proof electrical equipment suitable for use with explosives dusts. Do not drop containers of powder. Store at temperatures of less than 150°F in approved magazines.

### Section VIII—Control Measures

**Respiratory Protection (Specify Type)** Disposable NIOSH approved dust masks may be used, if desired.

**Ventilation**
- Local Exhaust: If used, should be equipped with well-maintained, continuously active water washing system.
- Mechanical (General): Use NEMA Class II, Division 1, Groups F&G motors or better.

**Protective Gloves** May be used if sensitivity of skin occurs. Wash daily

**Eye Protection** Use Goggles if sensitivity occurs.

**Work/Hygienic Practices** Work with small quantities, keeping main supply in the closed container. Shower after exposure and wash clothing daily.
1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: .............................................. WEST SYSTEM® 205 Fast Hardener®
PRODUCT CODE: .............................................. 205
CHEMICAL FAMILY: ........................................ Amine.
CHEMICAL NAME: ........................................... Modified aliphatic polyamine.
FORMULA: ......................................................... Not applicable.

MANUFACTURER: West System Inc.
102 Patterson Ave.
Bay City, MI 48706, U.S.A.
Phone: 866-937-8797 or 989-684-7286
www.westsystem.com

EMERGENCY TELEPHONE NUMBERS:
Transportation 
CHEMTREC: ..................... 800-424-9300 (U.S.)
703-527-3887 (International)
Non-transportation
Poison Hotline: .................... 800-222-1222

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

HMIS Hazard Rating: Health - 3 Flammability - 1 Physical Hazards - 0
DANGER! Corrosive. Skin sensitizer. Moderate to severe skin, eye and respiratory tract irritant. May cause allergic reactions. Amber colored liquid with ammonia odor.

PRIMARY ROUTE(S) OF ENTRY: .......................................................... Skin contact, eye contact, inhalation.

POTENTIAL HEALTH EFFECTS:

ACUTE INHALATION: .................................................. May cause respiratory tract irritation. Coughing and chest pain may result.

CHRONIC INHALATION: .................................................. May cause respiratory tract irritation, coughing, sore throat, shortness of breath or chest pain.

ACUTE SKIN CONTACT: .................................................. May cause strong irritation, redness. Possible mild corrosion.

CHRONIC SKIN CONTACT: ........................................... Prolonged or repeated contact may cause an allergic reaction and possible sensitization in susceptible individuals. Large dose skin contact may result in material being absorbed in harmful amounts.

EYE CONTACT: .......................................................... Moderate to severe irritation with possible tissue damage. Concentrated vapors can be absorbed in eye tissue and cause eye injury. Contact causes discomfort and possible corneal injury or conjunctivitis.

INGESTION: ............................................................. Single dose oral toxicity is moderate. May cause gastrointestinal tract irritation and pain. Aspiration hazard.

SYMPTOMS OF OVEREXPOSURE: ............................................. Respiratory tract irritation. Skin irritation and redness. Possible allergic reaction seen as hives and rash. Eye irritation. Possible liver and kidney disorders upon long term skin absorption overexposures.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: ............... Chronic respiratory disease, asthma. Eye disease. Skin disorders and allergies.

3. COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

<table>
<thead>
<tr>
<th>INGREDIENT NAME</th>
<th>CAS #</th>
<th>CONCENTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction products of TETA with Phenol/Formaldehyde</td>
<td>32618-77-8</td>
<td>&gt; 25%</td>
</tr>
<tr>
<td>Polyethylenepolyamine</td>
<td>68131-73-7</td>
<td>&lt; 25%</td>
</tr>
<tr>
<td>Triethylenetetramine (TETA)</td>
<td>112-24-3</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Hydroxybenzene</td>
<td>108-95-2</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Reaction Products of TETA and propylene oxide</td>
<td>26950-63-0</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Tetraethylenepentamine (TEPA)</td>
<td>112-57-2</td>
<td>&lt; 10%</td>
</tr>
</tbody>
</table>

4. FIRST AID MEASURES

FIRST AID FOR EYES: .................................................. Immediately flush with water for at least 15 minutes. Get prompt medical attention.

FIRST AID FOR SKIN: .................................................. Remove contaminated clothing. Immediately wash skin with soap and water. Do not apply greases or ointments. Get medical attention if severe exposure.
5. **FIRE FIGHTING MEASURES**

**FLASH POINT:** >270°F (PMCC)  
**EXTINGUISHING MEDIA:** Dry chemical, alcohol foam, carbon dioxide (CO₂), dry sand, limestone powder.  
**FIRE AND EXPLOSION HAZARDS:** During a fire, smoke may contain the original materials in addition to combustion products of varying composition which may be toxic and/or irritating. Combustion products may include, but are not limited to: oxides of nitrogen, carbon monoxide, carbon dioxide, volatile amines, ammonia, nitric acid, nitrosamines. When mixed with sawdust, wood chips, or other cellulosic material, spontaneous combustion can occur under certain conditions. If hardener is spilled into or mixed with sawdust, heat is generated as the air oxidizes the amine. If the heat is not dissipated quickly enough, it can ignite the sawdust.  
**SPECIAL FIRE FIGHTING PROCEDURES:** Use full-body protective gear and a self-contained breathing apparatus. Use of water may generate toxic aqueous solutions. Do not allow water run-off from fighting fire to enter drains or other water courses.

6. **ACCIDENTAL RELEASE MEASURES**

**SPILL OR LEAK PROCEDURES:** Stop leak without additional risk. Wear proper personal protective equipment. Dike and contain spill. Ventilate area. Large spill - dike and pump into appropriate container for recovery. Small spill - recover or use inert, non-combustible absorbent material (e.g., sand, clay) and shovel into suitable container. Do not use sawdust, wood chips or other cellulosic materials to absorb the spill, as the possibility for spontaneous combustion exists. Wash spill residue with warm, soapy water if necessary.

7. **HANDLING AND STORAGE**

**STORAGE TEMPERATURE (min./max.):** 40°F (4°C) / 90°F (32°C).  
**STORAGE:** Store in cool, dry place away from high temperatures and moisture. Keep container tightly closed.  
**HANDLING PRECAUTIONS:** Use with adequate ventilation. Do not breath vapors or mists from heated material. Avoid exposure to concentrated vapors. Avoid skin contact. Wash thoroughly after handling. When mixed with epoxy resin this product causes an exothermic reaction, which in large masses, can produce enough heat to damage or ignite surrounding materials and emit fumes and vapors that vary widely in composition and toxicity.

8. **EXPOSURE CONTROLS/PERSONAL PROTECTION**

**EYE PROTECTION GUIDELINES:** Chemical splash-proof goggles or face shield.  
**SKIN PROTECTION GUIDELINES:** Wear liquid-proof, chemical resistant gloves (nitrile-butyl rubber, neoprene, butyl rubber or natural rubber) and full body-covering clothing.  
**RESPIRATORY/VENTILATION GUIDELINES:** Use with adequate general and local exhaust ventilation to meet exposure limits. In poorly ventilated areas, use a NIOSH/MSHA approved respirator with an organic vapor cartridge.  
**ADDITIONAL PROTECTIVE MEASURES:** Use where there is immediate access to safety shower and emergency eye wash. Wash thoroughly after use. Contact lens should not be worn when working with this material. Generally speaking, working cleanly and following basic precautionary measures will greatly minimize the potential for harmful exposure to this product under normal use conditions.  
**OCCUPATIONAL EXPOSURE LIMITS:** Not established for product as whole. Refer to OSHA’s Permissible Exposure Level (PEL) or the ACGIH Guidelines for information on specific ingredients.

9. **PHYSICAL AND CHEMICAL PROPERTIES**

**PHYSICAL FORM:** Liquid.  
**COLOR:** Amber.  
**ODOR:** Ammonia-like.  
**BOILING POINT:** > 440°F.  
**MELTING POINT/FREEZE POINT:** Approximately 23°F.  
**pH:** Alkaline.  
**SOLUBILITY IN WATER:** Appreciable.  
**SPECIFIC GRAVITY:** 1.05
BULK DENSITY .................................................................................... 8.85 pounds/gallon.
VAPOR PRESSURE ............................................................................. < 1 mmHg @ 20°C.
VAPOR DENSITY ................................................................................. Heavier than air.
VISCOSITY ........................................................................................... 1,000 cPs
% VOLATILE BY WEIGHT .................................................................... ASTM 2369-07 was used to determine the Volatile Matter Content of mixed epoxy resin and hardener. 105 Resin and 205 Hardener, mixed together at 5:1 by weight, has a density of 1137 g/L (9.49 lbs/gal). The combined VOC content for 105/205 is 7.91 g/L (0.07 lbs/gal).

10. STABILITY AND REACTIVITY

STABILITY: ........................................................................................... Stable.
HAZARDOUS POLYMERIZATION: ........................................................... Will not occur.
INCOMPATIBILITIES: ........................................................................... Avoid excessive heat. Avoid acids, oxidizing materials, halogenated organic compounds (e.g., methylene chloride). External heating or self-heating could result in rapid temperature increase and serious hazard. If such a reaction were to take place in a waste drum, the drum could expand and rupture violently.
DECOMPOSITION PRODUCTS: ...................................................................... Very toxic fumes and gases when burned or otherwise heated to decomposition. Decomposition products may include, but not limited to: oxides of nitrogen, volatile amines, ammonia, nitric acid, nitrosamines.

11. TOXICOLOGICAL INFORMATION

No specific oral, inhalation or dermal toxicology data is known for this product.
Oral: ................................................................. Expected to be moderately toxic.
Inhalation: .............................................................................. Expected to be moderately toxic.
Dermal: ................................................................................ Expected to be moderately toxic.
Adsorption of phenolic solutions through the skin may be very rapid and can cause death. Lesser exposures can cause damage to the kidney, liver, pancreas and spleen; and cause edema of the lungs. Chronic exposures can cause death from liver and kidney damage.
CARCINOGENICITY:
NTP............................................................................................... No.
IARC ............................................................................................. No.
OSHA............................................................................................ No.

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA, NTP or IARC.

12. ECOLOGICAL INFORMATION

Wastes from this product may present long term environmental hazards. Do not allow into sewers, on the ground or in any body of water.
Hydroxybenzene (phenol) (CAS # 108-95-2) biodegradability = 99.5% at 7 days.

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHOD: ................................................................. Evaluation of this product using RCRA criteria shows that it is not a hazardous waste, either by listing or characteristics, in its purchased form. It is the responsibility of the user to determine proper disposal methods.
Incinerate, recycle (fuel blending) or reclaim may be preferred methods when conducted in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT
SHIPPING NAME: ................................................................. Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME ......................................................... (Triethylenetetramine)
D.O.T. HAZARD CLASS: ................................................................. Class 8
U.N./N.A. NUMBER: ................................................................. UN 2735
PACKING GROUP: ................................................................. PG III

IATA
SHIPPING NAME: ................................................................. Polyamines, liquid, corrosive, n.o.s.
TECHNICAL SHIPPING NAME ......................................................... (Triethylenetetramine)
HAZARD CLASS: ................................................................. Class 8
U.N. NUMBER: ................................................................. UN 2735
PACKING GROUP: ................................................................. PG III

15. REGULATORY INFORMATION

OSHA STATUS: ................................................................................... Corrosive; possible sensitizer.
TSCA STATUS: ................................................................. All components listed on TSCA inventory or otherwise comply with TSCA requirements.

Canada WHIMIS Classification: D2A, D2B, E

SARA TITLE III:
SECTION 313 TOXIC CHEMICALS: ............................................. This product contains hydroxybenzene (phenol) and is subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR Part 372.

STATE REGULATORY INFORMATION:
The following chemicals are specifically listed or otherwise regulated by individual states. For details on your regulatory requirements you should contact the appropriate agency in your state.

<table>
<thead>
<tr>
<th>COMPONENT NAME</th>
<th>CAS NUMBER</th>
<th>CONCENTRATION</th>
<th>STATE CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetraethylenepentamine</td>
<td>112-57-2</td>
<td>&lt;10%</td>
<td>MA, NJ, PA</td>
</tr>
<tr>
<td>Tetraethylenetriamine</td>
<td>112-24-3</td>
<td>&lt;10%</td>
<td>MA, NJ, PA</td>
</tr>
<tr>
<td>Phenol</td>
<td>108-95-2</td>
<td>&lt;10%</td>
<td>NJ, RI, PA, MA, IL</td>
</tr>
</tbody>
</table>

16. OTHER INFORMATION

REASON FOR ISSUE: ............................................................. Changes made in Sections 5, 10, 14 & 15.
PREPARED BY: .............................................................. G. M. House
APPROVED BY: .............................................................. G. M. House
TITLE: ................................................................. Health, Safety & Environmental Manager
APPROVAL DATE: .......................................................... February 10, 2011
SUPERSEDES DATE: ...................................................... January 3, 2008
MSDS NUMBER: .............................................................. 205-11a

Note: The Hazardous Material Indexing System (HMIS), cited in the Emergency Overview of Section 3, uses the following index to assess hazard rating: 0 = Minimal; 1 = Slight; 2 = Moderate; 3 = Serious; and 4 = Severe.

This information is furnished without warranty, expressed or implied, except that it is accurate to the best knowledge of West System Inc. The data on this sheet is related only to the specific material designated herein. West System Inc. assumes no legal responsibility for use or reliance upon these data.
Material Safety Data Sheet

Section 1 - Chemical Product / Company Information

Product Name: PTOUCH 2X +SSPR 6PK GLOSS CRANBERRY
Revision Date: 08/12/2011
Identification Number: 249863
Product Use/Class: Topcoat/Aerosols
Supplier: Rust-Oleum Corporation
11 Hawthorn Parkway
Vernon Hills, IL 60061
USA
Manufacturer: Rust-Oleum Corporation
11 Hawthorn Parkway
Vernon Hills, IL 60061
USA
Preparer: Regulatory Department

Section 2 - Composition / Information On Ingredients

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS Number</th>
<th>Weight % Less</th>
<th>ACGIH TLV-TWA</th>
<th>ACGIH TLV-STEL</th>
<th>OSHA PEL-TWA</th>
<th>OSHA PEL CEILING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>67-64-1</td>
<td>35.0</td>
<td>500 ppm</td>
<td>750 ppm</td>
<td>1000 ppm</td>
<td>N.E.</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas</td>
<td>68476-8-8</td>
<td>25.0</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Naphtha</td>
<td>8032-32-4</td>
<td>10.0</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Toluene</td>
<td>108-88-3</td>
<td>10.0</td>
<td>20 ppm</td>
<td>N.E.</td>
<td>200 ppm</td>
<td>300 ppm</td>
</tr>
<tr>
<td>Xylene</td>
<td>1330-20-7</td>
<td>10.0</td>
<td>150 ppm</td>
<td>150 ppm</td>
<td>100 ppm</td>
<td>N.E.</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>106-41-4</td>
<td>5.0</td>
<td>100 ppm</td>
<td>125 ppm</td>
<td>100 ppm</td>
<td>N.E.</td>
</tr>
</tbody>
</table>

Section 3 - Hazards Identification

*** Emergency Overview ***: Contents Under Pressure. Harmful if inhaled. May affect the brain or nervous system causing dizziness, headache or nausea. Vapors may cause flash fire or explosion. Harmful if swallowed. Extremely flammable liquid and vapor.

Effects Of Overexposure - Eye Contact: Causes eye irritation.

Effects Of Overexposure - Skin Contact: Prolonged or repeated contact may cause skin irritation. Substance may cause slight skin irritation. May be absorbed through the skin in harmful amounts.

Effects Of Overexposure - Inhalation: High vapor concentrations are irritating to the eyes, nose, throat and lungs. Avoid breathing vapors or mists. High gas, vapor, mist or dust concentrations may be harmful if inhaled. Harmful if inhaled.

Effects Of Overexposure - Ingestion: Aspiration hazard if swallowed; can enter lungs and cause damage. Substance may be harmful if swallowed.

Effects Of Overexposure - Chronic Hazards: IARC lists Ethylbenzene as a possible human carcinogen (group 2B). May cause central nervous system disorder (e.g., narcosis involving a loss of coordination, weakness, fatigue, mental confusion, and blurred vision) and/or damage. Reports have associated repeated and prolonged
occupational overexposure to solvents with permanent brain and nervous system damage. Overexposure to xylene in laboratory animals has been associated with liver abnormalities, kidney, lung, spleen, eye and blood damage as well as reproductive disorders. Effects in humans, due to chronic overexposure, have included liver, cardiac abnormalities and nervous system damage.

Primary Route(s) Of Entry: Skin Contact, Skin Absorption, Inhalation, Ingestion, Eye Contact

### Section 4 - First Aid Measures

**First Aid - Eye Contact:** Immediately flush eyes with plenty of water for at least 15 minutes holding eyelids open. Get medical attention. Do NOT allow rubbing of eyes or keeping eyes closed.

**First Aid - Skin Contact:** Wash with soap and water. Get medical attention if irritation develops or persists.

**First Aid - Inhalation:** If you experience difficulty in breathing, leave the area to obtain fresh air. If continued difficulty is experienced, get medical assistance immediately.

**First Aid - Ingestion:** Aspiration hazard: Do not induce vomiting or give anything by mouth because this material can enter the lungs and cause severe lung damage. Get immediate medical attention.

### Section 5 - Fire Fighting Measures

**Flash Point:** -156 °F (Setaflash)

**Extinguishing Media:** Film Forming Foam, Carbon Dioxide, Dry Chemical, Dry Sand, Water Fog

**Unusual Fire And Explosion Hazards:** FLASH POINT IS LESS THAN 20 ° F. - EXTREMELY FLAMMABLE LIQUID AND VAPOR! Perforation of the pressurized container may cause bursting of the can. Isolate from heat, electrical equipment, sparks and open flame. Keep containers tightly closed. Water spray may be ineffective. Closed containers may explode when exposed to extreme heat. Vapors may form explosive mixtures with air. Vapors can travel to a source of ignition and flash back.

**Special Firefighting Procedures:** Evacuate area and fight fire from a safe distance.

### Section 6 - Accidental Release Measures

**Steps To Be Taken If Material Is Released Or Spilled:** Contain spilled liquid with sand or earth. DO NOT use combustible materials such as sawdust. Remove all sources of ignition, ventilate area and remove with inert absorbent and non-sparking tools. Dispose of according to local, state (provincial) and federal regulations. Do not incinerate closed containers.

### Section 7 - Handling And Storage

**Handling:** Follow all MSDS/label precautions even after container is emptied because it may retain product residues. Use only in a well-ventilated area. Avoid breathing vapor or mist. Wash thoroughly after handling. Wash hands before eating.

**Storage:** Do not store above 120 ° F. Store large quantities in buildings designed and protected for storage of NFPA Class I flammable liquids. Contents under pressure. Do not expose to heat or store above 120 ° F. Keep containers tightly closed. Isolate from heat, electrical equipment, sparks and open flame.

### Section 8 - Exposure Controls / Personal Protection
Engineering Controls: Prevent build-up of vapors by opening all doors and windows to achieve cross-ventilation. Use explosion-proof ventilation equipment. Use process enclosures, local exhaust ventilation, or other engineering controls to control airborne levels below recommended exposure limits.

Respiratory Protection: A respiratory protection program that meets OSHA 1910.134 and ANSI Z88.2 requirements must be followed whenever workplace conditions warrant a respirator's use. A NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge or canister may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits.

Protection provided by air purifying respirators is limited. Use a positive pressure air supplied respirator if there is any potential for an uncontrolled release, exposure levels are not known, or in any other circumstances where air purifying respirators may not provide adequate protection.

Skin Protection: Nitrile or Neoprene gloves may afford adequate skin protection. Use impervious gloves to prevent skin contact and absorption of this material through the skin.

Eye Protection: Use safety eyewear designed to protect against splash of liquids.

Other protective equipment: Refer to safety supervisor or industrial hygienist for further information regarding personal protective equipment and its application.

Hygienic Practices: Wash thoroughly with soap and water before eating, drinking or smoking.

### Section 9 - Physical And Chemical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapor Density</td>
<td>Heavier than Air</td>
</tr>
<tr>
<td>Appearance</td>
<td>Aerosolized Mist</td>
</tr>
<tr>
<td>Solubility in H2O</td>
<td>Slight</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>0.749</td>
</tr>
<tr>
<td>Physical State</td>
<td>Liquid</td>
</tr>
<tr>
<td>Odor</td>
<td>Solvent Like</td>
</tr>
<tr>
<td>Evaporation Rate</td>
<td>Faster than Ether</td>
</tr>
<tr>
<td>Freeze Point</td>
<td>N.D.</td>
</tr>
<tr>
<td>pH</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

(See section 16 for abbreviation legend)

### Section 10 - Stability And Reactivity

Conditions To Avoid: Avoid temperatures above 120 ° F. Avoid all possible sources of ignition.

Incompatibility: Incompatible with strong oxidizing agents, strong acids and strong alkalies.

Hazardous Decomposition: By open flame, carbon monoxide and carbon dioxide. When heated to decomposition, it emits acrid smoke and irritating fumes.

Hazardous Polymerization: Will not occur under normal conditions.

Stability: This product is stable under normal storage conditions.

### Section 11 - Toxicological Information

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>LD50</th>
<th>LC50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>5800 mg/kg (Rat)</td>
<td>50100 mg/m3 (Rat, 8Hr)</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas</td>
<td>N.E.</td>
<td>N.E.</td>
</tr>
<tr>
<td>Naphtha</td>
<td>&gt;5000 mg/kg (Rat, Oral)</td>
<td>N.E.</td>
</tr>
</tbody>
</table>
Section 12 - Ecological Information

Ecological Information: Product is a mixture of listed components.

Section 13 - Disposal Information

Disposal Information: Dispose of material in accordance to local, state and federal regulations and ordinances. Do not allow to enter storm drains or sewer systems.

Section 14 - Transportation Information

<table>
<thead>
<tr>
<th>Proper Shipping Name:</th>
<th>Domestic (USDOT)</th>
<th>International (IMDG)</th>
<th>Air (IATA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard Class:</td>
<td>Consumer Commodity</td>
<td>Aerosols</td>
<td>Aerosols</td>
</tr>
<tr>
<td>UN Number:</td>
<td>ORM-D</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Packing Group:</td>
<td>N.A.</td>
<td>UN1950</td>
<td>UN1950</td>
</tr>
<tr>
<td>Limited Quantity:</td>
<td>No</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

Section 15 - Regulatory Information

CERCLA - SARA Hazard Category

This product has been reviewed according to the EPA "Hazard Categories" promulgated under Sections 311 and 312 of the Superfund Amendment and Reauthorization Act of 1986 (SARA Title III) and is considered, under applicable definitions, to meet the following categories:

IMMEDIATE HEALTH HAZARD, CHRONIC HEALTH HAZARD, FIRE HAZARD, PRESSURIZED GAS HAZARD

SARA Section 313:

Listed below are the substances (if any) contained in this product that are subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR part 372:

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toluene</td>
<td>108-88-3</td>
</tr>
<tr>
<td>Xylene</td>
<td>1330-20-7</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>100-41-4</td>
</tr>
</tbody>
</table>

Toxic Substances Control Act:

Listed below are the substances (if any) contained in this product that are subject to the reporting requirements of TSCA 12(B) if exported from the United States:

U.S. State Regulations: As follows -

New Jersey Right-to-Know:
The following materials are non-hazardous, but are among the top five components in this product.

### Chemical Name

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Alkyd</td>
<td>PROPRIETARY</td>
</tr>
</tbody>
</table>

**Pennsylvania Right-to-Know:**

The following non-hazardous ingredients are present in the product at greater than 3%.

### Chemical Name

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Alkyd</td>
<td>PROPRIETARY</td>
</tr>
</tbody>
</table>

**International Regulations: As follows -**

**CANADIAN WHMIS:**

This MSDS has been prepared in compliance with Controlled Product Regulations except for the use of the 16 headings.

**CANADIAN WHMIS CLASS:** AB5 D2A D2B

### Section 16 - Other Information

**HMIS Ratings:**

- Health: 2*
- Flammability: 4
- Physical Hazard: 0
- Personal Protection: X

**NFPA Ratings:**

- Health: 2
- Flammability: 4
- Instability: 0

**VOLATILE ORGANIC COMPOUNDS, g/L:** 533

**REASON FOR REVISION:** Regulatory Update

**Legend:** N.A. - Not Applicable, N.E. - Not Established, N.D. - Not Determined

Rust-Oleum Corporation believes, to the best of its knowledge, information and belief, the information contained herein to be accurate and reliable as of the date of this material safety data sheet. However, because the conditions of handling, use, and storage of these materials are beyond our control, we assume no responsibility or liability for personal injury or property damage incurred by the use of these materials. Rust-Oleum Corporation makes no warranty, expressed or implied, regarding the accuracy or reliability of the data or results obtained from their use. All materials may present unknown hazards and should be used with caution. The information and recommendations in this material safety data sheet are offered for the users’ consideration and examination. It is the responsibility of the user to determine the final suitability of this information and to comply with all applicable international, federal, state, and local laws and regulations.
MATERIAL SAFETY DATA SHEET

Section 1
PETR TECHNOLOGY
9420 Santa Anita Avenue
Rancho Cucamonga, CA 91730

PRODUCT IDENTIFICATION: Super Glue

Section 2 - HAZARDOUS INGREDIENTS INFORMATION:

<table>
<thead>
<tr>
<th>Hazardous Components</th>
<th>OSHA</th>
<th>ACGIH</th>
<th>OTHER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Common Names, CAS Number)</td>
<td>PEL</td>
<td>TLV</td>
<td>LIMITS</td>
<td>OPTION</td>
</tr>
<tr>
<td>Ethyl-2-Cyanoacrylate</td>
<td>NE</td>
<td>NE</td>
<td>0.2ppm TWA</td>
<td>60-100</td>
</tr>
<tr>
<td>Poly (Methyl Methacrylate)</td>
<td>NE</td>
<td>NE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydroquinone*</td>
<td>2mg/m3</td>
<td>2mg/m3</td>
<td></td>
<td>0-1</td>
</tr>
</tbody>
</table>

*This ingredient is subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments & Reauthorization Act of 1986 (SARA) and 40 CFR 372.

Section 3 - PHYSICAL/CHEMICAL CHARACTERISTICS:

- Boiling Point: 365 F
- Specific Gravity (H2O=1): 1.05
- Vapor Density (Air=1): nil-NE
- Melting Point: NE
- Vapor Pressure (mm Hg): 1 @ 20 C
- Evaporation Rate (Butyl acetate=1): nil-NE
- Solubility in Water: Insoluble, material reacts to hardened mass for non-hazardous waste.
- VOC: This product is VOC compliant for sale in California.
- Appearance & Odor: Transparent water-white to straw colored liquid with stimulative odor.

Section 4 - FIRE AND EXPLOSION HAZARD DATA:

- Flash Point (Method Used): 185 F (TCC)
- Flammable Limits: LEL: NE UEL: NE
- Extinguishing Media: Flush with large amounts of water or dry chemical extinguisher.
- Special Fire Fighting Procedures: Fumes may be irritating if not burning and require air supply with goggles while applying large amounts of water or dry chemical extinguisher.
- Unusual Fire and Explosion Hazards: None. Combustible requiring the above procedures.

Section 5 - REACTIVITY DATA:

- Stability: Stable XX
- Conditions to Avoid: Excessive heat above 176 F, moisture and alkalines. Stable up to 122 F. Store in a cool dry place.
- Incompatibility (Materials to Avoid): Polymerized by water, alcohol, amines, alkaline materials and direct UV.
- Hazardous Decomposition Products: Combustible by-products of carbon monoxide/dioxide.
- Hazardous Polymerization: May Not Occur XX

Section 6 - HEALTH HAZARD DATA:

- Route(s) of Entry: Inhalation: Yes Oral LD50 = > 5000 mg/kg (estimated)
- Dermal LD50 = > 2000 mg/kg (estimated)
- Health Hazards (Acute and Chronic):
  - Acute - Irritates eyes, mucous membranes.
  - Chronic - No residual effects of acute properties.
- Carcinogenicity: NTP: No IARC Monographs: No OSHA Regulated: No
First Aid Procedures:

Eye contact - Tearing from eye irritation. Remove to fresh air. Flush areas of contact with water. Adhesive will disassociate from eye/eyelids over time, usually within several hours. Temporary weeping of eyes,double vision may be experienced until clearance is achieved.

Skin contact - Immerse bonded areas in warm, soapy water. Peel or roll skin apart. Remove cured adhesive with several applications of warm, soapy water. Prolonged or repeated contact at elevated levels may cause dermatitis in sensitive individuals.

Inhalation - Irritation of mucous membranes/coughing. Remove to fresh air. Prolonged or repeated exposure at elevated levels may produce allergic reactions with asthma-like symptoms in sensitive individuals.

Ingestion - Lips may become stuck together: apply copious amounts of warm water & encourage wetting/pressure from saliva inside mouth. Peel or roll (do not pull) lips apart. It is almost impossible to swallow cyanoacrylate as adhesive solidifies upon contact with saliva & may adhere to inside of mouth. Saliva will lift adhesive in 1-2 days, avoid swallowing adhesive after detachment.

Medical Conditions Generally Aggravated by Exposure: Pre-existing skin, eye and respiratory disorders may be aggravated by exposure.

Section 7 - PRECAUTIONS FOR SAFE HANDLING AND USE:

Steps to Be Taken in Case Material is Released or Spilled: Polymerize with water. Solid material may be scraped from surface.

Waste Disposal Method: Incinerate solid combustible waste or dump as chemical waste according to local, state and federal regulations.

Precautions to Be Taken in Handling and Storing: Avoid contact with clothing as contact can cause burn. Avoid moisture, direct UV-sunlight and do not store above 25 C. Keep containers closed tightly when not in use. Ideal storage: 5-10 C.

Other Precautions: Avoid breathing vapor, contact with eyes/skin. Allow product to reach room temperature before use.

Section 8 - CONTROL MEASURES:

Respiratory Protection (Specify Type): A NIOSH-approved organic vapor canister may be used to maintain vapor concentration below TLV.

Ventilation: Local Exhaust: To maintain vapor concentration below TLV.

Mechanical (General): Large amounts used to 0.2ppm.

Protective Clothing or Equipment: Safety glasses with side shield, Vinyl (polyethylene) non-sticking gloves, rubber apron to protect clothing.

Work/Hygienic Practices: Soap and water helps remove adhesive from skin.

Section 9 - OTHER: Super Glue - Not regulated for transportation.

NE = Not established

The data contained herein is based upon information that Pacer Technology believes to be reliable. Users of this product have the responsibility to determine the suitability of use and to adopt all necessary precautions to ensure the safety and protection of property and persons involved in said use. All statements or suggestions are made without warranty, express or implied, regarding accuracy of the information, the hazards connected with the use of the material or the results to be obtained from the use thereof.
NOTICE
ALL INFORMATION APPEARING HEREIN IS BASED UPON DATA OBTAINED FROM THE MANUFACTURER AND/OR RECOGNIZED TECHNICAL SOURCES. THIS INFORMATION IS BELIEVED TO BE CORRECT, BUT DOES NOT PURPORT TO BE ALL INCLUSIVE AND SHALL BE USED ONLY AS A GUIDE. MARTINEZ SPECIALTIES, INC. MAKES NO WARRANTY, EXPRESS OR IMPLIED, AS TO THE ACCURACY OR COMPLETENESS OF THIS INFORMATION. IT IS THE USER'S RESPONSIBILITY TO DETERMINE THE SUITABILITY OF THIS INFORMATION FOR THE ADOPTION OF NECESSARY SAFETY PRECAUTIONS AND/OR COMPLIANCE WITH LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS.

Section I. - General Information

Identity: (As used on label and list) UN0454 Igniters 1.4S
Trade Name: J-Tek
Manufacturer's Name & Address: MJG Technologies, Inc.
Telephone Number: 856-228-6118
Date Prepared: September 1, 2009
Prepared By: J. Genzel

Section II. - Hazardous Ingredients / Identity Information

Per OSHA 29 CFR 1910.1200

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>CAS#</th>
<th>Exposure Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OSHA (PEL)</td>
<td>ACGIH (TLV)</td>
</tr>
<tr>
<td>Bismuth Trioxide</td>
<td>1304-76-3</td>
<td>15 mg / m3</td>
</tr>
<tr>
<td>Boron</td>
<td>7440-42-8</td>
<td>15 mg / m3</td>
</tr>
<tr>
<td>Potassium Perchlorate</td>
<td>7778-74-7</td>
<td>Not Established</td>
</tr>
<tr>
<td>Titanium</td>
<td>7440-32-6</td>
<td>Not Established</td>
</tr>
</tbody>
</table>

Section III. - Physical / Chemical Characteristics

<table>
<thead>
<tr>
<th>Physical / Chemical Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point (deg. F.) N/A</td>
</tr>
<tr>
<td>Vapor Pressure (mm Hg.) N/A</td>
</tr>
<tr>
<td>Vapor Density (Air = 1) N/A</td>
</tr>
<tr>
<td>Solubility in Water: Insoluble with lacquer coating intact.</td>
</tr>
</tbody>
</table>

Appearance and Odor: Medium brown colored bead of pyrotechnic composition on a copper-clad chip with two PVC insulated connecting wires of various lengths. Red or blue lacquer coating on igniter head.

Section IV. - Fire and Explosion Hazard Data

<table>
<thead>
<tr>
<th>Fire and Explosion Hazard Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Point: N/A</td>
</tr>
<tr>
<td>Flammable Limits N/A</td>
</tr>
<tr>
<td>LEL N/A</td>
</tr>
<tr>
<td>UEL N/A</td>
</tr>
<tr>
<td>Extinguishing Media: N/A</td>
</tr>
<tr>
<td>Special Fire Fighting Procedures: Do not use suffocating methods - devices contain their own oxygen.</td>
</tr>
<tr>
<td>Unusual Fire and Explosion Hazards: Burning igniters will project sparks several feet and can cause secondary fires. Igniters may rupture a container if ignited under confinement. Igniters may be ignited by extreme impact, friction or electrostatic discharge.</td>
</tr>
</tbody>
</table>
Section V. - Reactivity Data

Stability: Stable

Conditions To Avoid: Sources of ignition - heat, sparks, open flames and smoking. Do not subject igniter heads to impact or friction.

Incompatibility (Materials to Avoid): Acids and reducing agents.

Hazardous Decomposition or Byproducts: Smoke contains oxides of Boron and Titanium.

Hazardous Polymerization: Will not occur.

Section VI. - Health Hazard Data

Route(s) of Entry: Inhalation? Skin? Ingestion?

Not with match head intact. No Not with match head intact.

Health Hazards (Acute and Chronic): Primary hazard is from thermal burns caused by accidental ignition of igniters. Deliberate inhalation or ingestion of large amounts of crushed igniter head composition may cause respiratory discomfort. Not absorbed through skin.

Carcinogenicity: NTP? ARC Monographs? OSHA Regulated?

No No No

Signs and Symptoms of Exposure: See Boric Acid exposure. Large doses of Boron compounds can cause depression of the circulation, persistent vomiting and diarrhea, followed by shock and coma. Bismuth Trioxide ingestion has no known adverse effects. However, ingestion is not advised.

Medical Conditions Generally Aggravated By Exposure: Smoke generated by burning igniters may cause respiratory irritation in those individuals with asthma, allergies or other preexisting respiratory conditions.

Emergency First Aid Procedures: Move patient to source of fresh air. Do not induce vomiting. Get prompt medical attention from qualified medical personnel.

Section VII. - Precautions For Safe Handling And Use

Steps To Be Taken In Case Material Is Released Or Spilled: Immediately remove sources of ignition and isolate spill from any other flammable or pyrotechnic materials. Sweep up any crushed igniter heads using non-sparking tools. Avoid inhaling igniter head dust.

Waste Disposal Method: Dispose of in accordance with local, state and federal regulations. Small quantities can be disposed of by open burning if permitted.

Precautions To Be Taken In Handling And Storage: Keep away from sources of heat and ignition such as sparks or open flames. Avoid impact or friction to igniter head. Store igniter containers in a cool place. Do not store igniters with flammable, explosive or other pyrotechnic compositions. Keep out of the reach of children and uninformed persons.

Other Precautions: Avoid sources of strong electromagnetic fields and static electricity.

Section VII. - Control Measures

Respiratory Protection (Specify Type): Nuisance dust/particulate filter mask if large numbers of igniters are ignited in a confined area.

Ventilation: Yes. Local Exhaust: Acceptable.

Mechanical (General): Special:

Protective Gloves: Not normally required. Other:

Eye Protection: Goggles or safety glasses with side shields.

Other Protective Clothing or Equipment: Long sleeve cotton garments advised if handling a large quantity of igniters.

Work / Hygienic Practices: Wash thoroughly after handling igniters and before eating, drinking or smoking.
Goex Powder, Inc.

Material Safety Data Sheet

MSDS-BP (Potassium Nitrate)

Revised 3/17/09

<table>
<thead>
<tr>
<th>PRODUCT INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Name</td>
</tr>
<tr>
<td>Trade Names and Synonyms</td>
</tr>
<tr>
<td>Manufacturer/Distributor</td>
</tr>
<tr>
<td>Transportation Emergency</td>
</tr>
</tbody>
</table>

PREVENTION OF ACCIDENTS IN THE USE OF EXPLOSIVES

The prevention of accidents in the use of explosives is a result of careful planning and observance of the best known practices. The explosives user must remember that he is dealing with a powerful force and that various devices and methods have been developed to assist him in directing this force. He should realize that this force, if misdirected, may either kill or injure both him and his fellow workers.

WARNING

All explosives are dangerous and must be carefully transported, handled, stored, and used following proper safety procedures either by or under the direction of competent, experienced persons in accordance with all applicable federal, state and local laws, regulations, or ordinances. ALWAYS lock up explosive materials and keep away from children and unauthorized persons. If you have any questions or doubts as to how to use any explosive product, DO NOT USE IT before consulting with your supervisor, or the manufacturer, if you do not have a supervisor. If your supervisor has any questions or doubts, he should consult the manufacturer before use.

<table>
<thead>
<tr>
<th>HAZARDOUS COMPONENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material or Components</td>
</tr>
<tr>
<td>Potassium nitrate</td>
</tr>
<tr>
<td>Charcoal</td>
</tr>
<tr>
<td>Sulfur</td>
</tr>
<tr>
<td>Graphite¹</td>
</tr>
</tbody>
</table>

N/A = Not assigned
NE = Not established

¹ Not contained in all grades of black powder.
<table>
<thead>
<tr>
<th>PHYSICAL DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point</td>
</tr>
<tr>
<td>Vapor Pressure</td>
</tr>
<tr>
<td>Vapor Density</td>
</tr>
<tr>
<td>Solubility in Water</td>
</tr>
<tr>
<td>Specific Gravity</td>
</tr>
<tr>
<td>PH</td>
</tr>
<tr>
<td>Evaporation Rate</td>
</tr>
<tr>
<td>Appearance and Odor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HAZARDOUS REACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instability</td>
</tr>
<tr>
<td>Incompatibility</td>
</tr>
<tr>
<td>Hazardous decomposition</td>
</tr>
<tr>
<td>Polymerization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIRE AND EXPLOSION DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashpoint</td>
</tr>
<tr>
<td>Auto Ignition Temperature</td>
</tr>
<tr>
<td>Explosive temperature (5 sec)</td>
</tr>
<tr>
<td>Extinguishing media</td>
</tr>
<tr>
<td>Special fire fighting procedures</td>
</tr>
</tbody>
</table>
Unusual fire and explosion hazards

Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

<table>
<thead>
<tr>
<th>HEALTH HAZARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
</tr>
<tr>
<td>Carcinogenicity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIRST AID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalation</td>
</tr>
<tr>
<td>Eye and skin contact</td>
</tr>
<tr>
<td>Ingestion</td>
</tr>
<tr>
<td>Injury from detonation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SPILL OR LEAK PROCEDURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spill/leak response</td>
</tr>
<tr>
<td>Waste disposal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SPECIAL PROTECTION INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Respiratory</td>
</tr>
<tr>
<td>Eye</td>
</tr>
<tr>
<td>Gloves</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>
SPECIAL PRECAUTIONS

- Keep away from friction, impact, and heat and open flame. Do not consume food, drink, or tobacco in areas where they may become contaminated with these materials.
- Contaminated equipment must be thoroughly water cleaned before attempting repairs.
- Use only non-spark producing tools.
- No smoking.

STORAGE CONDITIONS
Store in a cool, dry place in accordance with the requirements of Subpart K, ATF: Explosives Law and Regulations (27 CFR 55.201-55.219).

<table>
<thead>
<tr>
<th>Proper shipping name</th>
<th>Black Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard class</td>
<td>1.1D</td>
</tr>
<tr>
<td>UN Number</td>
<td>UN0027</td>
</tr>
<tr>
<td>DOT Label &amp; Placard</td>
<td>DOT Label EXPLOSIVES 1.1D</td>
</tr>
<tr>
<td></td>
<td>DOT Placard EXPLOSIVES 1.1</td>
</tr>
<tr>
<td>Alternate shipping</td>
<td>Limited quantities of GOEX black powder (1# cans only) may be transported as “Black powder for small arms – flammable solid” pursuant to U.S. Department of Transportation 49 CFR.</td>
</tr>
</tbody>
</table>

The information contained in this Material Safety Data Sheet is based upon available data and believed to be correct; however, as such has been obtained from various sources, including the manufacturer, military and independent laboratories, it is given without warranty or representation that it is complete, accurate, and can be relied upon. GOEX, Incorporated, has not attempted to conceal in any manner the deleterious aspects of the product listed herein, but makes no warranty as to such. Further, GOEX, Incorporated, cannot anticipate nor control the many situations in which the product or this information may be used; there is no guarantee that the health and safety precautions suggested will be proper under all conditions. It is the sole responsibility of each user of the product to determine and comply with the requirements of all applicable laws and regulations regarding its use. This information is given solely for the purposes of safety to persons and property. Any other use of this information is expressly prohibited.

For further information contact: GOEX Powder, Incorporated
P. O. Box 659
Doyline, LA 71023-0659
Telephone Number: (318) 382-9300
Fax Number: (318) 382-9303
BLACK POWDER

FRICITION TEST
PA
Steel – Snaps
Fiber – Unaffected

IMPACT TEST
PA
16 Inches (10% Point)

ELECTROSTATIC DISCHARGE TEST

Bureau of Mines
0.8 Joules (Confined)
12.5 Joules Unconfined

STABILITY
75° C International Heat Test – 0.31% Loss
Vacuum Stability – 0.5cc @ 100° C

BRISANCE – Sand Test 8 gm.

VELOCITY

In the open, trains of black powder burn very slowly, measurable in seconds per foot. Confined, as in steel pipe, speeds of explosions have been timed at values from 560 feet per second for very coarse granulations to 2,070 feet per second for the finer granulations. Confinement and granulation will affect the values.

CHEMICAL DECOMPOSITION

Use water to dissolve the potassium nitrate. By leaching out the potassium nitrate, the residue of sulfur and charcoal is non-explosive but combustible when dry – dispose separately.

SPECIAL REQUIREMENTS:

Black Powder is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement.

When dry, it is compatible with most metals. However, it is hydroscopic and when wet, attacks all common metals except stainless steel.

CAUTION: Explosives must be tested for compatibility with any material not specified in the production/procurement package with which they may come in contact. Materials include other explosives, solvents, adhesives, metals, plastics, paints, cleaning compounds, floor and table coverings, packing materials and other similar materials, situations and equipment. Explosives include propellants and pyrotechnics.
1.0 PRODUCT / COMPANY IDENTIFICATION

Product Name: Pro29, Pro38, Pro54, Pro75, and Pro98 Rocket Motor Reload Kits
Synonyms: Rocket Motor
Proper Shipping Name: Articles, Explosive, N.O.S. (Ammonium Perchlorate)
Part Numbers:
- Reload kits: P29R-Y-#G-XX, P38R-Y-#G-XX, P54R-Y-#G-XX,
- P29R-Y-#GXL-XX, P38R-Y-#GXL-XX, P54R-Y-#GXL-XX,
- Propellant grains: P75AC-PG-XX, P98AC-PG-XX, P98AC-MB-PG-XX
  Where: Y = reload type (A = adjustable delay, C = C-slot)
  # = number of grains &
  XX = propellant type

Product Use: Solid fuel motor for propelling rockets

Manufacturer: Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, Ont.
Canada  L0H 1G0

Telephone Numbers:
- Product Information: 1-905-887-2370
- 24 Hour Emergency Telephone Number: 1-613-996-6666 (CANUTEC)

2.0 COMPOSITION / INFORMATION ON INGREDIENTS

<table>
<thead>
<tr>
<th>Propellant</th>
<th>CAS Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Perchlorate</td>
<td>7790-98-9</td>
<td>40-85 %</td>
</tr>
<tr>
<td>Metal Powders</td>
<td></td>
<td>1-45 %</td>
</tr>
<tr>
<td>Synthetic Rubber</td>
<td></td>
<td>10-30 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Black Powder Ignition pellet</th>
<th>CAS Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium Nitrate</td>
<td>7757-79-1</td>
<td>70-76 %</td>
</tr>
<tr>
<td>Charcoal</td>
<td>n/a</td>
<td>8-18 %</td>
</tr>
<tr>
<td>Sulphur</td>
<td>7704-34-9</td>
<td>9-20 %</td>
</tr>
<tr>
<td>Graphite</td>
<td>7782-42-5</td>
<td>trace</td>
</tr>
</tbody>
</table>

3.0 HAZARDS IDENTIFICATION

Emergency Overview:
There articles contain cylinders of ammonium perchlorate composite propellant, encased in inert plastic parts. The forward closure also contains a few grams of black powder. ProX Rocket motor reload kits are classified as explosives, and may cause serious injury, including death if used improperly. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced personnel in accordance with all applicable federal, state and local laws and regulations. Avoid inhaling exhaust products.
General Appearance:
Cardboard tubes contain various plastic parts. Inside the plastic tube are cylinders of composite propellant (rocket fuel). The forward closure also contains a small quantity of black powder. All parts are odourless solids.

Potential Health Effects:

**Eye:**
Not a likely route of exposure. May cause eye irritation.

**Skin:**
Not a likely route of exposure. Low hazard for usual industrial/hobby handling.

**Ingestion:**
Not a likely route of exposure.

**Inhalation:**
Not a likely route of exposure. May cause respiratory tract irritation. Do not inhale exhaust products.

4.0 FIRST AID MEASURES

**Eyes:**
Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

**Skin:**
Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists.

**Ingestion:**
Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

**Inhalation:**
Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.

**Burns:**
Burns can be treated as per normal first aid procedures.

5.0 FIRE FIGHTING MEASURES

**Extinguishing Media:**
In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam to contain surrounding fire.

**Exposure Hazards During Fire:**
Exposure to extreme heat may cause ignition.

**Combustion Products from Fire:**
During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.

**Fire Fighting Procedures:**
Keep all persons and hazardous materials away. Allow material to burn itself out. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear.

**Special Instructions / Notes:**
These articles burn rapidly and generate a significant flame for a short period of time. Black powder is a deflagrating explosive. It is very sensitive to flame and spark and can also be ignited by friction and impact. When ignited unconfined, it burns with explosive violence and will explode if ignited under even slight confinement. Do not inhale exhaust products.

6.0 ACCIDENTAL RELEASE MEASURES

**Safeguards (Personnel):**

**Spills:**
Clean up spills immediately. Replace articles in packaging and boxes and seal securely. Sweep or scoop up using non-sparking tools.

7.0 HANDLING AND STORAGE

**Handling:**
Keep away from heat, sparks and flame. Avoid contamination. Do not get in eyes, on skin or on clothing. Do not taste or swallow. Avoid prolonged or repeated contact with skin. Follow manufacturer’s instructions for use.
Storage: Store in a cool, dry place away from sources of heat, spark or flame. Keep in shipping packaging when not in use.

8.0 EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering Controls:
Use adequate explosion proof ventilation to keep airborne concentrations low. All equipment and working surfaces must be grounded.

Personal Protective Equipment:
- **Eyes:** Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
- **Skin:** Clothing should be appropriate for handling pyrotechnic substances.
- **Clothing:** Clothing should be appropriate for handling pyrotechnic substances.
- **Respirators:** A respirator is not typically necessary. Follow the OSHA respirator regulations found in 29CFR1910.134 or European Standard EN 149. Always use a NIOSH or European Standard EN 149 approved respirator when necessary.

9.0 PHYSICAL AND CHEMICAL PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical State</td>
<td>solid</td>
</tr>
<tr>
<td>Appearance</td>
<td>rubber cylinders inside plastic parts</td>
</tr>
<tr>
<td>Odour</td>
<td>none</td>
</tr>
<tr>
<td>Odour Threshold</td>
<td>Not available</td>
</tr>
<tr>
<td>pH</td>
<td>Not available</td>
</tr>
<tr>
<td>Vapour Pressure</td>
<td>Not available</td>
</tr>
<tr>
<td>Vapour Density</td>
<td>Not available</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Not available</td>
</tr>
<tr>
<td>Evaporation Rate</td>
<td>Not available</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>Not available</td>
</tr>
<tr>
<td>Freezing/Melting Point</td>
<td>Not available</td>
</tr>
<tr>
<td>Coefficient of water/oil dist</td>
<td>Not available</td>
</tr>
<tr>
<td>Autoignition Temperature</td>
<td>280°C</td>
</tr>
<tr>
<td>Flash Point</td>
<td>Not available</td>
</tr>
<tr>
<td>Explosion Limits, lower (LEL)</td>
<td>Not available</td>
</tr>
<tr>
<td>Explosion Limits, upper (UEL)</td>
<td>Not available</td>
</tr>
<tr>
<td>Sensitivity to Mechanical Impact</td>
<td>unprotected black powder can be ignited by impact</td>
</tr>
<tr>
<td>Sensitivity to Static Discharge</td>
<td>unprotected black powder can be ignited by static discharge</td>
</tr>
<tr>
<td>Decomposition Temperature</td>
<td>&gt; 400°C</td>
</tr>
<tr>
<td>Solubility in water</td>
<td>black powder is soluble in water</td>
</tr>
<tr>
<td>Specific Gravity/Density</td>
<td>black powder = 1.7-2.1</td>
</tr>
<tr>
<td>Propellant</td>
<td>not available</td>
</tr>
<tr>
<td>Molecular Formula</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

10.0 STABILITY AND REACTIVITY

Chemical Stability:
Stable under normal temperatures and pressures.

Conditions to Avoid:
Heat, static electricity, friction, impact

Incompatibilities with Other Materials:
Combustible or flammable materials, explosive materials

Hazardous Products Of Decomposition:
Oxides of nitrogen

Hazardous Polymerization:
Will not occur.
11.0 TOXICOLOGICAL INFORMATION

Routes of Entry:
- Skin contact – not likely
- Skin absorption – not likely
- Eye contact – not likely
- Inhalation – not likely
- Ingestion – not likely

Effects of Acute Exposure to Product: No data available
Effects of Chronic Exposure to Product: No data available

Exposure Limits:

Black Powder Pellets

<table>
<thead>
<tr>
<th>Ingredient Name</th>
<th>CAS Number</th>
<th>OSHA PEL</th>
<th>ACGIH TLV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium Nitrate</td>
<td>7757-79-1</td>
<td>not established</td>
<td>not established</td>
</tr>
<tr>
<td>Charcoal</td>
<td>n/a</td>
<td>not established</td>
<td>not established</td>
</tr>
<tr>
<td>Sulphur</td>
<td>7704-34-9</td>
<td>not established</td>
<td>not established</td>
</tr>
<tr>
<td>Graphite</td>
<td>7782-42-5</td>
<td>2.5 mg/m$^3$</td>
<td>15 mmpct (TWA)</td>
</tr>
</tbody>
</table>

Propellant

<table>
<thead>
<tr>
<th>Ingredient Name</th>
<th>CAS Number</th>
<th>OSHA PEL</th>
<th>ACGIH TLV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Perchlorate</td>
<td>7790-98-9</td>
<td>not established</td>
<td>not established</td>
</tr>
<tr>
<td>metal powder</td>
<td>varies</td>
<td>varies</td>
<td>varies</td>
</tr>
<tr>
<td>Synthetic Rubber</td>
<td></td>
<td>not established</td>
<td>not established</td>
</tr>
</tbody>
</table>

Irritancy of the Product: No data available
Sensitization to the Product: No data available
Carcinogenicity: Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA
Reproductive Toxicity: No data available
Teratogenicity: No data available
Mutagenicity: No data available
Toxically Synergistic Products: No data available
LD50: No data available

12.0 ECOLOGICAL INFORMATION

Environmental Data:
Ecotoxicity Data: Not determined.
EcoFaTE Data: Not determined.

13.0 DISPOSAL CONSIDERATIONS

Product As Sold: Pack firmly in hole in ground with nozzle pointing up. Ignite motor electrically from a safe distance and wait 5 minutes before approaching. Dispose of spent components in inert trash.
Product Packaging: Dispose of used packaging materials in inert trash.
Special Considerations: Consult local regulations about disposal of explosive materials.
14.0 TRANSPORT INFORMATION

Shipping Information – Canada
TDG Classification: Class 1.4 Explosive
Proper Shipping Name: Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number: 0351
UN Classification Code: 1.4 C
Packing Group: II
UN Packing Instruction: 101

Shipping Information - USA / IMO
Proper Shipping Name: Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number: 0351
UN Classification Code: 1.4 C
DOT / IMO Label: Class 1 – Explosive – Division 1.4C

Shipping Information - IATA
Proper Shipping Name: Articles, Explosive, N.O.S. (Model Rocket Motors)
UN Number: 0351
UN Classification Code: 1.4 C
IATA Labels: Class 1 – Explosive – Division 1.4C
Cargo Aircraft Only

15.0 REGULATORY INFORMATION

Canada
This product has been classified according to the hazard criteria of the Canadian Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.
WHMIS Classification: Not Controlled (explosive)
Domestic Substance List (DSL) Status:
All ingredients are listed on Canada's DSL List.
Canadian Explosives Classification: Class 7.2.5
This product is an authorized explosive in Canada.
These products are not considered "Controlled Good" in Canada under the Controlled Goods Regulations.

United States of America
TSCA Inventory Status:
All ingredients are listed on the TSCA inventory.

Hazardous Chemical Lists
CERCLA Hazardous Substance (40 CFR 302.4) No
SARA Extremely Hazardous Substance (40CFR 355) No
SARA Toxic Chemical (40CFR 372.65) No

European/International Regulations
The product on this MSDS, or all its components, is included on the following countries' chemical inventories:
EINECS – European Inventory of Existing Commercial Chemical Substances

European Labelling in Accordance with EC Directives
Hazard Symbols: Explosive.
Risk Phrases:
R 2 Risk of explosion by shock, friction, fire or other sources of ignition.
R 11 Highly flammable
R 44 Risk of explosion if heated under confinement.
Safety Phrases:
S 1/2 Keep locked up and out of the reach of children.
S 8 Keep container dry.
S 15 Keep away from heat.
S 16 Keep away from sources of ignition -- No smoking.
S 17  Keep away from combustible material.
S 18  Handle and open container with care.
S 33  Take precautionary measures against static discharges.
S 41  In case of fire and/or explosion do not breathe fumes.

16.0 OTHER INFORMATION

MSDS Prepared by:  Regulatory Affairs Department
Cesaroni Technology Inc.
P.O. Box 246
2561 Stouffville Rd.
Gormley, ON
Canada      L0H 1G0

Telephone:  905-887-2370 x239
Fax:  905-887-2375
Web Sites:  www.cesaronitech.com
            www.Pro38.com

The data in this Material Safety Data Sheet relates only to the specific material or product designated herein and does not relate to use in combination with any other material or in any process.

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no way shall the company be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, however arising, even if the company has been advised of the possibility of such damages.