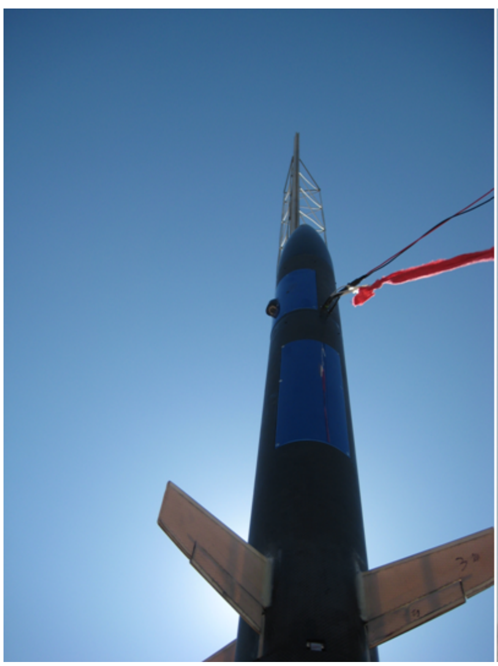
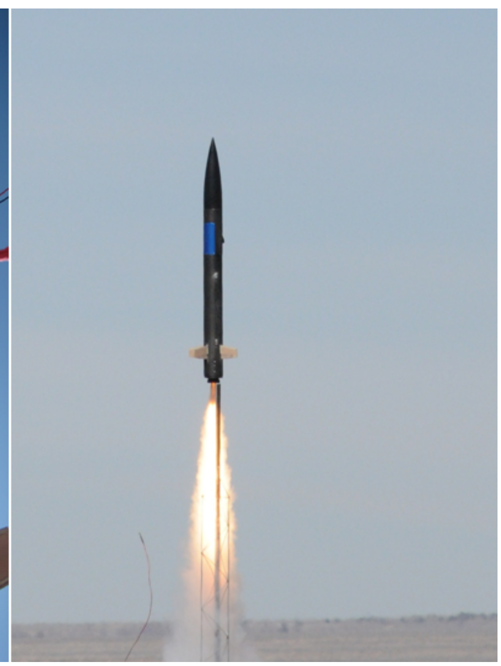
CHIMAERA
EXPERIMENTAL HYBRID ROCKETRY

Energy Management of a Sounding Rocket Using Cold-Gas Impulse Augmentation

Utah State University Chimaera Project





Contents

Nomenclature

γ	Flight path angle
ρ	Density
A_b	Ballistic parameter
A_{refp}	Reference area of the parachute
A_{refr}	Reference area, rocket
A_{ref}	Reference area of rocket
C_{dop}	Coefficient of drag, parachute
C_{dor}	Coefficient of drag, rocket
C_D	Coefficient of drag
C_d	Coefficient of drag, combined
C_g	Center of gravity
C_p	Center of pressure
C_x	Opening coefficient
D	Diameter
F_p	Peak opening force
h	Altitude
h_{apogee}	Altitude of apogee
h_{min}	Altitude at which drag drops below available thrust
$h_{potential}$	Potential altitude estimate
h_{target}	Target altitude
I_{sp}	Specific impulse
m	Mass
n	Canopy fill constant
q_1	Dynamic pressure
S	Parachute surface area
t	Time
t_{apogee}	Time of apogee
$V_{horizontal}$	Horizontal velocity
V_{op}	Parachute opening velocity
V_t	Terminal velocity
$V_{vertical}$	Flight path angle
X_1	Opening force reduction factor
$\left(\frac{E}{M}\right)_{total}$	Mass-specific potential energy

I. Project Overview

I.A. Team Summary

The Chimaera Rocket Team is comprised of students from the Mechanical and Aerospace Engineering (MAE) and Electrical and Computer Engineering (ECE) departments at Utah State University. Utah State University is located in Logan, Utah. Utah State University's Rocket is going to be named "The Javelin" and will be referred to as such throughout the report. The team is led by Dr. Stephen Whitmore with the help of several graduate teaching and research assistants, who serve as subject matter experts for the project, and assist the undergraduate design team with technical issues.

I.B. Launch Vehicle Summary

The Javelin has several major components and subsystems. The bottom section of the rocket will have a solid motor propellant as well as the isentropic expansion ramps for the cold-gas base-bleed augmentation system (C-BAS). The C-BAS will be used to manage the total mass-specific energy of the vehicle to control the achievable apogee altitude. The solid motor propellant has been limited to the Cesaroni L820 with AMW L777 as a backup. Both the solid motor and C-BAS will be tested to verify their available impulse levels are sufficient to meet mission objectives. The avionics section, located near the front end of the rocket just behind the nosecone, will house flight instrumentation. The avionics suite will include an inertial measurement unit (IMU), two pressure-based altimeters, and a three-axis magnetometer. Navigation data are processed in a small on-board avionics computer to continuously estimate the total specific energy and potential altitude of the vehicle. The flight computer also operates the energy management system. Additional flight instruments will include the C-BAS plenum pressure and expansion ramp surface pressures. The two pressure altimeters, PerfectFlight MAWD and R-DAS, are used for dual redundant deployment of the recovery system's parachutes. The PerfectFlight altimeter also provides the official measurement of the achieved altitude, for which the team is judged in the USLI competition. The avionics suite will be discussed in detail later in this design document. The rocket body has been limited to two materials for the main body tubing. We are considering blue tube[a] and carbon fiber tubing. We are currently testing them to further identify which one would work best for our specific needs.

I.C. Payload Summary

The Javelin payload is a cold-gas energy management system based on aerospike nozzle theory. While the aerospike[b] nozzle has long been known for its altitude compensation ability for endo-atmospheric flight, its unconstrained plume is ideal for integration into the Javelin airframe structure. Here the aerospike-derived isentropic expansion ramps are "wrapped around" our primary solid motor core and add negligible aerodynamic drag to the external configuration. The Javelin design will use a solid propellant primary rocket motor, which will expectedly get the vehicle close to the desired one mile target altitude. During flight however, the vehicle will lose energy due to drag losses. At different waypoints during flight, the on-board avionics will calculate the energy lost from drag and execute the C-BAS raising the overall energy level of the rocket. Raising the overall energy level will augment the rockets' projected apogee altitude. The ramp pressure measurements will be a first-ever measurements of in-flight plume-induced compression for an over-expanded aerospike nozzle. These measurements can be analyzed post flight for increasing accuracy in later flights and further our understanding about the aerospike nozzle.

[a] Blue Tube is a high-strength tube originally developed by Always Ready Rocketry, details can be found at http://www.apogeerockets.com/blue_tubes.asp

[b] The linear aerospike was developed and tested for the X-33 and can be researched at http://www.nasa.gov/centers/marshall/news/background/facts/aerospike.html

II. Overview of Changes Since Proposal

The overall design of the Javelin has remained consistant, however the design of individual components have been significantly improved since USU's initial proposal. The primary changes and improvements to the Javelin include the following: design, terminology, structural layout of base-bleed expansion ramps, selection of primary motor canidate by simulation, and selection of cold-gas/components for energy augmentation system.

II.A. Vehicle Criteria

- USU rocket team is no longer considering a flared lower body tube as initially proposed.
- Javelin's total length has increased from 5.94 ft to 7.09 ft to accommidate new payload components.
- Javelin's cold-gas base-bleed expansion ramps are now designed to accommodate both 54 mm and 75 mm motor configurations.
- USU rocket team performed trade studies while researching system components in order to increase the fidelity of Javelin's mass budget.
- Javelin's primary motor candidate Cesaroni L820 was selected by method of 3-degree of freedom ballistic simulations and high fidelity mass budget trade studies.
- CO_2 has been selected as Javelin's cold-gas providing a higher potential lift capacity over HPA (High Pressure Air) tank configurations.
- 24 oz CO_2 tank, regulator, and related payload components have been purchased for data acquisition during base-bleed analysis.

II.B. Payload Criteria

- Reference to the technology used on the Javelin payload have been modified accordingly to meet all NASA and NAR High Power Rocketry Safety regulations.
- USU rocket teamcontinues to honor these regulations by referencing payload technology as "cold-gas base-bleed augmentation system " (C-BAS).
- The preliminary shape and size for Javelin's base bleed injection ramps have been designed and a model prototype has been created for physical representation.
- Payload components and layout of isentropic expansion ramps have been redesigned since initial proposal in order to stabilize expansion ramps during base-bleed.

II.C. Activity Plan

- No changes have been made by Utah State University rocket team at this time regarding the activity plan as outlined in the proposal.

II.D. Team Organization

Figure 1: The Utah State University Rocket Team.

The Chimaera Rocket Team is comprised of students from the Mechanical and Aerospace Engineering (MAE) and Electrical and Computer Engineering (ECE) departments at Utah State University. The majority of the team consists of undergraduate students, with these students completing the design as a partial fulfillment of the requirements for their senior design capstone course. Several graduate teaching and research assistants serve as subject matter experts for the project, and assist the undergraduate design team with technical issues. Every member of the team plays a vital role in the production and presentation of the rocket. All team members are responsible for accomplishing assigned tasks in a timely manner. Team members, with their assigned responsibilities are listed in Table 1.

School:	Utah State University
Project Title:	Chimaera
Rocket Name:	Javelin
Team Official:	Dr. Stephen Whitmore
Team Instructor:	Dr. Stephen Whitmore
Graduate Research Assistants:	Shannon Eilers[a],Zach Peterson[a], Matt Wilson[a]
	Bowen Masco[b], Nate Erni[c]
Chief Engineer:	Richard P.[d]
Assistant Chief Engineer:	Colin W.[d]
Systems Engineer:	Jamie W.[d]
Safety Officer:	Kyle H.[d]
NAR Section:	Utah Rocket Club (UROC)
NAR Section Contact:	Tim Boschert

Table 1: 2010-2011 USLI team members and responsibilities.

Students Involved	Responsibilities
Andrew B.[e]	Propulsion
Annika J.[d]	Recovery, Outreach, Solid Modeling
Colin W.[d]	Assistant Chief Engineer, Flight Mechanics
Craig B.[d]	Website, Controls
Jamie W.[d]	Systems Engineer, Outreach, Controls
Joshua K.[d]	Propulsion
Josue R.[d]	Structures, Simulation
Kyle H.[d]	Safety Officer, Simulation
Mansour S.[d]	Propulsion, Simulation, Controls
Nathan M.[f]	Avionics, Controls
Richard P.[d]	Chief Engineer, Structures, Flight Mechanics
Ryuichi Y.[d]	Flight Mechanics, Recovery, Simulation
Samuel M.[d]	Modeling, Controls, Procurement, Simulation
Stewart H.[f]	Avionics, Controls

[a]Graduate Research Assistant, Mechanical and Aerospace Engineering
[b]Graduate Research Assistant, Computer Science
[c]Graduate Research Assistant, Electrical Engineering
[d]Undergraduate, Mechanical and Aerospace Engineering
[e]Graduate Student, Mechanical and Aerospace Engineering
[f]Undraduate, Electrical Engineering

To effectively coordinate design efforts, the project is broken down along technical discipline lines that emulate an industry or NASA program. Each discipline team has technical leads with several subordinate members. All students are members of at least two technical teams. Team memberships were selected based on the individual students' areas of technical expertise and personal interest. Figure 2 shows the project breakdown structure (PBS).

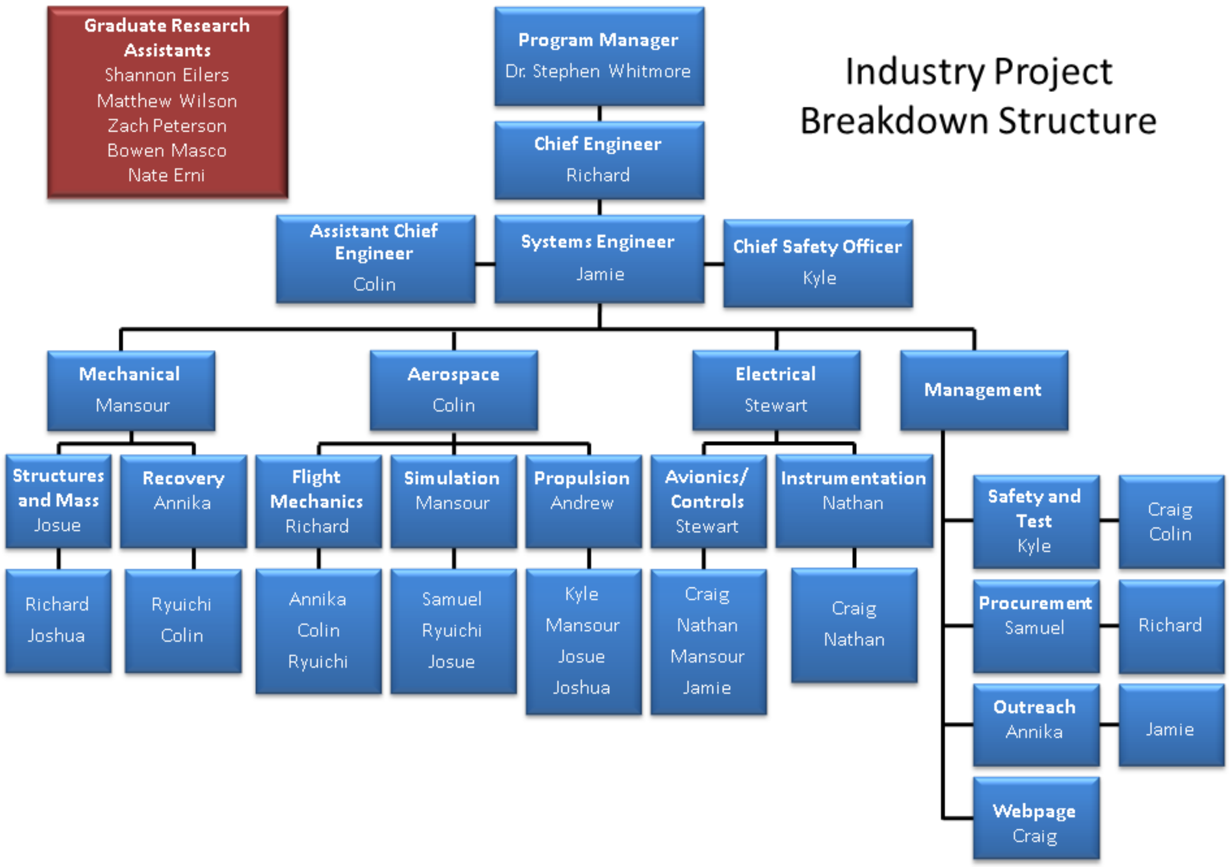


Figure 2: Industry project breakdown structure.

II.E. Launch Vehicle Summary

The Javelin has several major components and subsystems as seen in Figure 3. The bottom section of the rocket will have a solid motor propellant as well as the isentropic expansion ramps for the C-BAS. The C-BAS will be used to manage the total mass-specific energy of the vehicle to control achievable apogee altitude. The solid motor propellant has been limited to the Cesaroni L820, with the AMW L777 as a backup. Both the solid motor and C-BAS will be tested to verify their available impulse levels are sufficient to meet mission objectives. The avionics section is located near the front end of the rocket just behind the nosecone and will house flight instrumentation. The avionics suite will include an inertial measurement unit (IMU), two pressure-based altimeters, and a three-axis magnetometer. Navigation data are processed in a small on-board avionics computer to continuously estimate the total specific energy and potential altitude of the vehicle. The flight computer also operates the energy management system. Additional flight instruments will include the C-BAS plenum pressure and expansion ramp surface pressures. The two pressure altimeters, PerfectFite MAWD and R-DAS, are used for dual redundant deployment of the recovery systems parachutes. The PerfectFlite altimeter also provides the official measurement of the achieved altitude, for which the team is judged in the USLI competition. The avionics suite will be discussed in detail later in this design document. The rocket body has been limited to two materials for the main body tubing. The team is considering Blue Tube 2.0[c] and carbon fiber tubing. Tests are currently being performed to further identify which one would work best for the team's needs.

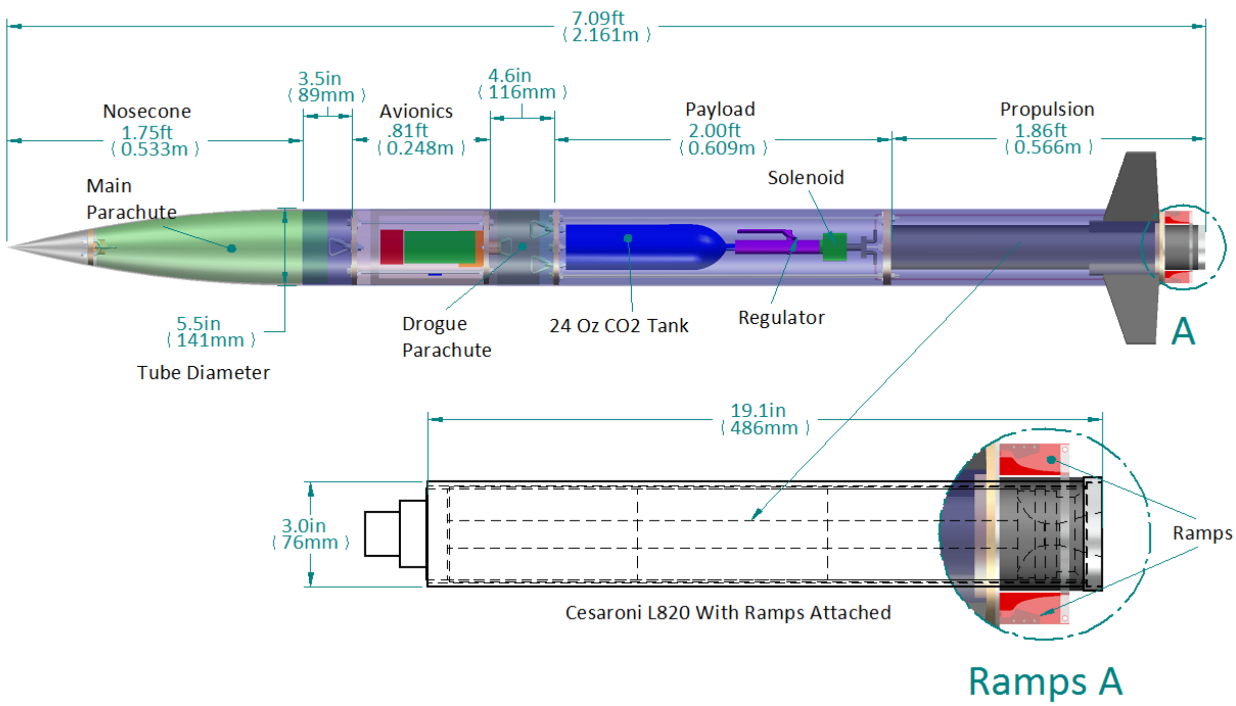
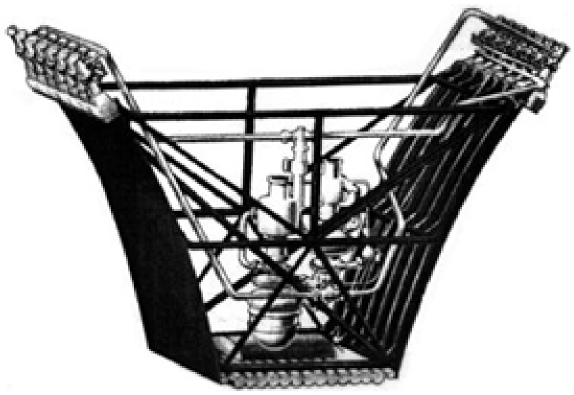


Figure 3: Overview of the Javelin Rocket.

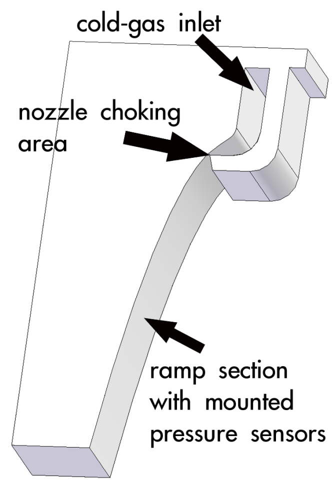
[c]Blue Tube is a high-strength tube originally developed by Always Ready Rocketry, details can be found at http://www.apogeerockets.com/blue_tubes.asp

II.F. Payload Summary

The Javelin payload is a cold-gas energy management system based on aerospike nozzle theory. While the aerospike[d] nozzle has long been known for its altitude compensation ability for endoatmospheric flight, its unconstrained plume is ideal for integration into the Javelin airframe structure. Here the aerospike-derived isentropic expansion ramps are "wrapped around" the primary solid motor core and add negligible aerodynamic drag to the external configuration. The Javelin design will use a solid propellant primary rocket motor, which will expectedly get the vehicle close to the desired one mile altitude. During flight, however, the vehicle will lose energy due to drag losses. At different waypoints during flight, the on-board avionics will calculate the energy lost from drag and execute the C-BAS, raising the overall energy level of the rocket. Raising the overall energy level will augment the rocket's projected apogee altitude. The ramp pressure measurements will be a first-ever measurements of in-flight plume-induced compression for an over-expanded aerospike nozzle. These measurements can be analyzed post flight for increasing accuracy in later flights and further our understanding about the aerospike nozzle. Figures 4a and 4b show the comparison of the conventional linear aerospike nozzle and the isentropic expansion ramps the Javelin will have for the C-BAS which is formed using the concepts of linear aerospike theory.



(a) Conventional Aerospike Nozzle.



(b) Isentropic Expansion Ramp Model.

Figure 4: Comparison of isentropic nozzle ramp to linear aerospike.

[d]The linear aerospike was developed and tested for the X-33 and can be researched at http://www.nasa.gov/centers/marshall/news/background/facts/aerospike.html

II.G. Selection, Design, and Verification of Launch Vehicle

II.G.1. Introduction and Mission Statement

The Chimaera Team's mission is to design and build a recoverable, reusable rocket that will carry an engineering payload to an altitude of no more than one mile and collect valuable in-flight data from the engineering payload. This objective will be achieved by thorough design and testing of the rocket. A key feature of the Javelin is a base-bleed energy augmentation system. This system, composed of mechanical CO_2 base-bleed hardware, associated avionics, and energy management algorithms will serve as the engineering payload for this project.

The CO_2-based system will vent the cold inert gas through a novel insentropic expansion ramp, patterned after a linear aerospike nozzle. This sophisticated energy management system can increase and regulate the apogee altitude. Sensors mounted on the ramp will obtain important first time, in-flight pressure data on the linear aerospike-type expansion ramp.

II.G.2. Requirements and Mission Success Criteria

Design requirements for the Javelin come from three primary sources: competition specified conditions, safety codes, and team-specified design requirements. The most fundamental design requirements governing the design of the rocket are shown in Figure 5. The top-level USLI rules mandated by the competition are strictly observed in the design and construction of the rocket. The NAR and NFPA codes regulate the launch of any and all high-power rockets. Beyond these outside design requirements, the team has determined additional requirements that will govern the specific design of the Javelin.

Success criteria for the Javelin is based on three factors: 1. Achieving an altitude within 10 meters of a mile; 2. Successful deployment of the parachutes and recovery; 3. Gathering good in-flight pressure data along the isentropic expansion ramp. Fulfilling these criteria will constitute a successful USLI launch of the Javelin.

Summary of Key Requirements	Source
Rocket shall not fly higher than 5600 feet AGL	USLI
Rocket shall carry scientific payload	USLI
Rocket shall be recoverable and reusable	USLI
Rocket shall land within 2500 ft. of pad	USLI
Cost of flight hardware and payload shall not exceed $5000	USLI
Students shall do all critical design and fabrication	USLI
Team shall use launch and safety checklists	USLI
Propulsion Requirements • Shall use commercially available certified motor • Total cold-gas impulse less than 320 N-s • Cold gas thrust less than 80 s – NFPA 1122 Code for Model Rocketry – NFPA 1127 Code for High Powered Rocketry	USLI, NFPA
The rocket shall get within meters of the one mile target altitude • 95% confidence level to resolution of primary sensor • Shall not exceed one mile	USU
The cold gas CO_2 components shall fit within the rocket case (drag minimization)	USU
The rocket shall launch from a rail with velocity no less than 15 m/s	USU
The structural members shall have a 2.5 factor of safety	USU
Shall gather first time in-flight 2D aerospike surface pressure data	USU

Figure 5: Overview of key requirements.

II.G.3. Major Milestone Schedule

As the design progresses, the major milestones and critical path items become more apparent. For all design activities there is an initial trade study performed to facillitate decisions, and a later high fidelity and verification phase to ensure the requirements are met. The major milestones are depicted in Figure 6. The milestones are grouped according to category, and displayed in-line with similar type milestones. They are then linked to their successors with an arrow.

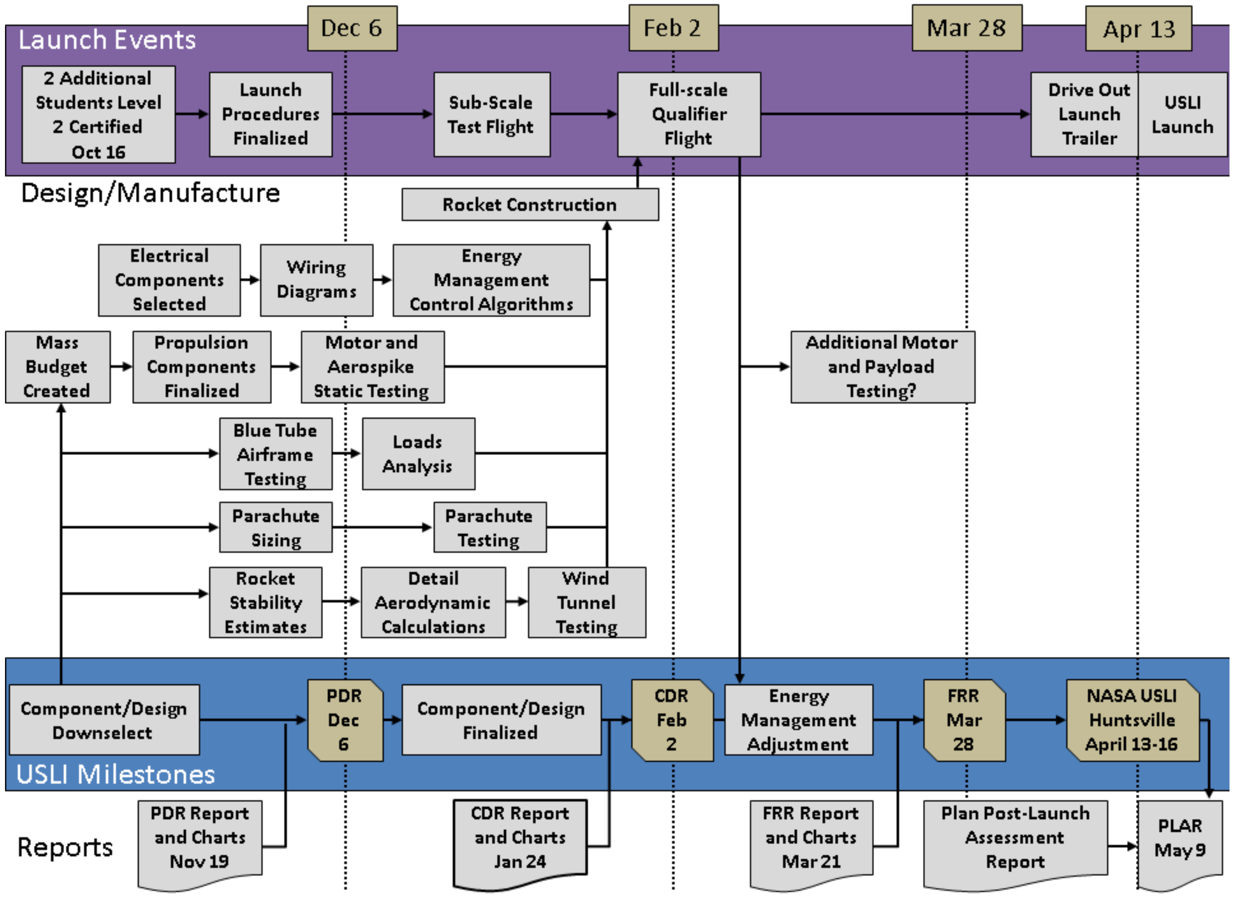


Figure 6: Milestone map.

II.G.4. Mission Concept of Operations (CONOPS)

The Javelin is designed to reach, without exceeding, the mile altitude required by the USLI competition. The competition guidelines specify that launch teams must use a National Association of Rocketry (NAR) certified, commercially available, hobby rocket motor for the main boost element of the vehicle. Hobby rocket motors are not as well characterized as professionally-certified motors, and total impulse among a particular type or class of motors can vary by as much as 20 percent. An impulse variability of 20 percent results in an apogee altitude error in excess of 300 meters. Consequently, the USU design team determined that the motors were not precise enough to achieve the desired apogee by ballasting the rocket.

Previous USU entries into the USLI competition solved this problem with a closed-loop energy management system that used air brakes to modulate the total energy of the rocket. The design philosophy was to "aim high" and then bleed off energy using four deployable and retractable airbrakes mounted circumferentially near the rocket boat tail. The brakes were deployed at prescribed waypoints, and the energy management system running on the onboard avionics flight computer determined the deployment times.

The previous energy management system consisted of airbrakes, an inertial navigation algorithm, and an asymptotic guidance algorithm. Navigation sensors include an inertial measurement unit (IMU), a pressure-pressure based altimeter, and a single-axis magnetometer. Following the motor burnout, the navigation data were processed in a small onboard avionics computer using a Kalman filter to continuously estimate the total specific energy and drag coefficient of the vehicle (based on a ballistic trajectory). At each waypoint the airbrake deployment times depended on the estimated potential altitude. The target total energy state was approached from above.

Because of newly established launch-range safety restrictions, the USLI scoring rubric for the altitude prize has been significantly modified to severely penalize teams that exceed the one mile altitude limit. Furthermore, any rocket exceeding the target altitude by more than 100 meters will be disqualified from the competition. Thus the previous "aim high" strategy is far too risky with regard to the competition rules, and has been replaced by an "aim low and boost" strategy. The airbrakes are to be replaced with small aerospike-based expansion ramps, and energy is added instead of depleted, allowing the desired energy state to be approached from below. Figure 7 shows this concept of operations (CONOPS).

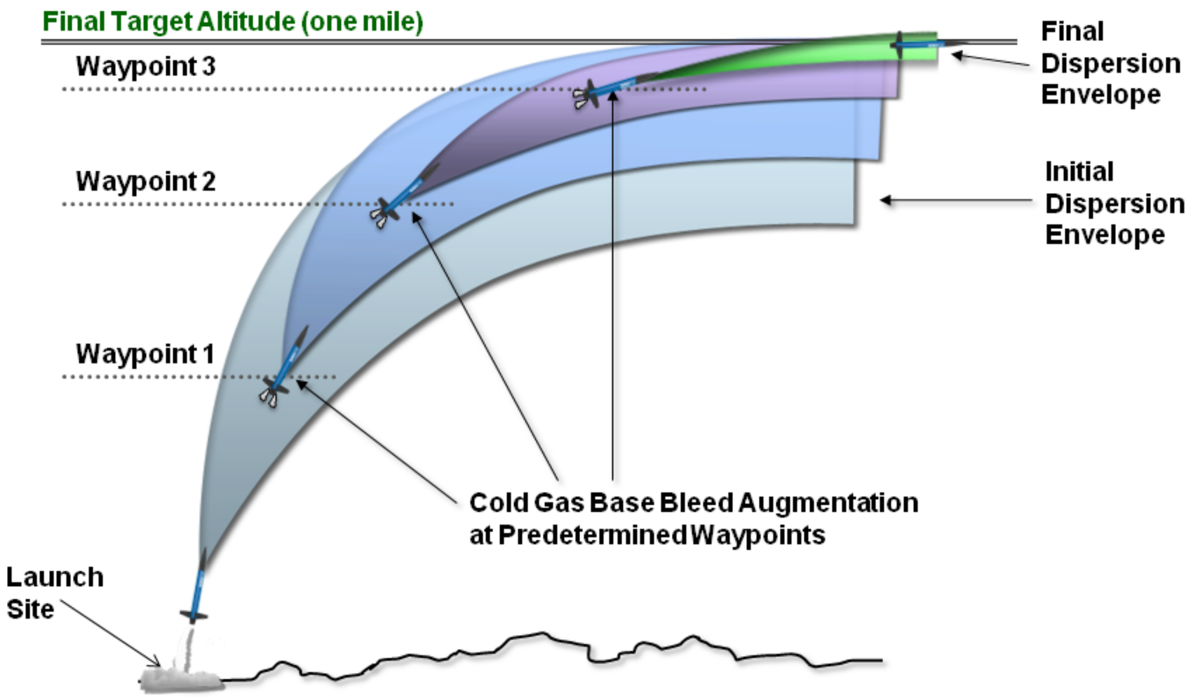


Figure 7: Concept of operations.

The Javelin will use an L-class impulse solid rocket motor to boost the launch vehicle to a projected altitude 50-150 meters below the one mile altitude. At certain altitude ranges along the trajectory, the C-BAS will rapidly expel the inert ballast CO_2 through the isentropic expansion ramp and thereby increase the potential energy in the rocket, using principles of momentum flux. This increase in energy adds to the altitude potential of the rocket. By carefully maintaining how much CO_2 is expelled, the rocket can hone up to the target apogee altitude.

This process will be carefully studied and refined, to make it most efficient. The system will be governed by a robust, time-optimal, control algorithm. If the energy management system executes too early in the flight, the potential altitude gain will be completely absorbed by an increase in drag loss. If activated too late, there will not be enough angle and velocity to make up the distance to target apogee. High-fidelity analysis performed before CDR will outline the final details of this process. The following sections will discuss the component designs that are needed to safely fly and recover the payload.

III. Selection, Design, and Verification of Launch Vehicle

III.A. Airframe and Structural Design

The structures team is responsible for providing an economical and durable rocket body and tracking the evolving mass properties including center of gravity location and moments of inertia. Figure 8 shows the overall structure integrity for the Javelin. The avionics are enclosed by a bulkhead on each side of the avionics section. The motor section is also capped with a bulkhead. The motor is held in place using a slimline motor retainer. The slimline motor retainer avoids extra drag, it's a simple design, and it's low cost The parachutes are attached to the nosecone and the bulkheads transmitting opening loads. Figure 8 also shows the C-BAS integrated into the boat tail. The 2009 Chimaera team's work suggests that increased accessibility to the rocket's payload and avionics bays is necessary, so larger access doors will be designed along the rocket to ease accessibility.

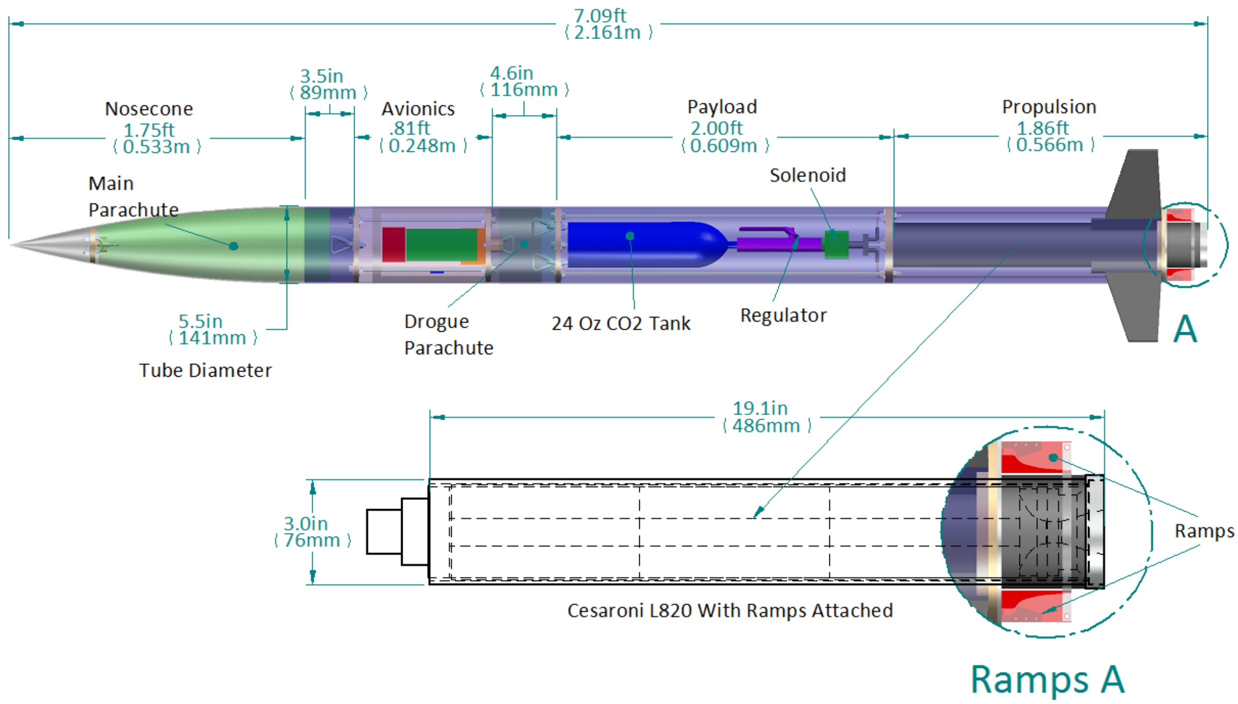


Figure 8: Javelin structure integrity.

III.B. Load Structure

In considering the load events, the primary compressive loads are transmitted along the structure from motor and cold gas augmentation system. Figure 9 shows the integration of the expansion ramps with the main motor nozzle and retainer. The isentropic expansion ramps will be attached to the wood bulkhead in the bottom of the Javelin. In addition, a thin aluminum plate and a small clamp will be used to ensure axial alignmnet of the ramps. When the cold-gas system is deployed, the expansion ramp will need to withstand a maximum pressure of 400 psi. Both static and finite element analyses will be conducted on the ramps to see the deflections of the material and eventually improve it if necessary. An internal structure is necessary to transmit loads throughout the rocket. The opening loads of the parachutes are transmitted through the bulkheads of the avionics structure and the payload section. Stress concentrations due to the bulkheads and the avionics structure will be of particular interest. The avionics support structure will be analyzed to verify that is capable of withstanding the loadings as the recovery system is deployed. All components will be designed with a 2.5 factor of safety. Key components will be proof tested at 1.25 times the calculated ultimate design load (UDL).

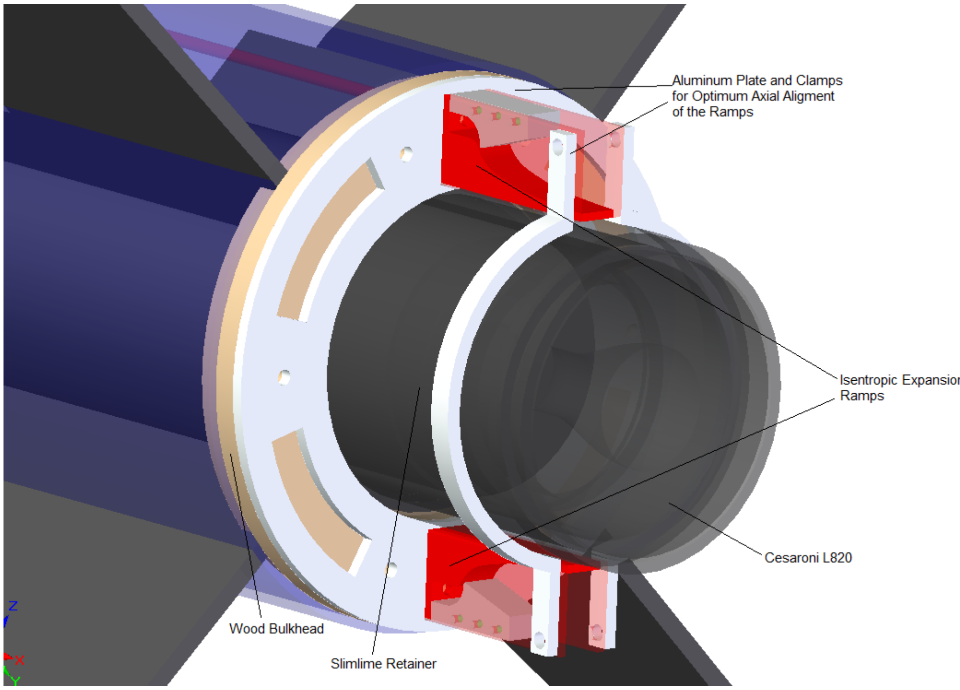


Figure 9: Integration of C-BAS expansion ramps into vehicle base area.

Figure 10 shows the threaded rods supporting the avionics bay. Finite element analysis will be performed on the supporting rods for deciding which material to use for the threaded rods and then structural tests will be performed to verify the finite element analysis. The bulkheads and the avionics structure will be tested with a tensile test to verify they can support the recovery loads with a given safety factor.

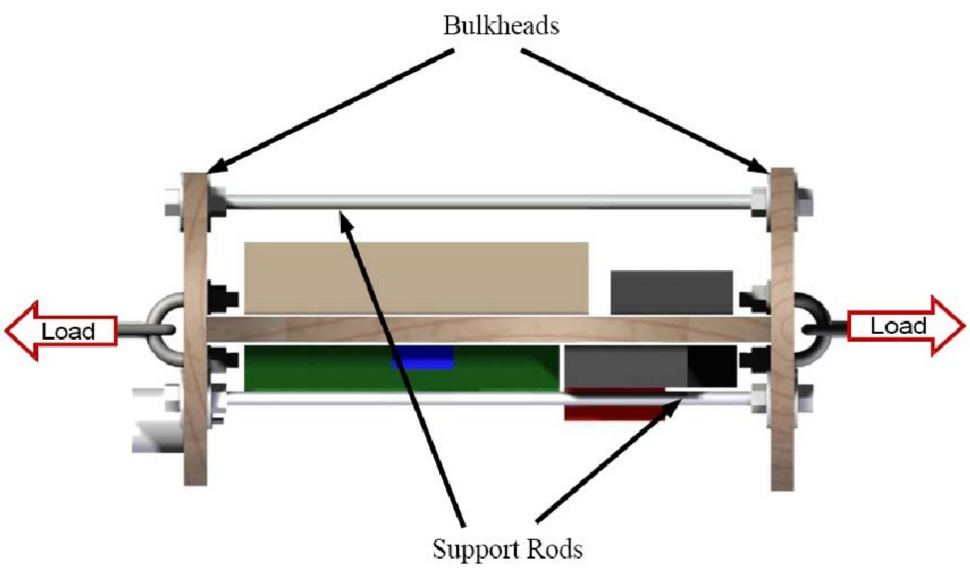


Figure 10: Avionics bay support rods.

III.C. Analysis and Testing

A compression test will be performed on the Blue Tube 2.0™. The maximum load that the tube must withstand is 126.688 kg (279.299 lbs). Figure 11 shows the body tube test stand where the Blue Tube 2.0™ will be tested. Sand bags will be placed on the top board to approximate the ultimate load. The result of this test will be to determine how the material reacts to compression loads given a maximum G load.

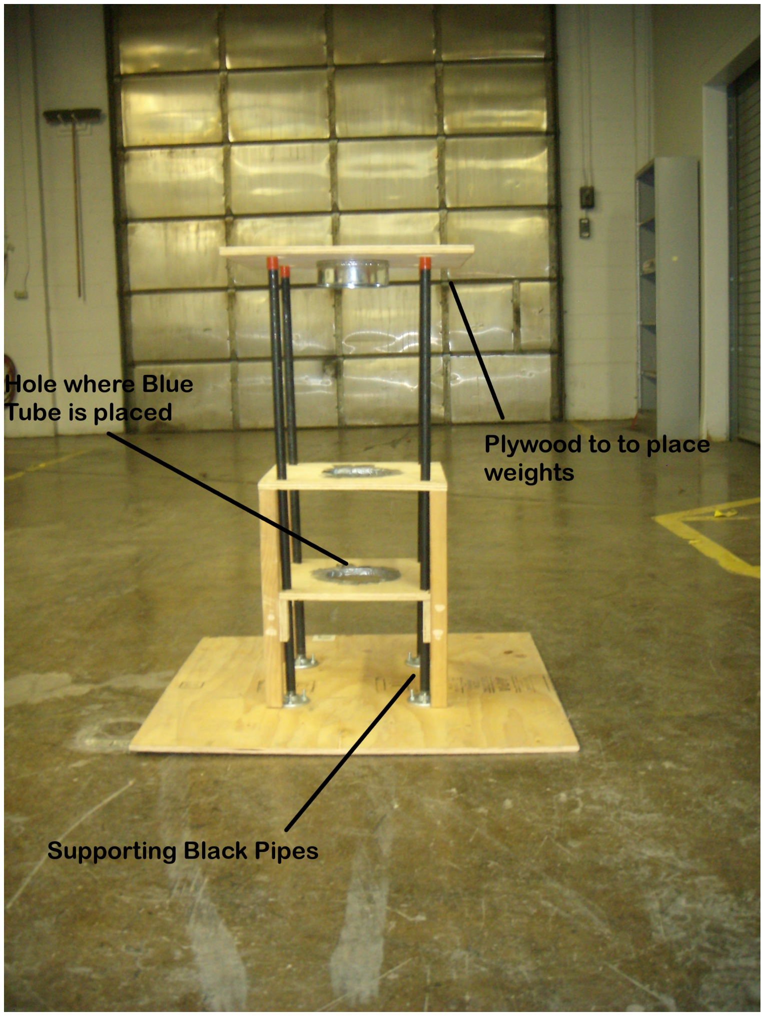


Figure 11: Body tube test stand.

III.D. Mass Budget

The external dimensions and mass breakdown of the Javelin were derived using the 2009 Chimaera rocket design as a starting point. These starting estimates were subsequently modified to account for components unique to the current design. The length of the solid rocket motor being considered is 486 mm (19.13 inches). The length of the 24 oz CO_2 tank being considered is 304.8 mm (12 inches). The overall estimated clean mass, or everything excluding the propellant mass of the Javelin, is 8.777 kg (19.35 lbs). The estimated total launch weight of the Javelin is 13.778 kg (30.37 lbs), and the projected length is 2.161 m (7.09 ft). Figure 12 shows the team's most current projected mass budget divided for different sections of the Javelin.

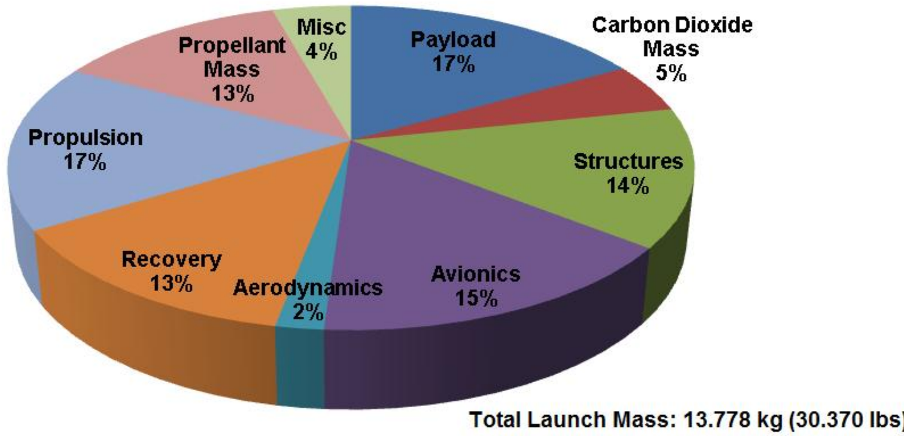


Figure 12: Projected mass budget.

Carbon fiber and Blue Tube 2.0™ are still the two options considered for the airframe design, as seen in Table 2. The biggest differences between these two materials are their strength and price. Blue Tube 2.0™ is a new material for this year's team. Due to the infamiliarity about this material, a 48 inch tube was purchased so that tests can be conducted prior to final decision.

Table 2: Tubing comparison.

Tubing	Tensile Strength (MPa)	Density (g/cm^3)	Price ($/48in)
Carbon Fiber	4000	1.75	312.00
Blue Tube 2.0	110.3	1.20	54.95

III.E. Recovery Subsystem

A dual, redundant recovery system will be used on the Javelin. The primary controller will be a PerfectFlite altimeter, backed up by an R-DAS. When either altimeter senses apogee, it will send a signal to the electronic matches, which will separate the avionics bay from the main airframe, deploying the drogue parachute. Figure 13 shows the functional block diagram of the parachute deployment system. Under the drogue parachute, the rocket will descend at a design rate of 50 ft/s (15.24 m/s). In order to reduce drift, but slow the rocket enough for a safe landing, the main parachute will be deployed at approximatley 300 m (92 ft) AGL, reducing the design descent rate to 17 ft/s (5.2 m/s). A milestone map detailing the steps of the recovery system design is shown in Figure 14. The team has begun analysis to determine parachute opening loads on the rocket, as well as horizontal wind-drift rates.

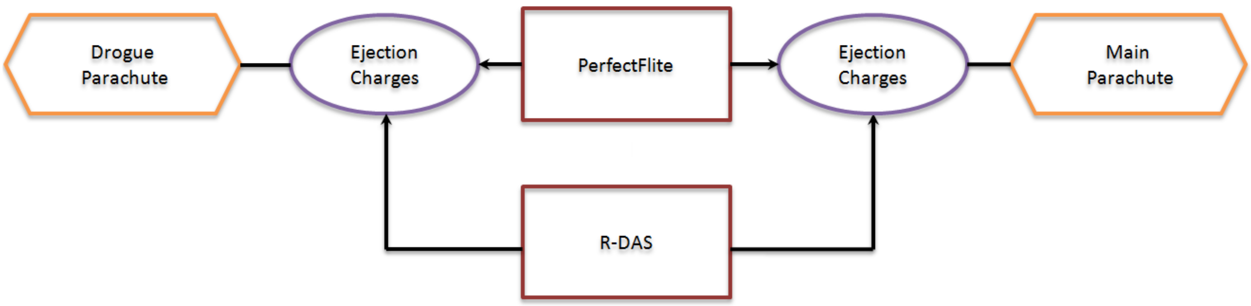


Figure 13: Functional block diagram of parachute deployment system.

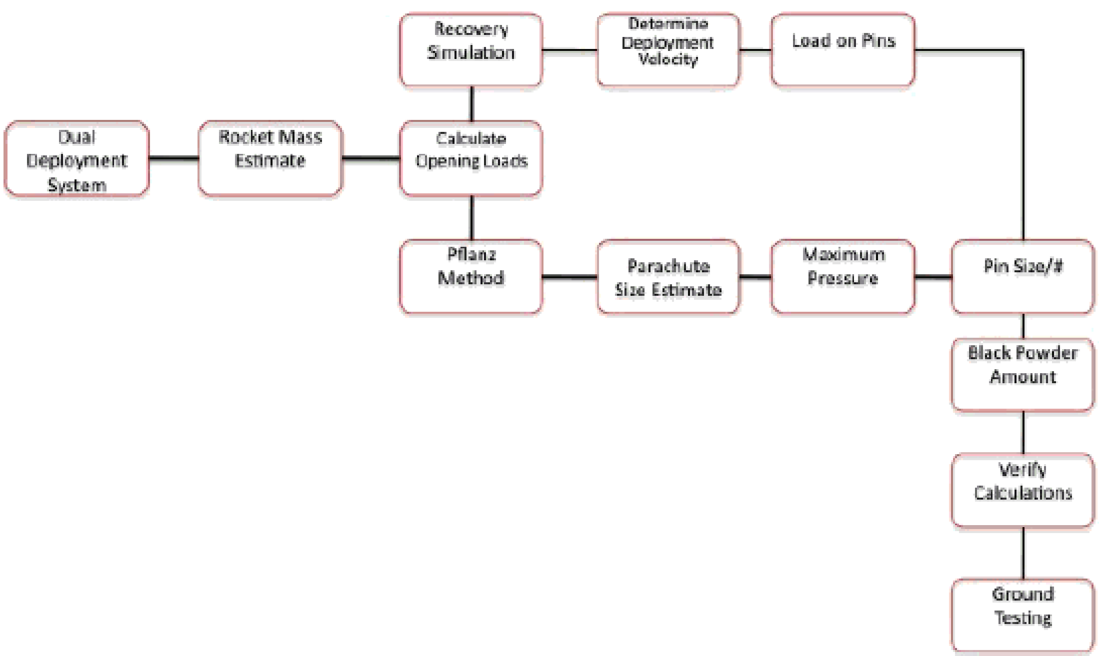


Figure 14: Recovery subsystem design milestone chart.

III.E.1. Parachute Sizing

The first step in the recovery subsystem design process was to determine the sizes of the parachutes. This was done using the terminal velocity method. The team used the minimum allowable descent rates as the desired terminal velocities under the parachutes. The team has decided to use conical parachutes because of their stability, drag capabilities, and successful use by former USU rocket teams. The reference area of the parachute was calculated by

$$A_{refp} = \frac{\frac{2mg}{V_t^2 \rho} - 2C_{dor}A_{refrock}}{C_{dop}} \tag{1}$$

where m is the mass of the rocket upon descent, ρ is the air density at deployment altitude, V_t is terminal velocity under the parachute, C_{dop} and C_{dor} are coefficients of drag for the parachute and rocket, respectively, and A_{ref} and A_{refr} are the reference areas of the parachute and rocket, respectively. The drag coefficient is 0.8 for conical parachutes, and the drag coefficient of the Javelin is 0.35. The reference area of the rocket, 0.015 m^2, is multiplied by two because the rocket will be in two pieces under the drogue parachute. It is multiplied by three when calculating the area of the main parachute. The mass for the initial analysis was 11.58 kg, which is the launch mass of the rocket, minus the mass of the motor propellant and the mass of the used cold gas.

III.E.2. Opening Loads

Pflanz's Method[3] was used to determine opening loades of the parachute. First, the inflation time of the parachute was found with the equation

$$t_{inf} = n\frac{D}{V_{op}^{0.85}} \tag{2}$$

where n is the canopy fill constant, V_{op} is the velocity of the rocket as the parachute opens, and D is the diameter of the parachute. The canopy fill constant for elliptical parachutes is four. The opening velocity for the drogue parachute was estimated to be no more than 42.93 m/s. This estimate is based on the velocity that the rocket would reach after four seconds of free fall. It was decided that, should the drogue parachute fail to deploy at apogee as planned, it would take no more than four seconds for the responsible team member to recognize this fact and deploy the drogue parachute manually. Next, a ballistic paramter, A_b, is found using

$$A_b = \frac{2mg}{(C_dS)_p \rho V_{op} t_f} \tag{3}$$

where S is the parachute surface area and C_d is the combined drag coefficient of the rocket and parachute. With this A_b , Figure 15 was used to determine X_1, the force reducing factor, for conical parachutes, assuming a parachute fill constant of n=1. The peak opening force, F_p, was then calculated using

$$F_p = (C_dS)_p q_{1,} C_x X_1 \tag{4}$$

where q_1 is the dynamic pressure at start of parachute inflation and C_x is the opening coefficient, which is 1.7 for conical parachutes. This force will cause stress on the plastic shear pins attaching the nose cone to the avionics section. The shear pins will be sized so that they are able to withstand this stress. Shear pin size and number will be determined when parachute size and rocket mass have been finalized. The amount of cold gas consumed throughout ascent will determine the mass of the rocket under the parachutes, which in turn affects the opening forces. Table 3 shows the recovery parameters for the most likely descent mass at 37 percent CO_2 consumption.

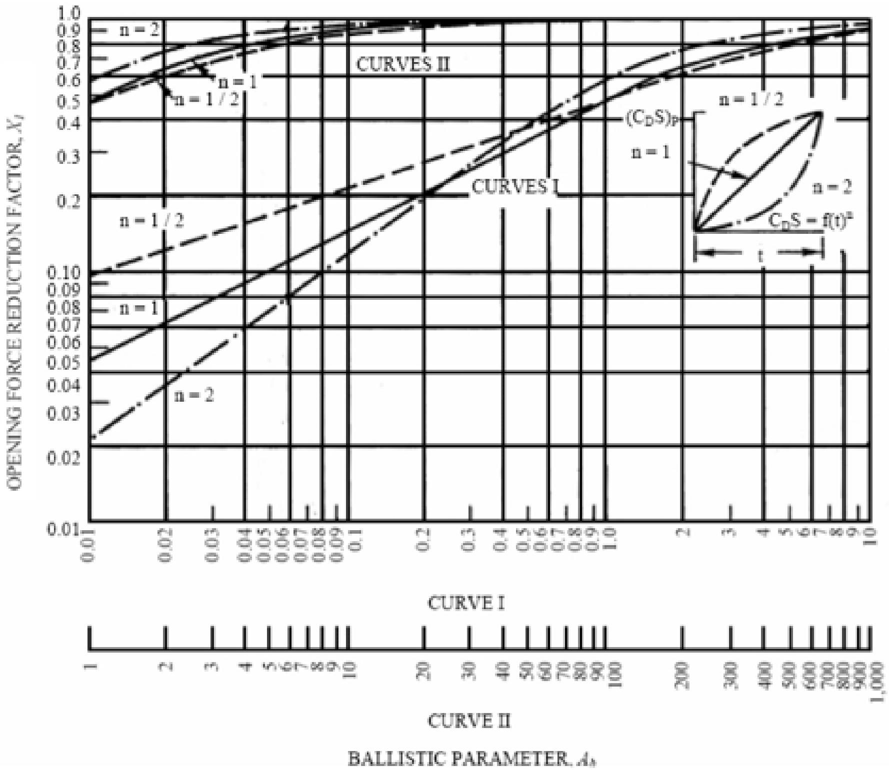


Figure 15: Opening load factor curve.

Knowing the forces exerted on the rocket upon deployment is critical to the design of a successful recovery system. The system will be proof tested for a factor of safety of 1.25. Once it has been determined the system can withstand a load 1.25 times that of the maximum possible opening load during test flights, the system will be designed for a factor of safety of 2.5 for competition, along with the rest of the Javelin.

Table 3: Recovery system parameters for 37 percent CO_2 consumption.

Parameter	Drogue Parachute	Main Parachute
Parachute Type	Conical	Conical
Deployment Altitude (m AGL)	300	300
Deployment Velocity (m/s)	42.93	15.24
Nominal Terminal Velocity (m/s)	15.24	5.2
Drag Coefficient	0.8	01‘.8
Reference Area (m^2)	1.167	10.189
Peak Opening Load (N)	801.90	297.16

III.E.3. Recovery System Failure Modes

Black powder involves a high risk of heat damage to other system components, but this will be prevented through careful packing procedures. A procedure developed by the 2009 rocket team for packaging the black powder will be adapted and used. Burn retardant material will be used on the harnesses, and no heat-sensitive components will be touching the charges. A summary of other possible failure modes and the team's proposed solutions are outlined in Figure 4.

Table 4: Recovery system possible risks and solutions.

Failure Mode	Design Location	Likelihood	Proposed Solution
Tangled Parachute Lines	Packing Procedures	High	Properly fold parachutes so lines will not cross on deployment
Torn Parachute	Opening Load	Low	Minimize opening loads, inspect housing to avoid snag points
Burned Parachute	Charges, Packing Procedures	High	Surround heat-sensitive parachute components in protective material and ensure charges are placed such that they do not touch unprotected areas.
Charge Failure	Charges	Moderate	Use redundancy in avionics. Store black powder in a dry environment. Check e-match wires for continuity.
Rocket Separation Failure	Shear Pins, Charges	Moderate	Use redundancy in avionics. Apply appropriate charge sizes.
Parachute Separation	Opening Load	High	Use harness materials capable of withstanding opening loads.
Excessive Drift	Parachute Size, Descent Rate	Moderate	Correctly size parachute, accurately predict descent rates.
Airframe Damage	Charges, Opening Loads, Descent Rate	Moderate	Accurately predict opening loads and charge sizes.

III.F. Trajectory Modeling and Simulation

III.F.1. Performance Analysis

The team developed deterministic and Monte-Carlo simulations to predict the flight path of the rocket using simulation tools MATLAB/Simulink and LabVIEW. Preliminary analysis determined that an L-class motor would be required for the Javelin design. The simulations account for aerodynamic drag, variable thrust due to atmospheric back pressure and launch rail characteristics. Prescribed time-varying or constant motor thrust profiles can be input to the model. The predictions of the MATLAB/Simulink and LabVIEW Simulation models are compared to verify the trajectory predictions.

Preliminary analysis for an L-class motor is required for the Javelin design. L-class motors have total impulse between 2560 N-s and 5120 N-s.[4] In order to simulate the rocket behavior using a specific L-class motor, a motor profile needs to be obtained for each motor from thrustcurve.org. After the motor list was obtained, several motors were selected using simple simulation for high fidelity design analysis. The high fidelity design analysis was completed for each selected motor using two different materials for tubing and three different types of energy augmentation. Figure 16 shows motor and design selection procedure.

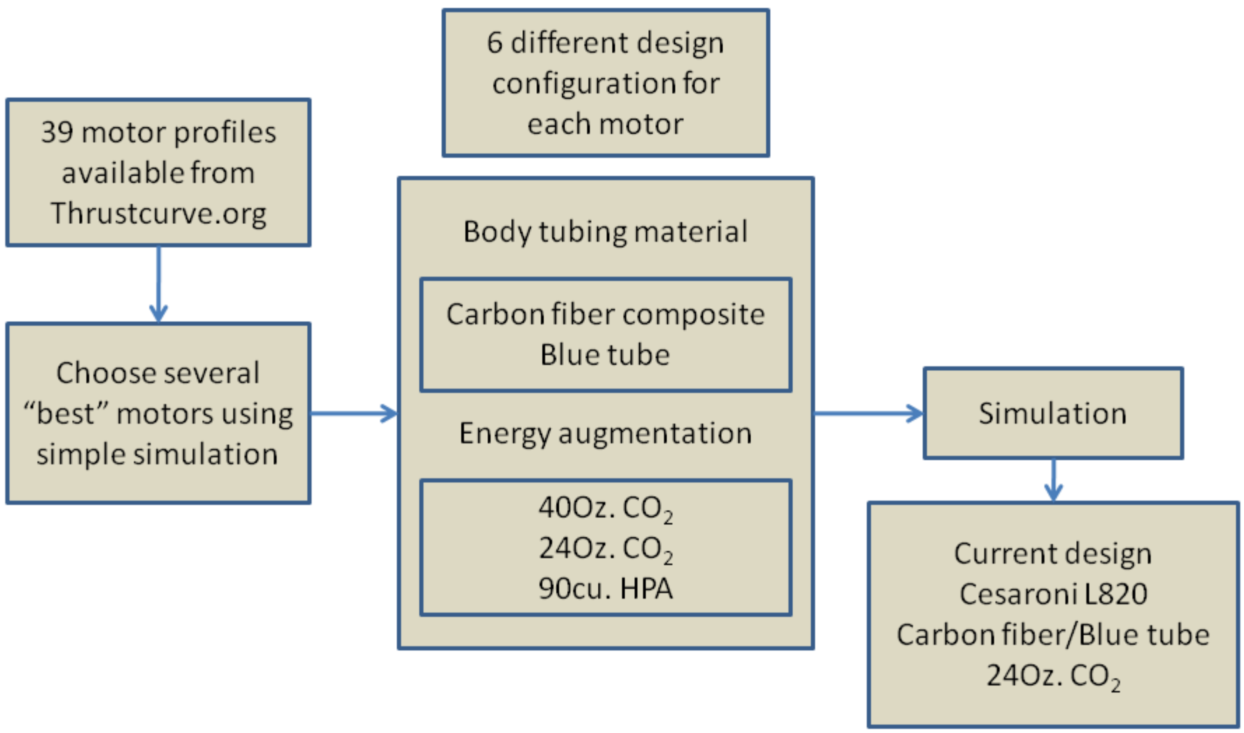


Figure 16: Motor and design selection procedure.

Based on the procedure in Figure 16, the current choice of the solid motor is the Cesaroni L820. Table 5 lists the properties of the down-selected Cesaroni L820 solid rocket motor used for the simulations.

Table 5: Cesaroni L820 Solid Rocket Motor Properties

Diameter	75mm
Length	486mm
Average Thrust	820 N
Total Impulse	2945 Ns
Cost per Reload	$185
Projected Maximum G load	7.4G's

Table 6 shows status for each body material and augmentation system.

Table 6: Possible choices for high fidelity design analysis

Body tubing material	Carbon fiber	Blue Tube 2.0™
Weight per length	1.258 kg/m	1.009 kg/m

Energy augmentation	40 oz. CO_2	24 oz. CO_2	90 cu. in. High Pressure Air
Tank mass	2.95 kg	0.90 kg	1.36 kg
Propellant mass	1.13 kg	0.68 kg	0.55 kg

For current optimal design, Blue Tube 2.0™ was chosen because of its lower mass fraction compared to carbon fiber. The 24 oz CO_2 will be used with Cesaroni L820 motor for current optimal design. The LabVIEW simulation accounts for base bleed energy augmentation, assuming CO_2 as the cold gas with total 40 N of thrust and 50 s of specific impulse. Table 7 lists the parameters used in these simulations to plot the trajectory profiles of Javelin.

Table 7: Table of Parameters Used in Simulation Analysis

Condition	No Augmentation	With Augmentation
Launch Mass (kg)	13.40	13.40
Main Motor Burnout Mass (kg)	1.76	1.76
Vehicle Drag Coefficient	0.35	0.35
Reference Area (m^2)	0.0156	0.0156
CO_2Mass (kg)	0.68	0.68
Estimated Specific Impulse (s)	N/A	50
Available Augmentation Thrust (N)	N/A	40

Figure 18 shows the rocket trajectory data for current design without and with energy augmentation system

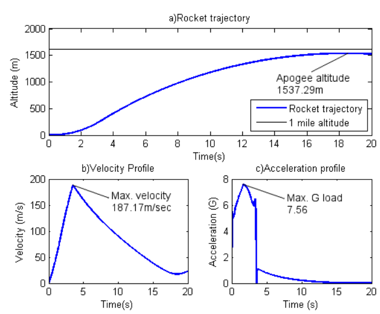


Figure 17: Rocket simulated trajectory with C-BAS inactive; a)Altitude, b)Velocity, c)Acceleration profiles

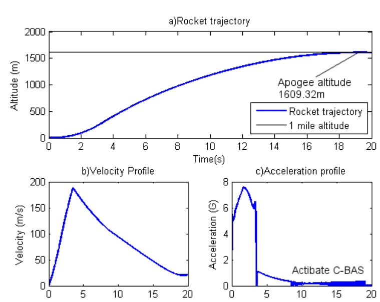


Figure 18: Rocket simulated trajectory with C-BAS active; a)Altitude, b)Velocity, c)Acceleration profiles

Figures 17 and 18 plot the predicted altitude, velocity, and acceleration time histories, with and without thrust augmentation. A simple but effective pulse-width modulation algorithm uses the C-BAS to manage the energy of the vehicle once the aerodynamic drag drops below the available augmentation momentum flux level. Key to the energy management is the potential altitude of the vehicle, derived from the sum of the gravitational potential energy and kinetic energy in the vertical direction. At any point along the trajectory the sum of the mass-specific potential energy is given by

$$\left(\frac{E}{M}\right)_{total} = gh + \frac{V^2}{2} \tag{5}$$

The total specific energy at apogee is related to the energy at any time following motor burnout by

$$\left(\frac{E}{M}\right)_{total} = gh + \left(\frac{V^2_{horizontal}}{2}\right)_{apogee} = gh + \left(\frac{V^2}{2}\right) - \int_t^{t_{apogee}} \left[\left(\frac{1}{2}\rho V^2\right)\left(\frac{C_D A_{ref}}{m}\right) V\right] dt \tag{6}$$

The last term on the right hand side of Equation 6 is the energy depleted by drag forces action on the rocket. For ballistic trajectories with a nearly vertical initial launch angle, the horizontal velocity of the rocket at motor burnout remains approximately constant throughout increasing altitude, and Eq.6 can be rearranged to predict the rocket's apogee altitude based on the energy state estimated at any point along the trajectory.

$$h_{apogee} = h(t) + \frac{(V(t)\sin\gamma)^2}{2g} - \int_t^{t_{apogee}} \left[\left(\frac{1}{2}\rho V^2\right)\left(\frac{C_D A_{ref}}{m}\right) V\right] dt \tag{7}$$

where $V(t)\sin\gamma$ is the vertical component of velocity. Neglecting the effects of aerodynamic drag, the potential altitude is defined as

$$h_{potential} = h(t) + \frac{V^2_{vertical}(t)}{2g} \tag{8}$$

Clearly, as apogee is approached and the overall vehicle drag diminishes because rocket velocity also diminishes, the potential altitude defined by Equation8 becomes an increasingly accurate predictor of the vehicle apogee altitude. If h_{min} is the altitude at which the drag drops below the available thrust level, and h_{target} is the target apogee altitude, then the augmentation algorithm is shown in Figure 19. The C-BAS will be turned on when altitude is between h_{min} and h_{target}, and $h_{potential}$ is lower than h_{target}. Otherwise the C-BAS will be turned off. Other more-fuel optimal algorithms are currently under development and will be presented in the final publication.

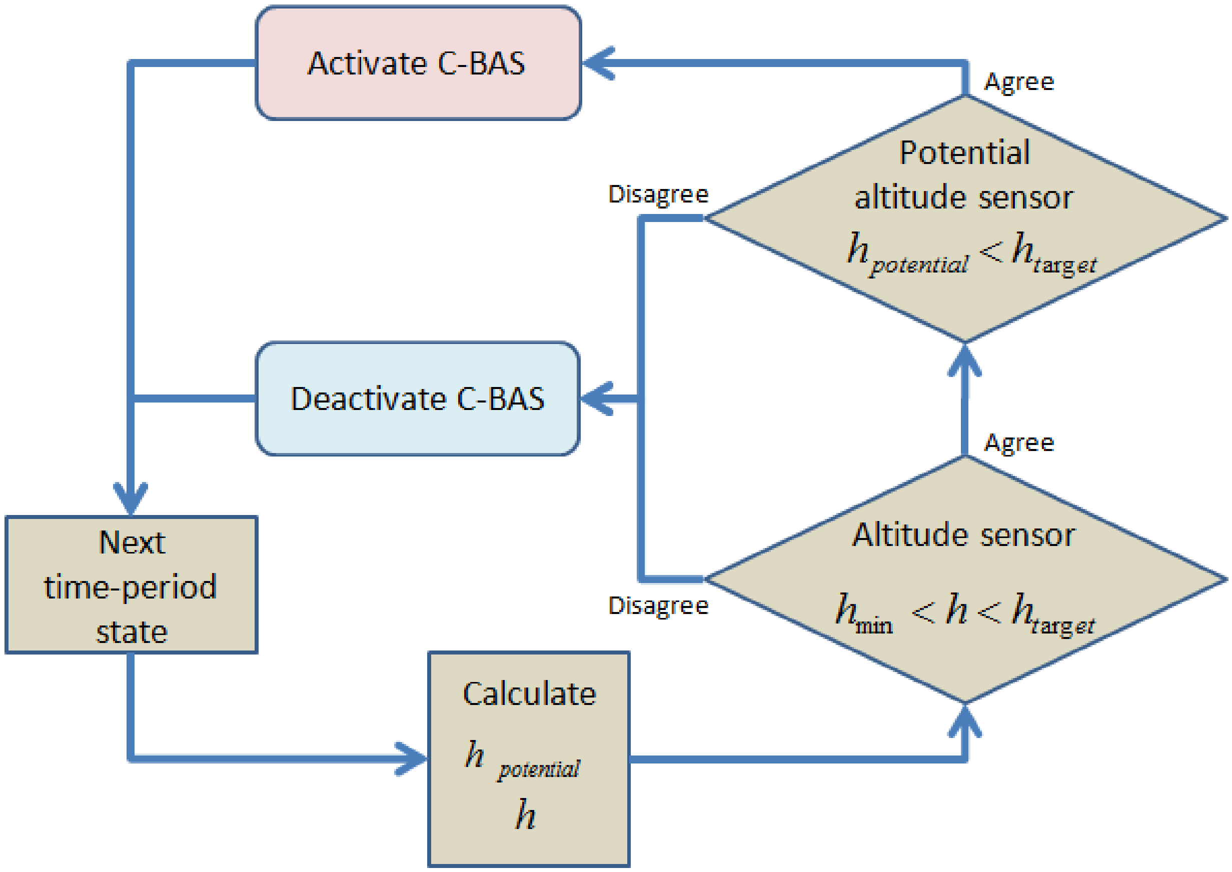


Figure 19: C-BAS algorithm for simulations

III.F.2. Aerodynamic Performance and Stability

Static and dynamic flight stability of the Javelin is one of the key factors for a successful launch. Static stability means that as the rocket travels through the air a disturbance will not cause the rocket to lose control and tumble. Instead, lift acting at the center of pressure (C_p) behind the center of gravity (C_g) causes a restoring moment and the rocket remains facing into the oncoming airflow. Without the restoring moment due to lift on the vehicle, the rocket would never reach its intended target. As such, careful attention is given to locating and accounting for rocket stability.

The current center of pressure is located at 1.700 m and the center of gravity is at 1.336 m from the tip of the nosecone. The current design estimate has a static margin of 2.60 caliber. The static margin is measured by the caliber (the number of rocket diameters) that the center of pressure is located behind the center of gravity. One to two caliber is typically required for static stability. Greater than two caliber can cause the rocket to weathercock into the crosswind causing an undesirable angle of attack or an overly stiff system, giving rise to dither drag.

The initial estimate of the center of pressure comes from the Barrowman Equations.[6] These equations provide a straightforward method to calculate the center of pressure, assuming small angles of attack. The C_p result from the Barrowman Equations is not only reliable, but provides a method to quickly adjust the rocket fin dimensions for the desired stability margin. As the design progresses, more Missile DATCOM, an industry standard software program will be used for a higher-fidelity calculation of the aerodynamic calculations. This will allow the team to more accurately model the Javelin's performance and fine-tune the C-BAS system. All of these value will ultimately be verified in a wind tunnel so the analytical solutions can be compared with real testing data.

The center of gravity calculation locates the center of mass based on the weights of all the individual components. The center of mass will change during the flight as the motor burns and the ballast CO_2 is released, so the center of mass will be calculated for every instant during the flight. Table 8 shows the possible failure modes for this aerodynamic design.

Table 8: Possible modes of failure for the aerodynamic design.

Failure Modes	Rocket Reaction	Likelihood	Mitigation
Rocket becomes unstable	Rocket could crash	Low	Ensure accurate center of mass location, and perform wind tunnel testing to verify C_p, understand effects of fin misalignment
Rocket is over stable	Rocket will not too far into crosswind	Moderate	Verify that the speed of the rocket leaving the launch rail is large enough to minimize weathercocking, and utilitze simulator to measure the effects of fin size on stability, possibly lengthen launch rail
Incaccurate drag predictions	Insufficient Delta V to achieve 1-mile apogee	Low	Verify simulator drag results with wind tunnel testing, and preliminary flight measurements lighten mass, switch to higher impulse fuel grains

III.G. Launch Operation

III.G.1. Mobile Launch System

During both the competition and test flights, the Javelin will launch using the mobile launch rail system designed by previous Chimaera rocket teams. The mobile launch system incorporates a launch rail, motor test stand, and storage bins for transporting the Javelin and other support equipment. This is all mounted on a mobile, highway legal trailer. The 4.57 m launch rail and ARRX LOK truss are mounted to the trailer with steel pins. This allows the rail to be stowed horizontally on the trailer during transport and pivoted vertically during launch. The launch angle will be checked using an inclinometer. Adjustments to the launch angle will be made via adjustable jacks, as shown in figure 20, on either side of the trailer. The mobile launch system has undergone extensive operational testing to ensure that all launch requirements will be met and that the trailer will be capable of safely launching the Javelin.

To evaluate the safety of the mobile launch rail, the platform was tested to ensure the electrical connections will remain secure during transit. The launch rail has also been evaluated to ensure it will remain rigid, stable, and will not extend beyond vertical tolerances during launch. This year's team will improve the mobile launch system by designing and constructing a new launch controller to use during the tests flights of the Javelin. This new launch controller will extend the capabilities and reliability of the existing system. In addition to this the Chimaera team will perform the needed maintenance and safety checks to ensure the mobile launch system complies with all highway safety regulations.

Figure 20: Launch stand leveling jack.

III.G.2. Launch Procedures

The final assembly of the Javelin will be conducted using a series of checklists to ensure that everything is accounted for and the Javelin is prepared efficiently for a safe flight. The team will follow extensively developed procedures during launch, all of which will be performed with the use of multiple checklists as well. These checklists can be found in Appendix A.

III.H. Safety and Environment

III.H.1. Failure Mode Analysis

The team safety officer, Kyle Hodgson, is responsible for ensuring the safety plan is followed. Every effort is being made to ensure the safety of those involved in the fabrication, testing, and flight of the Javelin. This plan includes determining all possible failure modes of the rocket, payload integration, and launch operations. Many failure modes have already been identified and are included in Table 9. By understanding where the weak points are in the system, the team is better equipped to eliminate them through design and implementation of controls. The mission success of the Javelin is ensured by the identification of all possible failure modes.

The team gained critical experience in eliminating failure modes when Kyle and Colin built and flew rockets to obtain level II certification. The problems faced were:

- Ignition failure- While trying to launch a rocket for level I certification, the igniter was not properly installed and the motor did not ignite. The igniter had to be reinstalled and fastened to the rocket in a way that it could remain in the correct location for motor ignition.
- Motor retention- The selected motor retainer was not compatible with the rocket kit used. The fins for the rocket were attached to the motor tube too far aft and prevented the motor retainer from seating correctly. There was a chance for the motor casing to fall out of the rocket unless the team could develop a way to properly attach the motor retainer. The problem was solved by using a dremel tool to remove some of the material that was in the way. All components functioned nominally during flight.
- Parachute deployment- While a PerfectFlite was used for parachute deployment on most of the certification flights, a secondary deployment method was desired. The solution was to model the certification flights using the student built simulation to predict the apogee of the flight for the motors used. The ejection charges within the motor were then set to ignite shortly after the predicted apogee. Without incident, all certification flights had a successful parachute deployment and recovery.

Table 9: Failure modes of the rocket, payload integration, and launch operations.

Failure Modes	Possible Effect of Failure	Planned Mitigation
Rocket:		
-Motor retention failure	Motor and casing are blown out of rocket when parachutes deploy	Properly adhere motor retainer to body tube and motor tube
-E-matches do not light ejection charges (drogue and main)	Rocket descends too quickly and/or becomes unrecoverable	Manual override available to set off e-matches if they do not ignite at the correct times; Set main motor ejection charge with a time delay
-Main bulkhead blow-through	Motor tears through the rocket	Test the motor and design bulkheads to withstand 2.5 times the maximum load
Payload Integration:		
-Regulator malfunction	Incorrect amount of gas reaches the C-BAS	Test the cold gas system and regulator to ensure all components function properly
-Gas system o-ring failure	All of the gas leaks out of the system	Ensure o-rings are not bumped while installing
-Solenoid malfunction	Valve remains open or closed, not allowing the gas to be pulsed; improper cycling rate	Test the solenoid valve to determine reliability; see if it can cycle as quickly as needed
Launch Operations:		
-Ignition failure (igniter and launch system)	Rocket won't launch	Verify continuity before launch. Make sure batteries in the launch system are new
-Body tube test stand support failure	Test stand collapses	Install platform guides so the platform cannot tip when body tube fractures. Use a plexiglass shield to protect observers from falling/flying parts

III.H.2. Hazard Evaluation and Risk Mitigation

The Chimaera team will not accept any risk that will endanger the life of anyone, negatively impact the environment, or affect the flight-worthiness of the Javelin. As the team identifies the hazards inherent to the project, the hazards are added to a running list of safety issues, outlined in AppendixG. A level of risk is assigned to each hazard based on the likelihood and severity of each event occuring. Appropriate controls are applied in order to mitigate the risks to acceptable levels;

The team is aware of, and compliant with, all the National Association of Rocketry (NAR) requirements outlined in Appendix B. Contact information for USU Environmental, Health, and Safety personnel, as well as the Utah Rocket Club (UROC) contact person is listed in Appendix E.

The team plans to build on the rich history of safety established by years of experience building and testing amateur and high-power rockets at USU. The current team has inherited an extensive list of materials and procedures that has led to the safe and successful launch of many rockets. The safety protocols and launch procedures will be adopted with little if any modification.

Material Handling A solid rocket motor containing Ammonium Perchlorate Composite Propellant (APCP) will be used by USU in the USLI competition. Solid motors use compounds which have strict storage, handling, and transportation requirements. The team has access to facilities capable of storing APCP motors and other low explosives according to applicable laws. All students will be briefed on the risks associated with the propellant to ensure safe preparation and launch practices.

Black powder and electric matches will be used for recovery deployment. Material Safety Data Sheets (MSDS) for potentially hazardous construction materials are included in Appendix C. As other potentially hazardous materials are encountered, an MSDS for each will be obtained and made readily available in the areas where the materials are present.

EXPLOSIVES PERMITS Because the rocket design will include black powder charges, electric matches for recovery deployment, and an APCP motor, a low explosives permit is required. A Low Explosives User's Permit (LEUP) has been obtained through the Bureau of Alcohol, Tobacco, and Firearms (BATF) by Dr. Stephen Whitmore, the team instructor. The permit in Appendix D expires in March 2011. The team will renew or obtain a new permit before that time in order to remain compliant to all safety codes and regulations.

PURCHASE, SHIPPING, STORING, AND TRANSPORT OF MOTOR National Fire Protection Association (NFPA) 1127 and safety codes of both the National Association of Rocketry (NAR) and the Tripoli Rocketry Association (TRA) require that high-power motors be sold only to or possessed by certified users. This certification may be granted by a nationally recognized organization to individuals over 18 years of age who demonstrate competence and knowledge in handling, storing, and using such motors. High-power motors include all motors above F-class, and all motors that use metallic casings, including reloadable motors, regardless of power class.

The USU USLI rocket design will include an L-class, reloadable rocket motor. The Canadian Association of Rocketry (CAR), NAR, and TRA offer the certification required to use this type of motor. High-power rocket motors contain highly flammable substances, such as black powder or ammonium perchlorate, and are considered to be hazardous materials or explosives for shipment purposes by the U.S. Department of Transportation (DOT). The DOT regulations concerning shipment of hazardous materials is contained in the Code of Federal Regulations (CFR) Title 49, Parts 170-179. These regulations specify that it is illegal to send rocket motors by commercial carriers, or to carry them onto an airliner except under exact compliance with these regulations. NFPA 1127 Section 4.19 contains the storage requirements of motors over 62.5 grams. High-power rocket motors, motor reloading kits, and pyrotechnic modules are to be stored at least 7.6 m (25 ft) from smoking, open flames and other sources of heat.

Propellant for high-power rocket motors is subject to the storage requirements of 27 CFR 55. This states that propellant shall be stored in a type 3 or 4 indoor magazine, and that no more than 23 kg (50 lb) of propellant shall be stored in one location. The magazine shall be painted red and have the words "explosive-keep fire away" in white block letters at least 76 mm high on the top of the box. The motor must be stored without the ignition element installed. The vehicle used for transportation will not be left unattended with black powder or APCP inside it. No open flame or smoking will be allowed within close proximity of the vehicle containing the magazine. The magazine will be strapped down securely to the floor with fire resistant material. The doors of the vehicle leading to the magazine will be locked at all times. A CO_2 or foam extinguisher along with the MSDS sheets and the contact information of the safety officer and the designated personnel will be made available to the driver and the attendant accompanying the driver. A first aid kit for minor burns will also be made available in the vehicle. Whenever possible, rocket motors and black powder will be bought near the launch site to help mitigate the hazards involved in transporting these materials.

LAUNCH SITE SAFETY Before launch day the student team will receive training in hazard recognition and accident avoidance. On the day of launch the safety officer will conduct a systems safety check on the motor, payload, and recovery. A pre-launch briefing will be conducted with the team before each launch. The recognized hazards will be discussed, as well as methods for mitigating the hazards. Each launch site will be controlled by the local NAR section. The test launches will be overseen by the Utah Rocketry Club (UROC), while the Huntsville Area Rocketry Association (HARA) will regulate the competition launch. High-power rocket launches must comply with local, state and federal regulations. The Federal Aviation Administration (FAA) has specific laws governing the use of airspace during high-power rocket launches, as specified in 14 CFR 101. The local NAR section controlling the launch must notify the local FAA Air Traffic Control facility of the details of the launch. It is the responsibility of each rocket's operator to ensure that the launch is conducted within the operating limitations outline in 14 CFR 101.23.

HARA REGULATIONS Each member of the USU Chimaera team will sign a consent form, verifying that each understands the following: 1) HARA will conduct range safety inspections of each rocket before it is flown The

USU Chimaera team will comply with the inspection determination. 2) The HARA Range Safety officer has the final say on all rocket safety issues, and has the ability to deny the launch based on safety reasons. 3) If the team is in noncompliance with safety and mission assurance, the rocket will not be launched. The consent form can be found in Appendix F.

LEVEL II CERTIFICATION To purchase and use high power rocket motors, an individual must be certified by either the NAR or the TRA. The certification is designed to ensure that the high power motors are being used only for the purpose for which they were designed. Although there are three different levels of certification, the team requires only up to Level II certification for the USLI competition, which allows for the use of J-, K-, and L-class motors.

The certification process is designed to allow the candidate to demonstrate their understanding of the basic physics and safety guidelines that govern the use of high power rockets. Level II certification requires that one obtain Level I certification first; construct, fly and recover a high power rocket in a condition that it can immediately be flown again. Then to obtain Level II, a written exam that tests knowledge of rocket aerodynamics and safety is required. A 90% score is the pass rate for this test.

Shannon Eilers, a graduate research assistant working with the team, has previously obtained Level II certification. For the 2011 USLI competition, Kyle H. and Colin W. received Level II certification through the TRA on October 16, 2010. Tim Boschert, the Utah Tripoli Prefect, administered the written and flight tests. UROC obtained the waiver for the flights. The Level II certified persons will ensure that all members of the USU Chimaera team are aware of the risks of high-powered rocket launches, and will help create a safe launch environment.

Selection, Design, and Verification of Payload Experiment

As described in the introductory sections, the C-BAS will be the scientific payload on the Javelin. The primary objective of the C-BAS is to manage the energy state of the rocket at predetermined way-points by utilizing an on-board CO_2 system that will provide cold gas to an isentropic expansion ramp. This action will decrease drag and create momentum flux, which will increase the energy state of the Javelin and thus the potential altitude. The secondary objective of the payload is to prove that energy management can be accomplished by using an isentropic expansion ramp designed using linear aerospike nozzle theory. This allows for the collection of in-flight ramp pressure data. Because this kind of data has never been collected before, this payload is groundbreaking. In order to consider this rocket design and payload a success, meaningful in-flight ramp pressure data must be collected and logged for analysis, and the C-BAS must augment the energy state of the rocket sufficient to reach the desired altitude.

III.I. Pneumatic Components

The pneumatic components consist of a carbon dioxide (CO_2) tank, pressure regulator, solenoid valve, tubing, and pressure sensors. The CO_2 tank will store sufficient propellant to raise the apogee to the target altitude. A standard 24 oz paintball tank will be used to store the CO_2 in a liquid form. Due to liquid being in a saturated state there will be a two-phase flow effect; the CO_2 will exit the tank in liquid phase and vaporize to the gas phase. The two-phase flow may affect the pressure of the CO_2 being delivered to the isentropic expansion ramps. Tubing will connect the tank to the linear isentropic expansion ramps, and a Gems Sensor (series A) solenoid valve will be used to turn on/off the cold gas flow electronically. Pressure sensors will take meaningful in-flight ramp pressure data.

Figure 21 depicts the propellant feed system for the augmentation thrusters. Carbon dioxide was selected over high-pressure air as the cold-gas propellant due to significantly better volumetric-impulse efficiency. Insuring that the thrust exceeds the drag of the vehicle before operation (as mentioned in the previous section) will force the fluid leaving the tank exit as a liquid, which minimizes propellant cooling due to boil-off. In flight measurements will include the propellant temperature (an indirect measurement of the gas saturation pressure), regulator exit pressure, aerospike plenum pressure, and three ramp surface pressures.

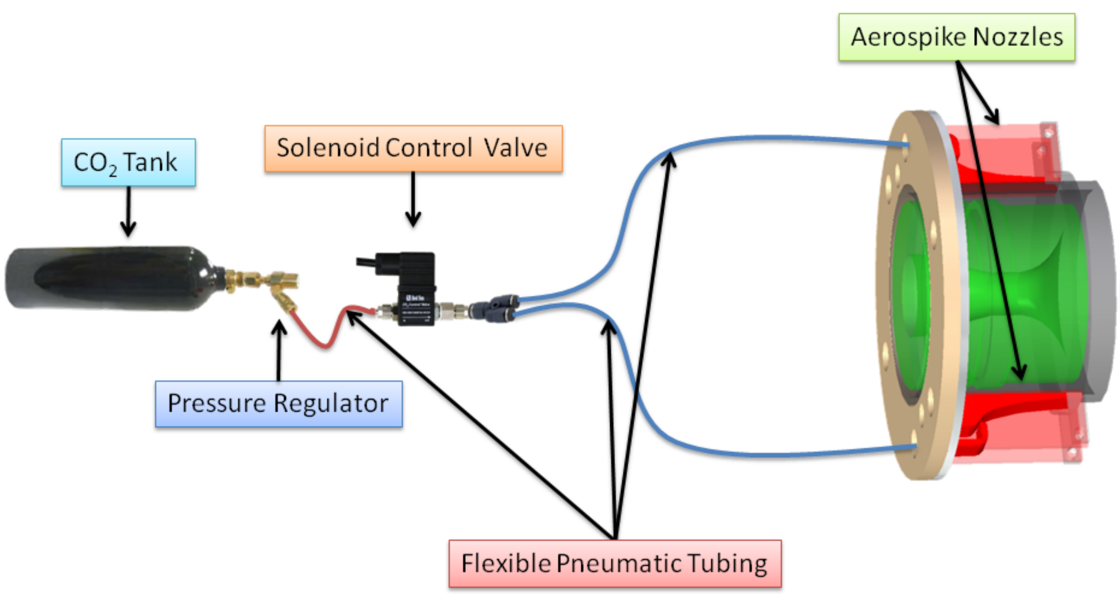


Figure 21: C-BAS component layout.

III.I.1. Avionics System Architecture

As with the previous USU entries into the USLI competition, navigation sensors include an inertial measurement unit (IMU), a pressure-pressure based altimeter, and a single-axis magnetometer. Navigation data is processed in a small onboard avionics computer using a Kalman filter to continuously estimate the total specific energy and potential altitude of the vehicle. Figure 22 depicts the suite of instruments comprising the avionics system.

The IMU, manufactured by Micro-Strain, Inc., features a high-performance miniature attitude heading reference system that includes embedded tri-axial accelerometers, rate-gyros, magnetometers, and a temperature sensor. The form factor and weight are very small, and this device is mounted on the inner platform of the vehicle without significantly affecting the weight and inertia of the platform. The IMU sensor data is blended in an internal microprocessor running a sensor fusion algorithm to provide inertial navigation quality output parameters. User-selectable output parameters include Euler angles, rotation matrix components, velocity vector components, acceleration vector components, 3-axis angular rates, and 3-axis magnetic field components.

Onboard control law calculations and data flow management are controlled using a GumStix® Overo-Tide micro-computer. The GumStix is a 17 mm x 58 mm, 720 MHz single-board computer that features the open-source Overo development platform. The name of the computer is derived from its small size. The computer also comes standard with 6 Pulse Width Modulation (PWM) I/O ports. The control law design leveraged both the built in wireless capability for down-link to the ground, and the PWM ports to control both the cold-gas throttle commands.[10]

A Ubiquiti® Bullet 2HP WiFi device will be used to communicate between a ground based laptop computer and the onboard Gumstix flight computer via an industry standard IEEE 802.11g wireless telemetry link. This laptop runs an interface program, written in the National Instruments Labview 2010® programming language that allows direct control of all onboard functions including built-in test diagnostics, startup, and navigation algorithm startup settings. The program also allows the controller gains and reference angles to be modified in real time and uplinked to the flight computer. Finally, this program receives and logs pertinent flight data including the cold-gas measurement parameters, IMU outputs, and system health bits.

III.I.2. Verifying Subsystems

In order to verify the subsystems and evaluate their performance a test stand will be constructed to conduct tests of the the science payload section of the Javelin. The test stand is currently being designed and will be implemented as soon as it is ready for use. The data gathered from these tests will give meaningful information for the implementation of the C-BAS on the Javelin. Testing the acquired equipment will also provide us with information as to how precise the pressure sensors are, as well as how fast the solenoid valve will open and close. A test will also be conducted with the PerfectFlite and a R-DAS for verification of the recovery system. Both the R-DAS and PerfectFlite will be logging the data from the pressure sensors.

Two small altimeters, standard to the model rocketry industry, are used for dual-redundant recovery system deployment. The achieved altitude for the competition is based on the output from the PerfectFlite MAWD Altimeter depicted in Figure 22. As apogee is approached the Kalman filtering algorithm is weighted to bias the potential altitude reading to the PerfectFlite value.

Figure 22: Avionics suite used for energy management algorithm and flight data management.

III.I.3. Testing

There will be three points along each ramp where plumbing will route ramp pressures to the pressure sensors that will be used to aquire data from the static testing and during flight. Because the energy augmentation system will produce momentum flux, the test stand that is being designed will use a load cell to measure any forces generated by the C-BAS. All tests will be accomplished multiple times to ensure the acquired data is accurate. The instrumention that will be used during testing will include an Adams® model CPWplus15 scale, Omega PX139 pressure sensor, and Omega® LC101-25 load cell. These instruments will be attached to a NI® USB-6009 multifunction data aquisition unit with an accuracy of 14 bits, which will aid in data collection and interpolation for analysis. During the flight test, the rocket will be equipped to record ramp pressure data in-flight, and also to store the data to memory for later analysis. The flight test will provide an opportunity to verify that the avionics of the rocket responsible for collecting and logging the data are working properly.

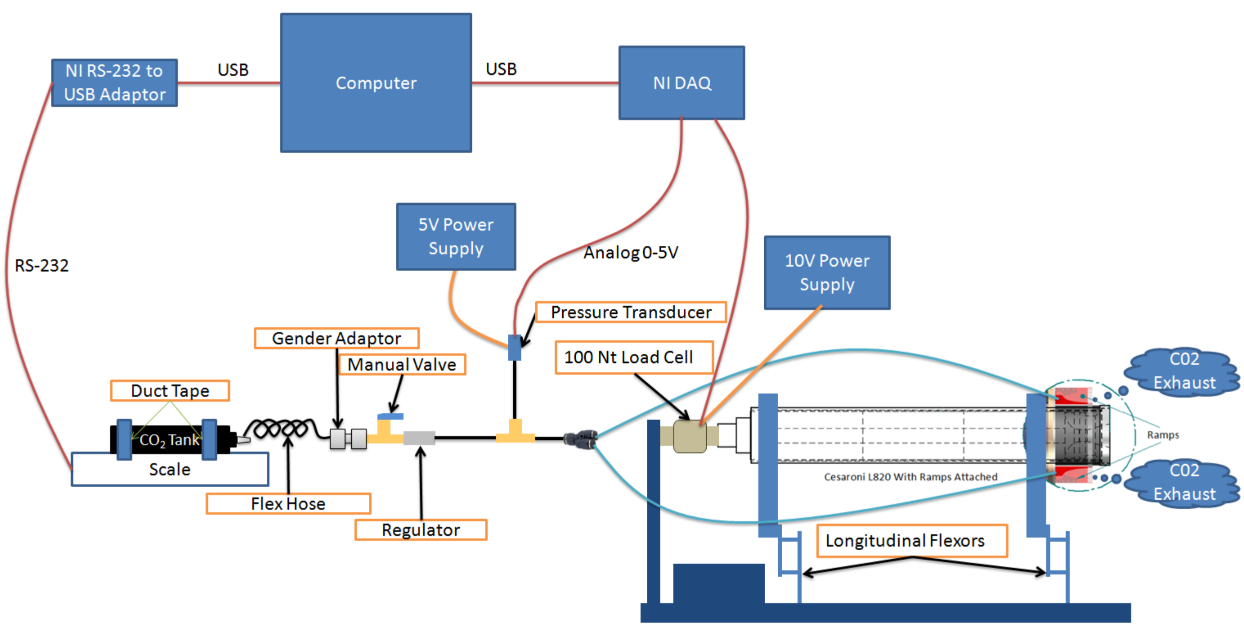


Figure 23: Cold gas test stand.

III.I.4. *Solid Motor Test Stand and Instrumentation*

An existing static-thrust test stand at USU, shown in Figure 24, will be used to obtain motor burn profiles for a minimum of 3 fuel-grain reloads on the Cesaroni L820 motor. The test stand was designed to be portable to allow testing in remote areas, where people and materials will not be exposed to explosion or rocket plume exhaust hazards. After normal business hours, motor tests can also be performed in a secured jet engine test cell on campus.

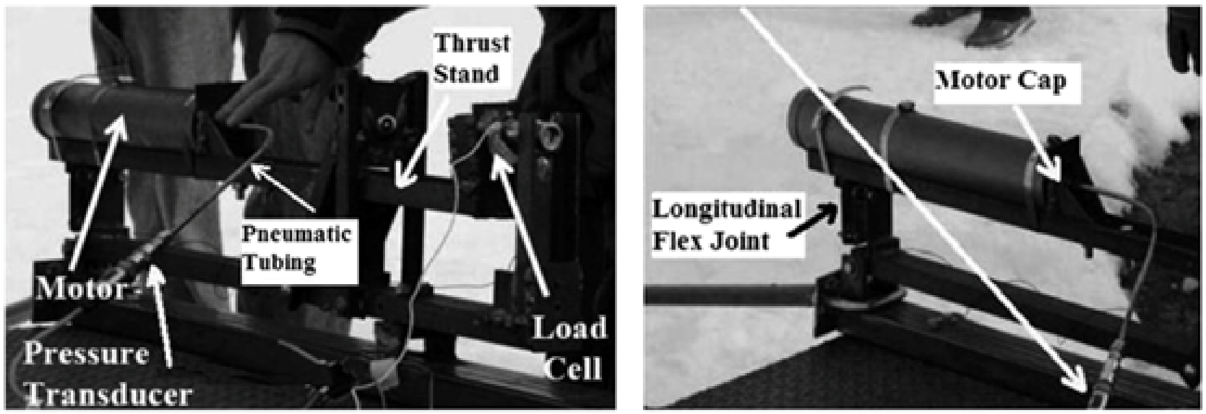


Figure 24: Rocket motor static test stand showing instrumentation locations.

The stand provides both axial thrust and chamber-pressure measurements. Thrust is measured using an Entrant® ELHS-T4E thread-mounted, 2250 N (500 lbf), load cell. The load cell was connected to the forward end of the test stand. To field calibrate the load cell, before and after each static test, the load cell is calibrated in the field using a calibrated proving ring. Turning an adjustment bolt generated calibration loads.

A Measurement Specialties, Inc.® 0–4150 kPa (0–600 psig) gauge pressure transducer was used to measure the internal pressure of the motor. The internal combustion temperature of the motor significantly exceeded the operating temperatures of the transducers and precludes close-coupled mounting. The pressure transducer was mounted to the motor cap via a threaded port in the cap and then a length of pneumatic tubing. During previous motor tests tubing length and diameter was varied for these tests to assess configuration effects on the chamber pressure measurements.

Figure 25 shows the measurement and control system. Data acquired from the load cell and the pressure transducer was transmitted to a LabVIEW VI, where it was processed and recorded. The Data Acquisition System (DAQ) has 16 analog input channels, which can have a separate voltage input range of ± 10, 5, 0.5, and 0.05 V. The voltage was selected depending on the range and resolution desired for each piece of instrumentation. The load cell and the pressure transducer were wired to the BNC 2110 connection block, and the connection block was wired to the National Instruments®, 6024E multifunctional Data Acquisition System (DAQ). Figure 26 shows the motor plume during a typical test firing.

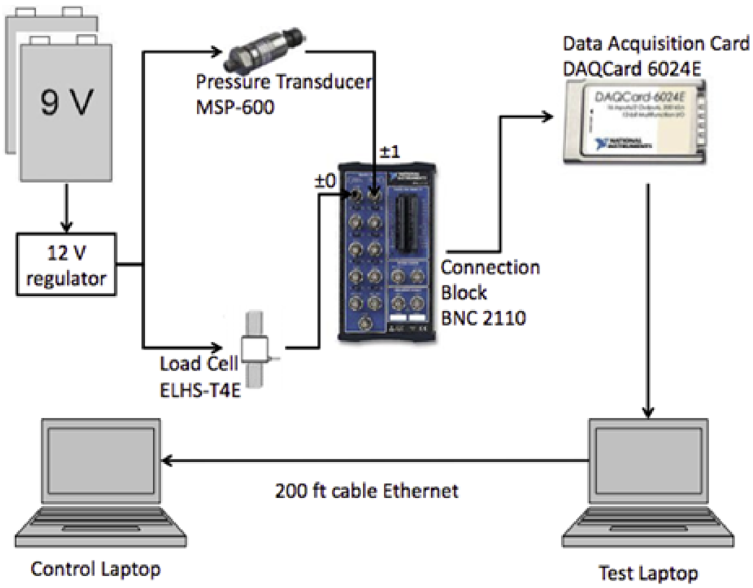


Figure 25: Schematic of static thrust instrumentation.

Figure 26: Rocket Pplume during test fire an Animal Works™ L-777 motor.

IV. Selection, Design, and Verification of Payload

IV.A. Payload Concept

The Javelin is using two isentropic expansion ramps as expansion valves of the C-BAS system as a form of energy management for the Javelin during the flight. The team selected a motor for the Javelin that cannot reach the required altitude. The C-BAS system will activate at predetermined waypoints during the flight to increase the energy of the Javelin, allowing it to reach the target altitude. The earlier the C-BAS system activates, the more effective it becomes, but it increases uncertainty in its performance. This is why multiple waypoints along the flight are used to activate the system. Earlier activations increase the energy to roughly the correct state to reach one mile, and later waypoints fine-tune the final altitude such that by the time the Javelin reaches apogee, it will be within meters, or even centimeters, of its target.

Figure 27 plots the velocity and drag as a function of time for a typical one-mile launch trajectory. Figure 27 plots time histories of velocity components, true (above ground level) and potential altitudes, drag, and rate of energy change. Note that the potential altitude parameter defined by equation 8 becomes an increasingly accurate predictor of the apogee altitude as the vehicle slows. In fact, once the vehicle clears 1200 meters above ground level, the potential altitude remains virtually constant. Note also that at this altitude, rate of energy dissipation due to the aerodynamic drag is negligible. Figure 28 compares a typical thrust-augmented trajectory to an unaugmented trajectory. The data presented in Figure 28 is taken from thrustcurve.org and represents a Cesaroni L820[5] High-powered Rocket Motor for the main propulsion system. This motor was selected after a detailed trade study performed as part of the class assignments.

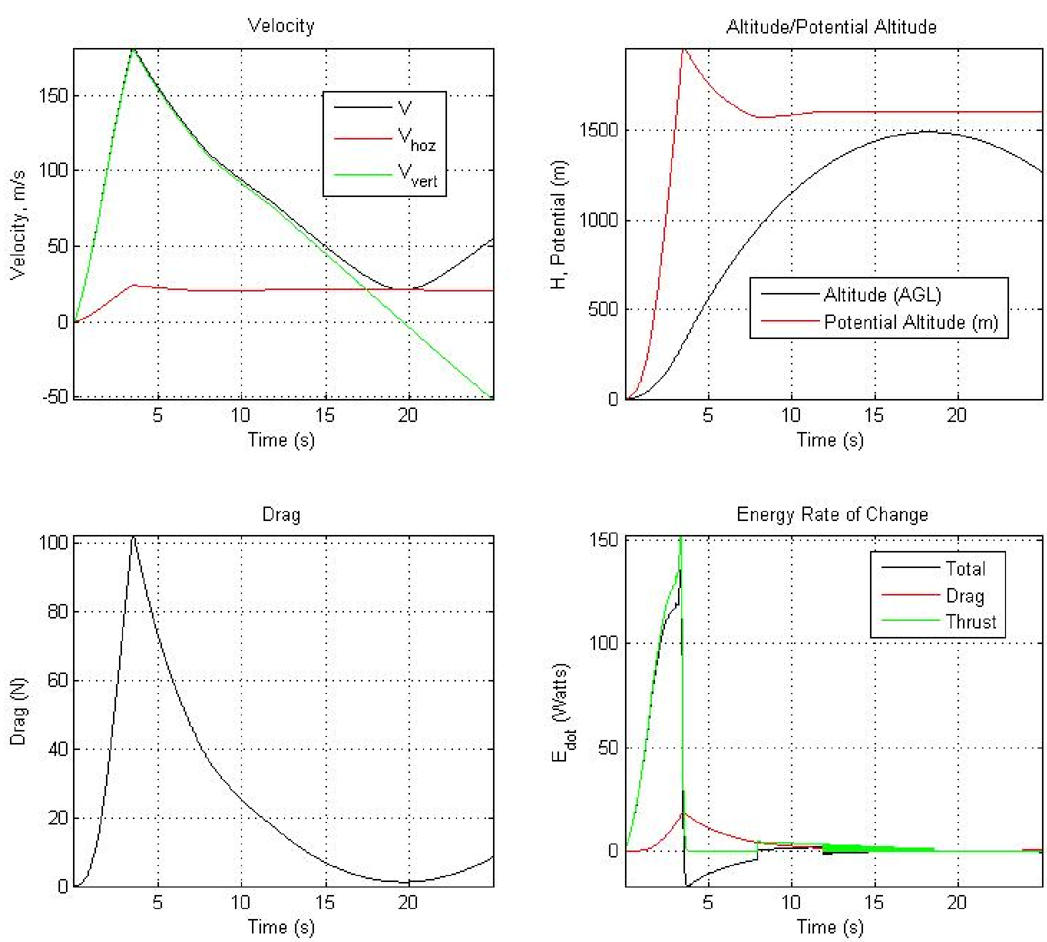


Figure 27: Comparison of augmented and unaugmented trajectories.

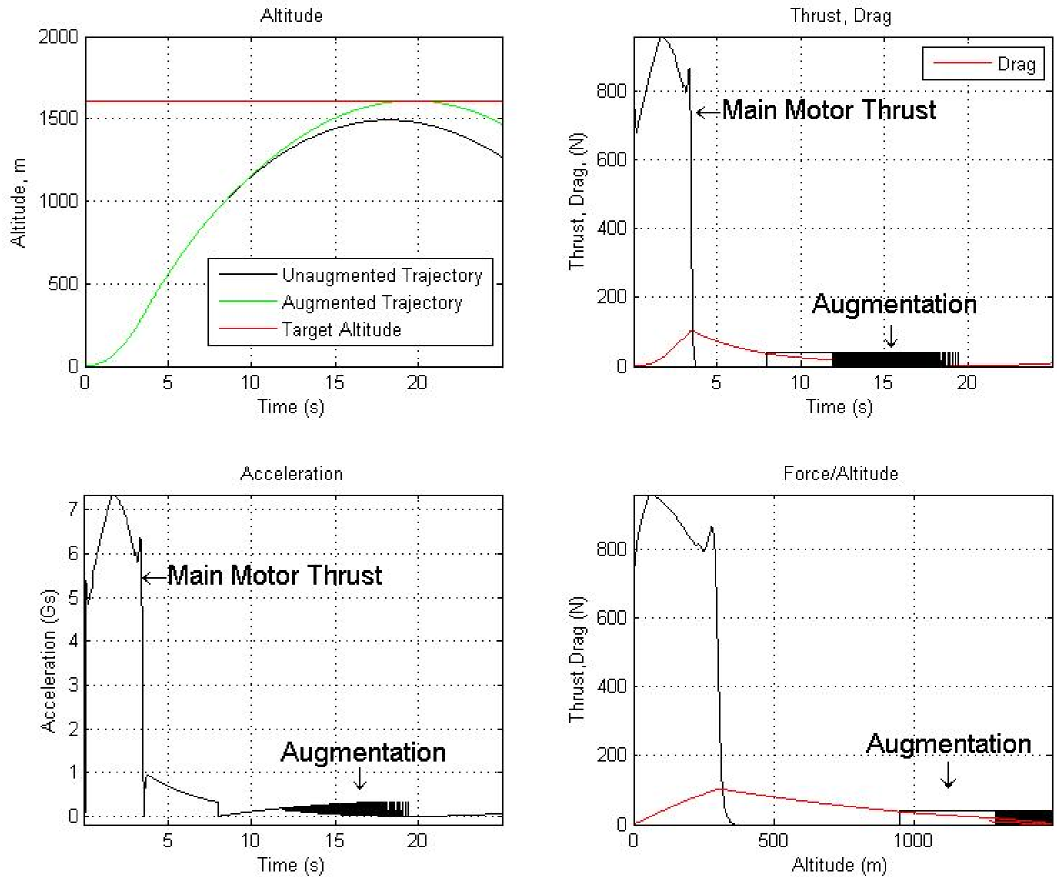


Figure 28: Comparison of augmented and unaugmented trajectories.

The Javelin payload will be one of the first to actually include an isentropic expansion ramp based on an aerospike nozzle as the expansion valve of the C-BAS in a rocket flight. Typically, cold gas injection is done without any special expansion nozzle, but the C-BAS will become more effecient when ideally expanded at all altitudes. Expansion ramps and aerospike nozzles have been attempted before, but have always been canceled or otherwise stopped before any significant flight tests are performed. As such, this will be a payload that has never before flown. The C-BAS expansion ramps will be placed concentrically about the solid motor of the Javelin in an idea package. The nozzles themselves are extremely small, only 2 cm in length, so they do not change the overall diameter of the Javelin by a substantial amount.

In order to use an expansion ramp in the C-BAS, a detailed model must be developed to calculate the exact dimensions of the nozzle, including choking area, ramp profile, and ramp length. Additionally, a great deal of modeling must be done to determine the required input pressures and mass flow rates to achieve the desired drag reduction effects of the C-BAS. With exception of the nozzles, all other components of the C-BAS will be COTS (commercial off the shelf) components to reduce production time. This, however, also means that all components purchased must be tested extensively to determine their performance characteristics. The testing and validation of the C-BAS will provide a very substantial level of challenge. There will only be one to two test flights of this sytem before the competition launch, so the drag reduction of the C-BAS must be known as exactly as possible before any test flight occurs.

IV.B. Science Value of Payload

There are other additional considerations that make this payload scientifically valuable. The first is the integration and implementation of the energy management system. This system is designed to augment the energy state of a rocket that cannot reach the desired apogee with the motor alone. The second is the analagous nature of the C-BAS system to linear aerospike nozzle theory. These measurements, if successful, will represent the first time isentropic expansion ramp surface pressures have been obtained in flight.

Achieving the large range of human and robotic space exploration missions, as outlined in NASA's space vision, will require significant advances in technology for all systems of the space vehicle, especially propulsion systems. Advances in propulsion technologies offer the greatest potential for spacecraft mass reduction. Mass reductions are especially critical for planetary landing and ascent propulsive systems like those proposed for the Mars Ascent Vehicle or the Altair Lunar Lander, were the cost of delivering mass to the surface is high.

While aerospike nozzles have long been known for their altitude compensation ability during endoatmospheric flight, they also present significant potential advantages for purely in-space applications.[14] Aerospike nozzles can be both more efficient and significantly smaller than conventional high expansion ratio bell nozzles. Given a fixed vehicle base area, an aerospike nozzle can present higher area expansion ratio than a bell nozzle, providing better performance in a space environment or near vacuum environment like Mars. The potential for nozzle mass reduction and increased specific impulse (I_{sp}) using an aerospike nozzle translates to a 15-18 percent decrease in the propellant mass and total system weight. Additionally, one of the often overlooked advantages of the aerospike nozzle is the ability to achieve thrust vectoring aerodynamically without active mechanical nozzle gimbals, with a significant potential for reduced system complexity and weight.

Despite its well-known potential benefits over conventional conical or bell-nozzle designs, because of a perceived low technology readiness level, the aerospike rocket configuration has never been deployed on an operational space vehicle. One of the major reasons for this is the lack of high quality ground and flight test data, and its correlation with analytical flow predictions. The proposed analytical and experimental work will seek to conduct fundamental research to fill in the gaps in the experimental data chain.[15]

IV.B.1. Experimental Approach and Relevance of Data

The data collected from static testing will play an important role in the successful completion of payload objectives. First, the static test data will provide information about how much energy can be augmented via the onboard CO_2. The expulsion of the CO_2 using the expansion ramps increases the total energy of the Javelin, thus increasing potential altitude. When this occurs the pressure transducers will collect ramp pressure data and route it to memory for storage. The data will be checked against the data collected during static testing in order to better understand the impact of flight environment on expansion ramp pressures. Because the expansion ramp was developed from linear aerospike nozzle theory, the collected data will provide invaluable information about how a motor using a linear aerospike nozzle will be impacted by flight environment. The data collected will also validate existing rocket nozzle theory that has not been tested in flight.

IV.C. Safety of Payload

The C-BAS that will fly on the Javelin stands to produce a great deal of scientific data. While the system has never been used before, the team does not anticipate any kind of problem with integrating the C-BAS on the rocket.

The hazards attributed to the C-BAS have been considered and evaluated. The biggest hazard with the system would be a failure of the flow regulation, resulting in a complete blow-out of the system. With the manual shut off valve installed the risk of this happening before flight remains low. The risk of a complete blow-out while in flight depends on the integrity of the components in the system. Proper testing and verification will be completed before the build phase to insure the components can withstand the pressures and rigors needed for the desired performance.

Although a complete cold-gas blow-out would eliminate the Javelin's ability to augment its energy properly, resulting in a possible mission failure, there would be no harm to the rocket or its surroundings. Since the C-BAS will use CO_2 as the working fluid, a total system failure would be the equivalent of opening a fire extinguisher. If this occurs during the main motor burn, the C-BAS would possibly extinguish the motor. Never is there a risk of the C-BAS causing a fire, either in transit, on the launch pad, or in the air. In fact, the possibility remains to use the payload as a fire extinguisher should the main motor burn uncontrollably.

The team has access to a large quantity of pressurized CO_2 that can be used for testing purposes. The large tank is chained to the wall to prevent it from tipping over and potentially bursting. While refilling the tanks for the C-BAS the team will follow proper safety guidelines to prevent injury, bursting o-rings, or dropping tanks. The MSDS sheet for CO_2 is located in Appendix C and will be available for those working with the payload.

Each tank used by the team has a bleed valve that prevents the tank from being over-pressurized. While in transit, the tanks will be stored unattached to the rocket to make sure there is no unwanted venting of CO_2.

V. Activity Plan

V.A. Budget Plan

After a formal presentation to the dean of the College of Engineering, the USU Chimaera Team was provided \$5000. This brings the total confirmed available resources to \$16,500. Of the allowed \$5000 that will fly along with the Javelin, the team has already spent 19.70 percent (\$985.22). This corresponds to the purchase of the final motor (Cesaroni L820), the PerfectFlite, instrumentation components, the Gumstix Overo Fire, and an onboard camera. For testing, the Chimaera team has already spent 38.06 percent of the budgeted amount (\$2237). This includes the purchase of three reload kits for the L820, structural Blue Tube 2.0™, and the preparation of test stands and procedures.

Hardware	Spent	Allocatted	% Used
IMU: Microstrain 3DM-GX3	\$0.00	\$1,700.00	0.00%
RDAS	\$0.00	\$300.00	0.00%
miniAlt/WD Altimeter	\$219.90	\$219.90	100.00%
Fins and Servo Motors*	\$0.00	\$460.00	0.00%
Gumstix Overo Fire	\$270.26	\$270.26	100.00%
Pressure Transducers and other Intrumentation	\$45.71	\$200.00	22.86%
Motor and Solid Fuel	\$343.40	\$450.00	76.31%
Onboard Camera	\$105.95	\$105.95	100.00%
Recovery	\$0.00	\$350.00	0.00%
Carbon Tubing	\$0.00	\$325.00	0.00%
24 CO2 Tank	\$0.00	\$60.00	0.00%
Isentropic Expansion Ramps	\$0.00	\$100.00	0.00%
Payload Tubing and valves	\$0.00	\$50.00	0.00%
24 CO2 Regulator	\$0.00	\$100.00	0.00%
Assembly(Bolts, Nuts, Bulkheads, Epoxies, etc)	\$0.00	\$100.00	0.00%
Other Uncategorired Expenses	\$0.00	\$208.89	0.00%
Subtotal	\$985.22	\$5,000.00	**19.70%**
Certifications, Testing and Outreach			
Certifications	\$1,162.98	\$1,162.98	100.00%
Outreach	\$9.65	\$100.00	9.65%
Testing	\$851.42	\$2,237.02	38.06%
Subtotal	\$2,024.05	\$3,500.00	**57.83%**
Travel and Transportation Expenses	\$0.00	\$8,400.00	**0.00%**
Total	\$3,009.27	\$16,900.00	**17.81%**

Figure 29: Procurement status.

V.B. Timeline

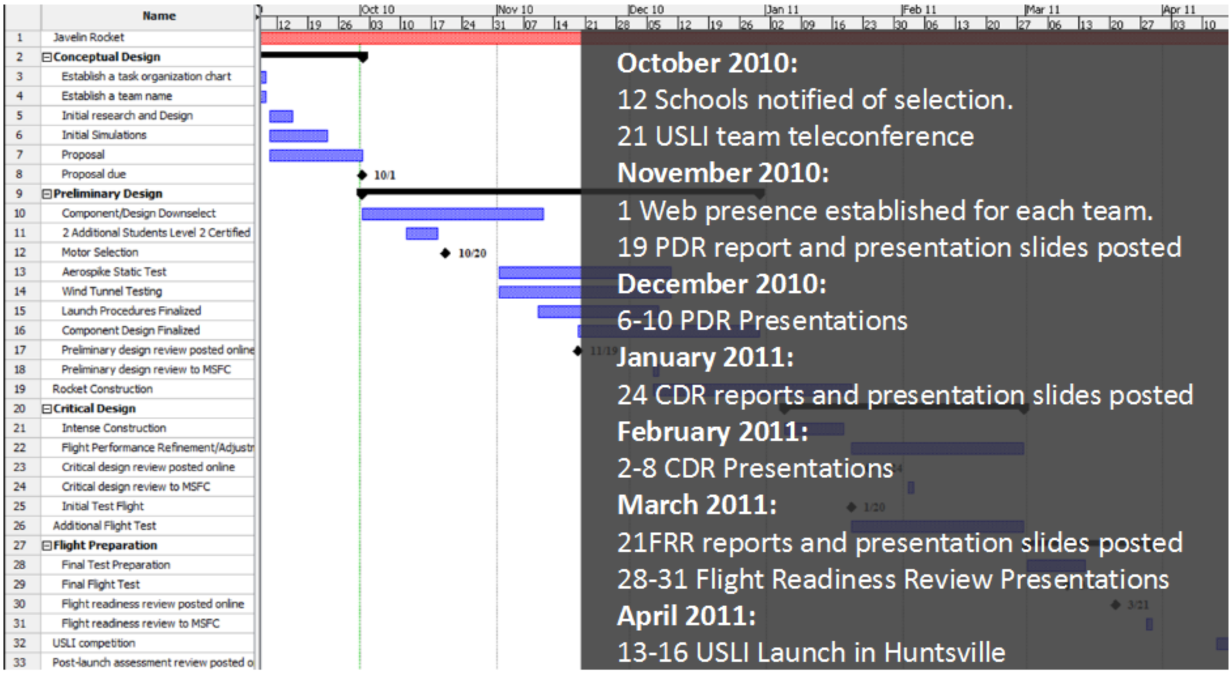


Figure 30: Top level milestone schedule.

V.C. Educational Engagement

It is critical to the USU Chimaera rocket team to have support from the community. Rocket design is a senior project, but the team could not be successful without the immense support and encouragement they receive from the University, interested companies and individuals, and students throughout Cache Valley.

V.C.1. Community Support

As the reputation of the Chimaera program has spread, the Utah State rocket team has been offered monetary support from several sponsors. The Space Dynamics Laboratory (SDL), a space research center operated by Utah State University Research Foundation, has asked the USU Chimaera Team for help in numerous outreach events. Even before acceptance into the USLI competition, the team cohosted an event on campus in September, in which more than 150 students participated in a hands-on rocket experience. SDL has donated $5000 toward the development of the rocket.

The team has also received monetary and physical support from NASA Exploration Systems Mission Directorate (ESMD), Rocky Mountain Space Grant Foundation, and the American Institute of Aeronautics and Astronautics.

The team is heavily supported and encouraged by the College of Engineering. The team is in the process of requesting funds from the Associated Students of Utah State University (ASUSU) for travel. ASUSU sets aside funds for groups on campus engaged in extracurricular educational programs. Several of the sponsors have requested that the team give a presentation about the project.

V.C.2. Outreach

The purpose of Utah State's outreach program is to promote interest in math, science, and engineering education throughout the next generation of young minds. The team has conducted and will continue to host various outreach programs at local schools and in the community. Figure 31 shows some of the activities the team has done thus far.

Figure 31: USU Chimaera Team outreach activities.

In an effort to bring the community closer to the project, each child that is affected through the team's outreach program this year will have the opportunity to fly with the rocket. The name of each child will be placed on a flash drive, attached to the rocket, and sent one mile into the atmosphere; "Almost to space!" as one excited first grader exclaimed. This unique opportunity creates excitement in even the most disinterested children about rockets, space, and what the team is doing. The outreach campaign has thus been titled, "Fly with the USU Rocket Team!" as demonstrated in Figure 32.

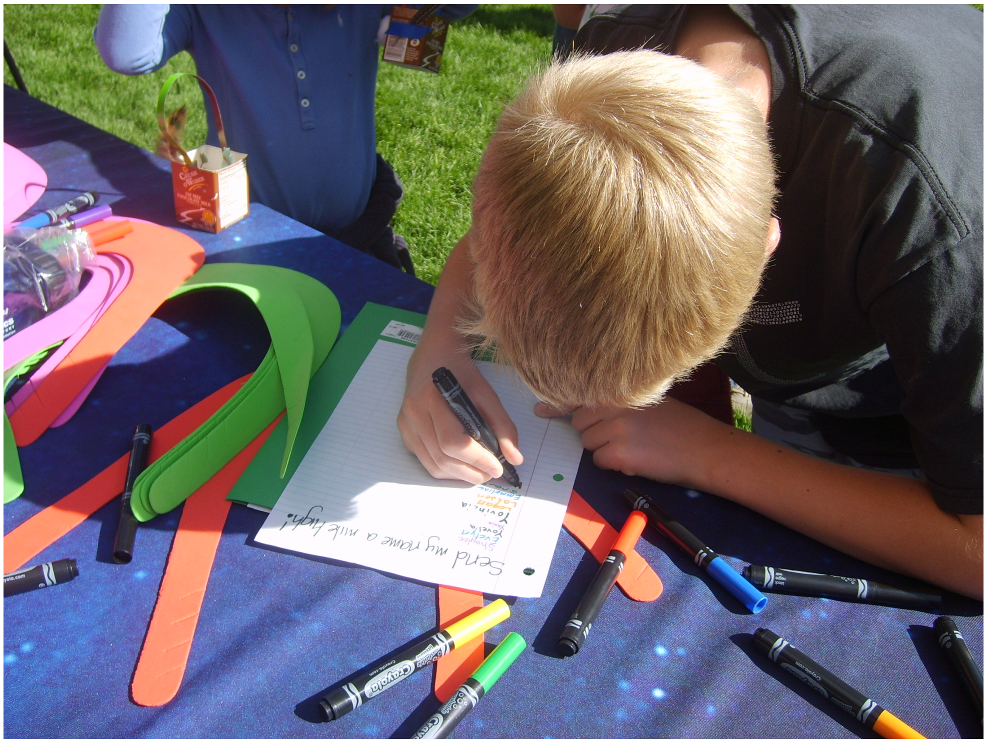


Figure 32: Fly with the USU Rocket Team!

Aggie CARE Day Each year, Utah State University holds an activity day on campus for faculty and their families. The USU Chimaera team, in conjunction with SDL, provided an activity booth for the event. Members of the rocket team displayed rocket and lunar lander designs from past Utah State teams, and talked to children ages 3-15 about rockets, space, and research at USU. With assistance from team members, children had the opportunity to launch water bottle rockets. Those interested could answer questions about rockets to earn a free water bottle, supplied by SDL.

Hillcrest Elementary School Science Club The Hillcrest Science Club is made up of 30 third, fourth, and fifth grade students, selected by their teachers because they have shown an exceptional skill and interest in science. The rocket team prepares and teaches a lesson for the club once a month. The first lesson was an exploration of forces on an airplane, culminating in an intense paper airplane competition. In November, the team taught a lesson in satellites and students had the opportunity to construct their own, as well as experiment with the effects of momentum. Future lesson plans include spacesuits, Newton's Laws of Motion, and Astronaut Training.

USU Rocket Day The rocket team joined the experimental rocket club on campus to hold a Rocket Day on the Quad. The team talked USU students about USLI, NASA, the rocket design process, and their project. They displayed the rockets built by two team members for Level II certification and the Pike, the rocket built for USLI two years ago. Serving hot chocolate on the coldest day of the year brought 100 students to the booth.

Sunrise Elementary School Literacy Fair Sunrise Elementary School held a Literacy Fair on November 9 to demonstrate to students age K-5 the importance of reading in various careers. The rocket team hosted a booth at which students learned about the importance of communication in the aerospace industry, then had to follow instructions to build their own model satellite. About 100 students visited the team's booth at this event.

Logan High School MESA Club MESA (Math, Engineering and Science Achievements) is a club designed to introduce women and minorities to the world of math and science, and provide them opportunities to excel in these areas. The rocket team visited Logan High on November 10. They presented about the USLI competition, the design process, and project goals. Team members answered questions about rocket design, engineering, and college coursework. The club is participating in an invention fair at the end of the school year, and the rocket team has been asked to help students with their designs.

Other School and Community Outreach The team has spoken with several other groups that are excited to have their students learn about rockets. In the spring they will help the local Boy Scout Troop 1 earn merit badges in rocketry. Team members plan on visiting the Mt. Crest High School MESA Club. The rocket team continues to partner with SDL and search for other opportunities to talk to students about the rocket project.

VI. Conclusion

The Utah State University Chimaera Team has created a unique rocket design, the Javelin, that will satisfy all requirements. The team has performed trade studies and run simulations in order to narrow down design decisions. In addition, tests will be conducted to further refine the rocket design. This will ensure that the Javelin will be safely launched and recovered at the competition.

The Javelin will deliver a cutting edge scientific payload, a Cold-gas Base-bleed Augmentation System (C-BAS) inspired by aerospike nozzle designs, that will gather in-flight data for the first time for any device of its kind. Aerospike nozzles promise significant efficiency increases over traditional bell nozzles. Although developed over forty years ago, aerospikes have not been flight tested before. C-BAS will be used to verify this fact, which will significantly upgrade the overall technology readiness level and make aerospikes more attractive to future projects. C-BAS will also help reduce drag on the aft portion of the Javelin, which will help the rocket acheive its mile altitude goal.

The energy management techniques demonstrated by C-BAS are directly analogous to the closed-loop energy management systems used to perform orbital transfer maneuvers. Even on sophisticated space vehicles like the Space Shuttle, closed-loop orbital transfers using propulsive throttle are rarely done. The C-BAS will help prove the utility of these energy management techniques for future NASA, military, and commercial payloads.

The team is well-positioned to succeed in the USLI competition. Capitolizing on the talents of team members, the support of community sponsors, as well as Utah State University, and simulations and design processes developed by the team, the Javelin represents the pinacle of achievement for the students involved.

A. Javelin Launch Procedures Checklist

A.A. Persons Conducting Launch

- ☐ Team Supervisor Approval:_________
- ☐ Team Instructor Approval:_________
- ☐ Team Safety Officer Approval:_________

Rocket Details and Launch Environment

- ☐ Rocket Clean Mass:_____________________________
- ☐ Motor Initial Mass:_________________________
- ☐ Motor Final Mass:__________________________
- ☐ Nozzle Throat Diameter:____________________
- ☐ Temperature at time of launch:______________
- ☐ Barometric Pressure:_______________________
- ☐ Launch Altitude:___________________________

Traveling Preparation (To be completed before leaving campus facilities; items placed in vehicle)

- ☐ Charge all batteries.
- ☐ Install batteries.
- ☐ Check tire pressure.
- ☐ Check lights.
- ☐ Secure rail to bed.
- ☐ Check hitch to ensure it is secure.
- ☐ Remove loose materials from trailer.
- ☐ Place spare tire in towing vehicle.

Recovery Preparation

- ☐ Inspect parachutes.
- ☐ Inspect harnesses.
- ☐ Inspect quick links.
- ☐ Check impedance in electric matches.
- ☐ Slip Nomex sleeve and cloth over the short ends of the harnesses.
- ☐ Attach quick links to loops in the ends of the harnesses.
- ☐ Apply baby powder to parachutes.
- ☐ Untangle shroud lines.
- ☐ Attach parachutes to harnesses.
- ☐ Fold parachutes.
- ☐ Place parachutes in deployment bags.

Prepare Drogue Parachute.

- ☐ Extinguish all cigarettes.
- ☐ Verify that no flame sources are located within 25 feet of recovery charge preparation area.
- ☐ Put on PPE.
- ☐ Measure out drogue chute black powder charges.
- ☐ Pour black powder into ejection charge canister underneath the avionics section.
- ☐ Tape two electric matches to the side of the ejection canister with 1.5" free to bend into black powder.
- ☐ Bury match heads in black powder.
- ☐ Insert plug on top of black powder and pack with a wooden dowel.
- ☐ Seal ejection charge canister with tape.
- ☐ Attach quick links on the fabricated end of the drogue harness to the two U-bolts in the payload section bulkhead.
- ☐ Connect the electric match leads to the wire posts on the avionics section bulkhead.
- ☐ Attach quick link in loose end of harness to remaining U-bolt.
- ☐ Wrap harness and parachute in Nomex cloth.
- ☐ Being careful not to disconnect any wires, insert the parachute into the avionics section coupler.
- ☐ Ensure that all between bulkheads are still connected.
- ☐ Slide avionics section into booster section and insert shear pins.

Prepare Main Parachute.

- ☐ Extinguish all cigarettes.
- ☐ Verify that no flame sources are located within 25 feet of recovery charge preparation area.
- ☐ Put on PPE.
- ☐ Measure out main chute black powder charge.
- ☐ Pour black powder into ejection charge canister.
- ☐ Attach leads from two electric matches to the wires in the nosecone bulkhead.
- ☐ Tape the electric matches to the side of the ejection canister with 1.5" free to bend into black powder.
- ☐ Bury match heads in black powder.
- ☐ Insert plug on top of black powder and pack with a wooden dowel.
- ☐ Seal ejection charge canister with tape.
- ☐ Attach the quick link on the short end of the harness to the U-bolt in the nose cone.
- ☐ Wrap harness and parachute with Nomex cloth.
- ☐ Being careful not to disturb the ejection charge; insert the parachute into the nose cone with the electric match wires and unconnected end of the harness protruding.
- ☐ Attach loose quick link to U-bolt in the top avionics section bulkhead.
- ☐ Connect the e-matches to the avionics section.
- ☐ Slide nose cone into avionics section and insert shear pins.

Motor Preparation   Motor Preparation Leader:_____

☐ Visually inspect to make sure the motor is clean and free from defects.

☐ Extinguish all cigarettes.

☐ Verify that no flame sources are located within 25 feet of motor preparation area.

☐ Inspect reload components.

☐ Assemble motor per manufacturer's instructions.

☐ Lightly coat the inside of the tracking smoke well in the forward bulkhead with grease.

☐ Lightly coat grease on the outside surface of the tracking smoke element.

☐ Lightly grease the four small o-rings.

☐ Place the tracking smoke module with vertical orientation on a flat horizontal surface.

☐ Slide the O-rings onto the module. It is necessary to have the o-rings tied to one end of the smoke element.

☐ With the o-rings on the tracking smoke element flush to the bottom of element and on a flat surface, align and slide the forward bulkhead onto the assembled tracking module.

☐ Set the forward bulkhead pre-assembly to one side for now.

☐ Lightly grease two large o-rings.

☐ Place two greased large o-rings into the grooves in the nozzle.

☐ Wipe a film of grease on the inside diameter of both ends of the motor case.

☐ Using a twisting motion, install the nozzle into the end of the case.

☐ Install three (3) propellant grains into the liner tube.

☐ Apply a light coat of grease to the outside of the liner.

☐ Install liner assembly into the case until seated against the nozzle.

☐ Lightly grease two large o-rings.

☐ Place two greased large o-rings into the grooves in the forward bulkhead

☐ Using a twisting motion, install the forward bulkhead into the forward end of the case until it is seated against the propellant grains. The forward bulkhead is oriented so that the threaded hole faces outwards.

☐ Install the 75 mm threaded ring into the internally threaded Slimline motor retainer.

Igniter Installation   Igniter Installation Leader:________

☐ To be preformed after Javelin is loaded on the rail and in the launch position.

☐ Continuity check on igniter.

☐ Insert igniter into motor.

☐ Make sure that igniter is at the top of the motor and tape leads to side of Blast bucket.

☐ Touch wires from launch control box together to verify that they are not receiving current.

☐ Attach wires to igniter leads.

- ☐ Leave wires in a position where they will not short out.
- ☐ Recheck the continuity of the igniter.
- ☐ Flip launch control box to pad armed.
- ☐ Retreat to safety zone.

SETUP ON LAUNCHER Launcher Setup Leader:________

- ☐ Send spotters (with radios!) out to watch for rocket landing.
- ☐ Clear the area of anything that could impede mounting the rocket (trip hazards, obstructions, etc).
- ☐ Put on hard hats.
- ☐ Load the rocket on the rail gently.
- ☐ Insert assembled motor into motor mount tube.
- ☐ Insert spacing ring.
- ☐ Insert retaining ring and tighten.
- ☐ Ensure motor retaining ring is properly tightened and there is no longitudinal play in the motor.
- ☐ Lift the rail to vertical.
- ☐ Secure rail to trailer.
- ☐ Level trailer again.
- ☐ Setup Blast plate.
- ☐ Ensure all non-essential personnel are beyond 300 ft from rocket.
- ☐ Power on PerfectFlite and RDAS.
- ☐ Verify that the PerfectFlite has continuity (three quick beeps, repeating).
- ☐ Verify that the RDAS has continuity (one short beep per second).
- ☐ Wait until all devices complete powering on.
- ☐ After the Gumstix is powered on, wait for "Booted" and "Logged In" lights to turn on (this may take several minutes).
- ☐ Press "Execute Program"; confirm avionics is sending data.

TROUBLESHOOTING PROCEDURE Troubleshooting Leader________
Launch Failure Troubleshooting

- ☐ Remove safety interlock key from launch controller or disconnect the battery.
- ☐ Do not approach the rocket for a minimum of two minutes.
- ☐ Wait for range safety officer to declare the range open.
- ☐ The range safety officer carefully approaches the rocket wearing personal protective equipment (PPE).
- ☐ Remove the igniter from the motor.
- ☐ If the igniter is burned replace it.
- ☐ Check for shorts in the wiring.
- ☐ Check battery power.

- ☐ Follow the appropriate launch procedures to re-attempt the launch.
- ☐ Two people carefully approach the rocket wearing PPE. Hang Fire
- ☐ Wait for the motor to stop burning and cool down.
- ☐ Wait for range safety officer to declare the range open.
- ☐ Try to minimize all volatile components before approaching the rocket.
- ☐ Contact the safety officer of the launch site.
- ☐ Do not approach the rocket for at least five minutes after the motor has stopped.
- ☐ Two people carefully approach the rocket wearing PPE.
- ☐ Insert PerfectFlite and RDAS safety RBF plugs to disarm the recovery system.

Recovery System Deployment Failure

- ☐ Keep all personnel at a safe distance and contact the launch site safety officer.
- ☐ Cautiously approach the rocket with a CO_2 or foam fire extinguisher and proper PPE (hardhat, gloves, safety glasses).
- ☐ Attempt to locate deployment charges. If intact, follow "Undeployed Recovery Charges" procedure.
- ☐ Locate and remove all rocket debris from the crash site.
- ☐ Store and document the debris for further investigation. Undeployed Recovery Charges
- ☐ Clear all personnel except one (range safety officer or recovery team member) from the site.
- ☐ Point the charge in a safe direction.
- ☐ Wearing PPE, complete the circuit in an electric match using a battery.

Post Flight Inspection   Post Flight Inspection Leader:________

- ☐ Receive go-ahead from range safety officer.
- ☐ Insert safety interlock key into launch controller.
- ☐ Perform a five second countdown, pressing and holding the ignition button at zero.
- ☐ In-Flight .
- ☐ Watch for parachute deployments.
- ☐ Keep track of rocket during descent.
- ☐ At touchdown, take pictures and make note of landmarks that will aid in ground recovery.
- ☐ Leave at least one spotter with a radio or cell phone at the launch area to keep the ground recovery team on course.
- ☐ Carry a radio or cell phone and keep in contact.
- ☐ Two team members (team leader and assistant), wearing safety glasses, approach the rocket slowly and check for safety hazards such as unexpended recovery charges.
- ☐ If undeployed recovery charges, follow emergency safety procedures.
- ☐ Team leader sounds "all clear".
- ☐ Stop recording on the flight camera.

- ☐ Insert the PerfectFlite/RDAS safety RBF-plug into the top stereo jack.
- ☐ If connected via modem, issue shut down command. then insert power-plug into bottom stereo jack. if not connected insert power-plug into the bottom stereo jack to power down main flight computer.
- ☐ Carefully fold parachutes taking care to not tangle shroud lines.
- ☐ Disconnect harnesses from the rocket.
- ☐ Allow motor case and nozzle to cool before handling.
- ☐ Carry rocket parts back to launch area.
- ☐ Disassemble parts for transport/storage.
- ☐ Vent excess CO_2.
- ☐ Remove motor case from motor mount tube (Make sure it is no longer hot before handling).
- ☐ Remove spent reload from motor casing and discard in trash bag.
- ☐ Clean any parts that will be reused.
- ☐ Perform an overall inspection of the rocket looking for any damage that may have occurred during flight or landing.
- ☐ Perform an overall cleaning to remove dirt/burned black powder/etc.

A.B. Motor Assembly Procedure

Adapted from Pro75® Instructions, March 2005 revision

Motor Assembly Procedure 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.

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 a 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 so as not to 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.

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 retainer 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. Preflight Preparation.

3.1. Prepare the rocket's recovery system, before motor installation if possible.

3.2. 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.

3.3. 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/or the National Fire Protection Association (NFPA) Code 1127 where applicable.

3.4. 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.

3.5. Launch the rocket in accordance with all Federal, State/Provincial, and municipal laws as well as the Safety Code of the Tripoli Rocketry Association, as well as NFPA Code 1127 where applicable.

4. Post Flight Cleanup.

4.1. Unthread and remove the forward and rear closures. Remove the nozzle holder from the nozzle.

4.2. Remove the phenolic tracking smoke charge insulator from the forward closure.

4.3. Remove all o-rings.

4.4. Discard all reload kit components with regular household waste, after they have completely cooled down.

4.5. 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.

4.6. Apply a light coat of grease or o-ring lubricant to all threaded sections and reassemble threaded components for storage.

B. Safety Code

High Power Rocket Safety Code

Provided by the National Association of Rocketry

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 at least one half the minimum launch site dimension, or 1500 feet (whichever is greater) 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.

C. MSDS Sheets

5-MINUTE EPOXY GEL RESIN

This product appears in the following stock number(s):
14240 14240G 14265 6206 DA052 DA221 DA240

Last revised: 06/10/04
Printed: 7/2/2004

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Tradename: 5-MINUTE EPOXY GEL RESIN

Product Identifier: EPOXY RESIN

General use: This information applies to the resin component of the two-part kit; handle freshly-mixed resin and hardener as recommended for the hardener. After curing, the product is not hazardous.

Chemical family: Epoxy resin

MANUFACTURER

ITW Devcon
30 Endicott St.
Danvers, MA 01923

EMERGENCY INFORMATION

Emergency telephone number
(CHEMTREC): (800) 424-9300
Other Calls: (978) 777-1100

2. COMPOSITION/INFORMATION ON INGREDIENTS

HAZARDOUS CONSTITUENTS

Constituent	Abbr.	CAS No.	Weight percent	Exposure limits: ACGIH TLV	OSHA PEL	Other Limits
Bisphenol A diglycidyl ether resin	DGEBPA	25068386	70-90	n/e	n/e	n/e
Phenol, polymer with formaldehyde, glycidyl ether		28064144	10-20	n/e	n/e	n/e

"TLV" means the Threshold Limit Value exposure (eight-hour, time-weighted average, unless otherwise noted) established by the American Conference of Governmental Industrial Hygienists. "STEL" indicates a short-term exposure limit. "PEL" indicates the OSHA Permissible Exposure Limit."n/e" indicates that no exposure limit has been established. An asterisk (*) indicates a substance whose identity is a trade secret of our supplier and unknown to us.

3. HAZARDS IDENTIFICATION

Emergency Overview

Appearance, form, odor: viscous liquid with little odor.

WARNING! Eye and skin irritant. Potential skin sensitizer.

Potential health effects

Primary routes of exposure: ☒ Skin contact ☐ Skin absorption ☒ Eye contact ☐ Inhalation ☐ Ingestion

Symptoms of acute overexposure:

Skin: Moderate irritant. Contact at elevated temperatures can cause thermal burns which may result in permanent damage. May cause skin sensitization (itching, redness, rashes, hives, burning, swelling).

Eyes: Moderate irritant (stinging, burning sensation, tearing, redness, swelling). Contact at elevated temperatures can cause thermal burns which may result in permanent damage or blindness.

Inhalation:
The low vapor pressure of the resin makes inhalation unlikely in normal use. In applications where vapors (caused by high temperature) or mists (caused by mixing) are created, breathing may cause a mild burning sensation in the nose, throat and lungs.

Ingestion:
Acute oral toxicity is low. May cause gastric distress (nausea, vomiting, diarrhea).

Effects of chronic overexposure:
Prolonged or repeated skin contact may cause sensitization, with itching, swelling, or rashes on later exposure.

Carcinogenicity -- **OSHA regulated: No** **ACGIH: No** **National Toxicology Program: No**
International Agency for Research on Cancer:No
Cancer-suspect constituent(s) : None

Medical conditions which may be aggravated by exposure:
Preexisting eye and skin disorders (e.g. eczema). Development of preexisting skin or lung allergy symptoms may increase.

Other effects:
See section 11.

4. FIRST AID MEASURES

First aid for eyes:
Flush eye with clean water for at least 20 minutes while gently holding eyelids open, lifting upper and lower lids. Get immediate medical attention.

First aid for skin:
Immediately remove contaminated clothing and excess contaminant. Flush skin with water for at least 15 minutes. Wash thoroughly with soap and warm water. Consult a physician if irritation develops.

First aid for inhalation:
Remove patient to fresh air. Administer oxygen if breathing is difficult. Get medical attention if symptoms persist.

First aid for ingestion:
Do NOT induce vomiting. Rinse mouth out with water, then sip water to remove taste from mouth. Never give anything by mouth to an unconscious person. If vomiting occurs spontaneously, keep head below hips (if sitting) or to the side (if lying down) to prevent aspiration. Get medical attention.

5. FIRE FIGHTING MEASURES

Extinguishing media:
☐ Water ☒ Carbon dioxide ☒ Dry chemical ☒ Foam ☐ Alcohol foam

Flash Point (°F): >400 **Method:** PMCC

Explosive limits in air (percent) -- **Lower:** n/d **Upper:** n/d

Special firefighting procedures:
Material will not burn unless preheated. Do not enter confined space without full bunker gear. Firefighters should wear self-contained breathing apparatus and protective clothing. Cool fire exposed containers with water.

Unusual fire and explosion hazards:
Heating above 300 deg F in the presence of air may cause slow oxidative decomposition and above 500 deg F may cause polymerization. Personnel in vicinity and downwind should be evacuated.

Hazardous products of combustion:
When heated to decomposition it emits fumes of Cl- , carbon monoxide, other fumes and vapors varying in composition and toxicity.

6. ACCIDENTAL RELEASE MEASURES

Spill control:
Avoid personal contact. Eliminate ignition sources. Ventilate area.

Containment:
Dike, contain and absorb with clay, sand or other suitable material.

Cleanup:
For large spills, pump to storage/salvage vessels. Soak up residue with an absorbent such as clay, sand, or other suitable material and dispose of properly. Flush area with water to remove trace residue.

Special procedures:
Prevent spill from entering drainage/sewer systems, waterways, and surface waters. Collect run-off water and transfer to drums or tanks for later disposal. Notify local health authorities and other appropriate agencies if such contamination occurs.

7. HANDLING AND STORAGE

Handling precautions:
Avoid contact with skin, eyes, or clothing. Wash thoroughly with soap and water after using and particularly before eating, drinking, smoking, applying cosmetics, or using toilet facilities.
Launder contaminated clothing and protective gear before reuse. Discard contaminated leather articles.
Handle mixed resin and hardener in accordance with the potential hazard of the curing agent used. Provide appropriate ventilation/respiratory protection against decomposition products (see Section 10) during welding/flame cutting operations and to protect against dust during sanding/grinding of cured product.

Storage:
Store in a cool, dry area away from high temperatures and flames.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering controls

Ventilation :
Use ventilation that is adequate to keep employee exposure to airborne concentrations below exposure limits (or to the lowest feasible levels when limits have not been established). Although good general mechanical ventilation is usually adequate for most industrial applications, local exhaust ventilation is preferred (see ACGIH - Industrial Ventilation). Local exhaust may be required for confined areas (see OSHA 1910.146).

Other engineering controls :
Have emergency shower and eye wash available.

Personal protective equipment

Eye and face protection:
Chemical goggles if liquid contact is likely, or Safety glasses with side shields.

Skin protection:
Chemical-resistant gloves (i.e. butyl) and other gear as required to prevent skin contact.

Respiratory protection:
None needed in normal use with proper ventilation. In poorly ventilated areas use NIOSH approved organic vapor cartidge respirator for uncured resin, dust/particle respirator during grinding/sanding operations for cured resin, or fresh airline respirator as exposure levels dictate (see OSHA 1910.134).

9. PHYSICAL AND CHEMICAL PROPERTIES

Specific gravity:	1.1-1.3	**Boiling point (°F):**	>500
Melting point (°F):	n/d	**Vapor density (air = 1):**	>1
Vapor pressure (mmHg):	0.03 mm Hg at 171 °F	**Evaporation rate (butyl acetate = 1):**	<<1
VOC (grams/liter):	0	**Solubility in water:**	Negligible
Percent volatile by volume:	0	**pH (5% solution or slurry in water):**	neutral
Percent solids by weight:	100		

10. STABILITY AND REACTIVITY

This material is chemically stable. Hazardous polymerization will not occur.

Conditions to avoid :
Open flame and extreme heat

Incompatible materials:
Strong Lewis or mineral acids, strong oxidizing agents, strong mineral and organic bases (especially primary and secondary aliphatic amines).

Hazardous products of decomposition:
Oxides of carbon; aldehydes, acids and other organic substances may be formed during combustion or elevated temperature (>500 deg F) degradation.

Conditions under which hazardous polymerization may occur:
Heat is generated when resin is mixed with curing agents; Run-a-way cure reactions may char and decompose the resin, generating unidentified fumes and vapors which may be toxic.

11. TOXICOLOGICAL INFORMATION

Acute oral effects: LD50 (rat): Not available.

Acute dermal effects: LD50 (rabbit): Not available.

Acute inhalation effects: LC50 (rat): Not available. Exposure: 4 hours.

Eye irritation:
Not available.

Subchronic effects:
No data available.

Carcinogenicity, teratogenicity, and mutagenicity:
1) MUTAGENICITY: Liquid resins based on diglycidyl ether of Bisphenol A (DGEBPA), have proved to be inactive when tested by in vivo mutagenicity assays. These resins have shown activity in in vitro microbial mutagenicity

screening and have produced chromosomal aberrations in cultured rat liver cells. The significance of these tests to man is unknown. 2) CARCINOGENICITY: Recent 2-year bioassays in rats and mice exposed by the dermal route to DGEBPA yielded no evidence of carcinogenicity to the skin or any other organs. This study clarifies prior equivocal results from a 2-year mouse skin painting study, which were suggestive, but not conclusive, for weak carcinogenic activity. 3) The International Agency for Research on Cancer (IARC) concluded that DGEBPA is not classifiable as a carcinogen (IARC group 3), that is human and animal evidence of carcinogenicy is inadequate.

Other chronic effects:

Prolonged or repeated skin contact may cause sensitization, with itching, swelling, or rashes on later exposure. Studies have shown bisphenol A diglycidyl ether resin to cause allergic contact dermititis.

Toxicological information on hazardous chemical constituents of this product:

Constituent	Oral LD50 (rat)	Dermal LD50 (rabbit)	Inhalation LC50 4hr, (rat)
Bisphenol A diglycidyl ether resin	11.4 g/kg	>20 ml/kg	no deaths
Phenol, polymer with formaldehyde, glycidyl ether	> 5000 mg/kg	> 6000 mg/kg	> 1.7 mg/L

'n/d' = 'not determined'

12 ECOLOGICAL INFORMATION

Ecotoxicity:

No data available.

Mobility and persistence:

No data available.

Environmental fate:

No data available.

13. DISPOSAL CONSIDERATIONS

Please see also Section 15, Regulatory Information.

Waste management recommendations:

If this resin becomes a waste, it would not be a hazardous waste by RCRA criteria (40CFR 261). Dispose of according to applicable federal, state, and local regulations. Incineration is the preferred method of disposal.

14. TRANSPORT INFORMATION

Proper shipping name: Non-regulated
Technical name : N/A
Hazard class : N/A
UN number: N/A
Packing group: N/A
Emergency Response Guide no.: N/A
IMDG page number: N/A
Other: N/A

15. REGULATORY INFORMATION

U.S. Federal Regulations

TSCA
All ingredients of this product are listed, or are exempt from listing, on the TSCA inventory.

The following RCRA code(s) applies to this material if it becomes waste:
None

Regulatory status of hazardous chemical constituents of this product:

Constituent	Extremely Hazardous*	Toxic Chemical**	CERCLA RQ (lbs)	TSCA 12B Export Notification
Bisphenol A diglycidyl ether resin	No	No	0.0	Not required
Phenol, polymer with formaldehyde, glycidyl ether	No	No	0.0	Not required

*Consult the appropriate regulations for emergency planning and release reporting requirements for substances on the SARA Section 301 Extremely Hazardous Substance list.

**Substances for which the "Toxic Chemical" column is marked "Yes" are on the SARA Section 313 list of Toxic Chemicals, for which release reporting may be required. For specific requirements, consult the appropriate regulations.

For purposes of SARA Section 312 hazardous materials inventory reporting, the following hazard classes apply to this material: - Immediate health hazard -- Delayed health hazard -

Canadian regulations

WHMIS hazard class(es) : D2B
All components of this product are on the Domestic Substances List.

16. OTHER INFORMATION

Hazardous Materials Identification System (HMIS) ratings:	Health	Flammability	Reactivity
	2*	1	1

The information and recommendations in this document are based on the best information available to us at the time of preparation, but we make no other warranty, express or implied, as to its correctness or completeness, or as to the results of reliance on this document.

5-MINUTE EPOXY GEL HARDENER

This product appears in the following stock number(s):
14240 14240G 14265 5348 5368 DA052 DA221 DC048

Last revised: 08/12/02
Printed: 7/2/2004

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Tradename: 5-MINUTE EPOXY GEL HARDENER

General use: The following information applies to the hardener component of the two-part kit and to freshly mixed resin and hardener. After curing, 5-Minute Epoxy Gel is not hazardous.

Chemical family: Polymercaptan/polyamine mixture

MANUFACTURER

ITW Devcon
30 Endicott St.
Danvers, MA 01923

EMERGENCY INFORMATION

Emergency telephone number
(CHEMTREC): (800) 424-9300
Other Calls: (978) 777-1100

2. COMPOSITION/INFORMATION ON INGREDIENTS

HAZARDOUS CONSTITUENTS

Constituent	Abbr.	CAS No.	Weight percent	Exposure limits: ACGIH TLV	OSHA PEL	Other Limits
Mercaptan amine blend		*	30-50	n/e	n/e	n/e
Polymercaptan curing agent		*	50-60	n/e	n/e	n/e

"TLV" means the Threshold Limit Value exposure (eight-hour, time-weighted average, unless otherwise noted) established by the American Conference of Governmental Industrial Hygienists. "STEL" indicates a short-term exposure limit. "PEL" indicates the OSHA Permissible Exposure Limit."n/e" indicates that no exposure limit has been established. An asterisk (*) indicates a substance whose identity is a trade secret of our supplier and unknown to us.

3. HAZARDS IDENTIFICATION

Emergency Overview

Appearance, form, odor: Viscous, amber liquid with Mercaptan odor.

WARNING! Eye, skin and respiratory irritant. Potential skin sensitizer. Overexposure may cause delayed lung effects.

Potential health effects

Primary routes of exposure: ☒ Skin contact ☐ Skin absorption ☒ Eye contact ☒ Inhalation ☐ Ingestion

Symptoms of acute overexposure:

Skin: Can cause severe irritation, especially on prolonged contact. Potential sensitizer.
Eyes: Causes severe irritation with possible permanent damage and even blindness.

Inhalation:
Considered slightly toxic. Can cause irritation of respiratory tract. Over exposure to fumes or vapors may cause delayed lung injury and chemical pneumonia.

Ingestion:
Slightly toxic. May cause fatigue, muscle weakness, gastrointestinal irritation, nausea, vomiting and diarrhea.

Effects of chronic overexposure:
Prolonged or severe overexposure to DMP vapor can cause delayed lung damage and chemical pneumonia. Prolonged or repeated contact with this material may cause skin sensitization.

Carcinogenicity -- OSHA regulated: No **ACGIH: No** **National Toxicology Program: No**
International Agency for Research on Cancer:No
Cancer-suspect constituent(s) : None

Medical conditions which may be aggravated by exposure:
May aggravate existing skin, eye, and lung conditions.

4. FIRST AID MEASURES

First aid for eyes:
Flush eye with clean water for at least 15 minutes while gently holding eyelids open. Get immediate medical attention.

First aid for skin:
Remove contaminated clothing and shoes. Wash thoroughly with soap and warm water. Consult a physician if irritation develops.

First aid for inhalation:
Remove patient to fresh air. Provide oxygen if breathing is difficult. Consult a physician if symptoms persist.

First aid for ingestion:
Do not induce vomiting. Give large amounts of water followed by milk if available. Consult a physician.

5. FIRE FIGHTING MEASURES

General fire and explosion characteristics:
Class IIIB.

Extinguishing media:
☐ Water ☒ Carbon dioxide ☒ Dry chemical ☒ Foam ☐ Alcohol foam

Flash Point (°F): >200 **Method:** PMCC

Explosive limits in air (percent) -- Lower: n/d **Upper:** n/d

Special firefighting procedures:
Firefighters should wear self-contained breathing apparatus and protective clothing in confined areas. Cool containers with water spray.

Unusual fire and explosion hazards:
Toxic smoke and vapors may form during combustion.

Hazardous products of combustion:
Oxides of carbon, oxides of sulfur, oxides of nitrogen.

6. ACCIDENTAL RELEASE MEASURES

Spill control:
Avoid personal contact. Eliminate ignition sources. Ventilate area.

Containment:

Dike, contain and absorb with clay, sand or other suitable material.

Cleanup:

For large spills, pump to storage/salvage vessels. Soak up residue with an absorbent such as clay, sand, or other suitable material and dispose of properly. Flush area with water to remove trace residue. Clean-up waste water should be placed in appropriate containers for proper disposal.

Special procedures:

Prevent spill from entering drainage/sewer systems, waterways, and surface waters. Collect run-off water and transfer to drums or tanks for later disposal. Notify local health authorities and other appropriate agencies if such contamination occurs.

7. HANDLING AND STORAGE

Handling precautions:

Avoid contact with skin, eyes, or clothing. Wash thoroughly with soap and water after using and particularly before eating, drinking, smoking, applying cosmetics, or using toilet facilities.
Launder contaminated clothing and protective gear before reuse. Discard contaminated leather articles.
Handle mixed resin and hardener in accordance with the potential hazard of the curing agent used. Provide appropriate ventilation/respiratory protection against decomposition products (see Section 10) during welding/flame cutting operations and to protect against nuisance dust during sanding/grinding of cured product.

Storage:

Store in a cool, dry area away from high temperatures and flames. Keep container tightly closed when not in use.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering controls

Ventilation :

General mechanical ventilation is adequate for occasional use. For prolonged or repeated use, local exhaust is recommended.

Other engineering controls :

Have emergency shower and eye wash stations available.

Personal protective equipment

Eye and face protection:

Safety glasses with sideshields or chemical goggles.

Skin protection:

Chemical-resistant rubber (for example, neoprene, butyl rubber or nitrile) gloves and other protective gear as needed to prevent skin contact.

Respiratory protection:

None needed in normal use with proper ventilation. In poorly ventilated areas use NIOSH approved organic vapor cartidge respirator for uncured resin, dust/particle respirator during grinding/sanding operations for cured resin, or fresh airline respirator as exposure levels dictate (see OSHA 1910.134).

9. PHYSICAL AND CHEMICAL PROPERTIES

Specific gravity:	1.13	**Boiling point (°F):**	n/d
Melting point (°F):	n/d	**Vapor density (air = 1):**	n/d
Vapor pressure (mmHg):	<<1 at 70 °F	**Evaporation rate (butyl acetate = 1):**	n/d
VOC (grams/liter):	0	**Solubility in water:**	Negligible
Percent volatile by volume:	0	**pH (5% solution or slurry in water):**	9.5
Percent solids by weight:	100		

10. STABILITY AND REACTIVITY

This material is chemically stable. Hazardous polymerization will not occur.

Conditions to avoid :
Open flame and extreme heat.

Incompatible materials:
Strong oxidizing agents.

Hazardous products of decomposition:
Oxides of carbon, oxides of sulfur, oxides of nitrogen.

Conditions under which hazardous polymerization may occur:
Heat is generated when resin is mixed with curing agents; Run-a-way cure reactions may char and decompose the resin, generating unidentified fumes and vapors which may be toxic.

11. TOXICOLOGICAL INFORMATION

Acute oral effects: LD50 (rat): Not available.

Acute dermal effects: LD50 (rabbit): Not available.
Rabbit: Severe irritant;

Acute inhalation effects: LC50 (rat): Not available. Exposure: 0 hours.

Eye irritation:
Rabbit: Severe irritant.

Subchronic effects:
No data.

Carcinogenicity, teratogenicity, and mutagenicity:
No data.

Other chronic effects:
No data.

Toxicological information on hazardous chemical constituents of this product:

Constituent	Oral LD50 (rat)	Dermal LD50 (rabbit)	Inhalation LC50 4hr, (rat)
Mercaptan amine blend	n/d	n/d	n/d
Polymercaptan curing agent	n/d	n/d	n/d

'n/d' = 'not determined'

12 ECOLOGICAL INFORMATION

Ecotoxicity:
No data.

Mobility and persistence:
No data.

Environmental fate:
No data.

13. DISPOSAL CONSIDERATIONS

Please see also Section 15, Regulatory Information.

Waste management recommendations:
If this material becomes a waste, it would not be a hazardous waste by RCRA criteria (40CFR 261). Dispose of according to applicable federal, state, and local regulations.

14. TRANSPORT INFORMATION

Proper shipping name: Non-regulated
Technical name : N/A
Hazard class : N/A
UN number: N/A
Packing group: N/A
Emergency Response Guide no.: N/A
IMDG page number: N/A
Other: N/A

15. REGULATORY INFORMATION

U.S. Federal Regulations

TSCA
All ingredients of this product are listed, or are exempt from listing, on the TSCA inventory.

The following RCRA code(s) applies to this material if it becomes waste:
None

Regulatory status of hazardous chemical constituents of this product:

Constituent	Extremely Hazardous*	Toxic Chemical**	CERCLA RQ (lbs)	TSCA 12B Export Notification
Mercaptan amine blend	No	No	0.0	Not required
Polymercaptan curing agent	No	No	0.0	Not required

*Consult the appropriate regulations for emergency planning and release reporting requirements for substances on the SARA Section 301 Extremely Hazardous Substance list.

**Substances for which the "Toxic Chemical" column is marked "Yes" are on the SARA Section 313 list of Toxic Chemicals, for which release reporting may be required. For specific requirements, consult the appropriate regulations.

For purposes of SARA Section 312 hazardous materials inventory reporting, the following hazard classes apply to this material: - Immediate health hazard -- Delayed health hazard -

Canadian regulations

WHMIS hazard class(es) : D2B
All components of this product are on the Domestic Substances List.

16. OTHER INFORMATION

Hazardous Materials Identification System (HMIS) ratings:	Health	Flammability	Reactivity
	3*	1	1

The information and recommendations in this document are based on the best information available to us at the time of preparation, but we make no other warranty, express or implied, as to its correctness or completeness, or as to the results of reliance on this document.

OWEN COMPLIANCE SERVICES, INC.

Material Safety Data Sheet
(MSDS-BP)

PRODUCT IDENTIFICATION	
Product Name	BLACK POWDER
Trade Names and Synonyms	N/A
Manufacturer/Distributor	GOEX, Inc. (Doyline, LA) & various international sources
Transportation Emergency	**800-255-3924 (24 hrs — *CHEM • TEL*)**

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 handled and used following approved 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. 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.

HAZARDOUS COMPONENTS				
Material or Component	**%**	**CAS No.**	**TLV**	**PEL**
Potassium nitrate[1]	70-76	007757-79-1	NE	NE
Sodium nitrate[1]	70-74	007631-99-4	NE	NE
Charcoal	8-18	N/A	NE	NE
Sulfur	9-20	007704-34-9	NE	NE
Graphite[2]	Trace	007782-42-5	15 mppct (TWA)	2.5 mg/m^3
N/A = Not assigned NE = Not established				

1 Black Powder contains either potassium nitrate ***or*** sodium nitrate in the percentages indicated. Black powder ***does not contain both***.

2 Not contained in all grades of black powder.

PHYSICAL DATA	
Boiling Point	N/A
Vapor Pressure	N/A
Vapor Density	N/A
Solubility in Water	Good
Specific Gravity	1.70 - 1.82 (mercury method) ◆ 1.92 - 2.08 (pycnometer)
PH	6.0 - 8.0
Evaporation Rate	N/A
Appearance and Odor	Black granular powder. No odor detectable.

HAZARDOUS REACTIVITY	
Instability	Keep away from heat, sparks, and open flame. Avoid impact, friction, and static electricity.
Incompatibility	When dry, black powder is compatible with most metals; however, it is hygroscopic, and when wet, attracts all common metals except stainless steel. Black powder 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.
Hazardous decomposition	Detonation produces hazardous overpressures and fragments (if confined). Gases produced may be toxic if exposed in areas with inadequate ventilation.
Polymerization	Polymerization will not occur.

FIRE AND EXPLOSION DATA	
Flashpoint	Not applicable
Auto ignition temperature	Approx. 464°C (867°F)
Explosive temperature (5 sec)	Ignites @ approx. 427°C (801°F)
Extinguishing media	Water
Special fire fighting procedures	**ALL EXPLOSIVES: DO NOT FIGHT EXPLOSIVES FIRES.** Try to keep fire from reaching explosives. Isolate area. Guard against intruders. Division 1.1 Explosives (heavily encased): Evacuate the area for 5000 feet (1 mile) if explosives are heavily encased. Division 1.1 Explosives (not heavily encased): Evacuate the area for 2500 feet (½ mile) if explosives are not heavily encased. Division 1.1 Explosives (all): Consult the *2000 Emergency Response Guidebook, Guide 112* for further details.
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.

HEALTH HAZARDS	
General	Black powder is a Division 1.1 Explosive, and detonation may cause severe physical injury, including death. All explosives are dangerous and must be handled carefully and used following approved safety procedures under the direction of competent, experienced persons in accordance with all applicable federal, state, and local laws, regulations, and ordinances.
Carcinogenicity	None of the components of Black powder are listed as a carcinogen by NTP, IARC, or OSHA.

FIRST AID	
Inhalation	*Not a likely route of exposure*. If inhaled, remove to fresh air. If not breathing, give artificial respiration, preferably by mouth-to-mouth. If breathing is difficult, give oxygen. Seek prompt medical attention.
Eye and skin contact	*Not a likely route of exposure*. Flush eyes with water. Wash skin with soap and water.
Ingestion	*Not a likely route of exposure*.. If ingested, induce vomiting immediately by giving two glasses of water and sticking finger down throat.
Injury from detonation	Seek prompt medical attention.

SPILL OR LEAK PROCEDURES	
Spill/leak response	Use appropriate personal protective equipment. Isolate area and remove sources of friction, impact, heat, low level electrical current, electrostatic or RF energy. Only competent, experienced persons should be involved in cleanup procedures. Carefully pick up spills with non-sparking and non-static producing tools.
Waste disposal	Desensitize by diluting in water. Open train burning, by qualified personnel, may be used for disposal of small unconfined quantities. Dispose of in compliance with federal regulations under the authority of the *Resource Conservation and Recovery Act* (40 CFR Parts 260-271).

SPECIAL PROTECTION INFORMATION	
Ventilation	Use only with adequate ventilation.
Respiratory	None
Eye	None
Gloves	Impervious rubber gloves.
Other	Metal-free *and* non-static producing clothes

SPECIAL PRECAUTIONS

- Keep away from friction, impact, and heat. 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).

SHIPPING INFORMATION		
Proper shipping name	Black powder	
Hazard class	1.1D	
UN Number	UN0027	
DOT Label & Placard	DOT Label	EXPLOSIVE 1.1D
	DOT Placard	EXPLOSIVES 1.1
Alternate shipping information	Limited quantities of black powder may be transported as “Black powder, flammable solid” pursuant to U.S. Department of Transportation Exemption DOT-E 8958.	

For further information contact: David W. Boston, President
OWEN COMPLIANCE SERVICES, INC.
12001 County Road 1000
P.O. Box 765
Godley, TX 76044
Telephone number: 817-551-0660
FAX number: 817-396-4584

MSDS prepared by: David W. Boston
Original publication date: 12/08/93
Revision date: 12/03/03

MSDS# CO01

AGA

AGA GAS, INC. (216) 642-6600
6055 ROCKSIDE WOODS BLVD
P.O. BOX 94737
CLEVELAND, OH 44101-4737

DISTRIBUTED BY: PIONEER MANUFACTURING CO.
4529 INDUSTRIAL PARKWAY
CLEVELAND, OH 44135
TELEPHONE: 800-877-1500

MATERIAL SAFETY DATA SHEET

No. 015

PRODUCT NAME Carbon Dioxide (CO2 CYLINDER)	**CAS #** 124-38-9
TRADE NAME AND SYNONYMS Carbon Dioxide; Carbonic Anhydride	**DOT I.D. No.:** UN 1013
CHEMICAL NAME AND SYNONYMS Carbon Dioxide	**DOT Hazard Class:** Division 2.2
	Formula CO_2
ISSUE DATES AND REVISIONS Revised January 1995 CONFIRMED AS CURRENT ON: 6-6-00	**Chemical Family:** Carbonate

HEALTH HAZARD DATA

TIME WEIGHTED AVERAGE EXPOSURE LIMIT

5,000 Molar PPM; STEL = 30,000 Molar PPM (ACGIH 1994-1995). OSHA 1993 PEL (8 Hr. TWA) = 5,000 Molar PPM .

SYMPTOMS OF EXPOSURE

Inhalation: Low concentrations (3-5 molar %) cause increased respiration and headache.

Eight to 15 molar % concentrations cause headache, nausea and vomiting which may lead to unconsciousness if not moved to open air or given oxygen.

High concentrations cause rapid circulatory insufficiency leading to coma and death.

TOXICOLOGICAL PROPERTIES

Carbon oioxide is the most powerful cerebral vasodilator known. Inhaling large concentrations causes rapid circulatory insufficiency leading to coma and death. Chronic, harmful effects are not known from repeated inhalation of low (3-5 molar %) concentrations.

Carbon dioxide is not listed in the IARC, NTP or by OSHA as a carcinogen or potential carcinogen.

Persons in ill health where such illness would be aggravated by exposure to carbon dioxide should not be allowed to work with or handle this product.

RECOMMENDED FIRST AID TREATMENT

PROMPT MEDICAL ATTENTION IS MANDATORY IN ALL CASES OF OVEREXPOSURE TO CARBON DIOXIDE. RESCUE PERSONNEL SHOULD BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS.

Inhalation: Conscious persons should be assisted to an uncontaminated area and inhale fresh air. Quick removal from the contaminated area is most important. Unconscious persons should be moved to an uncontaminated area, given assisted respiration and supplemental oxygen. Assure that vomited material does not obstruct the airway by use of positional drainage. Further treatment should be symptomatic and supportive.

FOR CHEMICAL EMERGENCY
Call INFOTRAC
1-800-535-5053
24 Hrs. per day, 7 days per week

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES

Forms carbonic acid in the presence of water

PHYSICAL DATA

BOILING POINT Sublimation point = -109.3ºF (-78.5ºC)	LIQUID DENSITY AT BOILING POINT Solid Density = 97.5 lb/ft³(1562 kg/m³)
VAPOR PRESSURE @ 70ºF (21.1ºC) = 856 psia (5900 kPa)	GAS DENSITY AT 700F. 1 atm .124 lb/ft³ (1.99 kg/m³)
SOLUBILITY IN WATER Very Soluble	FREEZING POINT -69.8ºF (-56.6ºC) @ 75.1 psia (518 kPa)
EVAPORATION RATE N/A (Gas)	SPECIFIC GRAVITY (AIR=1) @ 70ºF (21.1ºC) = 1.65
APPEARANCE AND ODOR Colorless, odorless gas	

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used) N/A	AUTO IGNITION TEMPERATURE N/A	FLAMMABLE LIMITS % BY VOLUME (See Page 4) LEL N/A UEL N/A
EXTINGUISHING MEDIA Nonflammable, inert gas		ELECTRICAL CLASSIFICATION Nonhazardous
SPECIAL FIRE FIGHTING PROCEDURES None		
UNUSUAL FIRE AND EXPLOSION HAZARDS If cylinders are involved in a fire, safely relocate or keep cool with waier spray.		

REACTIVITY DATA

STABILITY		CONDITIONS TO AVOID
Unstable		None
Stable	X	
INCOMPATIBILITY (Materials to avoid) None		
HAZARDOUS DECOMPOSITION PRODUCTS Carbon Monoxide		
HAZARDOUS POLYMERIZATION		CONDITIONS TO AVOID
May Occur		None
Will Not Occur	X	

SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Evacuate all personnel from affected area. Use appropriate protective equipment. If leak is in user's equipment, be certain to purge piping with an inert gas prior to attempting repairs. If leak is in container or container valve, contact your closest supplier location or call the emergency telephone number listed herein.

WASTE DISPOSAL METHOD

Do not attempt to dispose of waste or unused quantities. Return in the shipping container properly labeled, with any valve outlet plugs or caps secured and valve protection cap in place to your supplier for proper disposal. For emergency disposal, contact your closest supplier location or call the emergency telephone number listed herein.

SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (Specify type)
Positive pressure air line with mask or self-contained breathing apparatus should be available for emergency use. (ContinuedonPage 4)

VENTILATION	LOCAL EXHAUST	SPECIAL
See Local Exhaust	To prevent accumulation above the TWA	N/A
	MECHANICAL (Gen.)	OTHER
	N/A	N/A

PROTECTIVE GLOVES
Any Material

EYE PROTECTION
Safety goggles or glasses

OTHER PROTECTIVE EQUIPMENT
Safety shoes

SPECIAL PRECAUTIONS*

SPECIAL LABELING INFORMATION

DOT Shipping Name:	Carbon Dioxide	DOT Hazard Class:	Division 2.2
DOT Shipping Label:	Nonflammable gas	I.D. No.:	UN 1013

SPECIAL HANDLING RECOMMENDATIONS

Use only in well-ventilated areas. Valve protection caps must remain in place unless container is secured with valve outlet piped to use point. Do not drag, slide or roll cylinders. Use a suitable hand truck for cylinder movement. Use a pressure reducing regulator when connecting cylinder to lower pressure (<1500 psig) piping or systems. Do not heat cylinder by any means to increase the discharge rate of product from the cylinder. Use a check valve or trap in the discharge line to prevent hazardous back flow into the cylinder.

For additional handling recommendations, consult Compressed Gas Association's Pamphlets P-1, G-6, G-6.1, and G-6.2.

SPECIAL STORAGE RECOMMENDATIONS

Protect cylinders from physical damage. Store in cool, dry, well-ventilated area away from heavily trafficked areas and emergency exits. Do not allow the temperature where cylinders are stored to exceed 125ºF (52ºC). Cylinders should be stored upright and firmly secured to prevent falling or being knocked over. Full and empty cylinders should be segregated. Use a "first in - first out" inventory system to prevent full cylinders being stored for excessive periods of time.

For additional storage recommendations, consult Compressed Gas Association's Pamphlets P-1, G-6, G-6.1, and G-6.2

SPECIAL PACKAGING RECOMMENDATIONS

Dry carbon dioxide can be handled with most common structural materials. Moist carbon dioxide is corrosive by its formation of carbonic acid. For these applications, 316, 309 and 310 stainless steels may be used as well as Hastelloy® A, B and C and Monel®. Ferrous nickel alloys are slightly corroded.

At normal temperatures carbon dioxide is compatible with most plastics and elastomers.

OTHER RECOMMENDATIONS OR PRECAUTIONS

Compressed gas cylinders should not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with his (written) consent is a violation of Federal Law (49CFR).

(Continued on Page 4)

*Various Government Agencies (i.e. Department of Transportation, Occupational Safety and Health Administration, Food and Drug Administration and others) may have specific regulations concerning the transportation, handling, storage or use of this product which will not be reflected in this data sheet. The customer should review these regulations to ensure that he is in full compliance.

SPECIAL PRECAUTIONS

OTHER RECOMMENDATIONS OR PRECAUTIONS: (Continued)

Always secure cylinders in an upright position before transporting them. NEVER transport cylinders in trunks of vehicles, enclosed vans, truck cabs or in passenger compartments. Transport cylinders secured in open flatbed or in open pick-up type vehicles.

Reporting under SARA, Title III, Section 313 not required.

NFPA 704 No. for gaseous carbon dioxide = 2 0 0 None

MSDS

SECTION 1 – Chemical Product and Company Identification

J-B Weld Company

P.O. Box 483
1130 Como Street
Sulphur Springs, TX 75482
Tel: (903) 885-7696
Fax: (903) 885-5911

PRODUCT NAME:	**JB Weld Epoxy Steel Hardener**
PRODUCT CODE:	**(48008), 48105, 48155, 48171**
SYNONYM/CROSS REFERENCE:	**Epoxy Steel Hardener**
SCHEDULE B NUMBER:	**3214.10.0090**

SECTION 2 – Hazard Identification

OVEREXPOSURE EFFECTS:
ACUTE EFFECTS:
EYES: Contact with eyes can cause severe irritation, possible irreparable eye damage.
SKIN: Contact with skin can cause irritation, (minor itching, burning and/or redness), Dermatitis, defatting may be readily absorbed through the skin.
INHALATION: Inhalation of vapors can cause nasal and respiratory irritation, dizziness, weakness, fatigue, nausea, headache, possible unconsciousness and/or asphyxiation. Aspiration of material into lungs may result in chemical pneumonitis which can be fatal.
INGESTION: Ingestion can cause gastrointestinal irritation, nausea, vomiting, diarrhea.

PRIMARY ROUTES OF EXPOSURE: skin, inhalation

SECTION 3 – Composition, Information or Ingredients

INGREDIENTS	WGT%	CAS #
Furfuryl Alcohol	1-5%	98-00-0
Calcium Carbonate	5-10%	1317-65-3, 471-34-1
Non-fibrous Talc	15-25%	14807-96-6
Barium Sulfate	20-30%	7727-43-7
Aminophenols	1-5 %	Mixture
Polyamide Resin	15-25%	68410-23-1
Titanium Dioxide	1-5%	13463-67-7

SECTION 4 – First Aid Measures

INHALATION: If inhaled, remove victim from exposure to a well-ventilated area. Make them comfortably warm, but not hot. Use oxygen or artificial respiration as required. Consult a physician.
SKIN: For skin contact, wash promptly with soap and excess water.
EYES: For eye contact, flush promptly with excess water for at least fifteen minutes. Consult a physician.
INGESTION: If ingested, do not induce vomiting. Give victim a glass of water. Call a physician immediately.

MSDS

SECTION 5 – Fire-Fighting Measures

FLASH POINT: >200°F/93°C Seta Flash Closed cup
LOWER FLAMMABLE LIMIT %: N/E
UPPER FLAMMABLE LIMIT %: N/E
FIRE EXTINGUISHING MEDIA: Carbon Dioxide, Dry Chemical, Foam
SPECIAL FIRE FIGHTING PROCEDURES: Fight like a fuel oil fire. Cool fire exposed containers with water spray. Firefighter should wear OSHA/NIOSH approved self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARD: Closed containers exposed to high temperatures, such as fire conditions may rupture.

SECTION 6 – Accidental Release Measures

SPILLS, LEAK OR RELEASE: Ventilate area. Remove all possible sources of ignition. Avoid prolonged breathing of vapor. Contain spill with inert absorbent.

SECTION 7 – Handling and Storage

STORAGE AND HANDLING: Use with adequate ventilation. Avoid contact with eyes and skin. Avoid breathing vapors. Do not store the product above 100°F/38°C. Do not flame, cut, braze weld or melt empty containers. Keep the product away from heat, open flame, and other sources of ignition. Avoid contact with strong acids, alkalis, and oxidizers.

SECTION 8 – Exposure Controls and Personal Protection

INGREDIENTS	CAS #	TLV/PEL
Calcium Carbonate	1317-65-3 471-34-1	ACGIH TWA 10 mg/m^3 OSHA PEL 15 mppcf
Non-fibrous Talc	14807-96-6	ACGIH TWA 2 mg/m^3 OSHA PEL 20 mppcf
Barium Sulfate	7727-43-7	ACGIH TWA 10 mg/m^3 OSHA 15 mg/m^3 Total dust OSHA 15 mg/m^3 Respirable dust
Aminophenols	Mixture	N/E
Polyamide Resin	68410-23-1	N/E
Titanium Dioxide	13463-67-7	ACGIH TWA 10 mg/m^3 OSHA PEL 20 mg/m^3
Furfuryl Alcohol	98-00-0	ACGIH TWA 10 ppm

RESPIRATORY PROTECTION: If component TLV limits are exceeded, use NIOSH/MSHA approved respirator to remove vapors. Use an air-supplied respirator if necessary.
VENTILATION: Use adequate ventilation in volume and pattern to keep TLV/PEL below recommended levels. Explosion-proof ventilation may be necessary.
PROTECTIVE GLOVES: To prevent prolonged exposure use rubber gloves; solvents may be absorbed through the skin.
EYE PROTECTION: Safety Glasses or goggles with splash guards or side shields.
OTHER PROTECTIVE EQUIPMENT: Wear protective clothing as required to prevent skin contact.

<u>MSDS</u>

<u>ACTION 9 – Physical and Chemical Properties</u>

APPEARANCE: White Paste
SPECIFIC GRAVITY: 1.78
VAPOR PRESSURE (mmHG): Heavier than air
BOILING POINT: N/Av
VAPOR DENSITY: Heavier than air
EVAPORATION RATE (Ethyl Ether = 1): Slower than Ethyl Ether
VOLATILES BY WEIGHT:
SOLUBILITY IN WATER: None
VOC: Grams/Liter = 72
Lbs/Gallon = 0.6

<u>SECTION 10 – Stability and Reactivity</u>

STABILITY: Stable
CONDITIONS TO AVOID: Open flames, sparks, heat, electrical and static discharge.
INCOMPATIBILITY MATERIALS TO AVOID: Strong acids, alkalis, oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon Dioxide, Carbon Monoxide, and Carbon.
HAZARDOUS POLYMERIZATION: Will not occur.

<u>SECTION 11 – Toxicological Information</u>

CHRONIC EFFECTS:
Overexposure to this material has apparently been known to cause the following effects in lab animals: Eye, skin, lung, and central nervous system damage.

CARCINOGEN: YES __ NO <u>X</u>
TERATOGEN: YES __ NO <u>X</u>
MUTAGEN: YES __ NO <u>X</u>

<u>SECTION 12 – Ecological Information</u>

NOT A MARINE POLLUTANT

<u>SECTION 13 – Disposal Considerations</u>

WASTE DISPOSAL: Dispose of in accordance with local, state, and federal regulations.

<u>SECTION 14 – Transport Information</u>

For Ground Transport: In USA
Not Regulated

For Air Transport:
Not Regulated

For Ocean Transport:
Not Regulated

MSDS

SECTION 15 – Regulatory Information

CALIFORNIA PROPOSITION 65:
Trace amounts of some chemicals known to the State of California to cause cancer, birth defects, or other reproductive harm may be present in this product.

SECTION 313 SUPPLIER NOTIFICATION:
This product contains the following toxic chemicals subject to the reporting requirements of the Emergency Planning and Community Right-To-Know Act of 1986 and 40 CFR 372:

CHEMICAL NAME	CAS	% BY WGT

N/Ap

This information must be included in all MSDS that are copied and distributed for this chemical.

SECTION 16 – Other Information

HMIS RATING:	Health	2	4 = Extreme
	Fire	1	3 = High
	Reactivity	1	2 = Moderate
			1 = Slight
			0 = Insignificant

Personal Protection - See Section VIII

ABBREVIATIONS

IARC	= International Agency for Research on Cancer
ACGIH	= American Conference of Governmental Industrial Hygienists
NIOSH	= National Institute of Occupational Safety and Health
TLV	= Threshold Limit Value
PEL	= Permissible Emission Level
DOT	= Department of Transportation
NTP	= National Toxicology Program
N/AV	= Not Available
N/AP	= Not Applicable
N/E	= Not Established
N/D	= Not Determined

<u>MSDS</u>

PREPARED BY: J-B Weld Company

P.O. Box 483
1130 Como Street
Sulphur Springs, TX 75482
Tel: (903) 885-7696
Fax: (903) 885-5911

DATE REVIEWED: February 6, 2009
DATE REVISED: February 6, 2009
REVISION: New Format

The information in the Material Safety Data Sheet has been compiled from our experience and from data presented in various technical publications. It is the user's responsibility to determine the suitability of this information for the adoption of the safety precautions as may be necessary. We reserve the right to revise Material Safety Data Sheets from time to time as new technical information becomes available. The user has the responsibility to contact the Company to make sure that the MSDS is the latest one issued.

J-B Weld Company

P.O. Box 483
1130 Como Street
Sulphur Springs, TX 75482
Tel: (903) 885-7696
Fax: (903) 885-5911

SECTION I - IDENTIFICATION OF PRODUCT

PRODUCT NAME:	JB WELD - EPOXY STEEL RESIN
PRODUCT CODE:	(48009), 48102, 48153, 48170
SYNONYM/CROSS REFERENCE:	Resin Solution
SCHEDULE B NUMBER:	3506.91.0000

SECTION II - HAZARDOUS INGREDIENTS

INGREDIENTS	WGT%	CAS #	TLV/PEL
Calcium Carbonate	40-50%	1317-65-3	ACGIH: TWA 10 mg/m^3 OSHA: PEL 15 mppcf
Iron Powder	10-20%	65997-19-5	ACGIH TLV 15 mg/m^3 OSHA: PEL 15 mppcf
Epoxy Resin	30-40%	25068-38-6	N/E
Aromatic Hydrocarbons	1-5 %	64742-94-5	N/E

SECTION III - PHYSICAL DATA

APPEARANCE: Dark gray or black smooth paste
SPECIFIC GRAVITY: 1.80
VAPOR PRESSURE (mmHG): N/Av
BOILING POINT: N/E
VAPOR DENSITY: Heavier than air
EVAPORATION RATE (Ethyl Ether = 1): Slower than Ethyl Ether
VOLATILES BY WEIGHT: N/D
SOLUBILITY IN WATER: Not Soluble
VOC: Grams/Liter = Nil
Lbs/Gallon = Nil

SECTION IV - FIRE AND EXPLOSION DATA

FLASH POINT: >200°F/ 93°C Seta Flash Closed cup
LOWER FLAMMABLE LIMIT %: N/E
UPPER FLAMMABLE LIMIT %: N/E
FIRE EXTINGUISHING MEDIA: Carbon Dioxide, Dry Chemical, Foam
SPECIAL FIRE FIGHTING PROCEDURES: Fight like a fuel oil fire. Cool fire exposed containers with water spray. Firefighter should wear OSHA/NIOSH approved self-contained breathing apparatus.
UNUSUAL FIRE AND EXPLOSION HAZARD: Closed containers exposed to high temperatures, such as fire conditions may rupture.

SECTION V - HEALTH HAZARD/TOXICOLOGICAL PROPERTIES

OVEREXPOSURE EFFECTS:

ACUTE EFFECTS:

EYES: Contact with eyes can cause irritation, redness, tearing, blurred vision, and/or swelling.
SKIN: Contact with skin can cause irritation, (minor itching, burning and/or redness), Dermatitis, defatting may be readily absorbed through the skin.
INHALATION: Inhalation of vapors can cause nasal and respiratory irritation, dizziness, weakness, fatigue, nausea, headache, possible unconsciousness and/or asphyxiation. Aspiration of material into lungs may result in chemical pneumonitis which can be fatal.
INGESTION: Ingestion can cause gastrointestinal irritation, nausea, vomiting, diarrhea.

CHRONIC EFFECTS:
Overexposure to this material has apparently been known to cause the following effects in lab animals: skin sensitization, respiratory system irritation.

CARCINOGEN: YES ____ NO __X__
TERATOGEN: YES ____ NO __X__
MUTAGEN: YES ____ NO __X__

PRIMARY ROUTES OF EXPOSURE: skin, inhalation, eyes

FIRST AID:

INHALATION: If inhaled, remove victim from exposure to a well-ventilated area. Make them comfortably warm, but not hot. Use oxygen or artificial respiration as required. Consult a physician.
SKIN: For skin contact, wash promptly with soap and excess water.
EYES: For eye contact, flush promptly with excess water for at least fifteen minutes. Consult a physician.
INGESTION: If ingested, do not induce vomiting. Give victim a glass of water. Call a physician immediately.

SECTION V I - REACTIVITY DATA

STABILITY: Stable
CONDITIONS TO AVOID: Open flames & heat. .
INCOMPATIBILITY MATERIALS TO AVOID: Strong acids, alkalis, oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Carbon Dioxide, Carbon Monoxide and Carbon.
HAZARDOUS POLYMERIZATION: Will not occur.

SECTION VII - SPILL AND DISPOSAL PROCEDURE

SPILLS, LEAK OR RELEASE: Ventilate area. Remove all possible sources of ignition. Avoid prolonged breathing of vapor. Contain spill with inert absorbent.
WASTE DISPOSAL: Dispose of in accordance with local, state, and federal regulations.

SECTION VIII - PROTECTION INFORMATION

RESPIRATORY PROTECTION: If component TLV limits are exceeded, use NIOSH/MSHA approved respirator to remove vapors. Use an air-supplied respirator if necessary. With general ventilation, does not require a respirator.
VENTILATION: Use adequate ventilation in volume and pattern to keep TLV/PEL below recommended levels.
PROTECTIVE GLOVES: To prevent prolonged exposure use rubber gloves; solvents may be absorbed through the skin
EYE PROTECTION: Safety Glasses or goggles with splash guards or side shields.
OTHER PROTECTIVE EQUIPMENT: Wear protective clothing as required to prevent skin contact.

SECTION IX - HANDLING AND STORAGE PRECAUTIONS

STORAGE AND HANDLING: Use with adequate ventilation. Avoid contact with eyes and skin. Avoid breathing vapors. Do not store the product above 100®F/38®C. Do not flame, cut, braze weld or melt empty containers. Keep the product away from heat, open flame, and other sources of ignition. Avoid contact with strong acids, alkalis and oxidizers.

SECTION X - ADDITIONAL INFORMATION

SHIPPING INFORMATION: Please comply with DOT regulations in USA

HMIS RATING:	Health	2	4 = Extreme
	Fire	1	3 = High
	Reactivity	1	2 = Moderate
			1 = Slight
			0 = Insignificant

Personal Protection - See Section VIII

CALIFORNIA PROPOSITION 65:

Trace amounts of epichlorohydrin, a chemical known to the State of California to cause cancer, are present in this product. However, given the low level and application of this product, typical uses do not constitute a significant risk under the standard.

SECTION 313 SUPPLIER NOTIFICATION:

This product contains the following toxic chemicals subject to the reporting requirements of the Emergency Planning and Community Right-To-Know Act of 1986 and 40 CFR 372:

CHEMICAL NAME	CAS	% BY WGT

Not Applicable

THIS INFORMATION MUST BE INCLUDED IN ALL MSDS THAT ARE COPIED AND DISTRIBUTED FOR THIS CHEMICAL

ABBREVIATIONS

IARC = International Agency for Research on Cancer
ACGIH = American Conference of Governmental Industrial Hygienists
NIOSH = National Institute of Occupational Safety and Health
TLV = Threshold Limit Value
PEL = Permissible Emission Level
DOT = Department of Transportation
NTP = National Toxicology Program
N/AV = Not Available
N/AP = Not Applicable
N/E = Not Established
N/D = Not Determined

PREPARED FOR: **J-B Weld Company**

P.O. Box 483
1130 Como Street
Sulphur Springs, TX 75482
Tel: (903) 885-7696
Fax: (903) 885-5911

REVIEWED ON	May 17, 2004
SUPERSEDES	March 1, 2003
REVISION	Format

The information in the Material Safety Data Sheet has been compiled from our experience and from data presented in various technical publications. It is the user's responsibility to determine the suitability of this information for the adoption of the safety precautions as may be necessary. We reserve the right to revise Material Safety Data Sheets from time to time as new technical information becomes available. The user has the responsibility to contact the Company to make sure that the MSDS is the latest one issued.

D. Low Explosives User Permit

STEPHEN A WHITMORE

Responsible Person Letter of Clearance for:

U.S. Department of Justice
Bureau of Alcohol, Tobacco, Firearms and Explosives
Federal Explosives Licensing Center
244 Needy Road
Martinsburg, West Virginia 25405

901090: CRR/FLS
5400
File Number: 9UT00363

02/07/2008

SUBJECT: **RESPONSIBLE PERSON LETTER OF CLEARANCE for:**

STEPHEN A WHITMORE 11/19/1956 287943765

FACULTY ADVISOR
(435)753-3699

1691 MT LOGAN DRIVE
LOGAN, UT 84321

and is ONLY valid under the following Federal explosives license/permit:

9-UT-005-34-1C-00363

UTAH STATE UNIVERSITY
USA CHIMAERA
4130 OLD MAIN HILL
LOGAN, UT 84322

Dear STEPHEN WHITMORE:

You have been approved as a responsible person under the above-listed Federal explosive license or permit. You may lawfully direct the management or policies of the business or operations as they pertain to explosives. You may also lawfully transport, ship, receive or possess explosive materials incident to your duties as a responsible person. **This clearance is only valid under the license or permit referenced above.**

Sincerely,

Christopher R. Reeves

Christopher R. Reeves
Chief, Federal Explosives Licensing Center (FELC)

FELC Customer Service. If you believe that information on your "Letter of Clearance" is incorrect, please return a COPY of the letter to the Chief, Federal Explosives Licensing Center (FELC), with a statement showing the nature of the error. The Chief, FELC, shall correct the error, and return an amended letter to you.

Mail: ATF
Chief, FELC
Attn.: LOC Correction
244 Needy Road
Martinsburg, West Virginia 25405

Fax: 1-304-616-4401
Chief, FELC
Attn.: LOC Correction

Call toll-free: 1-877-283-3352

9UT00363-R-02/07/2008-287943765-WHITMORE-STEPHEN-A-11/19/1956-FACULTY ADVISOR

WWW.ATF.GOV

DEPARTMENT OF THE TREASURY - BUREAU OF ALCOHOL, TOBACCO AND FIREARMS

LICENSE/PERMIT (18 U.S.C. CHAPTER 40, EXPLOSIVES)

In accordance with the provisions of Title XI, Organized Crime Control Act of 1970, and the regulations issued thereunder (27 CFR Part 555)you may engage in the activity specified in this license/permit within the limitations of Chapter 40, Title 18, United States Code and the regulations issued thereunder, until the expiration date shown. See "WARNING" and "NOTICES" on back.

DIRECT ATF CORRESPONDENCE TO

Christopher R. Reeves
Chief, Federal Explosives Licensing Center (FELC)
Bureau of Alcohol, Tobacco, Firearms and Explosives
244 Needy Road
Martinsburg, West Virginia 25405
Telephone: 1-877-283-3352 Fax: 1-304-616-4401

LICENSE/PERMIT NUMBER: **9-UT-005-34-1C-00363**

EXPIRATION DATE: **March 1, 2011**

NAME

USA CHIMAERA

Premises Address CHANGES? You must notify the FELC at least 10 days before the move.

4130 OLD MAIN HILL
LOGAN, UT 84322-

TYPE OF LICENSE OR PERMIT

34-USER OF LOW EXPLOSIVES

CHIEF, FEDERAL EXPLOSIVES LICENSING CENTER (FELC) Christopher R. Reeves

Christopher R. Reeves

PURCHASING CERTIFICATION

I certify that this is a true copy of a license/permit issued to me to engage in the activity specified.

(SIGNATURE OF LICENSEE/PERMITTEE)

Mailing Address CHANGES? You must notify the FELC at least 10 days befo. re the change.

UTAH STATE UNIVERSITY
USA CHIMAERA
4130 OLD MAIN HILL
LOGAN, UT 84322-

The licensee/permittee named herein shall use a reproduction of this license/permit to assist a transferor of explosives to verify the identity and status of the licensee/permittee as provided in 27 CFR Part 555. The signature on each reproduction must be an ORIGINAL signature.

ATF F 5400.14/5400.15, Part 1 (8/89)

E. Contact Information

Rachel Curry	Chemical Hygienist	(435) 797-7423	rachell.curry@usu.edu
Eric Jorgensen	Asst. Director, Environmental Affairs (DOT Issues)	(435) 797-2856	ericj@cc.usu.edu
Raymond Cartee	Director of Research Firms	(435) 797-2209	
Tim Boschert	Tripoli Utah Prefect	(801) 274-8076	tboschert@utah.gov

F. Huntsville Area Rocketry Association Consent Form

Huntsville Area Rocketry Association Safety Regulations

As a member of the Utah State University Chimaera Rocket team I, ___________________________
(print name)
understand that the Huntsville Area Rocketry Association (HARA) will regulate all aspects of launch site safety on the day of the competition launch, and I agree to abide by the following regulations:

1. HARA will provide range safety inspections of each rocket before it is flown and the USU team will comply with said inspection determination.

2. The HARA Range Safety Officer has the final say on all rocket safety issues, and has the ability to deny the launch based on safety reasons.

3. If the team is in noncompliance with the safety and mission assurance, the rocket will not be launched.

____ __________________
Signature Date

G. Identified Hazards

1. motor ignites in transit
2. motor ignites on the launch pad
3. rocket is unstable, flies out of control
4. black powder ignites while loading deployment charges
5. test stand cannot hold motor
6. CO_2 tank dropped and the valve cracks, turning the CO_2 tank into a projectile.
7. exploding batteries

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