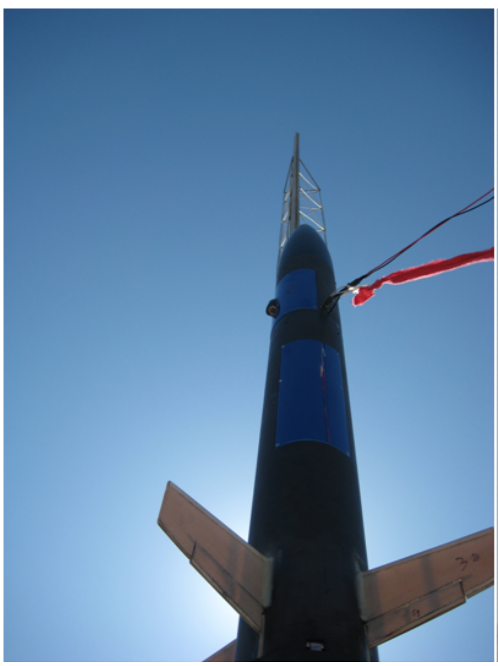
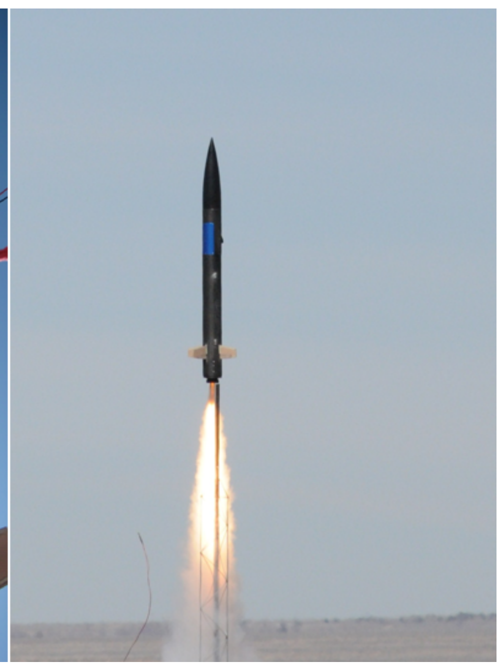
CHIMAERA
EXPERIMENTAL HYBRID ROCKETRY

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

Utah State University Chimaera Project





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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 (USU) in Logan, Utah. The rocket from Utah State is 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 a total launch weight of 12.48 kg. The aft section of the rocket houses the Cesaroni L730 solid propellant motor and cold-gas base-bleed augmentation system (C-BAS) payload. The C-BAS will be used to manage the total mass-specific energy of the vehicle to control the achievable apogee altitude. Both the solid motor and C-BAS will be tested exstensively to verify their available impulse levels are sufficient to meet mission objectives. The avionics section, located near the forward end of the rocket just behind the nosecone, will house flight instrumentation. The avionics suite includes 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 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 in section IV of this design document. The rocket body will be made from Blue Tube 2.0^{TM}.[a] The Blue Tube has been tested and shown capable of withstanding the maximum loads encountered during flight. The recovery system is a dual redundant deployment system using nylon parachutes with Kevlar harnesses sized to keep the descent rate within the specified ranges. The drogue parachute is 2.5 ft in diameter and the main parachute is 10 ft in diameter. The Javelin will launch on the same rail used by the 2009 USU Rocket Team. The rail is made of aluminum and is 4.5 meters in total length. The launch rail is an integral part of the trailer used to transport the Javelin.

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 aerodynamic drag. At different waypoints during flight, the on-board avionics will calculate the energy lost due to aerodynamic 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 flight measurements of plume-induced compression for an over-expanded aerospike nozzle. These measurements will 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 Preliminary Design Review

The overall design of the Javelin has remained consistant, however the design of individual components have been significantly improved since USU's preliminary design review. The primary changes and improvements to the Javelin include the following: selection of primary motor canidate by simulation, selection of C-BAS components for energy augmentation system, prototypes of various parts created, testing of various different components, and simulations updated to calculate constants used to write in-flight algorithms.

II.A. Vehicle Criteria

- Javelin's primary motor candidate Cesaroni L820 was replaced with the Cesaroni L730. This change was done as the CS L820 expels titanium and has a skid mark fuel grain which isn't permitted at USLI. This change was requested by NASA at the PDR.
- The Cesaroni L730 was chosen using 3-degree of freedom ballistic simulations, high fidelity mass budget trade studies, and by eliminating other possible motor candidates not meeting mission objectives.
- The motor size has changed from 75 mm to 54 mm in diameter.
- The Javelin's total length has increased from 7.09 ft to 7.40 ft to accommodate the longer Cesaronoi L730 motor.
- The L730 features a 6-grain propellant, where the L820 the team was originally using was a 3-grain propellant.
- USU rocket team concluded trade studies on system components and increased the fidelity of Javelin's mass budget.
- Blue Tube was tested to verify the body tube would meet mission requirements. Bulkhead mounting strength and body tube compression testing were performed on the Blue Tube.
- The recovery system was designed and optimized using spreadsheet calculations and verified by simulation to size the drogue and main parachute sizes to give appropriate descent rates and opening loads. The drogue parachute has 6 gores and is 2.5 ft in diameter. The main parachute has 16 gores and is 10.0 ft in diameter.
- Test stand built to verify solid motor propellant impulse and thrust levels.
- The launch ignition system was built and tested to ensure safety and ignition switches all function properly.
- Rocket design simulations were updated to include the following: variable thrust profile, pressure/thrust compensation as a function of altitude, C-BAS system, downrange calculations, lift and drag calculations, and a compressibility correction added on the pressure drag coefficient.
- Missile DAT-COM was used to calculate the aerodynamic coefficients: C_L,C_D, C_M, and C_p.
- Parachute opening loads and wind-drift calculations were added to the flight simulation.

II.B. Payload Criteria

- Test stand was created to allow for verification of the C-BAS.
- The CO_2 tanks were tested to measure mass flow rate when the regulator was set to 450 psi.
- The supporting structure for the CO_2 tank was designed for Javelin installation.
- A C-BAS prototype was manufactured, assembled, and initial tests performed using compressed air to check for leakage problems.
- All references 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 team continues to honor these regulations by referencing payload technology as the "cold-gas base-bleed augmentation system" (C-BAS).

II.C. Activity Plan

- No major changes have been made by the Utah State University rocket team at this time regarding the proposed activity plan as outlined in the proposal.
- Various educational engagement activities have been planned and performed by team members.
- Website has been updated to include all business sponsors, and educational engagement activities.
- "Frequently Asked Questions" page added for educational engagement questions.
- "Analysis and Test" page added to show what the team is currently working on in order to ensure the Javelin will win the USLI Competition.

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

II.D.1. Introduction and Mission Statement

The Chimaera Rocket Team's mission is to design and build a recoverable, reusable rocket that will carry an engineering payload to an altitude within meters of one mile. This objective will be achieved through careful design, manufacture and testing of the rocket. A cold gas base-bleed energy augmentation system (C-BAS), composed of mechanical CO_2 base-bleed hardware, associated avionics, and energy management algorithms serves as the engineering payload for this project. Valuable in-flight data will be collected from the C-BAS payload.

The CO_2-based system will vent the cold inert gas through a novel isentropic expansion ramp, patterned after a linear aerospike nozzle. This sophisticated energy management system is able to increase the overall energy of the rocket, regulating the apogee altitude and allowing the rocket to hone in on the one mile target altitude. Sensors mounted to the ramp assembly will obtain important first time, in-flight pressure data on the linear aerospike-type expansion ramp.

II.D.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 1. The top-level USLI rules mandated by the competition are strictly observed in the design and construction of the rocket, as are all NAR and NFPA codes regulating 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 of the rocket; 3. Gathering good in-flight pressure data along the isentropic expansion ramps. 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 1: Overview of key requirements.

II.D.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 facilitate decisions, and a later high fidelity and verification phase to ensure the requirements are met. The major milestones are depicted in Figure 2. 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.

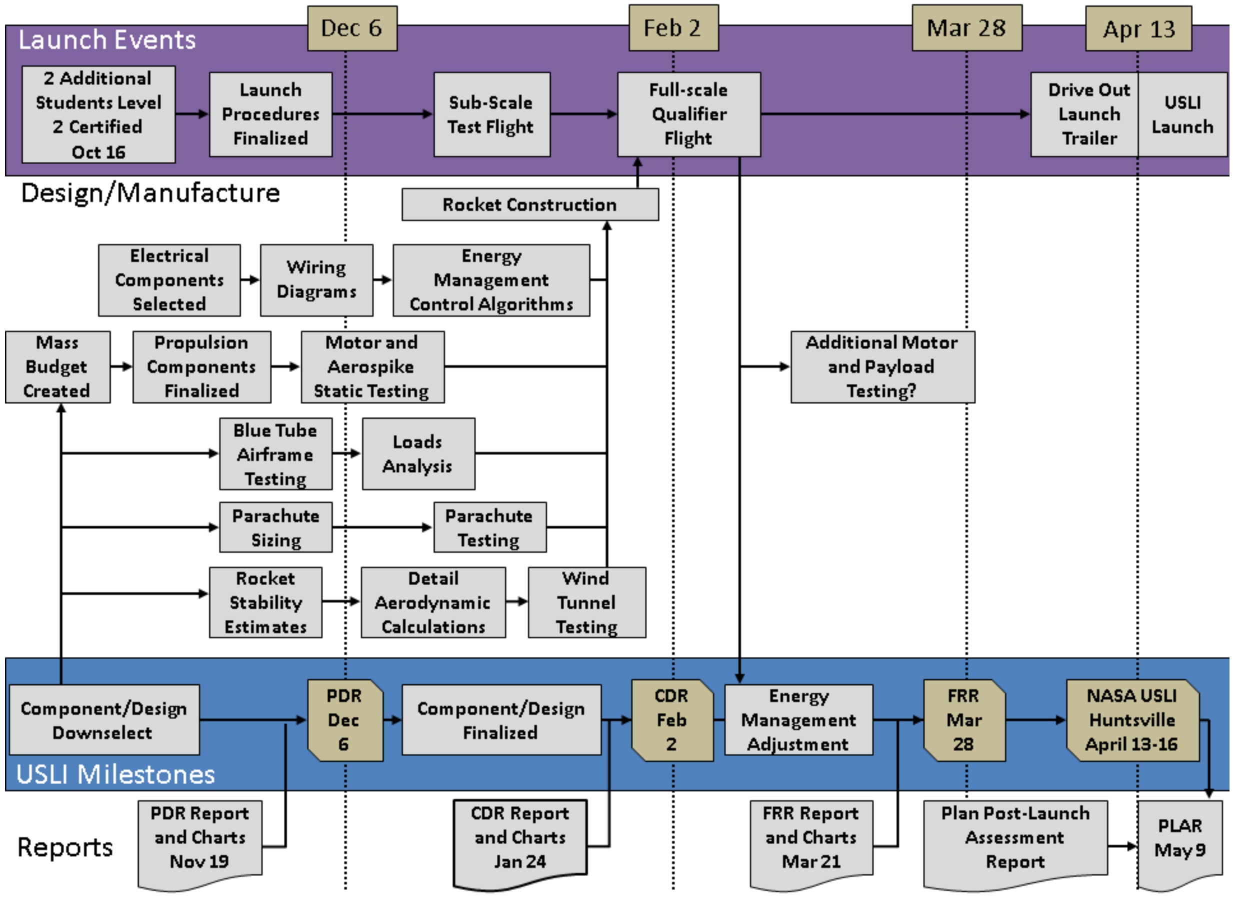


Figure 2: Milestone map.

II.D.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 included an inertial measurement unit (IMU), a 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 3 shows this concept of operations (CONOPS).

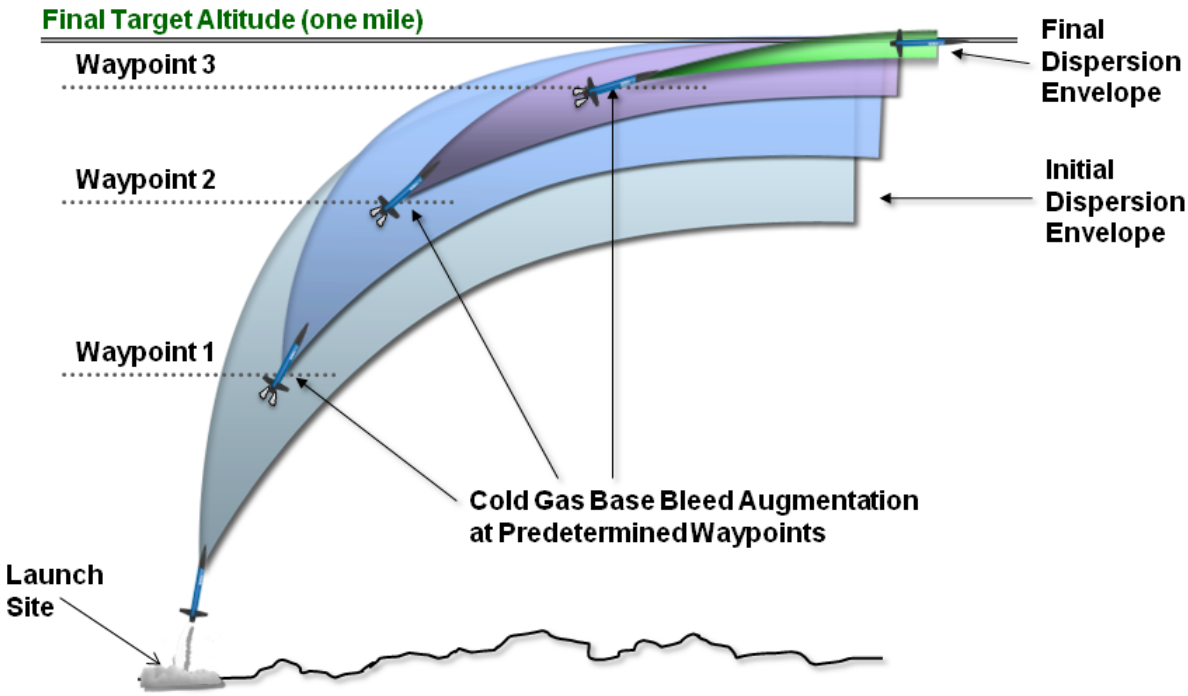


Figure 3: Concept of operations.

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 in on 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 and testing performed before FRR will outline the final details of this process. The following sections 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 4 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 avoids extra drag, is a simple design, and is low cost.[1] The parachutes are attached to the nose cone and the bulkheads transmitting opening loads. Figure 4 also shows the C-BAS integrated into the boat tail. The boat tail design uses an innovative "nozzle in a nozzle" configuration that minimizes interference drag caused by external protuberances. 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.

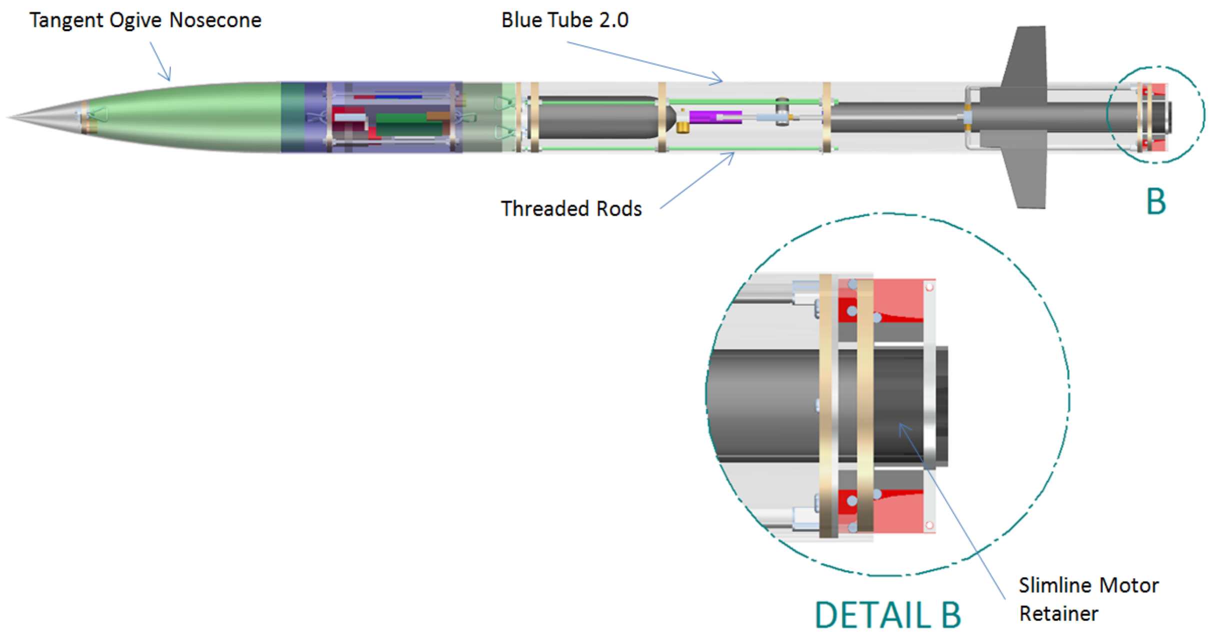


Figure 4: Vehicle structural layout.

III.B. Mass Estimate

The external dimensions and mass breakdown of the Javelin were derived using the 2009 Chimaera rocket design as a starting point. These initial estimates were subsequently modified to account for components unique to the current design. Since the PDR, the USU rocket team has significantly increased the fidelity of the mass budget by measuring the weight of each individual component. Furthermore, the mass budget has been broken into different categories. Table 1 shows this mass breakdown along with the most current general dimensions for the Javelin. Figure 5 presents this data in graphical format.

Table 1: General dimensions for the Javelin.

Grand Launch Mass	12.48 kg	27.50 lbs
Motor Length	0.649 m	25.55 in
Total Length	2.26 m	7.40 ft
Payload Mass	10.23 kg	22.55 lbs
Structural Mass	9.55 kg	21.05 lbs
Clean Mass	8.66 kg	19.09 lbs

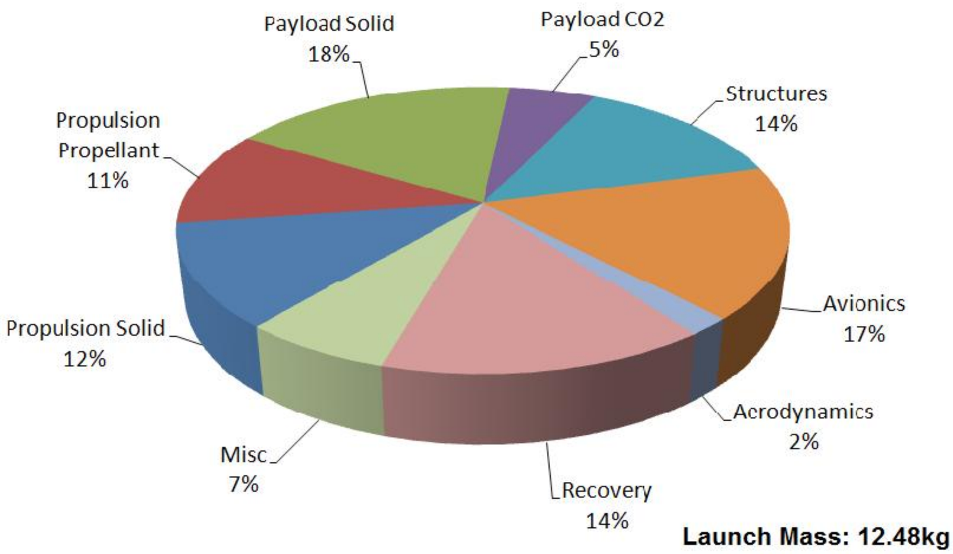


Figure 5: Projected vehicle mass breakdown.

For the Javelin, a high strength, light weight material was desired. Two options considered for the the airframe material were carbon fiber and Blue Tube 2.0™, a phenolic impregnated cardboard material specially designed for model rocketry use.[3] Table 3 shows a comparison between these two materials. The biggest differences between these two materials are their strength and price. Blue Tube is a new material for this year's team. Due to the infamiliarity with Blue Tube, a 48 inch tube section was purchased and tested under compression to verify that the Blue Tube can withstand the maximum compression load. After the design was verified, the Blue Tube was selected over carbon fiber. Always Ready Rocketry was chosen to purchase the tubing from because of the availabilty of Blue Tube in standard sizes and lower prices. Another reason Blue Tube was chosen is because of its price, which allows the team to save about $300 on flying hardware costs. This cost savings allows upgraded avionics to be budgeted and still allows project to stay within the USLI-mandated $5000 flight-hardware expense cap. There has been some concerns that the Blue Tube may warp when it is exposed to heat. After some research, it was discovered that Blue Tube warps only when it has been sitting in the sun with no internal supports for long periods of time.[4] The Javelin will be coated with some light paint, and it will be properly internally supported; thus warping should not be an issue.

Table 3: Airframe material 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.C. Vehicle Mass Properties

Mass and positioning of the payload components directly affects the stability of the Javelin; consequently accurate estimatest the mass properties that are necessary to simulate the Javelin's altitude and rotational dynamics during fight. The data in Table 4 shows the center of mass, and the moments of inertia at launch, at motor burnout, and at apogee with all CO_2 exhausted. These values will change based on the physical dimensions for the Javelin. Figure 6 defines the axis system for the vehicle.

Table 4: Mass and Moment of Inertia of the Javelin.

	Launch	Motor Burnout	Apogee
Center of Mass, in the x direction (m)	1.222352	1.124358	1.125592
Center of Mass, in the y direction (m)	-0.004128	-0.005011	-0.004700
Center of Mass, in the z direction (m)	0.000990	0.001202	0.001128
Moments of Inertia, I_{xx} (kg-m^2)	0.179055	0.178737	0.178737
Moments of Inertia, I_{yy} (kg-m^2)	24.225570	17.699621	18.582186
Moments of Inertia, I_{zz} (kg-m^2)	24.339074	17.813125	18.695689
Moments of Inertia, I_{xy} (kg-m^2)	-0.023415	-0.023415	-0.023415
Moments of Inertia, I_{xz} (kg-m^2)	0.093784	0.093784	0.093784
Moments of Inertia, I_{yz} (kg-m^2)	-0.006057	0.006057	0.006057

III.D. Design for Hardware Access in the Avionics and Payload Section

One of the the design requirements is to design doors to access the avionics and payload components. These doors will facilitate the quick access of components without disassembling the rocket. Figure 6 shows the locations of the doors in the avionics and payload sections. The doors are designed such that the strength of the rocket body is not compromised, and the drag coefficient will not be significantly increased. The doors are removable sections of the Blue Tube body tube. The doors are the length of the respective sections. The avionics section will have two doors to allow for access to both sides of the avionics board. The doors will be held in place using small screws will be installed into nuts epoxied to the inside of the coupler tube that lines the inside of the section. The payload section door will be designed and attached similarly. The position of the payload section door was decided based on the C-BAS installation design. Easy access to this area is required as the CO_2 tank will need to be refilled after each launch.

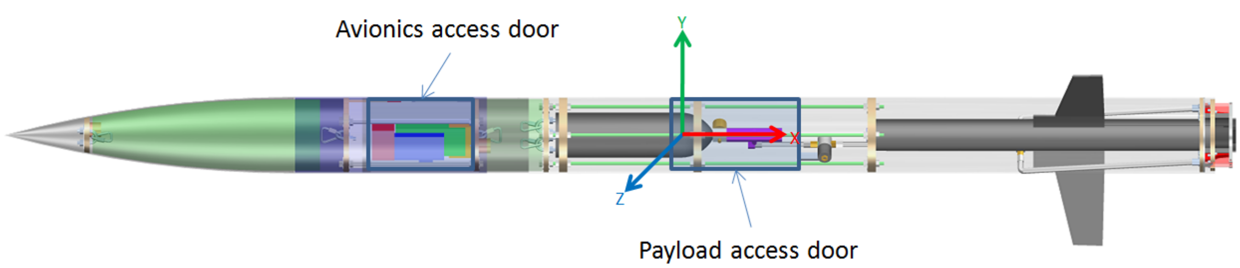


Figure 6: Access doors in avionics section.

III.E. Load Bearing Structure

In considering the load events, the primary compressive loads from the motor and cold gas augmentation system are transmitted along the structure. Figure 7 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 alignment of the ramps. When the cold gas system is deployed, the expansion ramp will need to withstand a maximum pressure of 450 psi. Both static and finite element analysis was conducted on the ramps to see the deflections of the material, and if necessary improvements will be made. The opening loads of the parachutes are transmitted through the bulkheads of the avionics structure and the payload section. Figure 8 shows the threaded rods supporting the avionics bay. Stress concentrations on the bulkheads and the avionics support structure were of particular interest. The avionics support structure was analyzed to verify that it is capable of withstanding the loads generated as the recovery system is deployed, as well as the load produced by the motor. Most components were designed with a 2.5 factor of safety. Key components were proof tested at 1.25 times the calculated ultimate design load (UDL).

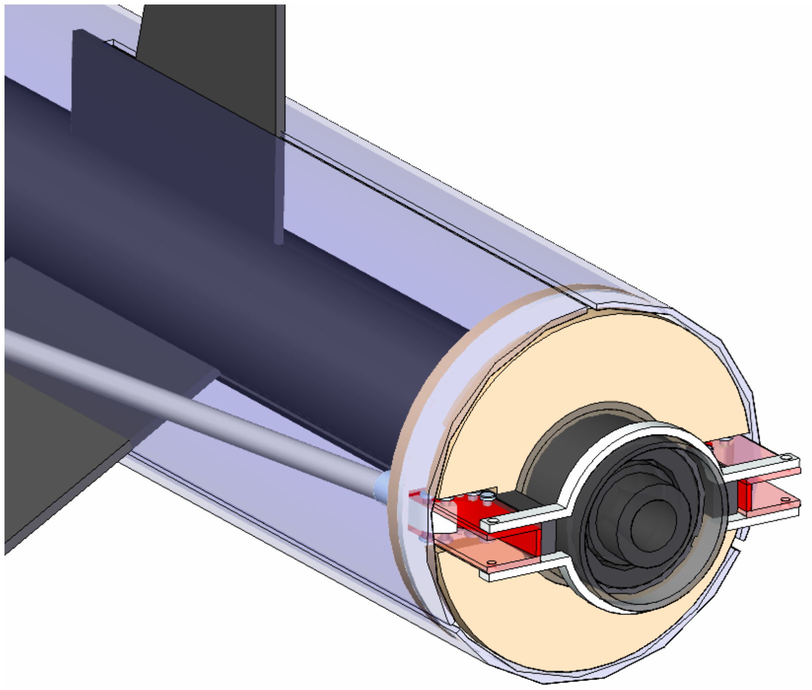


Figure 7: Integration of C-BAS expansion ramps into vehicle base area.

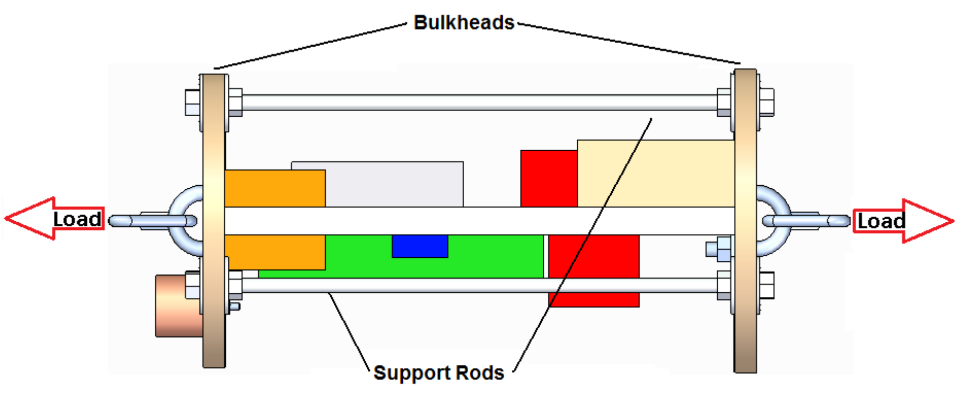


Figure 8: Avionics bay support rods.

III.F. Structure Analysis and Testing

Finite element analysis was performed on the isentropic ramp using a commercial solid modeling program (Solid-Edge™), to calculate the possible change in choking area from the thin part on the nozzle. Figure 9 shows the finite element analysis of the ramp. A safety factor of 33 was obtained. Thus, this part will not yield when the cold gas comes out at around 450 psi. However, the choking area will expand 0.3 micro-meters. The next step is to re-run the MATLAB simulations on the isentropic ramps to find the change in momentum flux resulting from this change in choking area.

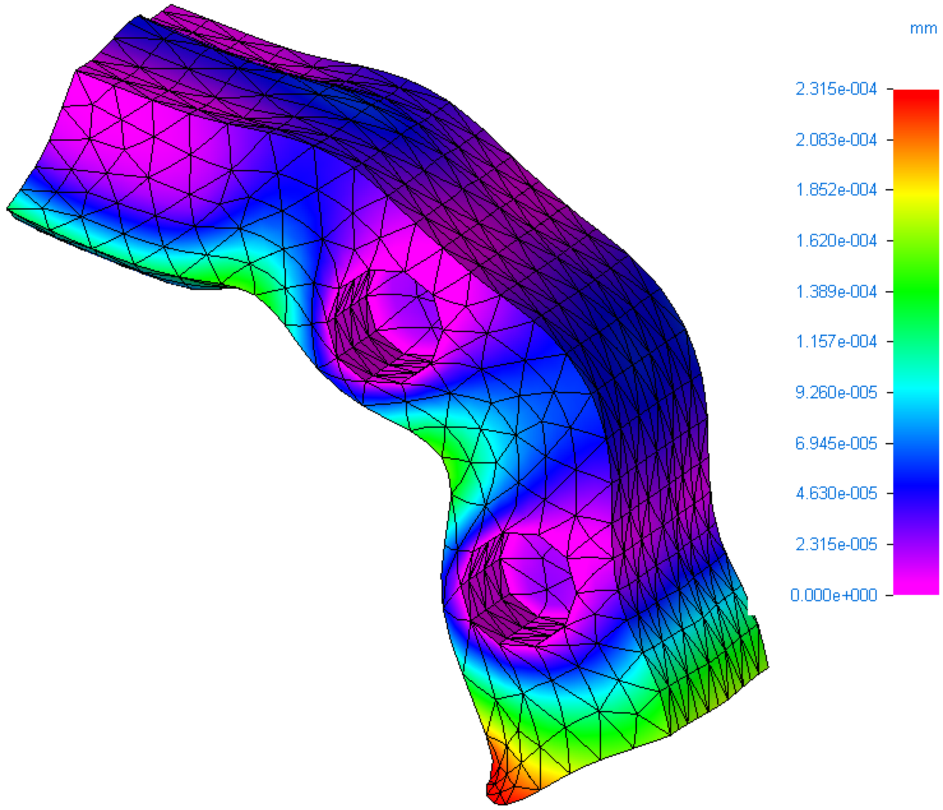


Figure 9: Finite Element of the Isentropic Ramp

The forces that would act on the screws attaching the thin part to the isentropic expansion ramps and case for the nozzle were also analyzed. Concluding that the maximum force on the screws will be 85N. With further finite element analysis on the screws, a safety factor of 2.1 was obtained, which doesn't comply with the established 2.5 minimum design safety factor. Therefore the spike system will be proof-tested at a 1.25 factor of safety before the first flight. Figure 10 shows a finite element analysis on the screw based on the force it experienced.

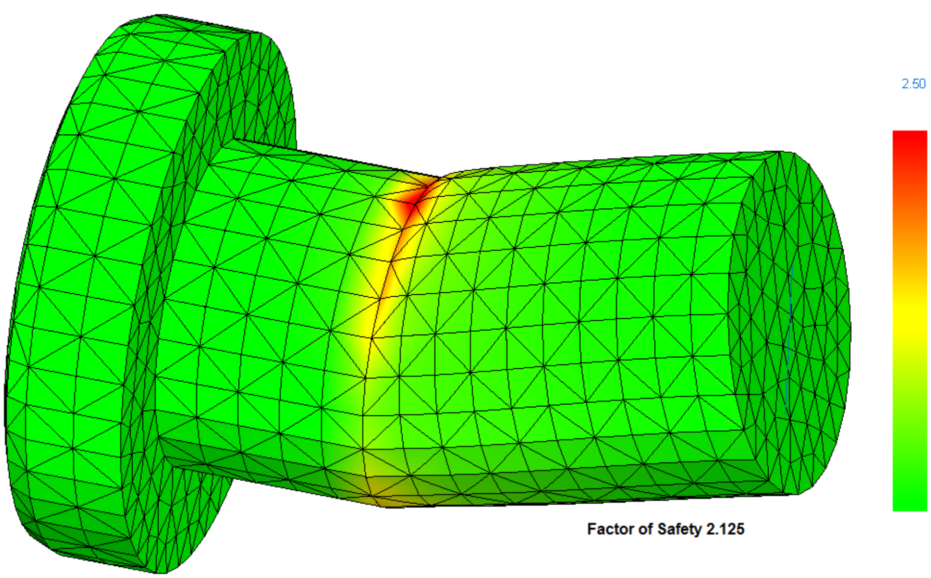


Figure 10: Finite Element Analysis on the screw

A compression test was be performed on the Blue Tube. This test was intended to make sure that the tubing for the Javelin can resist a maximum load. Using the maximum G load and the launch weight, the maximum load that the tube must withstand was approximately 163.80 kg (361.12 lbs). Figure 11 shows the body tube being tested under compression. The test stand was build to support the tube straight so that the compression load can be more accurate. Sand bags were placed on the top board to approximate the ultimate load. The Blue Tube was successfully able to withstand about 181kg (400 lbs), which is above the ultimate design load. After the test, there was no sign of buckling along the body, which confirmed the selection of Blue Tube 2.0 material as acceptable for the final airframe material. This test was done using a 1.25 proof-load factor of safety.

Figure 11: Body tube test stand.

The design of the avionics support structure is similar to the 2009 Pike's design. An avionics section was built and integrated in the Blue Tube, only one bulkhead was epoxied to the tube. The other bulkhead was just supported by the threaded rods. The reason the top bulkhead was not epoxied is to put all the components into the avionics section. Stress concentrations due to the bottom bulkhead and the avionics structure were of particular interest. For this particular case, a compression test is the same as the tensile test because the only thing that is of main concern is the bulkhead, which will experience a shear force due to the opening load and the motor loads. The maximum opening load due to operating the recovery system is slightly less than 600 N. The ultimate design load for the motor load is approximately 1055 N. The motor load was considered as the maximum load that the bulkhead would experience. The compression test showed that the avionics section would be able to withstand about 1300 N (300 lb). J-B Weld[5] was used to epoxy the bulkhead to the tube. J-B Weld is a strong two-part epoxy adhesive that can withstand high-temperature environments. Figure 12 shows the bottom bulkhead of the avionics section attached to tube using J-B Weld.

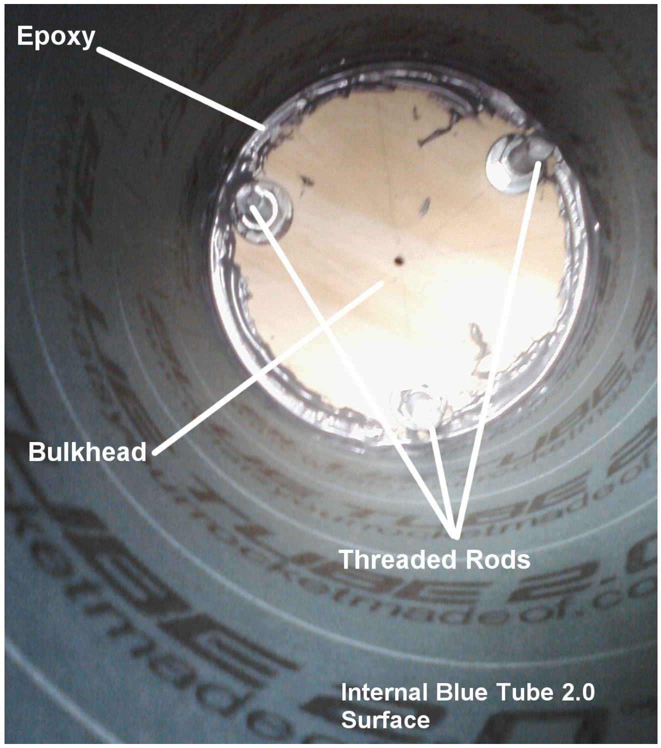


Figure 12: Bulkhead epoxied to the tube.

III.G. Motor Selection

The team developed deterministic and Monte-Carlo simulations to predict the flight path of the rocket using simulation tools build in MATLAB® /Simulink® and LabVIEW®. 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.To simulate the rocket behavior using a variety of L-class motors, motor profiles from the hobby rocket website. Following a preliminary analysis a "short list" of candidate motors was selected 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 13 shows motor and design selection procedure.

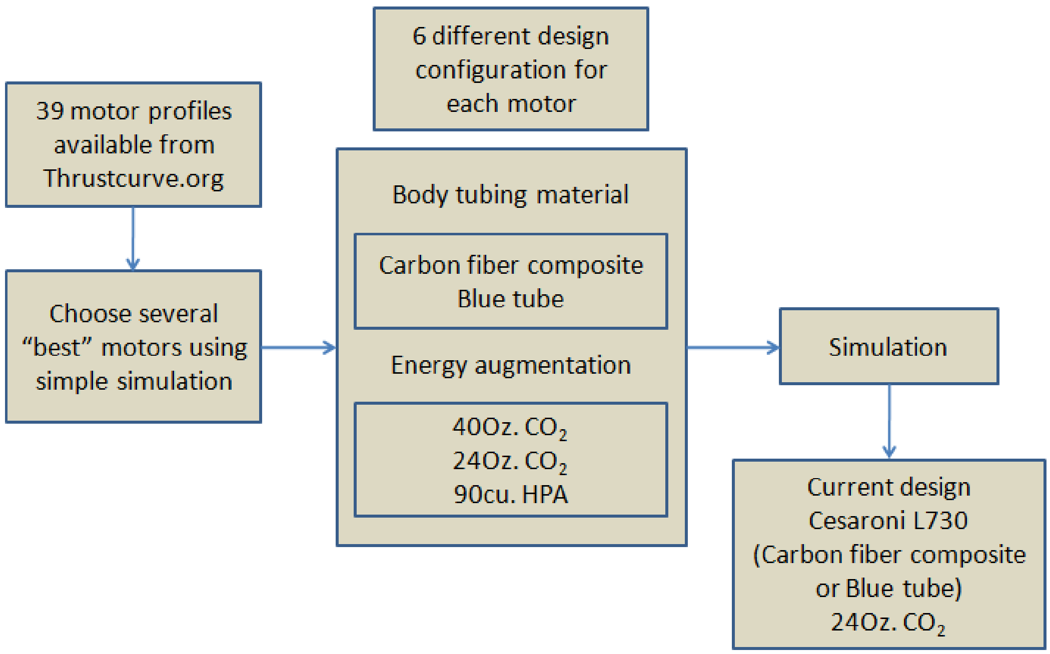


Figure 13: Motor and design selection procedure.

The motor trade study selected the Cesaroni L-820 as the optimal configuration. However; it was discovered during the PDR review that the L-820 used Skidmark propellant ; which violated the USLI competition rules. Based on the procedure in Figure 13, the next best choice of peaking a solid motor is the Cesaroni L730. Table 5 lists the properties of the down-selected Cesaroni L730 solid rocket motor used for the simulations. The G load is determined based on current mass budget.

Table 5: Cesaroni L730 Solid Rocket Motor Properties

Diameter	54.0mm
Length	64.9cm
Average Thrust	732.9N
Total Impulse	2763.2 Ns
Cost per Reload	$160.97
Projected Maximum G load	9.9G'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 and lower cost to carbon fiber. The 24 oz CO_2 will be used with Cesaroni L730 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 shows required launching mass to reach the apogee by comparing C-BAS active vs. solid motor itself. The waypoint is explained in Table 7 indicates that to reach 1 mile high apogee with using full tank of CO_2, the current Javelin's mass budget needs to be increased about 1.1 kg.

Table 7: Launching mass margin

Condition	C-BAS inactive	C-BAS active
Launch Mass (kg)	12.19	13.59
Waypoint (m)	0	800-apogee
CO_2 remaining (%)	100	0

Table 7 indicates that to reach 1 mile high apogee with using full tank of CO_2, the current Javelin's mass budget needs to be increased about 1.1 kg. Thus the USU Chimaera currently has mass margin of approximately 9%. This margin is very likely to diminish as the Javelin design continues to mature.

III.H. Recovery Subsystem

A milestone map detailing the steps of the recovery system design is shown in Figure 14.

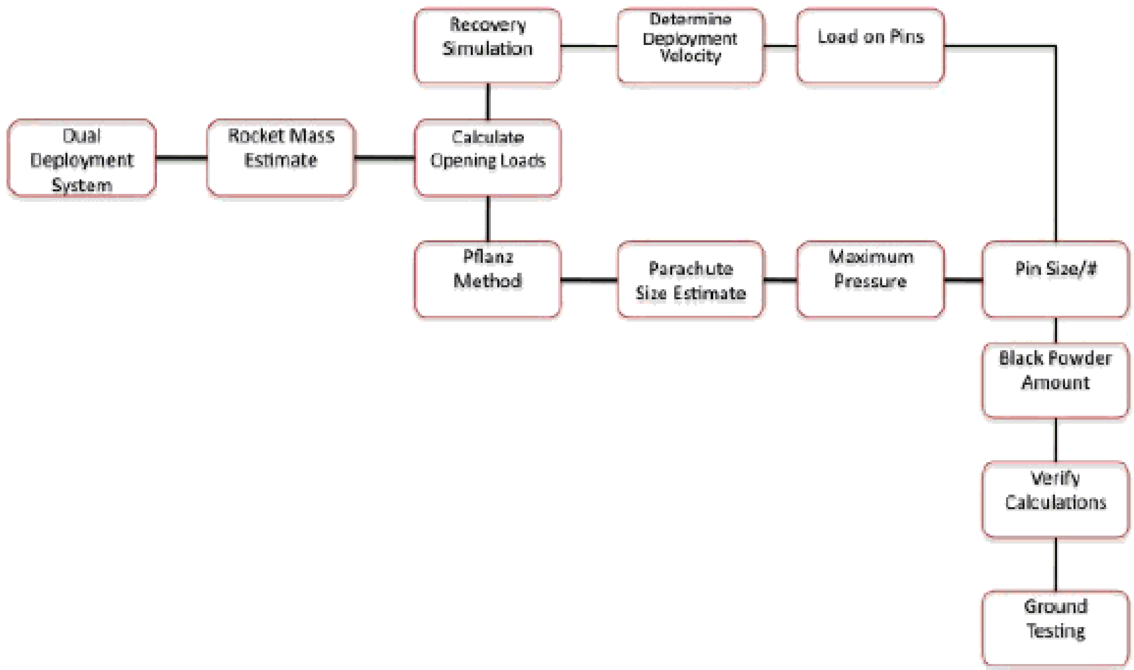


Figure 14: Recovery subsystem design milestone chart.

III.H.1. Recovery System Design

The first step in the recovery subsystem design process was to determine the sizes of the parachutes using the terminal velocity method, as shown in Figure 15. Under the drogue parachute, the rocket will descend at a design descent rate of 77.6 ft/s (23.7 m/s). The main parachute design rate is 18.5 ft/s (5.64 m/s).

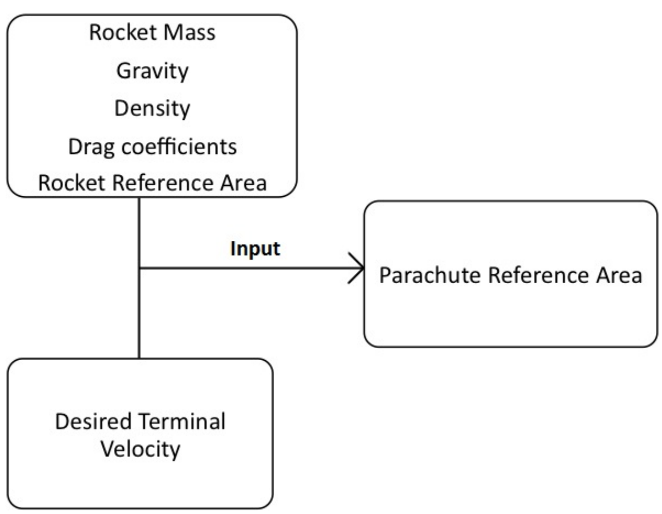


Figure 15: Summary of terminal velocity method.

All other data used in this calculation sequence were taken from reference five.[6] A mid-valued drag coefficient of 0.8 for conical parachutes was selected. The current best estimate of the drag coefficient of the Javelin airframe is 0.015 m^2.This value is multiplied by two for the first sizing calculation 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 used for this analysis was 11.02 kg, which is the launch mass of the rocket, minus the mass of the motor propellant and the mass of the used cold gas, assuming 63 percent consumption.

Pflanz's Method[6] was used to determine opening loads of the parachutes. Figure 16 is a flow chart demonstrating Pflanz's Method.

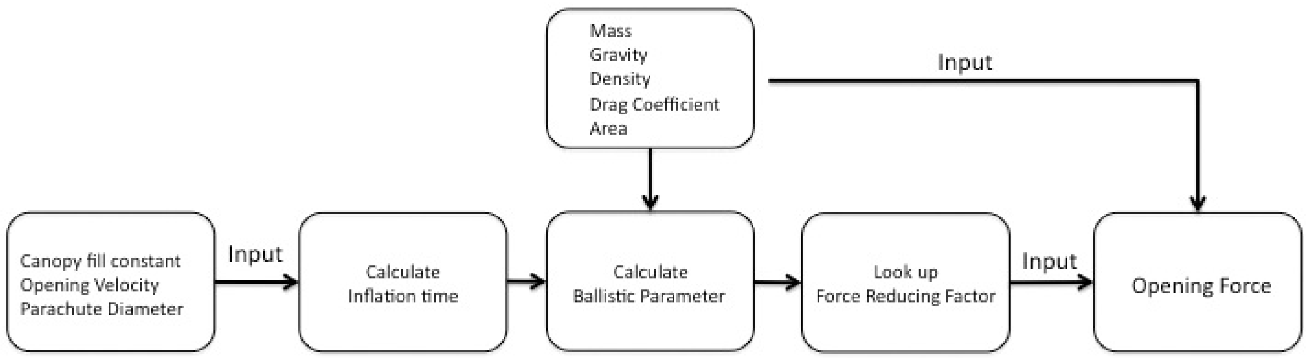


Figure 16: Summary of Pflanz's method.

The canopy fill constant for elliptical parachutes is four. The opening velocity for the drogue parachute is estimated to be no more than 42.6 m/s, according to direct simulation. This estimate is based on the velocity that the rocket will 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 remotely. The Javelin's descent will slow due to drag between parachute deployments, so the opening velocity for the main parachute is estimated to be 22.26 m/s, slightly less than the terminal velocity of the drogue parachute. This effect has been accounted for in Pflanz's Method and in the simulation verification.

Upon finding the ballistic parameter A_b , graphs presented in reference five were used to determine X_1, the force reducing factor, for conical parachutes, assuming a parachute fill constant of n=2.

III.H.2. Recovery System Sizing

The team initially used the minimum allowable descent rates as the desired terminal velocities under the parachutes. These rates were adjusted slightly until the opening loads had been optimized, that is, nearly equal. The opening loads of the drogue and main parachutes were 625 N and 627 N, respectively. Equal loading was the original goal, so the team moved forward expecting to use parachutes of diameters 2.35 ft and 11.61 ft. However, Top Flight Rocketry, the team's parachute supplier, only supplies standard sizes, so four combinations were put into the analysis to determine which available sizes would meet the criteria established by both the team and the competition. A slightly larger 2.5 ft drogue parachute and a smaller 10 ft main parachute will provide the most balanced loads, while still maintaining acceptable descent rates. This combination is also the most cost and mass efficient. Final parachute design parameters are shown in Table 8. These results reflect the most likely descent mass, 11.02 kg, assuming 63 percent CO_2 consumption.

Table 8: Recovery system parameters for 63 percent CO_2 consumption.

Parameter	Drogue Parachute	Main Parachute
Parachute Type	Conical	Conical
Deployment Altitude (m AGL)	1531.7	300
Deployment Density (kg/m^3)	1.02979	1.16274
Deployment Velocity (m/s)	42.57	22.26
Nominal Terminal Velocity (m/s)	23.65	5.64
Drag Coefficient	0.8	0.8
Reference Area (m^2)	.456	7.29
Peak Opening Load (N)	583.6	526.3

All recovery system analyses have been verified by direct simulation. Planz's Method tends to be conservative in predicting opening loads, but the test results show that the method is sufficiently accurate for our purposes. Simulation results for the recovery design are discussed further in Section III.I.6.

III.H.3. Recovery Hardware

A dual, redundant recovery system will be used on the Javelin. The primary controller will be a PerfectFlite altimeter, which will be backed up by an R-DAS altimeter. 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. 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. Figure 17 shows the functional block diagram of the parachute deployment system.

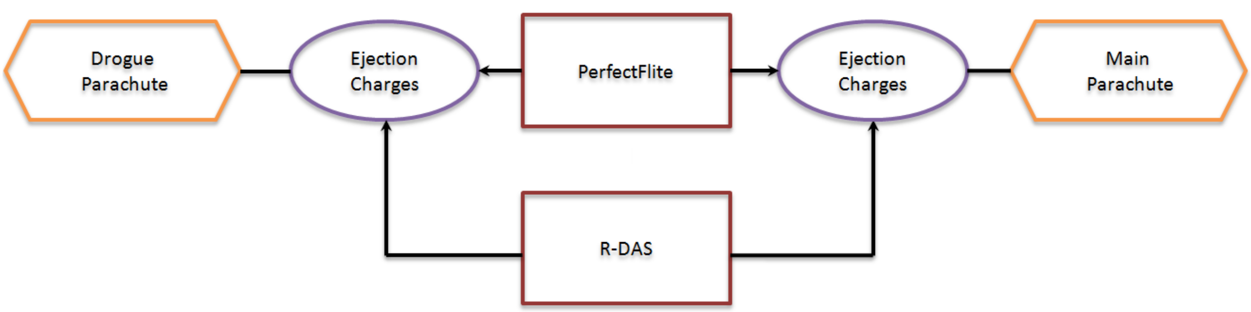


Figure 17: Functional block diagram of parachute deployment system.

The sections of the Javelin will be connected with 2-56 nylon shear pins, each rated to withstand a minimum force of 138 N, and a maximum force of 205 N. The pins must withstand all forces experienced prior to deployment, but still be able to separate smoothly when the black powder charges are triggered. The number of shear pins per section was determined by first finding the shear load at each deployment. The shear load, multiplied by a 2.5 SF and divided by the minimum shear strength of the shear pins, gives the number of pins required. Table 9 shows the shear pin analysis results.

Table 9: Shear pin estimates for 2.5 SF.

Pin data	Drogue deployment	Main deployment
Shear load (N)	213.3	241.3
Number of pins	4	5

III.H.4. 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. This procedure can be found in Appendix H.B. Kevlar, a burn retardant material, will be used for the harnesses, and no heat-sensitive components will be touching the charges. Appendix H.A contains the parachute folding procedure. A summary of other possible failure modes and the team's proposed solutions are outlined in Figure 10.

Table 10: Possible risks and solutions of recovery system.

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	Low	Correctly size parachute, accurately predict descent rates.
Airframe Damage	Charges, Opening Loads, Descent Rate	Moderate	Accurately predict opening loads and charge sizes.

III.I. Trajectory Modeling and Simulation

III.I.1. Simulation Procedure

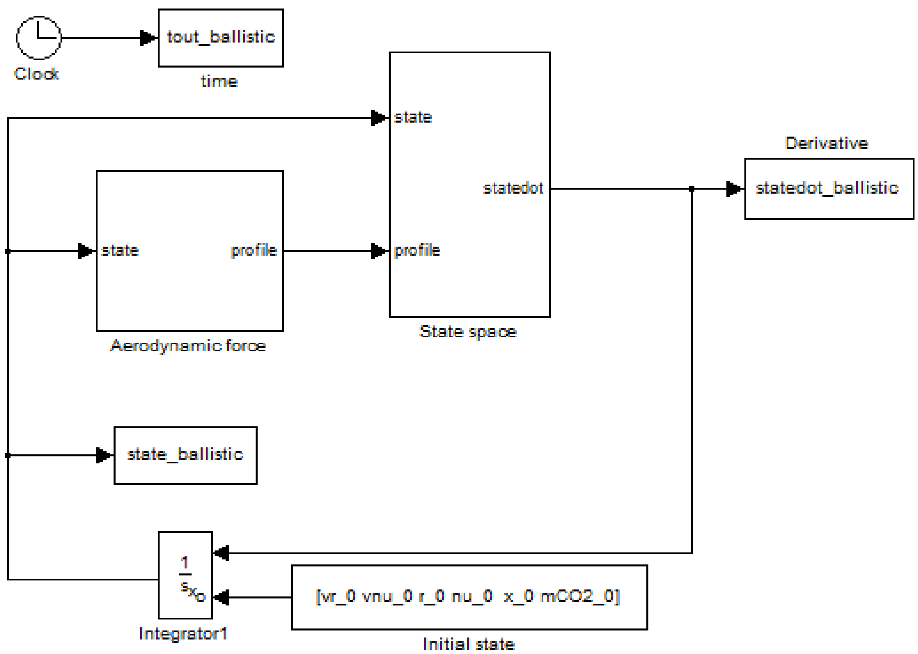
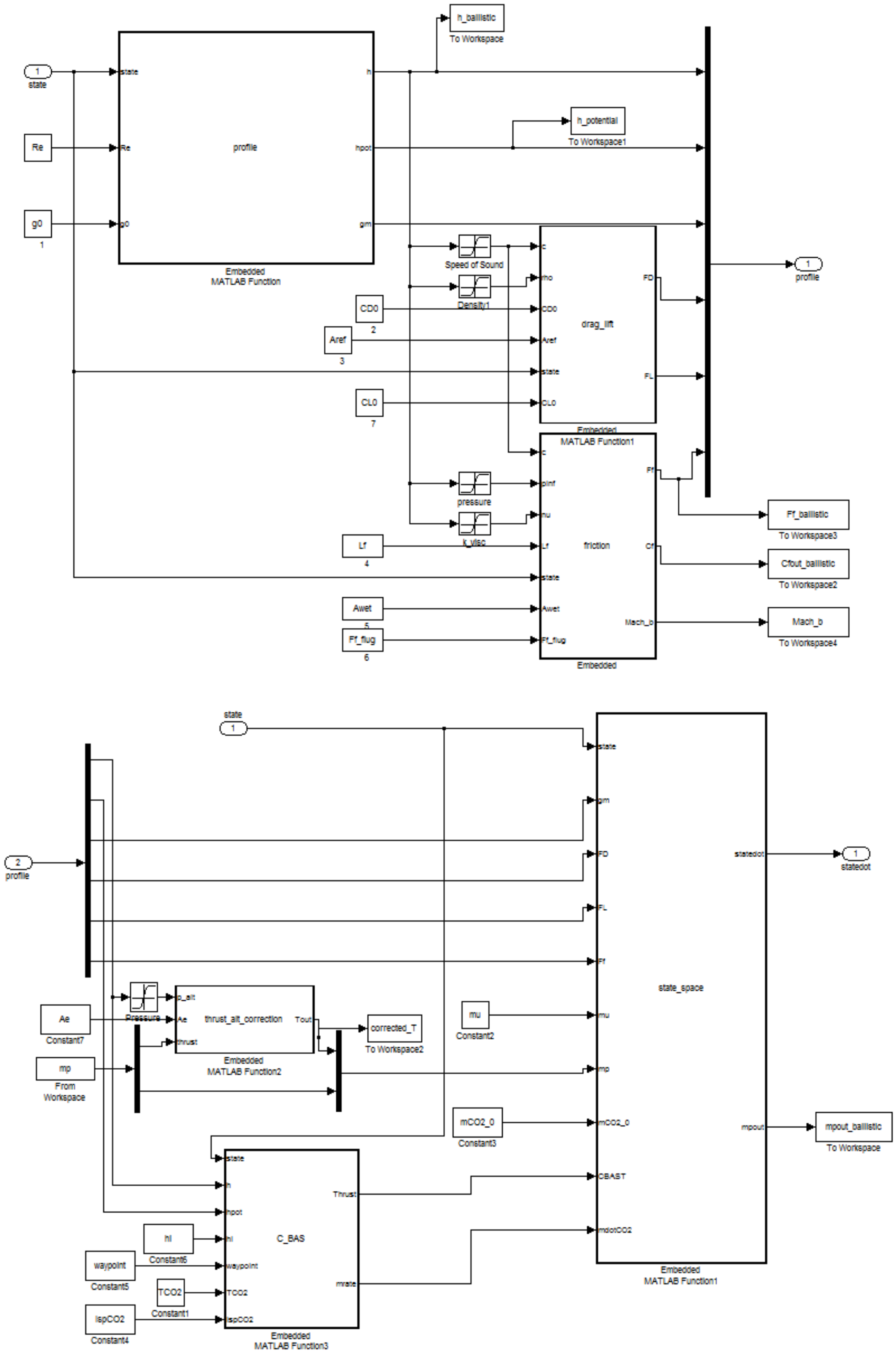


Figure 18: Rocket simulation model from MATLAB/Simulink

Figure18 shows the overview of the simulation model that predicts rocket trajectory. The simulation starts with initial conditions and calculates states for each time step period using a numerical integrator. Figure 19(a) and (b) shows the subsystems of the simulation. The current simulation program accounts for aerodynamic forces such as drag, lift and friction forces, pressure correction of the solid motor thrust, and C-BAS activation based on rocket altitude and potential altitude.



(a)

(b)

Figure 19: Rocket simulation subsystem: (a) Calculate aerodynamic forces (b) Find derivative of the state vector

III.I.2. Performance Analysis

Figures 20 and 21 plot the predicted altitude, velocity, and acceleration time histories, with C-BAS inactive and active, respectively.

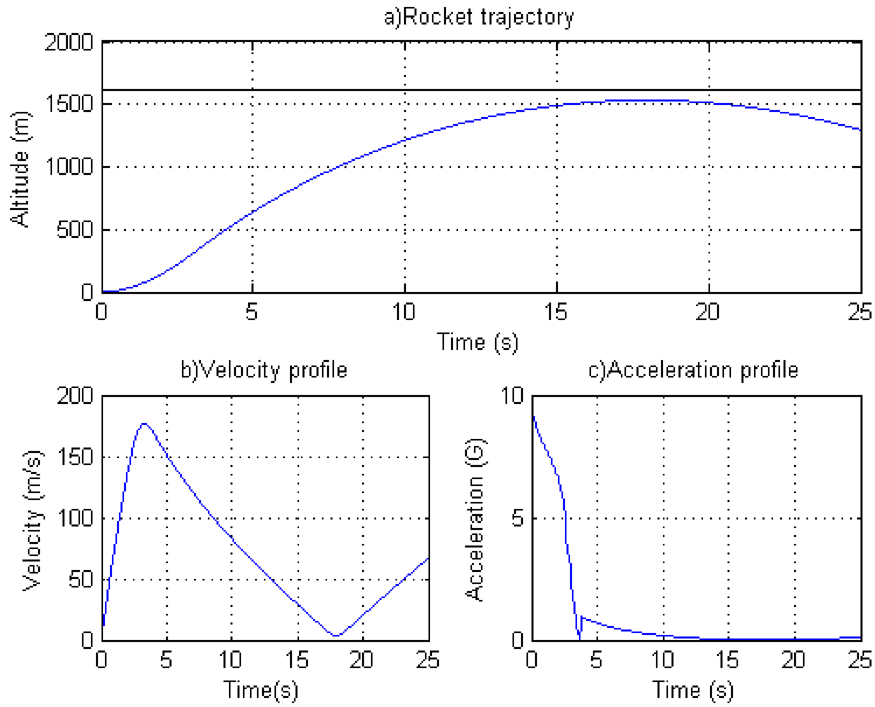


Figure 20: Rocket simulated trajectory with C-BAS inactive; a)Altitude, b)Velocity, c)Acceleration profiles

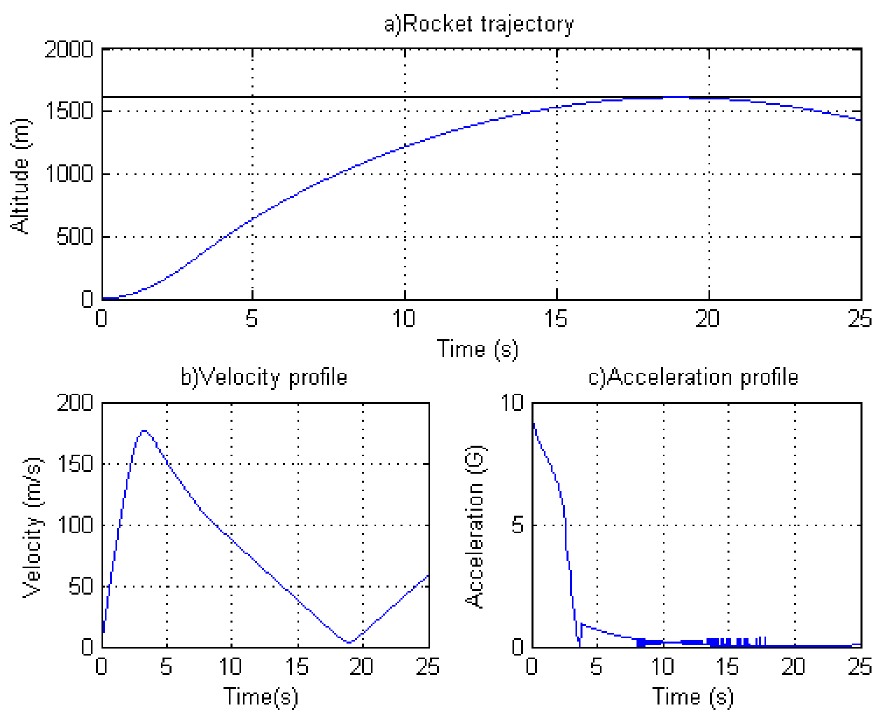


Figure 21: Rocket simulated trajectory with C-BAS active; a)Altitude, b)Velocity, c)Acceleration profiles

The C-BAS uses a simple but effective pulse-width modulation algorithm 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

$$\left(\frac{E}{m}\right)_{total} = gh + \frac{V^2}{2} \tag{1}$$

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

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

The last term on the right hand side of Equation 2 is the energy depleted by drag forces acting 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 while altitude increases, and Eq.2 can be rearranged to predict the rocket's apogee altitude based on the energy state estimated at any point along the trajectory.

$$h_{apogee} = h(t) + \frac{(V(t)\sin\gamma)^2}{2g} - \int_t^{t_{apogee}} \left[\left(\frac{1}{2}\rho V^2\right)\left(\frac{C_D A_{ref}}{m}\right) V\right] dt \tag{3}$$

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

$$h_{potential} = h(t) + \frac{V^2_{vertical}(t)}{2g} \tag{4}$$

Clearly, as apogee is approached and the overall vehicle drag diminishes, because rocket velocity also diminishes, the potential altitude defined by Equation4 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 22. 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.

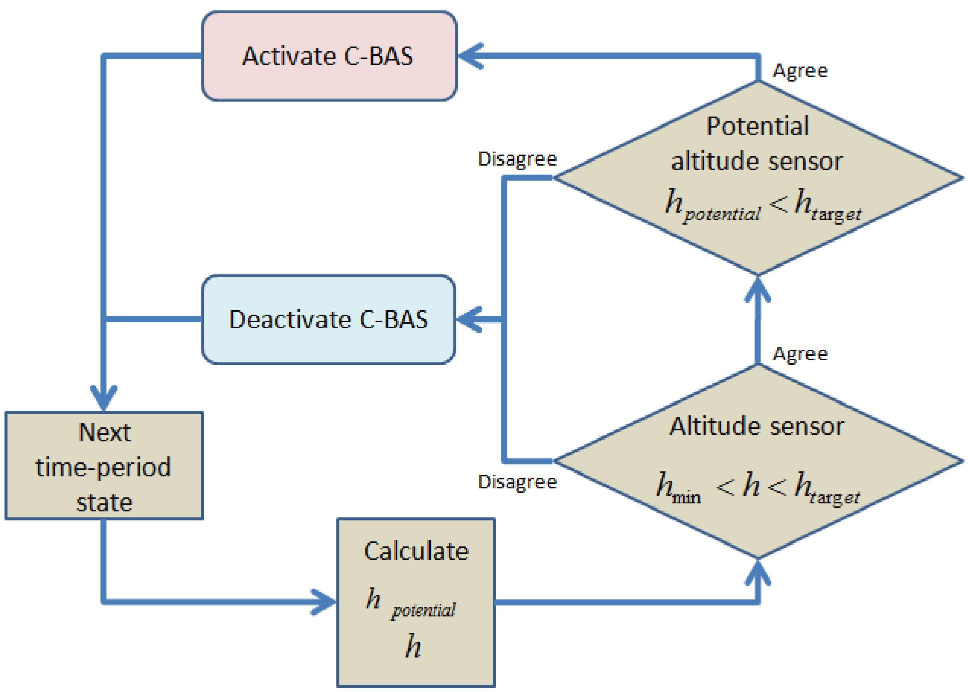


Figure 22: C-BAS algorithm for simulations

III.I.3. C-BAS Performance Analysis

To determine the change in velocity due to energy augmentation using C-BAS, the rocket equation5 was used.

$$\Delta V = g_0 \cdot I_{sp} \cdot \ln\left(1 + \frac{m_{propellant}}{m_{dry}}\right) \tag{5}$$

The rocket equation depends on specific impulse of the C-BAS and cold-gas mass over the rocket mass. But the rocket equation accounts for changing velocity only when the initial velocity is equal to zero. To determine the total changing altitude due to the initial velocity the energy state equation6 was used.

$$\frac{\Delta K.E}{m} = \frac{V_2^2 - V_1^2}{2} \tag{6}$$

Rearranging Equation6 in terms of ΔV and initial velocity gives

$$\frac{\Delta K.E}{m} \approx \Delta h_{potential} = \left(V_1 + \frac{\Delta V}{2}\right) \cdot \frac{\Delta V}{g} \tag{7}$$

The corresponding change of altitude due to cold gas depends on the initial velocity of the rocket and ΔV. The equation7 says that the sooner the C-BAS is activated the better result is expected to get for the changing potential energy.

In Equation 7 the drag force was neglected, and drag plays an important factor on the C-BAS performance. The total drag is shown on equation 8

$$(\Delta h_{potential})_{drag} = \int_{t}^{t_{apogee}} \frac{C_D \cdot A_{ref}}{2 \cdot m} \rho V^3 dt \tag{8}$$

Equation8 shows the total energy depleted by drag forces acting on the rocket. The equation depends heavily on the velocity of the Javelin. That means the higher the velocity of the Javelin the more energy is depleted due to drag.

Figure 23 shows the potential altitude change vs. the altitude above the ground level for each different cold-gas type that was considered for this design. The figure 23 also shows the total potential loss due to drag. This determines when to use the C-BAS.

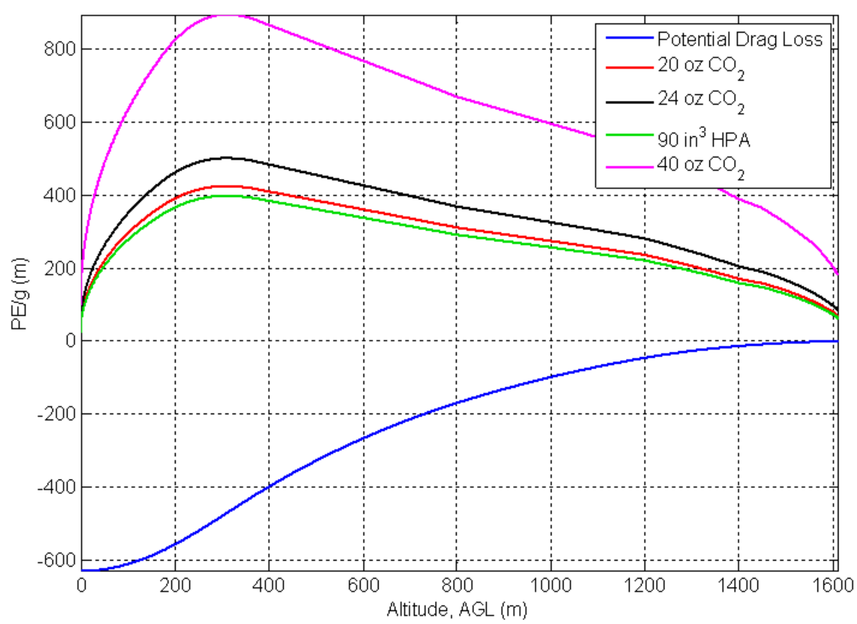


Figure 23: Cold-gas potential altitude change

Table11 provides a summary of the comparison of C-BAS activation early in the flight to C-BAS activation late in the flight. If the C-BAS is activated shortly after motor burnout the change in altitude performance is high, but the drag loss is also high. The opposite applies if C-BAS is activated late.

Table 11: Performance Comparison

	Earlier C-BAS activation	Later C-BAS activation
$\Delta h_{potential}$	High	Low
$(\Delta h_{potential})_{drag}$	High	Low

III.I.4. Required Augmentation Altitude Change

During flight, there are a lot of uncertainties that can change the trajectory of the rocket. Therefore the C-BAS should be able to compensate altitude based on the worst case scenario. Uncertainty analysis simulation varied uncertainties showed in Table 12 and was run 1000 times to find standard deviation. All 1000 trajectories are drawn in Figure 24. For apogee altitude distribution shown in Figure 25, a 95 percent confidence level for determining required altitude change by C-BAS was chosen. Simulation results are shown in Table 13 and it was determined that C-BAS will have sufficient energy to generate at least 177 meter change in altitude for the rocket. The current CO_2 capacity and C-BAS design meets this requirement.

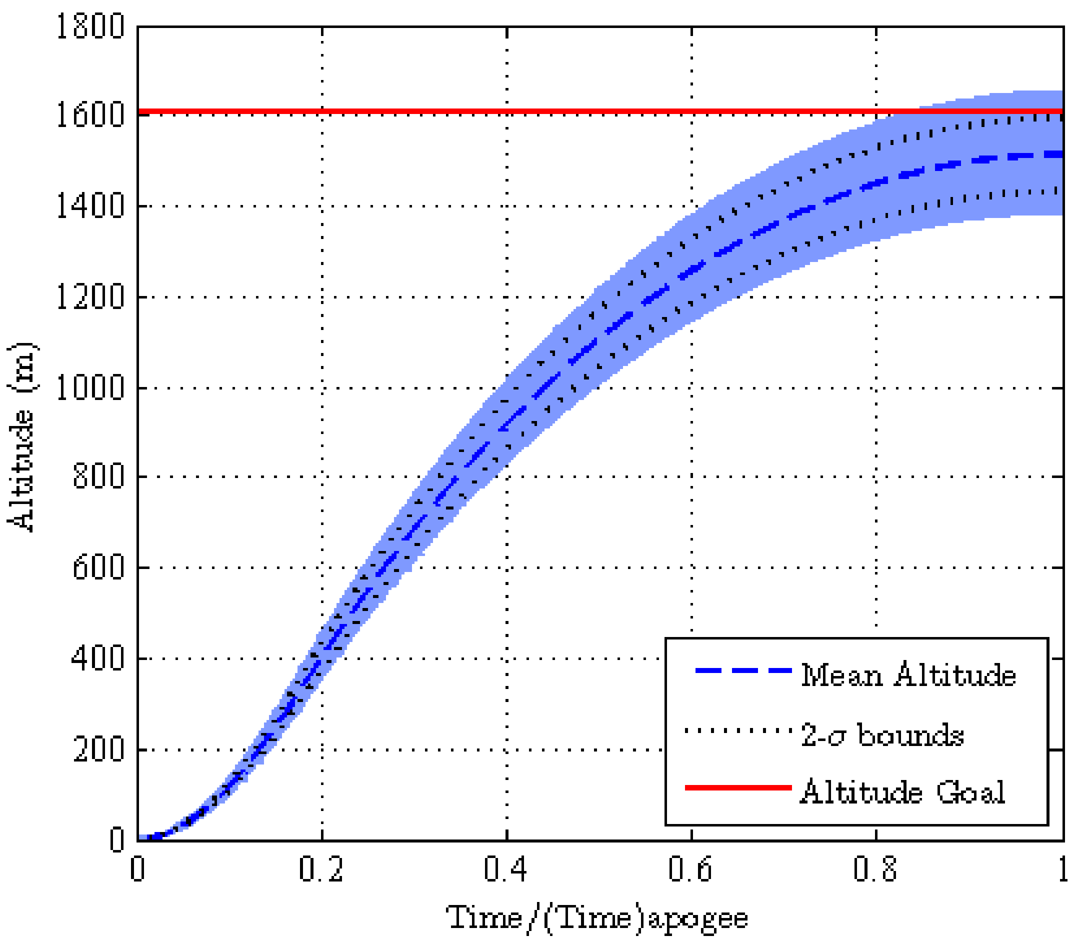


Figure 24: Rocket Trajectories with Uncertainties

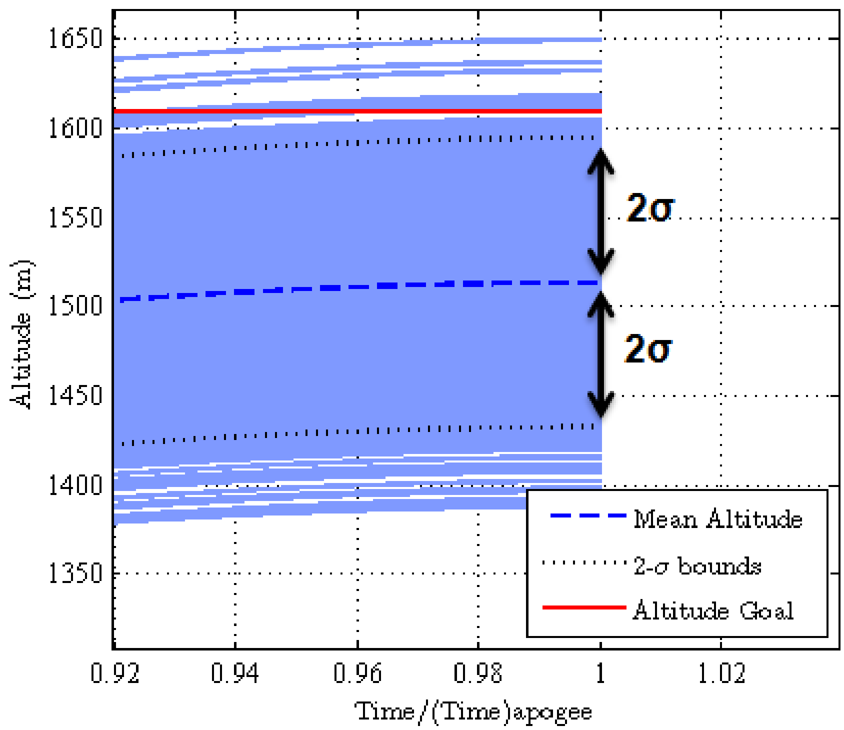


Figure 25: Apogee Altitude Distribution

	Thrust Amplitude	Drag Coefficient	Lift Coefficient
Uncertainty	$\pm 1.71\%$	$\pm 1\%$	$\pm 5\%$

Table 12: Uncertainty table from past USU USLI team

Number of Simulation	Mean Apogee Alt.(m)	Std.Deviation(m)	Required Altitude Change(m)
1000	1513.5	40.61	177.04

Table 13: Result from Monte-Carlo analysis

III.I.5. 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.

Center of Gravity In order to design the rocket with a stable center of pressure, the center of gravity must be known with reasonable accuracy throughout the duration of the flight. 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. At launch the center of gravity is located 1.22 meters behind the nose. As the solid propellant burns and the payload CO_2 is expelled the the the center of gravity moves forward to 1.12 meters behind the nose. These two center of gravity locations define the encountered stability range for the rocket.

Center of Pressure The center of pressure results come from Barrowman's equations.[7] 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, Missile DATCOM, an industry standard software program will be used for a higher-fidelity calculation of the aerodynamic calculations. This approach will allow the team to more accurately model the Javelin's performance and fine-tune the C-BAS. All of these value will ultimately be verified in a wind tunnel so the analytical solutions can be compared with real testing data.

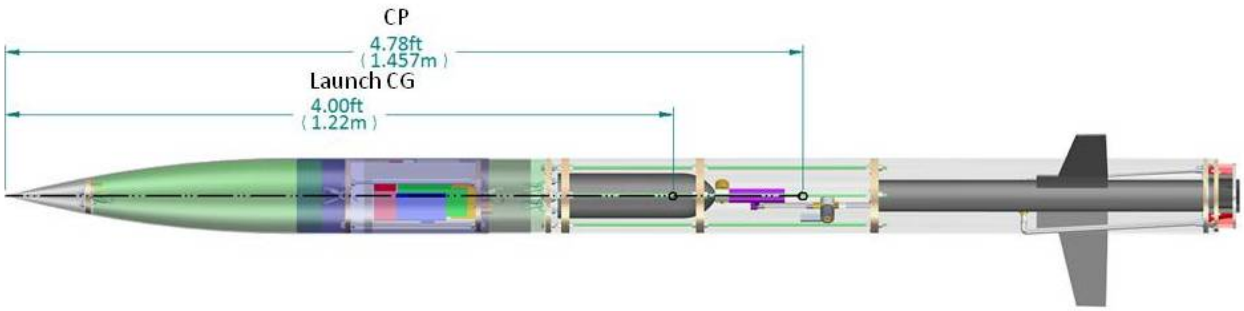


Figure 26: Launch center of pressure and center of mass.

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 a two caliber margic 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 Javelin's center of pressure is located 1.46 m aft of the nose tip, which gives a static margin of 1.75 at launch. As the center of gravity moves forward the maximum static margin becomes 2.48. Vehicle static margin with full and empty CO_2 tanks are effectively the same, this results because the CO_2 tank is placed at the center of the vehicle.

Stability Failure Modes At launch the rocket has a static margin of 1.75 which is stable. This ensures there is an adequate restoring moment and that there is not too much weathercocking. As the motor burns out, the static marigin becomes 2.48, which is slightly overstable, but is encountered when the rocket it already moving at a very high velocity, so weathercocking is not as much of an issue. In order to ensure a successful flight, the failure modes were considered and analyzed as well as risk mitigation procedures. Table 14 shows the possible failure modes for this aerodynamic design.

Table 14: 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 utilize simulator to measure the effects of fin size on stability, possibly lengthen launch rail
Inaccurate 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

Aerodynamic Performance Data The aerodynamic coefficients for lift (C_L), drag (C_D), and pitching moment (C_M), were calculated using Missile DATCOM and are plotted in Figure 27. This data is a direct input in the rocket simulation and is based on the geometry of the vehicle. The values were calculated at varying angles of attack (-15 to 15 degrees) and at different mach numbers (0.1 to 0.6).

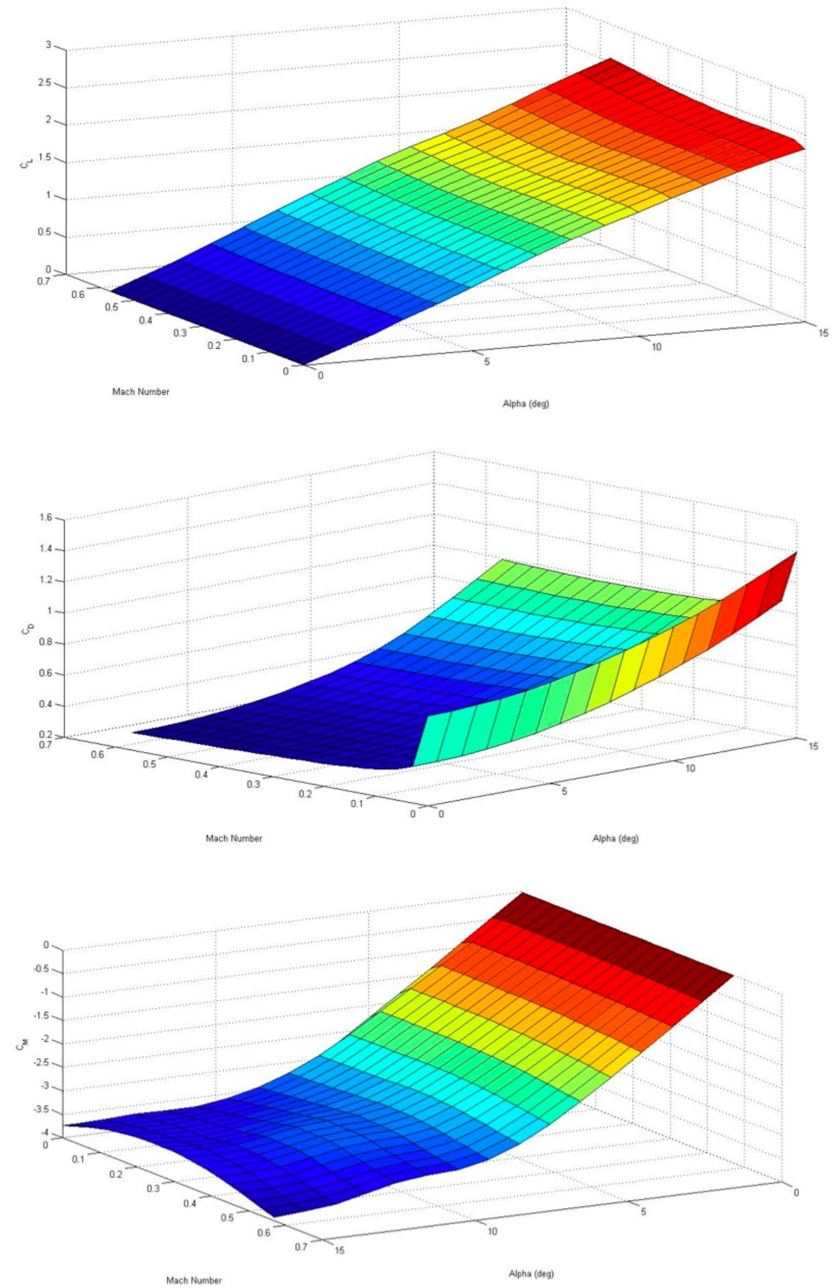


Figure 27: Aerodynamic coefficients plots (from top): C_L, C_D, C_M.

To verify the Missile DATCOM results, the zero angle of attack drag coefficient values were compared with measured values from previous USU entries in the USLI competition. Figure 28 compares the external mold lines of the Javelin (2011) to the Barracuda (2008) and the Pike (2009). The vehicle body tube diameters for the rockets are identical (14.06 cm). The Javelin is shorter than the Barracuda and significantly longer than the Pike. Accordingly, the C_D on the Javelin should fall somewhere between the actual values collected on the previous rockets. The C_D data from these flights is shown in Figure 29. On this figure both flight and wind tunnel drag coefficient estimates are presented. The flight data is dervied from the on-board acceleroemeter and inertially-derived dynamic pressure measurements and are plotted for the first eight seconds following motor burnout. The wind tunnel drag estimates were obtaines using wake survey methods and are plotted as constant horizantal lines on this graph. The large deviations in the flight data were due to airbrake deployment that was a part of the energy management system, designed to significantly increase the drag on the vehicle using specially designed airbrakes. The "clean vehicle" drag coefficient estimates clearly bound the current best value of $C_D = 0.35$ based on Missile DATCOM calculations for the Javelin airframe.

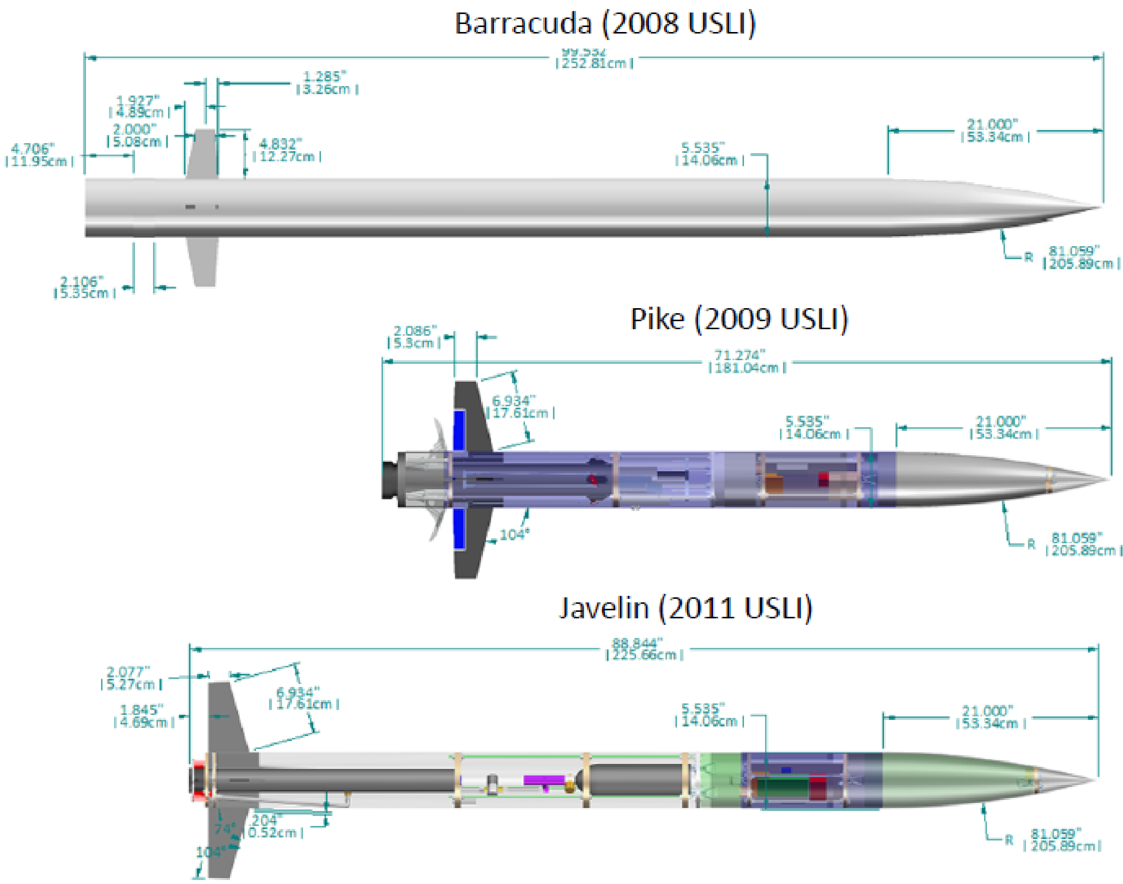


Figure 28: External mold-line comparison of the Javelin and previous USLI entries from Utah State.

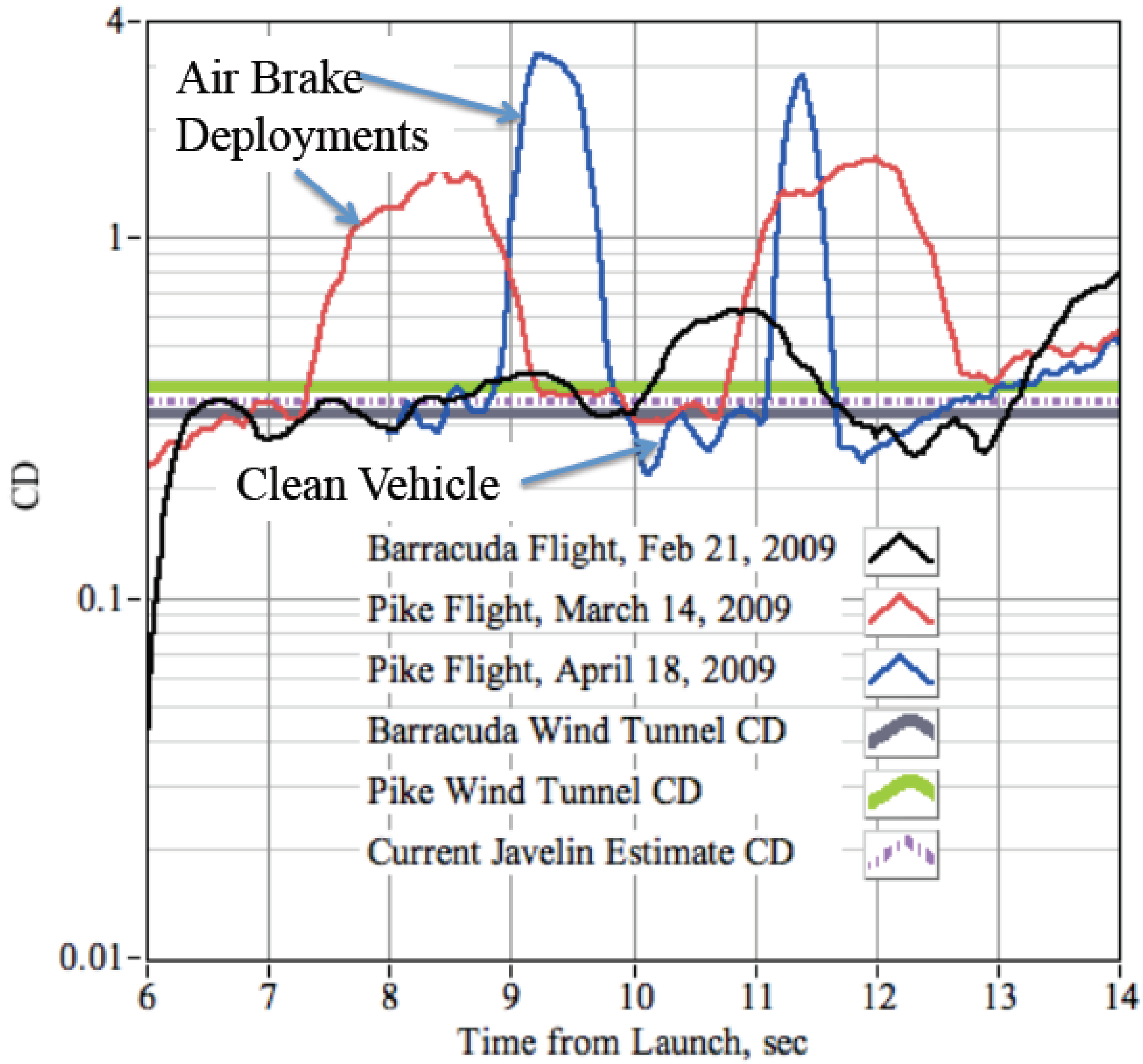


Figure 29: Drag coefficient comparisons from previous Utah State USLI entries give current best estimate.

III.I.6. Recovery System Performance

All recovery analysis has been verified through simulation. The opening loads found using Pflanz's method for the drogue and main parachutes were estimated to be 584 N and 526 N, respectively. Pflanz's method tends to be conservative in load prediction. As seen in Figure 30, simulation results estimate the opening forces to be 568.8 N and 430.2 N.

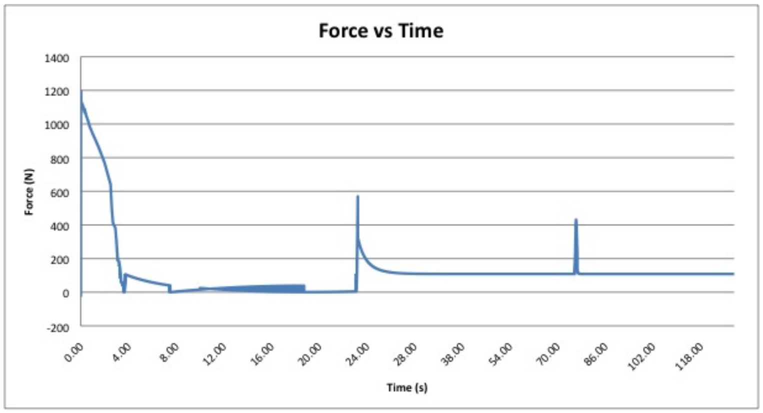


Figure 30: Recovery system analysis load verification.

The loads produced during deployment are significantly less than the forces the Javelin will experience due to the motor. The airframe and bulkheads were proof tested to 1.25 times the force of the motor, so by extension it is clear that the design can withstand the forces of parachute deployment.

Competition requirements state that the rocket must land within 2500 ft, or just over 800 m, of the launch pad. The rocket will launch into the wind at an angle of approximately 85 degrees from the horizontal. Figure 31 shows the downrange drift distances for the cases of no wind, a 10 mph wind, and a 22 mph wind. Once the first parachute has been deployed, the horizontal velocity component of the rocket essentially becomes zero. At that point, any countable horizontal velocity will come from wind. The rocket will not be launched in wind higher than 10 mph, in which case drift will be no more than 180 m downrange. The Javelin has been designed such that it could, theoretically, be launched in winds up to 22 mph and still be within the allowable landing radius.

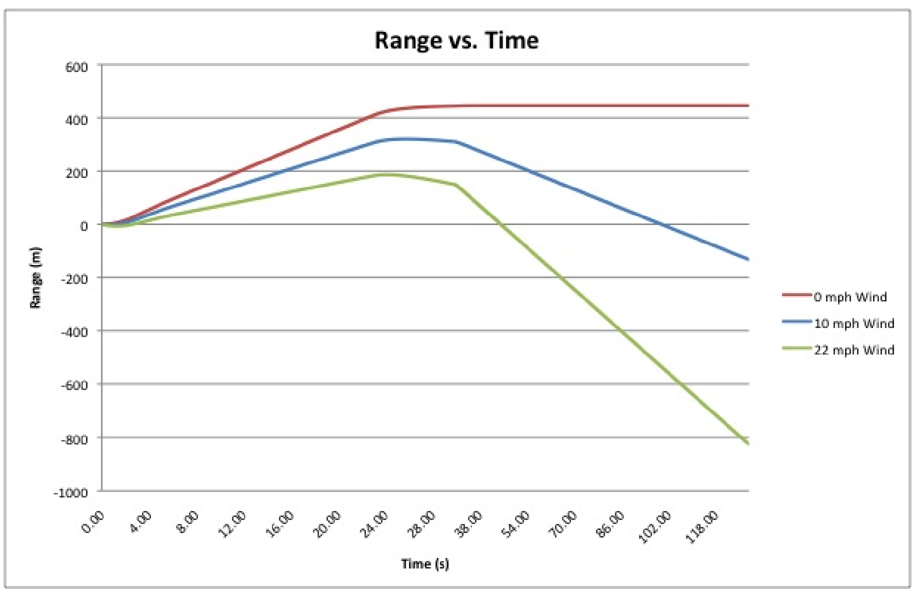


Figure 31: Landing footprint with effects of wind drift.

III.J. Launch Operation

III.J.1. Final Assembly and Launch Procedures

The final assembly of the Javelin will be accomplished using a series of checklists to ensure the Javelin is adequately prepared for a safe flight. Appendix A includes a detailed overview of the steps that will be taken when constructing the Javelin. The team will also follow extensively developed procedures during launch, all of which will be performed with the use of multiple checklists. The purpose of using checklists is to facilitate the safety of all team members, and mission assurance. These checklists include the procedures for troubleshooting a misfire, hang fire, parachute deployment failure, and undeployed recovery charges. Also included are the necessary steps to complete a successful post flight inspection. All checklists for launch and preparation can be found in Appendices A and B.

III.J.2. Recovery Preparation

Recovery preparation will be handled according to the already established procedures developed by the previous USU team. These procedures led to the successful preparation and deployment of every recovery system the previous team used. The procedures include proper folding patterns for the parachutes, as well as black powder/e-match preparation.

III.J.3. Motor Preparation

Motor preparation will be conducted according to the manufacturer's instructions. The procedure of preparing the motor for flight will be walked through and rehearsed so the team is proficient and familiar with the assembly of the L730. The goal is to assemble the motor and have it ready for installation within ten minutes. Ten minutes was determined to be the amount of time a person could maintain fine motor skills in inclement weather before they lost focus and started making mistakes.

III.J.4. Igniter Installation

By law, the igniter will not be installed into the rocket until the rocket is on the launcher, or in the area specified by the range safety officer. The team has ordered an igniter kit from Firefox Enterprises Inc. The igniters burn for 1-2 seconds at approximately 2000 degrees Fahrenheit, guaranteeing propellant ignition. The igniters will be attached to a thin wooden dowel which will be inserted into the rocket, keeping the igniter head at the top of the rocket. Once inserted, the nozzle cap will be replaced on the nozzle, keeping the igniter in place until motor ignition.

III.J.5. Setup on Mobile Launch System

During both the competition and test flights, the Javelin will be launched using the mobile launch rail system designed by previous Chimaera rocket teams. The mobile launch system incorporates a launch rail 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 are made via adjustable jacks on either side of the trailer, as shown in Figure 32. The mobile launch system has undergone extensive operational testing to ensure all launch requirements will be met and that the trailer will be capable of safely launching the Javelin. The launch rail has also been evaluated to ensure it will remain rigid, stable, and will not extend beyond vertical tolerances during launch.

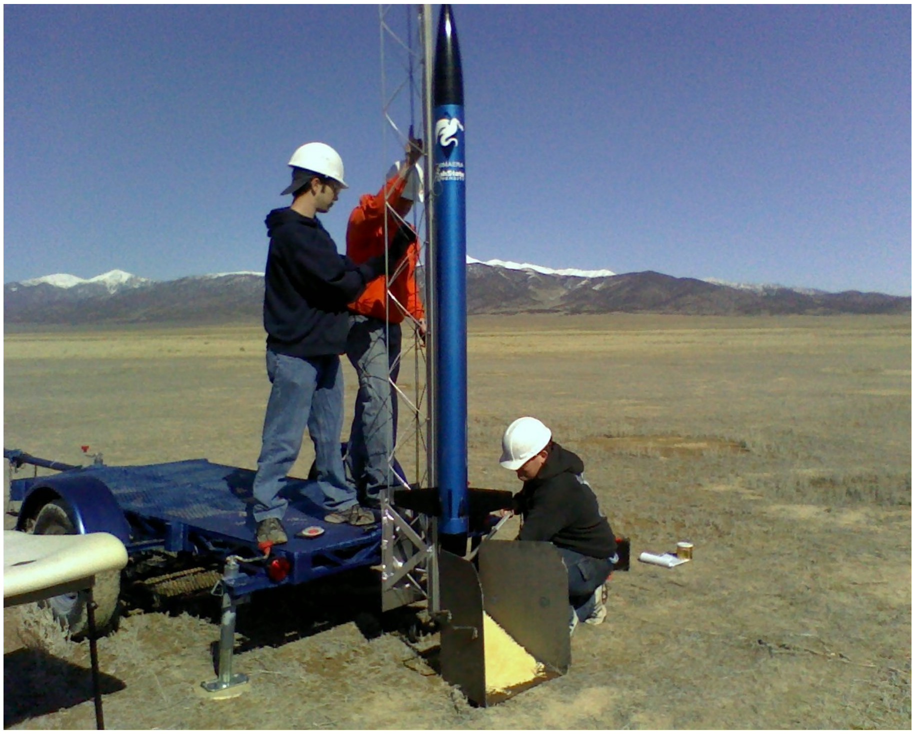


Figure 32: Launch stand leveling jack.

Launch System Improvements The electrical system on the trailer was not functional at the beginning of the semester. The team needed to re-wire the trailer lights to get the connection needed for functional lights during transit. To evaluate the road-worthiness of the mobile launch system, the trailer was tested to ensure the electrical connections remained secure during transit. 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.

This year's team has also improved the mobile launch system by designing and constructing a new launch controller to use during the test flights of the Javelin. This new launch controller gives greater reliability to the existing system by eliminating unnecessary components and updating worn hardware. Previous teams have used the "Universal Launch System, Module 1: Base Module" by Pratt Hobbies Inc. This system allows for multiple rocket configurations from cluster motors to hybrids. Over the years this system has fallen into disrepair. Since the current team is not concerned with cluster motors or hybrids, the decision was made to simplify the system and increase the reliability by focusing solely on the launch of single APCP motors. The new system was designed, built, and tested over the Christmas break. Figure 33shows the wiring diagram used to build the system. The controller was designed to include an in-line safety key; when the key is removed the system is incapable of launching a rocket. A continuity circuit including an LED was wired to make sure the igniter was getting power before launching. The continuity check only puts 12 mA through the igniter, which is well below the current required for ignition for most products. A mechanical relay was used to isolate the 12 VDC side of the controller where the rocket is, from the 9 VDC side 500' away where the launch switch is located. The actual launch switch is a momentary contact switch that returns to the "off" position after it is released. The controller can be switched from "pad ARMED" to "pad SAFE" when conducting continuity checks, or troubleshooting a misfire.

The launch controller is capable of successfully igniting devices that require as much as 3 A. The team successfully test-fired two different igniters, each requiring around 1 ampere to ignite. Figure 34 shows the new system in the testing phase. The controller performed flawlessly, giving the Chimaera team confidence in the supporting equipment that will aid in mission success.

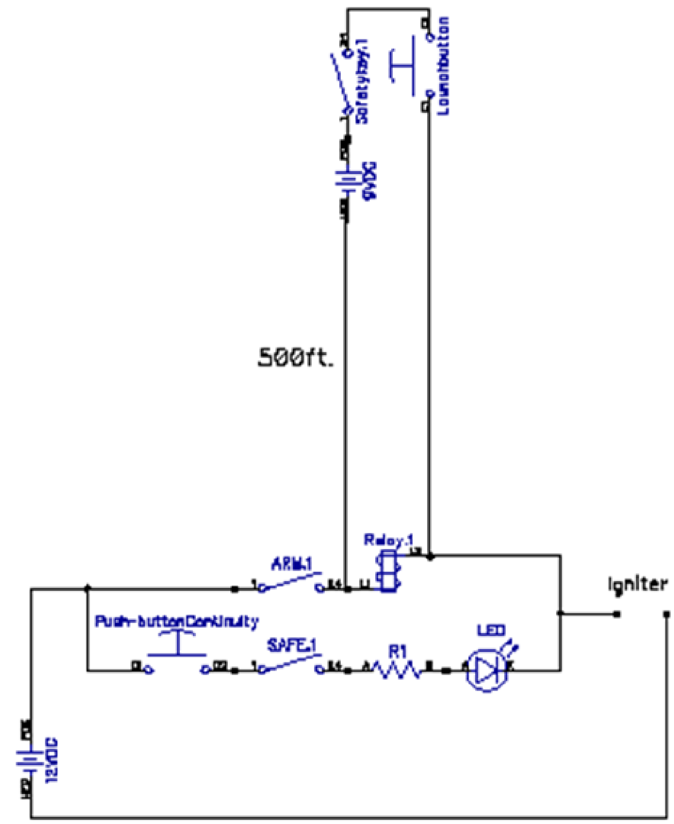


Figure 33: Launch controller wiring diagram.


Figure 34: New launch controller system in the testing phase.

III.K. Safety and Environment

III.K.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 15. 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 included:

- 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. The fins for the rocket were attached to the motor tube too far aft and prevented the motor retainer from sitting 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 15: 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.K.2. Hazard Evaluation and Risk Mitigation

The Chimaera team has adapted the risk assessment procedure outlined by the NASA Engineering and Safety Center (NESC)[c] to more accurately reflect the likelihood and consequences of the hazards that can be reasonably anticipated in high-power rocketry. The amount of risk the team will see is a function of the severity and the likelihood of an event happening. The greater the consequence and the more frequently an event happens, the more risk you can expect. Figure 35 shows the hazard evaluation matrix used to determine the level of risk for a given hazard. A detailed explanation of how the likelihood and consequence of a hazard can be classified is outlined below..

[c]http://www.rmc.nasa.gov/presentations/Yuchnovicz_NESC.pdf

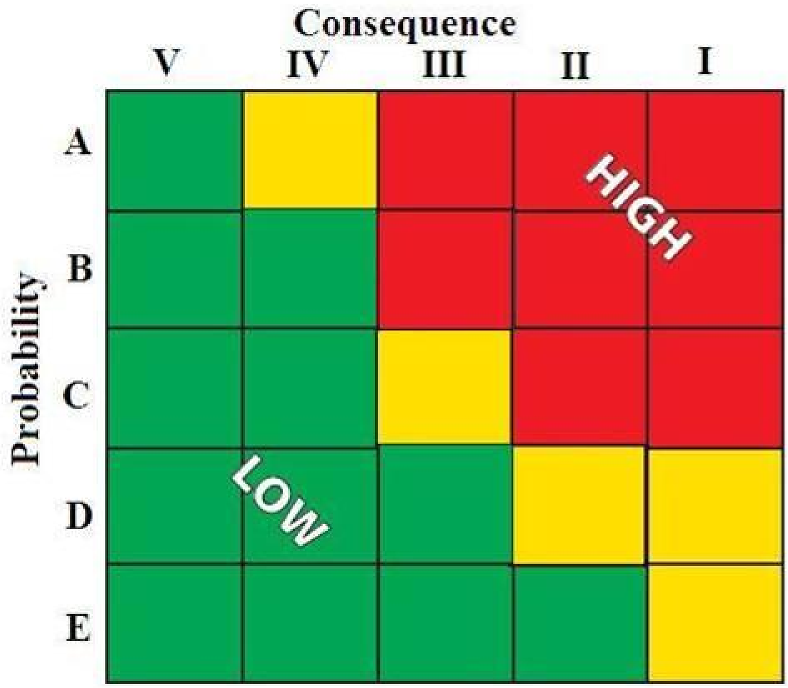


Figure 35: Hazard evaluation matrix used to determine risk level.

Event Likelihood The probability of an event happening is largely based on industry and personal experience. Materials can be characterized to an extent, giving the user an idea of how that particular material will react in a given situation. It is therefore a somewhat subjective matter prescribing the likelihood of any particular hazard or event. Table 16 gives a description of what each level of probability represents.

Table 16: What is the likelihood of a given situation happening?

Level	Likelihood/Probability	This means...
A	Very Likely	It is likely this will happen >90% of the time (9 in 10)
B	High	This happens more often than not (60%, or 3 in 5)
C	Moderate	There is a chance this will happen (25%, or 1 in 4)
D	Low	This rarely happens (1%, or 1 in 100)
E	Very Low	This occurs less than .1% of the time (1 in 1000)

Event Severity The severity can be conservatively estimated from experience and by assuming worst-case scenarios. Table 17 gives the classification for the different levels of consequence. The severity of an event will not impact personnel, payload, and environment in the same way. It is necessary to separate these areas in order to understand how an event impacts them differently.

Table 17: Level of consequence and threat to personnel, environment, and payload.

Level	Consequence/Severity	This means...
I	Catastrophic	**Personnel:** Life threatening or permanent disability **Environment:** Massive, irreparable loss or damage; damage results in legal action **Payload:** Complete system failure without ability to resolve; results in mission failure
II	Extreme	**Personnel:** Injury requiring hospitalization/emergency medical attention **Environment:** Large scale damage **Payload:** System failure
III	Moderate	**Personnel:** Requires medical aid, but manageable with a first-aid kit **Environment:** Requires clean up and/or fixing; evidence of incident remains **Payload:** Small damage prevents system from functioning as designed, but still mostly functional
IV	Minor	**Personnel:** Minor abrasions and contusions **Environment:** Requires clean up and/or fixing; no lasting effects **Payload:** Introduces small amount of variance in performance
V	Insignificant	**Personnel:** Temporary confusion, bewilderment, or discomfort **Environment:** Little or no damage; easily cleaned up or fixed with no lasting effects **Payload:** Nominal performance regardless of incident

Mitigating Risk Through Controls It is possible to mitigate, or alleviate, some amount of risk by introducing controls that will reduce the level of severity or likelihood. Reducing severity requires minimizing the impact of the event. Controls that will reduce the severity of an event include, but are not limited to:

- Personal Protective Equipment (PPE); this will vary depending on the material or situation at hand.
- Maintaining the proper stand-off distance and only operating in areas designated for high-power rocketry use.
- Minimizing the number of personnel involved in a situation.

It should be noted that reducing the severity of an event with respect to personnel may not change the severity with respect to environment or payload, and vice versa. Reducing the likelihood of an event requires limiting the opportunity for that event to happen, such as:

- Eliminating stray electricity.
- Using checklists and procedures that are designed to eliminate accidents.
- Separating explosives from conductive materials.

The Chimaera team will not accept any risks deemed high according to the hazard evaluation matrix. A high risk would expose the team or others, the environment, and the Javelin to situations that may be life threatening, or damaging beyond repair. As such, the controls outlined in Table 18 have been or will be implemented in order to reduce the severity of, and our exposure to hazardous situations.

Table 18: Risk reduction through control measures.

Identified Hazard	Initial Risk Level	Control Measures	Residual Risk
Motor ignites in transit	**Personnel:** I-E (M)	Store motor in explosives magazine; separate rocket components from the magazine; keep magazine in a locked container on the trailer instead of in the vehicle	V-E (L)
	Environment: III-E (L)		V-E (L)
	Payload: I-E (M)		V-E (L)
Igniter fires while conducting systems check	**Personnel:** I-E (M)	Don't install igniter until systems check is complete; ground out while handling/inserting the motor and igniter; keep launch controller in SAFE mode until systems check completed	I-E (M)
	Environment: V-E (L)		V-E (L)
	Payload: I-E (M)		II-E (L)
Rocket is unstable, tumbles during flight	**Personnel:** II-D (M)	Ensure C_P is aft of C_G in flight configuration every time before flight; install/remove ballast as necessary	III-E (L)
	Environment: III-D (L)		III-E (L)
	Payload: I-D (M)		III-E (L)
Black powder ignites while constructing/loading deployment charges	**Personnel:** II-D (M)	Ground out before using black powder; wear PPE; keep electronic devices off within 5' of black powder	III-E (L)
	Environment: IV-D (L)		IV-E (L)
	Payload: III-D (L)		IV-E (L)

Identified Hazard	Initial Risk Level	Control Measures	Residual Risk
Test stand cannot hold motor	**Personnel:** I-E (M)	Maintain minimum stand-off distance for the motor being tested; ensure test cell is vacant before initiating test; ensure surrounding area is clear of flammable material; check fasteners holding motor to ensure they are snug	IV-E (L)
	Environment: II-E (L)		IV-E (L)
	Payload: II-E (L)		V-E (L)
CO_2 tank dropped and the valve cracks, turning the tank into a projectile	**Personnel:** IV-E (L)	Do not toss tanks; carry extra tanks and o-rings in case of an accident	IV-E (L)
	Environment: V-E (L)		V-E (L)
	Payload: I-E (M)		V-E (L)
Batteries explode	**Personnel:** II-E (L)	Charge only rechargeable batteries; keep batteries out of extreme heat; have spare batteries on hand	III-E (L)
	Environment: III-E (L)		III-E (L)
	Payload: I-E (M)		V-E (L)

III.K.3. Regulation and Safety Compliance

The team is aware of, and in compliance with, all the National Association of Rocketry (NAR) safety requirements outlined in Appendix C. Each team member has also signed a Safety Compliance Form in Appendix D that verifies each student understands the following: 1) NASA will conduct range safety inspections of each rocket before it is flown. The USU Chimaera team will comply with the inspection determination; 2) The NASA 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.

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 are used 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 can be found on the Chimaera website at www.chimaera.usu.edu. 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) was obtained through the Bureau of Alcohol, Tobacco, and Firearms (BATF) by Dr. Stephen Whitmore, the team instructor. The permit expires in March 2011, however, a new permit will be obtained 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 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 Javelin design will include an L-class, re-loadable 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 UROC. 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.

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.

Manufacturing Safety The team has full access to the USU machine shop and wood shop, to include a drill press, table saw, sheet metal bender, welding machines, a CNC mill, and any power tools or hand tools that may be required during the construction of the Javelin. Before team members are allowed to use the facilities they are first given instruction on each piece of machinery. The team must abide by the strict rules and guidelines posted in the shop, and outlined in Appendix F.

IV. 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 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 with linear aerospike nozzle theory. This allows for the collection of in-flight ramp pressure data, which has never been done before. 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.

IV.A. Payload Concept

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 inches of its target.

Figure 36 plots the velocity and drag as a function of time for a typical one-mile launch trajectory. Figure 36 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 4 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. Figures 37 and 37 compare a typical unaugmented trajectory (C-BAS inactive) to an augmented trajectory (C-BAS active). The data presented in Figure 37 is taken from thrustcurve.org and represents a Cesaroni L730[2] 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.

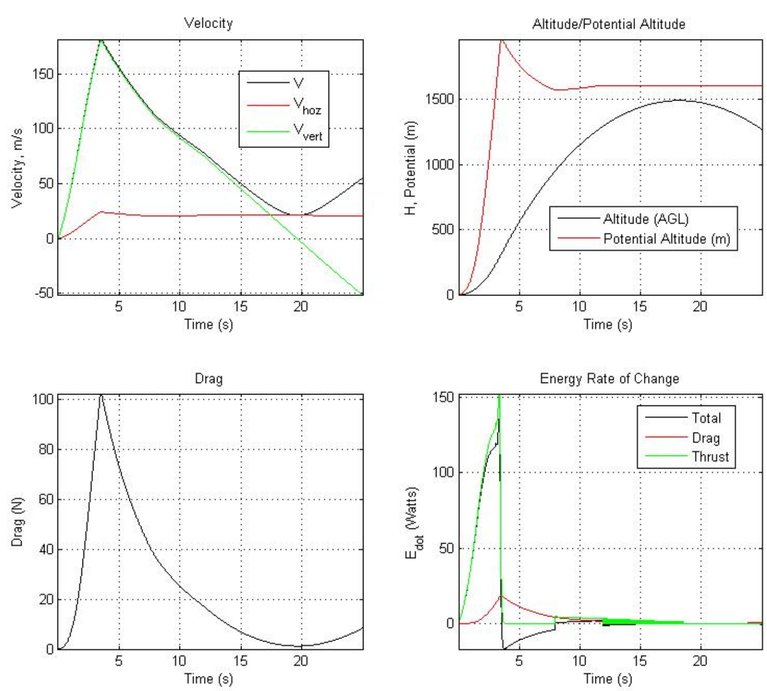


Figure 36: Unaugmented Javein trajectories. (C-BAS Inactive)

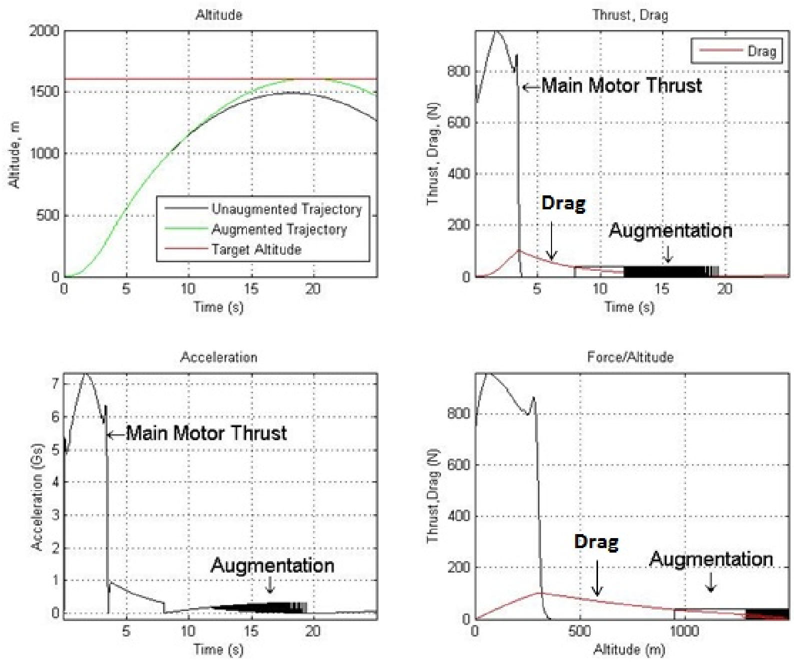


Figure 37: Augmented Javelin trajectory. (C-BAS Active)

The aerospike expansion ramps, with their altitude compensation ability, are the key innovation for the C-BAS. Typical cold gas systems inject the gas without any special expansion nozzle, but the C-BAS will become more efficient when ideally expanded at all altitudes. 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, 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 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 system 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. 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 Sensors® (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. The tank itself is rated to well over 3500 psi, and includes a built-in burst valve that will burst at over 3000 psi. These pressures are well over the expected pressures, as the tanks are filled to 800 psi. At this pressure and room temperature, CO_2 is a saturated liquid and requires either overfilling or extreme temperature change for the burst valve to fail.

Figure 38 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. Ensuring 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.

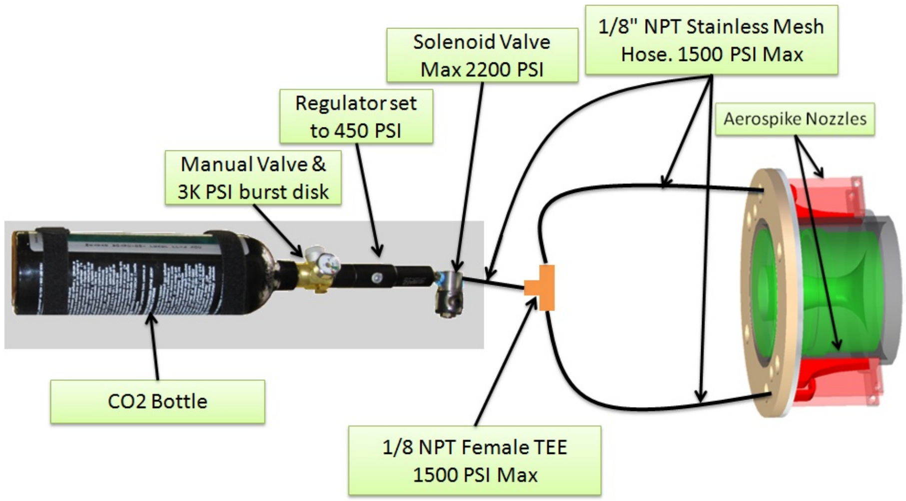


Figure 38: C-BAS component layout.

IV.C. 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 to continuously estimate the total specific energy and potential altitude of the vehicle. Figure 39 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 computer also comes standard with six 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.[11]

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.

V. Payload Verification

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 39. As apogee is approached the filtering algorithm is weighted to bias the potential altitude reading to the PerfectFlite value.

Figure 39: Avionics suite used for energy management algorithm and flight data management.

V..1. *Solid Motor Test Stand and Instrumentation*

A specially developed static-thrust test stand shown in Figure 40 will be used to obtain motor burn profiles for a minimum of 6 fuel-grain reloads on the Cesaroni L730 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.

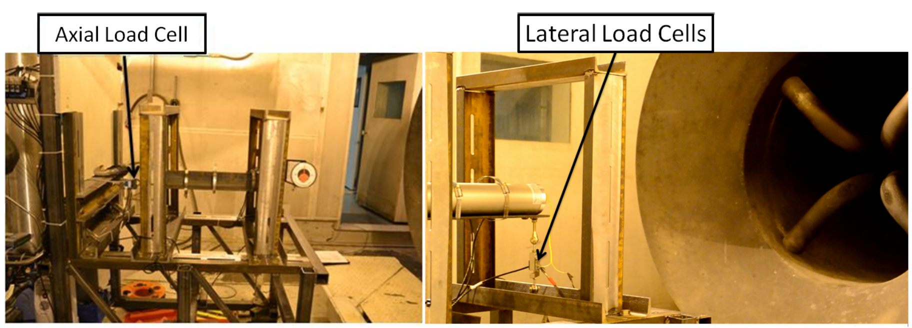


Figure 40: Rocket motor static test stand showing instrumentation.

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.® 0–7000 kPa (0–1000 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 41 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 42 shows the motor plume during a typical test firing.

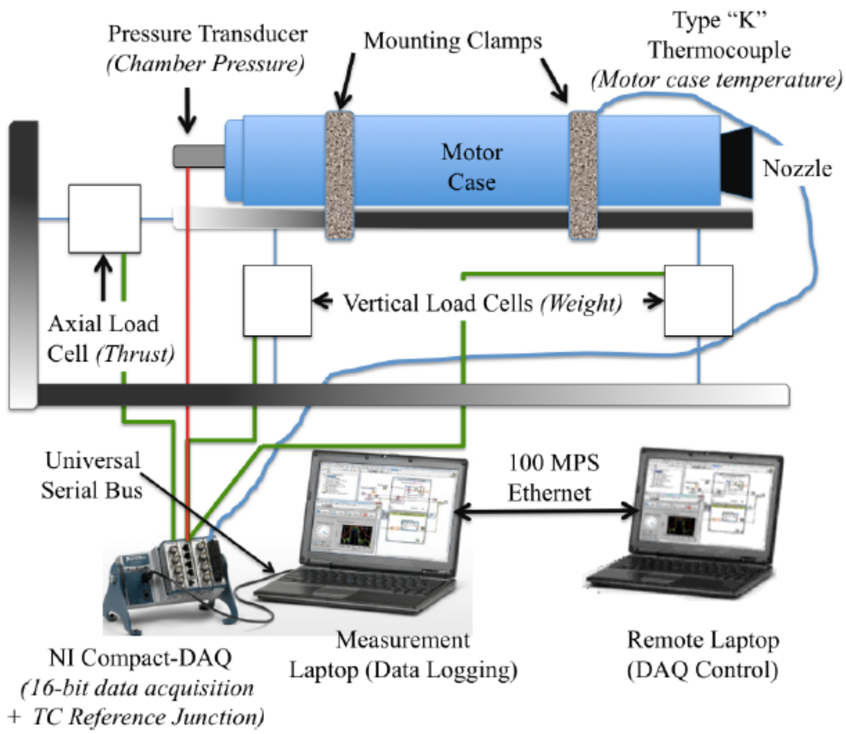


Figure 41: Schematic of static thrust instrumentation.

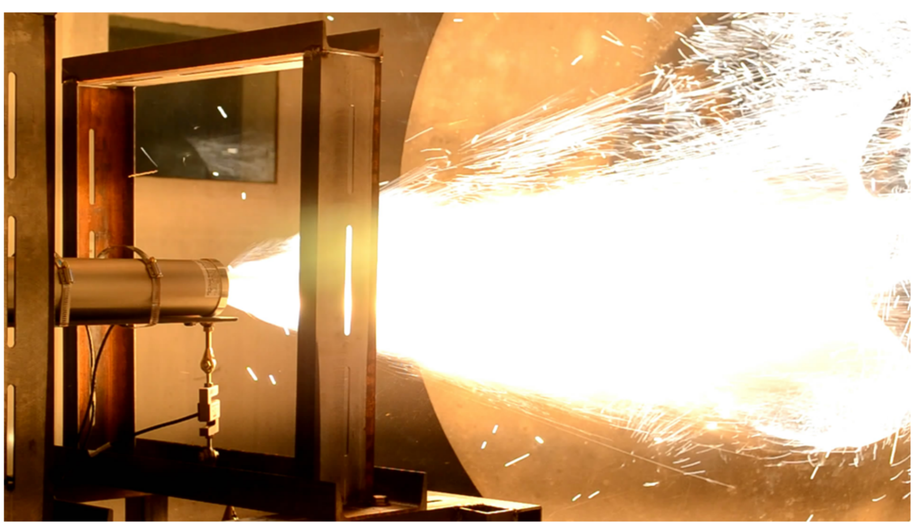


Figure 42: Rocket plume during test fire of a Cesaroni L820.

V.A. C-BAS Test Stand

There will be three points along each ramp where plumbing will route ramp pressures to the pressure sensors that will be used to acquire 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 instrumentation 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 acquisition 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 43 shows the layout of the C-BAS test stand.

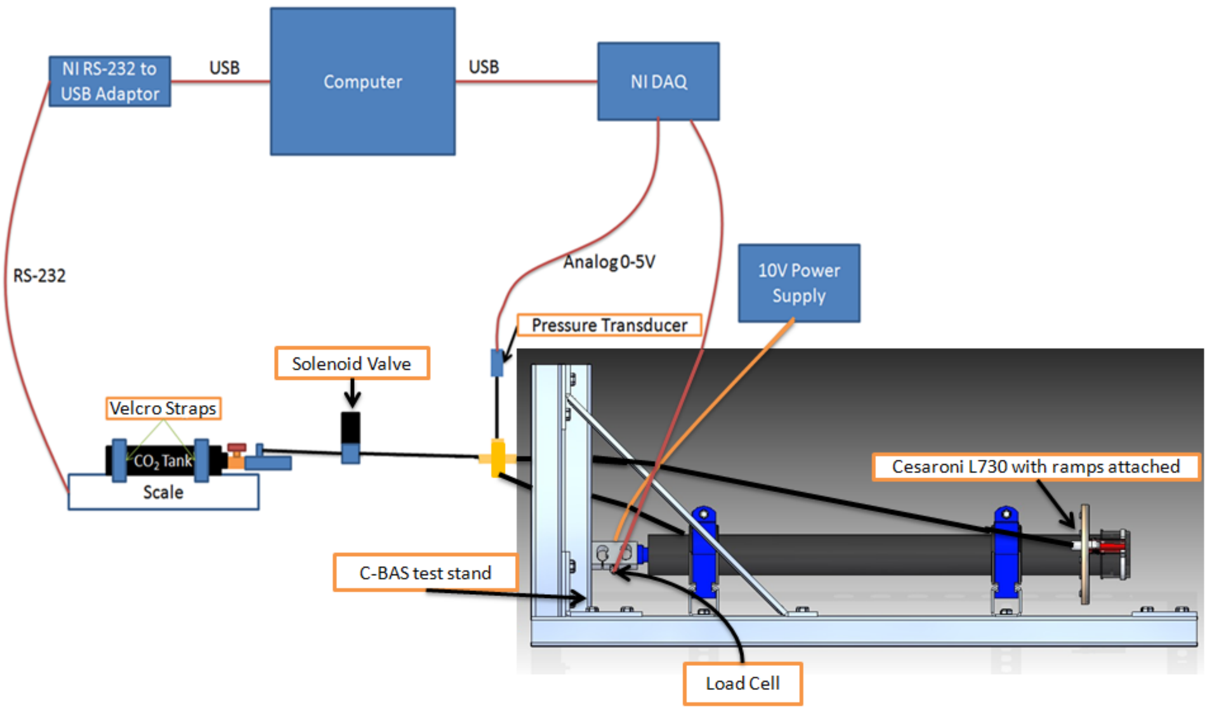


Figure 43: Cold gas test stand.

V.B. Flow Pressure Regulation

The output pressure of the regulator attached to the CO_2 tank was calibrated by attaching a T-junction to the output of the pressure regulator with a pressure transducer on one end of the junction, and allowing air to flow out through the other end. Additionally, a solenoid valve was attached between the pressure regulator and the T-junction to regulate the flow from the tank. The solenoid was then activated to allow for gas to flow through the system. The regulator was then calibrated to output as close to the desired output pressure of 450 psi as possible. The setup for the test is shown in Figure 44.

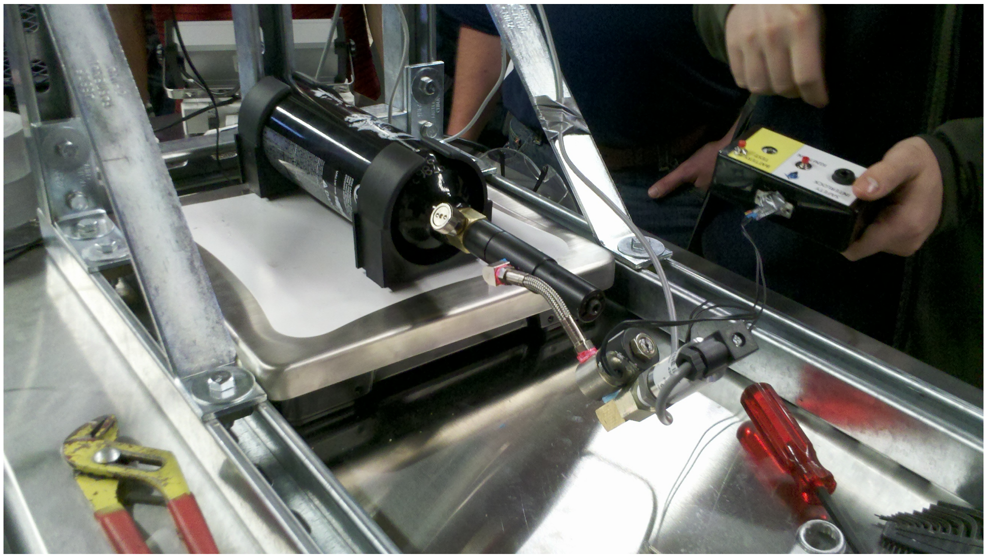


Figure 44: CO_2 output pressure calibration test.

V.C. Sealing

The ramps were sealed using a heat-activated stick designed to permanently seal leaks and cracks in Aluminum at 600 psi and up to 350º F (NSF 61 Certified). To melt the stick, it needed to be heated to 250º F. A heat gun was used to melt the stick, and the temperature of 250º F was carefully controlled using an infrared thermometer. The sealant used is the green substance that can be seen all over the ramps in figure 45.

V.D. Leak-Test

To test them for leaks, the ramps were tested at 120 psi with shop air at Utah State University's Senior Design Lab. The ramps were assembled using a 1/8" inside diameter (3/8" outside diameter) crack resistant flexible tube, rated for 540 psi at 70º F. At the ramps-end of the tube, we attached a 1/8" 10-32 miniature brass barbed fitting, and a 1/4" NPT to 1/8" ID tube adapter was used for the shop air connection. Figure 45 shows the test rig.

Before applying the sealant, the ramps had a major, noticeable leak in the area where the main and throat parts came together. Other leaks were found in the areas where the plates and main part came together as well. The leak tests were performed using a bubble-forming high visibility leak detector sprayed all over the ramps; then air was allowed to flow.

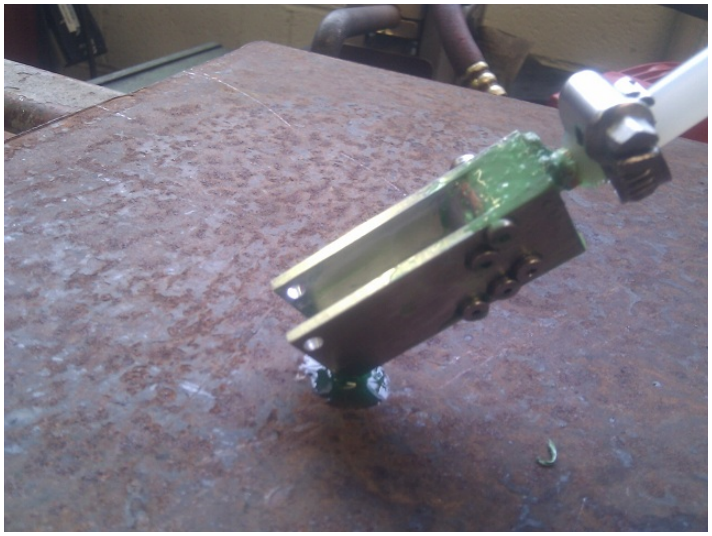


Figure 45: Ramps with leak detector.

All the leaks in the ramps were satisfactorily eliminated with the sealant. Nevertheless, the leak present at the barbed fitting with the clamp attached seen on Figure 45 was not eliminated. Fortunately, the tubes and fittings that will be flying in the Javelin are rated for 1500 psi, and unlike the low-pressure barbed fittings used for this test, they will not leak.

V.E. CO_2 Tank Supports

We will be using a very simple approach when it comes to fixing the CO_2 tank in place. The CO_2 tank will slide into the payload bay, from the drogue parachute-side of the rocket. One fixed bulkhead will be used to center the tank, and a removable one used to keep it in place. Figure 46 shows an overview of what the payload bay will look like, and how the CO_2tank will be kept in place.

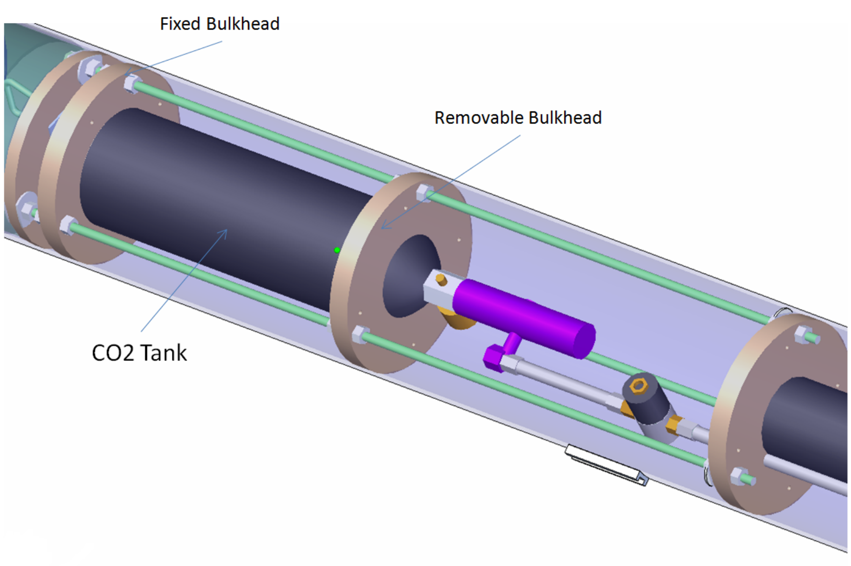


Figure 46: Supports for the CO_2 tanks.

We are also still considering the idea of having a side door, and wing nuts on the right-hand side of the removable bulkhead, for easier access. Nevertheless because of ergonomic concerns, we will be conducting a test to have a better idea of the difficulty of loosening the nuts, moving the bulkhead along the rods that support it, and taking the cylinder out and putting it back in. Depending on the results of these tests, we might only be able to take the CO_2 tank in and out sliding it from the drogue parachute-side of the rocket.

V.F. Future C-BAS Tests

The payload testing has been slightly delayed due to technical difficulties of obtaining a solenoid with sufficient flow and pressure capabilities. These issues have been resolved, but the lead time on solenoid valves is fairly long. The following tests will be performed once the new solenoid has been received; likely, before the CDR presentation has been given.

- Mass flow test
  - The mass flow rate of the C-BAS shall be measured by recording the change in mass of the CO_2 tank as the gas is allowed to flow through the system.
- Pressure test
  - The output pressure of each component shall be measured to determine whether the flow is being choked prematurely or not.
- System test
  - The full C-BAS shall be tested for its performance ability, measuring pressures down the ramp, mass flow rate, and momentum flux of the expansion ramps.

V.G. Science Value of Payload

One consideration that make this payload scientifically valuable 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. Another is the analogous 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 other planetary landers, where the cost of delivering mass to the surface is high. While aerospike nozzles have long been known for their altitude compensation ability during atmospheric flight, they also present significant potential advantages for space applications.[15] 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 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.[16]

V.G.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 that the flight environment has 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 yet been tested in flight.

VI. Activity Plan

VI.A. Budget Plan

The team is only allowed $5000 worth of flight hardware, but the cost of this project far exceeds that amount. The team requires funds for testing materials, back ups, certifications, and travel to the competition. Thanks to generous donations from the College of Engineering, the Utah chapter of AIAA, Rocky Mountain Space Grant Foundation, and others, the team has $16,500 at their disposal for the entire project.

Due to limited funding and the $5000 flyable hardware limit, the team keeps meticulous records of all of their spending. A copy of every receipt is given to both the team's procurement officer, Sam, and Program Manager, Dr. Whitmore. All donations, monetary and materialal, are tracked by the procurement officer. The team has currently spent 31 percent of their overall budget. This money has gone toward purchases for instrumentation, motors, payload equipment, and Level II certifications for two of the team members, and outreach supplies. To date, 41 percent of the hardware budget has been used. The team is on track to come in slightly under budget on the Javelin. Extra funds will be diverted to the travel fund, so that students will not have to pay as much out-of-pocket to travel to Huntsville. Figure 47 is a copy of the team's detailed budget.

Hardware	Spent	Allocated	% Used
IMU: Microstrain 3DM-GX3	$0.00	$1,500.00	0.00%
RDAS	$343.00	$343.00	100.00%
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	$165.11	$200.00	82.56%
Motor and Solid Fuel	$690.00	$690.00	100.00%
Onboard Camera	$105.95	$105.95	100.00%
Recovery	$0.00	$350.00	0.00%
Body Tube	$188.80	$325.00	58.09%
24 CO2 Tank	$45.00	$45.00	100.00%
Isentropic Expansion Ramps	$0.00	$100.00	0.00%
Payload Tubing and valves	$44.37	$50.00	88.75%
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	$140.89	0.00%
Subtotal	$2,072.39	$5,000.00	**41.45%**

Certifications, Testing and Outreach			
Certifications	$1,162.98	$1,162.98	100.00%
Outreach	$64.65	$100.00	64.65%
Testing	$1,951.66	$2,237.02	87.24%
Subtotal	$3,179.29	$3,500.00	**90.84%**

Travel and Transportation Expenses	$0.00	$8,400.00	**0.00%**

Total	$5,251.68	$16,900.00	**31.08%**

Figure 47: Overall procurement status.

VI.B. Timeline

The team is very aware of the deadlines set by USLI. They have scheduled tests for the coming weeks, and are set to test launch during the last week of February. Figure 48 is the team's top level milestone chart. Individual test dates, report deadlines, and upcoming outreach events can be found on the Chimaera website.

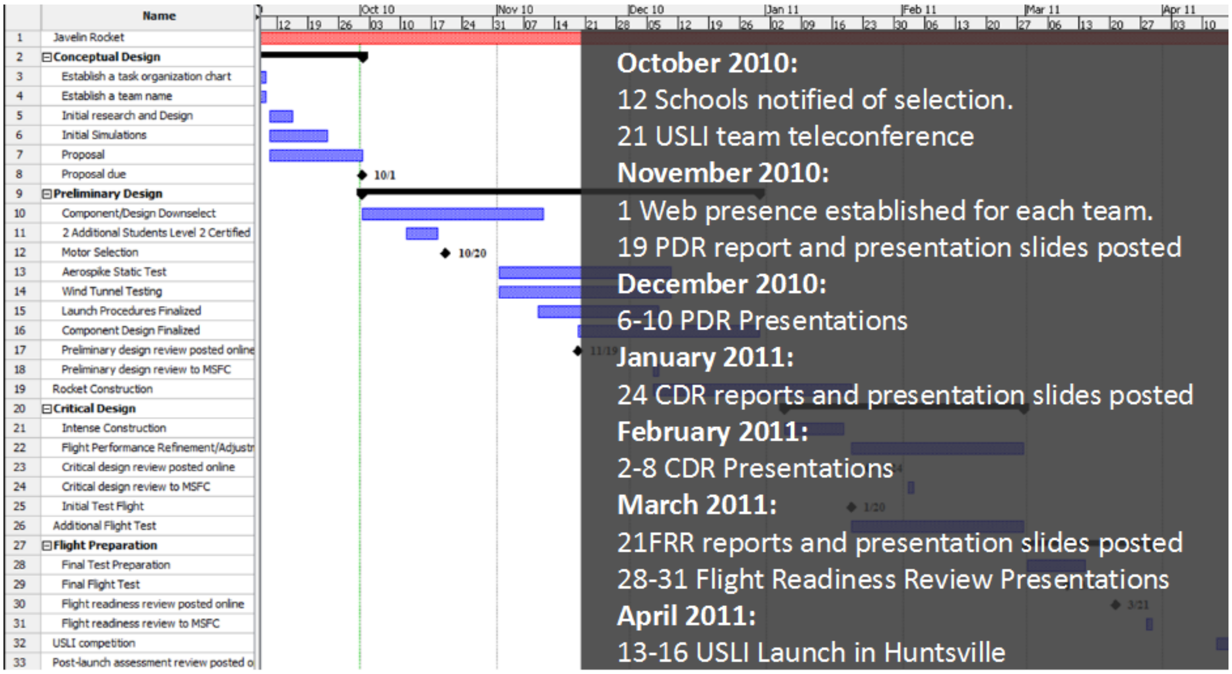


Figure 48: Top level milestone schedule.

VI.C. Educational Engagement

Community support is critical for the team's success. 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.

VI.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 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, Microstrain, Total Impulse Rocketry, and the Utah chapter of American Institute of Aeronautics and Astronautics.

The team is heavily supported by the College of Engineering and they are 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.

VI.C.2. Outreach

The purpose of the team'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 events at local schools and surrounding area. Figure 49 illustrates some of the activities the team has done thus far.

Figure 49: 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 teenagers 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 50.

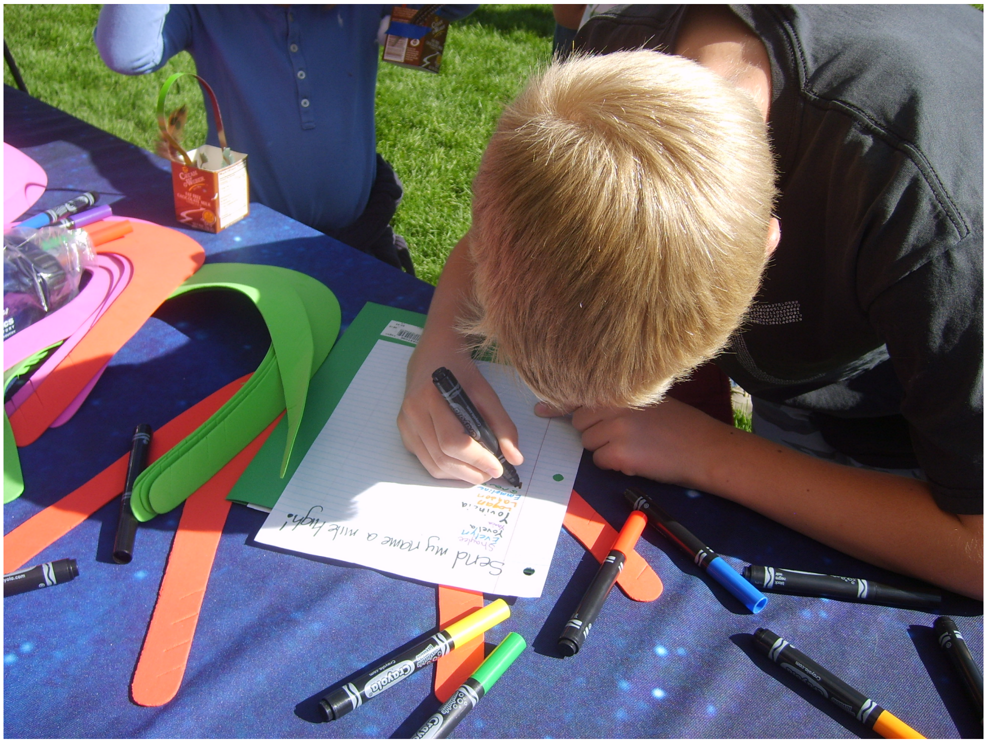


Figure 50: Fly with the USU Rocket Team!

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. December's lesson explored what it takes to live and work in space, and students had the opportunity to build a "spacesuit" to protect Astronaut Bob (an apple). Future lesson plans include 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 to 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.

Logan High School Physics Drew Neilsen teaches one AP and three general physics classes at Logan High School. The rocket team had the opportunity to visit each of these classes to give a presentation about the rocket project. They presented a modified PDR and discussed with the students the design process, the competition, and team goals. The students, for the most part, were very engaged and asked quite intelligent questions. Having recently designed and tested their own water bottle rockets, the classes were interested to see how the physics they know applies to something more sophisticated. As a result of the evaluations conducted at LHS, the team has added an FAQ page on its website for students to learn about the rocket in more simplified terms. Students may also submit new questions through the website at any time.

Utah AIAA Meeting The team was invited to present their project progress to the local AIAA chapter on January 20. They discussed their design selection process and upcoming tests. Utah State students and employees from Northrop Grumman and Space Dynamics Laboratory were in attendance. The team fielded questions about the C-BAS payload and general design. The highlight of the evening for many spectators was the team's first motor test! The team was able to test their instrumentation and safety procedures, as well as answer many questions about their motor selection process.

Other School and Community Outreach The team has spoken with several other groups that are excited to have their students learn about rockets. In April 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. In February, the team will present to Northrop Grumman employees at their Clearfield plant. They will participate in a community outreach day and other Engineering Week events on the USU campus. Adams Elementary School has asked the team to help with their science fair in March. The rocket team continues to partner with SDL and is continually searching for new opportunities to talk to students about the rocket project.

VI.C.3. Website

The current web design is set up as an organizational system to keep team members and the community up to date on changes and the current progress of the project. The website has a built-in tracking system, Gantt chart, and all important documents are uploaded as soon as they are completed.

The team launched two new web sections over the Christmas break to update and improve the website. A "Frequently Asked Questions" section was developed, devoted to answering questions posed by anyone interested in the rocket project, particularly those the team visits with during outreach events. Students' questions are clarified here, and anyone can submit new questions at any time. "Analysis and Testing" is the second new section. Here one can find explanations of current design theories and tests being performed to verify the Javelin will win the USLI competition. Lastly, the "Sponsors" page has been updated to include all current corporate and academic sponsors of the Chimaera team

VII. Conclusion

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 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 aerodynamic drag. At different waypoints during flight, the on-board avionics will calculate the energy lost due to aerodynamic 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 flight measurements of plume-induced compression for an over-expanded aerospike nozzle.

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, to include Monte Carlo simulations, in order to narrow down design decisions. In addition, tests have been conducted on some of the critical components of the rocket, such as the Blue Tube structure and wood bulkheads. This will ensure that the Javelin will be safely launched and recovered at the competition.

Since the Preliminary Design Review, the Javelin has experienced some changes to its design. The Cesaroni L820, which was the team's original choice for the motor, was found to be illegal. The Cesaroni L730 was instead selected to be the Javelin's propulsion unit. This motor has different dimensions than the L820, which led to a slight change in the rocket's mold lines. The length of the Javelin was increased, and the smaller diameter of the L730 has created more room for key components of the C-BAS.

The team continues to be well-positioned to succeed in the USLI competition. Capitalizing on the talents of team members, the support of community and university sponsors, and simulation and design processes developed by the team, the Javelin represents the pinnacle of achievement for the students involved.

[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

A. Manufacturing Instructions

A.A. Manufacturing Guidelines

- All adhesion surfaces must be sanded first using a 100-120 grit sandpaper. Dry fit all components before gluing them in place.
- Any time "glue" is referenced, epoxy should be used.
- All bulkheads must be bonded to the body tube using J-B WELD® and a Popsicle stick (or gloved finger) to create a fillet. All adhesion processes will be done using standard model rocketry epoxy or J-B WELD®. Instructions on mixing epoxy MUST be followed strictly to ensure correct bond integrity (i.e. If you are using 30-minute quick cure epoxy, make sure you have the bond ready to be cured within 30 minutes.)
- When attaching the fins to the rocket, use epoxy to create a fillet on the motor tube, and on both sides of the body tube.
  - Mix some talcum powder or baby powder into the epoxy until it forms a paste-like substance. Use this to make the fillets between the fins and exterior of the body tube.
- Use J-B WELD® when attaching the motor retaining bulkhead and motor retaining ring.
- A pressure relief hole measuring approx. 5/32" should be drilled in each component: payload section, avionics section, nosecone.
- DO NOT INSTALL THE MOTOR UNTIL YOU ARE READY TO LAUNCH!! When installing the motor, follow the manufacturer's instructions. Make sure the motor retaining ring is installed securely after the motor is installed.
- Black powder charges for the parachutes should not be installed until at the launch site.
- The igniter should not be installed until the rocket is in the launch configuration, or until the rocket is in a pre-designated area as instructed by the range safety officer.

A.A.1. Assembly instructions

COMPLETELY READ AND UNDERSTAND THE STEP BEFORE PROCEEDING

Motor and Fins

1. Drill holes through the forward centering ring for the CBAS hoses.
2. Glue forward centering ring to the motor tube.
3. Make slits in the body tube for the fins.
4. Cut out and attach the avionics access doors and payload access doors (if applicable).
5. Glue forward centering ring on motor tube to the airframe, making sure the holes for the CBAS are NOT lined up with the slots for the fins.
   (a) using clear tape, tape three-four pieces of tape onto the aft centering ring, leaving tabs you can use to pull on the centering ring. Place the aft centering ring on the motor tube while gluing the forward centering ring on, but DO NOT GLUE THE AFT CENTERING RING YET. Use the tape tabs to remove it after the forward centering ring is glued in place and dry.
6. Glue fins onto the motor tube one at a time by first placing a small bead of quick cure epoxy on the root of the fin (the part that actually touches the motor tube. Hold in place until it doesn't move anymore. Then make the fillets between the motor tube and fin root, and on the interior and exterior of the motor tube.
   (a) When attaching the fins it is essential to get them perpendicular to the motor tube and airframe. If the fins are not perpendicular it can increase drag, and make the rocket "wobble" during flight. For straight flight the fins **must** be perpendicular.

Payload

1. Drill holes in the aft payload bulkhead for threaded rods. Epoxy nuts on one side of the hole.
2. Glue the aft payload bulkhead in place.
3. Assemble solenoid valve, regulator, and tubing for the CBAS. Insert and fasten to the aft payload bulkhead.
4. Insert the threaded rods into the aft bulkhead and thread on nuts to the height required to give enough room for the solenoid valve and regulator.
5. Drill holes into the mid-bay payload bulkhead for the threaded rods. Glue onto the airframe just above the nuts previously threaded on in step 4. Thread three more nuts and lock washers onto the rods to lock the bulkhead in place.
6. Thread three more nuts onto the threaded rods to support the forward payload bulkhead. Place the CO_2 tank into the mid-bay bulkhead and dry fit the forward payload bulkhead to determine ideal positioning. Remove CO_2 tank and forward bulkhead. Drill two holes in the bulkhead for the eye-bolts that will be used to fasten the shock cord to the lower rocket assembly and the avionics bay. Attach the eye-bolts and glue the forward payload bulkhead in place. Attach shock cord to the eye-bolts.

Avionics

1. glue coupler to avionics bay, leaving approx. 3" exposed.
2. Cut a slit in the avionics aft bulkhead big enough to pass through a piece of shock cord.
3. Take one end of the shock cord and pass it through the slit. Using a D-ring, pass the shock cord through D-ring and back down through the slit. Pull the D-ring tight against the bulkhead, making a small tail with the short end of the shock cord. Epoxy the tail to the bulkhead, using a clamp to press it tightly against the bulkhead. Once dry, pull the D-ring snugly against the bulkhead and glue in place.
4. Glue the avionics aft bulkhead to the coupler and attach shock cord from the payload section to the D-ring.
5. Install the avionics package onto the threaded rods and line it up with the avionics access door. Once the correct position is known, glue it in place.
   (a) Lock the avionics bay in place using nuts and lock washers.
6. Drill a hole in the forward avionics bay bulkhead to slide it on the threaded rods. Drill a hole in the center of the bulkhead and insert an eye-bolt. Attach the shock cord connected to the nosecone to this eye-bolt.

Recovery See Appendices H.A and H.B.

Nosecone

1. Fashion small bulkhead, approx. 1.5-2" dia. Cut a slit in the middle of the bulkhead and attach D-ring as in Avionics-step 3.
2. Pack main parachute into the nosecone. Pack flame retardant cloth, then ejection charges.
3. Attach nosecone to the avionics bay using shear pins.

B. Static/Launch Checklist, Troubleshooting, Post-Flight

Checklist for the Static Test

Date: _______________

Time: _______________

0.0 Persons Conducting Static Test Fire.

Team Lead Approval: ___________________________

Team Instructor Approval: _____________________________

Team Safety Officer Approval: _________________________

1.0 Material Checklist.

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

1.1.0 Motor firing and Control Checklist

- 1.1.1.0 Motor.
  - 1.1.1.1 propellant grains.
  - 1.1.1.2 Large O-rings.
  - 1.1.1.3 Phenolic liner tube.
  - 1.1.1.4 Motor casing.
  - 1.1.1.5 Forward end closer with adapter.
  - 1.1.1.6 Nozzle.
  - 1.1.1.7 Nozzle washer.
- 1.1.2 Grease.
- 1.1.3 Nitrile/latex gloves.
- 1.1.4 Grounding wire.
- 1.1.5 Manufacturers motor assembly instructions.
- 1.1.6 Nut driver/flat head screwdriver (to tighten clamps).
- 1.1.7.0 Motor ignition system.
  - 1.1.7.1 Orange box.
  - 1.1.7.2 Alligator clips for the battery.
  - 1.1.7.3 Igniter wire.
  - 1.1.7.4 Launch controller.
  - 1.1.7.5 Safety interlock.
  - 1.1.7.6 Two small alligator clips for the igniter.
  - 1.1.7.7 Fully charged 12 V deep cycle battery.
- 1.1.8 Motor igniter and spares.
- 1.1.9 Wipes for motor clean up.
- 1.1.10 Wooden stick or broom-handle to push out burnt grains after the test.

1.2.0 Instrumentation Checklist

- 1.2.1 Wiring diagram.
- 1.2.2 Grounding wire.
- 1.2.4 Cables and connectors.
- 1.2.5 Pressure sensor (serial # _______________).
- 1.2.6 Electrical tape for securing wires.
- 1.2.7 Flash drive.
- 1.2.8 Test stand instrumentation (C-DAQ and supporting items).
- 1.2.9 Surge protector.
- 1.2.10 Laptop power cord for test computer (Toughbook).
- 1.2.11 Laptop power cord for control computer (Lance).
- 1.2.12 Laptop computer with LabView VI (Toughbook).

B.A. Launch Procedures

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.

B.B. Motor Assembly Procedure

Adapted from Pro54® Instructions, retrieved from http://www.pro38.com/pdfs/Pro54_instructions.pdf

Motor Assembly Procedure ☐ 1.0 Inspect the motor casing for damage. Discard and replace if damaged. Modification of the casing can cause property damage or result in serious personal injury.

☐ 2.0 Leave the protective cap on the nozzle for now.

☐ 3.0 Most reloads will only use one o-ring per closure, but provision has been made for two if required in future products. Check that the o-rings are installed in the forward and rear closures properly. Also check the o-rings for any inadvertent damage. If the o-rings appear damaged in any way, DO NOT proceed. Instead, contact your Pro54™ dealer to arrange for replacement or remedy.

☐ 4.0 The o-rings are pre-lubricated at the factory, but we recommended that you apply a light film of silicone o-ring lubricant to the inside edge of the motor casing where the reload kit will be inserted. This will make installation and removal of the reload kit much easier!

Insert the delay/ejection module into the forward end of the case liner. A small gap between the forward end of the liner and the shoulder on the delay/ejection module is normal.

☐ 5.0 Insert the reload kit assembly into the casing, forward closure first. There will be some resistance as the o-rings compress into the casing. To ease insertion, place the nozzle end against a smooth surface and push carefully on the forward end of the casing until the reload kit is completely inserted into the motor case. Be careful not to damage the nozzle. Once fully inserted, the rear closure/nozzle assembly should be flush or slightly protrude (up to about 1/16") of the threaded end of the motor case. If not, remove the reload kit and investigate.

☐ 6.0 Remove the nozzle cap, and screw the retaining ring onto the rear of the motor case. Snug it up until it feels seated against the rear closure, and the forward closure is firmly seated against the forward lip of the motor case. Do not over tighten - hand tight is sufficient. The cap will rotate approximately 3-3/4 turns to fully seat against an empty case, and it should engage by at least 3 turns when the reload is installed. Reinstall the nozzle cap.

☐ 7.0 Your Pro54™ motor is now ready to be installed in your rocket. DO NOT install the igniter until the rocket is mounted on the launch pad, or in a location approved by the Range Safety Officer.

C. 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.

D. Team Safety Compliance Form

Chimaera Rocket Team Safety Compliance Form

As a member of the Utah State University Chimaera Rocket team, I the undersigned understand that the National Association of Rocketry (NAR) and NASA 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. NASA will provide range safety inspections of each rocket before it is flown and the USU team will comply with said inspection determination.
2. The NAR and NASA Range Safety Officers have the final say on all rocket safety issues, and have the ability to deny launch based on safety reasons.
3. If the team is in noncompliance with the safety and mission assurance, the rocket will not be launched.

Kyle Hodgson
Printed Name

Signed Name — 1-18-11
Date

Andrew Bath
Printed Name

Signed Name — 1-18-11
Date

Annika Jensen
Printed Name

Signed Name — 1/18/11
Date

COLIN WHITE
Printed Name

Signed Name — 1/18/11
Date

JOSUE RICSI
Printed Name

Signed Name — 1/18/11
Date

Mansour Sabbi
Printed Name

Signed Name — 1/18/11
Date

Chimaera Rocket Team Safety Compliance Form

Samuel Mosquea
Printed Name

Samuel Mosquea — 01/18/11
Signed Name — Date

Ryuichi Yamamoto
Printed Name

[illegible signature] — 01/18/11
Signed Name — Date

Richard Perkins
Printed Name

Richard Perkins — 1/18/11
Signed Name — Date

NATHAN V. MADSEN
Printed Name

[illegible signature] — 1/18/2011
Signed Name — Date

Stewart Hansen
Printed Name

[illegible signature] — 1/18/2011
Signed Name — Date

Jamie Wilson
Printed Name

Jamie Wilson — 18 Jan 2011
Signed Name — Date

Joshua Kingsford
Printed Name

[illegible signature] — 01/20/11
Signed Name — Date

Craig Broome
Printed Name

[illegible signature] — 01/20/11
Signed Name — Date

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 Farms	(435) 797-2209	
Tim Boschert	Tripoli Utah Prefect	(801) 274-8076	tboschert@utah.gov

F. Student Prototype Lab/Shop Rules

Student Prototype Lab Users, All!!!

Some items may require consultation from our Department Head etc. which could take a bit.

The Phone number for the SPL is 797-3820

Please note the following Student Prototype Lab Policies as of 11-03-2010.   SUBJECT TO CHANGE

3 strikes and you are out!   COULD BE ON FIRST OFFENSE IF OBVIOUSLY DANGEROUS!

Buddy System. A minimum of TWO people per project group will be in the lab at the same time! NO EXCEPTIONS! SPL personnel should always be present when working with machinery or welders.

Safety glasses will be worn over your eyes. Not on top of your head. Please bring your own if you have some.

Hearing protection should be worn when high noise levels are present in the lab. We have some of the overhead types and some small personal in ear types available

Dust masks should be worn whenever grinding. We have these items available also.

No Jewelry will be permitted in the lab. This includes rings, watches and necklaces.

Please bring a padlock and use a locker in the hallway to store these items to avoid loss. We have permission to use the lockers which are nearest to the SPL. You will be required to furnish your name and locker number to SPL personnel before attaching any locks.

If your hair is longer than shoulder length, you will need to tie it up prior to working with machinery.

No shorts or sandals will be allowed in the SPL.

No long sleeves will be allowed when using machinery. Rolled sleeves are ok.

Cover skin when welding to avoid burns. Always use welding curtains around the welding area to help protect the eyes of other lab users. You are responsible to chisel or grind welding spatter from the welding table and sweep under the table also.

Beware of fuel from buggies and batteries which are being charged prior to welding. CHECK FOR THESE ISSUES BEFORE WELDING TO AVOID EXPLOSIONS!

You will be responsible to furnish a current MSDS for all chemicals that you bring into the lab.

No horseplay!

Leave the area cleaner than you found it! Your working area will be swept and or vacuumed prior to leaving the lab! DO NOT USE AIR HOSE TO BLOW OFF AREA! All chips will be discarded in appropriate trash containers! Area will be left in a ready condition for the next user! Wipe down machinery.

When using grinders or cut-off saws, it is your responsibility to sweep or vacuum a minimum 20 square foot area. EVEN IF IT LOOKS CLEAN! AGAIN, DO NOT USE AIR HOSE!! Wipe down Machinery. Do NOT leave the lab before cleaning around the grinders which you have used!!

Never walk up to a machine operator or welder from behind and touch them. If you need their attention, wait until they stop, then approach them from front or sides.

If you need to hammer or make loud noises, please inform all other users when this will happen and only after they have stopped their process.

No ear buds or headphones will be allowed in the SPL. All music should be at an acceptable level as decided by Mike Morgan. No offensive lyrics will be tolerated.

No personal projects allowed in the SPL Facility. Equipment and Supplies are to be used for USU projects only!

No personal vehicles allowed in SPL.

Project areas will be assigned as needed. Ask first. No Materials will be left in walking paths as designated by yellow lines. No materials will be stored around equipment.

All materials will be clearly marked indicating group of origin. Marked items will not be used by other groups.

Always sign in before and after hours using sheet near main door! A list indicating equipment used will also appear there shortly.

ALL broken Equipment, Tooling and ALL Injuries will be reported to Mike Morgan in person or mail to mike.morgan@usu.edu. Personal injuries call my cell #435-770-8528.

If an EMERGENCY arises, please use a USU phone and dial 911 so USU can respond. If this is not possible, use any working phone and dial 911. This is the Technology building #45.Building code is TECH.

It appears as though the SPL has been available for very limited use on Saturdays from 9:00am to 6:00pm. We can try this out and see how it works, but only after approval has been granted. Please plan SPL usage for weekdays. The lab is currently available Monday through Friday from 8:00 am until 9:00 pm with SPL personnel support.

No Access to the SPL on SUNDAYS!

Please send an e-mail to me indicating odd hours or days needed.

There will be times when conflicts arise concerning specific equipment needs and schedules. We will possibly need to alternate times or see if we can perform other procedures until the equipment becomes available. Some deadlines will have higher priorities than others. We can all minimize this issue by planning in advance and not wait until due dates. We will work through these situations separately as needed in an attempt to avoid barriers which could produce negative results for all. Please inform me of your specific equipment needs with approximate dates and daily timeframe as well as total hours needed. I understand that this can be very difficult to assess but a best guess will work. If your time allotment changes please notify me so that others can use open times. Once again, let's work on these projects continuously with goals being set and monitored to help avoid the crunch time bottleneck.

We are sharing the SPL with many other groups. We need to show them the same respect that we would want. We can all work together to have a fun time and learn some great skills.

I feel that we can all challenge each other to do better and remind each other when things are not quite up to par. Continuous improvement is a wonderful tool for us and our workmanship.

We all have strong points and areas for growth. As a TEAM we can be unstoppable. LET'S ALL WORK AS A LARGE TEAM!!

Please note that the building access code may change in the near future.

Please pass this on to all members.

Thanks, Mike Morgan   Revision 5   11-03-2010

G. Body Tube Test Procedures

Body Tube Test Procedure

Required PPE

- Safety glasses
- Plexiglass shield

1. Level the test stand
2. Insert body tube
3. Place plexiglass shield in front of the test stand, approximately 3-5 ft. away.
4. Put weight stand on top of body tube
5. Two people pick up a sand bag and gently place on top of weight stand
    - Once the weight is transferred to the stand, personnel stand behind the shield for 3-5 seconds.
6. **Has failure occurred?**

Yes-

- Record the weight

No-

- Repeat step 4-5 until failure occurs

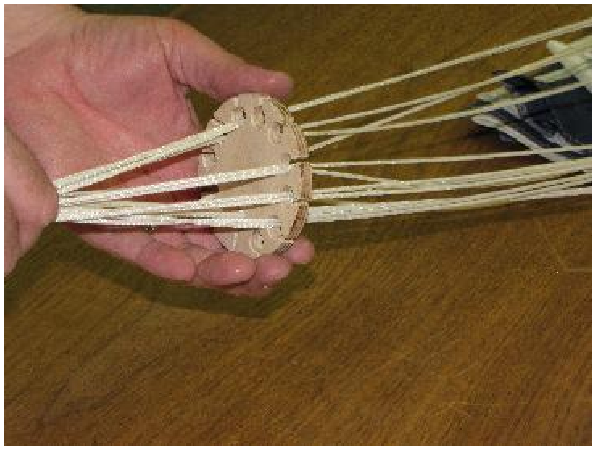
H. Recovery System Packing Procedures

H.A. Parachute

You will need a large, flat surface. At the launch site, this may mean a tarp on the ground.

Begin by giving the parachute fabric a light dusting of talcum powder. This will act as a drying agent and lubricant to help the parachute deploy.

Place the parachute on a flat surface and untangle the shroud lines.



Bring the shroud lines to the middle of the parachute. The panels will be folded in half.

Flatten the panels, making sure there are an equal number of panels on each side of the shroud lines. In this picture the edges are folded in only to show that there are an equal number of panels on each side.

Bring the outside edge (center) of each panel into the inside of the panel. This will create an accordion fold for all of the panels. This step may need to be repeated for very large parachutes.

Fold the shroud line up into the center of the parachute. Then bring the looped end of the lines back down below the bottom of the parachute.

Accordion fold the parachute, beginning at the bottom.

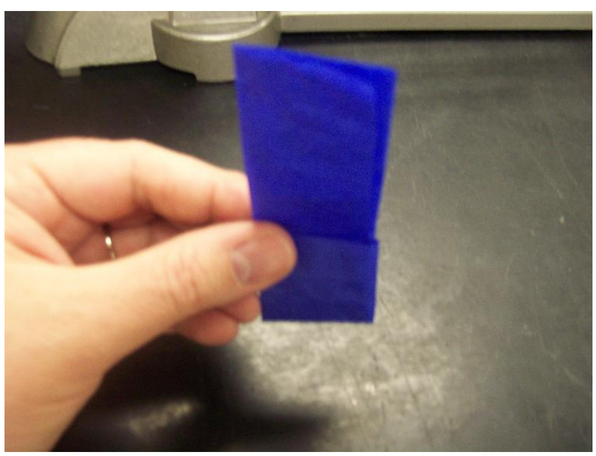
The parachute can now be attached to the recovery harness and placed in the protector sheet.

H.B. Ejection System

Black powder charges are measured and packaged into individual packets in the laboratory before leaving for the launch. Packets are stored without ematches installed. Ematches are placed into the packets just before installing the packets in the rocket's ejection charge canisters.

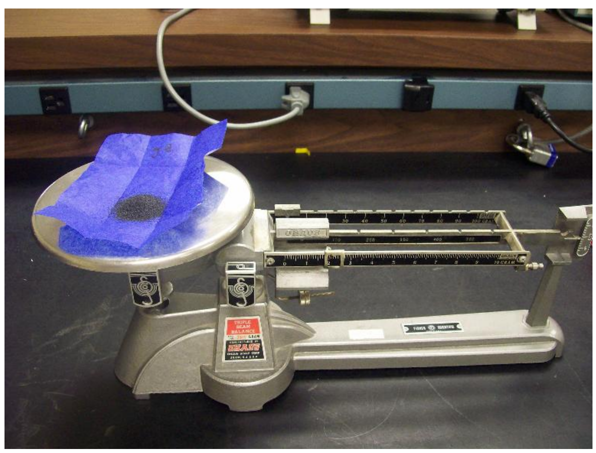
To prepare black powder packets, you will need 4 in × 4 in model rocket recovery wadding, scissors, small rubber bands, a laboratory scale with 0.1 gram or better resolution, a fine tip marker, and black powder.

Begin by cutting 1 inch off an edge of the recovery wadding, creating a 3 in × 4 in rectangle. Retain the piece that was cut off to be used as packing material.

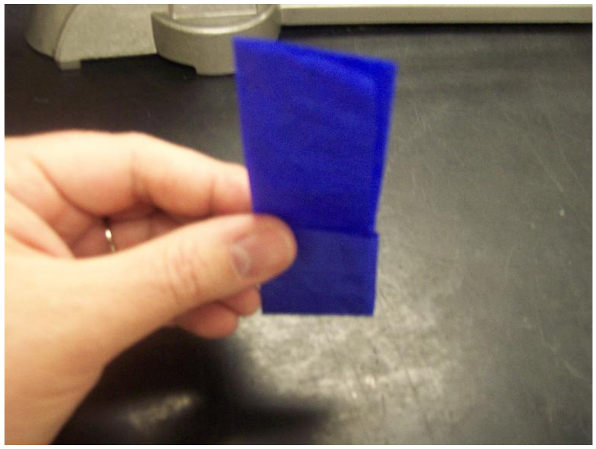


Fold the wadding to create a 1 inch grid and mark the wadding with the amount of powder to be packaged (2 grams in this case).

Place the wadding on the scale and note its weight. Next measure out the desired amount of black powder, taking into account the weight of the wadding. In this example, the wadding weighs 0.2 grams, so the final weight is 2.2 grams.



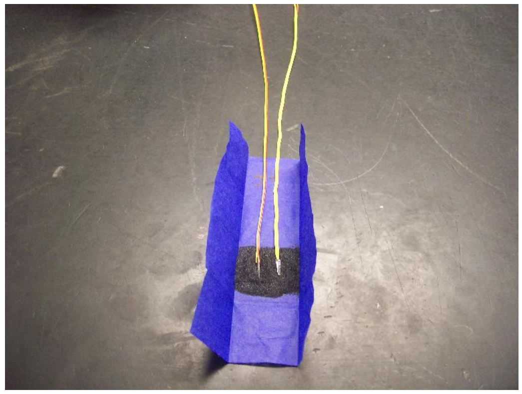
Now fold the bottom of the wadding up to cover the black powder. Then fold each side of the wadding to the center and hold the packet upright to ensure all the black powder is contained in the same square inch of the wadding.

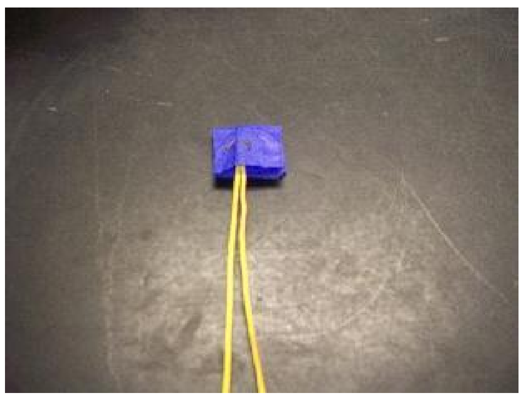


Continue to fold the packet to create a single 1 inch square. Use a small rubber band to hold the packet closed until ready to use.

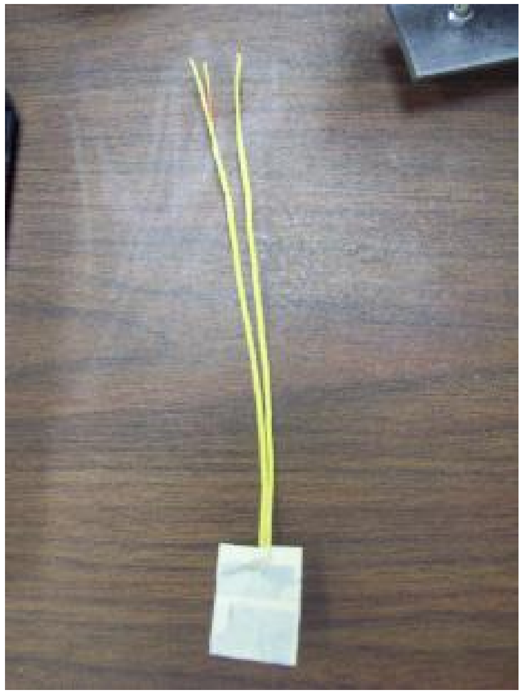
Ejection Charge Installation

At the launch site the packet will be opened and ematches inserted. The packet is then folded as before, bending the wires inside the packet.





Masking tape is used to seal the packets.



The packet is placed in the ejection charge canister. The ematch wires are bent down and secured to the outside of the canister with masking tape. The excess wadding that was trimmed from the full sheet is used as packing to fill the empty space in the top of the canister. The top of the canister is then sealed with masking tape and the ematch wires are attached to the appropriate terminals.

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