CHIMAERA

EXPERIMENTAL HYBRID ROCKETRY

Energy Management of a Sounding Rocket Using Cold-Gas Impulse Augmentation: Post-Flight Analysis Report

Utah State University Chimaera Team

Contents

I. Introduction and Project Overview

I.A. Team Overview

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). USU's rocket was named the "Javelin" and will be referred to as such throughout the report. The team upheld the tradition of naming USU rockets after various types of fish. Also, the rocket color scheme included having scales painted on opposite sides to provide a more "fish-like" motif. The team was mentored by Dr. Stephen Whitmore with the help of several graduate teaching and research assistants, who served as subject matter experts for the project.

I.B. Vehicle Statistics

Table 1 shows the final parameters for the launch vehicle, including dimensions and the official compeitition altitude. The corrected altitude reflects the altitude shown by the data after correcting for a spike just after apogee and is discussed in later sections. The launch mass is the mass of the rocket as it sat on the launch pad in Huntsville, and the flight mass is the mass of the rocket from motor burnout to recovery.

Table 1: Final configuration parameters.

Parameter	Value
Total Length	7.4 ft (2.25 m)
Total Diameter	5.54 in (.14 m)
Launch Mass	27.87 lb (12.64 kg)
Flight Mass	22.93 lb (10.40 kg)
PerfectFlite Altitude Achieved	5465 ft (1665.7 m)
PerfectFlite Corrected Altitude	5408 ft (1648.4 m)

I.C. Launch Vehicle Summary

The Javelin design used a solid propellant primary rocket motor, which would expectedly get the vehicle close to the desired one mile target altitude. The Javelin flew using a Cesaroni Technology L730 solid propellant motor. The Javelin had several major components and subsystems. The Cold-gas Base-bleed Augmentation System (C-BAS) was used to manage the total mass-specific energy of the vehicle to control the achievable apogee altitude. The avionics section, located near the front end of the rocket just behind the nosecone, housed the majority of the required flight instrumentation. The avionics suite included an inertial measurement unit (IMU), two pressure-based altimeters, and a three-axis magnetometer. Navigation data was processed in an on-board avionics computer and continuously estimated the total specific energy and potential altitude of the vehicle. The flight computer also operated the energy management system. Also, an onboard wireless-G modem was used to transmit flight data from the Javelin to a ground station monitored by the team, and additional flight instrumention in the form of pressure transducers and data acquisition components were used to record the C-BAS plenum pressure and expansion ramp surface pressures. The team used two PerfectFlite pressure altimeters for dual redundant deployment of the recovery system parachutes. One of the PerfectFlite altimeters was also used to provide the official measurement of the achieved altitude, for which the team was judged at the USLI competition. The rocket body was constructed using Blue Tube 2.0™ with an E-Glas Sock for added support.

I.D. Payload Summary

The Javelin payload featured a unique cold-gas energy management system designed around isentropic expansion ramps based on aerospike nozzle theory. While the aerospike nozzle has long been known for its altitude compensation ability for atmospheric flight, its unconstrained plume was ideal for integration into the Javelin airframe structure. The aerospike-derived isentropic expansion ramps were placed around the primary solid motor case and added negligible aerodynamic drag to the external configuration. It was simulated that the vehicle would lose more energy to drag than was actually observed in the competition flight. At different waypoints throughout the flight, the on-board avionics calculated the energy lost from drag and activated the C-BAS as needed to raise the overall energy level of the rocket. The system calculated that the energy state of the vehicle was constantly high, so the C-BAS performed as designed by not activating. Had the energy state been lower than needed, the overall energy level would have been augmented and the Javelin's apogee altitude increased.

II. Vehicle Summary

II.A. Data Analysis and Results of Vehicle

According to the competition PerfectFlite altimeter, the Javelin achieved an altitude of 5465 ft AGL. This higher than anticipated altitude was potentially due to several factors, including higher than predicted nominal motor thrust, lower vehicle drag, thermal effects, and lower than predicted vehicle weight. Consequently, the C-BAS did not need to be fired. The on-board computer properly calculated the apogee altitude above one mile, and as a result never actuated the energy augmentation system. Further details are discussed in upcoming sections.

The competition altimeter varied slightly from the back-up recovery system altimeter, which read 5443 ft. The discrepancy shows the lack of fidelity in low-end hobby rocketry components. The trajectories of both PerfectFlites are shown in Figure 1. The data was filtered to eliminate the spike in altitude seen at apogee, most likely caused by the ejection charges creating a vacuum in the avionics bay, causing the altimeters to register a sudden increase in altitude.

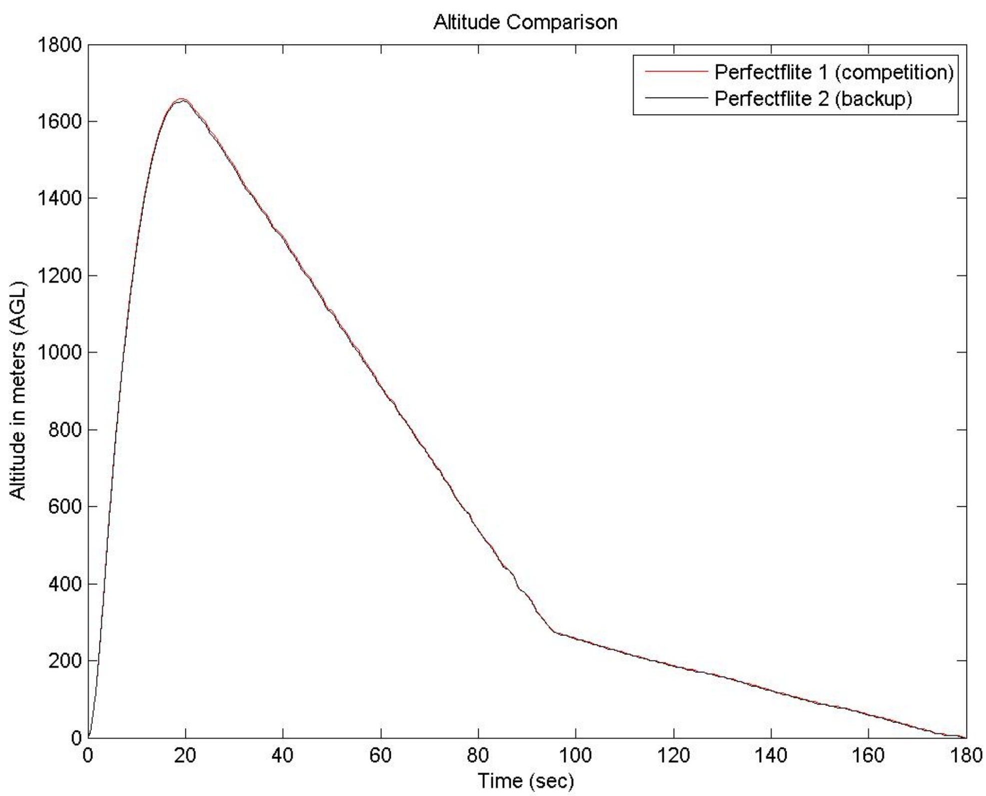


Figure 1: Altitude comparison of the competition and the back-up altimeters.

Acceleration data gathered from the IMU correlates very well with the data predicted by simulations performed earlier in the design process. Figure 2 shows the IMU data plotted with the simulation results. It is apparent from this plot alone that the estimate of drag coefficient would have been better represented by 0.285 than the value of 0.35 predicted by wind-tunnel testing and other analysis. Because this data is so closely correlated, the team has gained more confidence that the algorithm used to determine when to activate the C-BAS worked properly. The data seen by the IMU was fed directly to the program for filtering and potential altitude calculations. Had the program not received accurate data it may have actuated the C-BAS when it was not needed.

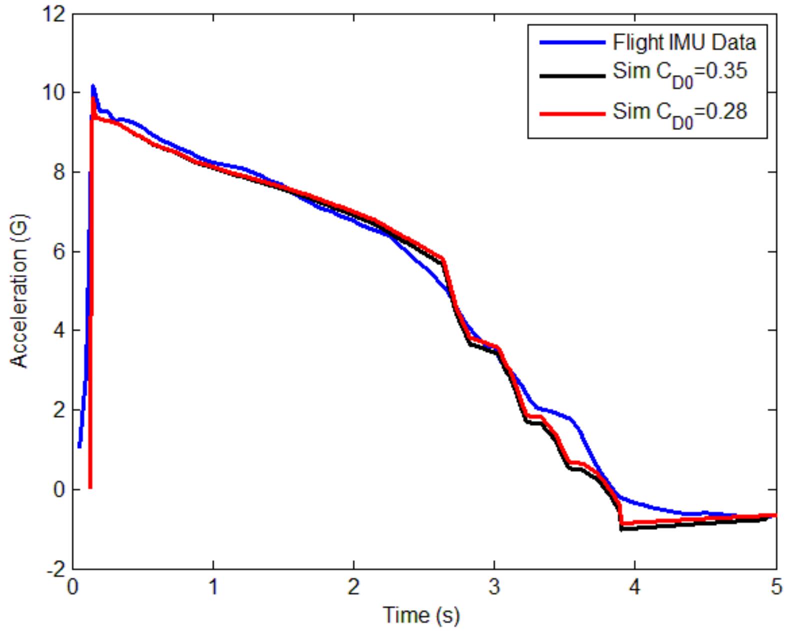


Figure 2: Comparison of acceleration seen during flight to predicted acceleration from simulation.

II.B. Motor Performance

The Javelin flew with a Cesaroni L730 motor. This motor provided an optimal amount of impulse without a very high g-load. Its flight performance was just as expected, based on previous test data from static and flight tests. In order to confirm that the performance of the motor was nominal, IMU data from the compeition flight was compared to the simulation accelerations shown in Figure 2. The peak thrust in both the simulated and flight data are in agreement. The energy loss due to drag after the motor burnout is less than the initial expected drag loss associated with a coefficient of 0.35. Adjusting the drag in the simulation to fit the data, a drag coefficient of 0.285 matches the flight data to a maximum likelihood level. This supports the team's conclusion that a loss in drag led to the unpredicted altitude and a dormant C-BAS.

II.C. Aerodynamics

II.C.1. Drag Analysis

With the flight information, the team was able to accurately model the flight trajectory and determine the aerodynamic drag on the vehicle for a given flight. Drag prediction for the competition launch relied heavily on the results from the second test flight. Figure 3 compares the profile for the second test flight with the simulation predictions. The second test flight results clearly predict a drag coefficient of 0.35. Figure 4 shows the profile for the competition flight.

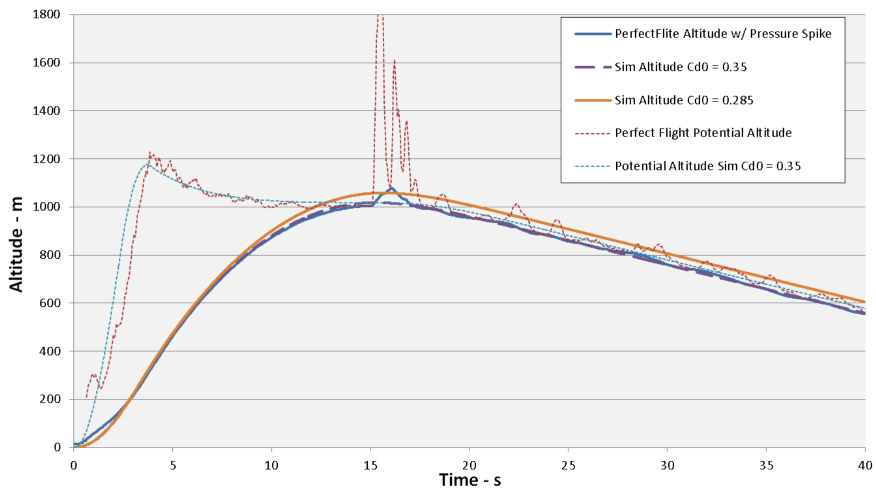


Figure 3: Flight data and simulation comparison for the second test flight..

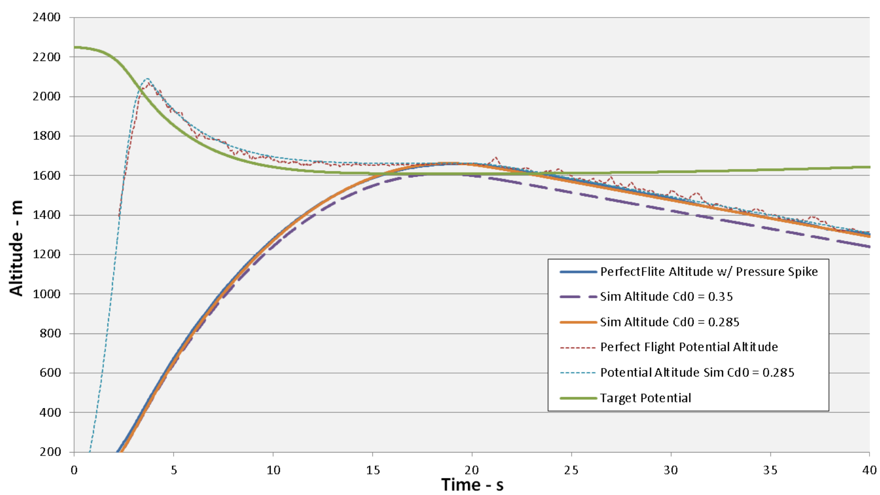


Figure 4: Flight data and post-flight simulation comparison of the competition flight.

In Figure 4 a dashed line shows the predicted altitude based on a drag coefficient of 0.35. The actual flight profile follows the solid line for a drag coefficient of 0.285, which is significantly lower than the expected drag. As a result, the rocket traveled beyond the mile altitude target. The target potential line shows the potential altitude cut-off for C-BAS activation. Since the rocket did not bleed off energy as expected, the energy state never dropped below the target line, thus never giving the signal for the C-BAS to activate. Because the potential altitude was so high, the Javelin reached a height approximately 160 feet over the target.

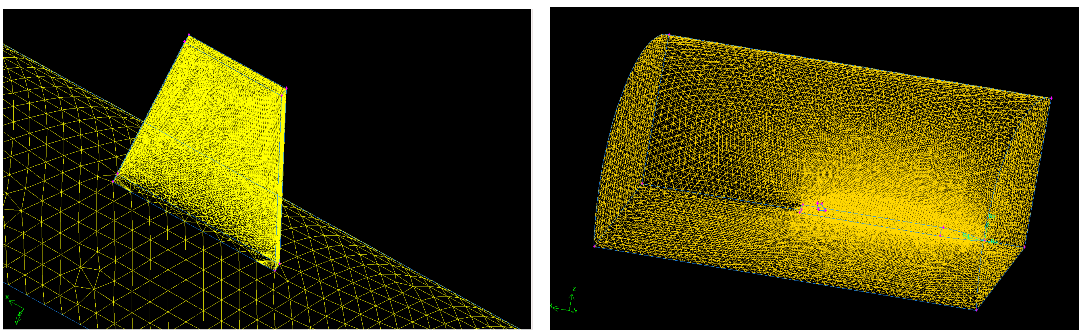
The drag coefficient was reduced by 0.065, a decrease of approximately 20 percent. This is in sharp contrast to the predicted drag coefficient. This result was initially surprising to the team, since it exceeded the predicted unaugmented altitude, based on the weight and previously characterized drag coefficient. Since the acceleration from the motor showed nominal performance (Figure 2) and the pre- and post-flight rocket mass measurements remained as predicted, the only clear explanation is a reduction in the expected drag force on the rocket. The reduction in drag most likely came from a change in the boundary layer profile along the rocket surface due to surface condition modifications.

Weather conditions are not considered to be a cause of the substantial decrease in drag. The Javelin launched at 12:39 PM on the 17th of April, and according to local weather data, the temperature was 64 $^{\circ}$F (18 $^{\circ}$C) with a sea-level atmospheric pressure of 14.8 psi (30.06 inHg). The atmospheric conditions at the time of launch were well within the ranges predicted by the GRAM 99 atmospheric model for April 16th. Using the rocket simulation, it was apparent that changing atmospheric properties do not significantly affect the drag on the Javelin. Rather than a weather phenomenon, the reduction in drag is related to a change in skin friction. In order to investigate this change in skin friction, a CFD analysis was done to look at laminar and turbulent flow effects on the drag of the Javelin.

II.C.2. CFD Drag Coefficient Analysis

In order to look at this dramatic change in drag, a CFD analysis was conducted to examine laminar and turbulent drag on the Javelin. A control volume of the subtracted model of the rocket was created using Solid Edge software, and a mesh was created using Gambit. Because the rocket can be considered periodic, the model and the control volume were cut in three to reduce the computational time. The triangular grid was chosen for the surface of the rocket and the interval size of the the body was set to 10 units. The fin mesh was then refined to an interval size of 1 unit, as shown in Figure 5a.

Tetrahedral elements were used at an interval size of 100 units in the control volume. Figure 5b shows the meshing of the control volume. The boundary condition for the upper surface of the volume was determined to be a wall for the faster convergence time. This did not affect the solution because the distance of the wall to the surface of the rocket is large enough.



(a) Detailed view of fin mesh. (b) View of control volume mesh.

Figure 5: Computational fluid flow models.

The FLUENT model has 523,980 cells, 1,092,745 faces, and 110,424 nodes. To solve for the drag of the Javelin, the highest velocity seen during flight, 607 ft/s after motor burnout, was chosen. Table 2 shows the parameters used, which were based on 2100 ft altitude.

Table 2: Parameters used in FLUENT.

Gauge pressure:	13.6 psi
x-velocity:	607 ft/s
Viscosity:	1.18887*10^{-5} lb/ft-s
Density:	0.0708 lbm/ft^3

A laminar model and three different turbulence models were used to compute the drag. Table 3 summarizes the results from FLUENT. The reference area in FLUENT was 0.16 ft^2. The model was solved using the SIMPLE scheme, first-order upwinding, and assuming incompressible fluid. A higher order solver would not converge with the given parameters.

Table 3: Resulting drag coefficients for various turbulence models.

Model	Drag Coefficient
Laminar	0.20464
Spalart-Allmaras	0.27690
k-epsilon	0.25172
k-omega	0.3084

The drag numbers in Table 3 are low compared to experimental data and other programs used to obtain the drag. This is due to the fact that the Solid Edge model uses perfectly aligned fins (zero fin angle of attack) and does not include induced drag. Note that the difference between the average turbulent drag coefficient of 0.279 and the laminar drag coefficients is 0.074, comparable to the drag coefficient reduction observed in flight data of 0.065.

II.C.3. Drag Reduction Factors

The skin friction on the Javelin was significantly lower than on the qualifying flight and wind tunnel model wake survey. On both tests the Javelin had a relatively rough sanded epoxy surface with gaps for the access doors. Such a surface allows the flow to quickly become turbulent along the length of the rocket. In preparation for the competition flight, the Javelin was covered in MonoKote over the majority of the exposed surface area and slick paint on the nose. MonoKote has an exceptionally smooth, glossy surface which reduces viscous forces from the air. The smoother surface may have kept the flow laminar longer and reduced the overall drag coefficient of the vehicle.

Two other changes were implemented prior to the competition flight. First, 1.5 inches were removed from the center of the rocket in order to adjust the center of gravity. This reduction in the length of the rocket gave it a lower Reynold's number and lessened the surface area that was exposed to turbulent flow. Second, tape was added to secure the access doors. The tape created a continuous surface, rather than the gaps previously present in the surface, further removing turbulent triggers from the rocket.

II.D. Recovery

The Javelin was designed with a dual, redundant recovery system. The system was originally designed with electric matches wired from one PerfectFlite and one R-DAS altimeter to a single ejection charge for each deployment. A system failure during the first test launch led to a redesign of the the recovery system. A schematic of the system layout is shown in Figure 6. The unpredictable R-DAS was replaced with a second PerfectFlite, and a back-up charge was added. Each PerfectFlite was wired independently, providing for four layers of redundancy, thereby reducing the possibility of another single point failure. The flight parameters of the recovery system flown in competition are shown in Table 4.

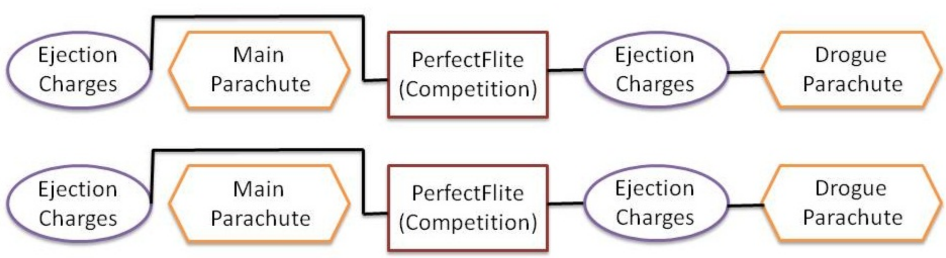


Figure 6: Schematic of recovery system.

Table 4: Competition flight parameters of Javelin recovery system.

Parameter	Drogue Parachute	Main Parachute
Parachute Type	Conical	Conical
Deployment Altitude (ft, AGL)	5397	900-1100
Effective Drage Coefficient	1.28	2.2
Deployment Velocity (ft/s)	39.4	59.0
Terminal Velocity (ft/s)	60.7	11.2
Reference Area (ft^2)	4.91	78.5

The recovery system performed nominally. The drogue parachute deployed at apogee, and the back-up charge fired one second later. The main parachute appears to have deployed at 1100 ft, when the first charge fired. The rocket fell about 200 ft before the main parachute fully deployed. All charges had been fired by the time the Javelin landed, and close inspection of the flight video and PerfectFlite data show the back-up charge firing at approximately 900 ft, as programmed. With almost no wind, the rocket was recovered approximately one quarter mile from the launch pad, just east of the spectators. Figure 7 shows the successful operation of the recovery system.

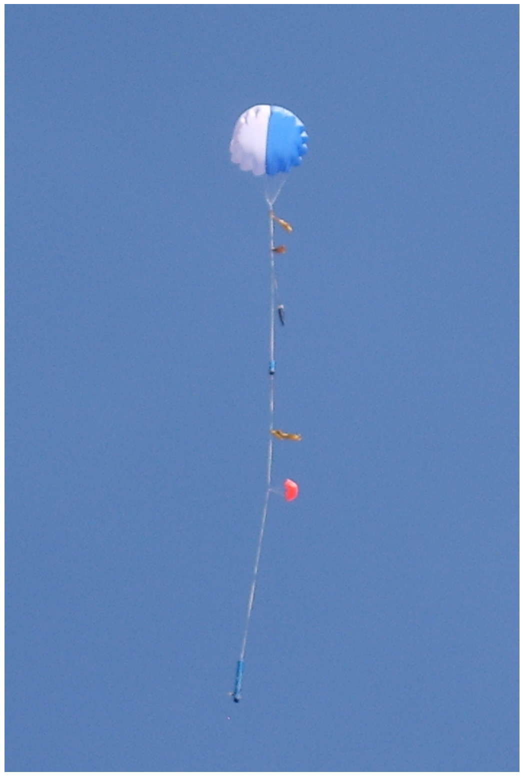


Figure 7: Nominal performance of the recovery system.

II.D.1. Physical Inspection

As one of the design requirements was to recover the rocket in one piece, a physical inspection was performed on the rocket after the landing to verify that the overall structure was intact. The Javelin experienced a soft landing for a successful recovery of the rocket. Before anyone touched the landed rocket, the certified members of the team inspected the Javelin to ensure all charges had been fired. When it was determined that there was no safety risk, the CO_2 tank was turned off and the rest of the rocket inspected.

Figure 8 shows the payload section of the Javelin after landing in Huntsville, Alabama. The airframe was undamaged on all three sections of the rocket. Prior to the competition flight, there was some concern of the Blue Tube warping at high temperatures. The team coated the airframe in an E-Glas Sock and MonoKote, and used structural supports throughout the airframe to eliminate this risk. The Javelin sat in full sunlight on the launch pad for nearly an hour, and there were no signs of warping upon recovery. The fins were intact upon landing, but cosmetic damage to the MonoKote was sustained from landing and subsequent dragging.

Figure 8: The Javelin after landing.

The rocket experienced extreme opening loads at both parachute deployments in the second test launch. Near failure of the drogue harness prompted the team to order a new, reinforced harness for the competition. Upon post-flight inspection, the shroud lines and harnesses showed no signs of tearing or excessive stretching. The parachutes also showed no sign of tearing, and there was no evidence of zippering on the airframe.

III. Scientific Value

Useful in-flight data was gathered from the C-BAS, even though the system was never activated. Pressure ports located on each of the expansion ramps read the local pressure throughout flight, from which the flight performance of the C-BAS could be deduced. This data yields valuable information on the expansion ramp performance in low mach number flow, as well as the available momentum flux.

III.A. Control System and Tracking

The control system for the C-BAS was a Kalman filter that determined the current energy state based on data received from the IMU and PerfectFlite. The current energy state was then used to calculate the minimum and maximum altitudes possible. An algorithm was used to determine if the potential altitude of the rocket was above or below the target altitude, and the C-BAS activated or deactivated accordingly. The C-BAS pressure data was recorded by the R-DAS, the onboard data aquisition system. The Kalman filter correctly calculated that the potential apogee altitude of the rocket was always higher than one mile, and as a result, the C-BAS did not activate in flight.

The avionics package included an on-board modem that transmitted telemetry data to the ground station at all times during the flight. The ground station computer was monitored by two team members throughout flight, and the data recorded by the ground station was validated against the data recorded by the avionics package. The ground station to modem connection was an IEEE-standard 802.11g wireless data connection. In order to maintain connectivity to the rocket during flight, a student-designed and fabricated antenna was mounted to an old satellite dish. The tracking system was successfully tested prior to flight to ensure that the range of the connection was sufficient for flight. A student monitored the powered avionics bay while a vehicle carrying the antenna, ground station, and a small crew drove a distance of at least one mile away. During the drive, connectivity was only lost when the line of sight between the antenna and avionics bay was lost. When line of sight was restored, the connection between the ground station and avionics bay was immediately restored. Connectivity strength was also monitored during the drive, with the ground station modem showing a signal strength of at least three bars out of four at all times, except when line of sight was lost.

Due to the nature of the launch location, it was determined there was no real concern of losing line of sight with the rocket during flight, thus no extra precautions were taken to prevent loss of connection. The data transmitted from the rocket to the ground station consisted of altitude reporting from the competition altimeter and attitude data from the IMU. A LabVIEW VI was written to interpolate the IMU data into realtime roll, pitch, and yaw angles of the rocket. The altitude data was displayed on the monitor and written to a file for later use.

III.B. Pressure Data

The primary purpose of the science mission was to collect in-flight pressure data along the length of the isentropic expansion ramps. Figure 9 shows the locations of the pressure transducers along the profile of the ramp, as well as the truncation point of the expansion ramp for reference.

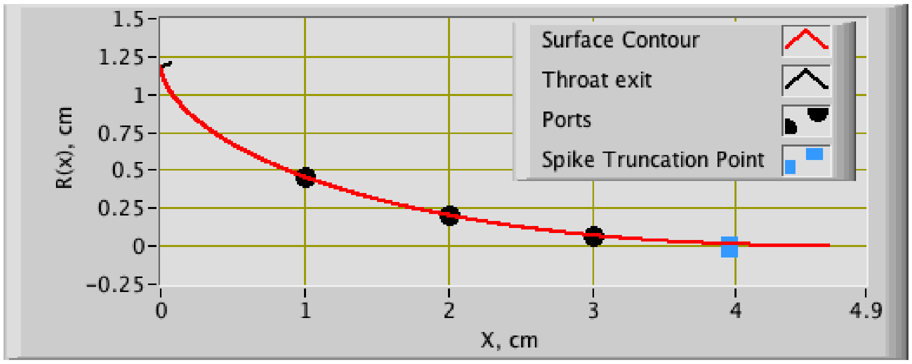


Figure 9: Expansion ramp profile and pressure port locations.

While the C-BAS did not activate, in-flight pressure data was still successfully logged, and provided useful information. Figure 10 shows the differential pressure measurements collected from each pressure port, which has been filtered to remove noise. Pressure curves for ramp 1 and ramp 2 for similar ports are very close to each other. The overall pressure profile shown in Plot d is of particular interest. An induced pressure variation is seen as the pressure profile of the expansion ramps actually follows a trend of increasing pressure along its length. This data can be used to infer the in-flight performance of the C-BAS had it fired.

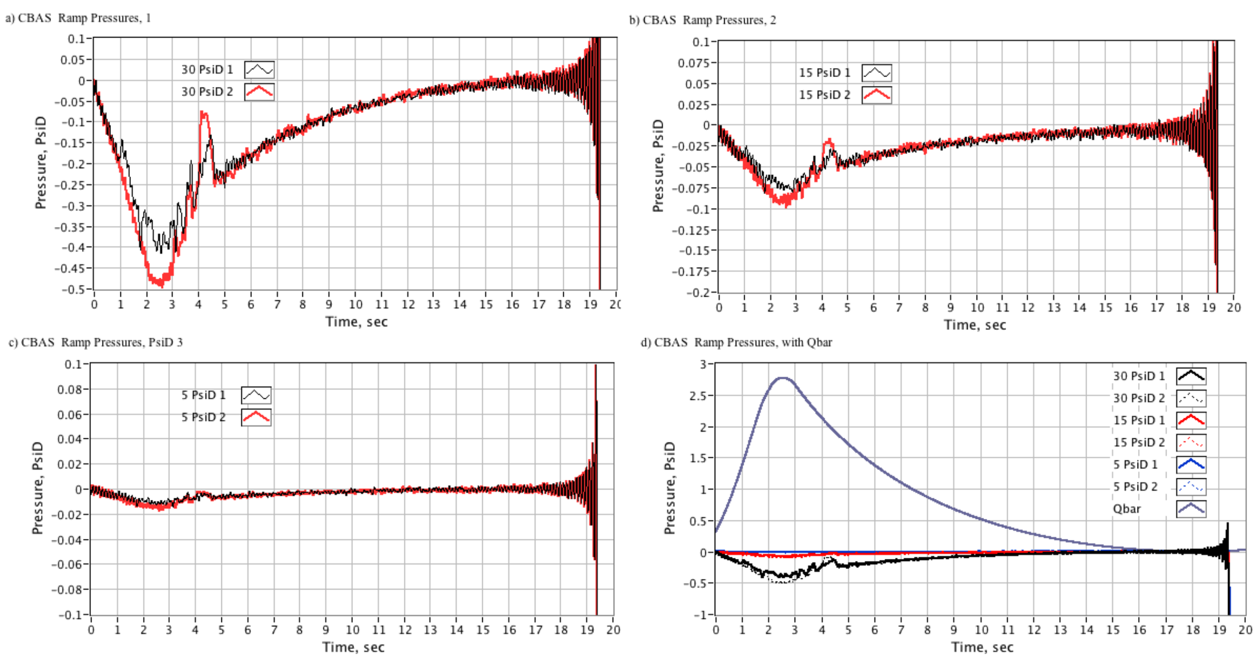


Figure 10: Expansion ramp pressure coefficients - zoom view.

Figure 11 shows the pressure coefficients of the expansion ramps. The pressure coefficients of all of the ports are fairly constant as mach number increases, meaning that compressibility effects on the nozzles are small. Also, the pressure coefficients are all negative, indicating that if the C-BAS had activated, there would have been a small loss in overall momentum flux compared to ground testing. To estimate the magnitude of this loss, observe that the pressure coefficient of port 2 is about -0.03. This corresponds to about 0.1 N of loss at $\bar{q} = 1.8$ psi, which is the dynamic pressure the rocket experienced six seconds into flight. The C-BAS would have first activated at this point. Compared to the nominal momentum flux of 10 N, the 0.1 N loss would have been negligible.

The change in performance of the expansion ramps versus mach number is also of interest. Figure 11 shows there is no correlation between the pressure coefficients of ports 1 and 2 as a function of mach number. The pressure coefficient is essentially constant as mach number increases, showing that during low speed, subsonic flight, plume effects are constant and secondary.

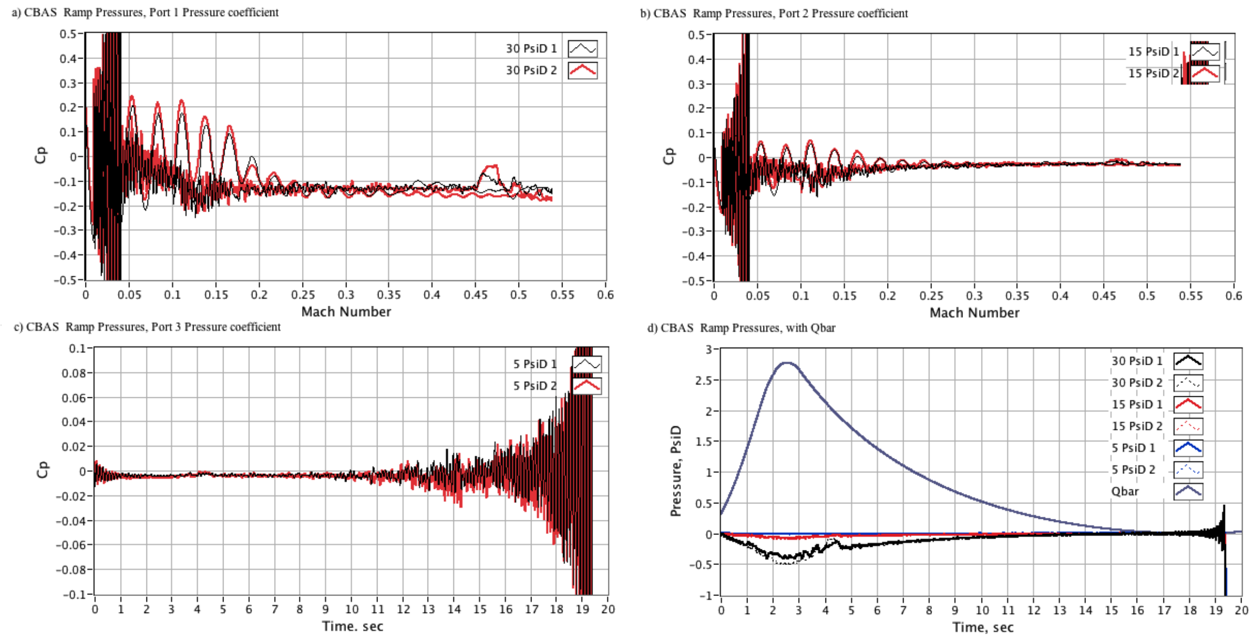


Figure 11: a-c: Expansion ramp pressure coefficients vs. mach number. d: Flight pressure profile.

In-flight ramp pressure data was correlated with ground test data to generate thrust profile coefficients. Figure 12 shows the predicted and tested performance of the expansion ramps, as well as the experimental ground data collected during testing. There is some correlation between the model and experimental data, however the last few pulses in the graph appear to begin diverging from the model. This is a result of the large temperature drop in the system as the CO_2 changes state from liquid to gas. The various spikes seen on the pulse data are due to the inconsistencies of an off-the-shelf pressure regulator used in most of the testing.

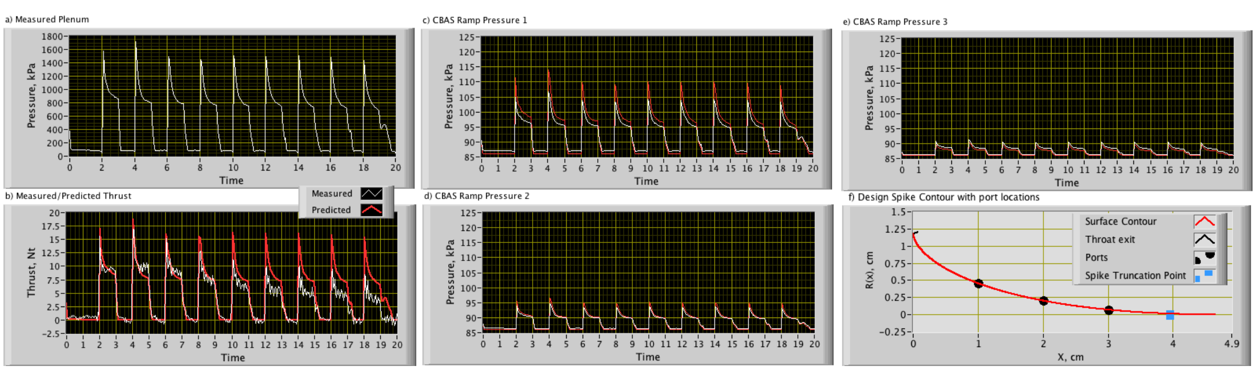


Figure 12: C-BAS momentum flux performance.

Combining the predicted pressure coefficients with the pressure coefficients that the flight slipstream induced yields a complete estimate of the expansion ramp axial pressure force, as shown in Figure 13. The top curve is the ramp pressure during ground tests, normalized by flow pressure. The lower curve is the flight pressure coefficient normalized by $\bar{q}$. Both curves are interpolated from the three data points. While these two curves are not normalized by the same value because $\bar{q}$ cannot be obtained in ground testing, the general trend of pressure distributions still applies via superposition. The main inconsistency between the two is the small suction induced into the flow which is the momentum flux loss discussed earlier.

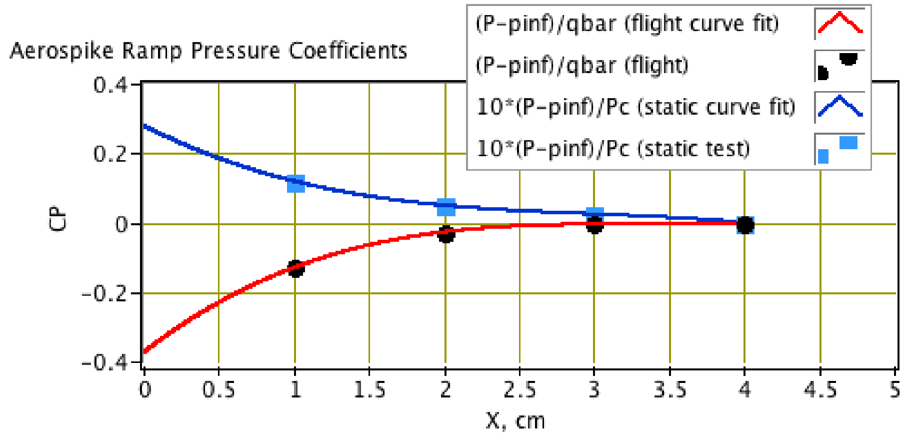


Figure 13: C-BAS flight data vs. model.

Both the experimental and analytical data provide a strong argument that if the C-BAS had activated, pressure data would have been collected that strongly correlates to the predicted performance of the isentropic expansion ramps.

IV. Overall Experience

IV.A. Educational Engagement

The Chimaera Team wanted to involve the community in the rocket project, so they did not limit their outreach endeavors to students. They outreached to nearly 800 students and community members ages three to 75 over the course of the year in 13 organized outreach events. Table 5 shows a summary of the community outreach performed by the team this year.

Table 5: Community outreach summary.

Event	Date	Participants
Aggie CARE Day	10-Sept-10	96
Hillcrest Elementary Science Club	Monthly	35
USU Rocket Day	26-Oct-10	99
Sunrise Elementary Literacy Fair	9-Nov-10	105
Logan High School MESA	10-Nov-10	13
Logan High School Physics	14-Dec-10	93
Utah AIAA Chapter	20-Jan-11	37
Northrop Grumman Demonstration	23-Feb-11	60
E-Week Community Outreach	23-Feb-11	103
Adams Elementary School Science Fair	16-March-11	50
InTech Collegiate High School: TALRC	18-Feb, 11-Mar, 25-Mar	12
Mt. Logan Middle School MESA	25-March-11	60
Edith Bowen Elementary Rockets	22-April-11	19
Total		782

The team involved participants in hands-on lessons and demonstrations in an effort to expose them to the exciting world of science, particularly the field of space exploration and research. The team submitted an educational engagement form for every outreach event, and descriptions of all of the activities can be found on the Chimaera website. As promised, the names of each student and community member to whom the team outreached was flown on the Javelin at the competition. A flash drive containing all of the names, including the astronauts who served as honorary team members, was placed in the avioinics bay for the competition flight. The Cache Valley community "Flew with the USU Rocket Team!"

IV.B. Budget Summary

The team was only allowed $5000 worth of flight hardware, but the overall cost of this project far exceeded that amount. The team required 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 had $18,500 at their disposal for the entire project.

Due to limited funding and the $5000 flyable hardware limit, the team kept meticulous records of all of their spending. A copy of every receipt was given to both the team's procurement officer, Sam, and Program Manager, Dr. Whitmore. All donations, monetary and material, were tracked by the procurement officer. Figure 14 is a copy of the team's detailed budget. The total value of the Javelin configuration flown at the competition was $4835.37. Other expenses came in the form of test materials, spare parts, certifications, and replacement parts. Funds left in the budget at this time are being distributed equally among the team members to help offset the cost of their travel to Huntsville in April.

Income (Sponsor Donations)	
American Institute of Aeronautics and Astronautics	$2,000.00
Associated Students of Utah State University	$2,000.00
Exploration Systems Mission Directorate	$4,500.00
Space Dynamics Lab	$5,000.00
College of Engineering	$5,000.00
Total Donations	$18,500.00

Flying Hardware Expenses			
Gumstix Overo Fire	Spent	Allocated	% Used
IMU: Microstrain 3DM-GX3	$1,199.00	$1,199.00	100.00%
RDAS	$343.00	$343.00	100.00%
miniAlt/WD Altimeter	$219.90	$219.90	100.00%
Fins	$72.04	$72.04	100.00%
Gumstix Overo Fire	$270.26	$270.26	100.00%
Pressure Transducers and other Intrumentation	$165.11	$165.11	100.00%
Motor and Solid Fuel	$348.00	$348.00	100.00%
Recovery (Parachutes, Harnesses, e-matches...)	$173.55	$173.55	100.00%
Structure (Body Tube, Couplers, rails)	$433.56	$433.56	100.00%
12 OZ CO2 Tank	$45.75	$45.75	100.00%
Isentropic Expansion Ramps	$479.74	$479.74	100.00%
Payload Tubing and valves	$480.00	$480.00	100.00%
Assembly(Bolts, Nuts, Bulkheads, Epoxies..)	$300.01	$300.01	100.00%
Avionics General	$299.97	$299.97	100.00%
Other Uncategorized Expenses	$5.48	$170.11	3.22%
Subtotal (Flying Hardware)	$4,835.37	$5,000.00	96.71%

Certifications, Testing and Outreach Expenses			
Certifications	$1,162.98	$1,162.98	100.00%
Outreach	$108.63	$108.63	100.00%
Testing	$2,992.34	$2,992.34	100.00%
Subtotal	$4,263.95	$4,263.95	**100.00%**

Travel and Transportation Expenses	$4,372.42	$9,236.05	**47.34%**

Total Expenses	$13,471.74	$18,500.00	**72.82%**

Figure 14: Detailed procurement tracker.

IV.C. Summary of overall experience

The Javelin launch at the USLI competition was a success. With a flawless flight trajectory and parachute deployment, the only flight anomaly present was the unexpected reduction of drag on the rocket body, which augmented the apogee altitude enough for the flight computer to determine that activating the C-BAS was not necessary. Flight IMU data relayed wirelessly during flight clearly shows that the rocket had an optimal trajectory, with nominal motor performance, though the data did not reflect the energy reduction due to drag, as predicted in multiple simulations and as seen in previous test flights.

From beginning to end, the experience of designing, reviewing, fabricating, and flying a high powered rocket that was representative of the College of Engineering at Utah State University as a whole was an incredible learning experience. It was a real challenge to pull together all of the necessary tools provided through years of schooling to accomplish such an enormous task. One aspect that was particularly educational was working in a multidisciplinary engineering team. As the project progressed, the team became a tight knit group often working incredibly late nights to accomplish the tasks before them. When the unthinkable happened, and the rocket was lost to a crash, no pointing fingers and laying blame occurred. The team as a whole scrambled to rebuild the rocket in order to fly again in just seven days.

The experiences from this competition will improve the team's proficiency and confidence as they go into industry already familiar with everything from design reviews, to professional presentation, to rebuilding an entire rocket in a week. Not only has the competition been a great learning experience, the team has also created a solid rocket design that came close to winning the altitude prize. The team also learned that mistakes often happen, and designs are imperfect and require modification. The drag issues provided the team with the opportunity to learn from errors made, and will go a long way to making them better design engineers. A quote from a former Deputy Administer of NASA, Dr. Hugh Dryden comes to mind: "[The purpose of flight research] is to separate the real from the imagined problems and to make known the overlooked and the unexpected."