Post Launch Assessment Review

Lion Tech Rocket Labs

"To demonstrate and gain knowledge in rocketry practice while implementing innovative scientific research and conducting exceptional community outreach. To continually evolve in both knowledge and creativity in all aspects of the USLI competition."

The Pennsylvania State University

List of Tables & Figures

I Summary of Report

Team Summary

Team Name:

Lion Tech Rocket Labs

Location:

46 Hammond Building
University Park, PA 16802

Mentor Name:

Robert Dehate, Level 3 Certified

Launch Vehicle Summary

Vehicle Size and Mass		
Parameter	Value	Units
Length	116	in
Diameter	4.25/3.25	in
Total Mass	22	lbs

Propulsion System Summary		
Parameter	Value	Units
Motor Manufacturer	Aerotech	
Motor Reload	K828FJ	
Motor Diameter	54	mm
Burn Time	2.5	sec
Total Impulse	2157	N-sec
Average Thrust	863	N
Maximum Velocity	655	ft/s
Maximum Acceleration	397	ft/s^2

Recovery System Summary		
Parameter	Value	Units
	Main Parachute:	
Manufacturer	Giant Leap	
Diameter	84	in
Descent Rate	66	ft/s
Deployment At	700	ft
Ejection Charge	3.5	g

	Drogue Parachute:	
Manufacturer	Giant Leap	
Diameter	24	in
Descent Rate	17.5	ft/s
Deployment At	Apogee	
Ejection Charge	3	g

Payload Summary

Gravity Gradiometer

The primary payload for Project Maverick is a relativistic gravity gradiometer. The payload contains three gradiometers—each a set of two dumbbell masses attached by a torsional spring—that measures differences in components of the Riemann Curvature Tensor. Its experimental operation consists of rotating each gradiometer at an angular frequency such that the torsional resonance is achieved. When a nearby massive object disturbs the dumbbell masses, the dumbbell arms are deflected sinusoidally based on local differences in space-time. From these values, the components of the local curvature tensor can be solved for and further analysis can be performed (such as estimation for Earth's space-time metric).

Stand Alone SMD

The secondary payload for this year's vehicle is a custom designed Science Mission Directorate. The custom SMD, being called "Stand Alone SMD (SAS)", contains all sensors necessary for collecting data for pressure, temperature, relative humidity, solar irradiance, real-time imagery, and global positioning. The SAS will be completely automated to collect data as the vehicle progresses through the stages of flight. All data will be stored on on-board Secure Digital (SD) cards and transmitted wirelessly to the team's ground station at the completion of the mission.

II Vehicle Flight Results

Structure

The launch vehicle did not have any structural issues during the launch. The acrylic payload section functioned safely as was predicted by testing and prior flight tests.

Recovery

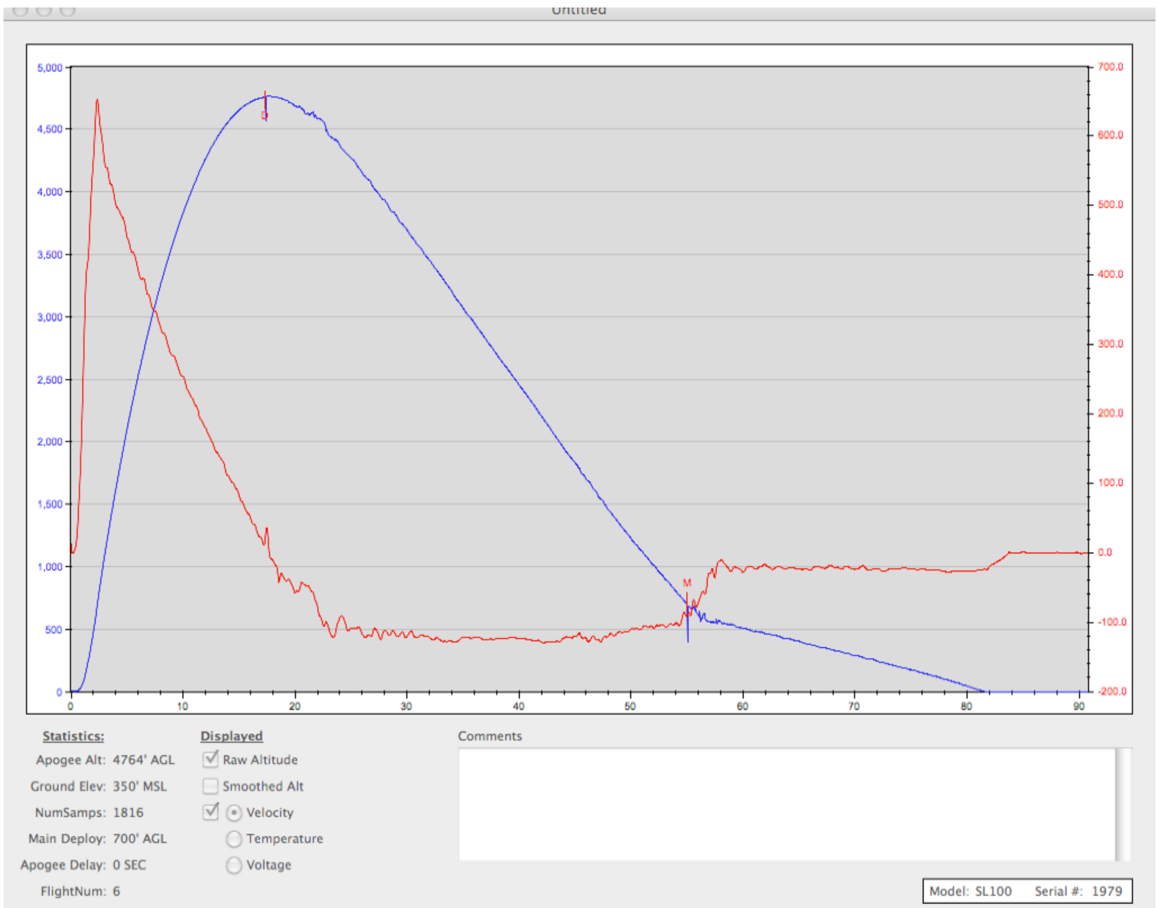

Figure II-1 Recorded Altimeter Data

Altitude Achieved

The maximum altitude achieved by the vehicle was 4764 ft AGL. This is significantly lower than the desired 1 mile apogee. The most likely cause of this undershoot is additional mass added to the payload section shortly before the competition.

Kinetic Energies

The altimeter data shows the descent rates under the drogue and main parachutes. From those the kinetic energies of the vehicle's sections can be calculated and are displayed in Table II-A.

Table II-A Descent Rates and Kinetic Energies

	Section	Descent Rate	Kinetic Energy
Drogue	Nosecone	127 ft/s	1840 ft-lb
	Booster	127 ft/s	2100 ft-lb
Main	Nosecone	22 ft/s	40.8 ft-lb
	Midsection	22 ft/s	34.4 ft-lb
	Booster	22 ft/s	65.7 ft-lb

The descent rates are slightly higher than predicted, especially for under the drogue chute. This is because the drogue chute partially pulled through an opening in its Kevlar heat shield and was unable to fully open. An image of this can be seen in Figure II-2. The root cause this error is to be determined, but the risk can be mitigated by reducing the recovery harness pass-through hole size on the chute protector.

Figure II-2 Drogue chute partial failure

The kinetic energies still always remained within the competition limit of 75 ft-lb under the main parachute.

- Drift

Data from GPS tracker in the vehicle indicated that the vehicle landed approximately 1880 ft away from the launch pad. This is well under the limit set by the competition rules, and the vehicle was recovered on the launch property, fairly close to the flight area.

III Payload Results (Gravity Gradiometer)

Data Analysis and Results

The experiment for the gravity gradiometer needed to be revised due to some problems encountered. During the construction of the payload bay, the bulkheads partitioning the gradiometers did not seem secure. To fix this, the gimbals were rigidly fixed to a permanent structure, so that they acted as a payload housing rather than a gimbal. During transportation, the gradiometers were structurally compromised and was fixed by epoxying the motor layer to the arm layer. It was hoped that the gradiometers would still pick up data even though they would be less sensitive. Another issue encountered was that the gradiometers would separate from the motor due to the damage suffered during transportation. Several epoxying attempts were made using JB Weld and other attempts using Loctite. Despite these efforts, the gradiometers would still fall off the motor shafts.

One of the gradiometers did not experience this problem. This gradiometer was mounted so that it would measure the Earth during the rocket's turn-over at apogee. Because epoxying the two bottom layers changes the natural frequency of the gradiometer, it was retroactively designed to slow down from a high angular velocity, so that it would do a frequency sweep and detect the Earth by sweeping through the measuring frequency. After reviewing the data, the gradiometer did not slow down enough to take a measurement and therefore no useful conclusions can be drawn.

Science Value

The relativistic gravity gradiometer's payload objective is to measure the Riemann Curvature Tensor and understand how the metric of space-time varies as a function of altitude above the Earth. Although many gravity surveys have been performed, measuring space-time curvature is less frequent since the derivative of the field needs to be measured. With this knowledge, empirical models could be constructed for Earth's space-time metric and be used to for GPS calculations.

Lessons Learned

Many things were learned in the construction and implementation of this year's gradiometer payload. Should the team decide to attempt this experiment another year, there are several tips to ensure better experimental results. One issue is in regard to the motor shaft connection: The shaft should be secured mechanically as epoxy has a hard time connecting the metal to the abs plastic. It is now known that the acrylic airframe will be able to handle screws, so if the gimbals are secured in a similar configuration, their bulkheads should be secured in that manner.

The results of the flight have determined that both arms must be able to move relative to the motor as their sensitivity is greatly reduced. It is known, however, that the gradiometers do work. As described in the FRR addendum, the response is given by

$$\alpha = Im[\frac{\frac{1}{2}\left(R_{\hat{x}\hat{0}\hat{x}\hat{0}} - R_{\hat{y}\hat{0}\hat{y}\hat{0}}\right)}{2\omega_0\left(\omega_0 - 2\omega + \frac{i}{2\tau_0}\right)} e^{i2\omega t}]$$

Where α is the arm deflection, ω_0 is the natural frequency, ω is the angular frequency of the gradiometer's rotation, τ_0 is the characteristic damping time of the vibration and the R's represent components of the Riemann Curvature Tensor in the local frame of the rocket.

When an experiment was performed the output displayed in Figure III-1 was observed.

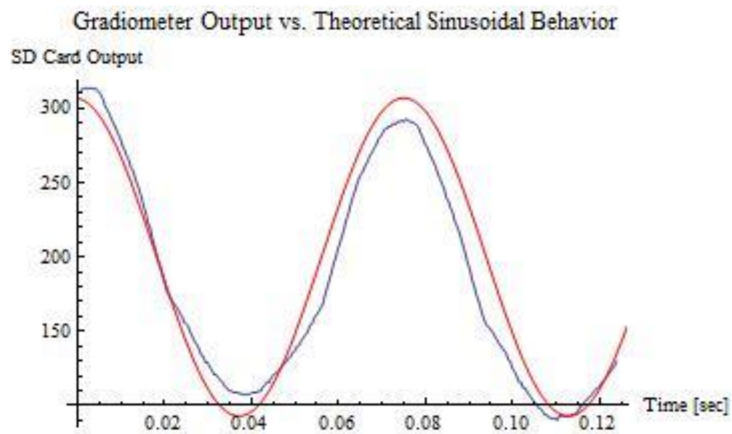

Figure III-1 Theoretical Behavior at 6.6 Hz (Red) vs. Measured Result (Blue)

The conversion factor for SD card output to volts was 0.0029296875 and the gain of the circuit was 5.25×10^{10}. This means that the input voltage was 2.65×10^{-12}V. Using the conversion factor of 1.32×10^{-2} radians to 460 nV, the arm deflection amplitude was then 7.6×10^{-10} radians. It was mentioned that the natural frequency was 3.3Hz and this result was found for 6.6Hz. By solving for the difference in Riemann Curvature components, a numerical result of -3.9×10^{-6} s^{-2} is given. Theoretically, under the Newtonian Limit, the curvature should be the second derivative of the Newtonian gravitational potential with respect to the radial direction. This value is then –g/R, where g is the acceleration of gravity at Earth's surface and R is Earth's radius, which numerically is -1.54×10^{-6} s^{-2}. As can be seen, this is a very close result. Improvements to this should be in the conversion factor, as this was found at a different order of magnitude than the expected range of the measurement, which introduces error. This fact did not impact the error too significantly, however, as the piezo laminates used are rated for <1% linearity.

Summary of Overall Experience

Despite the experiment going wrong at launch, this year was a very good year. Although no results were taken for the actual Riemann Curvature components (i.e. under no simplifications), LTRL has demonstrated that a low-cost device can be made to measure them with surprisingly good accuracy. Further, the team has developed advanced engineering skills when considering the work involved in the CFD analysis and the incredible work of shrinking advanced complicated circuits to a small single board (for both the gradiometer and SAS). The experience was very valuable because the team, in all its subsystems, overcame some very challenging engineering problems. In doing so, members are more confident and skilled engineers and will be able to accomplish similar challenging tasks in the work place.

IV Payload Results (Stand Alone SMD)

This year's vehicle contains a custom designed Science Mission Directorate. The custom SMD, begin called "Stand Alone SMD (SAS)", contains all sensors necessary for collecting data for pressure, temperature, relative humidity, solar irradiance, real-time imagery, and global positioning. The SAS will be completely automated to collect data as the vehicle progresses through the stages of flight. All data will be stored on on-board SD cards and transmitted wirelessly to the team's ground station at the completion of the mission. The SAS implementation is original in design for Penn State. LTRL has designed the SAS system from the initial component selection through the final PCB design and fabrication. The system incorporates all requirements of the SMD payload while creatively combining microcontroller systems to intelligently track the data collected and make decisions as the vehicle progresses through its mission.

Data analysis & results of payload

Although the SAS system did fulfill its designed function, there was an error in the data acquired. It was determined the fault in the data was due to an in-effective pressure tap system in the payload bay. The system itself operated as it was designed to but it detected apogee at a much lower point that could not be fully relied on due to a difference in internal and external pressure. The system accurately detected powered ascent of greater than 3 Gs. It then detected an early apogee due to the in-effective pressure tap system. From apogee it recorded data at a rate of once every five seconds until it falsely detected landing due to the pressure tap system again. Once "landed" it recorded data once per minute for ten minutes before wirelessly re-sending the data and shutting down. The team was able to receive wireless data from the SAS system but there was a large amount of noise due to the number of nearby wireless devices. All of the data was then collected completely from the on-board SD cards. All system functions operated correctly aside from the pressure tap fault.

Scientific value

The objective of the SAS system and means for LionTech Rocket Labs to create this system is to create at Science Mission Directorate that both completes the requirements for SMD as set by NASA and record data that the team can analyze afterward to determine any issues with its vehicle.

Lessons Learned

Creating this system presented a lot of learning opportunities for the team as far as electronic design and system implementation. We examined many options for each sensor selection and evaluated which would allow for the most beneficial data while reducing power usage. There were a lot of technical details not considered at first such as power usage, noise minimization, available space, etc that the team learned must be considered when creating a full electronic system.

Summary of overall experience

The overall experience of this project has proven to create a lasting product the team can use in future years while bringing new issues to the teams attention. For future years the team has discussed creating a better payload bay to house the SAS System that can allow the device to accurately collect the data necessary for successful operation.

V Outreach

This year's educational engagement plan has succeeded in its goals of fostering among young students an interest in the fields of science, technology, engineering, and mathematics as well as encouraging students to think about pursuing a career in those fields by providing a unique, hands-on perspective in instructional and curricular support in the STEM fields. In addition, to encourage team members to take an active role in developing their teaching and presenting skills, all members who attended the competition launch in Huntsville, AL participated in at least three outreach events throughout the year, with many members exceeding the required number.

The team focused on reaching out to local area middle schools as well as science fairs and STEM events to reach the target audience of students in grades 6 – 8. Other audiences, including all students in grades K-12, were also considered and planned for accordingly. Table V-A shows a list of all Outreach events that have occurred throughout this competition year.

Table V-A 2012-2013 Outreach Events

Event	Date	Interactions	Attendance
Penn State Science U Halloween Event	Oct 21, 2012	Direct	80
Discovery Space American Association of University Women (AAUW) and KidTech Engineering Challenge	Oct 24, 2012 – Nov 24, 2012	Direct	120
Discovery Space Science, Technology, Engineering, Arts, and Mathematics (STEAM) Advisory Board	Oct 26, 2012 – Dec 7, 2012	Direct	156
WPSU EventaPalooza	Nov 4, 2012	Indirect	500
Littlestown High School	Nov 21, 2012	Direct	52
Bellefonte Family Science Night	Nov 15, 2012	Indirect	400
Park Forest Middle School	Feb 12, 2013	Direct	87
State College Area High School	Feb 26, 2013	Direct	103
Mt. Nittany Middle School	Feb 28, 2013	Direct	357
Carlisle High School	Mar 8, 2013	Direct	241
FIRST Robotics Regional Exposition	Mar 15, 2013	Indirect	1100
Exploration U	Mar 19, 2013	Indirect	600
Cub Scouts Pack 322	Mar 21, 2013	Direct	78
Total			**3874**

Every event was started and supervised by a member of the Outreach Committee. Each event was open to all members of the team, and at least one member from the Outreach Committee attended to prepare the other members with their duties and ensure that the event ran smoothly. Following every event, feedback was collected from both participants and moderators in the form of follow-up conversations, feedback ratings, and feedback questionnaires.

VI Budget

The fiscal cycle of the 2012-2013 NASA USLI competition has broken new grounds for the LTRL. Through various cost-cutting initiatives, the team managed to cut the production costs of its full scale rocket by over $1000, bringing the cost of the full scale rocket to $2030.23, which is well under
the competition's $5000 full scale limit. By decreasing the size of the rocket, the team saved money since the rocket used less material to construct. Additionally, the team took advantage of University test-labs and products (3d printing) to lower costs.

Each of this competition cycle's expenses fell into one of these five categories: Full-Scale, Subscale, Operations, Travel, and Support. Full-scale expenses encompassed costs associated with the production of one model of the team's competition rocket, *Maverick.* Subscale expenses include the cost of producing and testing the subscale model of the competition rocket. Operations expenses include the costs of outreach events and club logistics. Travel expenses include food, transportation, and lodging for outreach events, test-launches, and the USLI Competition. Support expenses include other miscellaneous expenses such as equipment. Table VI-A shows a table illustrating the total expenses for the Pennsylvania State University USLI Team, Lion Tech Rocket Labs for the 2012-2013 competition cycle. The total expenses for the team were $12,048.40.

Table VI-A LTRL Total Expenses

2012-2013 Expenses	
Full-Scale	$ 2,030.23
Subscale	$ 421.19
Operations	$ 949.81
Travel	$ 8,314.41
Support	$ 332.76
Total	**$ 12,048.40**

LTRL would like to thank it's sponsors – The Pennsylvania State University Aerospace Department, The Pennsylvania Space Grant Consortium, Pratt and Whitney, Ion Corporation, NASA (SMD), and the Pennsylvania State University Association of Student Activities – for their funding and support.

VII Conclusion

Lessons learned

The 2012-2013 team was the largest (by far) team the LTRL has had in the clubs history. With this new growth, the team learned the need for integration was more necessary then ever. LTRL attempted new, revolutionary, and more challenging payloads then it had in the past. The need for integration was very evident as the project became more complex.

The Team also learned the importance of maintaining contacts. Strong contacts with MDRA allowed the team to have 2 successful tests launches rather then 1 as it has in the past, contacts with alumni allowed the team to have their presentations reviewed before the main presentation and strong connections within Penn State facilitated the teams focus on testing and development.

Summary of Overall Experience

Overall, LTRL's 2012-2013 presented the team with valuable learning experiences and provided a solid base for the 2013-2014 project. The team now has the ability to use and build on the legacy SMD. This provides the Payload subsystem with a solid base to start next years project. The payload subsystem also befits from lessons in research and scientific proficiency learned in the RGG payload process. The team also benefited from extending its membership to students of non-engineering majors (a practice which the team plans to continue in the future). Corporate partnerships were strengthened as the team's alumni base grew which provided LTRL with valuable recourses provided by industry engineers.

With this solid base along with the teams standing as a 3rd year member in the USLI competition, LTRL sees this past year as one which has allowed the team to grow not only in size but in experience and ambition.