Piedmont Student Launch Team

Post Launch Assessment Review

2017 NASA Student Launch

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Glossary of Acronyms

DC - Direct Current
GPS - Global Positioning System
IMU - Inertial Measurement Unit
LED - Light Emitting Diode
NAR - National Association of Rocketry
PSLT - Piedmont Student Launch Team

1 Launch Vehicle Analysis

1.1 Summary of Launch Vehicle

Statistic	Value
Length (in)	107.5
Body tube diameter (in)	5.525
Mass without motor (lbs)	29.17
Motor choice	Aerotech L1150R
Main parachute diameter (in)	84
Drogue parachute diameter (in)	18
Recovery harness length (ft)	27

Table 1.1 - Summary of Launch Vehicle

Key features of the launch vehicle are that it used fiberglass body tubes, nose cone, fins, bulkheads, and centering rings; it used 4 shear pins at each point of separation; it had 2 attachment points for the recovery harness on each section; and it used 3 g black powder ejection charges for primary and secondary charges on both the drogue and main parachutes.

1.2 Assessment of Launch Vehicle

Apart from an issue with reaching the target altitude, discussed later, the launch vehicle worked as expected. There are some areas that it was noticed could be improved on the launch vehicle though. In particular, the fin design, using more standard trapezoidal or elliptical fins would decrease the risk of damaging them during flight, recovery, transport, and ground fire testing.

2 Payload Analysis

2.1 Summary of Payload

The payload was designed to accomplish the Roll and Counter-Roll challenge. To complete this challenge, a reaction wheel was used. The wheel weighed 1.5 lbs and used the principle of conservation of angular momentum to change the angular velocity of the rocket.

As a secondary challenge, an externally mounted camera was used to attempt to identify the ground targets used for the Target Detection and Vertical Landing challenge during ascent.

Other electronics in the payload included a GPS, an IMU, and a transceiver to collect data both for use on the payload and to transmit back to the ground.

2.2 Payload Data Analysis

2.2.1 Sensor Performance

The payload detected launch and burnout using the accelerometer in the IMU. It also correctly measured the magnitude of the angular velocity using the magnetometer in the IMU, although the direction was inverted.

2.2.2 Roll

At burnout, the payload detected a passive roll of 365 °/s. It then activated the reaction wheel for 1.6 s, increasing the roll by 175 °/s. During this time, the rocket rolled 864°, 584° from the passive roll (365 °/s * 1.6 s) and 280° from the induced roll (175 °/s * 1.6 s). Due to a programming error, the payload switched to counter-roll mode early; if it had not, it would have taken 6.2 s for the reaction wheel to cause 3 rotations (on top of the 6.3 rotations from the passive roll).

2.2.3 Counter-Roll

In the counter-roll mode, the payload was supposed to return the rocket to the burnout roll rate of 365 °/s. Because the roll detection was inverted, it instead tried to set the roll rate to -365 °/s. The roll rate was reduced from 540 °/s to 315 °/s. This range includes the burnout roll rate of 365 °/s, meaning that, had the roll direction been measured properly, the payload would have been able to return the rocket to the burnout roll rate.

2.2.4 Target Identification

Target identification during ascent was not successful. The target detection algorithm was made less sensitive to avoid detecting objects that had a color similar to the colors of the targets, such as tents and cars. However, it ended up being too insensitive to detect the tarps.

2.3 Assessment of Payload

2.3.1 Requirements

Requirement	Success?	Notes
The payload shall detect motor ignition	Yes	The payload used the accelerometer in the IMU to detect motor ignition
The payload shall detect motor burnout	Yes	The payload used the accelerometer in the IMU to detect motor burnout
The payload shall detect the angular velocity of the rocket at motor burnout	Partial	The payload successfully detected the magnitude of the angular velocity, but the direction was inverted
The rocket shall roll 3 times around its long axis	Partial	Not counting the passive roll, the rocket rolled 0.78 times around its long axis
The rocket shall complete its 3 rotations within 12 s	Partial	The rocket completed 0.78 rolls in 1.6 s; had the payload not switched to counter-roll mode early 3 rolls would have taken 6.2 s
The payload shall identify the ground targets from the target identification challenge	No	The target identification algorithm was too insensitive to detect the targets

Requirement	Success?	Notes
The rocket shall return to within 5 °/s of its angular velocity at motor burnout	Partial	The data does show sufficiently fine roll control to achieve this, but, because the roll detection was inverted, the rocket did not return to burnout roll
The payload shall transmit the latitude, longitude, altitude, vertical velocity, horizontal velocity, acceleration in each axis, rotation about each axis, magnetic field strength in each axis, roll position of the rocket, and whether or not the reaction wheel is spinning during the entire flight	Yes	The data was transmitted throughout the flight

Table 2.1 - Payload Requirements

2.3.2 Scientific Value

Unlike most reaction wheel / flywheel designs, the reaction wheel was built using low cost, off-the-shelf parts. This allowed for a low cost, easy to manufacture, modular design. This has potential applications in low cost amateur CubeSats.

2.4 Payload Observations

2.4.1 In-Flight

By the time the rocket started rolling it was too high to observe visually. The onboard video however confirms the accuracy of the data from the IMU.

2.4.2 Post-Flight

Post-flight inspection of the payload showed no damage. In particular, the reaction wheel stayed firmly attached to the DC motor shaft which was the largest concern with the design.

3 Flight Analysis

3.1 Flight Data

3.1.1 Conditions and Gathered Data

Condition	Value
Wind (MPH)	0 - 5
Temperature (°F)	71
Altitude Above Sea Level (ft)	600

Table 3.1 - Launch Day Conditions

Statistic	Value
Apogee (ft)	4513
Maximum velocity (ft/s)	546
Drogue descent rate (ft/s)	80
Main descent rate (ft/s)	36
Drift (ft)	150
Time to burnout (s)	3.17
Time to apogee (s)	17.31
Time to main deployment (s)	110.13

Table 3.2 - Launch Statistics

3.1.2 Assessment

Overall, the flight went as expected. The primary issue was the altitude. It is believed that the reason the altitude fell short was friction with the launch rail; the temperature at the launch was significantly higher than at the test flight, so the metal of the launch rail and of the bolts securing the rail buttons may have expanded. Certainly, when the rocket was put on to the launch rail, there was noticeably more friction than expected.

Additionally, the main and drogue descent rates are different from expected. It is believed that this is the result of the altimeter averaging the rate over the entire period of descent for each stage. When the drogue parachute is deployed, the rocket would be going very slowly, accounting for the lower than expected drogue descent rate, and for the main parachute, the rocket would be going much faster at deployment than at landing, accounting for the higher than expected rate.

Given the probable overestimate of the velocity at landing, the error of which was corroborated by visual observations, it appears that the highest kinetic energy of a section at landing was over 75 ft-lbs. However, it is likely that the actual kinetic energy was lower than that.

3.2 Flight Observations

The flight, landing, and recovery were all successful. The rocket flew straight, with no significant oscillations coming off the launch rail. The rocket remained stable throughout the ascent. All recovery system events occurred at the correct times, and the rocket was safely recovered.

4 Project Analysis

4.1 Summary of Project

4.1.1 Results of the Project

Table 4.1 lists the stated requirements of the launch vehicle, payload, and the team derived goals for the project and whether or not they were met. For the launch vehicle and payload, they do not include any design requirements, only functional. The location of the analysis is linked for all items that were either not or only partially successful.

Requirement	Success?	Location of Analysis
The rocket can be prepared for flight in less than 4 hours	Yes	
The rocket deploys the drogue parachute at apogee	Yes	
The rocket achieves an apogee between 5000 ft and 5400 ft	No	Section 3.1.2
The rocket deploys the main parachute at 800 ft	Yes	
The rocket drifts less than 2500 ft	Yes	
The rocket separates into 3 sections after both ejection charges have fired	Yes	
All sections of the rocket land with less than 75 ft-lbs of energy	Partial	Section 3.1.2
The rocket is sufficiently undamaged by the flight that it is re-flyable without any repair	Yes	
The payload can remain in the launch ready configuration for at least 1 hour	Yes	
The payload can detect motor ignition	Yes	
The payload can detect motor burnout	Yes	
The payload can measure the roll of the rocket at motor burnout	Partial	Section 2.2.1
The payload can induce a moment capable of rolling the rocket 3 times around its long axis within 12 s	Partial	Section 2.2.2
The payload can identify the ground targets from the target identification and vertical landing challenge	No	Section 2.2.4
The payload can return the rocket to within 5 °/s of its burnout angular velocity	Partial	Section 2.2.3
The payload can transmit the latitude, longitude, altitude, vertical velocity, horizontal velocity, acceleration in each axis, rotation about each axis, magnetic field strength in each axis, roll position of the rocket, and whether or not the reaction wheel is spinning during the entire flight	Yes	
Engage at least 200 females in STEM activities.	Yes	
Ensure PSLT is able to continue in future years.	Yes	
Encourage Student Launch at other schools.	Yes	

Table 4.1 - Project Goals

Although not all of the goals were met, the majority of them were, and the team is overall pleased with the results. That said, all areas will be worked on further next year, and especially those where the goals were not met.

4.1.2 Value of the Experience

The team felt that overall the project was of immense value for both personal and professional development. Everyone learned a great deal about rocketry, engineering, team projects, and a variety of other topics. Additionally, the team has spoken to many industry professionals, all of who expressed the value that they saw in the project.

4.2 Summary of Budget

Expected Cost of Project	Actual Cost of Project	Difference
$10 327	$9 584	$743

Table 4.2 - Budget Summary

The main reason for the difference between the expected and actual costs was travel expenses. They were estimated based on the number of people originally expected to go to launch week, which was larger than the number of people who actually went.

4.3 Summary of Educational Engagement

Table 4.3 summarizes the number of participants engaged in educational activities over the course of the project year.

Participant's Grade Level	Education	
	Direct Interactions	**Indirect** Interactions
K-4	113	
5-9	83	2
10-12	65	4
12+	157	55
Educators (5-9)		
Educators (other)		2
Total	418	63

Table 4.3 - Summary of Educational Engagement Participants

In addition, the team set a goal of educating at least 200 female participants. Of the total number of participants engaged, approximately 250 were female, which not only reached the goal, but also means that more than 50% of the total participants were female.

Although the team had thought that this was a large number for the project, having now gained a better sense of the scope of the educational engagement portion of the project and what other teams have done, they have decided to strive for a significantly larger number of participants next year.

4.4 Lessons Learned

4.4.1 Project

- Conduct multiple full-scale test flights to have a better idea of how it will perform
- Get the subscale built as early as possible
- Fly the subscale as early as possible and as many times as possible to gather more data
- Get a photo booth to take better pictures to document the construction of both the launch vehicle and payload

- Do more detail documenting of the construction of the full-scale rocket and payload
- Have dedicated design meetings at the beginning of the project
- Split the launch vehicle and payload teams into design / construction and testing sub-teams
- Have at least one embedded deputy safety officer on each of the launch vehicle and payload teams
- Do more ground testing
- Have periodic meetings dedicated to safety
- Do more in-depth flight analyses both before and after each flight
- Have a director of engagement and outreach who is responsible for planning educational activities
- Use laser cut or 3D printed jigs during construction to ensure that parts are better aligned

4.4.2 Launch Vehicle

- Color the primary and secondary ejection charges to make it easy to identify which one is firing
- Never use disposable motors
- Set the arming altitude on altimeters as low as it will go
- Use a smaller full-scale rocket to reduce the cost and ensure that a large enough motor can be found
- Use counter sunk bolts on the rail buttons to avoid creating additional friction on the launch rail
- Use 4 fins to allow for smaller fins and to reduce the angle between the fins and vertical when the rocket must rest on the fins
- Use more standard fin shapes such as trapezoidal or elliptical
- Make more use of 3D printed parts

4.4.3 Payload

- If possible, find sensors that can be mounted more securely than the ones used this year
- Use a GPS module that updates more quickly than the one used this year
- Any communication from the payload to the ground should go to dedicated ground hardware
- Using external LED indicators would be good for the payload to communicate its status
- Any sensors that need to be calibrated should be calibrated in flight to get proper readings
- Make more use of 3D printed parts
- Be able to activate the payload externally to prevent issues with battery life

4.4.4 Operational

- Have different launch pad procedures for test launches and launch week to take into account how NAR runs the launch pads
- Inspect the full-scale for any damage several days before packing for launch week
- Assemble the rocket as for flight before packing it for launch week
- Use the full-scale motor when doing test flights of the full-scale rocket
- Include a final Go / No Go check in the launch operation procedures
- Double check all cameras to ensure that they are recording before flight

4.4.5 Educational Engagement and Outreach

- Have more resources on rocketry both for new team members and for educational engagement
- Do a single, large education project in addition to any smaller activities
- Keep all points of outreach, social media, website, etc., up-to-date
- Include a page on the website for educational engagement