University of Notre Dame

2017 - 2018

Notre Dame Rocket Team

Post-Launch Assessment Review

NASA Student Launch 2018

Deployable Rover and Air Braking System Payloads

Submitted April 26, 2018

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1 Overall Team Summary

1.1 Team and Budget Summary

This year the Notre Dame Rocketry Team (NDRT) competed in the NASA Student Launch competition, sending 23 undergraduate members, a graduate advisor, and team mentor to the launch in Huntsville, Alabama. This is the sixth time the team has competed in the competition and the following report highlights the launch results from the competition and the key takeaways from the year.

This year, the Notre Dame Rocketry Team received sponsorship from Boeing, Textron, TimkenSteel, and BizStream. The allocation of each company's contribution as well as a brief summary of the team's expenses for this year may be seen in Table 1. This metric and the remaining balance will serve as a basis and starting point for next year's budget.

Table 1. Team Expenses and Income for 2017-2018 Year.

Expenses		**Income**	
Supplies	($7469.15)	Initial Balance	$1140.46
Educational Outreach	($258.86)	University Funding	$0.00
Travel Expenses	($5127.40)	**Sponsors**	
Research	($537.88)	Boeing	$10,000.00
Travel Expenses		Textron	$2,000.00
Gas and Oil	($576.68)	TimkenSteel	$1,000.00
Lodging	($2198.08)	BizStream	$200.00
Food & Drink	($2352.64)		
Supplies			
Printing	($214.87)		
Construction	($7254.38)		
Food & Drink	($64.78)		
Overall Budget			
Total Expenses	($13,393.29)		
Total Income	$14,440.46		
End Balance	**$1047.17**		

1.2 Educational Engagement Summary

The Notre Dame Rocketry Team values every opportunity to engage with the community and cultivate interest in STEM fields. The team was very honored to receive the Educational Engagement Award at the competition. The goal for Notre Dame's educational engagement was to create events that inspired the community and youth to learn about STEM, introduce or reinforce concepts about rocketry, and provide mentorship to students. This year, the team exceeded NASA's goal of reaching 200 students and its personal goal of reaching 500, reaching over 1,300 students during the course of the year.

To accomplish this goal, the team focused on recurring interactive events in addition to presentations. The team partnered with 10 schools and organizations to reach a variety of students. Some major events this year were the Science Alive fair and the Society of Women's Engineers' Engineering Expo. At Science Alive, the team had a showcase of previous rockets to an estimated 500 children in the community, where they could ask questions and see the rocket up close. The Engineering Expo took place at Madison Primary Center where around 400 students in six separate groups were able to engage in conversation with team members about various topics in rocketry. The team was very excited to see the students be engaged and participative, making this event a great success.

Two recurring events consisted of the team's five-week program with the St. Joseph County Boys and Girls Club and the Robinson Community Learning Center. This program consisted of teaching students about rocketry basics, propulsion, motor selection, recovery systems/shock absorption, and culminated in the building and launching of Estes rockets. This demonstration allowed the students to apply their knowledge from previous lessons to build their own models. Students were able to form meaningful relationships with NDRT members and explore their interest in STEM fields.

The team participated in some other smaller-scale one-time events such as Physics is Phun with College Mentors for Kids, working with Harrison Primary School, and the Girl Scouts of St. Joseph Country. These events consisted of a combination of lessons and presentations about rocketry by the NDRT members. Activities such as building and flying paper rockets allowed the students to understand lessons in aerodynamics, flight stability, and overall vehicle design.

Overall, the team is very satisfied with the educational outreach events provided. These events allowed NDRT to reach a wide array of students without sacrificing the hands-on, personal learning that STEM fields require. The team continues to pursue opportunities to connect with the community and hopes to continue to be a positive influence on local students and residents.

1.3 Safety Summary

In the days leading up to the launch, the rocket was painted and the vehicle and payloads were prepped for the Launch Readiness Review and Competition Launch. When painting, aerosol spray paint was applied in a properly ventilated and controlled environment. Team members applying paint used personal protective equipment such as gloves and breathing masks to mitigate potential health hazards encountered during the use of aerosol spray paint. Additionally, team members performed repairs on the fins of the rocket and circuitry of the deployable rover payload. Potential hazards posed by the tools and materials used during these repairs, such as the soldering irons, CNC mills, and epoxy, were mitigated according the safety procedures in the most current team safety documentation.

All Launch Safety Procedures were reviewed by the team Safety Officer, Captain, and Design Leads. Revisions were made to procedures so that they accurately reflected the most current and safe launch preparations in the order they would be performed on launch day. Procedures were then printed out and packed with the other team equipment to be taken to the competition.

Upon arrival in Huntsville, the team attended a Launch Readiness Review to be cleared for launch. After thorough inspection of the vehicle and payloads, the Launch Readiness Review was passed without any potential hazards being identified to necessitate punch lists. Prior to launch the team conducted a secondary inspection and review to ensure that the rocket was launch ready.

On launch day, the vehicle was assembled according to the Launch Safety Procedures, and compliance was verified by supervising safety team personnel and signed off by the Safety Officer. The team mentor, who is NAR Level 2 certified, assembled and ensured the proper packing and integration of black powder charges, as well as the assembly and integration of the motor. The rocket was then brought to the launch pad, and under the supervision of a Range Safety officer, was mounted to the launch rail using the rail buttons and rotated to an upright position. The altimeters were then activated, and the pad was cleared except for the RSO and team mentor so that the igniter could be installed.

Drogue and main parachute deployment were visually confirmed to be successful by all team members. Due to high winds, the rocket drifted outside of property lines onto private property. After notifying NASA and the property owner, the rocket was located. After confirming that the rover landed in the proper orientation for deployment, deployment black powder charges were disarmed, and the rocket was successfully recovered and transported back to the launch site for rover deployment.

2 Launch Vehicle Summary

2.1 Vehicle Description

The launch vehicle this year had an overall length of 136 inches, a total weight of 764 ounces, and a stability margin of 2.78 calipers while loaded with the motor. A table containing the other parameters and dimensions of the launch vehicle can be found in Table 2. The rocket was launched on a 12 foot 1515 rail and experienced a successful and stable flight.

Table 2. Final vehicle and component dimensions.

Property	Dimension
Total Length (in)	136
Upper Outer Diameter (in)	7.74
Upper Inner Diameter (in)	7.5
Lower Outer Diameter (in)	5.5
Lower Inner Diameter (in)	5.38
Number of Fins	4
Tip / Chord Length (in)	7
Fin Height (in)	6
Fin Width (in)	.125
Weight with Motor (oz)	764
Weight without Motor (oz)	611
Stability Margin with Motors	2.82
Stability Margin without Motors	4.2

The vehicle is broken down into three sections based on a dual deployment recovery system. At apogee, Section I separates from II and III, and the drogue parachute deploys. At an altitude of 550 ft, sections II and III separate and the main parachute deploys. Additionally, the Deployable Rover Payload is located in section I of the rocket, the parachutes are located in section II, and the Air Braking System is located in section III. A more detailed breakdown of these sections can be seen in Figure 1 and dimensions are listed in Table 3.

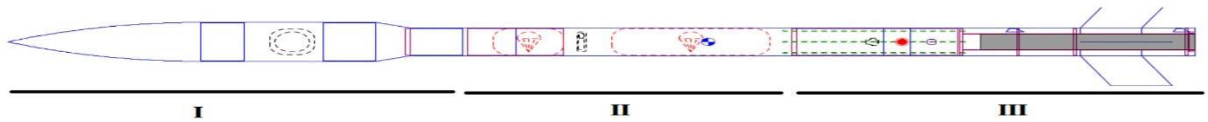

Figure 1. Breakdown of launch vehicle sections.

Table 3. Length of Various Rocket Components.

Section	Component	Length (in)
I	Nose Cone	22* (+5in shoulder)
	Rover Bay	20*
	Transition Section	4* (+6in shoulder)
II	Body Tube	42*
	Roll Control System Coupler	19
	Roll Control Mount	3*
III	Fin Can	32.5*
	Engine Mount	0.74*
	Total	136

*Indicates dimension adds to total length

2.1.1 Motor Choice

The motor used in the launch vehicle was a Cesaroni Technologies L1395-BS. This motor was selected after test launches and simulations showed that this motor achieved an apogee close to the target, but still exceeding it. Simulations showed that under the wind conditions (5 mph) that were predicted for the launch day, the motor would propel the launch vehicle to 5,220 feet using OpenRocket. The motor performed as expected, however, issues in modeling the paint finish on the rocket led to a predicted apogee below the one observed at competition.

2.2 Recovery Description

The recovery system deployed as designed, resulting in a successful landing where the launch vehicle was recovered and able to be prepped and launched again within two hours. The altitude at apogee was recorded at 5538 ft, and separation and drogue deployment at apogee occurred as expected. The maximum acceleration felt by the rocket was at main deployment, and never exceeded 997 ft/s^2. Total flight time was 127 seconds, and descent time was approximately 108 seconds. This was higher than expected due to a higher than predicted altitude and wind gusts at high altitudes. The altitude and acceleration data is from the launch is shown in Figure 2. The apparent sudden drop in altitude around apogee is likely due to a pressure wave caused by black powder ignition for drogue deployment. In future launches, the altimeters will be better shielded from the deployment charges to improve accuracy throughout flight. Triple redundancy in deployment charges was adequate for deployment of both the main and drogue parachutes. This procedure will be implemented or improved upon for future launches.

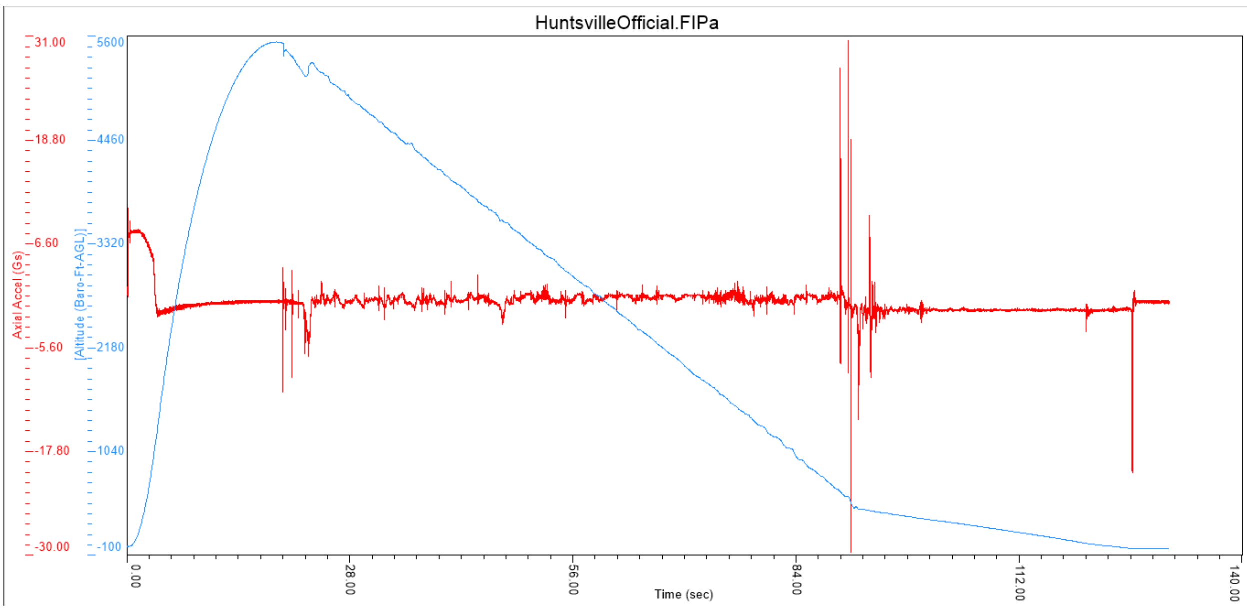

Figure 2. Official flight data from the Huntsville Launch.

2.3 Launch Performance

The Notre Dame Rocket Team launched their rocket at competition on April 8th, 2018 in Toney, Alabama at Bragg Farms. The launch had been delayed a day due to inclement weather, but the rain and wind abated in time for a successful launch on that Sunday.

Neither payload was active during launch due to safety concerns. The Air Braking System had not been flown fully active during previous test launches, and its effect on stability had not been tested enough to ensure its safety at competition. The rover had experienced electrical issues and was therefore tied down with zip ties to secure it the body tube in the event that the mechanical retention system failed. Because of this, the rover was unable to independently exit the nose cone upon landing and could not complete the mission requirement of driving 5 feet from the launch vehicle.

The launch itself was stable and recovery was successful. The drogue parachute successfully deployed at apogee, and the main parachute deployed at an altitude of approximately 500 feet as intended. Due to high winds and an apogee altitude higher than predicted, the launch vehicle drifted outside of the launch radius and onto private property. Due to possible damage to the ejection system in the nose cone, the black powder charges were disarmed using the shunt pins and then manually removed. This will be discussed further in Section 3.3.2.

The team's target range for apogee using OpenRocket as the primary simulation software was within 100 feet of a mile. Unfortunately, the launch vehicle failed to meet this goal. The rocket achieved an apogee of 5,538 feet which was substantially higher than the apogee predicted by OpenRocket. This was attributed to slight inaccuracies in the final weight and finish of the rocket. Due to time constraints the team painted the rocket themselves and the resulting finish was likely not modeled accurately in OpenRocket. In addition, the Air Braking System was not active during flight, eliminating the ability of the vehicle to dynamically influence apogee. OpenRocket simulations were however, fairly accurate in predicting maximum velocity, velocity off the rails, and time to apogee. A summary of the simulation and flight data is included in Table 4. From the standpoint of recovery, the launch was very successful. The launch vehicle was reusable after launch and all payloads were intact. More detail on the vehicle's recovery performance can be found in Section 3.1.

Table 4. Launch Results and Values Predicted by Simulations.

	Launch Results	**OpenRocket**
Apogee (ft)	5,538	5,220
Maximum Velocity (ft/s)	673	662
Maximum Axial Acceleration (g's)	30.51	36.08
Off Rail Velocity (ft/s)	62	59
Time to Apogee (s)	18.49	18.50
Average Thrust (N)	1395.7	1395.7

Thrust to Weight Ratio	6.569	6.569
Error vs Target (ft)	258	60
Percent Error (%) Target	4.89	1.14

3 Payload Summary

3.1 Payload Descriptions

The team constructed two experimental payloads this year. The scoring payload was a Deployable Rover, and the non-scoring payload was an Air Braking System to reduce apogee to exactly 5280 feet.

3.2 Air Braking System

The purpose of the Air Braking System was to assist the launch vehicle in reaching an apogee of exactly 5280 feet through a system of drag tabs extended into the freestream flow. Ultimately, the Air Braking System was not active during the competition flight because it had not been flown fully active in a test launch. In the first test flight, a faulty wire prevented the Air Braking System from being properly set, and it was turned off for safety concerns. In the second flight, the barometer sensor noise caused an error in the control code, preventing proper operation. Data from the servo motors further confirmed that the drag tabs did not extend during the test flights and it was decided in the interest of safety that the Air Braking System could not be deployed at competition. Furthermore, to ensure that the system did not unintentionally activate, it was turned off at competition and data was not collected.

At a later test flight on April 22nd, the Air Braking System was tested again. Upon analysis of the controller data stored on a microSD card, it was determined that the sensors used in the system did not work as intended, reading numerous noise spikes and negative altitudes, and are likely not suitable for this environment despite what their specifications suggested.

In the future, there are a number of changes that must be made to ensure a successful Air Braking System. Most importantly, a more robust choice of sensors is essential. Based on feedback from NASA, the team plans to implement a more sophisticated control code, utilizing a Kalman filter to suppress noise from flight data. Furthermore, the team plans to reduce the size of the system by designing a better printed circuit board to contain all the electronics on a single deck, reducing the number of servo motors to one, and moving the power supply to that additional space left by the motor.

3.3 Rover Payload

The final full-scale launch before the competition showed that the code used by the deployable rover to secure itself inside the body tube was too taxing on the servo that drove the securing mechanism. This caused it to stall for longer than it had been designed for. In response to this, code was in development that would reduce the stress on the servo, however, by the date of the competition not enough testing had been done on the program and it was determined that the rover should be secured without relying on the rover's securing mechanism. This decision was made to ensure a safe a recoverable flight for the entire launch vehicle.

During the flight the rover was held in place by a combination of passive placement inside the securing system without an active servo and with zip ties. The zip ties safely secured it in the body tube but meant that the rover would not be able to remotely deploy upon landing. The goal was to deploy the rover manually upon landing to serve as a proof of concept.

However, as the launch vehicle descended under the main parachute it drifted over a nearby neighborhood. The body of the rocket landed on private property and the nose cone section experienced a rougher landing than the rest of the rocket, causing damage to the axles of the rover. It is believed that an active securing mechanism would have prevented this damage as the rover would not have been resting on the tracks and in turn received less shock from the collision. The damage on the wheels prevented even a manual activation of the deployment as the back wheels no longer could drive.

Once the rover section of the launch vehicle landed the black powder charges were disarmed because the chance of damage to the ejection system meant that removing the nose cone with the charges had become unsafe. The charges were disarmed using the external shunt pins and once disarmed, the nose cone and ejection charges were manually removed.

During the launch the rover's data collection was active, however, the LoRa antenna was damaged during assembly of the rover on the morning of the competition. The damage to the LoRa antenna considerably reduced the range of communication possible between the rover and the base station, causing real-time data to cut out once the rocket reached a high enough altitude and continued to remain silent after the rocket landed.

4 Overall Experience

4.1 Lessons Learned

Throughout the course of the year, the team was faced with a multitude of challenges that served as learning opportunities in project management and navigating real engineering design challenges. An early challenge was a delayed materials order that ultimately had to be canceled. This put the team in a situation where it had limited time and resources to find a solution. Ultimately, many parts of the rocket had to be constructed using different materials than the original design. The effects of these changes were felt by every design sub-team and encouraged the team to streamline communication to quickly resolve issues. This lead to a successful construction and test launch and taught the team the importance of planning ahead to lessen the impact of such a change.

Additionally, the team recognizes the need to continue to improve payload testing procedures to better ensure their performance. While extensive analysis was done during PDR and CDR, construction of both the Air Braking System and Deployable Rover payloads was behind schedule. This led to the sub-teams encountering issues they had not considered during the design process, resulting in an inadequate amount of time to extensively test the payloads. Looking forward, it is vital to make sure the payload teams understand the timeline and push construction in the fall semester. This will allow for more tests to be performed in the spring to better understand the limits of each system and make any improvements deemed necessary to attain 100% mission success.

Finally, the team became more effective problem solvers throughout the year. Members were faced with the reality and setbacks of a real world design challenge, and were able to effectively navigate the situation. Overall, the year has been a great learning experience for the team and has provided many lessons going into next year's competition.

4.2 Summary of Experience

Overall, this year was a success for the team. While the payloads were only partially successful, the team overcame a number of design challenges and was still able to achieve its goal of competing in NASA Student Launch this year. After successful PDR and CDR reports, the team encountered an issue with a materials supplier not being able to deliver and had to overcome a complete materials change and redesign prior to FRR. This lead to a rushed test flight in which the main parachute deployed at apogee and inadequate payload in-flight testing. This is still an improvement on previous years because, besides an early main deployment, all launches experienced an otherwise successful recovery. The team launched the rocket at competition under a Cesaroni L1395-BS motor. The launch vehicle had a length of 136 inches, fully loaded weight of 726 ounces, and a static stability margin of 2.78 calipers. The rocket experienced a stable flight and successful recovery, reaching an altitude of 5,538 feet.

The team continues to make strides toward improvement on the more technical aspects of the competition as well as administration of the team. This year, communication was streamlined between the different design teams to ensure proper integration of each payload. This became critical during the material issue and during the redesign. Additionally, testing was increased from previous years to give a more thorough analysis of payload performance and provided a better chance of success at competition. Finally, educational outreach expanded to the largest outreach in the team's history. The team built on programs from previous years and has now established itself and gained recognition in the South Bend community, reaching over 1,300 kids in the community. This culminated in the team winning the Educational Outreach Award and coming back from competition already looking towards improvements for next year.


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