Post Launch Assessment Review

2020 NASA University Student Launch Initiative
April 14th, 2020

The University of Alabama in Huntsville – Propulsion Research Center
301 Sparkman Dr. NW, Huntsville, AL 35899
256.824.7209

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1 PLAR Summary

The University of Alabama in Huntsville (UAH) - Charger Rocket Works (CRW) 2020 team successfully designed, manufactured, built, tested, and flew a 6 in. nominal diameter, 136 in. long vehicle carrying a payload to a target altitude of 4500 ft. AGL. To accomplish the lunar ice collection mission, a rover was designed, featuring symmetrical, track-driven propulsion, and scoops for sample collection.

The final flight of CRW's 2020 entry, *Baedor*, resulted in vehicle flight and recovery success, as well as payload mission success. *Baedor* flew on an Aerotech L2200G motor to an altitude of 4454 ft. AGL, retained the payload during recovery, and was recovered with no damage. The rover, *Little Dipper*, was recovered with minimal damage and successfully completed a modified ice collection mission that was conducted at the launch field.

Figure 1-1: CRW 2020 Team and *Baedor*

2 Vehicle Summary and Results

The vehicle, *Baedor,* was a 6 in. nominal diameter, 136 inches in. long rocket. The vehicle was constructed of filament-wound G12 fiberglass body tubes and featured a filament-wound fiberglass 4:1 ogive nose cone with an aluminum tip, 3D printed ABS fin brackets and G10 fiberglass fins, and CNC machined 6061 Aluminum bulkheads, thrust plate, and centering ring. *Baedor* was powered by an Aerotech L2200G motor. At apogee, the rocket deployed a FruityChutes CFC-18 18 in. elliptical drogue parachute. The main parachute, a FruityChutes IFC-144 144 in. toroidal main parachute, was deployed at 600 ft. AGL.

Baedor's flight was nominal by all accounts, flying stable and straight just after liftoff and continuing to just shy of its target altitude. Both parachutes successfully deployed on time along with the payload, and the rocket landed within the drift radius and under the total flight time requirements. At the time of main parachute deployment, *Baedor*'s payload was deployed from the payload bay and carried to a safe landing, thus completing the launch vehicle's mission.

2.1 Flight Results and Analysis

Due to the COVID-19 outbreak, the Student Launch Initiative event was cancelled. The final flight of CRW's 2020 entry, *Baedor*, was the Payload Demonstration Flight. This flight occurred on March 14, 2020, at an event hosted by Huntsville Area Rocketry Association (HARA). Figure 2-1 shows *Baedor* moments after motor ignition during the Payload Demonstration Flight.

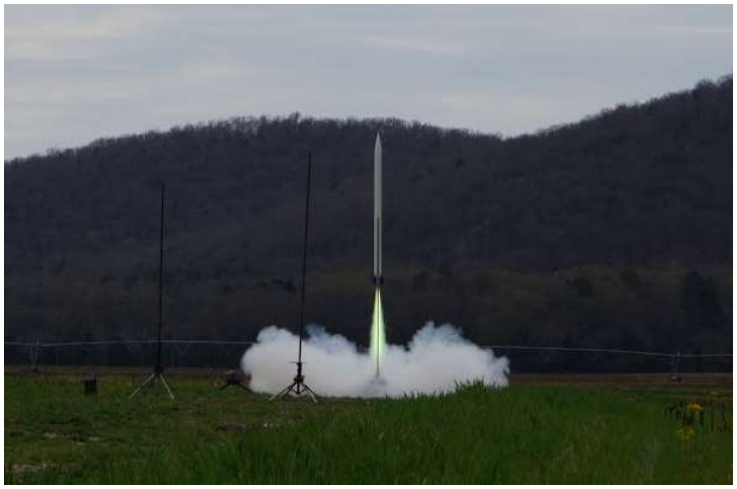

Figure 2-1: Vehicle Following Motor Ignition

The vehicle flew on an Aerotech L2200G motor, targeting an altitude of 4500 feet. The vehicle was launched on a 12 ft. launch rail angled 5 degrees off vertical away from the launch line and crowd, as well as into the wind. At the time of launch the wind speed was measured to be around 5 MPH on the ground. Prior to the flight, after the vehicle had been fully assembled, the final mass and actual center of gravity were measured. The vehicle had a loaded mass of 59.4 lbm. and a measured center of gravity of 81.5in. CRW had previously calculated an estimated drag coefficient, and terminal descent velocities from the results of the vehicle demonstration flight. These values, as well as launch field conditions, were entered into three separate simulations: OpenRocket, RASAero, and a custom MATLAB simulation. Each of the simulations provided similar results, shown in Table 2-1.

Table 2-1: Vehicle Trajectory Simulation Predictions

	OpenRocket	RASAero	MATLAB
Apogee (ft)	4443	4450	4437
Max Velocity (ft/s)	554	560	553
Max Acceleration (g's)	11.03	11.12	11.03
Time to Apogee (s)	16.93	16.89	16.85
Total Flight Time (s)	88.05	87.40	87.85
Thrust/Weight Ratio	8.34	8.33	8.33
Velocity at Rail Exit (ft/s)	68	N/A	N/A

The simulation data showed that the assembled rocket would satisfy all NASA requirements, including velocity at rail exit, total flight time, thrust to weight ratio, and apogee. Additionally, a worst case drift analysis was conducted, modeling a 20 MPH constant and unidirectional wind. Even under these conditions the maximum drift was predicted to be only 2086 feet, also satisfying NASA requirements. After the flight, the location data was collected from the GPS tracker for drift analysis, and the altimeter data from both the primary and backup altimeters was collected and plotted against the simulation data, shown in

Figure **2-2**.

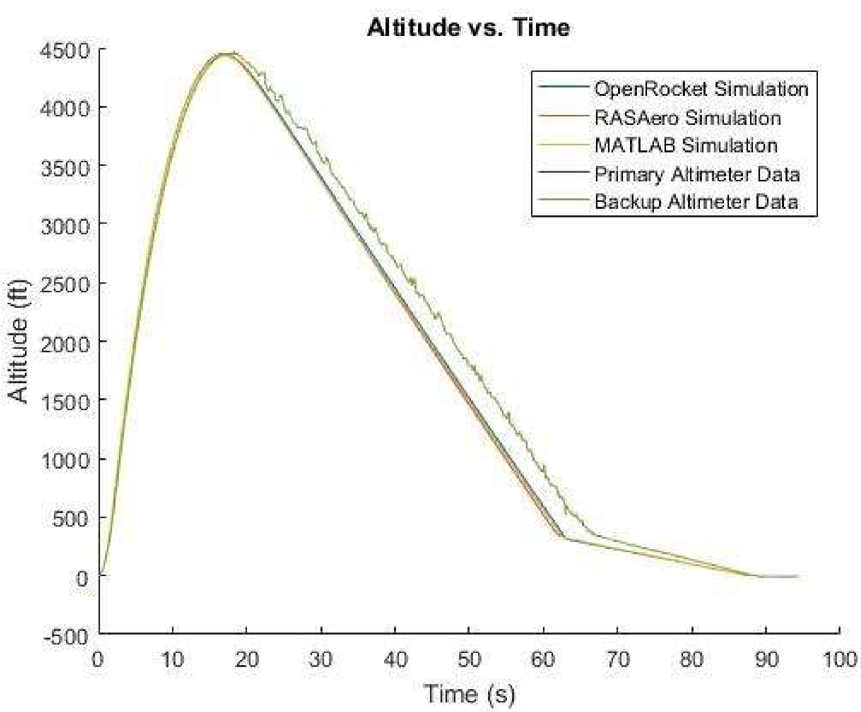

Figure 2-2: Altitude vs Time Plot

The result shows that the actual flight and simulation flight match up very closely. The true apogee reached was recorded at 4454 and 4451 ft by the primary and backup altimeters, respectively, which is very close to both the simulated apogee and official target altitude. The official apogee recorded by a HARA RSO following the launch was 4454 ft., meaning that *Baedor* missed its target altitude of 4500 ft AGL by only 46 ft.

From the location data, the total drift was measured as 1761 ft from the launch rail, which was less than the projected drift, and satisfied the NASA requirement. The only significant difference between the flight data and simulations is in regard to the descent times. The descent time under drogue was slightly slower than expected, and was slightly faster than expected under the main parachute. These errors corrected themselves with respect to the total flight time, as the measured flight time was nearly identical to the simulation data. This total descent time was 71 seconds, falling under the 90 second total flight time NASA requirement.

The team found that there was a discrepancy between the kinetic energy at landing predicted during the FRR and the calculated results based on data collected from the Payload Demonstration Flight. Simulations predicted a terminal velocity under the main parachute of 13.0 ft/s. Using altimeter data from the flight, the terminal velocity under the main parachute was calculated to be 15.2 ft/s. The cause of the increase in terminal velocity is uncertain, considering that the vehicle flew at a lower mass than the previous flight and the main parachute was not changed.

Because the lower airframe was the first independent section of the rocket to hit the ground, it's kinetic energy at landing was the most crucial, as the kinetic energy at landing of all subsequent independent sections reduces. At impact, the lower airframe had a kinetic energy of 61.7 ft-lbf, which is higher than the 57.4 ft-lbf predicted during simulations but is still within the kinetic energy requirement.

2.2 Vehicle Lessons Learned

From the vehicle demonstration flight, CRW learned that many changes had to be made to improve the rocket's performance for the competition. First, *Baedor* was significantly overweight. In order to correct this, the design of all aluminum parts were examined, and most were changed to include larger pockets, reducing weight while maintaining function and retaining the required strength. Additionally, as a result of the Vehicle Demonstration Flight, CRW discovered that the actual shock forces were significantly less than expected, allowing for a change to smaller, lighter recovery hardware. Secondly, CRW learned the rocket had significantly too much drag due to misaligned hardware and fins, gaps between sections, and the absence of paint. Using the experience of building the first rocket, steps were taken to improve the construction of the competition rocket. Improved jigs were designed to ensure alignment of components, a new body key design was implemented to allow for smaller panel gaps, the vehicle was painted, and fins were rounded. All of these changes, while mostly minor, culminated in an idealized version of the vehicle's design and added up to a much better performance. The boost in performance allowed *Baedor* to fly 600 ft higher and therefore reach an apogee very close to the declared target.

3 Payload Summary and Results

The payload was constructed primarily from machined aluminum and 3D printed ABS plastic and the tracks were 3D printed out of NinjaFlex material. The payload, a ground based rover, was capable of traversing a variety of terrain and collecting 10 mL of the simulated moon ice.

During the payload demonstration flight, the payload was loaded into the vehicle after verifying that it was functional. Having shown that all of its systems were working correctly, the payload was connected to the vehicle's recovery harness and stowed in the vehicle per the procedures outlined in the standard operating procedure (SOP). During the flight, the payload was properly deployed from the vehicle and descended to the ground, landing safely. The vehicle landed just outside of the launch field in a patch of thick, tall grass. Despite the non-ideal landing zone, the payload was able to disconnect from the recovery harness and drive two feet away from the vehicle before becoming stuck in the grass. To validate the payload mission, the payload was removed from the landing location and placed on the launch field, which was unplowed. With the payload in the field, the payload was able to traverse to the sample location tarp, collect the ice simulant, and drive ten feet away from the tarp, thus successfully completing its mission.

3.1 Payload Results and Scientific Value

The payload mission was broken down into three stages, which are listed below. Each stage of the mission contains information and pictures of the payload completing that stage of the mission.

3.1.1 Flight and Landing

Upon deployment of the main parachute, the payload also deployed from the vehicle; however, it remained secured to the recovery harness until landing. Figure 3-1 shows the payload connected to the recovery line while the vehicle is under the main parachute.

Figure 3-1: Payload Connected to Recovery Harness during Flight and at Landing

After the payload landed, the payload was visually examined for damage prior to operating. The only notable damage taken during flight or upon landing was a bent outrigger. The outrigger was not a mission critical element and it being bent did not stop the payload from operating as intended. The payload was able to separate from the recovery line shown in Figure 3-1, once on the ground, and drive away.

It is worth noting that CRW had to collect and move the payload upon recovery. Unfortunately, although the vehicle and payload were recovered within the acceptable range, they landed in neighboring property on the other side of a large body of standing water. After confirming that the payload was able to separate from the recovery harness as designed and begin to drive under its own power without intervention, the team collected the payload.

3.1.2 Payload Mission

Once the payload proved that it could separate from the main recovery harness, as intended, and drive away from the vehicle, the payload was transported to back to the farm field. While the field was unplowed, it offered a good comparison to the expected terrain at the official launch site. The payload was placed on the ground approximately fifty feet away from the ice collection site. To complete the mission, the payload was driven, via remote control, to the ice collection tarp as shown in Figure 3-2. While driving, one of the payload's tracks appeared to be loose, most likely due to excessive wear encountered during testing; however, it did not cause any issues with payload operation.

Figure 3-2: Payload Traveling to Ice Collection Site

The payload was able to successfully reach the ice collection site and when it reached the site, attempted to take an ice sample. To collect the sample, the payload was driven to the ice pile, the scoop was lowered, and then the payload drove across the ice pile until the scoop was full as shown in

Figure 3-3. After filling the scoop with ice, the payload closed the scoop and backed away from the tarp a total distance greater than ten feet.

Figure 3-3: Payload Scooping an Ice Sample

3.1.3 Payload Mission Results

After completing the payload mission, the ice sample was emptied from the payload and measured. The payload was able to collect 25 mL of ice, which far exceeded the required 10 mL of ice. Figure 3-4 shows payload next to a 25 mL graduated cylinder full of ice. Having been able to release from the vehicle, traverse a farm field, and collect more than the required amount of ice, the payload mission was deemed successful.

Figure 3-4: Payload with 25mL of Collected Ice

3.2 Payload Lessons Learned

Notwithstanding the overall success of the payload mission execution, there are a few useful takeaways. These provide an analysis of the benefits of the flight-day design and well as those aspects of the design which, while they performed well, could use improvement. This is meant to allow the payload team to put the best possible design forward and ensure consistent, repeatable results.

3.2.1 Notable Successes

The battery selection proved to be valuable in terms of functionality and peace of mind. The lengthy weather delays necessitated that the rocket system be in a ready-state, minus propellants, such that it could be launched at the first sign of a break in the rain. Because of this, the payload had to be in stand-by for several hours, and then function properly for the designated mission time. Because of the safety factor in choosing battery size, this posed no difficulty and instilled confidence that the rover would function at peak performance.

The scoop design was also highly successful, as it allowed collection of more than double the required volume of ice. Once again, it was a design choice made to trade 'peace of mind' or ease of use for the minimalist weight-centric approach, so there would be no trouble achieving success in this area. The improved geometry change at FRR proved to be a better fit, and was less taxing on the servo motors.

Placement of a through-rod along the load path of the recovery harness, another test-related modification, performed well. There was no visible damage to the rod or to the ABS cover pieces, despite the large snatch-load endured during chute deployment.

Along the same lines of safety factor was the frame design, which was intended to be sturdy enough to handle the aforementioned snatch loads as well as a variety of landing scenarios. The side and chassis plates remained in almost new condition throughout the rigors of the launch and ensuing mission, augmenting the durability claims made at the FRR and demonstrated through testing. There was a deformation along one edge of the chassis plate due to an impact against the eye bolt of the cage bulkhead, but this was entirely cosmetic.

The rover concept as a whole was highly successful, and allowed for a variety of terrains and launch conditions to be overcome. In conjunction with the design decisions to prioritize safety factors in loadings and mission criteria, this resulted in a durable, consistent, and safe design.

3.2.2 Notable Areas for Improvement

The Ninja-Flex tracks performed well in the test process as well as on launch day. The aggressive tread pattern improved ground clearance and allowed for a variety of difficult obstacles to be crossed without difficulty. They did, however, appear loose during operation on launch day. This suggests that the pre-launch checks consisted of enough fatigue loading to cause minor plastic deformation in the tracks. This can be combated through use of newly-printed, unused tracks on launch day, as well as some strengthening measures. Along the lines of this latter point would be a more inelastic material, such as cord or string, woven through the circumference of the tracks.

Outrigger performance was also good. The rover was tilted from upright upon landing, which was perhaps a function of the thick grass in the area as well as the lateral velocity at landing. The arms appeared to serve their purpose in preventing the rover from being entirely on its side. One of the arms was severely bent, although it did not have any visible dirt or other grime on it to indicate it was embedded in the ground. It is theorized that it was caught for a moment in the recovery harness and bent as a result of one of the snatch loading scenarios. This could be the load from either of the chutes opening, or of the payload harness coming taught after falling from the cage.

The landing zone posed some challenges due to the presence of very thick grass as well as a small creek which had to be crossed. The operation of the rover in grass was tested and documented pre-FRR, and was noted to be difficult. The rover's ability to traverse relatively deep water features was discussed and planned for, but it was decided to not risk an electrical short in favor of terrain more representative of the launch field. During the mission demonstration as well as post-launch, the payload successfully crossed a series of puddles, further demonstrating its capability. Possible changes to be made would involve water-proofing critical electrical components, especially circuit boards, and sealing contacts on the battery and other devices to prevent a short circuit. To be able to operate in thick grass, the aforementioned modification to the tracks would allow for better rigidity when navigating more taxing, strenuous terrain. It should be noted, however, that the latter terrain is not common on most launch fields, and therefore is a minor concern. Furthermore, neither obstacle is present on the moon, and so would not be a concern for a realistic sample recovery.

4 STEM Engagement Summary

The team impacted a total of 629 individuals at the conclusion of the competition. This exceeded the competition minimum requirement of 200 individuals. The CRW team's goal was to promote STEM to diverse groups throughout the competition. This was achieved through multiple events held since the beginning of the competition. The team was especially proud of the event held at Riverton Intermediate School. The team led a presentation on basic rocketry concepts to a few middle school classes. Then the team engaged the students in a hands on activity in which water rockets were launched with varying levels of water and air pressure. The students were able to observe the effects of the variables that were changed on the height of the rocket's flight. The CRW team received very strong feedback from the class. A full list of the events held by the team can be found in Table 4-1.

Table 4-1: STEM Outreach Event Summary

EVENT	DATE	PURPOSE	INDIVIDUALS ENGAGED
FIRST Lego League Qualifier	11/6/19	Interact with parents and students	100
FIRST Lego League	12/7/19	Interact with parents and students	97
Gretna Middle School	12/17/19	Present Rocketry Basics	20
Science Olympiad	2/15/20	Interact with parents and students	150
AIAA Paper Airplane Competition	2/21/20	Interact and help students	35
Riverton Intermediate School	2/28/20	Present Rocketry Basics	50
Tuscaloosa Academy	2/28/20	Lab Tour	27
STEM Fair	3/3/20	Interact with students	150
		Total Impacted	629

5 Budget Overview

With the conclusion of this year's USLI program, the final costs are available for a budget analysis. Since FRR, several purchases were made outside of the budget projections to facilitate both demonstration flights as well as provide for possible failures via surplus materials. To facilitate a PDF before the deadline, 2 L2200 motors were purchased in addition to various hardware to construct a suitable launch rail given the potential need to conduct a PDF launch in Samson, AL where a large enough launch rail was not available. Additionally, raw materials were purchased to construct a replacement launch vehicle and payload in the event of a catastrophic failure during the PDF launch. While these replacements were fortunately not necessary, the final cost of the program was brought to $7407.19. This is $1475.19 more than the FRR total of $5932.00, but still falls well under the $9193.00 of total available funding.

A categorized breakdown of the projected and final costs for the program can be viewed in Table 5-1. Here the launch vehicle subsection was the main portion of the final costs, due to the inherent costs of body tubes and motors. This could greatly be reduced in the future if CRW could complete implementation of the X-Winder to make in house body tube sections. Figure 5-1 further illustrates the breakdown of different subsections within the final total cost. Since FRR, total funding has not changed, with a total of $9193.00. Originally, it was intended that the residual funds would be used to purchase valuable tools and materials for the next USLI team, however with the closure of UAH campus facilities to students due to COVID-19 these funds will be left to the discretion of the team's professor for next year's program.

Table 5-1: Projected and Final Costs Breakdown

Section	Projected	Final
Subscale Vehicle	$940.30	$940.30
Full Scale Vehicle	$3,236.41	$4,408.16
Payload	$725.55	$1,802.73
Administrative	$256.00	$256.00
15% Margin	$773.74	-
Total	$5,932.00	$7,407.19

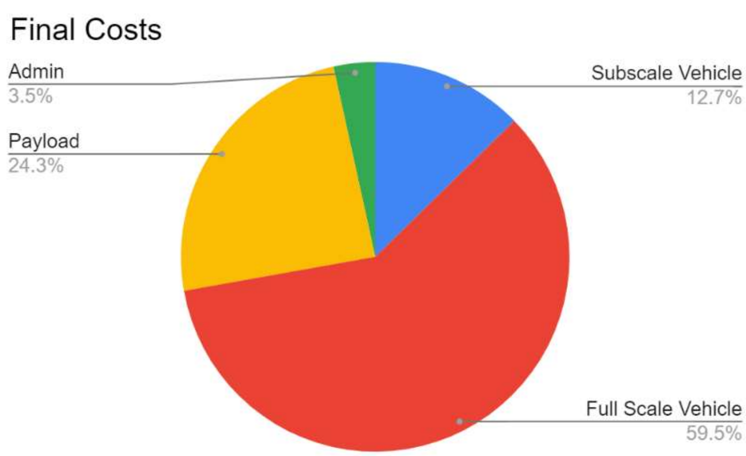

Figure 5-1: Final Cost Breakdown

6 Conclusion

In order to meet all goals, the UAH CRW team this year put an unprecedented amount of time and effort into this project, totaling over 3000 man-hours, which breaks down into an average of 150 hours for each student involved. The vehicle team used this time to design and manufacture a vehicle that came within 50 feet of its target altitude, which for the competition would have resulted in the highest possible score. The payload team created a rover more than capable of meeting all mission requirements. The management and safety teams ensured that budget and schedule were adhered to and that all work was done in a safe and orderly fashion. UAH CRW completed all requirements and met all deadlines given by NASA; and, before COVID-19 changed competition rules, had completed the Payload demonstration flight and created a video demonstration of the payload. UAH CRW was 100% compliant on all NASA and derived requirements and also stayed well within budget. UAH CRW also managed to reach over 600 individuals with various outreach programs throughout the year. This project was challenging but taught many valuable lessons and helped develop many skills that will be invaluable as students transition into the workplace.