NASA Student Launch

2017-2018

Post Launch Assessment Review (PLAR)

April 27th, 2018

Table of Contents

1 Vehicle Assessment ... 3
1.1 Vehicle Summary ... 3
1.2 Flight Summary ... 3
1.2.1 Data Acquisition and Analysis ... 4
1.3 Lessons Learned ... 6
1.3.1 Motor Packing ... 6
1.3.2 Pressure Test Altimeters ... 6
1.3.3 Prepare for the Worst ... 6
1.3.4 Ensure the Vehicle will not Exceed 5,600ft ... 7
1.3.5 Fail-safe Advanced Retention and Release Devices ... 7
2 Payload Assessment ... 7
2.1 Payload Summary ... 7
2.2 Payload Results and Visual Data Observed ... 8
2.2.1 Results ... 8
2.2.2 Visual Data Observations ... 8
2.3 Data Analysis ... 10
2.4 Scientific Value ... 10
2.5 Lessons Learned ... 12
2.5.1 Design Improvements based on Results ... 12
2.6 Summary of Experience ... 13
3 Educational Engagement Summary ... 13
4 Budget Summary ... 14

1 Vehicle Assessment

1.1 Vehicle Summary

For the competition flight, the launch vehicle stood 139 inches in height, weighed 52.4 lbs. fully loaded, and flew on an Aerotech L2200 motor. The vehicle consisted of 4 airframe sections and a parabolic nose cone. A separation event at apogee decouples the vehicle into two independent sections: the payload segment, and the booster segment. Both the nosecone and the coupler separate from their respective airframe counterparts during main deployment and be recovered under the drogue parachutes as independent sections. These two drogues acted as pilot parachutes for each respective main parachute. An OpenRocket model of the competition launch vehicle are shown below in Figure 1.

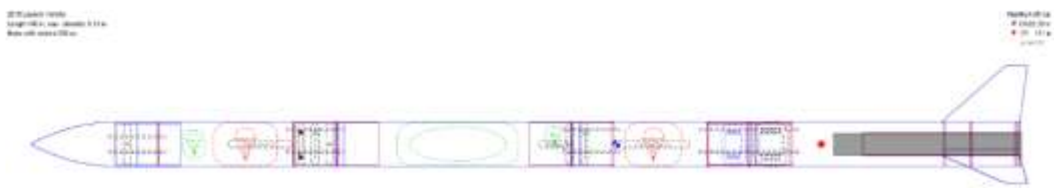

Figure 1: OpenRocket model of the competition launch vehicle.

To verify that the flight of the launch vehicle would occur in a safe manner, OpenRocket simulations were conducted. Several flight characteristics of the fully ballasted launch vehicle in 10mph winds are shown below in Table 1.

Property	Value
Exit Rail Velocity (ft./s)	87.7
Stability Margin at Rail Exit (cal.)	2.76
Maximum Acceleration (ft./s^2)	410
Maximum Velocity (ft./s)	637

Table 1: FLight Characteristics Summary.

To estimate the launch vehicle's apogee altitude, OpenRocket simulations were conducted in various weather conditions. The results of the OpenRocket simulations are shown in Table 2.

Wind Speed (mph)	Apogee Altitude (ft.)
0	5,159
5	5,151
10	5,129
15	5,098
20	5,058

Table 2: Estimated apogee altitudes of the competition launch vehicle.

1.2 Flight Summary

Upon ignition of the motor, an unusual smoking occurred for approximately 9 seconds. This smoking of the motor was not observed in any of the previous launches of the vehicle and will be further discussed in 1.2.1. Once the motor fully ignited, the vehicle exited the launch rail stably and ascended to an apogee altitude of 4,646 ft. An altitude versus time plot of the flight is shown below in Figure 2.

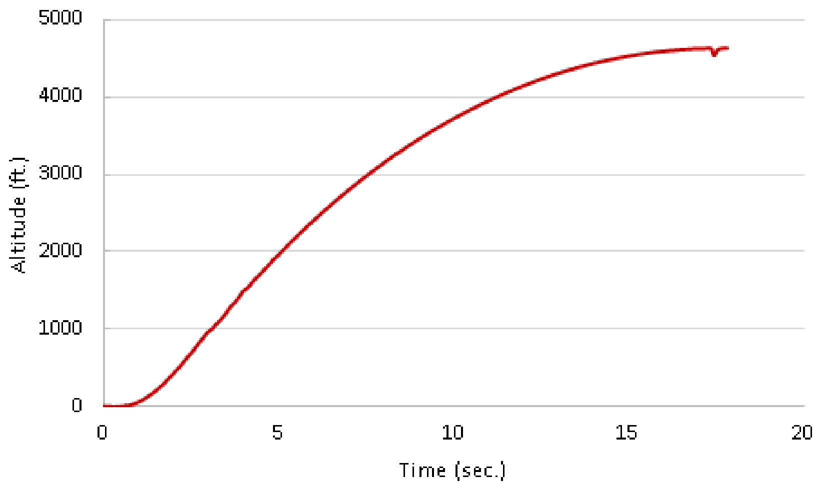

Figure 2: Altitude vs time plot of the competition flight.

Despite the motor anomaly, the ascent of the launch vehicle was nominal. The vehicle flew stably and ascended to apogee with minimal weather cocking and minimal spinning. The recovery of the vehicle occurred nominally apart from an ARRD failure, which deploys the main parachute for the payload section, causing an impact at high velocity. The failure was determined to be caused by pressure venting from the ARRD cylinder through the channel where the e-matches are inserted into the body and is talked about in section 0. The decent speeds are listed and shown below in Figure 3.

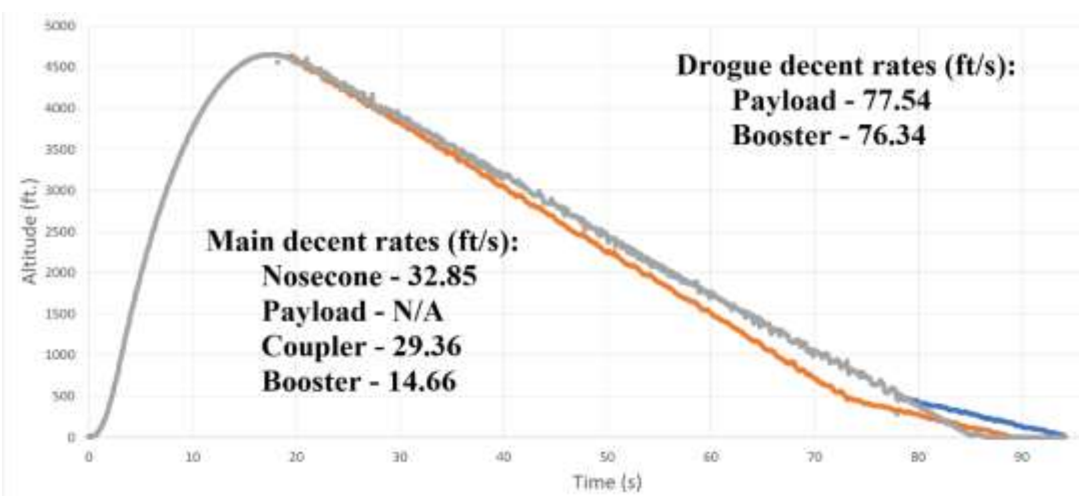

Figure 3: Flight data from StratoLoggers

1.2.1 Data Acquisition and Analysis

The apogee altitude was approximately 500 ft. lower than anticipated, likely due to a motor anomaly outside of the team's control. To test this hypothesis, the thrust produced by the motor was determined from acceleration data gathered during the flight. A thrust versus time curve from the competition flight is shown below in Figure 4.

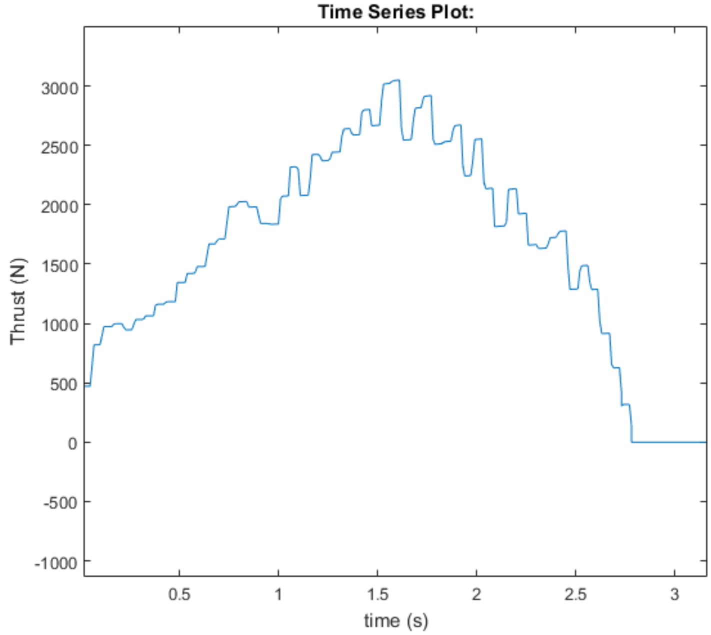

Figure 4: Motor thrust produced during competition flight.

The Aerotech L2200 rocket motors nominal thrust data and the recorded data from the competition flight, is shown below in Table 3.

Characteristic	Nominal	Recorded	Percent Difference
Maximum Thrust	3,114 N	3050.5 N	-2%
Average Thrust	2,200 N	1,814.5 N	-19%
Total Burn Time	2.32 s	2.78 s	18%
Impulse	5,104 Ns	5,044 Ns	-1%

Table 3: Motor thrust characteristics.

The above data provides reason to believe that the motor experienced an anomaly prior to igniting on the pad which resulted in an apogee altitude reduction.

The Variable Drag System (VDS) did not utilize its drag blades however its BMP280/BNO055 data acquisition functionality was active during the competition flight and was successfully used for post flight data analysis. The angles of ascent, including the roll, pitch, and yaw of the vehicle as recorded by the BNO55 are shown in Figure 5.

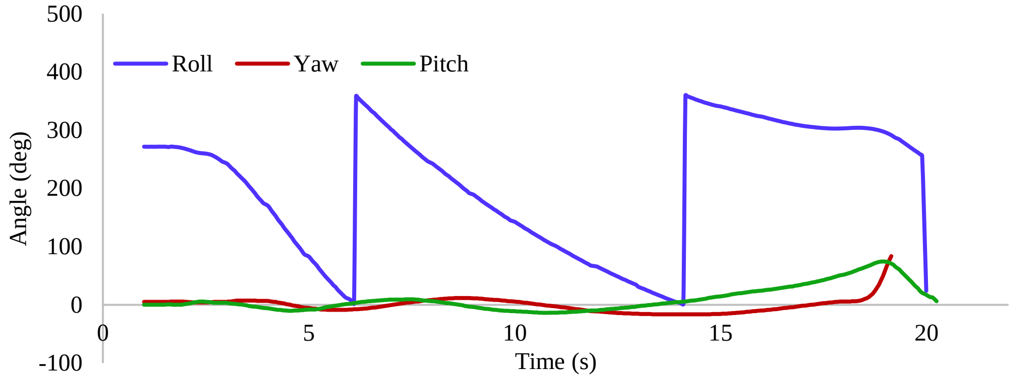

Figure 5: Roll, pitch, and yaw of flight recorded by VDS DAQ system.

The altitude versus time graph as taken by the BMP280 in the booster section of the vehicle is shown in Figure 6. This sensor recorded an apogee altitude of 4,669.5 ft.

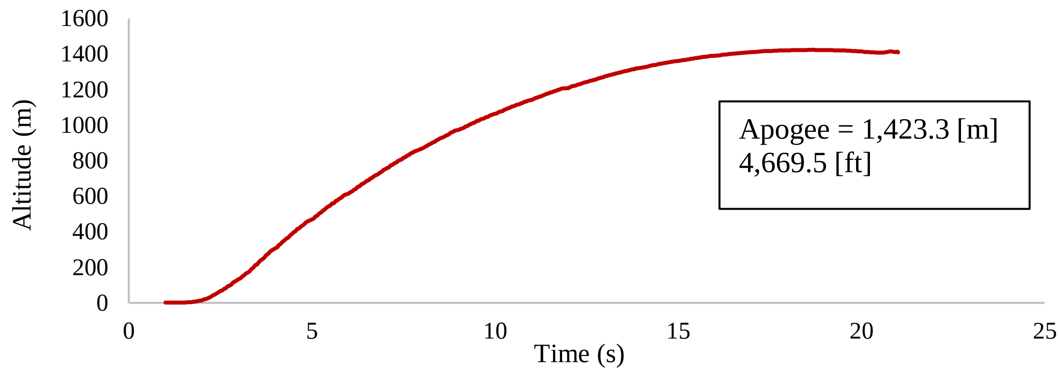

Figure 6: Flight altitude versus time as recorded by VDS DAQ system.

1.3 Lessons Learned

1.3.1 Motor Packing

During the season, the team was present for the packing of 6 Aerotech L2200 rocket motors. The first launch, the motor experienced a catastrophic failure in which the forward enclosure was blown from the casing. The team realized that of the 6 motors purchased, the grains for the 1st flight had come from two different batches. It has sense been learned that it is generally not a good idea to mix batches when packing motor grains.

1.3.2 Pressure Test Altimeters

On the second test launch, the vehicle experienced what was likely an altimeter failure that resulted in a ballistic flight. The altimeters were not pressure tested prior to launch which could have likely prevented such a failure. In the future, all altimeters responsible for vehicle separation events will be required to have been recently tested before flight.

1.3.3 Prepare for the Worst

After experiencing two catastrophic vehicle failures, it became evident that the team should always prepare for failure so that if failure does indeed happen, a plan for recovery is in place. With the team's current resources, backup airframe should be manufactured prior to any test launch so that in the event of a ballistic flight, the rebuild is quicker.

1.3.4 Ensure the Vehicle will not Exceed 5,600ft

This past season, the team conducted two successful test launches to qualify for competition, however they each resulted in apogee altitudes greater than 5,600ft. This meant that the team had to launch again to qualify for competition. Had the team ensured that the vehicle not exceed 5,600ft on either of the prior launches, an extra trip to Virginia to launch would not have been necessary. In the future, the team will ensure that no vehicle will exceed 5,600ft.

1.3.5 Fail-safe Advanced Retention and Release Devices

The competition launch ended with a failure in the payload main's deployment. The failure was determined to be caused by pressure venting from the ARRD cylinder through the channel where the e-matches are inserted into the body. The lack of pressure failed to force the piston upwards and subsequently the drogue was never released to act as a pilot parachute for the main. For all future flights, the e-matches will be inserted into the body of the ARRD and the hole sealed with hot glue and wrapped twice in heavy adhesive tape. This procedure has been added to the safety manual.

2 Payload Assessment

2.1 Payload Summary

The experimental payload onboard the launch vehicle was an autonomous rover capable of being deployed remotely and performing an autonomous mission after landing. The payload featured a robust locking mechanism, orientation correction system, lidar based obstacle avoidance, and surface imaging capabilities triggered by the power generation of an onboard foldable solar array for collection of scientific data. An image of the flight payload before final integration is shown below as Figure 7.

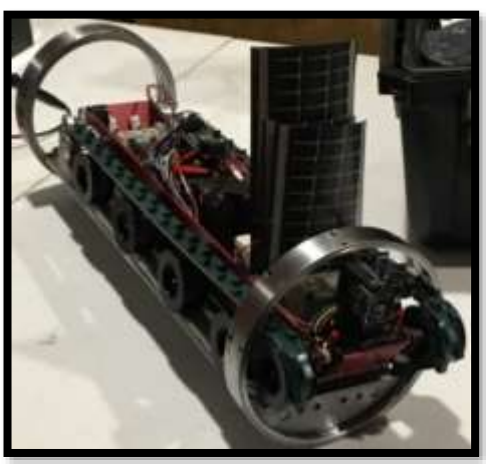

Figure 7: Flight ready payload.

2.2 Payload Results and Visual Data Observed

2.2.1 Results

The payload successfully retained the rover inside the launch vehicle throughout the flight and oriented the rover upright at landing at safe-to-deploy pitch and roll angles. However, during the hard landing of the payload bay under only the drogue parachute, the magnetic connectors that were used to connect the Deployment Trigger System's (DTS) receiver module to the rover's control board became and remained disconnected. Additionally, the solar tower disengaged from the latch that held it in the stowed position to deformation in the PLA material of the base at the spring hinge mounting screws caused by the hard landing. These factors prevented the rover from deploying from the vehicle once the deployment signal had been sent.

2.2.2 Visual Data Observations

Prior to any interaction with the payload bay, the rover was observed from the open end of the bay from which the rover was intended to exit. The rover was shown to be angled at 26° along the roll axis as shown in Figure 8.

Figure 8: Rover landing orientation.

Based on the tipping analysis described in the CDR document section 5.1.29, this was well within the orientation that would allow the rover to deploy successfully and continue its mission.

Closer inspection revealed that the servo horn to which the lidar/camera mount was secured had snapped upon impact as shown below in Figure 9.

Figure 9: Broken servo horn.

The rover's controls had a condition to account for damage such that if the system recognized faulty data from the sensor, the Obstacle Avoidance System (OAS) would be ignored for the remainder of the drive phase of the mission. The rover would have been able to complete its mission despite this broken mount.

The power switches were still in their proper "ON" state and the program was still running which was indicated by the LED on the Control Electronics System (CES) PCB. The light color, a purple-blue, indicated that it had not yet recognized the deployment signal.

2.2.2.1 Interaction with the Payload Bay

After preliminary visual inspections, the airframe section was rotated and examined for damage. Two large cracks propagated from the open end of the payload bay along the airframe section as shown below in Figure 10.

Figure 10: Payload Bay fracture.

The deformation of the bay caused by this fracture was not significant enough to impact the rover exiting the airframe.

The bay was then taken back to the team prep area and systematically disassembled. The payload recovery bay coupler was removed revealing the disconnected magnetic connectors for the DTS as shown in Figure 11.

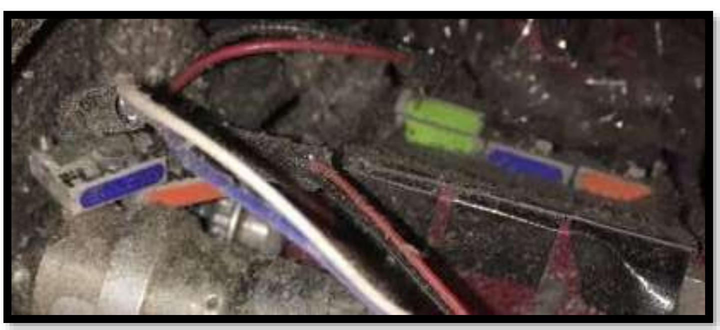

Figure 11: Disconnected magnetic connectors.

The orange and blue connectors shown in the image were the DTS power and communication lines respectively. Both sets of connectors disconnected resulting in the deployment signal not being received by the rover CES.

The payload was removed from the airframe to inspect it further for any damage. At this point it was recognized that the solar tower had disengaged from the latch holding it in the stowed configuration. All other components and systems of the payload including the orientation correction system and locking mechanism remained undamaged and fully functional.

2.3 Data Analysis

The Control Electronics System (CES) had been configured to log key steps of the mission as they were reached and information about the system such as the orientation of the rover at landing for the orientation check. Viewing this log confirmed that the deployment signal never reached the rover due to the disconnected magnetic connectors. The log for the flight vs a typical mission log is shown below as Figure 12.

Competition Log

Time	Action
10:8:3	>>Setup Complete
10:8:3	>>Enter DTS Phase

Typical Mission Log

Time	Action
20:47:45	>>Setup Complete
20:47:45	>>Enter DTS Phase
20:47:54	>>Packet Received: RCRdeploy
20:47:54	>>Rover Deployment Signal Recognized
20:47:54	>>Enter Orientation Check
20:47:55	>>Sums: Y28=-10.62, Z28=-50.62, Y29=-10.62, Z29=-50.62
20:47:55	>>Avgs: Y28=-1.06, Z28=5.06, Y29=-1.06, Z29=5.06
20:47:55	>>Orientation Check Passed. Pitch: -1.06°, Roll:5.06°
20:47:55	>>Attempt to Unlock RLM
20:47:57	>>RLM Unlocked
20:47:57	>>Attempt to Exit Bay
20:48:14	>>Exit Bay Complete
20:48:14	>>Drive Phase Initiated. Attempting to drive at least 5 feet
20:48:22	>>Object Detected
20:48:39	>>Turn to 131 degrees on local polar frame
20:48:39	>>Start Yaw: 356, Degrees to Turn: 41
20:48:44	>>Turn Complete
20:48:51	>>Drive Phase lasted 36.62s
20:48:51	>>Drive Phase Complete
20:48:52	>>Attemp to Unlock Array
20:48:54	>>Array Unlocked
20:48:58	>>Array Unfolded
20:48:58	>>Enter Camera Phase
20:48:59	>>Generation: 29580.84
20:48:59	>>Battery Voltage: 3.09V
20:49:9	>>Image 777 taken

Figure 12: Competition log vs typical mission log.

The rover did not record any lidar, solar power generation, or image data due to not reaching those respective phases of the mission.

2.4 Scientific Value

After completing root cause analysis of the failed mission, the payload was reset to its pre-flight configuration to be put through a mission as if nothing had malfunctioned while still having the true launch site conditions. The rover was oriented in the bay at the same roll angle (26°) that it had been at the time of recovering the bay from the landing site. The deployment signal was then sent to initiate the payload's mission. The rover recognized the deployment signal, passed the orientation check, unlocked the rover locking mechanism and drove off the bridging sled and T-slot. The rover exited the bay and continued traversing the farmland terrain. While driving, three of the passive wheels and corresponding bearings that were used to guide the drive tread dislodged from their housing. The rover is shown traversing the farmland in **Figure 13**.

Figure 13: Rover traversing farmland terrain.

The lidar sensor relayed faulty data to the control system as the servo horn could not be repaired prior to this mission test. The system successfully recognized this and ignored the Obstacle Avoidance System. Despite the loss of three passive wheels and the Obstacle Avoidance System, the rover reached a final distance of 12.25 ft. from the airframe as indicated below in Figure 14.

Figure 14: Rover's final distance reached.

The rover then successfully unfolded the solar array and collected enough energy to initiate the Surface Imaging System (SIS). The camera module was held by a team member in the position the camera would have been in had the servo horn not broken. The system took and stored 12 images before powering down. Two of the images showcasing the landscape are shown below in Figure 15.

Figure 15: Surface Imaging System images taken.

These high definition images would provide great scientific value had this mission been conducted on a foreign planet. The images clearly show the terrain and colors of the landscape around the rover which could be analyzed to determine characteristics of the planet.

Conducting this test mission also confirmed that the tread design and drive system were an effective means of traversing uneven and both soft and hard terrain. The competition flight also confirmed that the design of the orientation correction system and locking mechanism for the payload are effective at their respective operations.

2.5 Lessons Learned

Throughout this project, members of the payload sub-team gained skills in systems engineering, mechanical and electrical design and manufacturing, software development, technical documentation, failure analysis, project planning, and resource allocation. The rover challenge presented an interdisciplinary project requiring cooperation, collaboration, and extensive communication between members of different fields of engineering.

2.5.1 Design Improvements based on Results

Based on the results of the full-scale flight at competition, improvements to the design of the payload have been determined.

2.5.1.1 Solar Tower Latch

Options for improvement of this design include designing a new latching mechanism to better account for all degrees of potential freedom of the tower assembly, or a different material for the tower base to mitigate the possibility deformation after higher impact loading. An additional latch would be added for redundancy to increase the probability of mission success.

2.5.1.2 Magnetic Connectors

The magnetic connector method would be improved to ensure the connection would not break prematurely. Improvements to the design would include a new method to maintain the connection while still allowing the wires to disconnect, or developing a new method of mitigating the issue of carbon fiber impeding RF transmission and reception that does not require the connectors to disconnect. One such change would be the addition of a plate that would snap into the existing 3D printed motor mount that would prevent large radial displacement of the connectors.

2.5.1.3 Passive Wheel Bearings

Instead of relying on the press fit of the bearings in their housings, bushings with slip rings would be used to better restrain the wheel shafts. Bushings are also more simple and reliable ball bearings.

2.5.1.4 Rover Orientation Correction System

While the orientation correction system did perform as expected, an active as opposed to a passive system would more accurately orient the rover perfectly upright prior to deployment.

2.5.1.5 Servo Mount

A more robust servo mount for the lidar/camera module would be implemented to reduce the possibility of the mount failing prior to deployment of the rover.

2.6 Summary of Experience

In summary, the experience has provided opportunities for team members that would not be available in a classroom setting. This has provided team members with valuable skills that can be applied to the engineering field and promoted a mindset of continual improvement of design.

3 Educational Engagement Summary

Throughout the course of the entire season, NASA pushes each team to give back to the community in the form of teaching STEM based topics to elementary, middle school, and high school students. As the team learned and developed their own high-powered rocket the knowledge of rocketry was easily transitioned into outreach events that helped spread the STEM initiative.

With NASA requiring a total of 200 students to be reached by the end of the season, the team decided to reach ten times that by setting a requirement of 1,500 student. By the end of our 2017-2018 season, the team had reached a total of 2802 student.

Outreach Event	Number
First Lego League	25
Louisville Area Math Circle	21
MiniMaker Faire	200
Cardinal Preview Day	30
MathMovesU	18
Farmer Elementary STEM Expo	100
Cochran Elementary Science Expo	155
Blast off the Noon year	1488

Kentucky Aerospace Day	15
Engineering Expo with KY Science Center	500
Engineering Expo	250
Total	2802

Table 4: Outreach Totals

4 Budget Summary

Throughout the course of the season the team has monitored our expenses carefully and worked hard to project future costs ahead of time to ensure that we can prevent unexpected expenses and mitigate shipping costs. At the beginning of the year we set a goal of being able to afford all our expenses for the year while still having $10,000 left over at the end of the year to sustain the team through this coming summer and into next year. To do so we acquired funding from the following:

Source	Amount
Remaining Balance	$ 12,300.00
Alumni Donations	$ 20,000.00
NASA Prize Money	$ 5,000.00
Speed School Money	$ 5,000.00
Raytheon	$ 1,000.00
Misc. Donations	$ 200.00
Orbital Stipend	$ 300.00
Total	$ 43,800.00

Table 5: Income

From the table above shows how the team raised a total of $43,800 for the season. This budget allowed us to successful fund the season along with providing us with the necessary money to sustain ourselves. The total expenses for the year have been broken down based on the team divisions and sub-categories. This breakdown can be seen in the table below.

General Team	**$ 8,613.42**	
Outreach		$ 120.86
Team Improvement		$ 545.26
Safety		$ 117.04
General Team Cost		$ 993.19
Travel		$ 6,837.07
Payload	**$ 2,907.95**	
CES		$ 533.80
ROCS		$ 590.98
RDS		$ 1,331.69
OAS/SIS		$ 5.95
SAS		$ 146.95
Rover		$ 2.61
DTS		$ 174.12
RBS		$ 53.92
RES		$ 12.05

OAS		$ 20.90
RLM		$ 34.98
Recovery	**$ 1,634.53**	
Full Scale		$ 1,365.23
Subscale Vehicle		$ 122.80
Testing		$ 146.50
VDS	**$ 1,694.33**	
Level 2		$ 28.88
VDS 3.0		$ 923.45
Full Scale		$ 100.00
Telemetry		$ 200.09
VDS PCBs		$ 116.06
VDS 3.0 Remake		$ 325.85
Vehicle	**$ 5,310.51**	
Level 2		$ 29.95
Vehicle		$ 2,419.63
Subscale Vehicle		$ 176.83
Full Scale Vehicle		$ 2,182.97
Vehicle Tracking		$ 149.99
Testing		$ 27.49
Full Scale Rebuild		$ 323.65
Total	**$ (20,160.74)**	

Table 6: Team expenses.

The the team spent a total of $20,160.74 as shown in Table 6. These expenses are significantly lower than the projected expenses listed at the beginning of the year. This is due to finding solutions throughout the year on how to manufacture more ourselves, saving money on manufactured goods. This can be better seen in Table 7.

Budget Results			
Category	Budgeted Cost	Real Cost	Percent Difference
General Team	$ (17,803.41)	$ (8,613.42)	106.69%
Payload	$ (4,406.80)	$ (2,907.95)	51.54%
Recovery	$ (1,453.00)	$ (1,634.53)	-11.11%
VDS	$ (2,268.56)	$ (1,694.33)	33.89%
Vehicle	$ (6,542.18)	$ (5,310.51)	23.19%
Total	$ (32,473.95)	$ (20,160.74)	61.08%

Table 7: Budget results.

From the data in the table above, you can see we came in significantly below the projected budget for the season, leaving the team with $23,639.26 that will carry over and sustain the team.