OREGON STATE UNIVERSITY

2018 NASA SL TEAM

104 KERR ADMIN BLDG. # 1011

CORVALLIS, OR 97331

Post Launch Assessment Review

April 26, 2018

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Acronym Dictionary

ARRD Advanced Retention and Release Device. 12

HDPE High-density polyethylene. 9

NASA National Aeronautics and Space Administration. 11

PCB Printed Circuit Board. 11

PLEC Payload Ejection Controller. 11

RDO Range Deployment Officer. 11

USLI University Student Launch Initiative. 3

1 Project Summary

1.1 Team Summary

Table 1: Team Summary Chart

Team Name	Oregon State Rocketry Team
Mailing Address	104 Kerr Admin Bldg #1011 Corvallis, OR 97331
Name of Mentor	Joe Bevier
NAR/TRA Number, Certification Level	NAR #87559 Level 3, TRA #12578 Level 3
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The Oregon State Rocketry University Student Launch Initiative (USLI) Team successfully designed, launched, and recovered a launch vehicle carrying a deployable rover payload to 3332 ft. above ground level. The mission of the launch vehicle was to deploy an autonomous rover from the internal structure of the launch vehicle. After moving 5 ft. from any section of the launch vehicle, the rover was to deploy solar panels.

Figure 1: Team Photo

2 Launch Vehicle Summary

The launch vehicle was powered by an Aerotech L850W motor and is made from two sections of 5.2 inch carbon fiber tubing with a fiberglass section for RF transparency. The nose cone is made of fiberglass and follows a 4:1 ogive profile. The fins are made from a sheet of G10 fiberglass with four plies of unidirectional carbon fiber and one ply of carbon fiber weave on both sides. The launch vehicle is recovered in two sections, both using a single event dual deployment system.

Figure 2 shows an OpenRocket model of the launch vehicle. The launch vehicle is designed in two recoverable sections. The aft section contains the motor as well as its own tracking and recovery systems housed above the motor. The fore section contains a tracking system in the nose cone, its own recovery system, and the payload at the end. A single compartment is used for both recovery systems, and Jolly Logic Chute Releases keep the main parachutes closed until they open at 1000 ft.

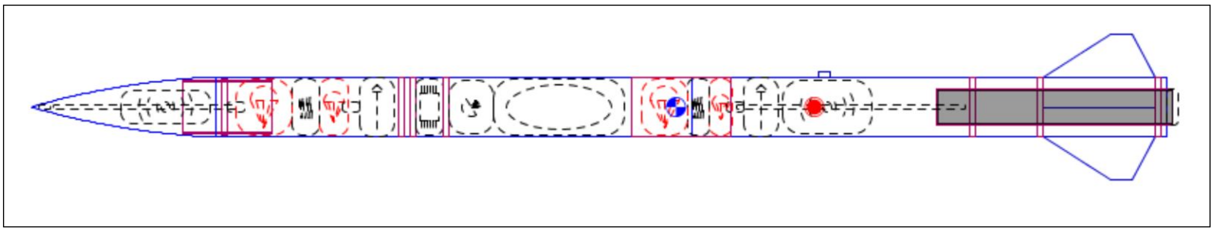

Figure 2: OpenRocket Model of Launch Vehicle

Figure 3 shows the built launch vehicle. At competition it was 102 inches long and weighed 39.5 pounds. The launch vehicle was launched from a 12 foot 1515 rail.

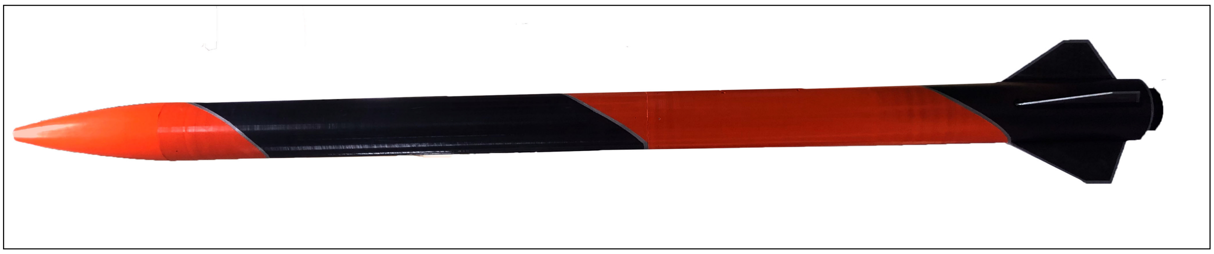

Figure 3: Completed Launch Vehicle

3 Competition Flight

3.1 Summary of Competition Flight

The competition flight was almost fully successful with two failures. Both sections drifted just outside of the allowable drift radius, and the rover was not successfully deployed. All other NASA and team derived requirements were met.

The other concern from the flight is that the motor appeared to be underpowered, like our second full-scale flight. The rocket was stable off the launch pad but began wind cocking while coasting to apogee. The rocket reached an altitude of 3355 ft. which was 1527 ft. lower than expected and 1948 ft. lower than the target altitude. In addition, the maximum velocity was 132 ft./s lower than expected. This is attributed to low initial thrust and poor-quality control of the L850Wmotor selected. The rocket off the launch pad is shown in Figure 4

At apogee, there was a successful separation of the two recovery sections and successful deployment of both drogues.

Figure 4: Competition Launch

The fore section main parachute opened as expected, but the descent rate under main was slower than in both previous flights and simulations. It drifted out of the allowed area to the edge of a group of trees. It was found 2572 ft. away tangled in a tree about 15 ft. off the ground, but damage to limbs above where it was found suggested it bounced off a couple higher trees before coming to rest. The fore section can be seen where it was found in Figure 5. The main parachute had a few large tears that will have to be patched before it can be used again.

Figure 5: Landed Fore Section

Figure 6: Landed Aft Section

The aft section had its main parachute slip out of the Jolly Logic Chute Release at around 1900 ft., 900 ft higher than expected. It drifted past the fore section where it landed high in a tree next to a swamp where the land owner of Bragg Farm was. According to him, the wind pulled the aft section out of the tree and it landed in the swamp, 3511 ft. away from the launch pad, where it was easily recovered. The aft section can be seen where it was found in Figure 6. There was no damage to any of the components.

3.2 Analysis of Competition Flight

Analysis data is based on the four barometric altimeters used for recovery and the two GPS tracking systems. A summary of the ascent, descent, and landing kinetic energies are provided in Tables 2, 3, and 4 respectively.

Table 2: Ascent Profile Summary

	Fore Altimeters		Aft Altimeters		Average
	RRC3	StratoLogger	RRC3	StratoLogger	
Apogee Altitude (ft.)	3263	3414	3280	3371	3332
Apogee Time (s)	15.65	16.85	15.7	16.55	16.19
Max Velocity (ft/s)	413.6	404.8	420.2	411.6	412.6
Motor Burn Time (s)	4.45	4.45	4.45	4.35	4.43
Rail Exit Velocity (ft/s)	-	72.8	-	62.3	67.5

Table 3: Descent Profile Summary

	Fore Altimeters			Aft Altimeters		
	RRC3	StratoLogger	Average	RRC3	StratoLogger	Average
Drogue Velocity (ft/s)	84.39	82.98	83.69	88.38	85.80	87.09
Landing Velocity (ft/s)	9.39	9.17	9.28	12.66	12.41	12.54
Main Deploy Altitude (ft.)	705	810	758	1882	1977	1929
Descent Time (s)	120.3	121.0	120.6	181.4	183.0	182.2
Drift Distance (ft.)	2572			3511		

Table 4: Landing Kinetic Energies

	Mass (lb.)	Velocity (ft/s)	KE (ft-lbf.)
Motor Section	16.01	12.54	39.12
Payload Section	15.50	9.28	20.75
Nosecone	4.31	9.28	5.77

The fore section altitude and drift are shown in Figure 7. The aft section altitude and drift are shown in Figure 8.

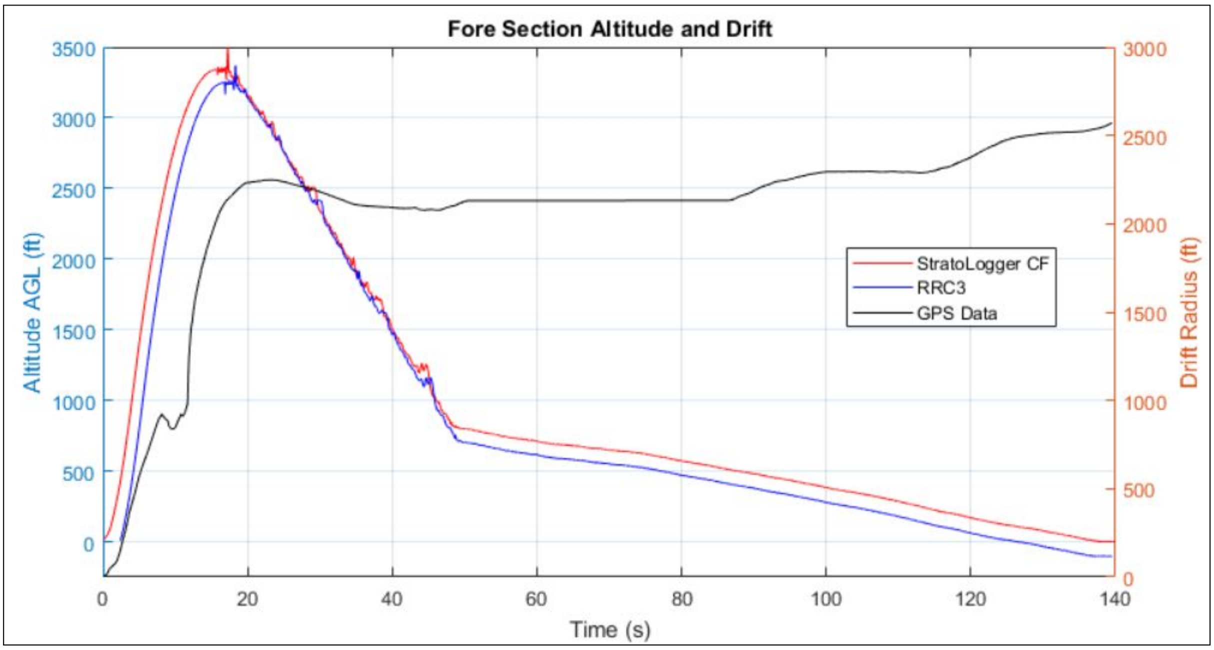

Figure 7: Fore Section Altitude and Drift Profiles

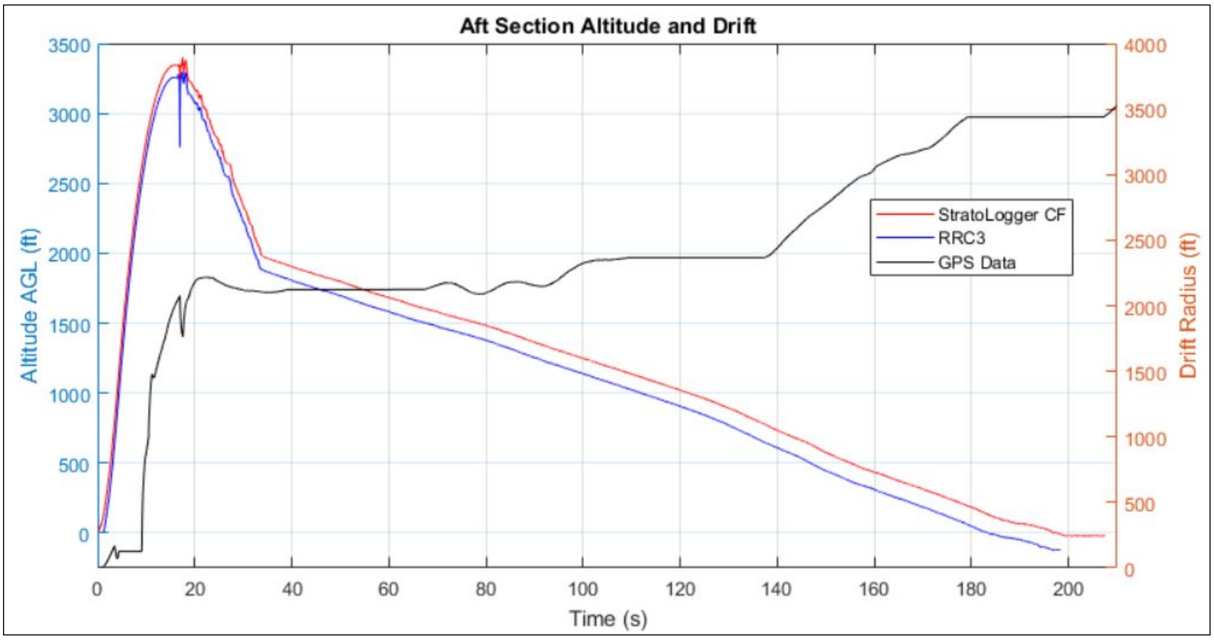

Figure 8: Aft Section Altitude and Drift Profile

3.3 Comparison of Predicted and Actual Flight

A summary of simulated flight characteristics from OpenRocket and a custom MATLAB script, as well as the actual recorded values from all three flights, are reported in Table 5.

Table 5: Comparison of Full-Scale Simulations and Flights

		Open Rocket	MATLAB	FS Flight 1	FS Flight 2	Competition
	Cross Winds (ft/s)	22	22	17	11	15
Ascent	**Apogee Altitude (ft.)**	4882	-	4845	3855	3332
	Apogee Time (s)	8.7	-	19.2	16.8	16.2
	Max Velocity (ft/s)	544	-	521	460	412
	Motor Burn Time (s)	4.40	-	3.30	4.35	4.45
	Rail Exit Velocity (ft/s)	64.7	-	148	61.2	67.5
Fore Descent	**Drogue Velocity (ft/s)**	102	77	N/A	79.15	83.69
	Landing Velocity (ft/s)	13	14.07	12.8	26.66	9.28
	Main Deploy Altitude (ft.)	1000	1000	4845	792	757
	Descent Time (s)	95.3	116.3	513.0	67.7	120.7
	Drift Distance (ft.)	698	853	23582	1790	2572
Aft Descent	**Drogue Velocity (ft/s)**	102	84.16	86.96	90.49	87.09
	Landing Velocity (ft/s)	13	15.16	16.24	12.08	12.54
	Main Deploy Altitude (ft.)	1000	1000	763	843	1929
	Descent Time (s)	95.3	107.6	79.5	94.7	182.2
	Drift Distance (ft.)	698	789	782	1913	3511

The recorded apogee altitude was 1550 ft. lower than expected and occurred 2.5 s earlier than predicted. The maximum velocity was 132 ft./s slower than predicted. All of these are attributed to a faulty and underpowered motor. Recorded rail exit velocity was 3 ft./s faster than simulated for a 12 ft. rail.

The recorded drogue descent velocities were slower than those from OpenRocket by about 22 ft./s, and were higher than the values from MATLAB by 3-6 ft./s. The fore section drogue velocity at competition was 4 ft./s. faster than our previous launch, but the aft section drogue velocity was almost the same as the previous two flights.

The Jolly Logic Chute Releases are programmed to open at 1000 ft., and previous flights have seen the main fully deployed by 800 ft. The fore section main opened at 758 ft. as expected, but the aft section main slipped out of its bundle at 1929 ft., almost 1000 ft. higher than expected. Issues with the Chute Releases not performing as planned has been an issue since the first full-scale flight.

The fore section main velocity was 4 ft./s slower than in the first full-scale flight and simulations, which contributed to the section drifting out of the allowable range. The aft main velocity was 2 ft./s slower predicted from OpenRocket and MATLAB, but almost the same as the second full-scale flight.

Both mains were deployed at landing so that all sections landed well under the allowable energy limitations. The only damage was fixable rips in the fore main parachute, and both sections were found and recovered successfully.

4 Payload

4.1 Summary of Payload

The chosen payload was a rover. The chassis is the assembly at the core of the rover, providing the structure to which each component is attached. As the structure of the rover it provides all of the strength to the system ensuring that it will not be damaged by any forces encountered throughout the flight of the launch vehicle. The drivetrain is central to the success of the mobile rover. Without a robust system that can withstand the immense forces of flight, the large stresses upon landing, and the variability of ejection, the mission cannot succeed. The wheels are made from High-density polyethylene (HDPE) material. The outer diameter wheel has a slot cut in the exterior that is infused with high-density memory foam. The wheel is attached to a steel hub that interfaces with a steel driveshaft. The solar panel system is a two-cell design with one degree of freedom. One panel remains parallel to the ground, while a second panel rotates away from it 180° to be coplanar with the fixed panel. Since the rover only has two wheels, a third point of contact with the ground is necessary for stable driving. These constraints necessitated the development of a folding stabilizer design. Several designs were evaluated for their robustness, simplicity and suitability for the application. The rover is guided by an array of electrical sensors including sonars, 9 DOF IMU, and a microphone array. Information was read and interpreted in a ROS based algorithm which was primarily used for object avoidance.

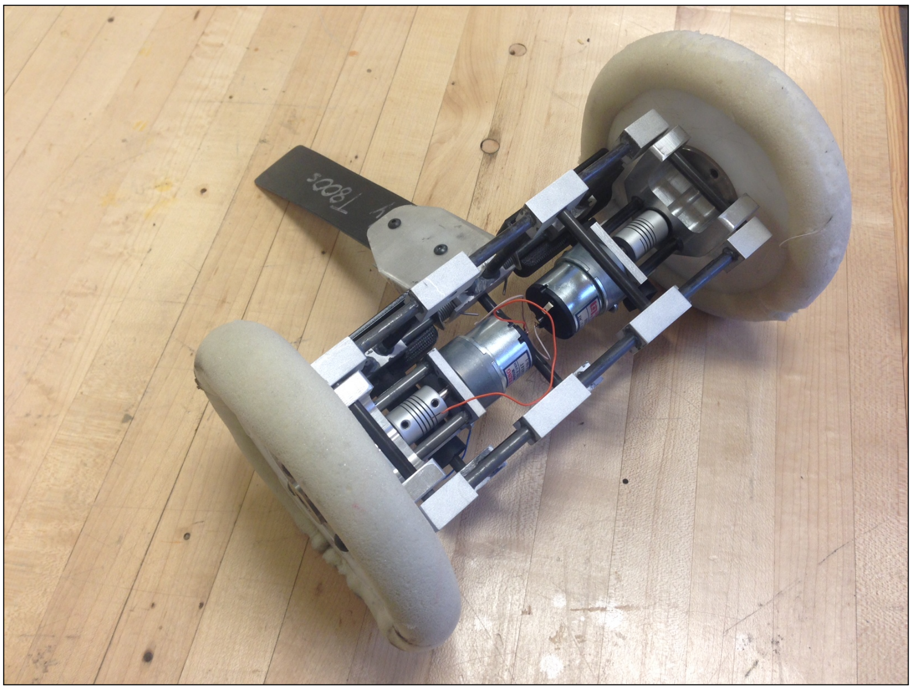

Figure 9: Assembled chassis, drivetrain, and wheels of rover

Figure 10: Rover successfully moving autonomously

4.2 Performance of Payload

After the launch vehicle sections were recovered out of the swamp and trees, the payload section was brought to the Range Deployment Officer (RDO)'s table to eject the rover. The rover would not deploy, and after about 10 minutes of troubleshooting the team exhausted all options and the deployment was considered a failure.

After disassembling the rocket, the rover was removed from its wrap where it was found to be powered on, indicating the Payload Ejection Controller (PLEC) had failed to supply the proper signal to keep it off. The rover was placed on the Bragg Farm soil where it traveled easily for 10 seconds to a distance of about 30 ft. before slowing to a stop and deploying its solar panel.

At the hotel right after the competition the PLEC was inspected and it was found that one of the battery terminals on the Printed Circuit Board (PCB) were loose and the battery was dead. A new battery was attached and the ejection sequence was tested with a multimeter to check the outputs. It functioned as expected, turning on each output long enough and at a sufficient voltage.

Ejection testing prior to competition showed that the charge sizes used were more than sufficient to eject the rover, and the PLEC had worked flawlessly many times in testing with a full battery. Since the PLEC's integration was not considered until the end of manufacturing it had no external power switch, only an external arming switch, and it had to the be the first component in the launch vehicle during assembly. It was turned on around 7:30 am and ejection was not attempted until 6 hours later, which is right at the expected battery life of the system.

5 Scientific Value

The scientific value for this project came from the autonomous rover payload. The mission profile reenacted an unmanned mission to Mars that will become a reality in the upcoming future. Seeing as how there are very few autonomous rovers actually being used on other planets, the project gave unique approaches to the securement, deployment, and design of the rover. Every team differed in some sort of way; these variations are quintessential for helping National Aeronautics and Space Administration (NASA) create the most robust, reliable, and innovative rover.

6 Lessons Learned

As a new team, it was difficult initially to keep up with the amount of required technical and safety documentation, and the actual design of the launch vehicle did not get as much attention as a result. Integration and assembly was not a major factor in the design, and as a result, the launch vehicle was moderately difficult to assemble. In the future, ejection bays will be designed so that they can be one of the last things to go into the rocket. Future teams will also be advised to stay away from the interior threaded rod design, as that caused both assembly and disassembly to be harder than an exterior mounting system.

Checklists were not as strong during the sub-scale and first full-scale launches as they were at competition. Several launches were delayed or had failures that could have easily been prevented with proper checklists and inspection procedures. Future teams will have our current checklist template to use, and since assembly and integration will be factored into the design, checklists will be created early and will develop as the design and manufacturing of the launch vehicle is finalized.

Single compartment recovery using Jolly Logic Chute Releases was selected for the recovery system to keep the number of sections under four while having an open end for the payload at landing, and because it was initially believed that a single compartment system would be simpler and more reliable. Two of the five recovery failures during the project were early main parachute deployments, and both of these are attributed to the parachutes being too large for the Chute Releases to hold. Instead of Chute Releases, a tether such as the Advanced Retention and Release Device (ARRD) or Tender Descender will be used for a single compartment system. Future teams will also be advised to use a two compartment system when possible since they proved more reliable at launched attended and at competition.

Mechanical systems for the rover payload were not completed for a few months, which made testing the electrical systems difficult. This gave the electrical engineers less time to test and develop the final rover and ejection systems and is a major factor in the failure of the rover ejection. For future payloads involving electro-mechanical systems, the team will spend time during the initial design phase building rapid prototypes of mechanical parts for the electrical teams to begin testing with.

7 Summary of Overall Experience

The greatest gain from the project was the experience of working in a large, diverse team for a specific end goal. Many of the team members had experience working in small groups for school projects or as an intern, but this experience of having to work together and take lead in projects was new. The first challenge that was encountered was trying to determine everyone's role for the course of the project. These roles were firmly defined and assumed that they would work for the entire project duration. Very quickly these roles morphed and changed due to an evolving understanding of the project. This division of labor issue evolved over time, but by the end of the project roles had solidified and will be used for next years team. The other challenge for the team was working as an interdisciplinary team. Each of the groups of students had different ideas on how the project was supposed to come together, and these views had to coalesce into a single goal. This experience was useful as all members gained experience working with people with different training and skill sets.

Working with this style of budget and scope directly under the team's control was a new experience for most of the team. Being responsible both for the components of a system and their cost required substantial planning within the group. It also required specific resource allocation for each subsystem based on the expected requirements. Control of the project also required that the team ensured limited scope creep because many of the project's requirements were set by the students. It also provided insight into how long and complicated a project like this can be. For instance, the team needed to scale back its efforts in what to manufacture in-house based on a realization that the scope of the project did not call for it and could not be fit into the schedule. Overall, the team gained a large amount of experience in team building and management and what a project of this style entails.

8 Educational Outreach Summary

In addition to successfully designing, launching, and recovering a launch vehicle and rover, the team created an educational outreach program from scratch. The goal of the outreach program was to engage as many students as possible while keeping the quality of the experiences high. Having no former schools/events from prior teams to fall on, our rookie team set out to establish new connections with nearby schools by building on networking systems and alumni schools. In total, the team reached over nine hundred students from elementary to high school across more than seven different schools spread across five different cities.

By working directly with the teachers, the team was able to send out lesson plans, supply lists, and representatives to coordinate with schools and ensure all proper procedures were followed. The established lesson plans pulled from textbooks, websites, and team members' prior science experiences. Before every engagement, teachers were provided with an array of options to give them a segue in future subjects they would cover or highlight concepts they had covered previously. Once selected, the team gathered supplies and established stations that would be worked on and rotated with for each school event. Students were given a combination of indirect presentation and direct hands-on interaction to ensure optimal learning experiences were had.

By building on former and current knowledge, the team constructed an educational outreach program that was met with enthusiasm by the schools. We have been invited back for future years and believe that the program can only continue to grow from here.

9 Budget Summary

The primary source of funding was from the Oregon Space Grant Consortium, with secondary funding coming from the local AIAA chapter and the College of Engineering. A total of $7,425.34 in capital expenses was spent on the launch vehicle and payload, with $5,433.39 in donations from various vendors. The largest part of the expenses was travel, which was mostly the cost of airfare and hotels for the 24 students that attended the competition. Around $3,500.00 of this year's expenses were tools or components that will be carried over for next year's team.

Table 6: Summary of Funding and Expenses

Funding Source	Project Expenses	Travel Expenses	Total
Oregon State School of Electrical Engineering and Computer Science	$ 246.87	$ -	$ 246.87
Oregon State AIAA Chapter	$ 920.75	$ 1,851.98	$ 2,772.73
Oregon Space Grant Consortium	$ 5,418.24	$ 4,923.32	$ 10,341.56
Vendor Donations	$ 5,433.39	$ -	$ 5,433.39
Student Expenses	$ 839.48	$ 7,975.34	$ 8,814.82
Total	$ 12,858.73	$ 14,750.64	$ 27,609.37