Project Photogator

NASA Student Launch 2023 Post Flight Assessment Review

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Swamp Launch Rocket Team
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1. Flight Summary

1.1 Flight Information

The University of Florida's Swamp Launch Rocket team performed the final competition flight in Huntsville, AL on April 15th, 2023. The results of the flight and flight conditions are shown below (Table 1).

Flight Information	
Flight Vehicle Details	
Motor	Aerotech L1090W
Ballast Flown	N/A
Vehicle Gross Mass (oz)	428
Primary Main Parachute Charge (g)	2.8
Primary Drogue Parachute Charge (g)	1.7
Declared Target Altitude (ft)	4600
Predicted Altitude (ft)	5074
Experimental Altitude (ft)	5073
Descent Time (s)	87.1
Drift Radius (ft)	865
Kinetic Energy (ft-lbs)	66.9
Flight Conditions (Huntsville, AL, 4/15/23, ~11:00 AM CDT)	
Average Measured Wind Speed (mph)	7.5
Average Measured Temperature (°F)	79
Launch Rail Angle (°)	5

Table 1: Flight Information

1.2 Payload Description

The payload consists of three camera systems staggered longitudinally, spaced 120° apart, and aligned with each of the three fins. Each system lies inside the airframe in three rectangular cutouts. The camera in the middle of the three landed vertically, relative to the ground, upon the launch vehicle's landing. The camera system deployed out of the airframe on a spring-loaded hinge, so the camera arm was oriented normal to the ground. The camera rotated on a stepper motor about the z-axis after receiving commands to do so.

2. Vehicle Summary

2.1 Vehicle Dimensions

The dimensions of the vehicle flown were measured and tabulated (Table 2).

Vehicle Dimensions	
Overall Dimensions	
Vehicle Diameter (in)	4.0
Vehicle Length (in)	115.0
Section Dimensions	
Forward Section Length (in)	45.0
Central Section Length (in)	21.0
Aft Section Length (in)	49.0

Table 2: Launch Vehicle Dimensions

2.2 Post Flight Vehicle Analysis

The launch vehicle was recovered without any damage sustained during launch, ascent, and descent. After launch the vehicle was deemed recoverable and reusable. Photos of the launch vehicle after recovery are included (Figure 1, Figure 2, Figure 3, Figure 4).

Figure 1: Drogue at Recovery Site

Figure 2: Forward and Central Airframe at Recovery Site

Figure 3: Aft Section at Recovery Site

Figure 4: Forward Section at Recovery Site

2.3 Flight Analysis

2.3.1 Ascent

During ascent, the launch vehicle exits the launch rail at 88.4 ft/s (Figure 6). The motor, whose maximum thrust occurs on the launch rod, incurs a burn time of 2.5 s. The vehicle reaches a maximum velocity of 640 ft/s and a maximum acceleration of 325 ft/s. The vehicle then reaches apogee, where the drogue parachute is deployed. The simulated and experimental apogee altitudes of each flight were tabulated (Table 3: Flight Apogee BreakdownTable 3) and the altimeter data were recorded (Figure 5).

Flight Apogee Breakdown			
Flight	**Predicted**	**Experimental**	**Percent Error**
Vehicle Demonstration	5603 ft	5590 ft	0.232%
Payload Demonstration	4974 ft	4975 ft	0.0201%
Competition Flight	5074 ft	5073 ft	0.01971%

Table 3: Flight Apogee Breakdown

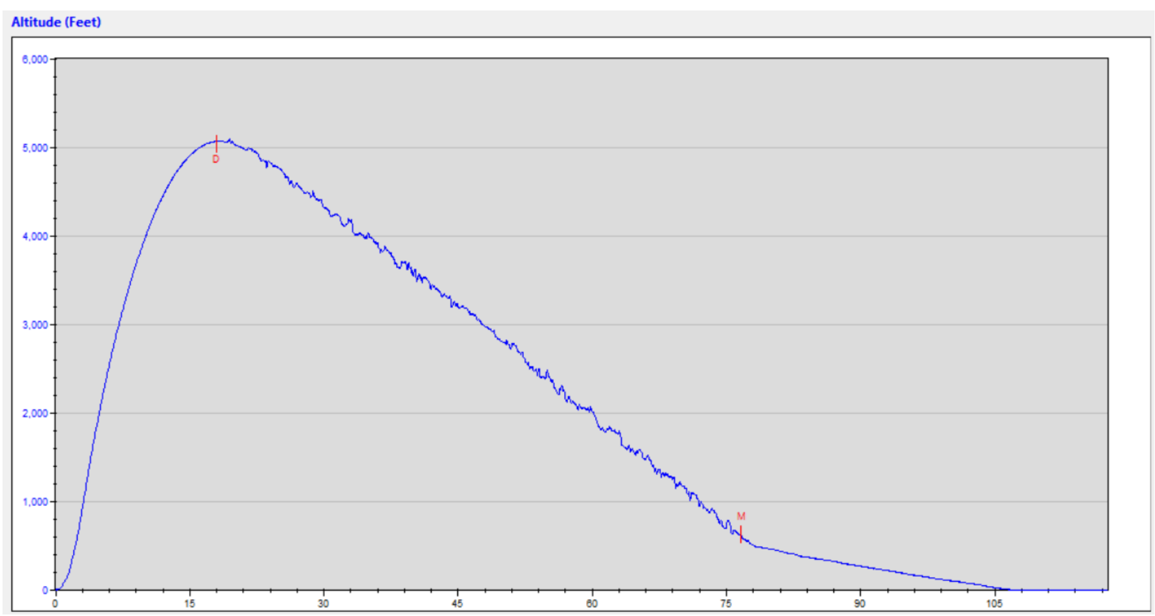

Figure 5: Altitude Data from the Primary Altimeter

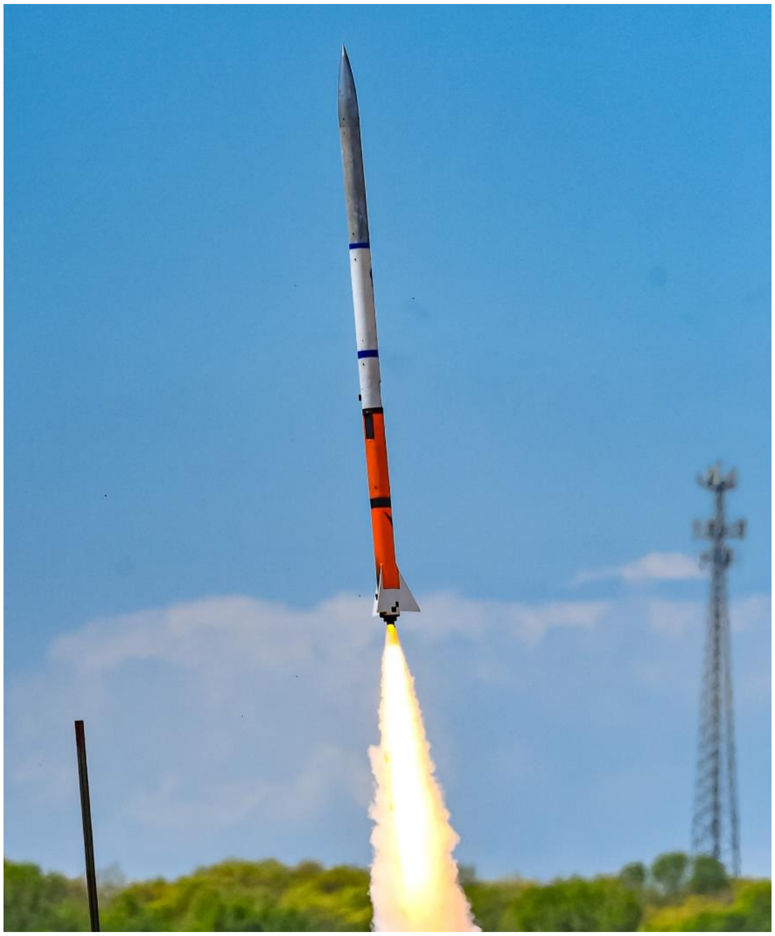

Figure 6: Vehicle During Ascent

2.3.2 Descent

The drogue parachute successfully deployed at apogee. The primary altimeter successfully set off the main ejection charge at 600 ft, causing separation and deploying the main parachute (Figure 7). The launch vehicle landed with the aft positioned horizontally with one camera system oriented upwards, and no damage was caused to the launch vehicle or parachutes during landing.

Figure 7: Descent Under the Main Parachute

The parachutes flown were a 24” Rocketman Standard for the drogue and a 72” Fruity Chutes Iris Ultra for the main (Table 4). These parachutes resulted in the launch vehicle descending at rates that roughly matched simulations run using the same parachutes, with percent errors of 2.84% and 2.83%, respectively (Table 5).

Parachutes Flown	
Drogue Parachute	24” Rocketman Standard
Main Parachute	72” Fruity Chutes Iris Ultra

Table 4: Parachutes Flown

Descent Rates			
Parachute	Predicted Descent Rate (ft/s)	Measured Descent Rate (ft/s)	Percent Error
Drogue	80.7	78.4	2.84
Main	17.4	17.7	2.83

Table 5: Predicted and Measured Descent Rates of the Launch Vehicle

Both parachute protectors were tied to their respective recovery harnesses at locations about 5 ft away from the parachutes. Additionally, tape was not used to keep the recovery harness together during ascent. These factors resulted in the parachute protectors quickly being moved away from the parachute during separation, allowing the parachutes to be deployed rapidly after separation occurred.

Descent time from apogee to landing was 87.1s and was determined from the primary altimeter's altitude vs. time data. This time meets the competition requirement for descent time.

Kinetic energy of each section at ground hit was also determined using the measured descent rate (Table 6). All the kinetic energies are less than the maximum allowed, with the largest being of the aft section at 66.9 ft-lb.

Kinetic Energy at Ground Hit During Huntsville Flight	
Section	Kinetic Energy (ft-lb)
Nosecone	8.6
Forward	36.1
Aft	66.9

Table 6: Kinetic Energy of Each Section of the Launch Vehicle at Ground Hit

The GPS was active during flight and start and landing coordinates of the launch vehicle were recorded (Table 7). The measured drift was the distance between these points and was determined using Google Maps (Figure 8).

Starting and Ending Coordinates (Decimal Degrees)	
Launch Rail	34.894632, -86.616478
Landing Position	34.892680, -86.614840

Table 7: Coordinates of the Launch Vehicle and the Start and End of its Fight Recorded by the GPS

Figure 8: Drift of the Launch Vehicle from Launch to Landing

3. Payload Summary

3.1 Payload Functionality

The payload consisted of three camera systems that will be positioned 120° apart so that one will always be aligned with the z-axis, normal to the ground, upon landing. Each camera system had a camera housing that integrated a camera, camera mount, and motors. An Inertial Measurement Unit (IMU) detected the orientation of the launch vehicle and determined which camera would be activated so that only one camera would be in use when taking photos of the surroundings. A Software Defined Radio (SDR) dongle was incorporated in the payload to receive Automatic Package Reporting System (APRS) commands from NASA.

3.1.1 Mechanical Systems

The payload successfully measured the orientation of the launch vehicle and retracted the correct solenoid tongue. The central camera system was the one aligned with the upright fin (Figure 9). The camera mount successfully rotated about the spring-loaded hinge by 90° to be vertical relative to the ground. The camera mount successfully rotated about the z-axis by 60° on the stepper motor after receiving the APRS commands (Figure 10). The orientation of the camera mount when retrieving the rocket was upright and rotated about the z-axis, which indicated that the commands were received, and the mechanical systems worked as expected.

Figure 9: Payload Camera System Deployed

Figure 10: Payload Camera System Deployed and Rotated Upon Retrieval

3.1.2 Electrical Systems

All the electronics of the payload performed their intended function and were undamaged. The electronics bay, with PCB, Raspberry Pi, power supplies, and motor controllers inside were undamaged (Figure 13). As for the camera housing, the camera housing facing up successfully deployed, and the other two remained securely locked inside the airframe (Figure 11, Figure 12). Those two figures also showed that the motors and camera in the camera housing were undamaged.

In addition, (Figure 11, Figure 12) showed that the correct camera housing was unlocked and rotated 180 degrees, this demonstrated that all electronic components functioned as intended. The IMU and barometer successfully detected landing and orientation. Combined with successfully retraction of solenoid shaft, the correct camera is unlocked and sprung up. After that, the RTL-SDR Radio Dongle successfully received radio command and Raspberry Pi decoded those commands. Finally, the stepper motor is activated to rotate the correct camera around z-axis and pictures are taken. The 180 degree rotated camera shown in (Figure 11, Figure 12) proved the successful execution of process described above.

The data saved in the Raspberry Pi indicated the correct radio sequence was received and the correct number of pictures were taken.

Figure 11: Side View of Camera Housing After Landing

Figure 12: Top View of Camera System After Landing

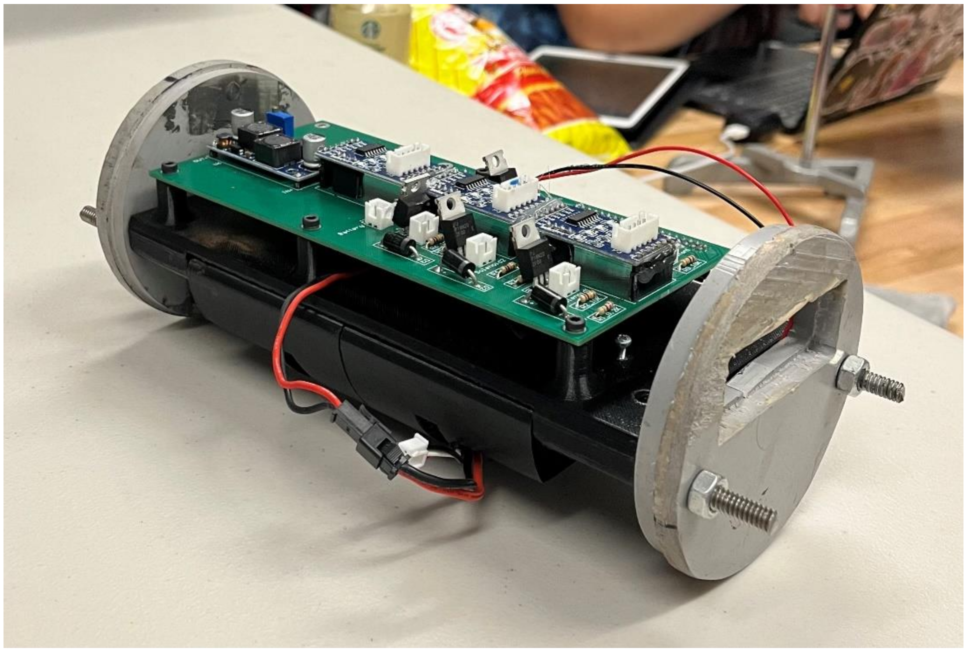

Figure 13: Undamaged Payload Electronics Assembly Post-Flight

3.1.3 Software Systems

The payload is fully controlled by the onboard Raspberry Pi 4 and software written by the team as well as two other additional programs. When powered on, the payload enters a setup state where it initializes the sensors and creates log files. Then it enters a launch detection phase where it reads the IMU acceleration data and waits until a specific threshold is reached that indicates launch. Then during flight, the payload does nothing besides waiting until it has successfully landed back on the ground. Once landed, it will determine what the orientation of the payload is via the IMU, extend the respective camera, and turn on the radio and begin listening for the radio command. Once a command is successfully received, it will be decoded, and the payload will begin execution. Photos are saved to the Raspberry Pi's SD card.

3.2 Payload Data Analysis & Results

The payload performed fully as intended, however there was an issue with the photos taken as they were massively overexposed in the Huntsville sunlight, to the point where nothing is visible (Figure 14, Figure 15, Figure 16, Figure 17).

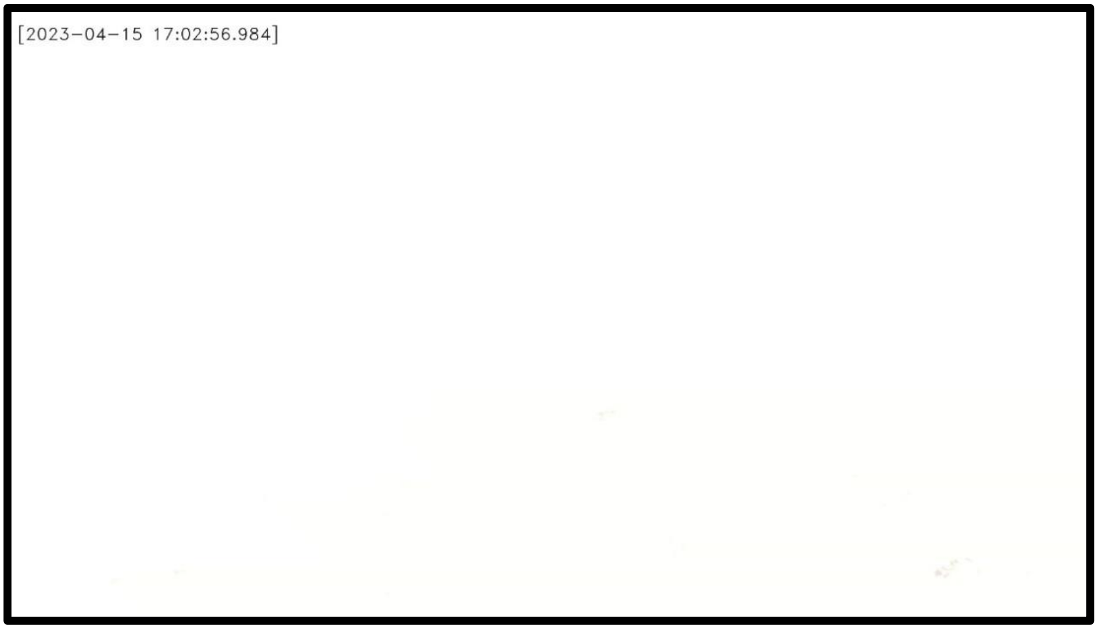

Figure 14: First image captured from radio commands with no filters applied.

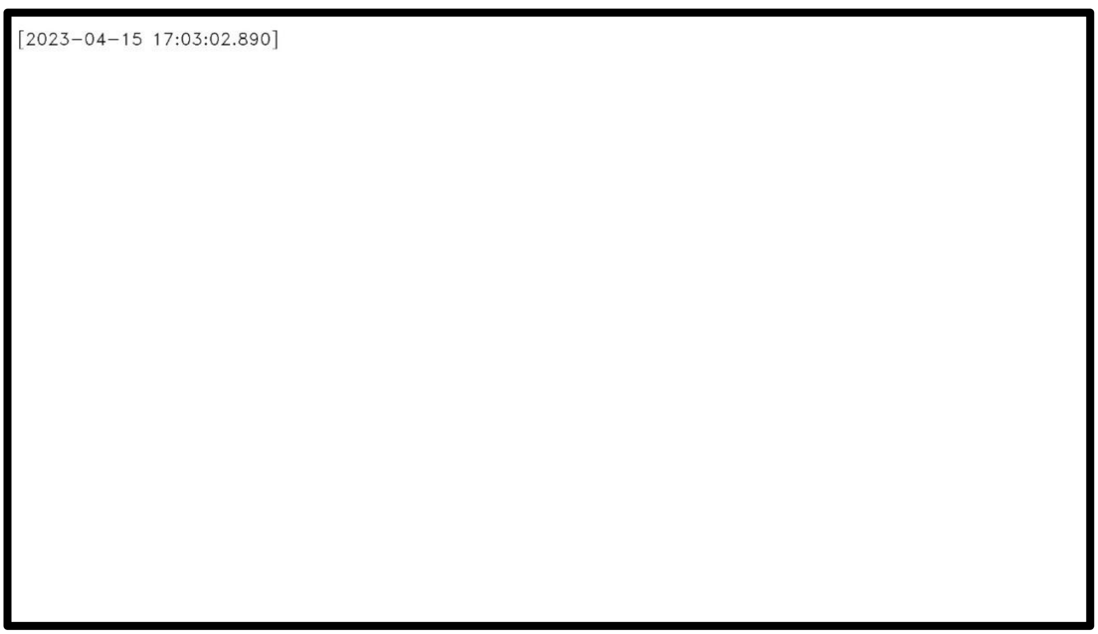

Figure 15: Second image capture from radio command rotated 180 degrees.

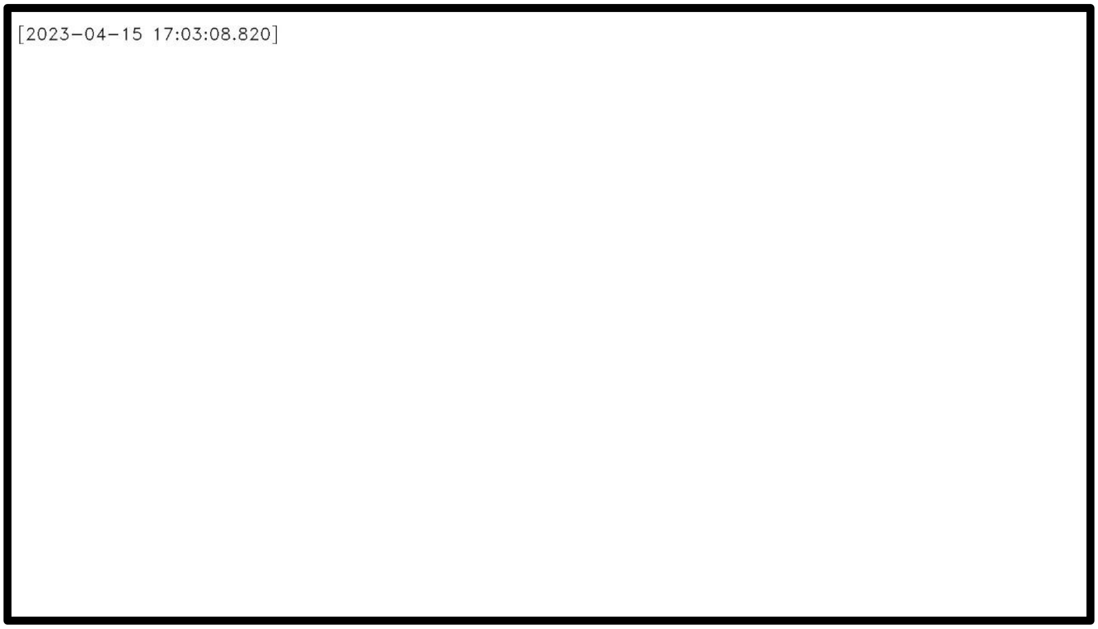

Figure 16: Third image capture from radio command with a grayscale filter

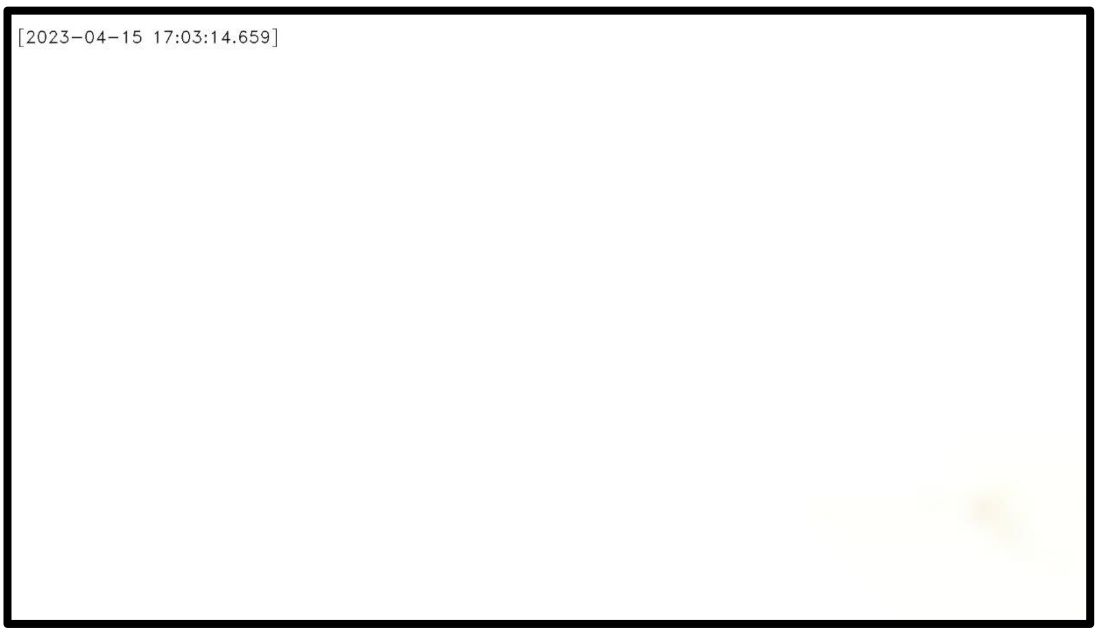

Figure 17: Fourth image capture from radio command with custom team filter.

Additional points to note about the images, the timestamps were added correctly and show that the photos were taken well within the 30 s constraint and averaged around 6 s between photos. One thing to note is that the time is UTC time which is 5 hrs ahead of Huntsville. Secondly, the time itself is offset slightly from the actual capture time because when the Raspberry Pi is powered off, it does not update the time and when it is powered on in the rocket, it has no internet connection to update the time.

The case of this was identified as overexposure because when performing diagnostic tests after at the launch side, this photo was taken by the same camera that took the images above (Figure 18).

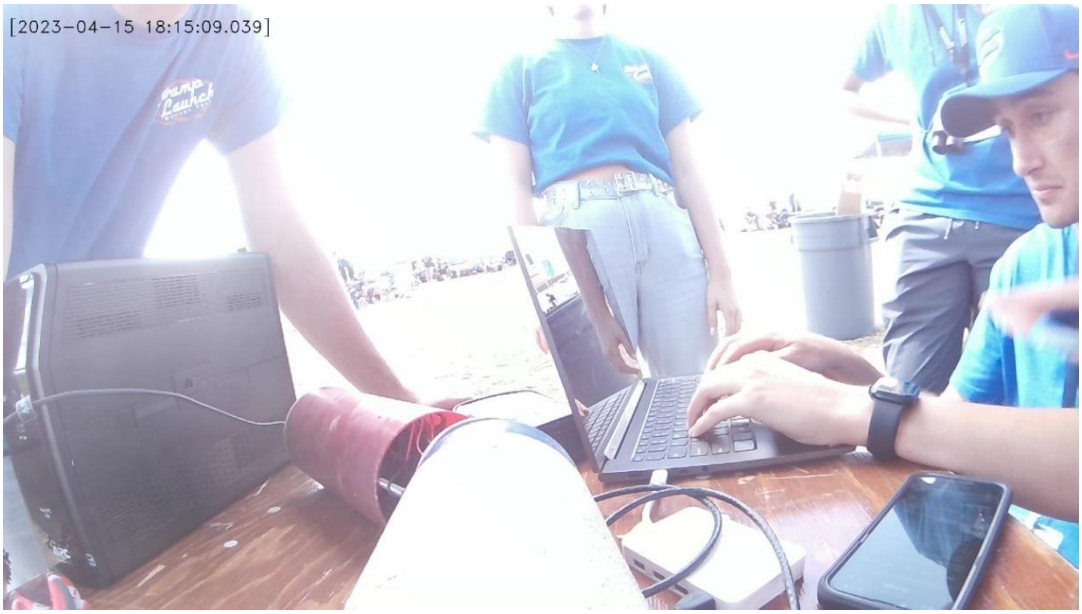

Figure 18: Image taken post launch to diagnose camera.

This photo was taken in the shade and cover of a tent, yet all the background content is not visible due to the sun. It can be determined then that in the full unprotected sun while the rocket was in the field, the overexposure would be much more intense and therefore provide a viable explanation for why the images are not correct.

Furthermore, just to prove that the cameras did indeed take a photo in the field, the following images show a logarithmic histogram analysis of the same photos (Figure 19, Figure 20, Figure 21, Figure 22).

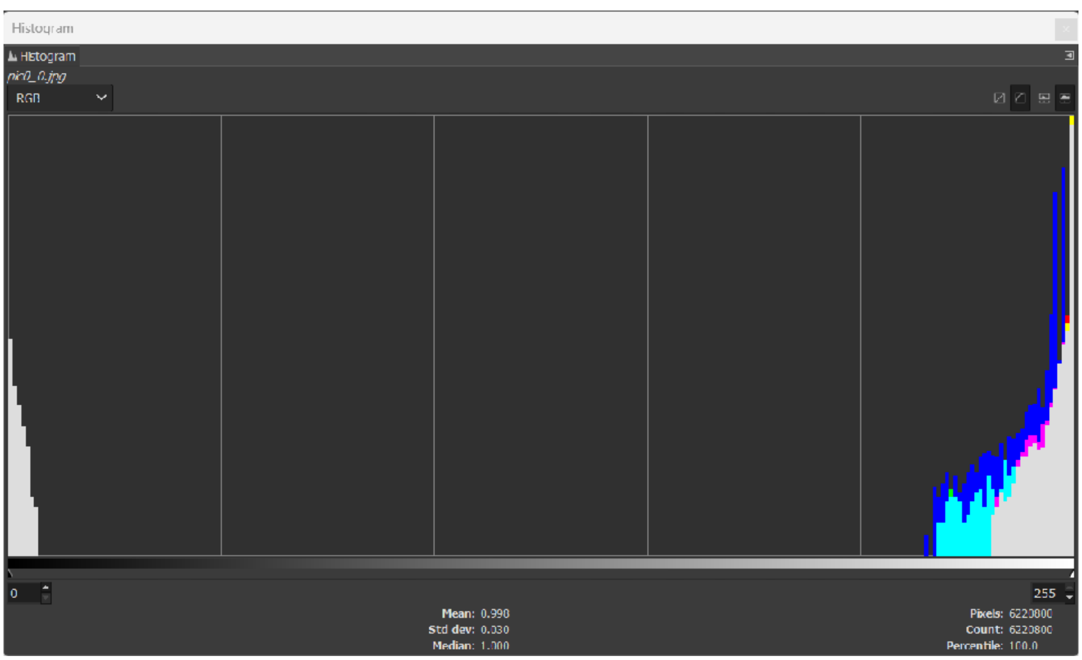

Figure 19: Pixel information of first photo taken.

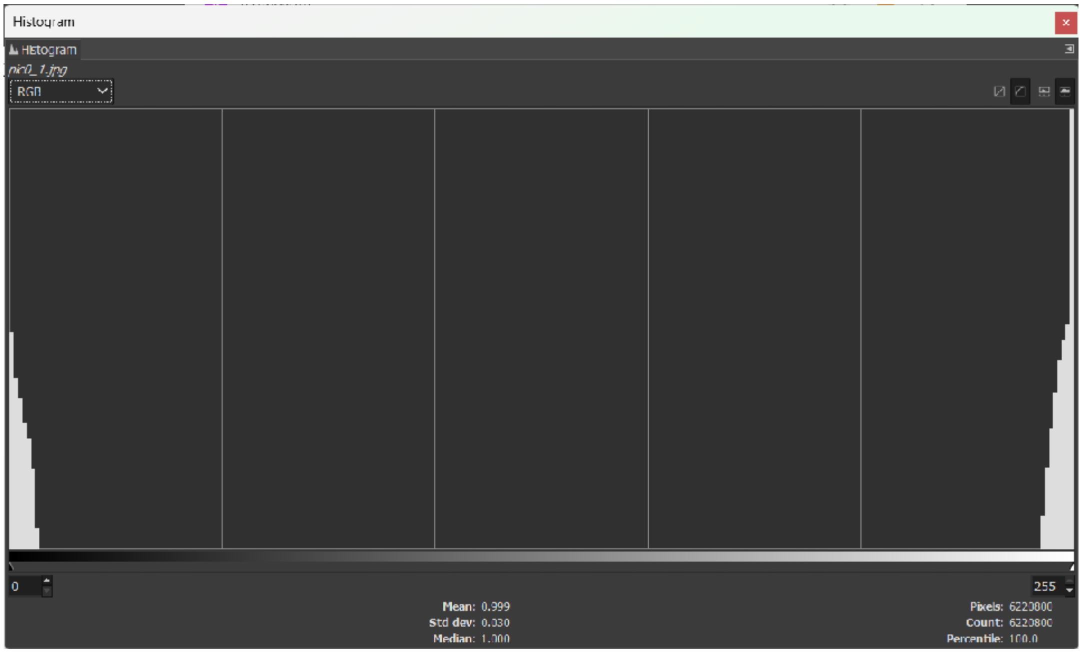

Figure 20: Pixel information of second photo taken.

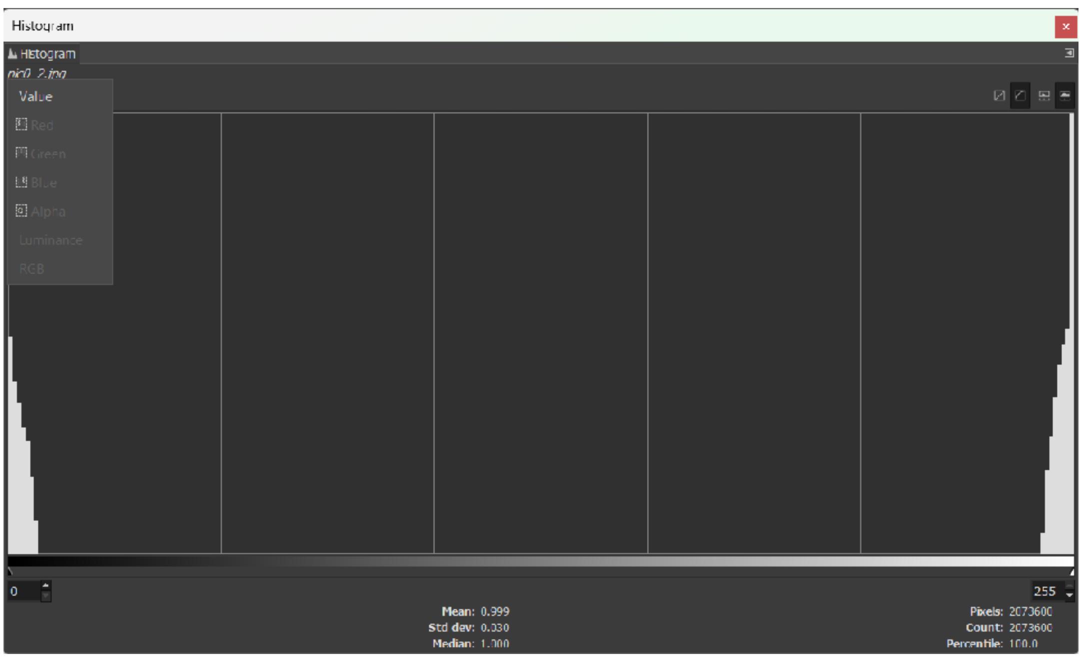

Figure 21: Pixel information of third photo taken.

Figure 22: Pixel information of fourth photo taken.

When looking at the histogram of the pixel color values, the data on the left represents the black part of the photo which is from the timestamp. Then the data on the right shows the white values from the overexposed image. Note that this is logarithmic, so the values are much higher than what the graph represents. Additionally, note that for the third image, when looking at the lop left, there is no red, green, or blue channel, meaning that the grayscale filter worked. Overall, this shows that, even though these images seem to be just a white photo, there is still a little variation from parts that were not completely overexposed.

Overall, the payload worked flawlessly from a design and execution standpoint and the payload achieved all mission criteria.

4. Lessons Learned

4.1 Overall Design Lessons

A lesson learned regarding the overall design of the launch vehicle and payload, is the incorporation of wider tolerances. Space within the launch vehicle was an issue during this project and the selection of a 4.0 in diameter airframe proved to be a difficult choice. For future projects with this level of electronic and mechanical complexity, a 5.0 in diameter airframe would be the better selection. The larger diameter airframe will allow for more space for wiring and fasteners and make the assembly of the vehicle and payload a more efficient process.

The team found through the payload demonstration launch that the secondary altimeter we selected, the Entacore AIM, was unreliable because it needs to be calibrated manually. This way of calibrating is more prone to error than automatic calibration, which is the method that the primary altimeter, the Stratologger CF, uses. During PDF, the Entacore AIM set off one of the ejection charges as soon as it was armed. The primary altimeter never had any such failures. To prevent this failure from happening in the future, altimeters with automatic calibration capabilities should be selected.

4.2 Flight Dynamics Lessons

The team experimentally determined how to distinguish between levels of surface roughness and learned a new method of applying surface roughness to the vehicle to increase skin friction drag and lower the apogee altitude. This lesson was learned because of initially overestimating the surface roughness of the launch vehicle during the design phase. The team will use these lessons going forward to continue improving simulation accuracy and mitigate the discrepancies between experimental altitudes and the declared target altitude.

4.3 Mechanical Lessons

When finding the best method for having the camera mount rotate out of the airframe on the spring-loaded hinge, the team considered manufacturing them. Steel hinges, 1.5in wide, were purchased along with .4mm diameter spring coil. The task was to make the ends of the coil stay on the hinge faces. The team learned that MIG welding is not the best for small welds like a thin coil to a thin hinge. TIG welds were more successful, but the added filament made the spring coil less flexible so the spring would not open. The final decision was made to allow the coil to deform naturally and use a small coil more tightly packed so that it would retract to 90°. The springs fatigued after several usages stopped opening all the way. The team learned that motor grease works as a good lubricant for spring coil and steel hinges. The problem was entirely resolved, and the three camera systems could open to the full 90°.

Wires and electronics were not modeled in from some of the earliest design processes. The team ended up 3D printing for prototyping many failed parts due to the lack of inclusion early on. The lessons learned include maintaining electronics organization and planning in the early phases of design and CAD modeling.

4.4 Electronics Lessons

The stepper motor wires lost connection during final payload integration because the solder was done poorly by the manufacturer. The team had to take the wires off and resolder them very meticulously. The team learned that soldering joints from the motors should not be trusted. All the electrical connections need to be rigorously reinforced before any testing is performed.

Another lesson from stepper motor connection is to have multiple backup components for modular replaceable parts. The team should expect at least a 50 percent failure rate on components like motors and transistors.

An additional lesson that was learned was to design the payload with all the predicted forces it will experience in mind. The payload locking mechanism was designed to remain locked even while experiencing the forces from launch, but the forces from the separation events were not factored in. Orienting the solenoid motor responsible for locking the camera systems closed perpendicular to launch and recovery forces would have addressed this issue.

4.5 Software Lessons

The payload software should be tested in as similar an environment as launch as possible. The issue with the overexposed camera could have been noticed earlier if the payload software had been tested in a sunny field. Additionally, it was learned early on that all data and debug info should be logged and saved to a file so that data and analysis can be performed.

5. Competition Summary

5.1 Summary of Experiences

The team's over-arching goal this year was to focus on being competitive, with learning occurring along the way. While the competition scores have yet to be released, the team is satisfied with our performance this year. The team certainly feels that the second part of that overarching goal was accomplished. The experiences had while working on this project can be broadly organized into two categories: technical learning and interpersonal growth.

Members and leads grew their technical skills significantly. Significant amounts of time were spent creating CAD models and assemblies for subsystems, with individuals significantly improving their fluency in Fusion 360 and other CAD programs. This CAD work was soon translated into manufacturing, where members learned how to operate 3D printers, lathes, milling machines, and a variety of other manufacturing processes. From there, members developed skills in simulation, using OpenRocket and MATLAB to model the launch vehicle. Others developed experience through testing the launch vehicle and payload subsystems. There, valuable experience with report-writing and documentation (as would be seen in industry) was gained.

Technical leads were also tasked with leading a subteam focused on one element of the project. Here, leads gained significant leadership experience; managing a group of as many as 20 students was found to be quite the learning experience. Subteam members also learned a lot about working in a team environment. No one person could have done this project; it truly was a team effort.

5.2 Scientific Value of Project

The opportunity to be a part of the NASA University Student Launch Initiative gave the team not only the opportunity to overcome a difficult challenge, but also the opportunity to delve into a fraction of the difficulties that will face the Artemis generation in space. As the Artemis program comes online, many of the students engaged by NASA USLI will eventually be a part of returning humanity to the moon and beyond. Surveying another planetary body is a necessary step in space exploration, and this challenge gave the team the opportunity to learn how this process works, and how the necessary systems to accomplish this are developed.

Additionally, this project allowed the team to learn various manufacturing and testing methods to ensure that the final vehicle and payload perform how they are predicted to perform. This is a valuable experience as this mentality and approach to project development translates directly into space exploration as exemplified in the complete success of Artemis 1. Without the necessary testing and high-quality manufacturing of the Space Launch System, Artemis 1 would likely not have been a success.

Being a part of NASA USLI was a valuable experience for the team as it vastly improved the team's approach to complex project development and scientific methodology.

5.3 Summary of Hours

The time spent developing the entire project was recorded and tabulated (Table 8).

Hours Spent on Project	
Project Element	Hours
Proposal	572

PDR	568
CDR	515
FRR	616
FRR Addendum	42
PLAR	13
STEM Engagement	35
Social Media	15
Launch Operations	45
Recovery Operations	23
Total	**2,444**

Table 8: Hours Spent on Project

5.4 STEM Engagement Summary

A detailed summary of the team's stem engagement program was recorded and tabulated (Table 9).

Event Title	Students Reached	Type of Event	Description
Stomp Rockets at Howard Bishop Middle School	110	Education/Direct Engagement	Student groups created bottle rockets and competed with them. By the end of the activity, the students should have been able to explain the different parts of the paper rocket, variables of design, and different factors that affect flight. After, they were challenged to think about what contributed to success or failure.
Grace at Fort Clarke Methodist Church Trunk-or-Treat	115	Outreach/Indirect Engagement	Team members decorated a car trunk and interacted with families by handing out candy to each child and telling them stories about space and the rocket team. The main goal was to inspire young kids to learn more about science, technology, engineering, and math.
Kanapaha Middle School Science Night	200	Education/Direct Engagement	Students visited a Swamp Launch table to learn about the team and launch paper rockets. The design process was emphasized by the activity and local opportunities were emphasized by a short presentation about Swamp Launch and other organizations the University of Florida has to offer.
Space/Rocket Demo at Baby Gator	17	Education/Direct Engagement	Kindergarteners learned about rocketry, engineering, and life in space. They each built a paper airplane. The team focused on things like the basic tasks of astronauts, the solar system, and the components and purposes of rockets. The team was able to maintain engagement during the short and simple lesson, and the students were excited to interact with real engineers.

Space/Rocket Demo at Wiles Elementary School	80	Education/Direct Engagement	Elementary school students were able to learn about different parts of rocketry, life in space, and current projects going on in the space industry. Activities consisted of interactive lessons with objects such as a rocket, a space suit, and planet models. In addition to this, a paper airplane competition in which the students learned about flight factors and helped each other do so.

Table 9: STEM Engagement Summary

Throughout the months of the Student Launch 2022-2023 competition, the team was able to create various events that reached many students of various ages. Some events were documented because they occurred in season, but there are other events that occurred outside the season such as tabling and school visits. The team wanted to continue to use the time to reach as many people as possible even if it was not in the normal season. A favorite activity that was not initially documented was an event at Wiles Elementary School. There were around 80 kids and they learned about space and engineering while getting to interact with rockets, posters, astronaut suits and more. huge paper air. To complete it, there was a paper plane competition, and they were all very excited.

Each opportunity provided a special opportunity to understand different students on a personal level and observe what types of engagement work best for them. One of the main goals during this time was to break the barrier between students' lack of understanding and the ability to understand these science concepts more fully. In addition, it was important to understand that it's not possible to fully engage every student, but in this way the team was versatile and gave best efforts to reach everyone.

As the season went on, the team learned how to plan more effective events and see if diversifying the types of people reached was possible. Some strategies included being intentional with the Gainesville areas visited and reaching out to different people to see if they needed help with any of their programs.

There is still work to be done to expand the types of events and people reached. It's important to visit places and make the team's presence known, but some ideas for the future include establishing a mentorship program or a pen-pal program to share knowledge even further.

5.5 Final Budget Breakdown

5.5.1 Cost Breakdown

The final project cost of Project Photogator is $8,505.48. This cost was under our declared budget of $9,000.00 by $494.52. The final cost was broken down into five categories: general costs, testing costs, subscale vehicle development costs, full-scale vehicle and payload development costs, and travel costs. General costs are any costs associated with the development of the entire project, but that do not pertain to any of the other categories specifically. The final cost of the project was graphed and tabulated (Figure 23, Table 10).

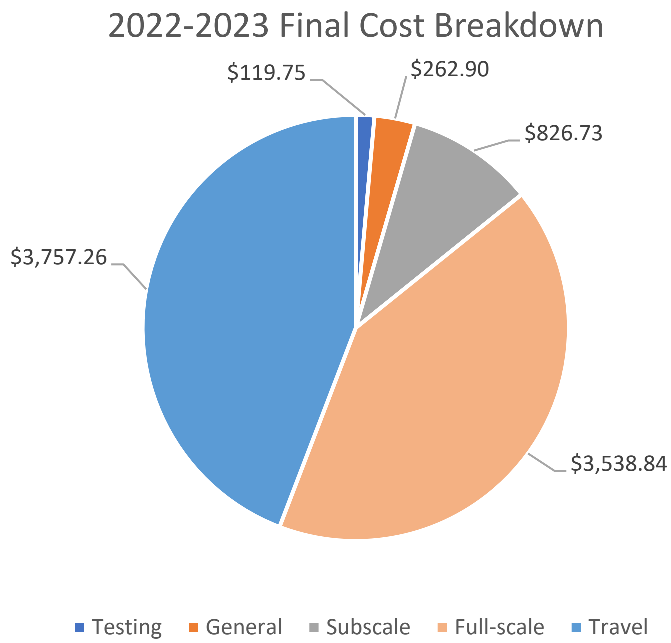

Figure 23: 2022-2023 Final Cost Breakdown Graph

Item	Cost
General	$262.90
Testing	$119.75
Subscale Vehicle Development	$826.73
Full-scale Vehicle & Payload Development	$3,538.84
Travel	$3,757.26
Total	**$8,505.48**

Table 10: Final Cost Breakdown Table

5.5.2 Final Funding Breakdown

Project Photogator was primarily funded by the University of Florida Mechanical and Aerospace Engineering Department, University of Florida student government and various corporate sponsorships. These funding sources yielded a final team fund of $11,676.00. The breakdown of the team fund was graphed and tabulated (Figure 24, Table 11).

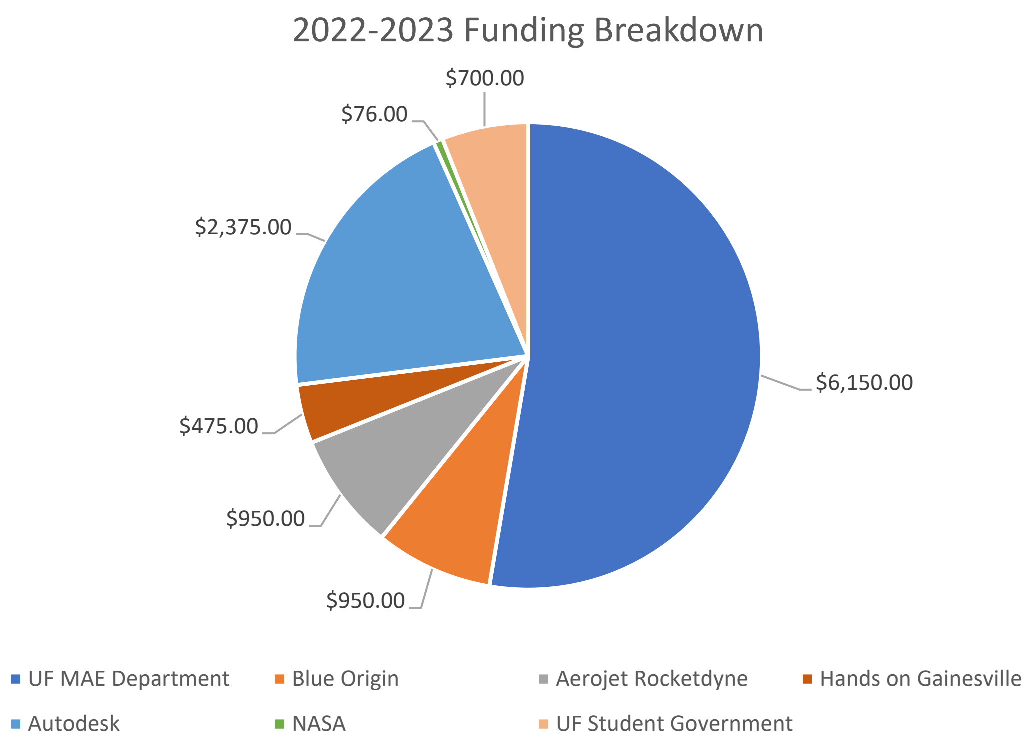

Figure 24: 2022-2023 Funding Breakdown

Funding Source	Amount
Aerojet Rocketdyne	$950.00
Autodesk	$2,375.00
Blue Origin	$950.00
Hands-On Gainesville	$475.00
UF MAE Department	$6,150.00
UF Student Government	$700.00
NASA	$76.00
Total	**$11,676.00**

Table 11: Final Funding Breakdown Table

6. Conclusion

On behalf of the University of Florida, the Swamp Launch Rocket Team would like to thank you for another great year and the privilege to compete in the NASA University Student Launch Initiative competition.