Gator Locator

NASA Student Launch 2022 Post-Launch Assessment Review

University of Florida
Swamp Launch Rocket Team
939 Center Dr, Gainesville, FL 32611
MAE-A 324

May 9th, 2022

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1. Flight Summary

The University of Florida's Swamp Launch Rocket Team performed its final competition flight in Huntsville, Alabama on April 23, 2022. Details of the launch vehicle and its flight are shown (Table 1).

Flight Vehicle "Alberta" Information	
Vehicle Dimensions	
Vehicle Diameter	4.02 in
Vehicle Length	111 in
Nosecone Section Length	16 in
Forward Section Length	38 in
Aft Section Length	57 in
Main Parachute	72 in Fruity Chutes Iris Ultra
Drogue Parachute	36 in Rocketman Standard (reefed)
Flight Information	
Ballast Mass	1 kg
Vehicle Gross Mass	27.04 lbs
Motor	Aerotech L1090W
Main Primary Ejection Charge	2.0 g black powder
Drogue Primary Ejection Charge	1.5 g black powder
Official Target Altitude	4578 ft
Actual Altitude	4768 ft
Descent Time	93 s
Drift Radius	1500 ft

Table 1: Flight Vehicle Information

The payload experiment uses inertial navigation in conjunction with image-based references to determine the vehicle's final landing location. Two OV5642 cameras capture images of the launch field near apogee, which are compared to known images of the launch field using the SIFT algorithm in OpenCV to determine a mid-flight location. Inertial data is then integrated twice to determine the vehicle's displacement from that known location upon landing.

Commented [MW1]: Put parachute sizes in here as well

Commented [MW2]: Include primary charge sizes below motor

2. Vehicle Summary

2.1 Flight Conditions

As stated, the vehicle was launched in Huntsville, Alabama on April 23, 2022, under the conditions shown (**Error! Reference source not found.**).

Competition Flight Conditions	
Average Wind Speed Measured	6 mph
Average Temperature Measured	85° F
Launch Rail Angle	5 degrees

Table 2: Competition Flight Conditions

2.2 Flight Analysis

2.2.1 Vehicle Analysis

The vehicle incurred no damage that would prevent another safe flight during launch, ascent, descent, and landing. Therefore, structurally, the vehicle was deemed successful as it was recoverable and reusable. Images of the recovery site are shown (Figure 1).

Figure 1: Launch vehicle at landing site

2.2.2 Ascent

The vehicle successfully ignited and began ascent. As the launch vehicle ascended, a few characteristics were noted. The vehicle launched at an angle as seen in the scoring altimeter altitude profile (Figure 2). The motor burned out in 3 seconds, as expected, and reached apogee in around 15 seconds. The scoring altimeter, a StratologgerCF, read the apogee to be at 4768 ft, 190 feet off from the target. In comparison to past demonstration flights, this was better than the vehicle demonstration but slightly worse than the payload demonstration. A breakdown of the apogee for each flight is summarized (Table 3).

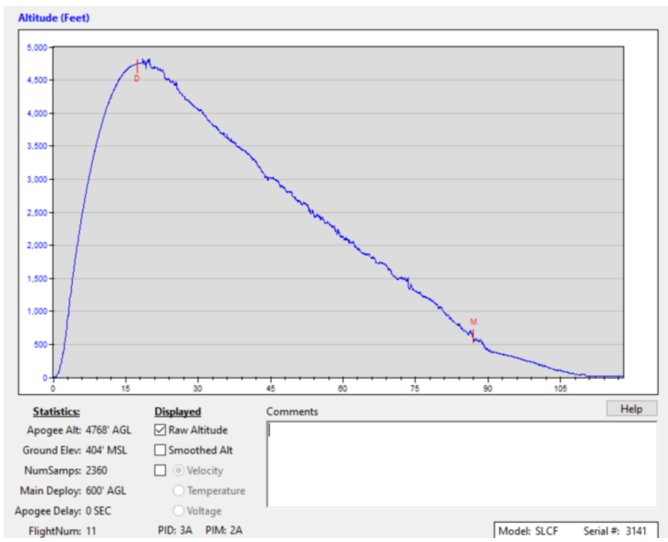

Figure 2: Altitude vs Time from scoring altimeter

The difference between the prediction and actual altitude in the flight demonstration flight was due to simulating the camera mounts with larger drag characteristics. The drag of the vehicle was far less than predicted. As a result, additional layers of paint were added to increase the weight and drag of the vehicle. In the payload demonstration flight, the difference between the predicted and actual altitude decreased due to the changes. For the competition flight, the difference was anticipated to be 116 feet off from the target but the difference was 190 feet (**Error! Reference source not found.**). This difference may have been due to simulation errors and large changes in wind gusts.

Flight Apogee Breakdown			
Flight	Predicted Apogee	Actual Apogee	Post-Simulation Apogee
Flight Demonstration	4560 ft	5079 ft	4961 ft
Payload Demonstration	4670 ft	4721 ft	4716 ft
Competition Flight	4694 ft	4768 ft	4700 ft

Table 3: Flight Apogee Breakdown

Commented [MW3]: Which was what, state the type

Commented [PJ4R3]: @Larke,Collin Thomas can you help me out with this?

Commented [MW5]: Vehicle demonstration flight and payload demonstration flight (use the names)

Commented [MW6]: Fix the placements of your figures/tables. Don't all go at the end of the section they should go throutout. Move the comparison table up to below this paragraph

Commented [Me7]: Don't think there's any reference to this data or anything that explicitly states "here's the scoring altimeters flight profile" that is very important

Commented [MW8]: Need to present a hypothesis as to why it may have differed

Commented [PA9]: "It" does not have a clear subject, make it clear that we're referring to the actual difference

Commented [PJ10]: lol who accidentally deleted the title

Commented [PJ11]: lol who accidentally deleted the title

2.2.3 Descent

The vehicle separated successfully at apogee and the drogue parachute deployed. The drogue fully inflated and slowed the descent of the vehicle. The vehicle also separated successfully at 600 ft and the main parachute deployed (Figure 3). The vehicle landed and incurred no damage. The parachutes remained completely attached to the vehicle and were not harmed.

Figure 3: Launch vehicle under drogue parachute (left) and main parachute (right)

A mistake in the sizing of the drogue parachute was discovered while packing for the Huntsville launch. A 36 in Rocketman standard parachute had been used during the vehicle and payload demonstration flights due to an error in the team's inventory sheet and a failure in the method of measuring the size of the parachute. The lead responsible did inspect the parachute and see the label that provided sizing information, but was confused by the label reading a "3" with no units, and the Rocketman website advertising the parachutes in inches. Due to the parachute being in inventory, the lead responsible believed that the Rocketman site may have changed their sizing system since the parachute was purchased and that they may have used a chart with numerical values associated with an approximate size in the past, like other sites, such as the Sktyangle Cert-3 parachutes that are advertised as Large, X-large, or Drogue. The parachute was measured, but measured incorrectly, as it was laid to rest instead of being stretched to its maximum diameter.

The team realized the mistake while packing for the competition launch and attempted to find or purchase a 24 in Rocketman standard parachute. A 24 in Rocketman standard parachute was not available, but a similar 24 in parachute was sourced at the launch field, however it was not flown. The team chose to fly the 36 in parachute because it had been flown and performed well during the vehicle and payload demonstration flights (Figure 4). The 24 in parachute acquired had not been tested by the team. The flown drogue parachute was reefed for the payload demonstration flight and the competition flight to help increase the descent rate. After the mistake had been realized, a simulation was run with a 36 in drogue parachute and it gave a predicted descent rate of 55 ft/s. During flight, even for the un-reefed vehicle demonstration flight, the parachute performed more like the 24 in drogue parachute simulation than the 36 in drogue parachute simulation. The performance of the flown drogue parachute has shown the team how altitude can affect the descent rate of a parachute, and that using the drogue descent rate at the main parachute deployment is not a close representation to the average descent rate for a parachute that travels from around 4500 ft to 600 ft as had been assumed during previous reports when calculating descent predictions. During the competition flight, the drogue parachute had an average descent rate of

Commented [JP12]: Descent

Commented [MW13]: Specifications for parachute

Commented [MW14]: Same comment

Commented [MW15]: In the method of measuring, make it clear that you did measure it

Commented [MW16]: At the launch field

Commented [MW17]: This is just a statement relate it to the scenario

Commented [PA18]: If we mention it being un-reefed in VDF, we need to say it was reefed for the competition flight

68 ft/s. This is 10 ft/s slower than the predicted descent rate of a 24 in parachute and 15 ft/s faster than the predicted descent rate of a 36 in parachute.

Figure 4: Drogue parachute flown

The main parachute performed as expected once it fully unfurled, descending slightly faster than the simulated descent rate, with an average descent rate near 20 ft/s. In the launch recording, it appeared to get caught on the protector for a second, but as the secondary charge went off, the nosecone pulled the parachute from the protector. The secondary charge did not assist in separating the protector from the parachute but was a good indication of the altitude that the main parachute began to inflate. A total descent time of around 93 seconds was determined from the altitude plot.

The launch vehicle drifted approximately 1500 ft from the launch pad during its flight and descent. 1500 ft is an upper estimate due to the uncertainty associated with the size of the marker used on Google Maps to measure distances (Figure 5, Figure 6, Figure 7).

Figure 5: GPS output of launch pad location

Figure 6: GPS output of landing location

Commented [MW19]: Compare to 24 in

Commented [PA20]: Should we state the uncertainty here, like "approximately 1500", or consolidate these 2 sentences into 1?

Commented [MW21]: Don't' use subjective terms like good just say what it is

Commented [MW22]: Put figures below words, we don't know what we are looking at right now

Figure 7: Drift measured using Google Maps

3. Payload Summary

3.1 Payload Functionality

The payload is titled Land-Mark Watney. The payload consists of two rear facing camera mounts and a payload sled assembly. The camera mounts are the mechanical structures that retain the cameras throughout flight. This ensures they are steady throughout flight for image capturing. The payload sled retains the electronic hardware including the raspberry pi and the two lithium-ion batteries, as well as the IMU. Two aft-facing OV5642 cameras collect images of the launch field throughout flight. These images are run through the SIFT algorithm in OpenCV to identify key points. These key points are then matched with those of a pre-uploaded satellite image to determine the vehicle's location at time of image capture. An ADIS16470 inertial measurement unit collects acceleration and gyroscopic data, which is integrated to determine the vehicle's displacement between the landing location and location at time of image capture. Using code written in Python, the IMU data is interpreted using a 3-2-1 Euler angle sequence to determine the final displacement. Each collected sample was split into multiple subdivisions where a constant acceleration and angular velocity were assumed based on the recorded data from the IMU. The acceleration was integrated twice to find the displacement and the angular velocity was integrated once to find the orientation of the IMU. The Euler angle sequence was used to map the collected IMU data to an inertial reference frame from the IMU's moving reference frame (Figure 8).

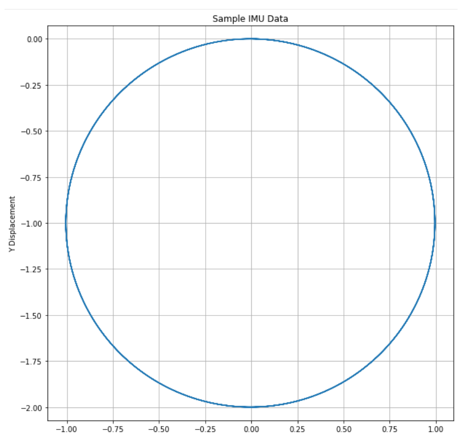

Figure 8: Generated test IMU data with constant acceleration in the IMU's X-direction and angular velocity about the Z-direction

The IMU displacement is calculated by finding the total magnitude of displacement since the time of the chosen image. The final vehicle landing grid location is then calculated and transmitted to a ground station using an XBee S3 Pro transceiver.

3.2 Payload Data Analysis and Results

The payload was not able to determine a landing location for the launch vehicle. The vehicle landed in grid box 68, as determined by the vehicle GPS (Figure 9, Figure 10). The inertial measurement unit (IMU) and cameras failed on the day of launch. The inertial measurement unit was able to produce data, but the data collected appeared to be pseudorandom and was not accurate. Because the IMU was using identical

Commented [MW23]: Summary is missing key features of the payload like the retention system/any of the mechanics, and the specifications of any of the electronics or programs we used

Commented [OR24R23]: Address electronics and software, just needs retention system/mechanics

Commented [MW25]: What kind of cameras

Commented [MW26]: Tell us how! On what and using what? This is way too vague

Commented [MW27]: Transmitter specification mentioned?

Commented [MW28]: Images go after words. Don't know what we are looking at

Commented [MW29]: This does not need to be it's on paragraph. Also order of sentences should be reversed software as when it was tested and verified, the issue was most likely in hardware. This could be the result of either internal electrical damage within the IMU, which could have been caused by a short circuit during testing and debugging.

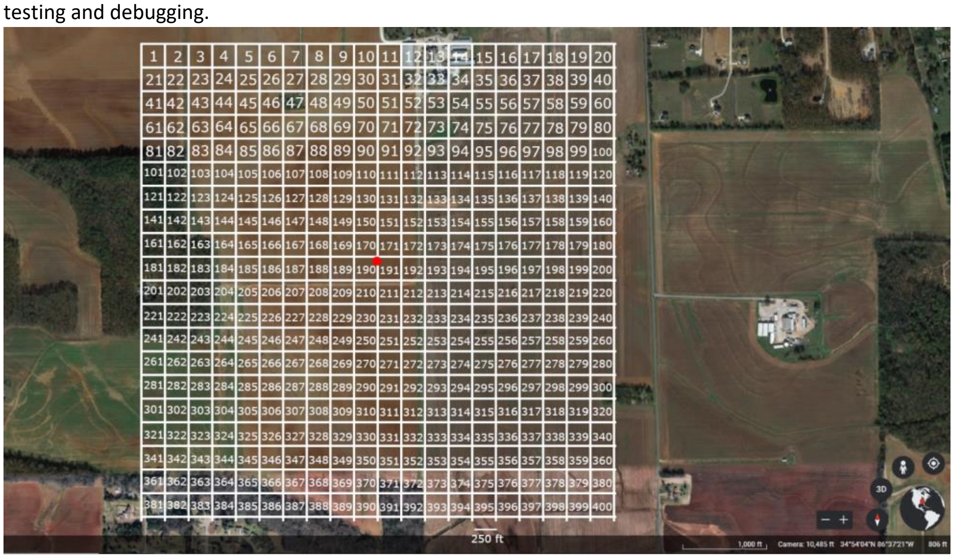

Figure 9: Gridded image of the launch field, with the launch pad marked in red

Figure 10: Vehicle landing location, as determined by vehicle GPS

The cameras failed to capture images upon start up. This was likely the result of poor contact within the connectors between the wiring harness and protoboards, which were crimped by hand and appeared loose on post-flight inspection. The combination of failures from the cameras and IMU prevented the payload from making a determination of its final landing location.

The payloads mechanical structures were successful throughout flight, keeping all the electrical components and cameras retained (Figure 11). Prior to the flight, the assembly of the payload was completed. The team ran into the issue of a camera mount being stuck to the launch vehicles aft airframe. Soon after, it was discovered that this occurred due to the paint behaving as an adhesive, sticking to the bottom of the camera mount. This was because they were left on for the duration of the team's travel from Florida to Alabama to ensure they did not get misplaced, which provided enough time for the camera mount to stick to the launch vehicle. The camera mount was eventually removed before flight, without any structural damage. This problem could be avoided in the future by removing all exterior mounts after any flight has occurred. The team also ran into the issue of wires sliding down the aft airframe and out of the electronics tubes into the payload bay. This occurred because the team forgot to tape down the wires in the camera mount location, allowing them to slide down the electronics tubes during transportation of the launch vehicle. This was rectified by sliding the wires back down the electronics tube and then reconnecting them to the camera. Incidentally, this provided a real-world impromptu test of the electronics tubes and proved that their design and function was sound. Other than these issues that arose during assembly, the payloads mechanical components experienced a successful flight and were all retrieved after the flight with all electronics retained (Figure 12).

Commented [MW30]: Noooo first person

Commented [MW31]: First person

Commented [MW32]: Talk about how this was a good proof of concept for the wire tubes design

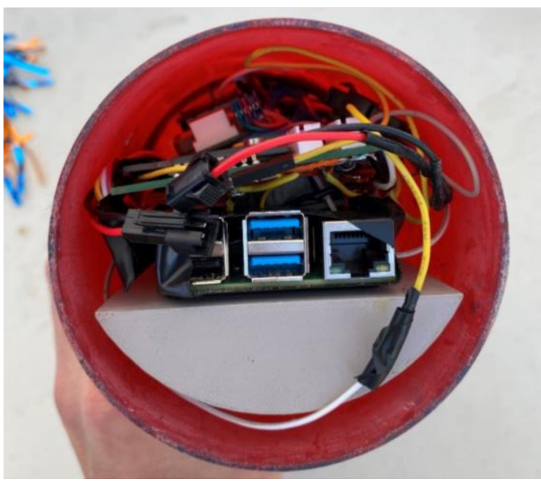

Figure 11: Payload Retained Inside of Coupler Post-Flight

Figure 12: Camera Mount on Launch Vehicle Post-Flight

4. Lessons Learned

4.1 Overall Design Lessons

During all phases of the vehicle's design and manufacturing, many lessons were learned that will be built upon in the future. One key lesson learned was the timing regarding the purchase of off-the-shelf parts. This year, the originally specified 5:1 Ogive filament-wound nose cone did not arrive in time for the full-scale vehicle demonstration flight. Instead, a 4:1 Ogive Plastic, fiberglass-reinforced nose cone already in inventory was used in all subsequent flights, a change approved by the NASA team. As a result, ballast mass and changes in paint jobs were considered to adjust the overall performance of the vehicle to its expected performance. To account for unexpected changes like this in the future, back-ups will be considered in the design phase to ensure redundancy in the design and its impact on the vehicle performance. Additionally, communicating with vendors beforehand is another method of ensuring the security of the parts needed.

Commented [MW33]: The anticipation isn't the lesson that's the thing we want to do better. Reword this

Commented [DW34R33]: good now?

Commented [WR35]: Talking about fullscale or subscale?

Commented [MW36]: Give actual specifications. First was fiberglass, actuallly was plastic, etc

Another key lesson learned was to double-check the proper sizing of all components. A 24 in drogue parachute was used in the simulations and the design of the rocket and the team had listed a 24 in parachute in inventory. However, a 36 in parachute of the same make and model was accidentally used during the vehicle demonstration flight due to the inventory being wrong. It was assumed to be 24 in because it was the smallest parachute of that make, and the size was incorrectly measured prior to the vehicle demonstration flight. This should have been the first reasoning considered in FRR on why the drogue descended 10 ft/s slower than in the simulations but was not considered because it was not a mistake that was anticipated by the team. Ultimately, the team has learned to inspect all parts more closely and verify what is on the inventory sheet with what is in storage.

Commented [MW37]: Run on sentence

Commented [WR38]: Can just say it was incorrectly measured, don't need to reference who did it

Commented [WR39]: No contractions

Commented [MW40]: This is all repeat and doesn't need to go here

From the parachute mistake, the team learned a valuable lesson in how parachutes perform at altitude. The drogue descent rate may decrease significantly from apogee to the main parachute deployment. This will encourage the team to not use the drogue descent rate at the main parachute deployment as a constant descent rate during drift radius and descent time calculations. The team will move towards using the average drogue descent rate for drift radius and descent time calculations to account for potential differences in speed.

4.2 Manufacturing Lessons

An important lesson learned from manufacturing the launch vehicle concerns the coupler bulkheads. For this vehicle, Type II PVC was used to construct the bulkheads that capped the aft end of the nosecone shoulder, the forward and aft ends of the avionics coupler, and the forward end of the payload coupler. The bulkheads were manufactured by using a lathe to turn a cylinder of Type II PVC stock until it was of a diameter that fit into the airframe. During the sub-scale manufacturing process, the team encountered a problem where a bulkhead was not able to retain the ejection charge gases within the airframe during testing. Therefore, the full-scale bulkheads were turned to an extremely tight tolerance due to concern about the bulkheads providing a proper seal. At some points, the lathe was used to turn the material by as little as 0.002 in (Figure 13). This method yielded bulkheads that provided a seal which prevented ejection charge gases from escaping before successful ejection, and which protected their respective components from said gases. In this respect, the design and manufacturing processes were successful. However, the airframe and bulkheads were prone to swelling due to high ambient temperatures and to debris accumulation from repeated ejection events, assembly, and handling. This normally would not have been an issue, but due to the tight tolerances used during manufacturing, these conditions made

Commented [MW41]: Didn't this happen on the subscale where we had to remake? Mention disassembly of the vehicle difficult. In the future, a larger tolerance will be used in constructing the bulkheads so that they will still retain their desirable features listed previously but will also not be as susceptible to environmental conditions during disassembly.

Figure 13: Bulkhead manufacturing on lathe

One benefit of manufacturing based on CAD drawings is that the vehicle's dimensions are known before the vehicle exists. This allows the flight dynamics and avionics and recovery sub-teams to develop realistic flight simulations during the design phase. However, the quantitative properties of the epoxy used in the construction of the vehicle can be more ambiguous due to inadvertently using too much. RocketPoxy was used in securing the payload bulkhead, nosecone bulkhead, all four recovery harness eyebolts, and the fins (Figure 14). During the design phase, the density of the RocketPoxy was determined experimentally and was used to extrapolate an approximate total weight of the epoxy to be used. This method proved to be effective in producing accurate simulations. When there were discrepancies between test flight results and simulation predictions, it also made causal determination easier, as it eliminated the weight of the epoxy as a variable. In the future, this method will continue to be used so that the differences between the CAD drawings, simulations, and the final launch vehicle are as minimal as possible.

Figure 14: Application of interior fin fillets

The most important lesson learned from manufacturing was the real-world characteristics of the materials used in construction of the launch vehicle. The airframe, motor tube, and couplers were all constructed using G12 fiberglass, the bulkheads were constructed using Type II PVC, the centering rings were made of plywood, and the fins were made of structural FRP fiberglass. Each of these materials had their credibility proven on three separate occasions. First, during the manufacturing process, no major difficulties were encountered regarding the material properties of any of the materials listed. Second, the launch vehicle was assembled, disassembled, and then reassembled multiple times without major incident. Finally, the launch vehicle was launched and successfully recovered three consecutive times. Therefore, structurally, all materials used were deemed successful as they did not break or alter to the point where flight was not safely possible. In the future, these materials will be considered again if similar design criteria are required due to their performance during manufacturing, ground operations, and during launch, flight, and recovery.

4.3 Safety Lessons

An important safety lesson was learned when the team noticed the tight fit of the bulkheads within the airframe. As stated, the tightness of the bulkheads caused the disassembly of the vehicle to be very difficult, especially after launch. The lengths the team went to in order to disassemble the vehicle may have put team members at risk of being struck by the vehicle when it was pulled apart. Additionally, team members strained themselves to disassemble the vehicle. It was noted that thoroughly cleaning the inside of the airframe as well as the couplers and bulkheads was essential to avoiding the strain required to pull the vehicle apart and preventing members from possibly being injured during disassembly. It would be a good idea to consider testing the fit of the vehicle after ejection testing to ensure that the vehicle is being correctly cleaned after each use. This would be accomplished by assembling and disassembling the vehicle after ejection testing and confirming that it will not fit too tightly on the launch field.

4.4 Payload Electrical Lessons

The payload was initially intended to be laid out on a printed circuit board with all components directly soldered on. To meet manufacturing deadlines for the Flight Readiness Review, components were instead connected to a protoboard and each PCB trace was replaced with a jumper wire that was soldered on. While this change eliminated PCB shipping time, it greatly increased the time and complexity of troubleshooting hardware. This change allowed hardware issues, such as wires disconnecting and wire leads shorting, to repeatedly occur. In the future, the team should allot more time for PCB development during the Preliminary Design Review and Critical Design Review phases so that the use of protoboards is not necessary.

This payload also demonstrated how much time is required for testing and debugging of electronic hardware. For both the cameras and IMU, implementations that were expected to take 1-2 days extended over the course of 1-2 weeks each. This was in part due to the complexity of the protoboard's wiring, which obscured underlying wiring issues which would have otherwise been simple to identify.

4.5 Payload Software Lessons

The payload software went through multiple iterations which were completely different from each other. This was because of poor planning and inadequate research on algorithms, libraries, and other software dependencies. In the future, the team should do more research before starting development of code.

In a similar manner, all potential conditions that the payload might encounter ought to be considered during the design phase. For example, during the team's payload demonstration flight, the effects of motor tracking smoke and clouds proved to cause issues to the programs that the team had not accounted for during the design phase (Figure 15).

Figure 15: Image obstructed by motor tracking smoke and/or clouds

Commented [MW42]: Make to sure to make a mention of the results of the payload demonstration flight (include the image that was obstructed my clouds because that is def something we didn't think of until too late)

The software also was not developed according to proper methodology. Utilizing something like the agile methodology while developing code and developing testing according to the methodology is something that the team should consider for future payloads. These tests should also include potential flight tests through the subscale and vehicle demonstration flights to give an idea of the possible results. Such tests would have assisted with the issues we faced with not knowing the impact of cloud cover and rocket motor trailing smoke on the images taken by the camera.

Lastly, the payload software team should diversify and include more physics, aerospace and mechanical engineering majors with expertise in solving dynamics, fluids, and various problems which are limited in the curriculum for computer science majors. Lack of this caused delays in developing and working with the IMU code to find the displacement.

4.6 Payload Mechanical Lessons

The payload experienced the most structural design changes between the Preliminary Design Review and the Critical Design Review. This was because a subscale model of the payload was flown and tested during the subscale flight. This subscale model provided extensive insight into where the structural components needed improvement and how to improve them. It was realized during subscale launch that the retention system could be simplified, the payload sled needed to be modified, and the camera mounts were too large and too difficult to assemble. All of these realizations occurred because of the subscale prototype. For future competitions, the team will attempt to fly a model of the payload. This will help the future team possibly identify any issues with the payloads mechanical systems and rectify them well before the final design is made.

The team also learned the benefits of 3D printing models of the payload as well as 3D printing final components that don’t experience large stresses during flight. Due to the nature of this year’s competition, the payload design was heavily software centered and thus required minimal mechanical systems. With a payload that wasn’t being deployed, 3D printing the components reduced manufacturing costs and time, as well as increased the amount of testing that could be completed. 3D printing allows multiple models to be made and iterated repeatedly without wasting large amounts of money on expensive materials. This was most important for the camera mounts, which went through many design changes throughout the competition. This was only possible because they were 3D printed, sometimes around three times a week. Also, 3D printing enables the use of complex or unconventional shapes to be used. This was most evident in the camera mounts design, which would have been difficult using another manufacturing process.

Commented [MW43]: Just say difficult impossible isn't a good word to use.

We could have CNC'd them (:

5. Competition Summary

5.1 Summary of Experiences

Overall, the team sustained experiences and grew in a variety of different aspects including design, manufacturing, technical documentation, scheduling, and budgeting. Members and leads alike gained technical experiences through the design and implementation of ideas for the project and learned how to properly describe and explain those ideas through a technical report. These experiences helped students feel increasingly prepared to enter careers in aerospace engineering.

Being a part of such a large group working towards a common goal emphasized the importance of constant communication. While the team sustained healthy communication, even more consistent and timely communication would have assisted in a smoother execution of the project. It also illustrated how important it was to have a schedule and consistently stick to it. While the team had and maintained a schedule, the complications that can arise, such as shipping times, funding, and unforeseen setbacks, were not always accounted for. Thus, despite the planning involved, on several occasions, the leadership team found themselves on a very tight timeline that the team would hope to avoid in the future. Plus, it was learned that just having a schedule is only one part of executing a project; it is also important that the timing of each item on the schedule be correct. The importance of prototype testing, testing early on, and allowing sufficient time to analyze and respond to test results is something the team hopes to improve upon in future years. Due to the compressed schedule that was experienced at certain times, some key tests, particularly those pertaining to the payload, were never performed and led to some of the difficulties that were encountered later in the project.

Commented [PJ44]: a little concerning to just leave in there

5.2 Scientific Value of Project

Engaging in projects such as the NASA Student Launch competition allows students the opportunities to learn about and contribute to the scientific community not just within their team but at their institutions and across the country through interactions with other student teams and representatives of Student Launch. The project NASA set forth this year focused on interplanetary solutions and gave students a perspective on the kinds of engineering problems engineers are solving today. Navigating a new planet comes with many fundamental problems that have already been solved on Earth. However, applying the same solutions on another planet involves different perspective solutions. In this instance, we were tasked with determining a vehicle's location on a planet where reference locations were unknown. On Earth, the solution involves GPS. However, this solution is not feasible on another planet or celestial body. In this regard, the NASA USLI competition has allowed us to grasp varying solutions that may be needed as we enter this era of human exploration.

In addition to the value obtained through working on the project this year, the experiment this year also prompted students to consider further studies building off the project this year and relating even further to the spirit of the competition. For example, the team has discussed how being able to determine location mid-flight could be utilized to land a vehicle in a specific location.

Finally, being a part of this project encouraged students to engage in collecting scientific data through material testing. Strength testing was performed on the fiberglass material utilized for the airframe and fins to determine its compressive and bending strength. This data allowed the team to numerically ensure that its choice in material would be durable enough to withstand landing forces instead of purely through trial and error. This data was crucial to understanding the benefits of fiber orientation for fins and confirming that fiberglass was a beneficial material to utilize as well as encourages the team to consider material testing in the future.

5.3 Hours Summary

The hours worked throughout the course of the entire project were kept track of using an Excel document where subteam leads input their time. A summary of the total hours spent on the project is shown (Table 4, Figure 16).

Proposal	293.5
Preliminary Design Review	405
Critical Design Review	502
Flight Readiness Review	628
Flight Readiness Review Addendum	102
Post-Launch Assessment Review	104
STEM Engagement	28
Social Media Engagement	36
Launch Activities	85
Total	**2183.5**

Table 4: Hours Summary

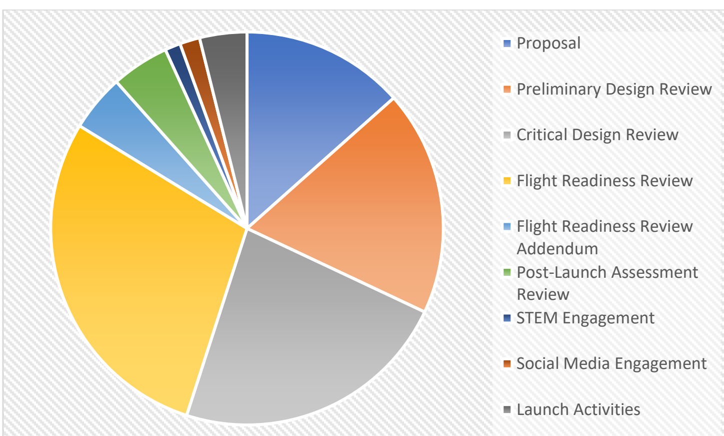

Figure 16: Hours Summary

5.4 STEM Engagement Summary

STEM engagement events were performed throughout the course of the year. A brief summary of the events is shown (Table 5).

Number	Event title	Students	Type	Description
1	P.K. Yonge Developmental Research School	12	Direct Educational	Assessment on understanding of stability, designed and built straw rockets
2	NEFEC College and Career Fair	315	Direct Educational	Assessment on understanding of stability, designed and ran OpenRocket simulations.
3	Benton Engineering Council Efair	162	Direct Outreach	Explained rocketry concepts and the team's design process and answered questions from students
4	Grace at Fort Clarke United Methodist Church Trunk or Treat	80	Indirect Outreach	Handed out straw rocket kits and candy to students.
Total	4	569	-	-

Table 5: STEM Engagement Summary

A Direct Education Engagement Event was conducted with P.K. Yonge High School in November 2021 with 12 students. The learning target for the rocket design and modeling challenge was to educate students on the basics of aerodynamics. Specifically, students were taught about center of gravity (CG), center of pressure (CP), and stability. The students were taught about the importance of these concepts to flight dynamics such as wind and drift and learned how stability can be calculated from CG and CP. From this, students learned how to create their own rocket design with an appropriate stability margin for flight. Students also heard a presentation on the team's structure. The students were assessed with a quiz that resulted in 92% correct results.

A Direct Education Engagement Event was conducted through the North East Florida Educational Consortium (NEFEC) College and Career Fair in February 2022 with 315 students. The learning target for this activity was to learn basic flight dynamics concepts, specifically understanding center of gravity (CG), center of pressure (CP), and stability of a model rocket. Students also learned the fundamentals of flight simulation through OpenRocket software and got to compare a specific rocket simulation with the physical rocket structure. A team member's personal National Association of Rocketry (NAR) Level 1 rocket and simulation was utilized for demonstration in this learning target. The students were assessed with a quiz that resulted in 68% correct results.

A Direct Outreach Engagement event was conducted with the Benton Engineering Council at their E-Fair event in February 2022 at the University of Florida with 169 students in attendance. The learning target for the activity was to learn about the design process and fabrication techniques of rocketry. The students learned through a presentation from team leaders, where each subteam and their purpose was introduced. The students were introduced to structures, avionics and recovery, flight dynamics, payloads, and testing. Following the presentation, the students engaged in a discussion centered around the design and components of a rocket. The discussion was supplemented by having various components, such as the payload, and some model rockets, such as a team member's personal National Association of Rocketry (NAR) Level 1 rockets, on display. The students were able to develop their understanding by engaging with the physical rockets and their components.

An Indirect Outreach Engagement Event was conducted with Grace at Fort Clarke United Methodist Church in November 2021. The learning engagement event was at a Trunk or Treat in October with 80 kids. The attendees met the members of the team and observed the posters and rockets on display. Candy and straw rocket coloring kits were passed out and some students took pictures with the rockets and team members.

5.5 Budget Summary

5.5.1 Final Cost Breakdown

The final overall cost and budget summary was calculated after the competition and is shown below.

Category	Total Cost ($)
Full-Scale	2215.90
Travel	2900
Subscale	737.33
Testing	35.90
Total:	5889.13

Table 6: Budget Breakdown

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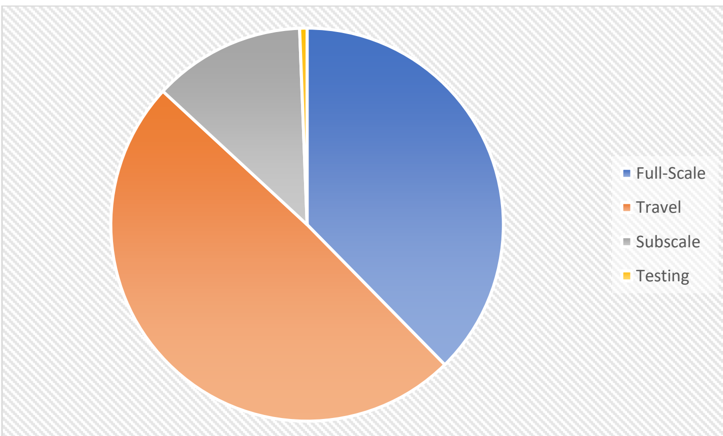

Figure 17: Budget breakdown pie chart

5.5.2 Final Funding Breakdown

The final breakdown for how the team was funded is shown below.

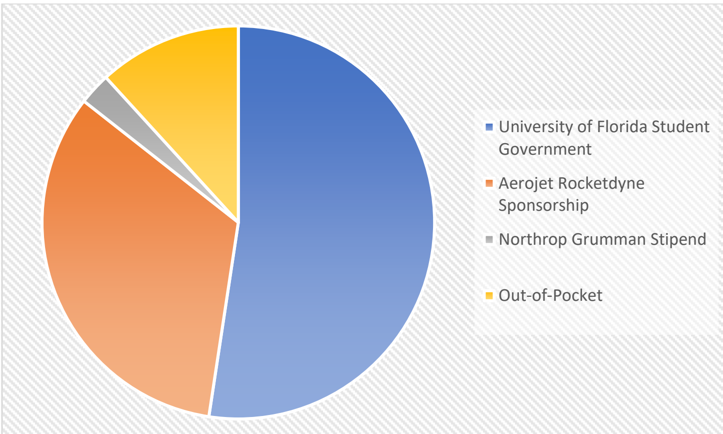

Figure 18: Funding breakdown by source