Gator Locator

NASA Student Launch 2022 Flight Readiness Review

University of Florida
Swamp Launch Rocket Team
MAE-A 324
939 Center Drive
Gainesville, FL 32611
March 7, 2022

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1. Summary of Flight Readiness Review Report

1.1 Team Summary

1.1.1 Team Name

Swamp Launch Rocket Team
University of Florida

1.1.2 Team Address

MAE-A 324
939 Center Drive
Gainesville, FL 32611

1.1.3 Team Mentor

Jimmy Yawn, Level 3 Certified
NAR #85660, TRA #09266
jimmy.yawn@sfcollege.edu
(352) 281-2025

1.1.4 Final Launch Location

Huntsville, AL
Primary date: April 23, 2022
Backup date: April 24, 2022

1.1.5 Backup Launch Location

Tripoli Tampa Rocketry Association, Prefecture #17
Launch date: April 16, 2022
Jim Harris, Range Safety Officer
rocketman@sprynet.com

1.1.6 Project Hours

The total number of hours spent on the design, manufacturing testing, planning, meeting, and writing for the Flight Readiness Review was 628 hours.

1.1.7 STEM Engagement

The team completed 2 Direct Educational events, engaging with 327 students total and meeting the requirements for direct engagement (Table 1). The team also performed 1 Direct Outreach event and 1 Indirect Outreach event, reaching a total of 242 additional students.

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.

Table 1: STEM Direct Engagement Summary

1.2 Launch Vehicle Summary

The presented measurements are taken from the as-built launch vehicle prior to launch (Table 2).

Vehicle Parameters		
Section	**Mass (oz)**	**Exterior Length (in)**
Nosecone	14.8	16
Forward	117.8	38
Aft	255.2	57
Full Launch Vehicle	387.8	111

Motor	Aerotech L1090W
Rail Size	1515, 12 ft
Target Altitude	4578 ft
Parachutes (drogue/main)	24 in Rocketman / 72 in Fruity Chutes Iris Ultra
Ejection Charge [drogue]/[main] (black powder)	[1.5 g / 1.875 g] / [2.0 g/2.5 g]
Deployment Altitudes [drogue]/[main]	[Apogee / Apogee + 1 s] / [600 ft/ 550 ft]
Altimeters	Stratologger CF / Entacore AIM

Table 2: Vehicle Summary

1.3 Payload Summary

The payload is titled Land-Mark Watney. Two aft-facing cameras collect images of the launch field throughout flight. These images are used in OpenCV to determine the vehicle's location at time of image capture. An 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. The final vehicle landing grid location is then calculated and transmitted to a ground station.

2. Changes Made Since CDR

2.1 Changes Made to Vehicle Criteria

- A 4:1 Ogive plastic, fiberglass reinforced nosecone was substituted for the previously listed 5:1 Ogive filament wound fiberglass nosecone. As a result, the recovery GPS location was changed to be within the payload bay. The recovery GPS is not a part of the payload mission.
- The avionics key mounts were made thicker, from 0.1 into 0.2 in. A chamfer was also added to ensure the key mount did not interfere with the coupler tube. The battery holders were also altered to pass the wires directly up to the sled instead of out to the side.
- The recovery harnesses as built are shorter than the recovery harnesses described in CDR. The as built recovery harnesses are 18 ft and 18.5 ft long compared to the 25 ft long recovery harnesses planned in CDR. The shorter harnesses were used due to budget constraints the team encountered, and the shorter harnesses were already available for the team to use.
- An additional hole was added to the avionics bay switch band to act as a pressure port for the barometers on the altimeters. The hole is 0.2 in in diameter. The pressure port was considered more consistent than allowing air to pass around the arming switches. Because of this, the holes made to access the arming switches of the launch vehicle were changed from a 0.75 in diameter hole to a 0.5 in hole to limit the amount of air passing around the arming switches. The combination of changing the hole size for the key and the addition of a pressure port was done to have more consistent static pressure readings in the avionics bay.
- The secondary ejection charge timing for the first separation event was changed from 0.5 s after apogee to 1 s after apogee. This change was made to further avoid over pressurizing the airframe and allow for separation to potentially occur before the second charge goes off.

2.2 Changes Made to Payload Criteria

- The electronics printed circuit board was replaced with a perforated board due to part arrival timing constraints.
- A multiplexer was added to the Arducam OV5642 I^2C communication pins to mitigate an address conflict encountered during camera testing.

2.3 Changes Made to Project Plan

- The primary funding source for the team, University of Florida’s Student Government, provided reduced funds, causing a budget decrease for the Spring 2022 semester.
- The team operated on a reduced budget, resulting in greater out-of-pocket and sponsorship expenses, and using components already in inventory available to the team.

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Reasons for Changes Since CDR

For the CDR report, the nosecone was listed as a filament wound G12 fiberglass 5:1 Ogive nosecone with a 4.02 in diameter base. The nosecone has changed to a plastic, fiberglass-reinforced 4:1 Ogive nosecone with a 4.02 in diameter base. This change was necessary as the team was not able to source another 5:1 Ogive nosecone within the time frame that had been set out for the vehicle demonstration flight on February 19, 2022. Therefore, the only option was a 4:1 Ogive nosecone that was already in inventory. This change was approved by the NASA Student Launch Board.

The location of the recovery Big Red Bee 900 GPS was changed from the nosecone to the payload bay because of the change in nosecone. This was done because the replacement nosecone and nosecone shoulder were no longer separable, so manipulation of the recovery GPS was no longer viable. This change was approved by the NASA Student Launch Board.

The recovery harnesses were changed to an 18 ft and 18.5 ft long harness. This change was necessary as the two 25 ft tubular Kevlar recovery harness was not acquired due to budget constraints and the availability of the slightly shorter harnesses. The material and width were kept as similar as possible from the selection of harnesses available. The length of the as built recovery is still sufficient to ensure the separated sections of the launch vehicle do not collide.

A pressure port was also added to the avionics bay switchband, and the holes for the arming switches were reduced in size to ensure the altimeters' barometers read the air pressure properly when at altitude. The holes used to access the key lock switches were also decreased in size so that less air would pass around the switches and interfere with the altimeter's barometers. The original hole sizes could have allowed moving air to interact with the barometers.

3.1.2 Separation Locations

There are two separation points on the launch vehicle (Figure 1). Black powder ejection charges were used to induce separation. The ejection charges were made using grams instead of ounces to make it easier to measure small amounts of powder.

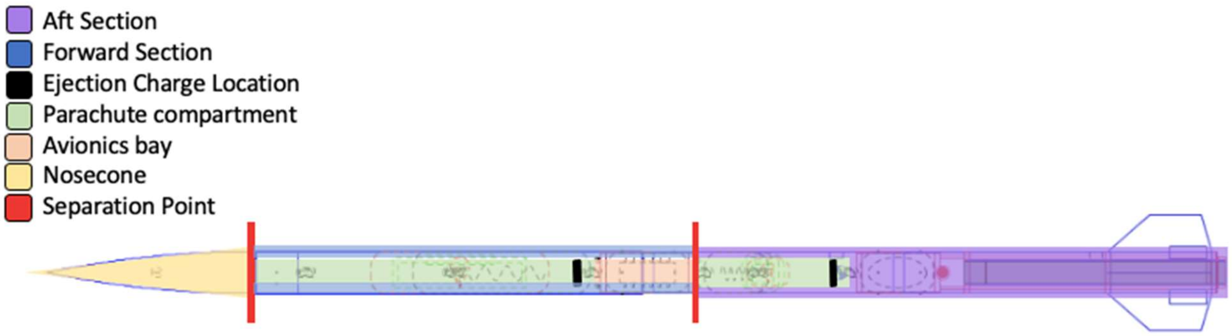


Figure 1: Separation Points

The Ideal Gas Law was used to calculate an approximate mass in grams for each primary ejection charge (1). The approximate mass was then rounded to make the values easier to work with. The rounded values were used in ejection charge separation demonstrations (Test #11, Test #12). The secondary ejection charges were made to be 25% larger than the primary ejection charges to ensure separation occurred (Table 3). An example calculation is presented with a charge size of 1.3 g.

$$\frac{F}{A} * V = nRT \tag{1}$$

$$360\,\frac{lbs}{ft^2} * 0.158\,ft^3 = \left(\frac{1.3\ g}{453.592^{g}/_{lbs}}\right)\left(5.97995\,\frac{ftlbs}{lbs*R}\right)(3307\ R)$$

Ejection Charge Masses		
Ejection Charge	**Primary (g)**	**Secondary (g)**
First Separation	1.50	1.88
Second Separation	2.00	2.50

Table 3: Ejection Charge Masses

The first separation event occurs at apogee to deploy the drogue parachute by separating the aft and forward sections at the avionics bay coupler (Figure 2). The primary ejection charge is programmed to go off at apogee. The secondary ejection charge is programmed to go off 1 s after apogee. The delay is to avoid over pressurizing the airframe. The ejection charge is located just above the payload bulkhead to help push the drogue parachute out of the Aft Section. The two separated sections remain tethered with the use of an 18.5 ft long 0.5 in wide tubular Kevlar recovery harness. The harness is secured to each section with the use of a 2 in ¼-20 304 Steel forged eyebolt and 2 in Zinc-plated Steel quick link. The eyebolt has a carrying capacity of 500 lbs. The quick link has a carrying capacity of 1000 lbs. The recovery harness carrying capacity was tested up to a limit of 50 lbs in Test #13. The drogue parachute will be secured to the recovery harness with the use of a swivel and quick link. It was protected from the hot ejection gasses with the use of a 12 in by 12 in flame-resistant fabric parachute protector.

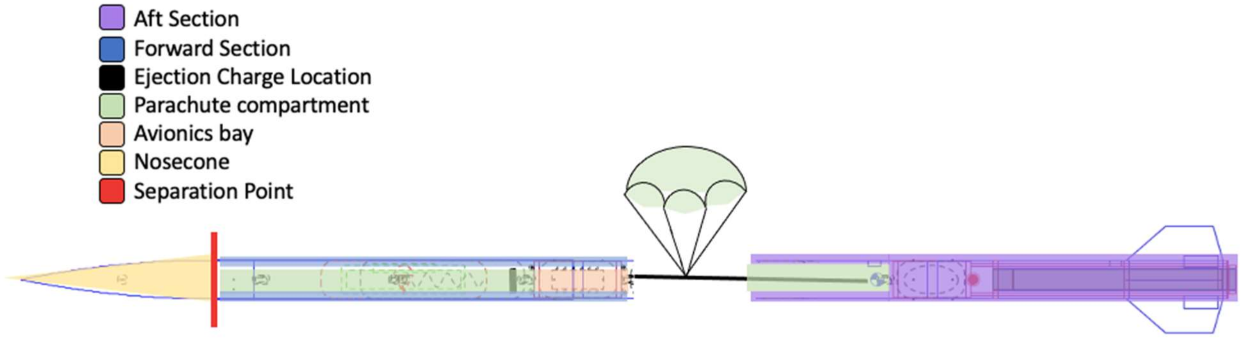


Figure 2: First Separation Event

The second separation event occurs at 600 ft above ground level to deploy the main parachute by separating the nosecone and forward sections (Figure 3). The primary ejection charge is programmed to go off at 600 ft above ground level. The secondary ejection charge is programmed to go off at 550 ft. The secondary ejection charge altitude allows for 0.7 s to pass after the primary ejection goes off to avoid over pressurizing the airframe. The ejection charges are located on the avionics bay bulkhead to push the main parachute out of the forward section. The separated sections remain tethered together with the use of an 18 ft long 0.5 in wide tubular Kevlar recovery harness. The harness is secured to eyebolts located on the bulkheads of each section with the use of quick links. The main parachute is secured to the harness with the use of a swivel and quick link. A 24 in by 24 in flame-resistant fabric parachute protector is also attached to the harness to protect the main parachute from the hot ejection gasses during separation.

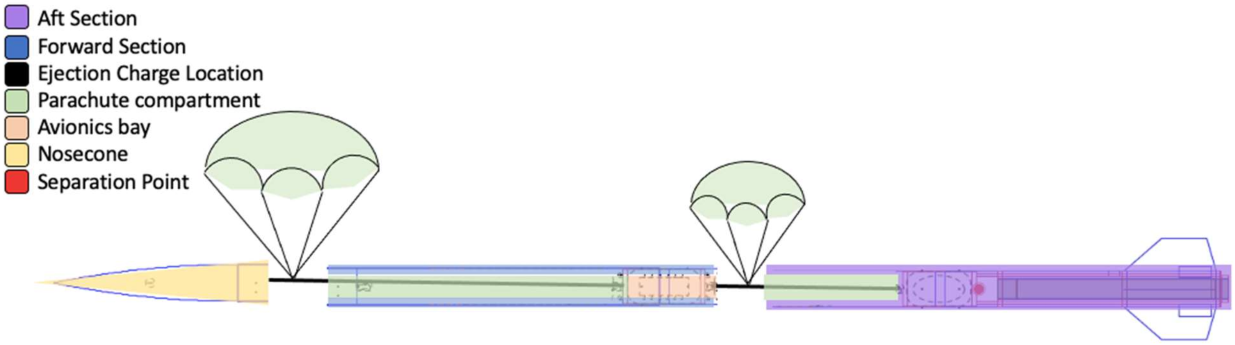


Figure 3: Second Separation

3.1.3 Launch and Recovery Features

3.1.3.1 Structural Elements

The launch vehicle fins are installed through fin slots that are milled in the aft section. The fins are first epoxied to the outer face of the motor tube and then epoxied to the inner and outer faces of the airframe using RocketPoxy. This epoxy configuration, in which the fins are epoxied in 6 separate locations each, yields a mechanical bond between the fins and the rest of the launch vehicle. As a result, the fins provide extra support for the motor assembly and help to achieve a maximum stability of 4.72 cal. There are two 1515 plastic rail buttons placed 8.0 in and 38.5 in from the aft of the launch vehicle, respectively (Figure 4).

Figure 4: Rail Button Distance from the Thrust Plate

The avionics bulkheads are made from Type II PVC stock of diameter 3.90 in outer diameter and a 3.76 in inner diameter. The total thickness is 1.0 in, with 0.5 in of outer diameter and 0.5 in of inner diameter (Figure 5). To keep them in place during flight, two 0.25 in threaded rods clamp the bulkheads together against the avionics coupler. The bulkheads protect the contents of the avionics bay from ejection charge gases. The payload bulkhead is also made from Type II PVC stock. The outer dimension of the bulkhead measured 3.90 in, and the inner diameter measured 3.76 in. Like the avionics bay bulkhead, the total thickness is 1.0 in with 0.5 in of outer diameter and 0.5 in of inner diameter. The payload bulkhead was epoxied into the forward end of the payload bay. The epoxy seals the payload bay from the hot ejection gasses of the first separation event. This prevents ejection charge gases from leaking into different sections, and causing the launch vehicle to not successfully separate, and the parachutes to not deploy.

Figure 5: As-built Bulkhead and Epoxied Eyebolt

Both the avionics and payload bulkheads are attached to the recovery harness with a 2.0 in long ¼-20 304 Steel eyebolt, which has a carrying capacity of 500 lbs (Figure 6). A pair of hex nuts are secured on the shaft of each eyebolt to the bulkhead. The hex nuts are epoxied to the shaft and bulkhead to seal any gaps and ensure there are no ejection gases leak. These structural features of the bulkheads allow for a safe separation and parachute deployment, as they keep the separated launch vehicle sections connected to prevent free-falling debris.

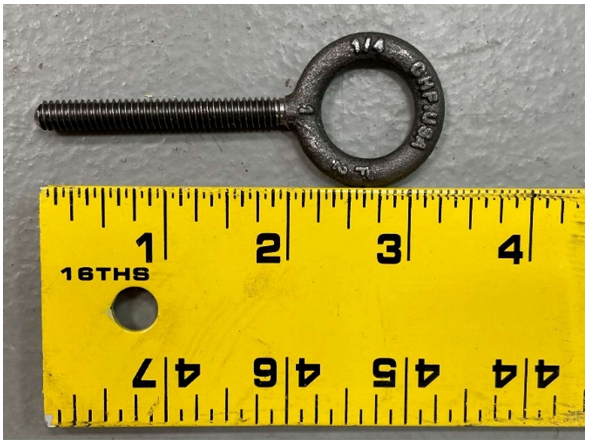


Figure 6: Eyebolt Used

A 2.0 in inner length Zinc-plated Steel quick link was used to connect the recovery harness to the eyebolts during assembly. The quick links have a carrying capacity of 1000 lbs (Figure 7).

Figure 7: Quick Link

The recovery harnesses in the launch vehicle are made from 0.5 in wide tubular Kevlar (Figure 8). The recovery harness connects the separated sections of the launch vehicle during descent. The width of 0.5 in helps mitigate the pressure on the airframe during parachute inflation. From mission performance predictions, the maximum load on the recovery harness is predicted to be around 40 Ibs, and the testing of the recovery harness shows that the recovery harness can sustain loads of 50 Ibs (Test #13).

Figure 8: Recovery Harness Thickness

3.1.3.2 Electrical Elements

The avionics bay was used to house the altimeters that control the separation events. The altimeters were attached to the avionics sled to ensure they were not damaged during flight. 4-40 screws and nuts were used to ensure the altimeters did not come off the sled during flight. The avionics sled was retained in the avionics bay by passing two threaded rods through the sled into the avionics bay bulkheads. 9V batteries were held inside a battery holder secured to the threaded rods below the sled. Their movement was restricted by the sled and threaded rods. Arming switches were wired in series between the battery and altimeter (Figure 9). Key lock switches were used as the arming switches to protect against sudden power failure from a loose switch. Wires were properly insulated to protect against shorts caused by incidental contact during flight. The switches for each altimeter were wired independently from each other.

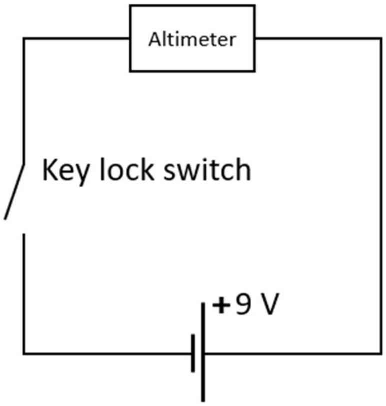


Figure 9: Altimeter and Battery Diagram

3.1.4 Flight Reliability Confidence

An analysis of different components on the launch vehicle demonstrated a conclusion on the flight reliability confidence (Table 4).

Mission Success Criteria	Verification
Apogee will be within competition range where target apogee is 4578 ft.	In the Vehicle Demonstration Flight, an apogee of 5079 ft was achieved.
The drogue will be deployed at apogee.	Drogue ejection demonstration, Test #12, and recovery altimeter functionality test, Test #7 ensured there was sufficient charge to deploy the drogue parachute and ensured the capability of the altimeter to deploy at the appropriate time.
The main parachute will deploy at 600 ft above the ground.	Main ejection demonstration, Test #11, and recovery altimeter functionality test, Test #7 ensured there was sufficient charge to deploy the main parachute and ensured the capability of the altimeter to deploy at the appropriate time.
The vehicle will remain within the drift radius.	In the Vehicle Demonstration Flight, the vehicle drifted 1458 ft, remaining within the 2500 ft drift radius.
The launch vehicle will land safely, being recoverable and reusable.	In the Vehicle Demonstration Flight, the launch vehicle had a ground hit velocity of 17 ft/s. The vehicle landed safely and did not sustain any damage.

Table 4: Mission Success Criteria

3.1.5 Vehicle Construction

The as-built vehicle was comprised of three main sections: the nosecone, forward, and aft sections (Figure 10, Figure 11).

Figure 10: NASA USLI Full-Scale Rocket

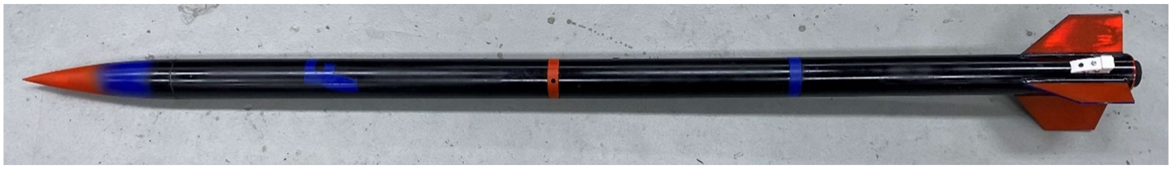
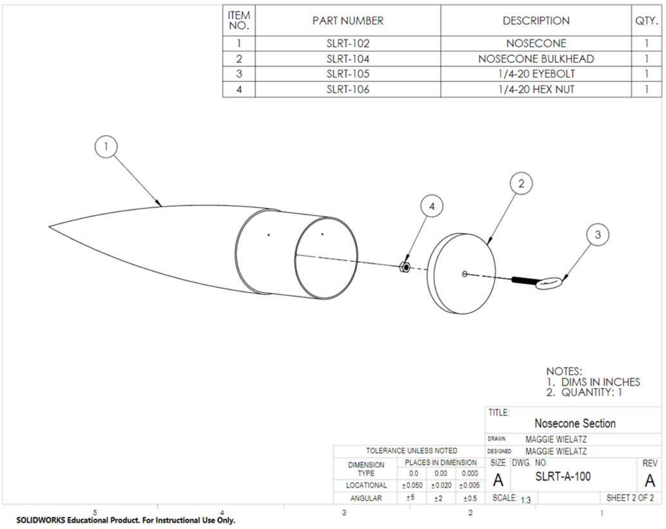


Figure 11: NASA USLI As-Built Full-Scale Rocket

3.1.5.1 Nosecone Section Construction

The nosecone section is comprised of a 4:1 ogive plastic fiberglass reinforced nosecone with a built-in coupler instead of the originally designed separable coupler, a nosecone bulkhead, and an ¼-20 eyebolt (Figure 12). As a result, the recovery GPS was moved from the nosecone to the payload bay but is not a part of the payload experiment.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-102	NOSECONE	1
2	SLRT-104	NOSECONE BULKHEAD	1
3	SLRT-105	1/4-20 EYEBOLT	1
4	SLRT-106	1/4-20 HEX NUT	1

Figure 12: Nosecone Section Assembly Drawing

The nosecone bulkhead was turned to size on a lathe (Figure 13). Before epoxying the bulkhead into the nosecone, both the bulkhead and nosecone were sanded using 80-100 grit sandpaper.

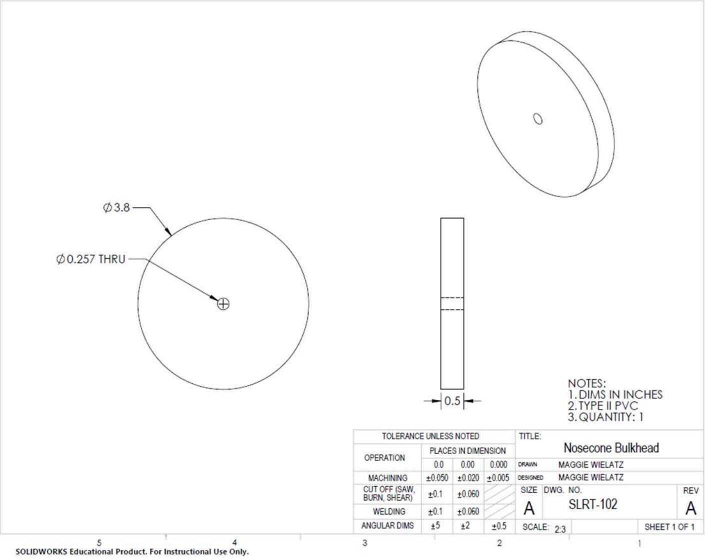


Figure 13: As-Built Nosecone Bulkhead Drawing

The eyebolt was secured in place using hex nuts and epoxied using RocketPoxy. Next, the bulkhead was inset into the nosecone and epoxied using RocketPoxy. The shear pin holes were drilled to a diameter of 0.081 in with the forward airframe in place around the nosecone coupler to ensure correct alignment of the holes. After completing construction of the nosecone section, the exterior was wet sanded using 600 grit sandpaper. The exterior was then spray painted with one layer of primer and two layers of paint. Painter's tape was used to protect the coupler on the nosecone (Figure 14).

Figure 14: As-Built Nosecone Section

3.1.5.2 Forward Section Construction

The forward section is composed of the forward airframe and avionics bay (Figure 15).

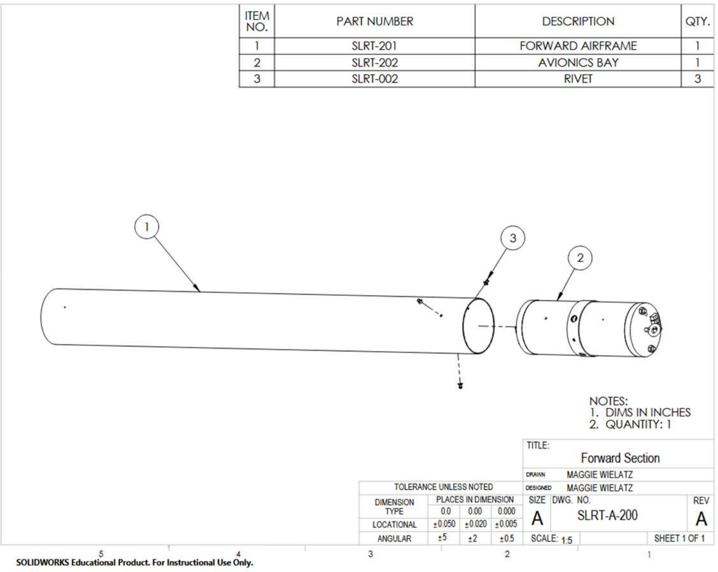


Figure 15: Forward Section Drawing

3.1.5.2.1 Forward Airframe Construction

The 4.02 in diameter fiberglass airframe was cut to a length of 37.0 in using a Roll-in Bandsaw. After the cuts were made on the Roll-in Bandsaw, 80-100 grit sandpaper was used to debur the edges of the airframe (Figure 16).

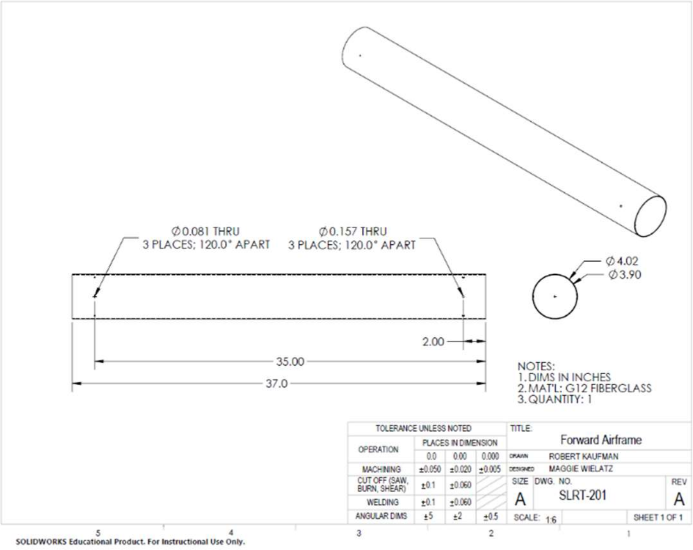


Figure 16: Forward Airframe Drawing

After cutting the airframe to size, the locations of the shear pins and rivets were measured and marked. Once the avionics bay switchband was epoxied using RocketPoxy, the avionics bay and forward airframe were assembled, and the 0.157 in diameter rivet holes (circled in blue) were drilled 2.00 in from the aft end of the airframe. This ensured proper alignment of the rivets between the forward airframe and the avionics bay (Figure 17).

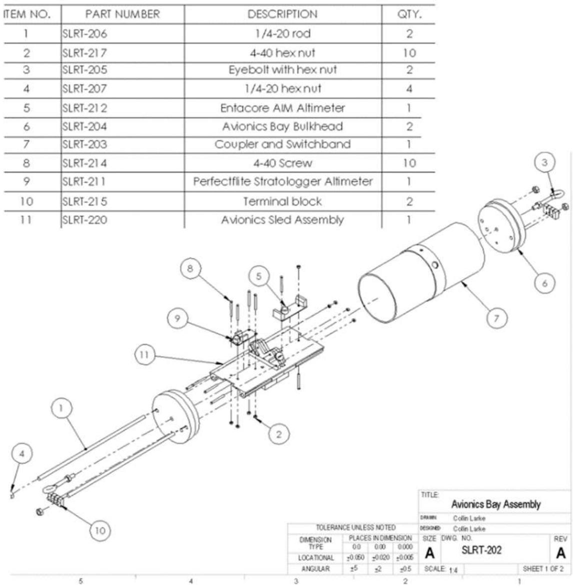
Figure 17: Rivet (left) and Shear Pin (right) Holes in Forward Airframe

After completing construction of the forward airframe, the exterior was wet sanded using 600 grit sandpaper. The exterior was then spray painted with three layers of paint. The “F” was spray painted using a stencil and blue painter’s tape was used to protect the original black coat on the airframe (Figure 18).

Figure 18: As-Built Forward Airframe

3.1.5.2.2 Avionics Bay Construction

A sled was retained inside the avionics bay with ¼-20 threaded rods. The threaded rods were passsed through the avionics bay and sled assembly. Hex nuts were fastened to the ends of the threaded rods to hold the bulk heads tightly to the avionics bay coupler. Terminal blocks were epoxied to the outside of the bulkheads to connect altimter wires to ejection charges (**Error! Reference source not found.**).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-206	1/4-20 rod	2
2	SLRT-217	4-40 hex nut	10
3	SLRT-205	Eyebolt with hex nut	2
4	SLRT-207	1/4-20 hex nut	4
5	SLRT-212	Entacore AIM Altimeter	1
6	SLRT-204	Avionics Bay Bulkhead	2
7	SLRT-203	Coupler and Switchband	1
8	SLRT-214	4-40 Screw	10
9	SLRT-211	Perfectflite Stratologger Altimeter	1
10	SLRT-215	Terminal block	2
11	SLRT-220	Avionics Sled Assembly	1

Figure 19: Avionics Bay Exploded View

The 3.90 in diameter G12 fiberglass tubing was cut to a length of 9.0 in using a Roll-in bandsaw. Then, 80-100 grit sandpaper was used to debur the edges of the avionics bay (Figure 20).

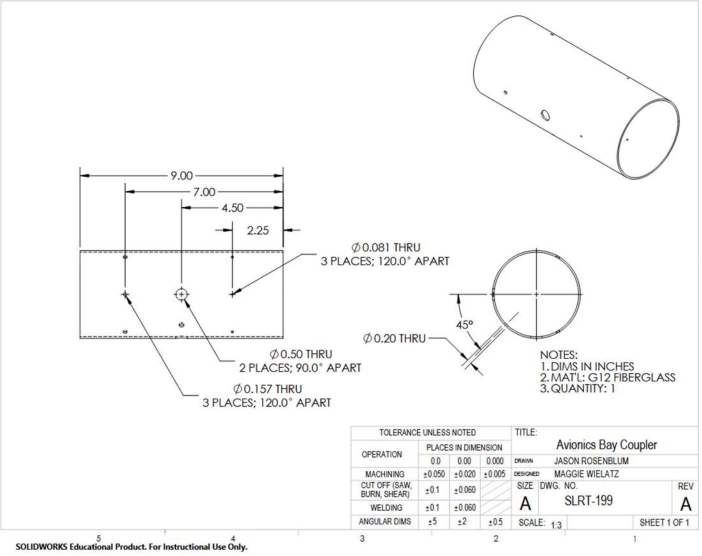


Figure 20: Payload Coupler Drawing

The same procedure was followed to cut the 1.00 in long fiberglass switchband from remaining 4.02 in diameter G12 fiberglass tube (Figure 21). The interior of the switchband and center of the avionics bay were sanded using 80-100 grit sandpaper in preparation for epoxying. The switchband was then placed over the avionics coupler and epoxied with RocketPoxy (Figure 22).

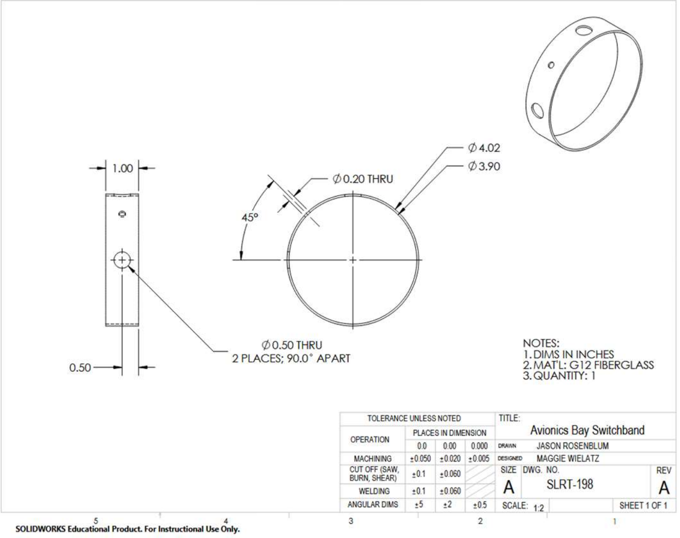


Figure 21: Payload Bay Switchband Drawing

Figure 22: As-Built Avionics Coupler With Switchband

After epoxying the switchband onto the coupler, two 0.5 in diameter holes were drilled through the switchband and coupler 90 deg apart to serve as the avionics electronics key-lock switch access ports. The 0.154 in diameter rivet holes were drilled when the avionics bay was inserted into the upper aft airframe. They were drilled 2.0 in from the forward end of the avionics bay. The 0.081 in diameter shear pin holes were drilled when the avionics bay was inserted into the upper aft airframe (Figure 23). They were drilled 2.25 in from the aft end of the avionics bay. This is 0.25 in further forward in the avionics coupler than the design intended. However, this discrepancy does not affect the function or performance of the vehicle.

Figure 23: Rivet (left) and Shear Pin (right) Holes in the Avionics Bay

The bulkheads that fit on the ends of the avionics bay were manufactured next. The stepped cylindrical shape of the bulkhead was machined on a lathe while the holes were drilled on milling machines (Figure 24, Figure 25).

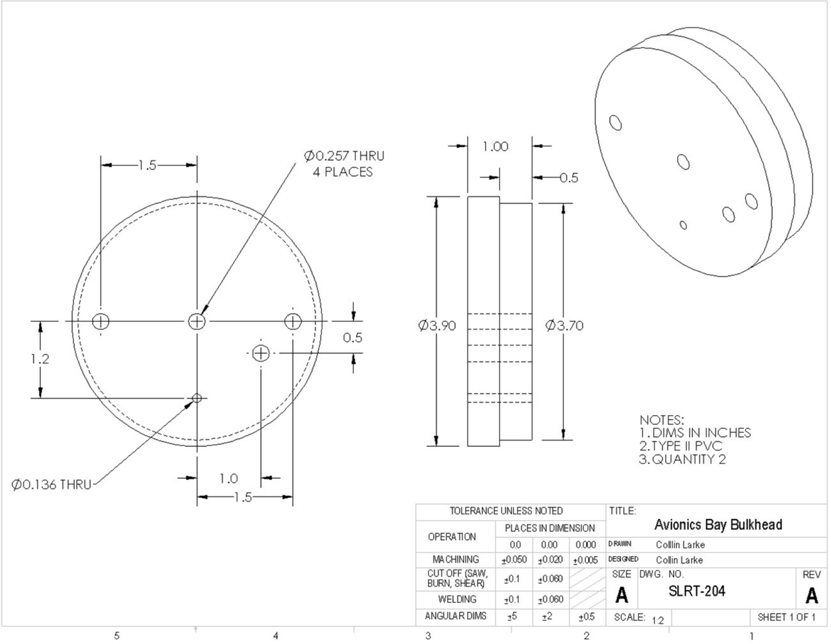


Figure 24: Avionics Bay Bulkhead Drawing

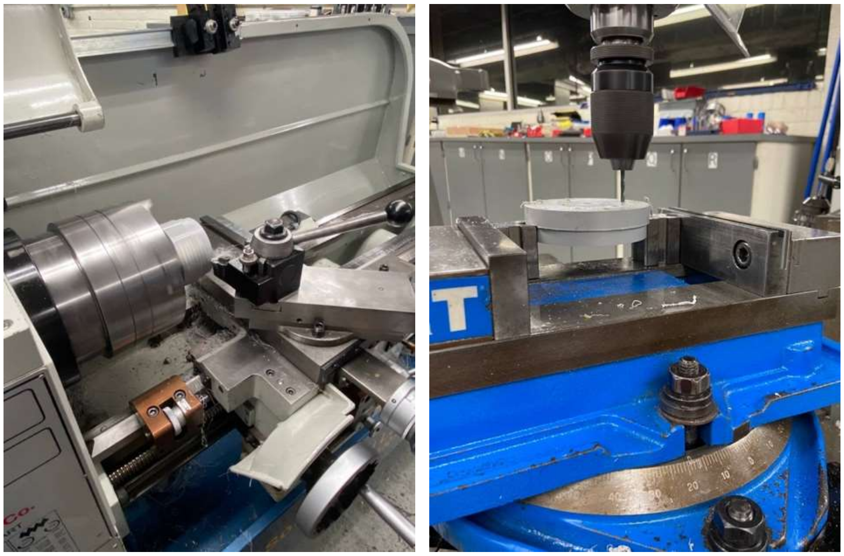


Figure 25: Turning the Bulkhead on the Lathe (left) and Drilling Holes on the Milling Machine (right)

After the holes were drilled, a 2 in ¼-20 eyebolt was epoxied into the center hole of each bulkhead. The eyebolt faced out of the wider diameter section of each bulkhead. The eyebolts were first coated in RocketPoxy then secured wrench tight with hex nuts in the bulkhead. The epoxy ensured no ejection gas passed around the threads of the eyebolts and into the avionics bay during separation. A terminal block was then epoxied over the 0.136 in hole using RocketPoxy (Figure 26).

Figure 26: As-built Bulkhead

The key mount piece was held in place with 4-40 screws and hex nuts. The threaded rod held the battery holder in place below the sled (**Error! Reference source not found.** 27).

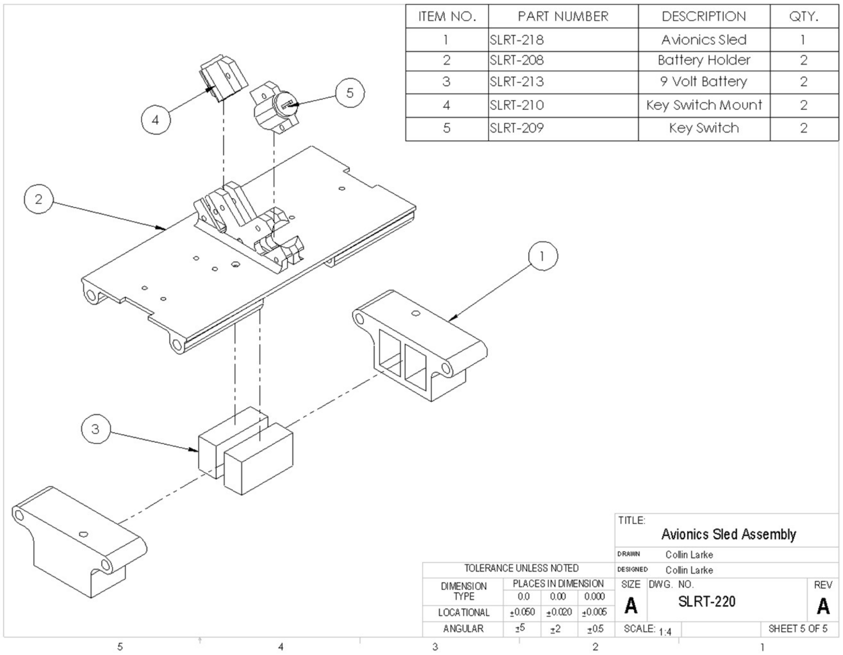


Figure 27: Avionics Sled Assembly Drawing

The 3D printed elements were assembled (**Error! Reference source not found.** 28).

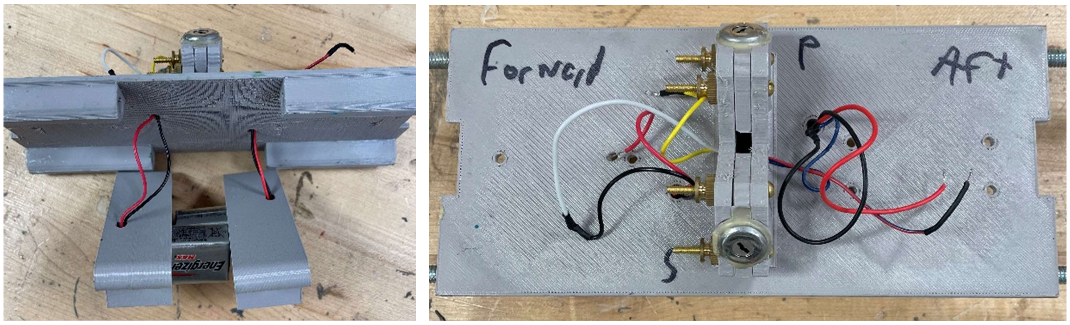


Figure 28: As Built Avionics Sled Assembly

An avionics sled was 3D printed to fit inside the avionics bay. The avionics sled was printed from PETG filament with a 20% infill (Figure 29).

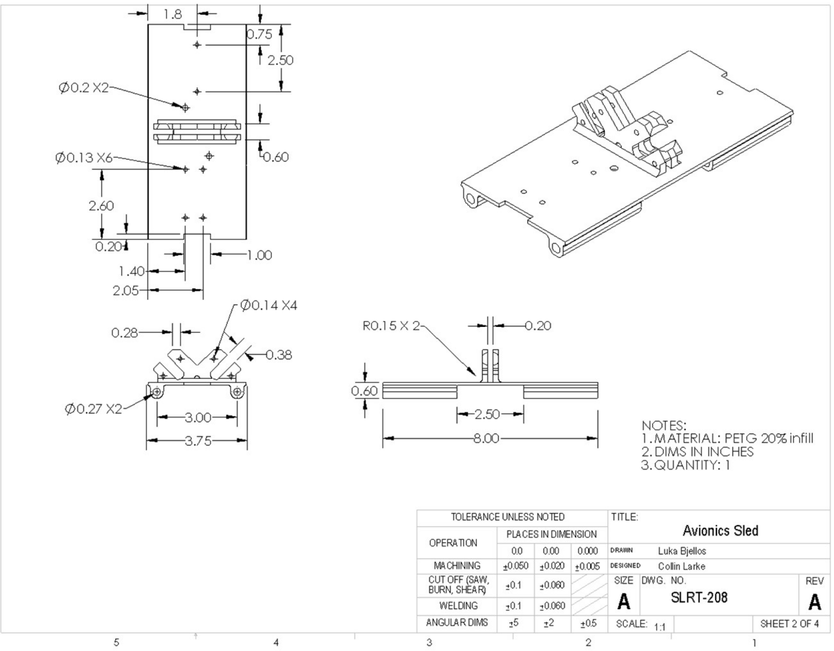


Figure 29: Avionics Sled Drawing

A modular key mount was 3D printed from PETG filament with a 20% infill. This allowed for the keys to be replaced without replacing the entire sled, or vice versa (Figure 30).

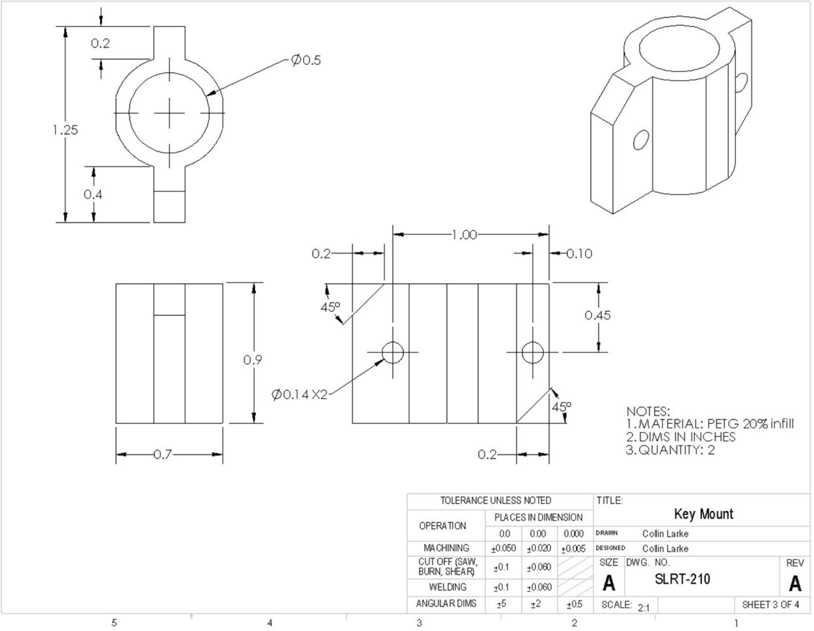


Figure 30: Key Mount Drawing

The keys were mounted to the sled by epoxying the key into an intermediary piece that was then secured to the sled with 4-40 screws and nuts (Figure 31).

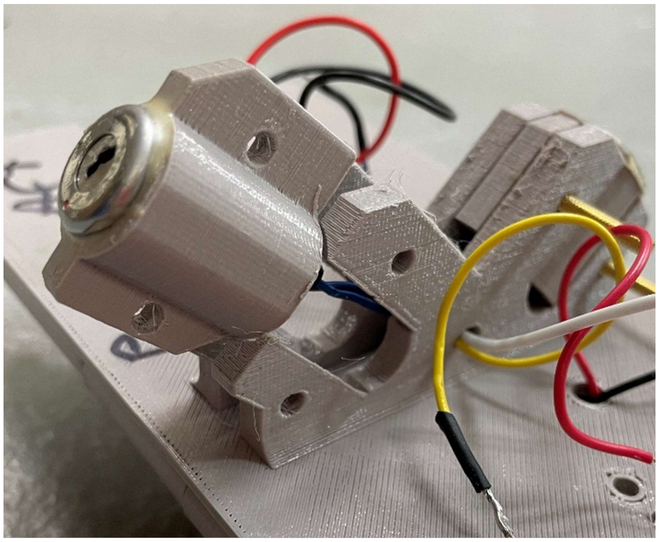


Figure 31: As-built Key Mount

Battery holders were also 3D printed from PETG filament with a 20% infill. They were secured to the avionics sled during assembly of the avionics bay with the threaded rods (Figure 32). Holes were located in the sled to allow for passage of wires between the batteries, switches, and altimeters. These holes help keep the wires organized and out of the way during assembly.

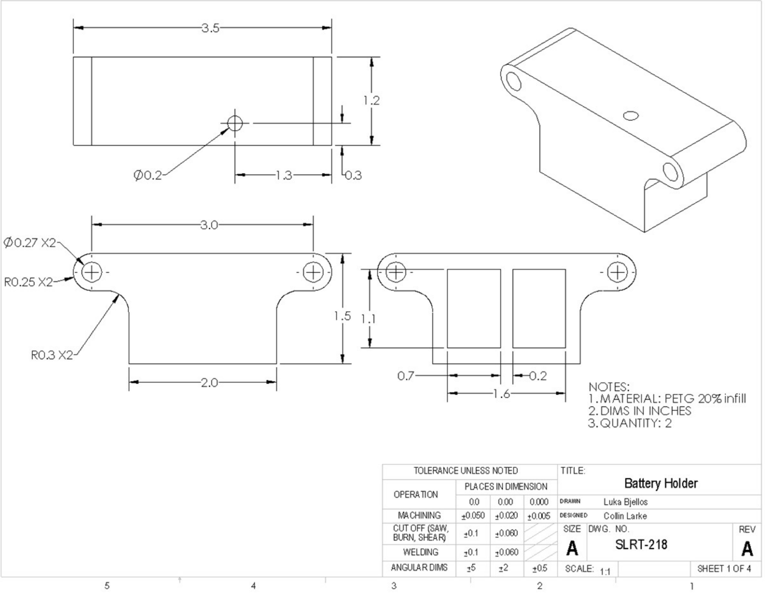


Figure 32: Battery Holder Drawing

The as-built battery holder was able to hold two 9V batteries. Each battery was used to power one altimter each (Figure 33).

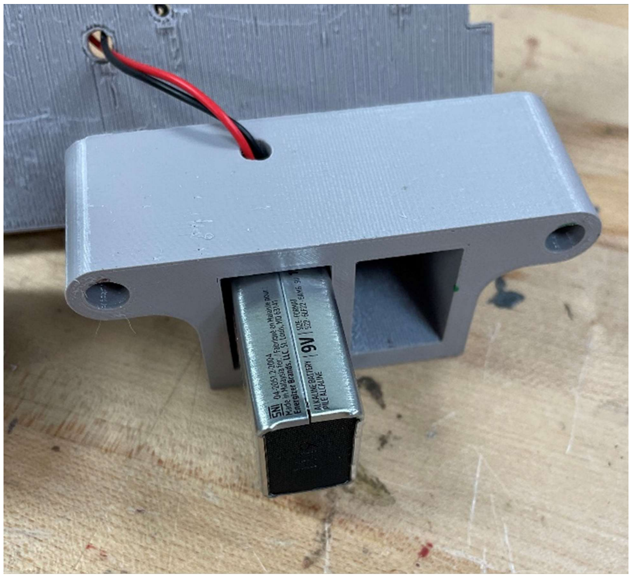


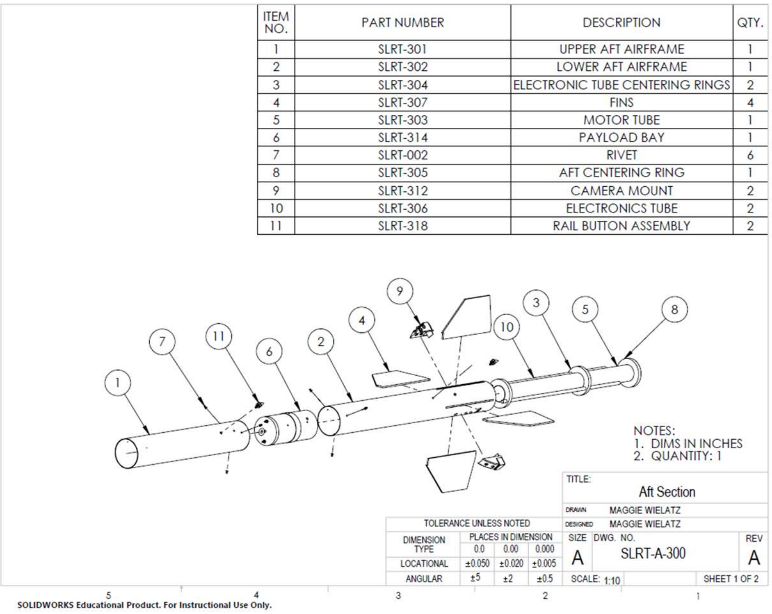
Figure 33: As-Built Battery Holder

Final orientation of the avionics sled and avionics bay was done with the use of markings on the coupler and switch band (Figure 34). The lock switches were aligned with the holes in the switchband, and the avionics bay was aligned with additional marking on the switch band and the forward and aft section.

Figure 34: Avionics Bay

3.1.5.3 Aft Section Construction

The aft section is comprised of the payload bay, lower aft airframe assembly, and upper aft airframe (Figure 35).



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-301	UPPER AFT AIRFRAME	1
2	SLRT-302	LOWER AFT AIRFRAME	1
3	SLRT-304	ELECTRONIC TUBE CENTERING RINGS	2
4	SLRT-307	FINS	4
5	SLRT-303	MOTOR TUBE	1
6	SLRT-314	PAYLOAD BAY	1
7	SLRT-002	RIVET	6
8	SLRT-305	AFT CENTERING RING	1
9	SLRT-312	CAMERA MOUNT	2
10	SLRT-306	ELECTRONICS TUBE	2
11	SLRT-318	RAIL BUTTON ASSEMBLY	2

NOTES:
1. DIMS IN INCHES
2. QUANTITY: 1

Figure 35: Aft Section Assembly Drawing

3.1.5.3.1 Payload Bay Construction

The 3.90 in diameter G12 fiberglass tubing was cut to a length of 8.0 in using a Roll-in bandsaw. Then, 100 grit sandpaper was used to debur the edges of the payload coupler (Figure 36).

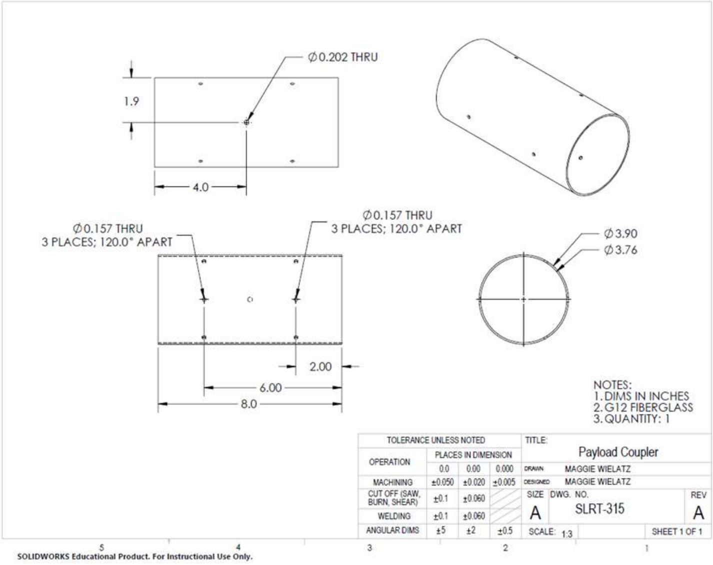


Figure 36: Payload Coupler Drawing

The same procedure was followed in cutting the 1.0 in long fiberglass switchband from remaining 4.02 in diameter G12 fiberglass tube (Figure 37). The switchband was then epoxied using Rocketpoxy in the center of the coupler.

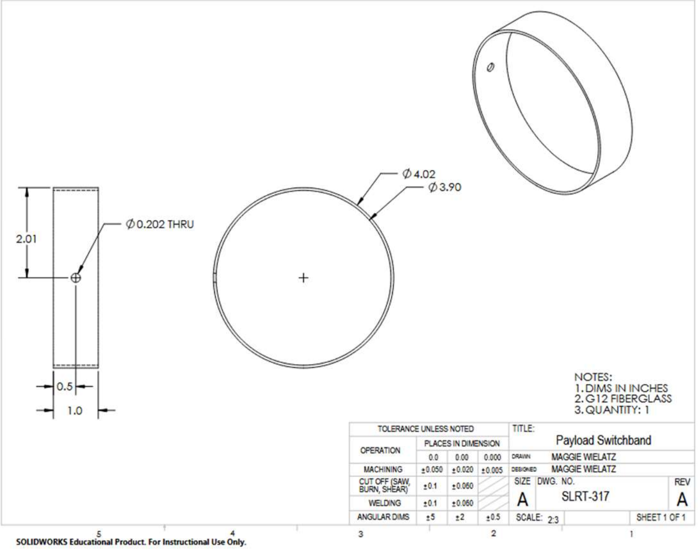


Figure 37: Payload Switchband Drawing

The payload bulkhead was constructed like the avionics bay bulkheads. It was first turned to size on a lathe and the holes were drilled on a milling machine (Figure 38).

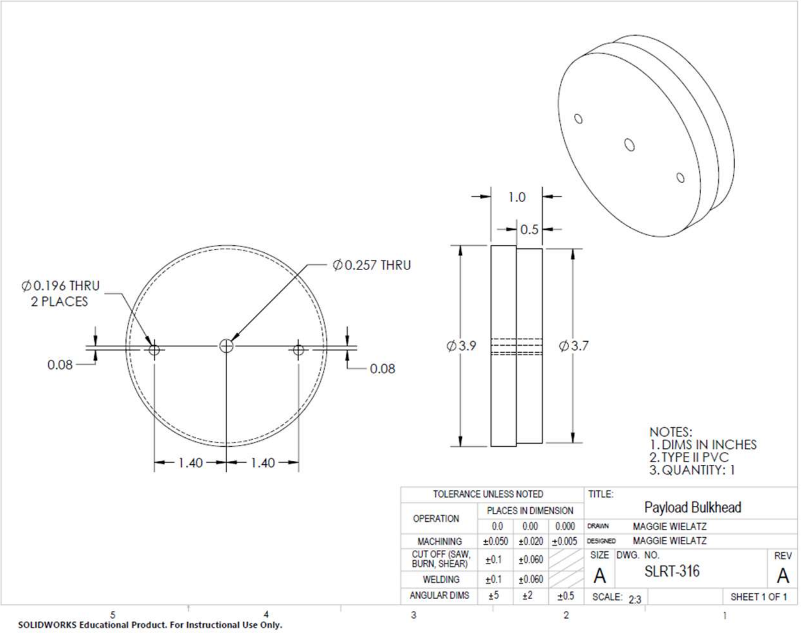


Figure 38: Payload Bulkhead Drawing

Next, a ¼-20 eyebolt in was secured into the payload bulkhead with two hex nuts and epoxied into place using RocketPoxy. The payload bulkhead and coupler were sanded using 100 grit sandpaper to prepare for epoxying. RocketPoxy is used again to epoxy the payload bulkhead to the payload coupler. After completing construction of the payload bay, the switchband was wet sanded using 600 grit sandpaper. The switchband was then spray painted with one layer of primer and two layers of paint (Figure 39). Painter's tape was used to protect the coupler from paint.

Figure 39: As-Built Payload Bay Without Payload Installed

3.1.5.3.2 Lower Aft Airframe Assembly Construction

The lower aft airframe assembly is composed of the fins, centering rings, lower aft airframe, electronics tubes, motor tube, thrust plate, and aft motor retainer. The centering rings were cut from 0.5 in plywood sheets (Figure 40).

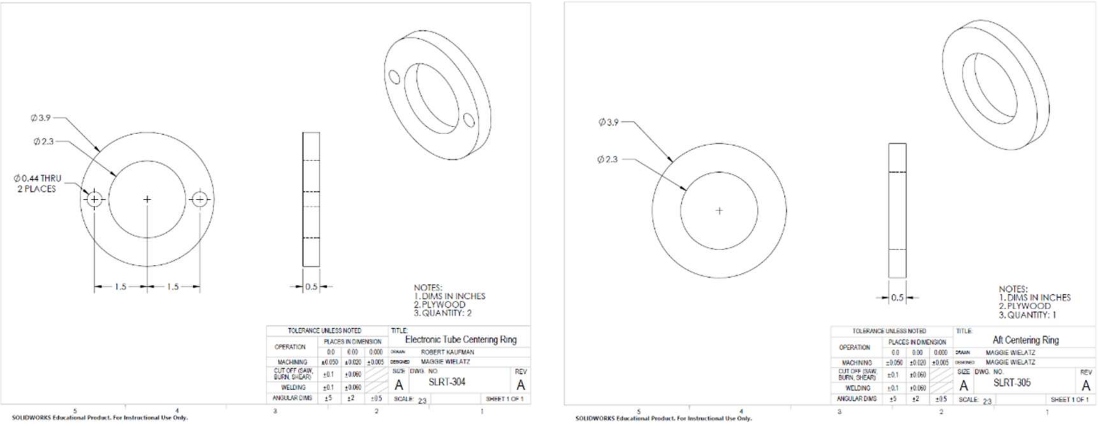


Figure 40: Forward Centering Rings (left) and Aft Centering Ring (right) Drawings

The fins were cut from 3/16 in structural FRP fiberglass (Figure 41).

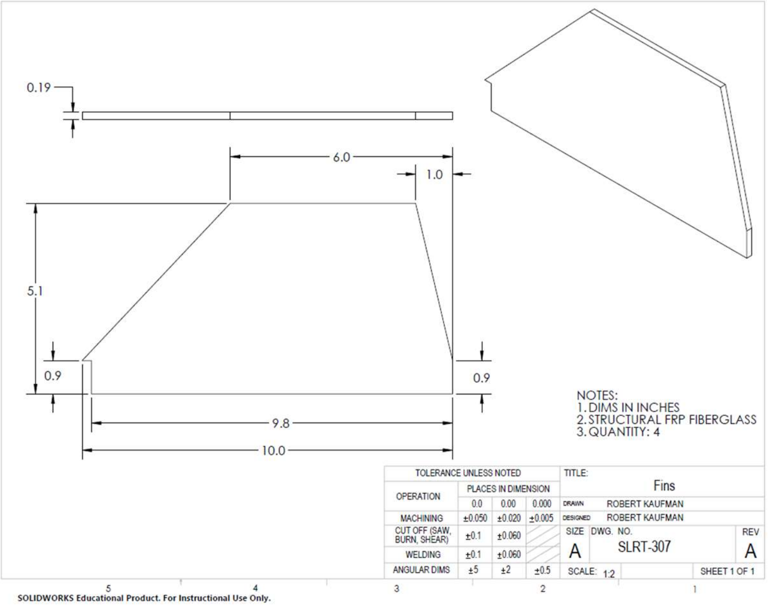


Figure 41: Fin Drawing

The fins and centering rings were cut on an abrasive waterjet (AWJ) pressurized to 55,000 psi (Figure 42).

Figure 42: Fins and Centering Rings After Being Cut on the AWJ

The 4.02 in diameter G12 fiberglass tubing was cut using a Roll-In bandsaw to a length of 32.0 in. Then, 80-100 grit sandpaper was used to debur the ends of the airframe (Figure 43).

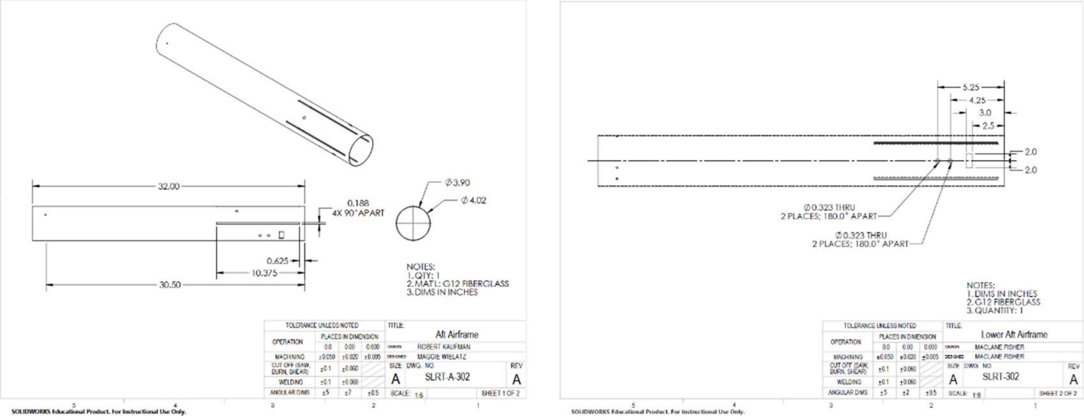


Figure 43: Lower Aft Airframe Drawing

Once the airframe was cut to size, the locations of the fin slots were marked. The fin slots were cut on a milling machine to ensure the fin slots were aligned vertically with the vehicle. Large, V-shaped vise jaws were used to secure the airframe during machining and a 1/8 in endmill was used to create the fin slots over two passes. Furthermore, the centering rings were placed in the airframe to prevent the vise jaws from deforming the airframe. After milling the fin slots, the slots were deburred (Figure 44).

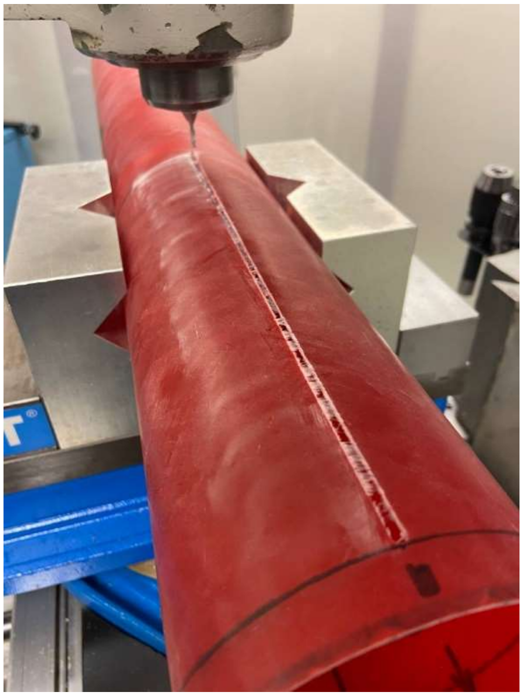


Figure 44: Fin Slot in Aft Airframe After One Pass of the End Mill

Next, rivet holes were drilled 1.5 in from the forward end of the airframe. These holes (circled in blue) were drilled while the airframe and coupler were fit together to ensure the holes were aligned properly (Figure 45).

Figure 45: Rivet Hole in Aft Airframe

Two pairs of 0.323 in diameter camera mount holes were then drilled into the aft end of the airframe. Each pair of holes was drilled 4.25 in and 5.25 in from the aft end of the airframe. These pairs were spaced 180 deg apart, and directly between fin slots. After camera mount holes were drilled, a Dremel was used to cut two camera slots along the same axis as the camera mount holes. These slots begin and end 2.5 in and 3.15 in from the aft end of the airframe, respectively (Figure 46).

Figure 46: Camera Mount Holes and Camera Mount Slot in Lower Aft Airframe

After the camera slots were cut, a 0.323 in diameter rail button mount hole was drilled 8 in from the aft end of the airframe. This hole was spaced 90 deg from the camera mount holes and 45 deg from the fin slots. The ¼-20 t-nuts for the rail button and camera mounts were epoxied to the aft airframe using five-minute epoxy to prevent them from shifting during assembly of the lower aft airframe. Electronics tubes were made by wrapping strips of kraft paper around a 3/8 in steel rod and applying wood glue to the paper. The tubes were made to be 24 in long (Figure 48, Figure 48).

Figure 47: Electronics Tube Manufacturing

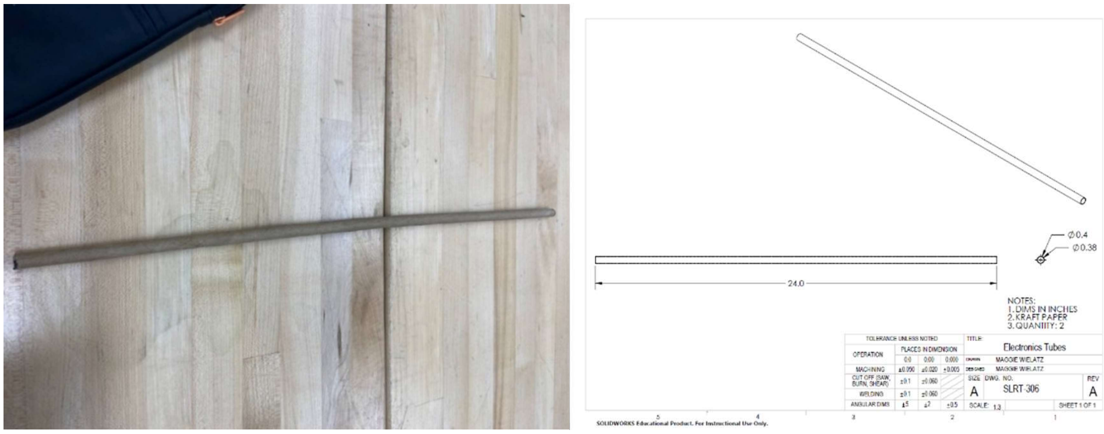


Figure 48: As-Built Electronics Tube (left) and Electronics Tube Drawing (right)

The motor tube was cut from 2.24 in diameter G12 fiberglass to a length of 27.0 in on a Roll-in bandsaw (Figure 49Figure 49).

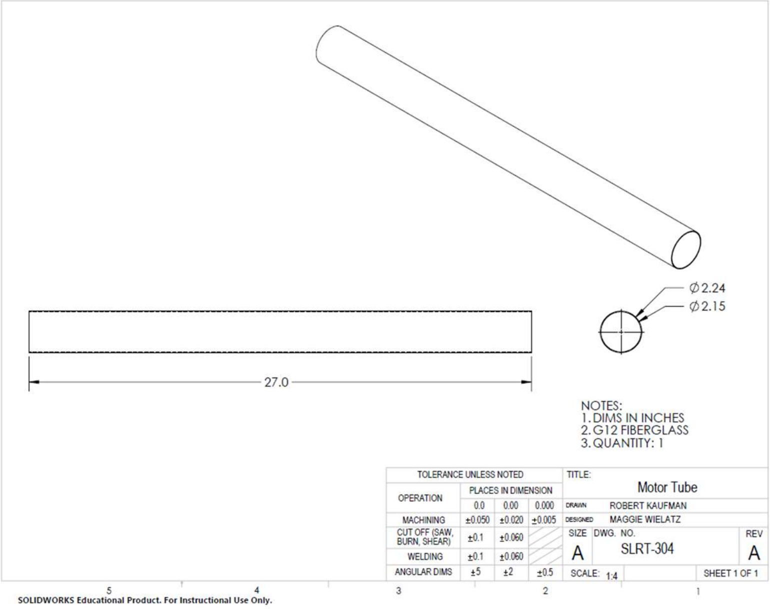


Figure 49: Motor Tube Drawing

The locations of the forward two centering rings (26.5 in and 10.6 in from the aft end of the motor tube) were marked and sanded with 80-100 grit sandpaper to prepare for epoxying. The forward two centering rings were then slid to their respective locations on the motor tube and the electronics tubes were fed through the centering rings. The centering rings were epoxied to the motor tube and electronics tubes were epoxied to the centering rings using JB Weld (Figure 50, Figure 51).

Figure 50: Centering Rings Epoxied to Motor Tube

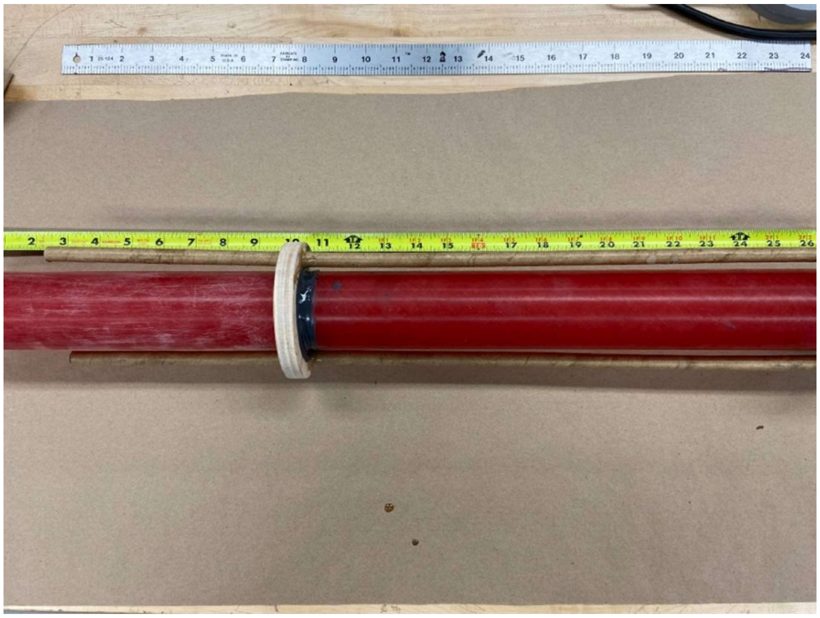


Figure 51: As-Built Motor Tube with Forward Centering Rings and Electronics Tubes

The interior of the lower aft airframe was sanded using 80-100 grit sandpaper to prepare for epoxying. The motor tube was then epoxied into the lower aft airframe using JB Weld. The aft end of the motor tube was placed 1/8 in into the airframe so the lip of the thrust plate sat flush with the end of the lower aft airframe. Furthermore, the motor tube was rotated so the electronics tubes were in between the camera mount and fin slots. This prevents interference with both the fins and camera mounts. The fins were first sanded using 100 grit sandpaper to prepare for epoxying. Next, the fins were epoxied into place using a small bead of five-minute epoxy and a 3D-printed fin jig to ensure the correct alignment of the fins while the epoxy cured (Figure 52).

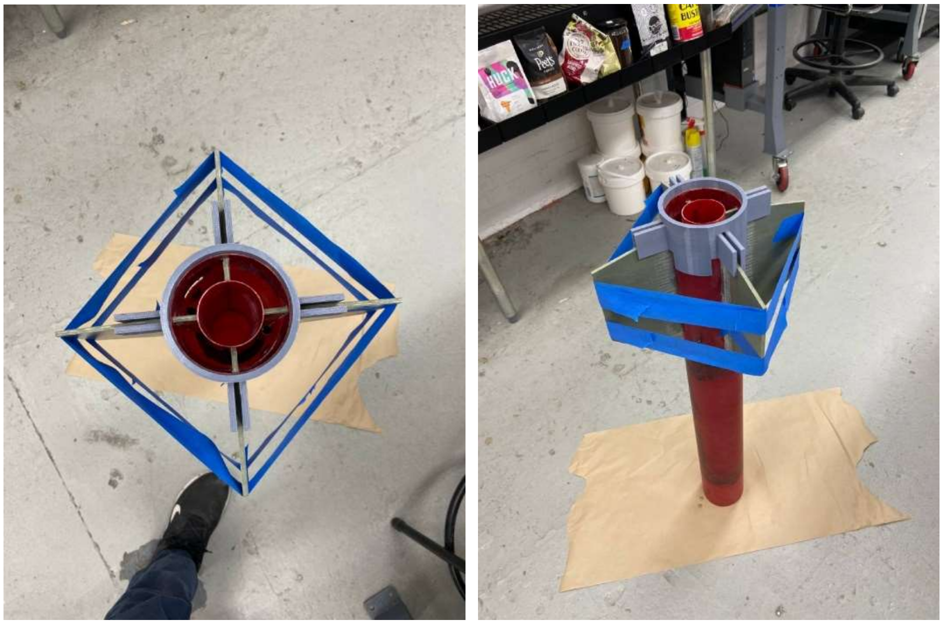


Figure 52: Setup with Fin Jig to Epoxy Fins into Lower Aft Airframe

Once the five-minute epoxy had cured, the fins were fully secured using fillets of RocketPoxy. Four rounds of epoxying with six hours of cure time for each round was required to epoxy all sides of the fins. Each round of epoxying created four internal and two external fillets around the fin. The aft section was rotated 90 deg before each round of epoxying. The external fillets (fillets 1 and 4 from Figure 53) were smoothed using a popsicle stick.

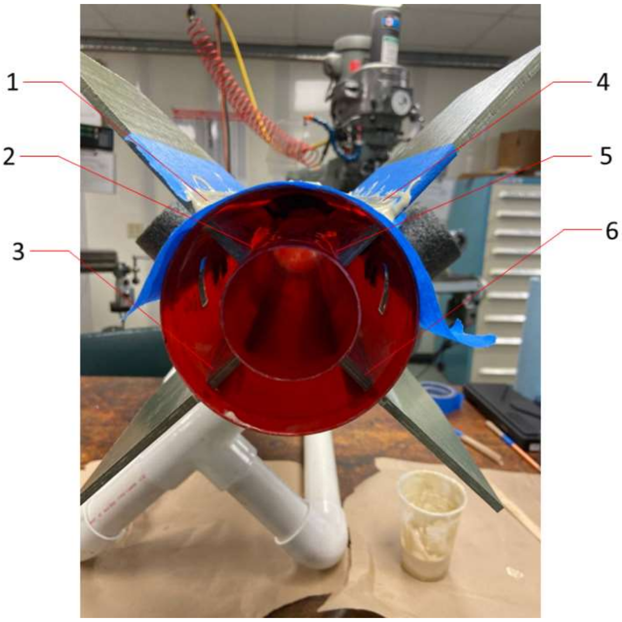


Figure 53: Two External (1 and 4) and Four Internal (2, 3, 5, and 6) Fin Fillets

After creating all the fin fillets, the wires were fed through the electronics tubes. Next, 10-24 threaded inserts were inserted into the aft centering ring and the centering ring was epoxied into the end of the airframe. The centering ring was aligned such that the threaded inserts did not align with any fins. This was done to prevent interference between the screws and the fins when screwing the thrust plate in. The thrust plate and aft motor retainer were screwed together and connected to the aft airframe. After completing construction of the upper aft airframe, the exterior was wet sanded using 600 grit sandpaper. The exterior was then spray painted with one layer of primer and two layers of paint. The fins were painted after the airframe. Painter's tape was used to protect the black coat of paint on the airframe. The cameras mounts are attached by threading ¼-20 screws into the installed t-nuts on the lower aft airframe (Figure 54).

Figure 54: As-Built Lower Aft Airframe Assembly

3.1.5.3.3 Upper Aft Airframe Construction

The 4.02 in diameter G12 fiberglass tubing was cut using a Roll-In Bandsaw to a length of 23.0 in. Next, 80-100 grit sandpaper was used to debur the edges of the airframe (Figure 55Figure 55).

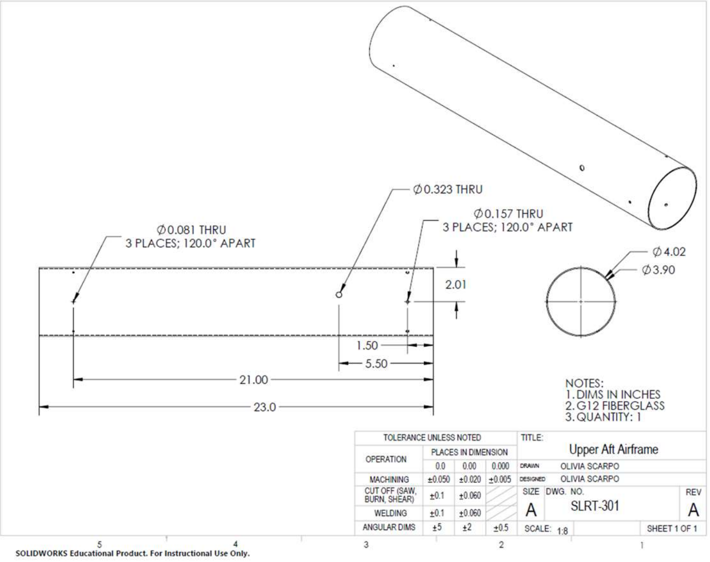


Figure 55: Upper Aft Airframe Drawing

Once the airframe was cut and deburred using 80-100 grit sandpaper, rivet and shear pin holes were drilled 2.00 in and 21.00 in from the aft end of the airframe, respectively. These holes were drilled while the airframe and coupler were connected to ensure exact alignment of the holes (**Error! Reference source not found.**).

The 0.323 in diameter rail button hole was drilled after the entire lower aft airframe assembly construction was completed. This was done to ensure that the rail button locations were lined up as accurately as possible. To line up the rail buttons, the aft section was assembled and loaded into a milling machine. A marker was lined up with the aft rail button and then used to mark the location of the rail button on the upper airframe by moving the x-axis of the milling machine to the correct location on the aft section. The aft section was then disassembled and the forward rail button hole was drilled using a drill press. The hole was not drilled on the milling machine when the lower aft assembly was attached to prevent damage to the lower aft assembly (Figure 56).

Figure 56: The Setup Used to Align the Forward and Aft Rail Button Locations.

The ¼-20 t-nut for the rail button was epoxied to the airframe to prevent it from shifting during assembly. The rail button was then connected to the t-nut using a countersunk ¼-20 screw. After completing construction of the upper aft airframe, the exterior was wet sanded using 600 grit sandpaper and spray painted with one layer of primer and two layers of paint (Figure 57).

Figure 57: As-built Upper Aft Airframe

3.1.6 Changes Made from Earlier Models

The constructed launch vehicle represents the final design of the fullscale launch vehicle for the NASA USLI competition (Figure 58). There has only been a single previous model: the subscale version of the launch vehicle that performed a successful launch in LaBelle, FL (Prefecture #19) on December 4th, 2021 (Figure 59). The fullscale launch vehicle differs from the subscale in that it has a 4:1 Ogive nosecone whereas the subscale used a 5:1 Ogive nosecone. Additionally, the fullscale launch vehicle has slots in the lower aft airframe which allow the cameras to be partially inserted into the lower aft airframe. This made for a more aerodynamic camera housing.

The payload camera housings and avionics coupler length were not scaled down by 25% on the subscale launch vehicle as they still needed to be able to house the payload cameras and avionics electronics, during the subscale demonstration flight. The avionics coupler diameter was scaled down by 25%; however, the length of 9 in has not changed between models.

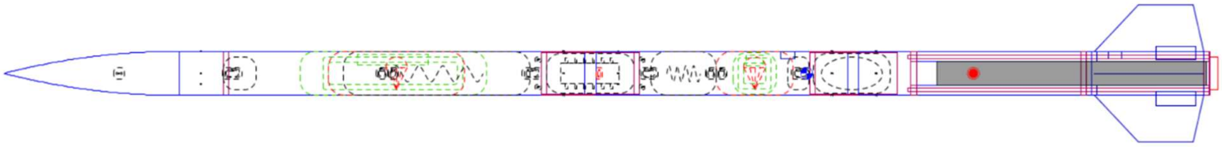


Figure 58: NASA USLI Full-scale Rocket, 111 in length, 4.02 in diameter

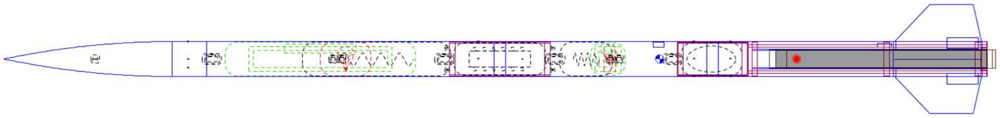


Figure 59: NASA USLI Subscale Rocket, 88.5 in length, 3.13 in diameter

3.2 Recovery Subsystem

The recovery subsystem consists of the parachutes, recovery harnesses, eyebolts, quick links, the recovery GPS, and the avionics bay. Structural components were tested for robustness and electrical components were tested for accuracy and/or range. Structural elements of the recovery system are discussed in Section 3.1 Vehicle Criteria.

3.2.1 Electrical Elements

The primary altimeter is the StratoLogger CF Altimeter (Figure 6060). The StratoLogger CF measures changes in air pressure relative to when it is turned on and uses that data to determine the altitude above ground level. This was tested by turning on the StratoLogger CF at ground level, then lifting the altimeter to a height of approximately 95 ft above ground level and recording the change in altitude as determined by the altimeter (Test #7). The StratoLogger CF accurately determined the altitude within 1% of actual with a resolution of 1 ft. The StratoLogger CF Altimeter is structurally fragile. Therefore, it was made to be robust as built by firmly securing it onto the avionics sled with 4-40 screws and nuts, preventing it from getting damaged by the movement of the launch vehicle.

Figure 60: Perfectflite Stratologger CF Altimeter

The secondary altimeter is the Entacore AIM Altimeter (Figure 61). The Entacore AIM measures altitude by adding height to a programmed ground level. This was tested in the same manner that the StratoLogger CF was tested (Test #7). The Entacore AIM was programmed to have a ground level of 170 ft. The altimeter was then lifted to a height of approximately 95 ft and the change in altitude determined by the altimeter was recorded. The Entacore AIM accurately determined the altitude within a foot. Moreover, like the StratoLogger CF Altimeter, the Entacore AIM Altimeter is structurally fragile. Therefore, it was also made to be robust as built by firmly securing it onto the avionics sled, preventing it from getting damaged by the movement of the launch vehicle.

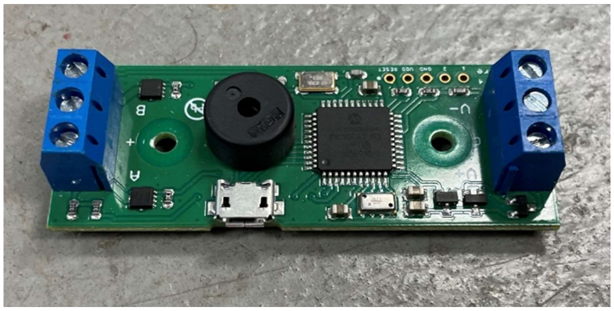


Figure 61: Entacore AIM USB Altimeter

Altimeters were connected to ejection charges via terminal blocks mounted to the exterior of the bulkheads. Wires coming from the altimeter passed through the bulkhead and were secured in the terminal block. Clay was used to seal the wire hole during flight and protect against ejection charge gasses leaking into the avionics bay. Ejection charge wires were secured to the opposing side of each terminal block.

3.2.2 Redundancy Features

The launch vehicle has two altimeters for redundancy (Figure 62). The primary altimeter and secondary altimeter are wired independent of one another to protect against the failure of one affecting the other. Two different models of altimeter were used to protect against any malfunctions due to how the altimeters were manufactured. The ejection charges controlled by the secondary altimeter were also sized to be 25% larger than the primary altimeters ejection charges in case the primary charges were insufficient to cause separation.

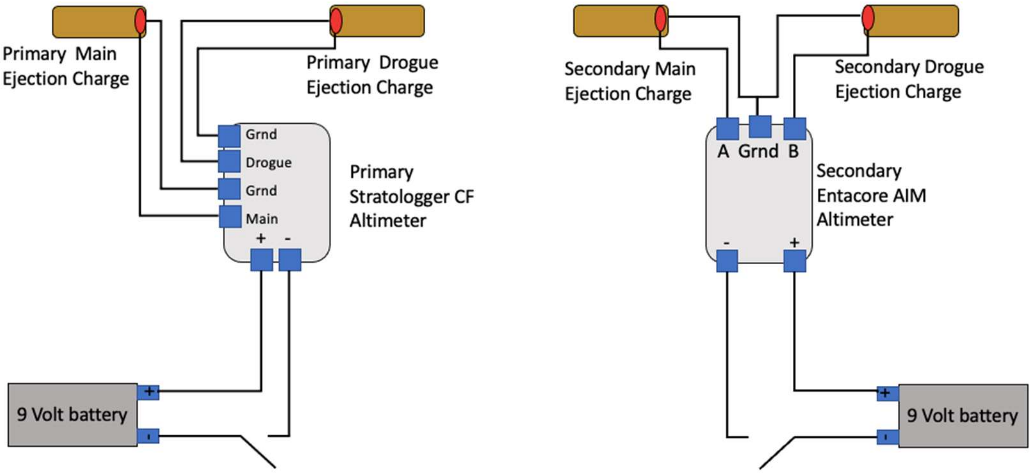


Figure 62: Altimeter Wiring Diagram

3.2.3 Parachutes

The parachutes used in the launch vehicle are a 24 in Rocketman parachute for the drogue parachute. The 24 in Rocketman parachute has a coefficient of drag of 0.97 from the manufacturer (Figure 63). The drogue parachute is located in the aft section. The drogue parachute has a primary deployment at apogee and a secondary deployment 1 s after apogee. The parachute will be protected from the ejection gasses with the use of a 12 in by 12 in parachute protector. The protector is made of flame-resistant fabric.

Figure 63: Drogue Parachute

The 72 in Fruity Chutes Iris Ultra parachute has a coefficient of drag of 2.2 (Figure 64). The main parachute is located in the forward section. The main parachute has a primary deployment at 600 ft above ground level and a secondary deployment 550 ft above ground level. The distance between the primary and secondary ejection charge gives the nosecone and forward section around 0.7 s to separate before the secondary ejection charge goes off. The parachute will be protected from the ejection gasses with the use of a 24 in by 24 in parachute protector. This protector is made of 7 oz fabric.

Figure 64: Main Parachute

The dimensions of the parachutes are tabulated (Table 5).

Parachute Dimensions			
Parachute	**Diameter (in)**	**Coefficient of Drag**	**Manufacturer**
Drogue Parachute	24	0.97	Rocketman
Main Parachute	72	2.2	Fruity Chutes

Table 5: Parachute Dimensions

The drogue parachute provided a descent rate of 78.9 ft/s in the OpenRocket simulation and a descent rate of 70 ft/s during the Vehicle Demonstration Flight (Table 6). The main parachute provided a descent rate of 17.3 ft/s in the OpenRocket simulation and a descent rate of 17 ft/s during the Vehicle Demonstration Flight (. Predicted descent rates are analyzed in 3.3.3 Descent Predictions.

Parachute Descent Rates		
Parachute	**Drogue (ft/s)**	**Main (ft/s)**
OpenRocket Prediction	78.9	17.3
MATLAB Prediction	80.6	17.8
Vehicle Demonstration Flight	70	17

Table 6: Parachute Descent Rates

The drogue parachute was positioned 1/3 the length of the recovery harness away from the avionics bay. The drogue was positioned here to have the forward section hang above the aft section during drogue descent. The forward section being above the aft section during drogue descent helps prevent the main parachute from tangling with the aft recovery harness during deployment because it will have to pass by less harness while it inflates. The drogue being located here also helps prevent sections from colliding during descent as the forward section will already be above the aft section prior to the main parachute deploying from it (Figure 65).

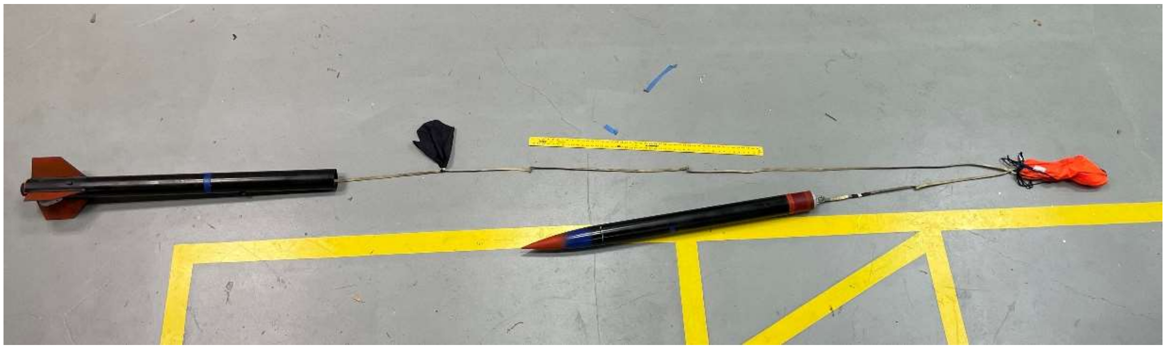


Figure 65: Drogue Parachute Placement

The main parachute was positioned 1/3 the length of the recovery harness away from the nosecone. Positioning the main parachute here helps the nosecone pull the parachute out of the airframe during separation instead of only pulling the slack of the recovery harness out of the airframe (Figure 66).

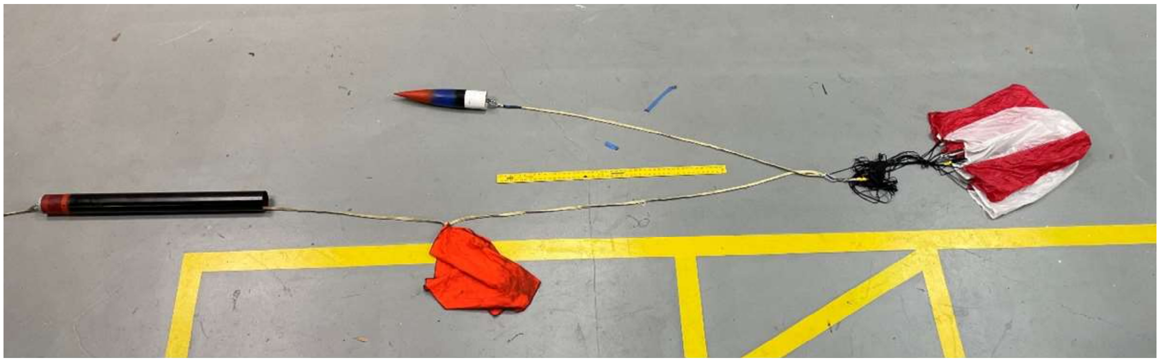


Figure 66: Main Parachute Placement

3.2.4 Launch Vehicle Locating Transmitter

The launch vehicle was equipped with a Big Red Bee 900 transmitter and receiver, which has a range of 6 miles. This range was included in the user manual of the component and was verified up to a distance of 1 mile by separating the transmitter and receiver (Test #19). The Big Red Bee 900 uses a 900 MHz spread spectrum transmitter to send location data to the receiver. The team will be using a transmission frequency of 904 MHz to receive data from the transmitter. The transmitter uses a Single cell Lithium Poly battery (3.5 to 4.2 Volts), which can store enough energy to power the transmitter during the entire launch and recovery process with a battery life of 6 hours (Test #29). The GPS range testing was conducted by having the receiver at a specified location and moving the transmitter up to one mile range to verify the range of transmitter and the accuracy of the GPS module (Test #19). Altimeters and ejection charges have the potential to be sensitive to devices that generate electromagnetic fields. Aluminum foil has been placed between the payload bulkhead and the payload sled to protect the altimeters and ejection charges from the transmitters located in the Payload Bay (Figure 67).

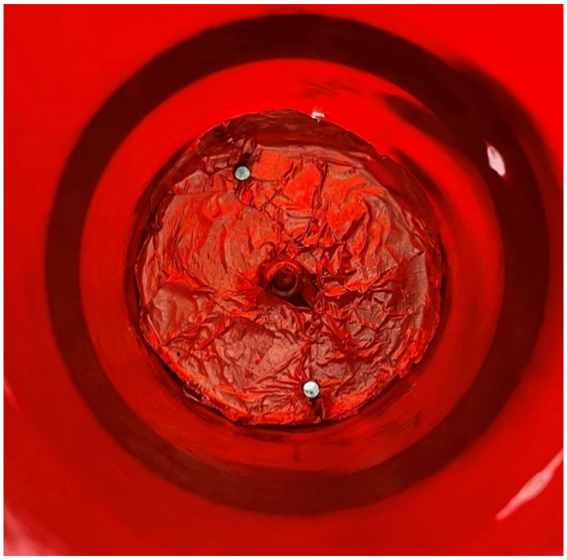


Figure 67: Aluminum Foil on Payload Bulkhead

3.3 Mission Performance Predictions

3.3.1 Simulation Profile Predictions

3.3.1.1 Simulation Conditions

The flight simulation assumes the flight conditions in Huntsville, Alabama (Table 7). These conditions were used for all simulations calculated via MATLAB, and OpenRocket.

Simulated Launch Conditions in Huntsville, Alabama	
Wind	10 mph
Launch Angle	5 deg
Launch Rod Length	144 in
Latitude	34.6 °N
Longitude	-86.7 °E
Altitude	800 ft
Temperature	75 °F
Pressure	1 atm

Table 7: Simulated Launch Conditions in Huntsville for Competition Day

3.3.1.2 Altitude Prediction

Based on the simulation the launch vehicle achieves an apogee of 4948 ft (Figure 68). This apogee is about 400 ft higher than the target apogee that was declared. The ballast used was 1kg (which is the maximum ballast that can be flown), where 335 grams were placed in the forward and 665 grams were placed in the aft. This value was determined through iterative testing of ballast distributions from 100 g to 1000 g.

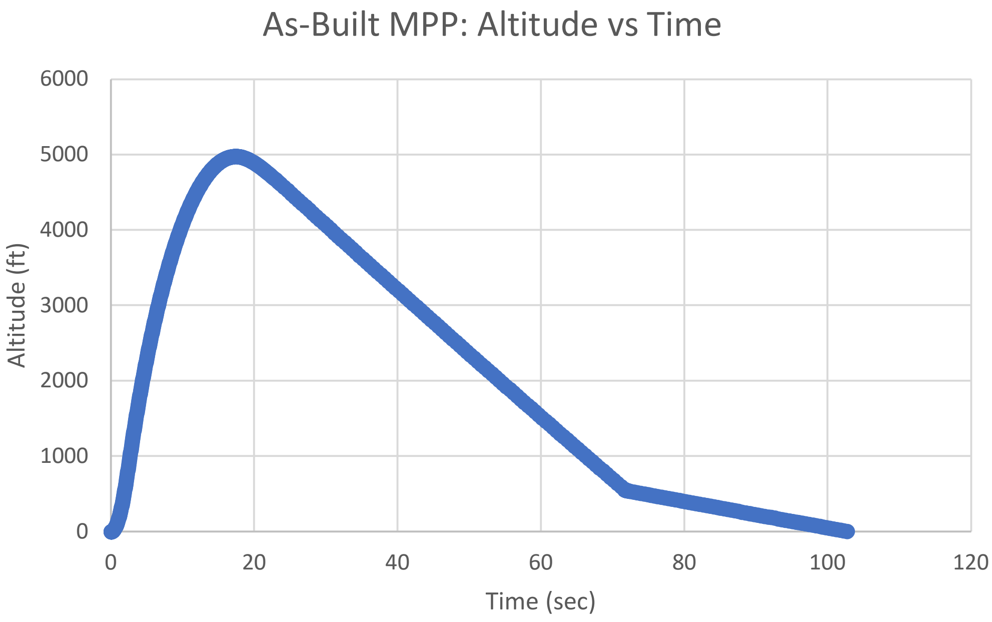


Figure 68: As-Built Altitude vs Time Profile

3.3.1.3 Maximum Velocity Prediction

The maximum velocity is 643 ft/s reaching a Mach number of 0.58 (Figure 69). The simulated velocity of the vehicle at rail exit is 89.5 ft/s with the Aerotech L1090W motor, and the ground hit velocity is 17.6 ft/s.

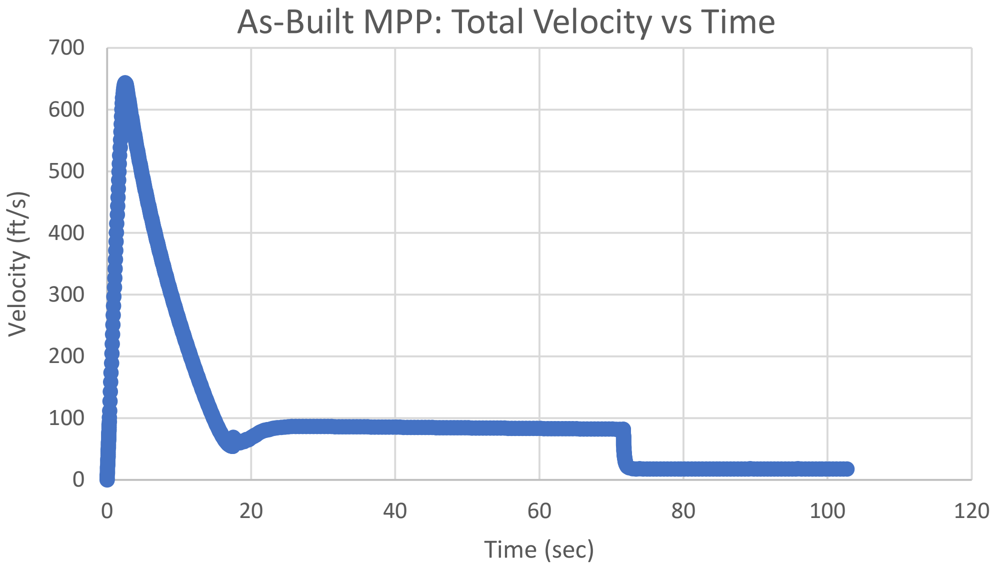


Figure 69: As-Built Velocity vs Time Profile

3.3.1.4 Acceleration Prediction

The maximum acceleration calculated was 329 ft/s^2 (Figure 70). The peak in the plot occurs at main parachute deployment and is instantaneous. Therefore, it is ignored.

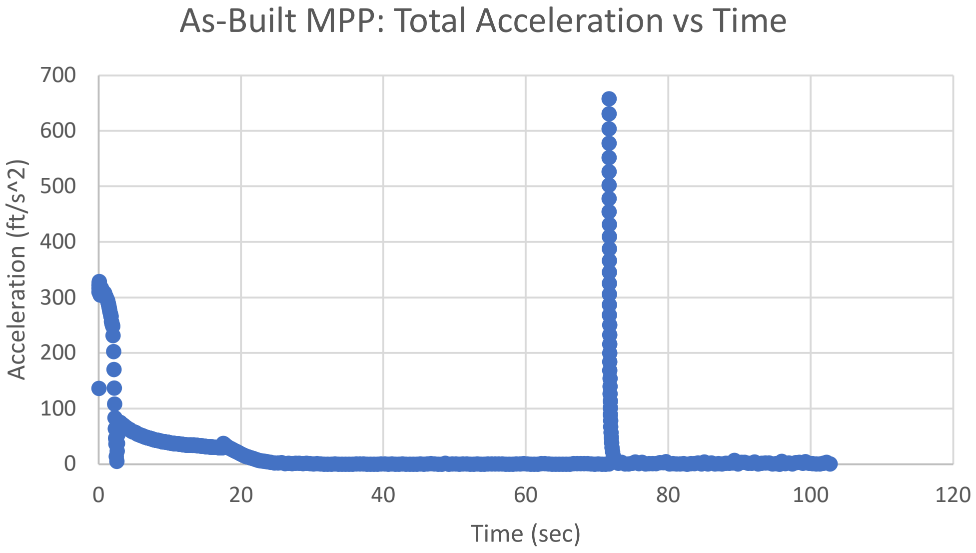


Figure 70: As-Built Acceleration vs Time Profile

3.3.1.5 Simulated Motor Thrust Curve

The selected motor is the Aerotech L1090W. The L1090W has a total impulse of 2736 N-s, and a maximum thrust of 1334 N. The maximum thrust occurs at the launch rod to propel the launch vehicle at 89.5 ft/s. The motor uses 1400 grams of propellant to produce a burn time of 3 seconds (Figure 71). The as-built total weight of the launch vehicle is 423 oz, and the thrust-to-weight ratio is 9.27:1, fulfilling the competition's requirement of a minimum thrust-to-weight ratio of 5.0:1.

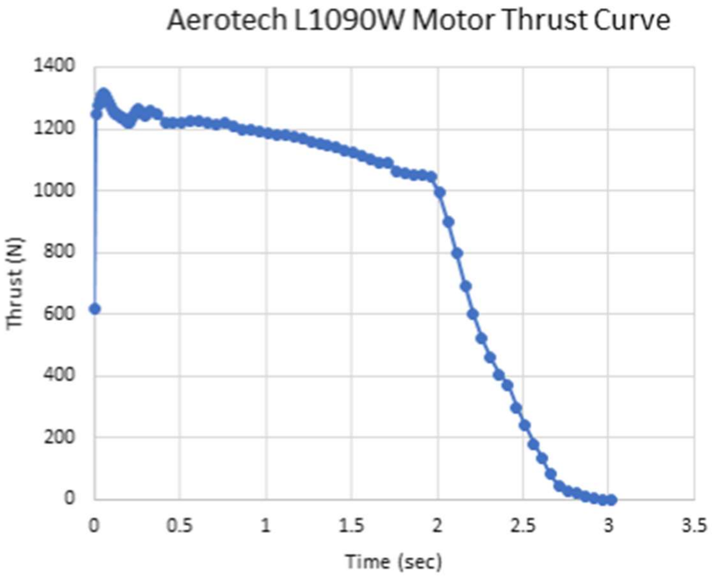


Figure 71: Aerotech L1090W Thrust Curve

3.3.1.6 Vehicle Robustness

The maximum force the launch vehicle experiences was calculated from the acceleration data to be less than 1 kN. In Test #1, the vehicle material was tested to a force of 30 kN and did not yield. This data verifies the vehicle is robust enough to withstand the forces of flight.

3.3.1.7 Simulation Verifications: Monte Carlo Simulations

The predicted apogee was estimated using a MATLAB Monte Carlo Simulation to confirm the accuracy of the OpenRocket calculations. The MATLAB simulation used random values of wind profiles ranging from 0 mph to 20 mph and it was run a total of 10,000 times to predict the range that the altitude will remain between. All other parameters matched the parameter used in the OpenRocket Simulation. The table indicates the average predicted performance of the Gator Locator (Table 8). The probability weights were assigned by allocating the likely condition with the largest probability and determining the rest accordingly. The values were allocated as results of the Monte Carlo Simulation and considering the climate of the launch site. While the launch angles for the simulated conditions in the table include 0 and 2.5 deg, the launch angle will be between 5 to 10 deg on the launch day as the competition requires. However, the analysis uses these given angles to ensure proportional altitude changes between launch conditions.

Average Altitude			
Launch Angle	Wind Condition	Probability Weight	Predicted Altitude
0	0 mph	5%	5111 ft
2.5 deg	5 mph	10%	5020 ft
5 deg	10 mph	70%	4964 ft
7.5 deg	15 mph	10%	4828 ft
10 deg	20 mph	5%	4674 ft
Average Altitude			**4948.9 ft**

Table 8: Monte Carlo Simulation Results

3.3.2 Stability Margin

The launch vehicle is stable when the center of pressure is located at least 2 body calibers behind the center of gravity. The as-built center of gravity with the motor was located 72.75 in from the nosecone of the rocket. The as-built center of pressure was located 88.45 in from the tip of the nosecone. With these values, the static stability margin of the as-built rocket on the launch pad was 3.05 calibers. The static stability of the launch vehicle when it is clearing the launch rod is 3.20 calibers, fulfilling the competition's requirement of 2.00 calibers off the launch rod. During the flight, the stability gradually increases to 4.25 calibers, due to the reduction of mass in the motor. Additionally, the stability reaches a maximum of 4.75 calibers, at burnout, and a minimum of 2.10 due to the decrease in velocity as it reaches apogee (Figure 72). The oscillations indicate the simulated wind gusts on the launch vehicle.

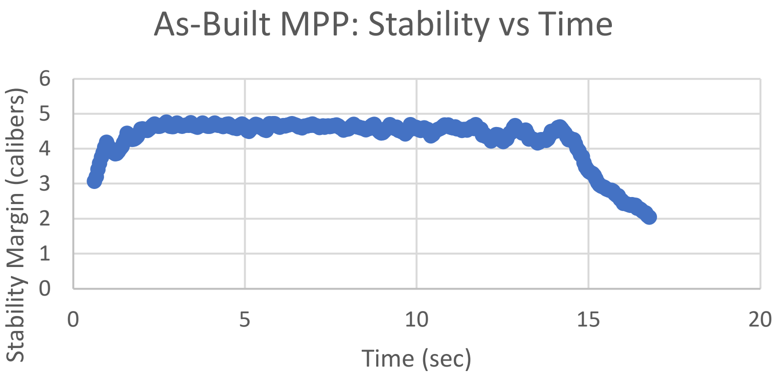


Figure 72: As-Built Stability Margin vs Time

3.3.3 Descent Predictions

Descent predictions were performed using conditions expected at the Huntsville, Alabama launch site. Three methods were used to calculate descent performance. An OpenRocket simulation was used to solve for the overall launch and descent of the launch vehicle. Values from the OpenRocket were also plugged into an Excel spreadsheet to calculate the desired values. A MATLAB ordinary differential equation (ODE) solver was also used to simulate the descent by solving the ODE made by balancing the weight of the vehicle with the forces of drag from the parachutes. *"i" subscripts to be replaced by element the value is describing.

Table of Variables	
h_i	Altitude
t_i	Time
v_i	Descent rate
m_i	Mass
X_i	Drift
KE_i	Kinetic energy
s_i	Area of parachute
C_i	Coefficient of drag
ρ	Density
g	Acceleration due to gravity
V	Wind speed

Table 9: Table of Variables

3.3.3.1 Descent Time Predictions

OpenRocket does not output total descent time, but it does output time to apogee and the total flight time. The time to apogee was subtracted from the total flight time to find the descent time of the launch vehicle (2). A sample calculation is included.

$$t = t_{total} - t_{apogee} \tag{2}$$

$$86.4s = 104s - 17.6s$$

The Excel spreadsheet divides distance by velocity in order to find the descent time under each parachute (4). The distance the launch vehicle traveled under the drogue parachute was found by subtracting the main parachute deployment altitude from the apogee (3). The descent times for each parachute are added together for total descent time (5). The descent rates for each parachute were kept constant during the calculations. The apogee was set to the target apogee, 4578 ft. The main deployment altitude was set to the primary ejection charge detonation altitude, 600 ft. The descent rate of the drogue parachute was taken from the OpenRocket simulation as the velocity during main parachute deployment, 78.9 ft/s. The descent rate of the main parachute was taken from the OpenRocket as the velocity at ground hit, 17.3 ft/s. A sample calculation is included for each equation.

$$t_{drogue} = \frac{h_{apogee} - h_{main}}{v_{drogue}} \tag{3}$$

$$50.4s = \frac{4578\,ft - 600\,ft}{78.9\,ft/s}$$

$$t_{main} = \frac{h_{main}}{v_{main}} \tag{4}$$

$$34.7s = \frac{600\,ft}{17.3\,ft/s}$$

$$t = t_{drogue} + t_{main} \tag{5}$$

$$85.1s = 50.4s + 34.7s$$

The MATLAB simulation uses the ode45 function to solve the ODE produced by balancing the weight of the launch vehicle with the force of drag during descent using the Runge-Kutta method (6). The solver is stopped once the altitude reaches 0 ft. The final time value is then outputted as the descent time of the launch vehicle.

$$0 = \begin{cases} -mg + \frac{1}{2}\rho v^2 s_{drogue} C_{drogue} & h_{main} < h \leq h_{apogee} \\ -mg + \frac{1}{2}\rho v^2 s_{main} C_{main} & 0 \leq h \leq h_{main} \end{cases} \tag{6}$$

Descent Time Predictions		
OpenRocket simulation	t_{total} (s)	104
	t_{apogee} (s)	17.6
	t (s)	86.4
Spreadsheet calculation	t_{drogue} (s)	50.4
	t_{main} (s)	34.7
	t (s)	85.1
MATLAB simulation	t (s)	82.6

Table 10: Descent Time Predictions

The OpenRocket simulation predicted the longest descent time of 86.4 s. The MATLAB simulation predicted the shortest descent time of 82.6 s. The difference between the two was 3.8 s. The difference between the two descent times may be due to the different way the two solve for the descent rate of the vehicle. The OpenRocket simulation adjusts atmospheric conditions as altitude changes, but the MATLAB simulation assumes constant atmospheric conditions during descent. The Excel spreadsheet predictions were similar to the OpenRocket simulation with a difference of 1.3 s. It was expected that the Excel would have the longest descent time because the descent rates plugged into it were the slowest. The OpenRocket simulation taking the longest to descend shows how the apogee has increased from the target apogee (Table 10).

3.3.5.2 Drift Predictions

The OpenRocket simulation is able to simulate drift due to constant wind, however it does not have a setting to force apogee to occur directly over the launch pad. To account for the correction into the wind of the launch vehicle, the drift to apogee was removed from the calculation. This was done by either adding the maximum drift near apogee to the final drift after the launch vehicle had drifted back over the launch pad, or in the cases where the launch vehicle did not drift back over the launch pad, the final distance from the pad was subtracted from the maximum distance the launch vehicle traveled. This occurred for the simulations run at 0, 5, and 10 mph wind speeds. The plot of lateral distance vs. time was used to find drift at apogee and final drift (Figure 73).

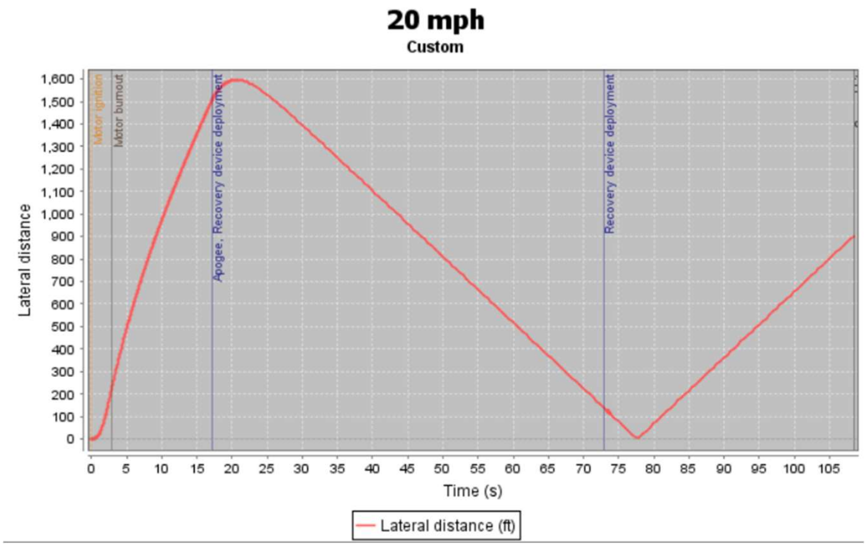


Figure 73: Lateral Distance vs. Time

In the plot of lateral distance versus time from the OpenRocket simulation, the launch vehicle had already drifted 1595 ft at apogee due to weathercocking and the angle of the launch rod (Figure 73). It then drifted back over the launch pad around 78 s into the flight. It landed 902 ft away from the launch pad after drifting back over it for a predicted drift of 2497 ft (7).

$$X = X_{apogee} \pm X_{final} \tag{7}$$

$$2497\ ft = 1595\ ft + 902\ ft$$

The spreadsheet and MATLAB simulation multiply the descent time by the wind speed to find total drift (8).

$$X = V * t \tag{8}$$

$$1248\ ft = (10\ mph * 1.46667\ ft/s/mph) * 85.1s$$

Drift Predictions					
Wind Speed	**0 mph**	**5 mph**	**10 mph**	**15 mph**	**20 mph**
Drift at apogee (ft)	852	1165	1300	1392	1595
Final drift (ft)	1015	545	67	489	902
Openrocket total (ft)	163	620	1233	1881	2497
Spreadsheet (ft)	0	624	1248	1872	2496
MATLAB (ft)	0	607	1214	1820	2427

Table 11: Drift Predictions

The OpenRocket simulation showed the largest lateral drift from the launch pad with a drift of 2497 ft. The MATLAB simulation had the least drift at 20 mph with a drift radius of 2427 ft. The difference between the two potential drift values may be due to the OpenRocket simulation having a launch rod angle of 5 deg giving the launch vehicle some additional horizontal velocity at apogee. The MATLAB simulation assumes that the wind speed matches the horizontal velocity of the launch vehicle throughout descent. For wind speeds of 5 mph and 10 mph, the Excel spreadsheet predicted the largest drift value. This helps highlight how the variation of descent rate is possible in the other simulation methods while the spreadsheet relies on a constant value for each parachute (Table 11).

3.3.3.3 Kinetic Energy Predictions

OpenRocket does not calculate the kinetic energy of the launch vehicle. The OpenRocket descent rates were plugged into the Excel spreadsheet to calculate the kinetic energy of each section. The mass of each section was taken from the mass table (Table 2). The mass of the aft section used for kinetic energy is different than mass present in the mass table due to the propellant in the motor no longer being present. The mass table includes the propellant, but the kinetic energy calculations do not. The propellant weighs around 50 oz. The MATLAB simulation performs the same calculation as the Excel spreadsheet, but using the descent rates the ODE solver found for the parachutes. The horizontal velocity of the launch vehicle is ignored for both calculation methods. Kinetic energy was found by multiplying the mass of each section by the velocity of the main parachute descent rate squared and divided by two (9). A sample calculation is presented.

$$KE_i = \frac{{v_{main}}^2 * m_i}{2} \tag{9}$$

$$5.9\ ftlbs = \frac{(17.3\ ft/s)^2 * (0.0397\ slugs)}{2}$$

Kinetic Energy Predictions			
Section	**Nosecone**	**Forward**	**Aft**
Spreadsheet (ft-lbs)	5.9	31.4	50.3
MATLAB (ft-lbs)	6.3	33.3	53.5

Table 12: Kinetic Energy Predictions

The MATLAB simulation provided the maximum predicted kinetic energy of 53.3 ft-lbs. The Excel spreadsheet predicted a value 3.2 ft-lbs less than the MATLAB simulation. The difference between the two values is due to how the velocity component for each calculation method was found. The OpenRocket simulation predicted a slower ground hit velocity than the MATLAB simulation, and therefore would provide a smaller kinetic energy value on ground hit (Table 12).

3.3.3.4 Main Parachute Deployment Load Prediction

The main parachute deployment load was predicted by dividing the change in kinetic energy from drogue parachute descent to main parachute descent of the aft section by a distance (10). The distance selected was 50 ft. The aft section was chosen because it is the section with the most mass and will always have the highest kinetic energy when it is assumed that all the sections are traveling at the same speed. 50 ft was chosen as the distance it takes for the main parachute to slow the launch vehicle to its terminal velocity by observing the distance it took for the OpenRocket simulation to slow the launch vehicle to the main parachute's descent rate after it passed the main parachute deployment altitude. The value was also deemed reasonable due to the performance of the subscale flight. An example calculation is shown (Test #23).

$$\text{Load} = \frac{\Delta KE}{d} \tag{10}$$

$$19.9 \text{ lbs} = \frac{(1047\ ftlbs - 50.3\ ftlbs)}{50ft}$$

Deployment Load Predictions		
Method	**Excel**	**MATLAB**
$KE_{Drogue\ aft}$ (ft-lbs)	1047	1085.8
ΔKE (ft-lbs)	997	1032.6
d (ft)	50	50
Load (lbs)	19.9	20.7

Table 13: Deployment Load Predictions

The maximum predicted deployment load is an additional 20.7 lbs of force on the recovery equipment using the kinetic energy values found with the MATLAB simulation (Table 13). The total force expected on the recovery harness, quick links, and eyebolts includes this 20.7 lbs and the total weight of the launch vehicle, 19.3 lbs (Table 2**Error! Reference source not found.**). This totals to 40 lbs. All structural components are expected to perform nominally under these loading conditions (Test #13).

4. Payload Criteria

4.1. Changes since CDR

4.1.1 Electrical Changes

A multiplexer integrated circuit was added to the I^2C data pins for the Arducam OV5642 modules to mitigate address conflicts encountered during camera troubleshooting.

The printed circuit board was replaced with a perforated board due to part arrival timing constraints. All electrical connections intended on the printed circuit board were replicated on the perforated board.

4.1.2 Mechanical Changes

The length of the fasteners used on the payload retention system was increased from 5 in to 6 in. During testing it was realized that the 5 in screws were not long enough to secure a hex nut to the back of the payload bulkhead. The 6 in 10-24 fastener allows ample room for the 10-24 style hex nuts to be secured to the back side of the payload bulkhead.

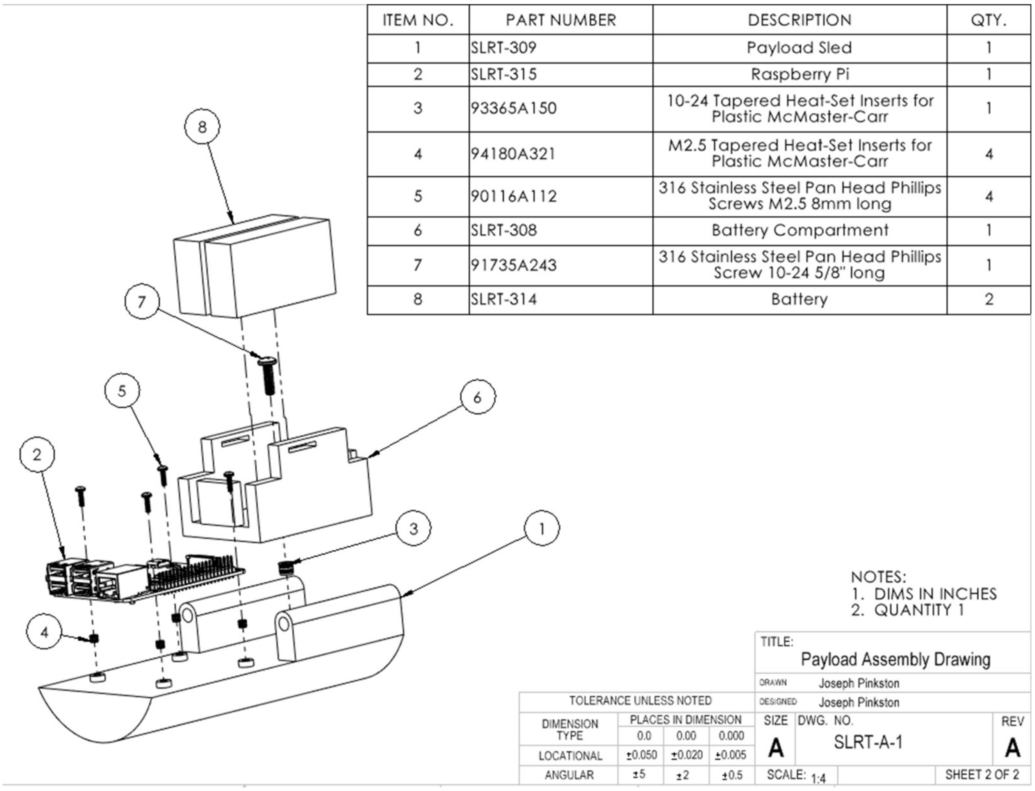
4.2 Unique Features

4.2.1 Structural Features

The payloads structural elements consist of the payload sled assembly and the camera mount assembly. All the components in both assemblies are 3D printed using PETG filament and are printed at 30% infill. The infill was determined through printing different test parts and noting their strengths. A 30% infill was determined to be strong enough without having to use large amounts of filament.

4.2.1.1 Payload Sled Assembly

The payload sled assembly consists of the payload sled and the battery compartment (Figure 74). This assembly is responsible for housing all of the payload’s electronics, except for the cameras. The payload sled assembly is located in the aft section of the launch vehicle, inside of the payload coupler.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-309	Payload Sled	1
2	SLRT-315	Raspberry Pi	1
3	93365A150	10-24 Tapered Heat-Set Inserts for Plastic McMaster-Carr	1
4	94180A321	M2.5 Tapered Heat-Set Inserts for Plastic McMaster-Carr	4
5	90116A112	316 Stainless Steel Pan Head Phillips Screws M2.5 8mm long	4
6	SLRT-308	Battery Compartment	1
7	91735A243	316 Stainless Steel Pan Head Phillips Screw 10-24 5/8" long	1
8	SLRT-314	Battery	2

NOTES:
1. DIMS IN INCHES
2. QUANTITY 1

TITLE: Payload Assembly Drawing
DRAWN Joseph Pinkston
DESIGNED Joseph Pinkston

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

SIZE A
DWG. NO. SLRT-A-1
REV A
SCALE: 1:4
SHEET 2 OF 2

Figure 74: Payload Sled Assembly Drawing

4.2.1.1.1 Payload Sled

The payload sled is the main component of the payload sled assembly. This part's purpose is to provide structural support for the onboard electronics. The payload sled utilizes M2.5 size threaded inserts for plastic to ensure a strong mating between the associated electronics and the sled, as well as the 10-24 size threaded inserts for the battery compartments mating to the sled. The payload sled also has the two-retention system mounting holes, which allow 10-24 style fasteners to connect the payload sled to the payload bulkhead. The payload sled has a total length of 7.00 in and a total height of 2.02 in (Figure 75).

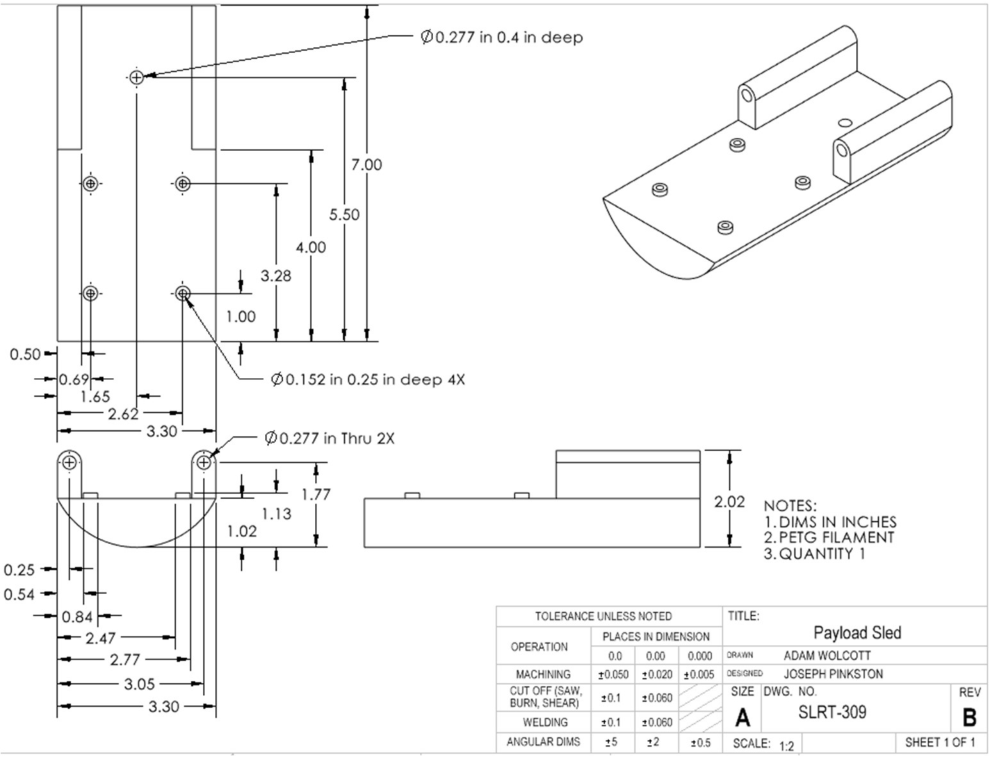


Figure 75: Payload Sled Drawing

4.2.1.1.2 Battery Compartment

The battery compartment is the final component on the payload sled assembly. The purpose of the battery compartment is to provide structural support for the two lithium-ion batteries that power the electronics. The battery compartment is mated to the payload sled using a 10-24 style fastener and the threaded insert in the payload sled. The battery compartment features a Velcro slot cutout that allows Velcro zip ties to slide over the top of the batteries, fully retaining the batteries inside of the battery compartment. The battery compart has an overall height of 1.85 in, width of 2.25 in and length of 3.1 in (Figure 76).

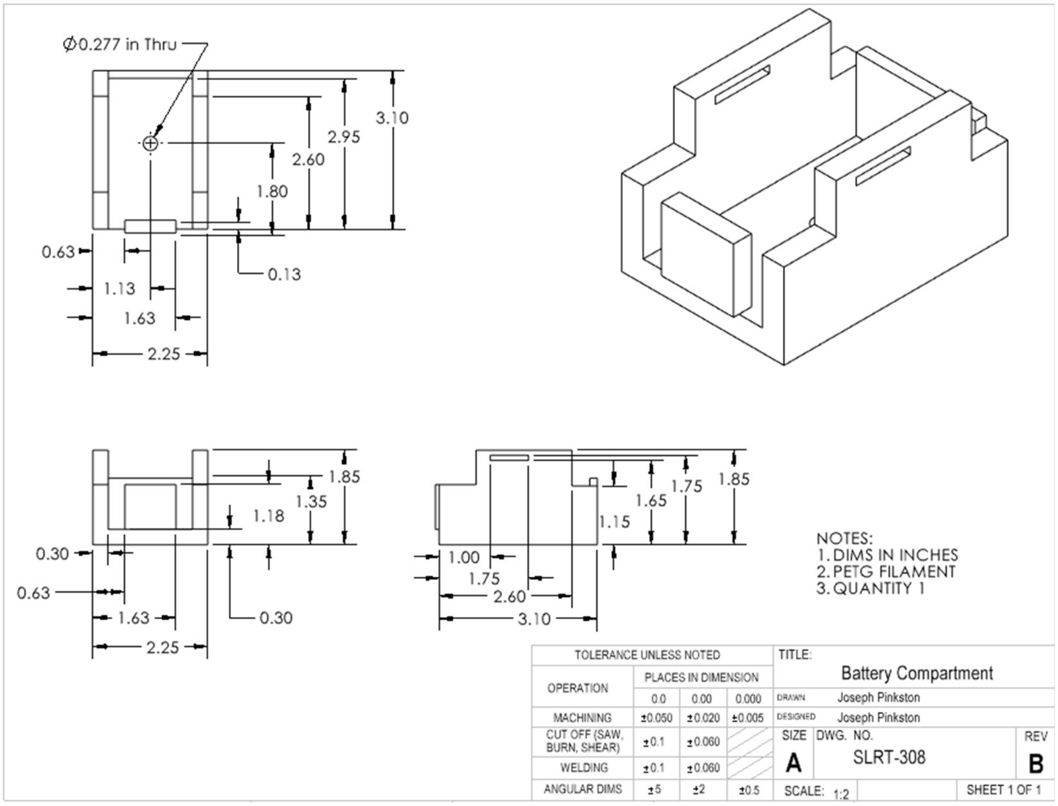
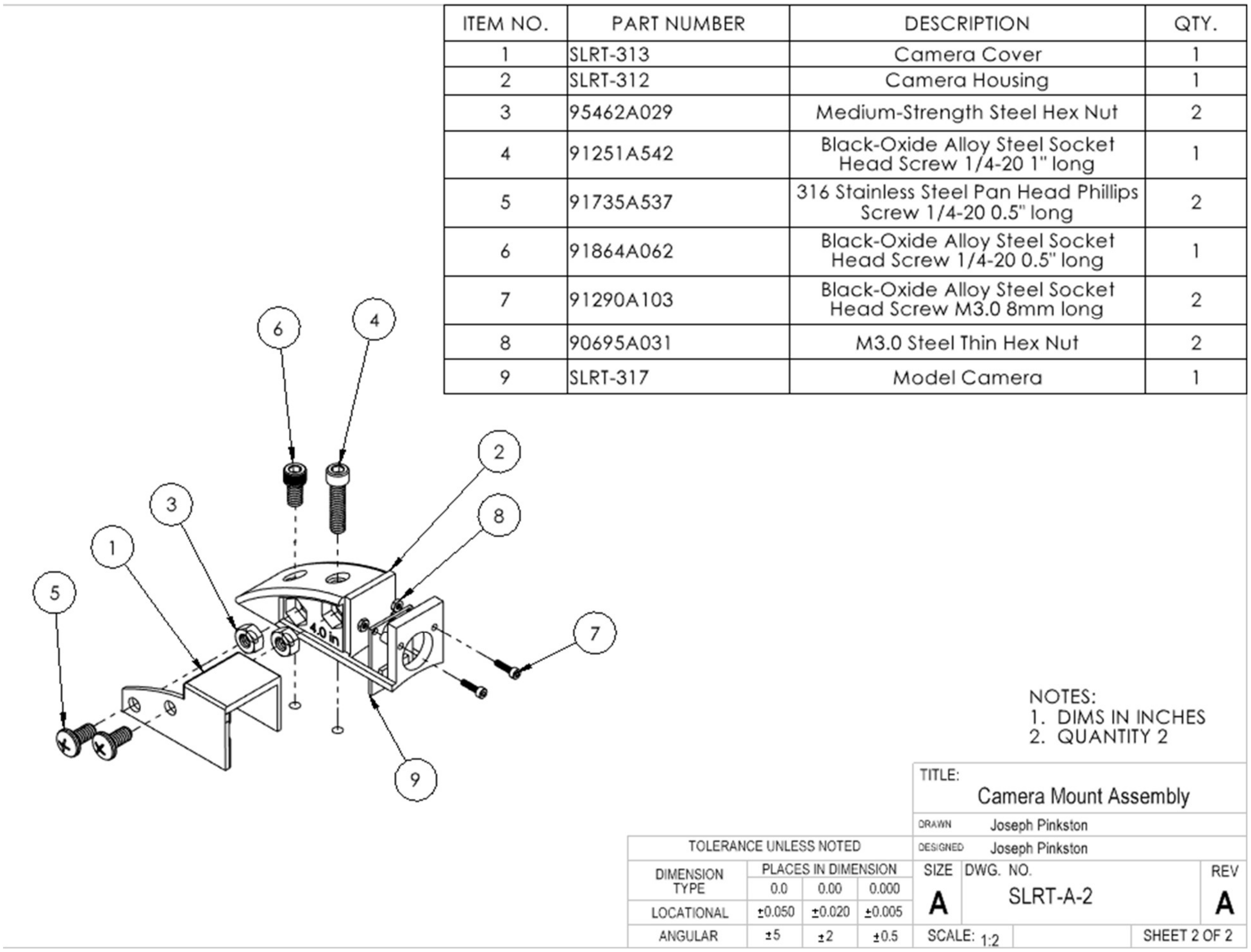


Figure 76: Battery Compartment Drawing

4.2.1.2 Camera Mount Assembly

The camera mount's purpose is to provide housing for cameras as well as shield them during launch and landing of the launch vehicle. The camera mount assembly consists of the camera housing and the camera cover (Figure 77). The camera mounts are located on the exterior of the aft section, 180 deg apart and spaced 90 deg from the fins (Figure 78). The camera mounts are placed towards the aft of the launch vehicle to get the clearest image of the launch field as possible without the launch vehicles airframe interfering.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	SLRT-313	Camera Cover	1
2	SLRT-312	Camera Housing	1
3	95462A029	Medium-Strength Steel Hex Nut	2
4	91251A542	Black-Oxide Alloy Steel Socket Head Screw 1/4-20 1" long	1
5	91735A537	316 Stainless Steel Pan Head Phillips Screw 1/4-20 0.5" long	2
6	91864A062	Black-Oxide Alloy Steel Socket Head Screw 1/4-20 0.5" long	1
7	91290A103	Black-Oxide Alloy Steel Socket Head Screw M3.0 8mm long	2
8	90695A031	M3.0 Steel Thin Hex Nut	2
9	SLRT-317	Model Camera	1

NOTES:
1. DIMS IN INCHES
2. QUANTITY 2

TITLE: Camera Mount Assembly
DRAWN Joseph Pinkston
DESIGNED Joseph Pinkston

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

SIZE A
DWG. NO. SLRT-A-2
REV A
SCALE: 1:2
SHEET 2 OF 2

Figure 77: Camera Mount Assembly Drawing

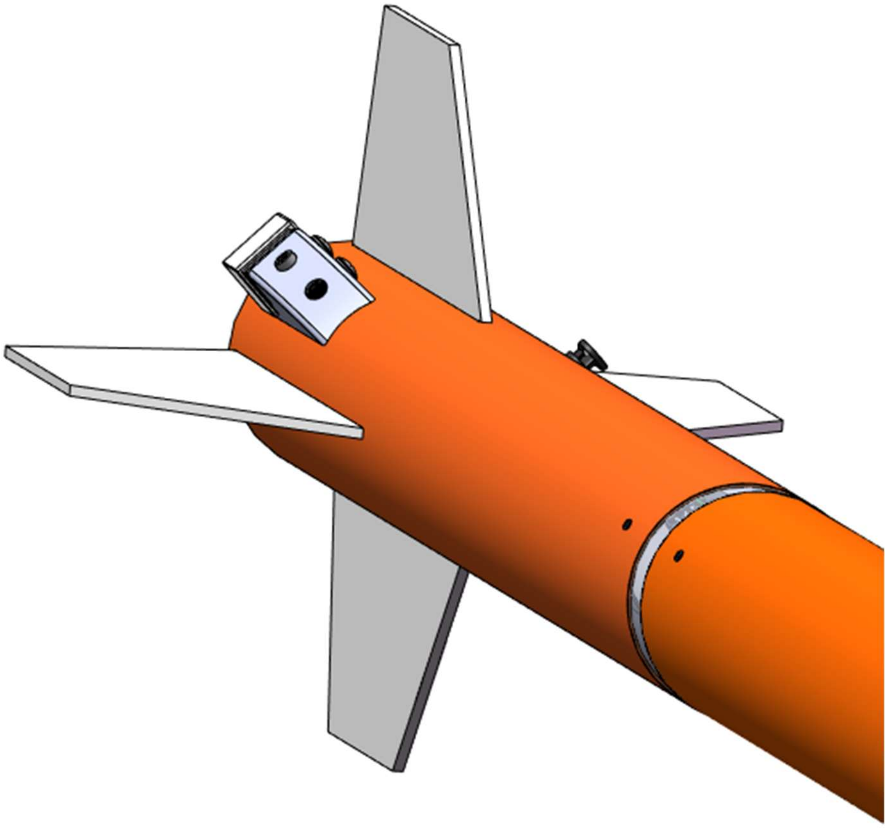


Figure 78: Camera Mount on Aft

4.2.1.2.1 Camera Housing

The camera housing is the main structural component of the camera mounts. The camera housing's purpose is to provide a secure structure for the cameras to be mated to, as well as being the component that mates to the aft airframe. The camera housing features a sloped design that progressively increases in height. This shape was chosen to allow the air to flow smoothly over the camera housing, minimizing the effects of drag on the camera housing's structure. Also, this shape reduces the overall protrusion of the camera housing from the launch vehicle, thus reducing its effects on the drag the launch vehicle experiences. The camera housing features two ¼-20 clearance holes for the camera housing to be mated to the aft airframes embedded T-nuts. It also features two cutouts for ¼-20 style hex-nuts. These cutouts allow two hex-nuts to sit inside of, providing a secure connection for the camera cover to mate to. Finally, the front face of the camera housing contains two M3.0 clearance holes to allow an M3.0 fastener through. The camera is mated to the spacers on the front face of the camera housing, in which two M3.0 fasteners pass through, and hex-nuts securing the cameras PCB to the camera housing. The camera housing has an overall height of 1.25 in, width of 1.2 in and length of 3.71 in (Figure 79).

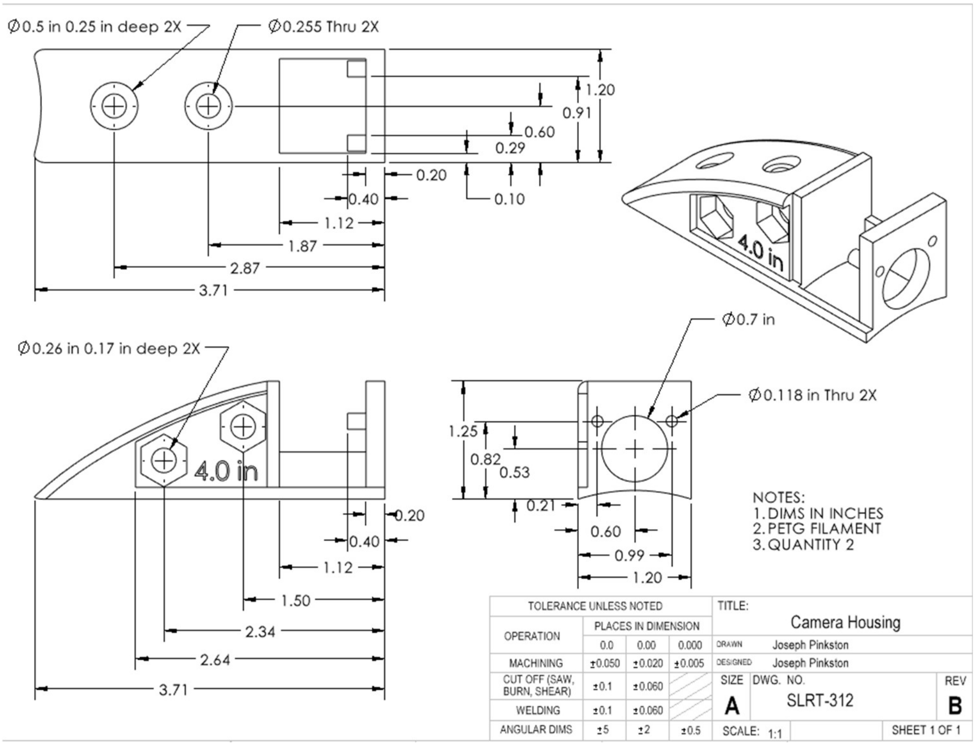


Figure 79: Camera Housing Drawing

4.2.1.2.2 Camera Cover

The camera cover is the final component of the camera mount assembly. The camera covers purpose is to protect the camera from the aerodynamic forces it would experience during flight, as well as seal the camera mount assembly. The camera cover features two ¼-20 clearance holes. These holes allow two ¼-20 style fasteners to mate to the hex-nuts in the camera housing. The camera cover has an overall height of 1.27 in, width of 1.30 in and length of 2.41 in (Figure 80).

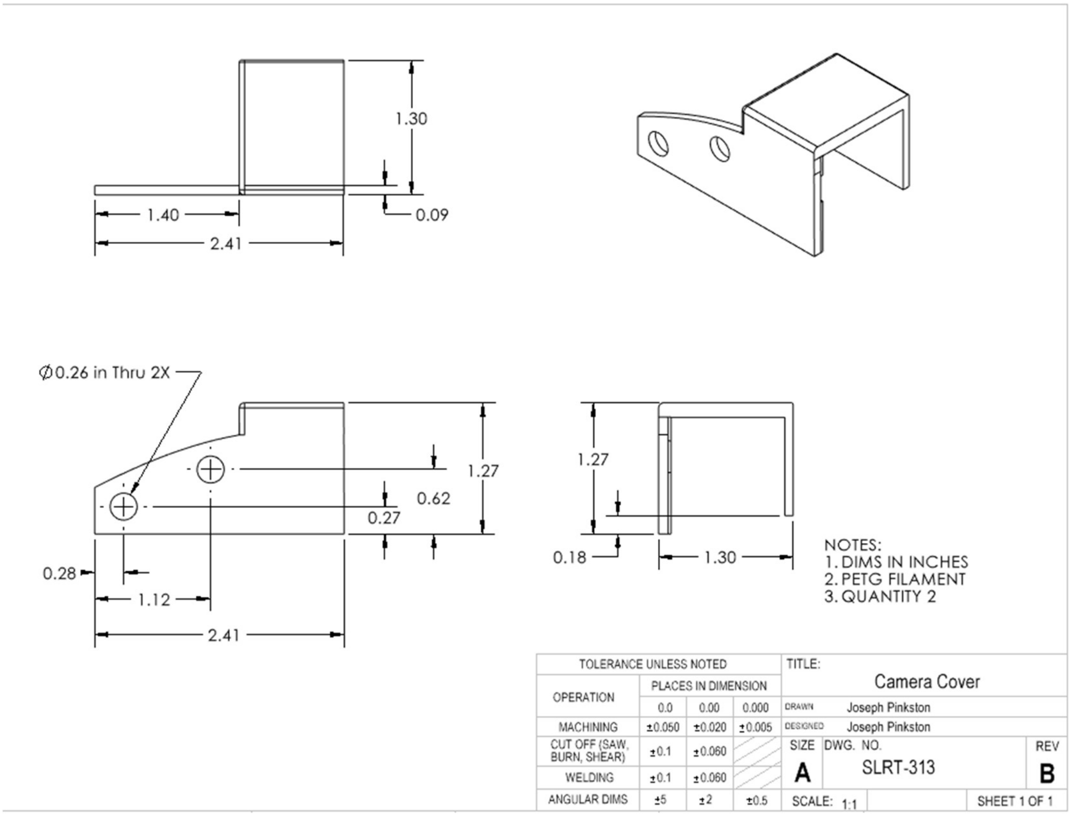


Figure 80: Camera Cover Drawing

4.2.2 Electrical Features

The payload features an ADIS16470 inertial measurement unit, two Arducam OV5642 camera and a Grove altimeter. This suite of sensors enables a hybrid inertial and image-based location system. A Raspberry Pi 4 serves as the payload's central processing unit. The ArduCAM OV5642 cameras feature two different lenses, with one capturing a 65 deg field of view and the other capturing a 90 deg field of view. The narrower field of view lens allows the camera to capture detailed images near apogee with a smaller viewable area. The wide field of view lens allows the camera to capture a larger area of the launch field, with less detail (Figure 81).

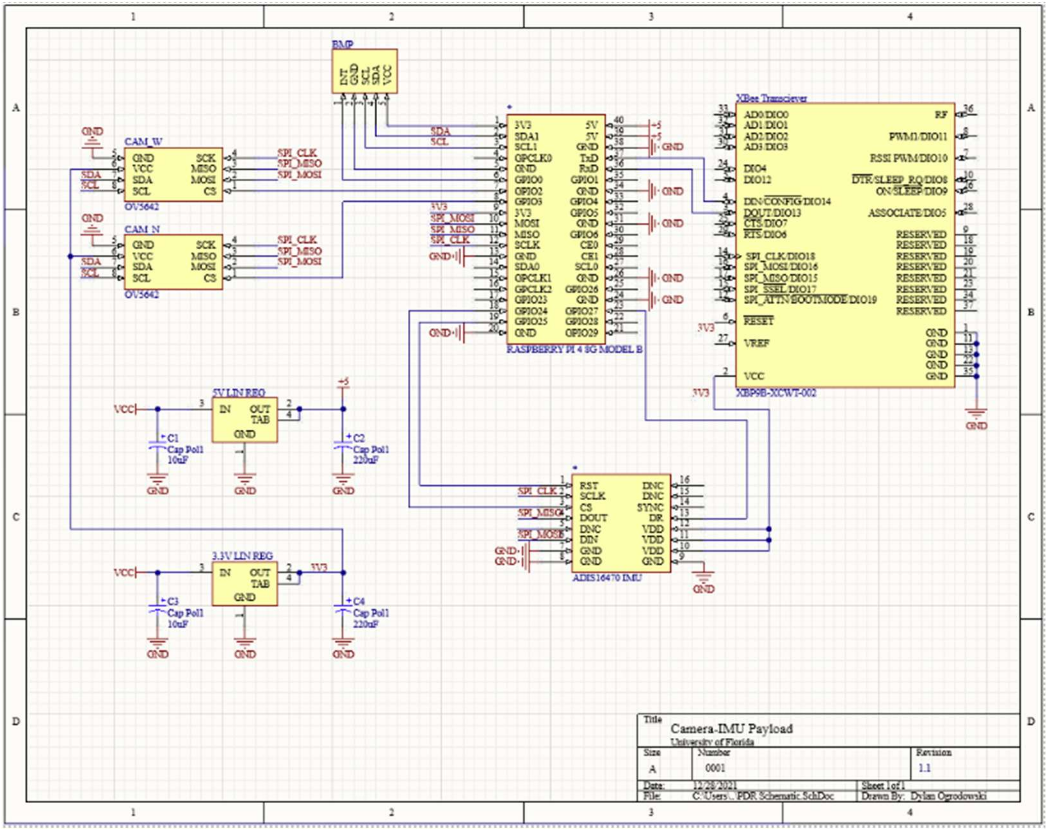


Figure 81: Payload Schematic

4.2.3 Software Features

The payload software controls all aspects of the payload including the cameras, the IMU, and the data processing. Images taken by the cameras are filtered based on capture state. The camera and IMU data are both stored by time stamp. The images are compared to a pre-uploaded image of the launch field to find an initial reference location. This is performed by the Scale Invariant Feature Transform (SIFT) algorithm in OpenCV. Once a reference location has been determined, IMU acceleration data starting from that time stamp is integrated to find displacement to the final landing location. The final location on the image can then be compared to the gridded image to determine the final grid location for transmission. A software flow chart is shown (Figure 82).

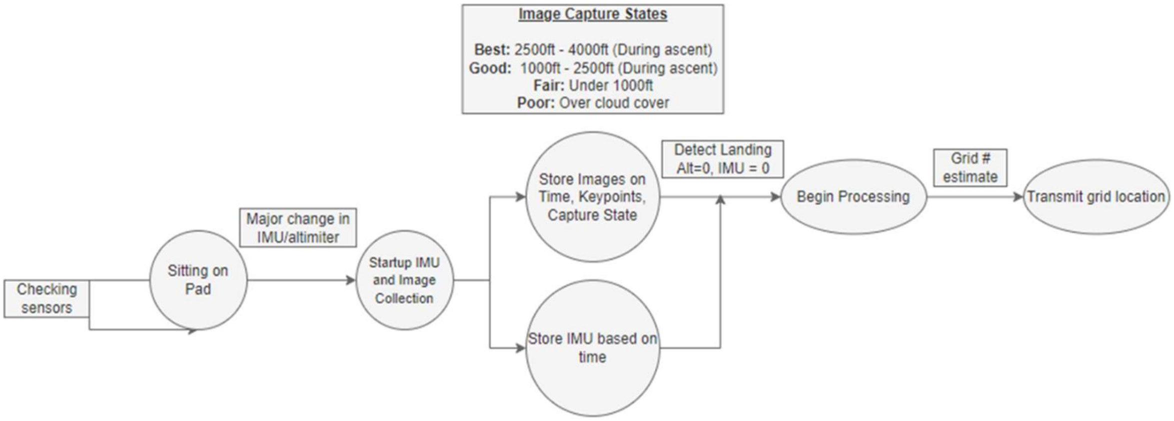


Figure 82: Software Flow Chart

4.2.3.1 SIFT Point Generation

As stated, the images taken by the camera on-board the rocket are compared against a pre-uploaded image of the launch field. This is done by generating SIFT points on both the images (Figure 83). A SIFT point is a unique location or feature within the image and then comparing the images by mapping the SIFT points to each other (Figure 84). The image taken during flight is then superimposed upon the pre-uploaded image and a bounding box is created. This, combined with tilt data from the IMU, allows for calculation of the location of the rocket at the specific time stamp that the image was captured. The data from three images taken at different times is used to determine the orientation of the rocket in 3D space. This location will then be used, along with the acceleration data from the IMU, to calculate the displacement to landing and thus the final landing location of the rocket.

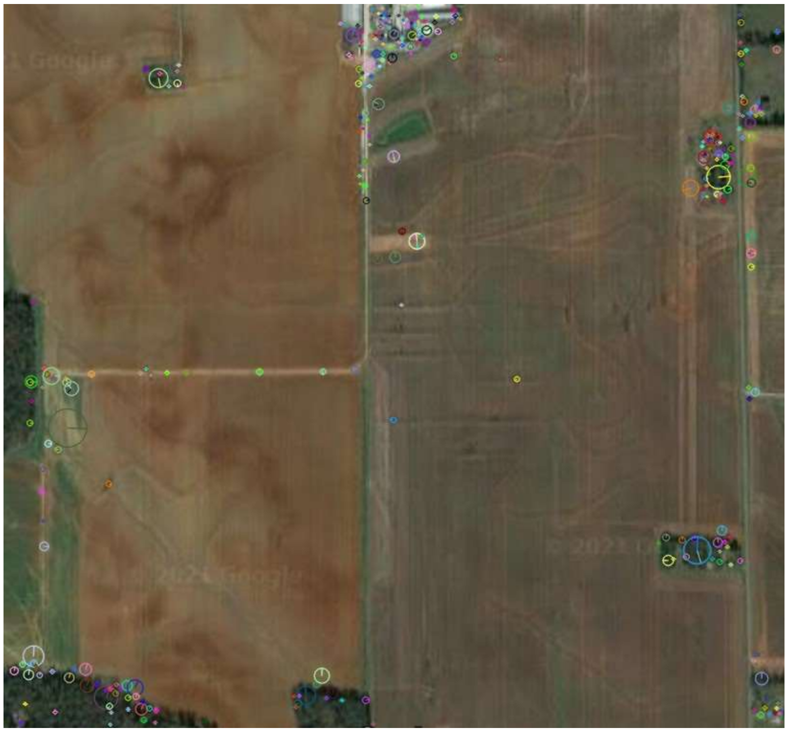


Figure 83: SIFT Points on Launch Field

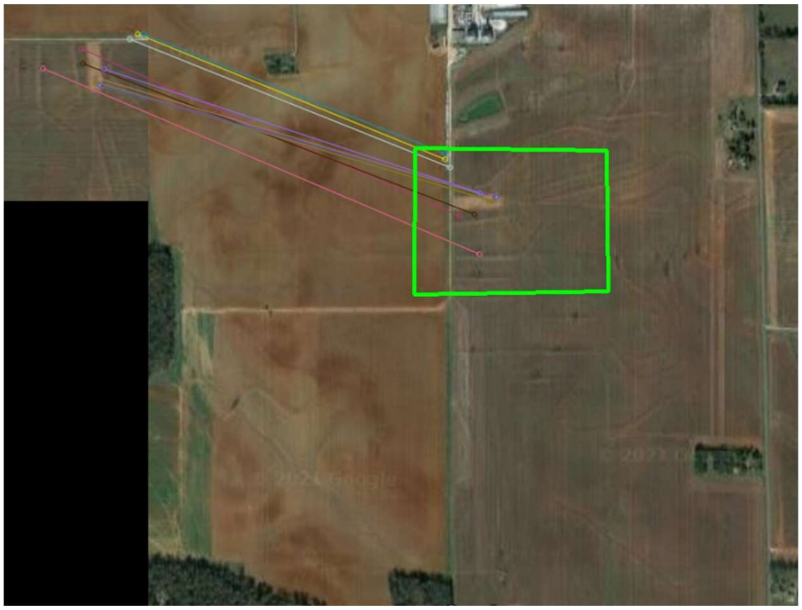


Figure 84: SIFT Point Location Matching on Sample Square of Launch Field

Payload software is currently in the development and testing stage as the team works to finalize all stages of the mission.

4.3 Flight Reliability Confidence

During the Vehicle Demonstration Flight, the camera mounts and payload sled assembly were flown. This was done because the camera mounts are exterior to the launch vehicle, thus affecting the aerodynamics.

Also, the payload mass needed to be simulated during the flight, so the payload sled and a ballast mass of 10.6 oz for the electronics were flown. The payload sled and camera mounts remained retained during the launch vehicle demonstration flight, ensuring the reliability of the retention systems. Due to the electronics being designed to attach to the payload sled using threaded inserts, the electronics will reliably stay mounted to the payload sled. This was also proven during the subscale flight in which a model of the payload was flown. The PCB flown on subscale stayed mounted throughout the flight and landing, ensuring the attachment method was successful. Similarly, the camera is mounted onto the camera housing using fasteners and hex-nuts. This was tested during Vehicle Demonstration Flight and was successful at keeping the cameras mounted and retained during flight and landing (Figure 85). Therefore, the design has been proves successful to complete the mission success criteria for the upcoming Payload Demonstration Flight.

Figure 85: Camera Mount Post Vehicle Demonstration Flight

4.4 Payload Construction

The payload structure consists of two main assemblies: the payload sled assembly and the camera mount assembly. All of the structural components manufactured on the payload were 3D printed using PETG filament. All 3D printing was done on Prusa 3D printers, provided by the University of Florida.

4.4.1 Payload Sled Assembly

To prepare the payload sled for assembly after printing, the threaded inserts needed to be put into the Raspberry Pi mounting holes, battery compartment hole, and retention system holes. Before the threaded inserts were implemented on the payload sled, testing was done on a test part to properly assess the sizing of the holes needed (Figure 86). This was done to prevent any errors during installation on the final sled, which would result in a large waste in PETG filament.

Figure 86: Threaded Inserts Testing

To begin this process, each of the threaded inserts were placed on top of their respective holes and pushed in enough so that they would not move on their own. Then, the soldering iron was turned on. For each threaded insert, the soldering iron was directly applied to the threaded insert until the insert was 90% of the way into the hole. Then, a flathead screwdriver was used to push the insert the rest of the way and to make sure the insert was flush with the surface of the sled. Finally, the soldering iron was turned off and put away safely so that it could cool down. After the threaded inserts cooled off, fit tests were performed on each of the inserts to ensure the screws could be fastened properly. With the appropriate fit achieved, the same procedure was followed to incorporate the inserts into the printed payload sled (Figure 87).

Figure 87: Threaded Inserts Installed on Payload Sled

Next, the battery compartment was printed and ready for attachment to the payload sled. The battery compartment attaches to the sled using a standard 10-24 style fastener. The battery compartment has a clearance hole for the fastener, and the payload sled has a corresponding threaded insert for the fastener to be threaded into (Figure 88).

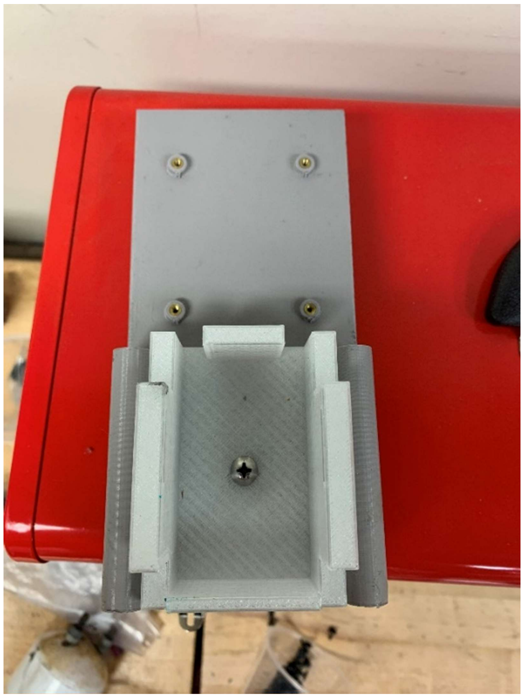


Figure 88: Battery Compartment Mounted onto Payload Sled

Finally, the Raspberry Pi, the associated electronics, and the batteries were mounted onto the payload sled and battery compartment. The Raspberry Pi's PCB features four M2.5 mounting holes. These holes aligned with the corresponding M2.5 threaded inserts on the sled for the Raspberry Pi to be mounted to. Standard M2.5 fasteners were used to mount the Raspberry Pi to the sled. The two lithium-ion batteries were placed inside of the battery compartment, with their wires facing towards the Raspberry Pi. The batteries were then sealed in the vertical direction by passing Velcro through the battery compartments Velcro cutout. This fully retained the batteries inside of the compartment (Figure 89).

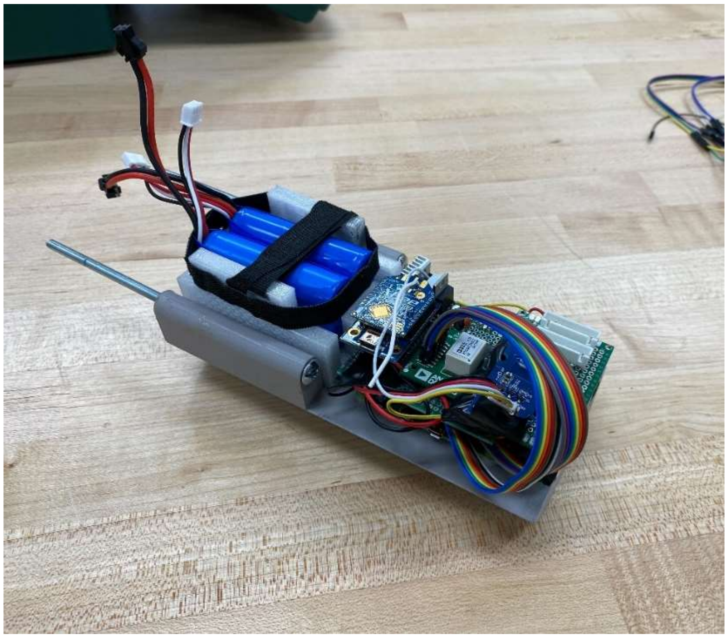


Figure 89: Fully Assembled Payload Sled

4.4.2 Camera Mount Assemblies

Manufacturing of the camera mounts began with 3D printing the camera housing and the camera cover, using PETG filament. Two camera covers and two camera housings were printed. The camera housing features two M3.0 clearance holes for the camera's PCB, two ¼-20 style clearance holes to mount the housing to the aft airframe, and two ¼-20 style hex-nut cutouts to mount the camera cover to the housing. The camera cover features two corresponding ¼-20 style clearance holes to allow a fastener to mate the cover to the housing (Figure 90).

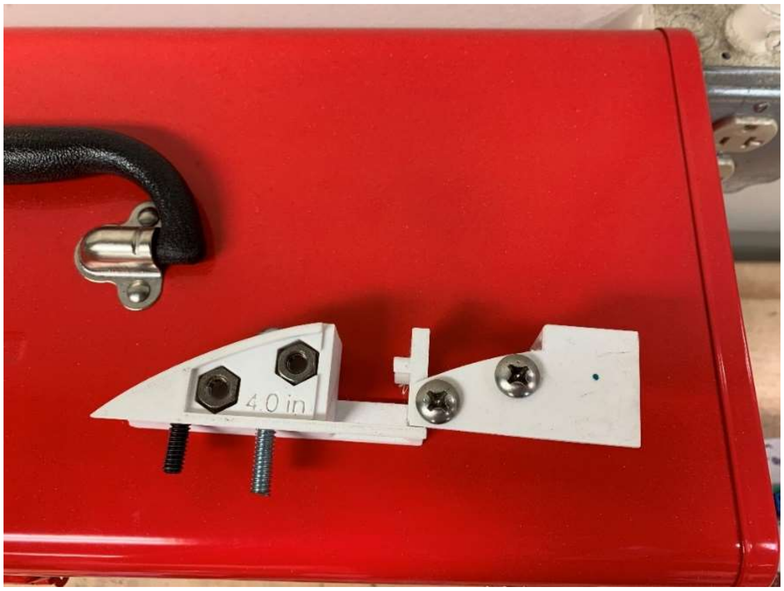


Figure 90: Camera Mount Components

To begin assembling the camera mounts, the cameras were mated to the camera housing. This was done by using the cameras provided PCB mounting holes, and the camera housings corresponding clearance holes. The cameras' PCB was lined up with the camera housings M3.0 clearance holes, and standard M3.0 fasteners were used to mount the camera to the camera housing. Hex nuts were used on the back side of the cameras PCB to secure the connection between the camera and the camera housing (Figure 91).

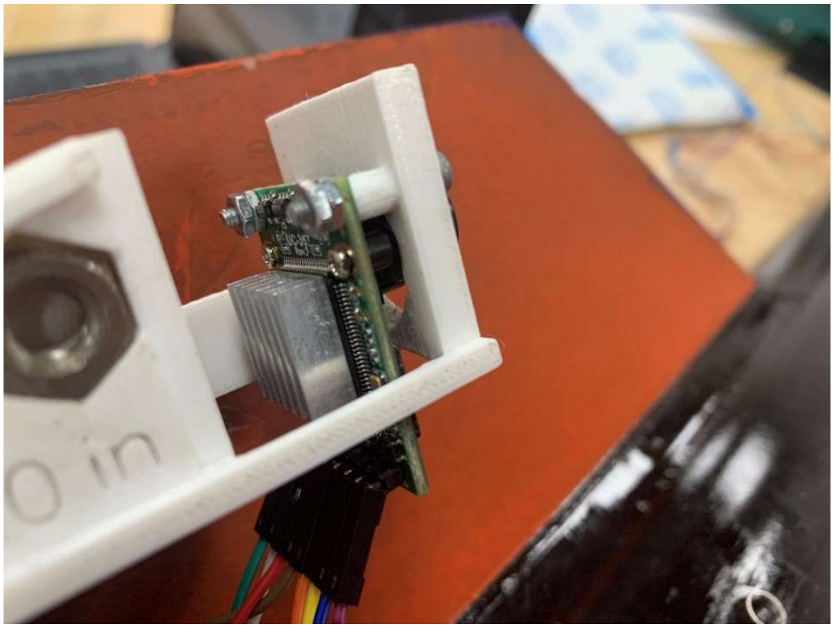


Figure 91: Camera Mating to Camera Housing

Next, the camera cover was attached to the camera housing using the ¼-20 style clearance holes in the camera cover and the ¼-20 style hex nuts in the camera housing. The camera cover was aligned with the hex nuts' orientation, and the ¼-20 fasteners were used to mate the camera cover to the camera housing (Figure 92).

Figure 92: Camera Mount on Aft Airframe

Finally, the camera mounts were ready to be mounted to the launch vehicles airframe. The camera mount was mated to the launch vehicles airframe using two ¼-20 fasteners and their corresponding t-nuts, which were epoxied to the inside of the launch vehicle's airframe. These fasteners were tightened down to be flush with the camera housings rounded face, minimizing their protrusion, and therefore minimizing their effects on drag (Figure 93).

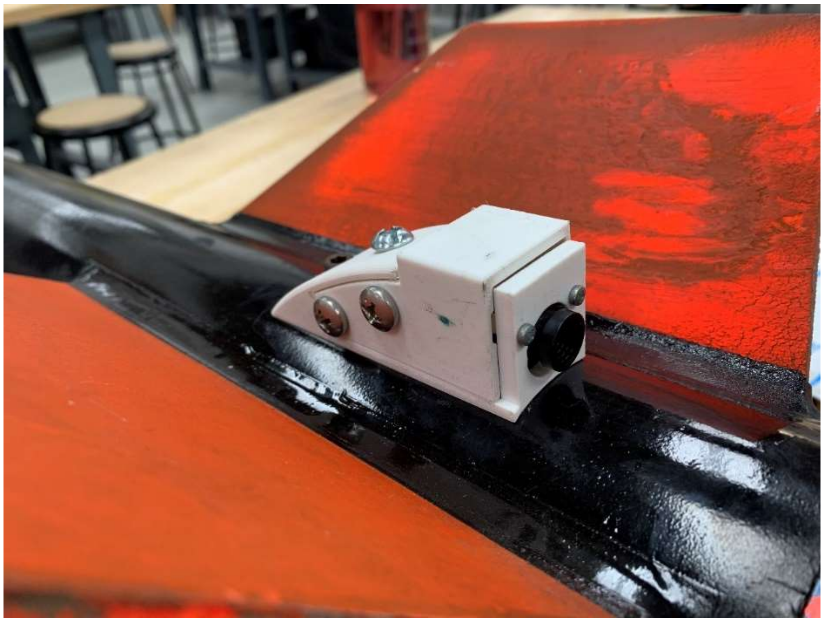


Figure 93: Camera Mount Fastened to Aft Airframe

4.4.3 Perforated Board Assembly

The inertial measurement unit, barometer, XBee radio, and power systems were mounted on two perforated boards, stacked vertically above the Raspberry Pi. A 2x20 grid of female Dupont headers was soldered to the lower perforated board. This header grid served as the interface between the perforated boards and the Raspberry Pi 4. A second 2x20 grid of Dupont headers connected the upper perforated board to the lower board. Insulated jumper wires were soldered between the female Dupont headers and the pins of each component to create an electrical connection between the Raspberry Pi and each device (Figure 94 - Figure 97).

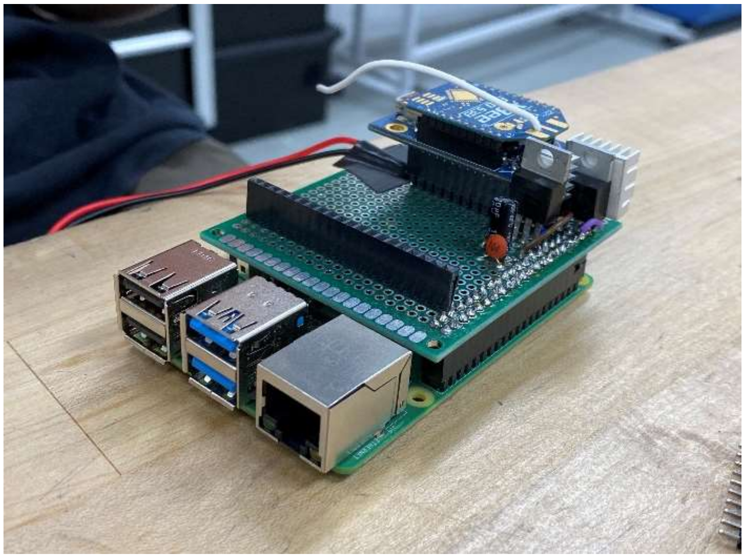


Figure 94: Lower Perforated Board During Assembly Mounted to Raspberry Pi 4

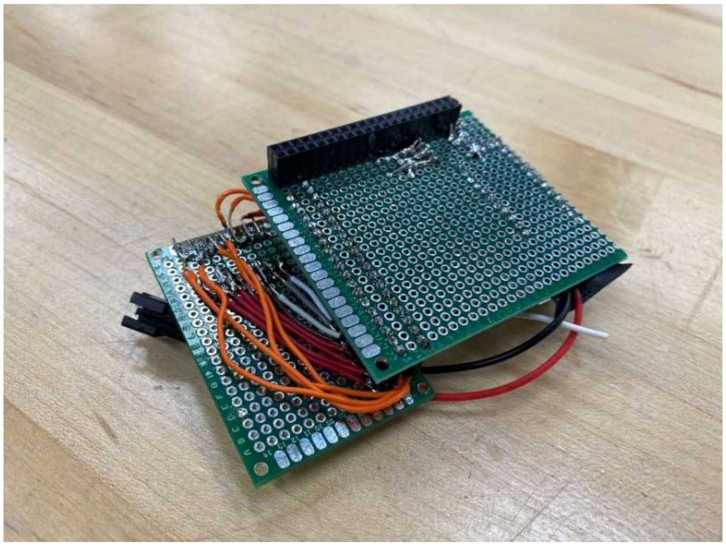


Figure 95: Underside of Perforated Boards During Assembly with Jumper Wires

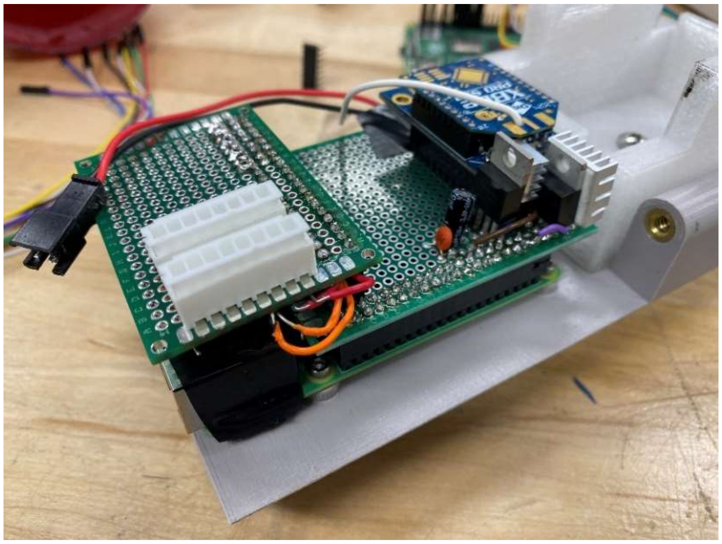


Figure 96: Perforated Board Mounted to the Raspberry Pi 4 with Upper Board Attached

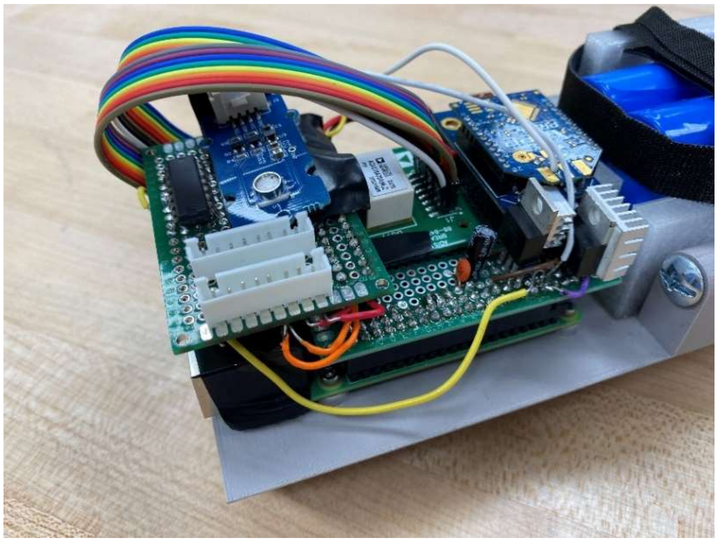


Figure 97: Finished Perforated Boards Mounted to the Raspberry Pi 4

The 3.3 V linear regulator, 5 V linear regulator, and capacitors were soldered directly to the perforated board. Capacitors were placed directly adjacent to their corresponding linear regulators to minimize output voltage fluctuations.

All components were soldered using a Hakko 951X soldering iron at 700 °F. The perforated board was held in place using adjustable arm clamps while soldering. While soldering, all through-hole components were secured to the top face of the board with masking tape to prevent shifting when the board was inverted. The tape was removed from each component after soldering (Figure 98).

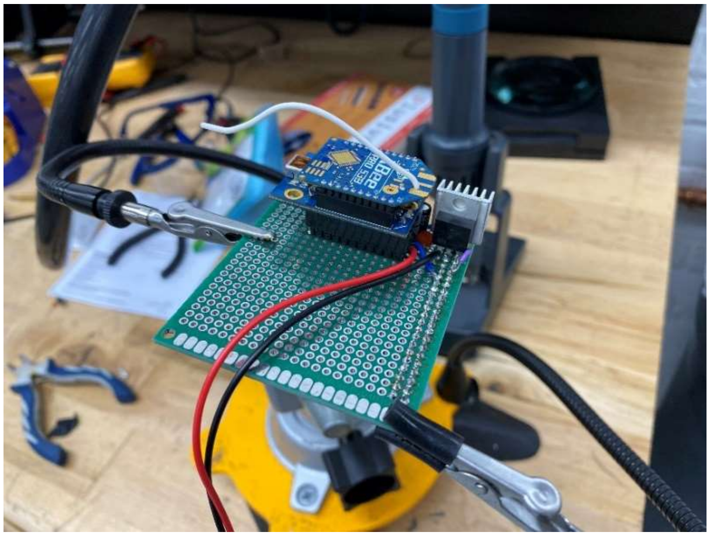


Figure 98: Perforated Board Soldering

A Fluke digital multimeter was used to verify that the soldered board did not contain any unintended short circuits. To complete this verification, the multimeter was placed in continuity mode and each pin was probed with its adjacent pins.

4.4.4 Payload Retention System

The payload sled is located in the aft of the launch vehicle, inside of the payload coupler. The payload sleds retention system consists of the payload bulkhead, two 10-24 style fasteners, and two 10-24 style hex nuts. The two 10-24 style fasteners were threaded into the payload sleds retention system mounting holes until the head of the screw was flush with the mounting holes surface (Figure 99). The fasteners were then placed through the corresponding clearance holes in the payload bulkhead. The fasteners were then secured on the back side of the payload bulkhead using the 10-24 hex-nuts (Figure 100). The payload sled assembly was firmly mated to the payload bulkhead and can be removed by removing the hex nuts and the fasteners.

Figure 99: Payload Sled Assembly Retained Inside of Coupler

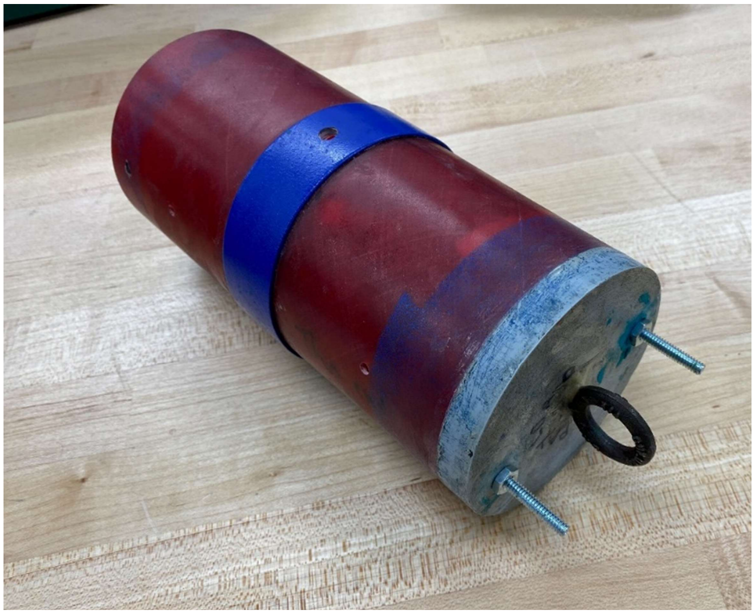


Figure 100: Payload Retention System Sealing on Payload Bulkhead

4.5 As-Built Payload

4.5.1 Payload Sled Assembly Schematics

The payload sled assembly's width was measured to be 3.31 in. This was a 0.01 in difference to the drawing dimensions provided for the sled assembly. This could be compound error in the 3D printer and the calipers used to take the measurement (Figure 101).

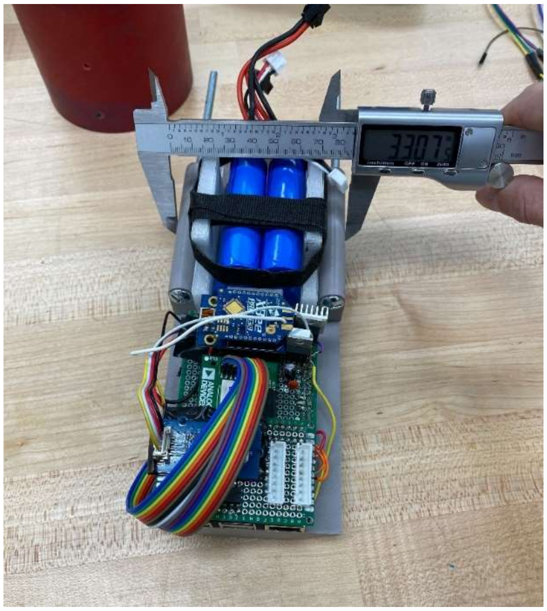


Figure 101: Width Measurement of Payload Sled Assembly

The measured height of the payload sled assembly was 2.86 in. This was 0.84 in greater than the drawing dimensions height provided for the payload sled assembly. This was due to the height of the Velcro and the battery cover not being considered, which ended up being roughly 0.84 in together (Figure 102).

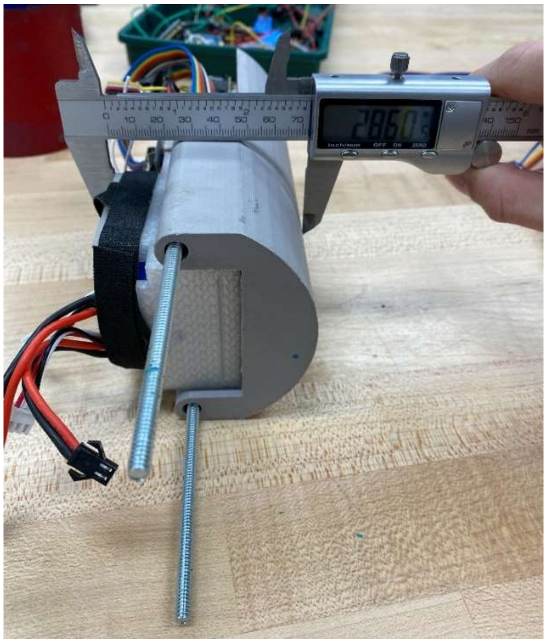


Figure 102: Height Measurement of Payload Sled Assembly

The measured length of the payload sled assembly was found to be 7.25 in. This was 0.25 in greater than the drawing dimensions provided for the payload sled assembly. This was due to the small section of electronics, namely the attached PCB, hanging off the front end of the sled. This protruding section was measured to be 0.25 in total, which accounts for the difference in length (Figure 103).

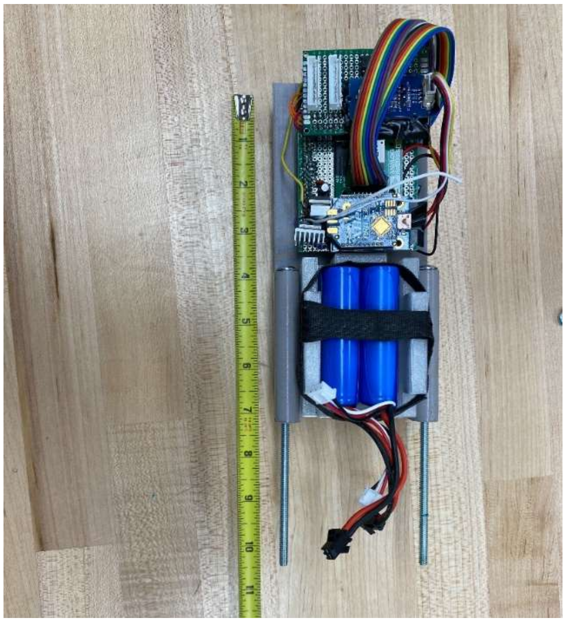


Figure 103: Length Measurement of Payload Sled Assembly

4.1.5.2 Camera Mounts Assembly Schematics

The width of the camera mount was measured at 1.31 in. This was off by 0.1 in compared to the drawing dimensions provided for the camera mount. This is possibly due to the circular ending on the camera mount being printed with error (Figure 104).

Figure 104: Width Measurement of Camera Mount

The length of the as built camera mount was measured as 3.71 in. This was in perfect agreement with the drawing dimensions provided for the camera mount (Figure 105).

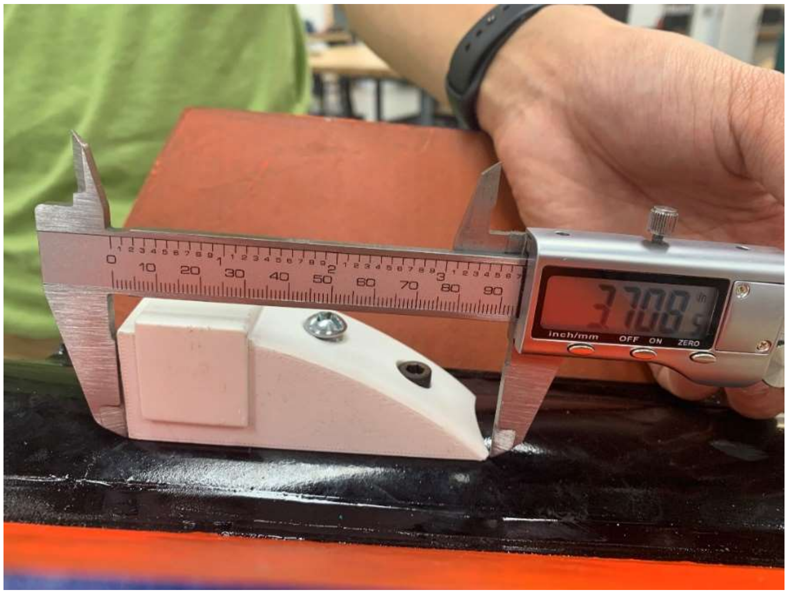


Figure 105: Length Measurement of Camera Mount

The height of the camera mount was measured to be 1.25 in. This was also in perfect agreement with the drawing dimensions provided for the camera mount (Figure 106).

Figure 106: Height Measurement of Camera Mount

4.6 Constructed Payload vs Earlier Models

4.6.1 Camera Mount Assembly

The camera mounts were changed from PDR to CDR due to testing during the subscale launch of the launch vehicle. During the subscale launch, the decision was made that the camera mounts protrusion was an issue for the full-scale model and needed to be minimized (Figure 107). This was because the protrusion of the camera mounts was large enough that their effects on the drag of the launch vehicle needed to be reduced. This was noticed by the flight dynamics team when running simulations of the launch vehicles flight with the camera mounts mounted. Also, the assembly process of mating the cameras to the PDR design was difficult and could be streamlined. To correct the camera mounts protrusion, a small slot was made in the aft airframe. This allowed the camera to be partially submerged in the launch vehicles airframe, thus decreasing the protrusion needed for the camera mounts from 1.76 in to 1.2 in (Figure 108). The camera housings design was altered to fit this new model and the camera cover was similarly altered to properly seal the camera housings new dimensions.

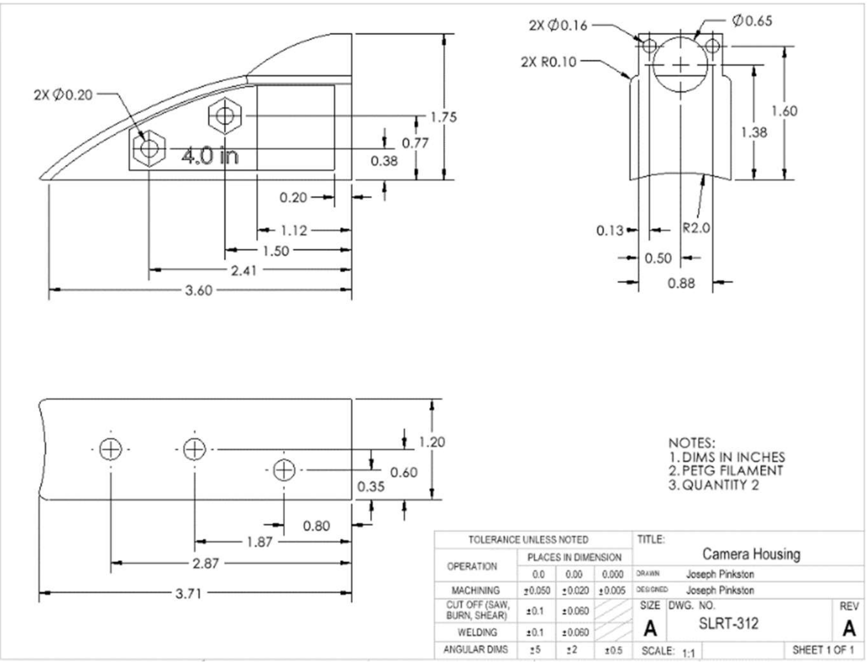


Figure 107: PDR Camera Housing Drawing

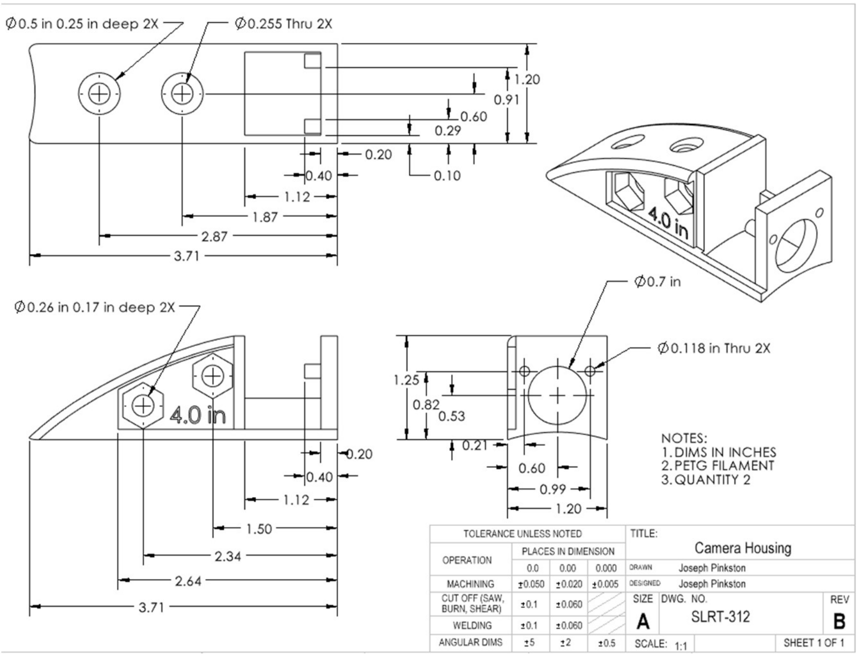


Figure 108: Final CDR Camera Housing Drawing

4.6.2 Payload Retention System

The payload retention system changed between PDR and CDR. During the subscale launch, a more modular and reliable design of the payloads retention system was tested and flown. This design was successful at retaining the payload sled and its hardware, and thus was chosen as the payload's new retention system. The previous retention system was separate from the payload and required the use of epoxy. It also required a separate rail system and latch system (Figure 109). This meant that there were two more parts that needed to be manufactured and tested to ensure they were designed well. The final retention system however utilized two mounting holes on the payload sled and the payload bulkhead (Figure 110). This design was much more modular, avoided the permanent nature of epoxy, and was tested during subscale and now the Vehicle Demonstration flight with success.

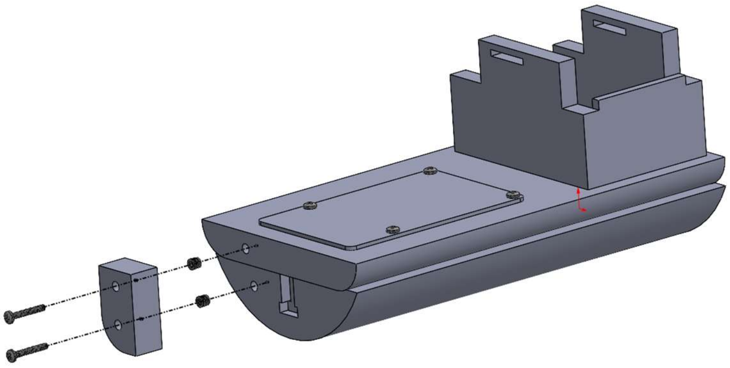


Figure 109: PDR Payload Retention System

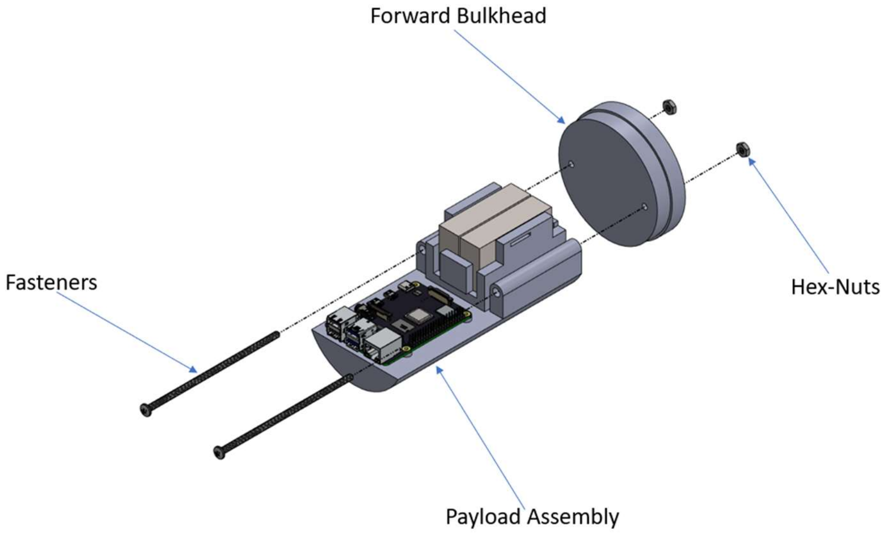


Figure 110: Final CDR Payload Retention System

4.7 Payload Demonstration Flight

A payload demonstration flight is planned for March 19th, 2022, at Tampa Tripoli (Prefecture #17). The flight will be considered successful based off Requirement 2.19.2. That is, if the payload system is fully constructed and active, is fully retained throughout the flight, and is recovered without damage.

5. Demonstration Flights

5.1 Vehicle Demonstration Flight

Only one flight was needed to meet the requirements for the Vehicle Demonstration. All flight information was documented and an analysis comparing predictions with the actual flight data was performed.

Flight Overview	
Demonstration Flight	Vehicle Demonstration Flight
Date of Flight	February 19th, 2022
Location	Plant City, Florida (Prefecture #17)
Motor	Aerotech L1090W
Launch Rail Angle	0 deg
Ballast	2.2 lbs.
Final Payload Flown	No
Official Target Altitude	4,578 ft
Predicted Altitude from Simulations	4,582 ft
Measured Altitude	5,079 ft

Table 14: Vehicle Demonstration Flight Overview

5.1.1 Launch Day Conditions

The conditions on launch day were recorded and utilized in simulations and post-flight analysis (Table 15).

Launch Day Conditions	
Wind Speed	1.5 mph
Altitude Above Sea Level	128 ft
Latitude	29 deg
Longitude	-82.2 deg E
Temperature	79 deg Fahrenheit
Air Pressure	30.21 Hg

Table 15: Launch Day Conditions

5.1.2 Predicted Flight Performance

The predicted flight simulation was performed using the flight conditions of the launch site. Using these conditions, the altitude with respect to time was simulated (Figure 111). The predicted altitude from the simulation was 4582 ft.

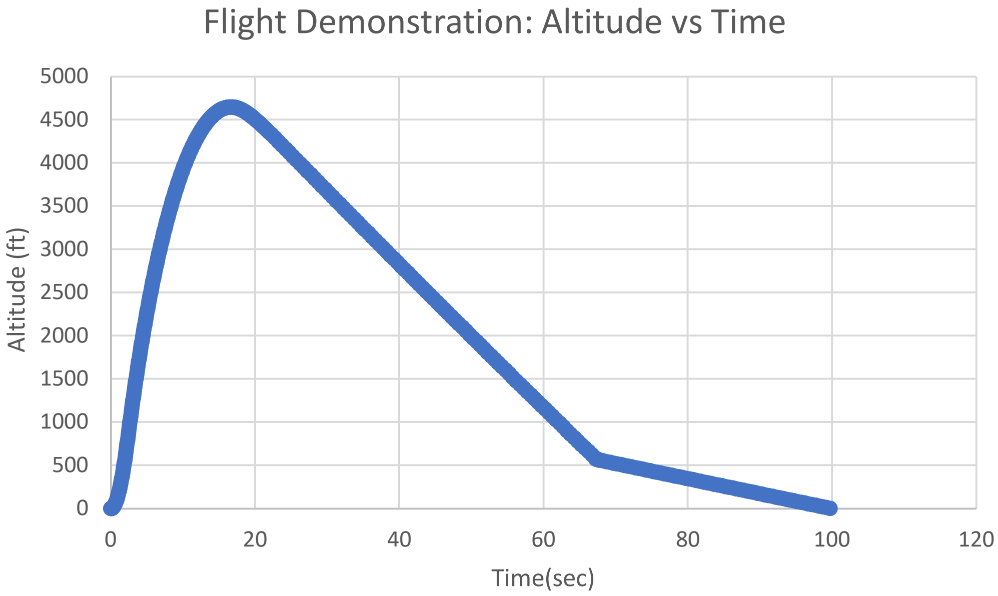


Figure 111: VDF Predicted Altitude vs Time

The total velocity and total acceleration were also simulated (Figure 112 and Figure 113). The peak in the acceleration plot was associated with main parachute deployment and was instantaneous. Therefore, it was not taken into consideration. Maximum velocity was simulated to be 643 ft/s and maximum acceleration was 329.24 ft/s^2.

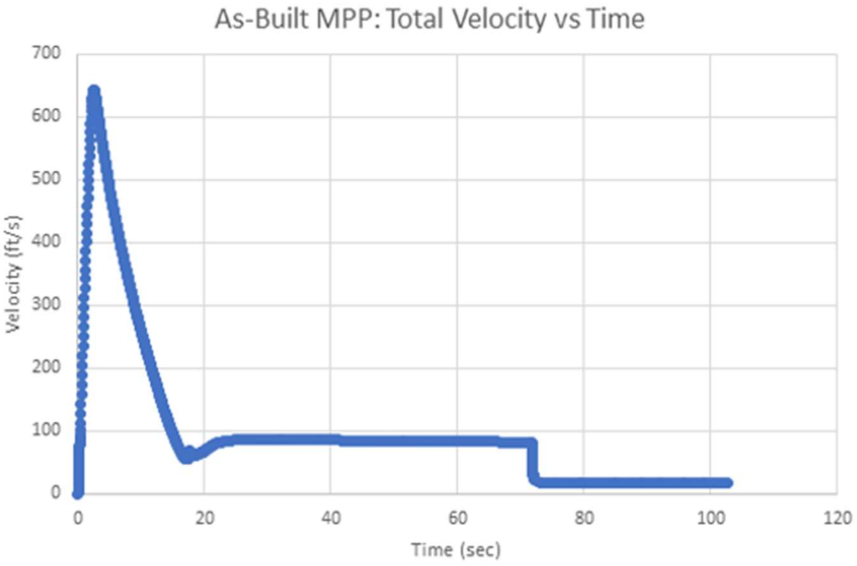


Figure 112: VDF Predicted Velocity vs Time

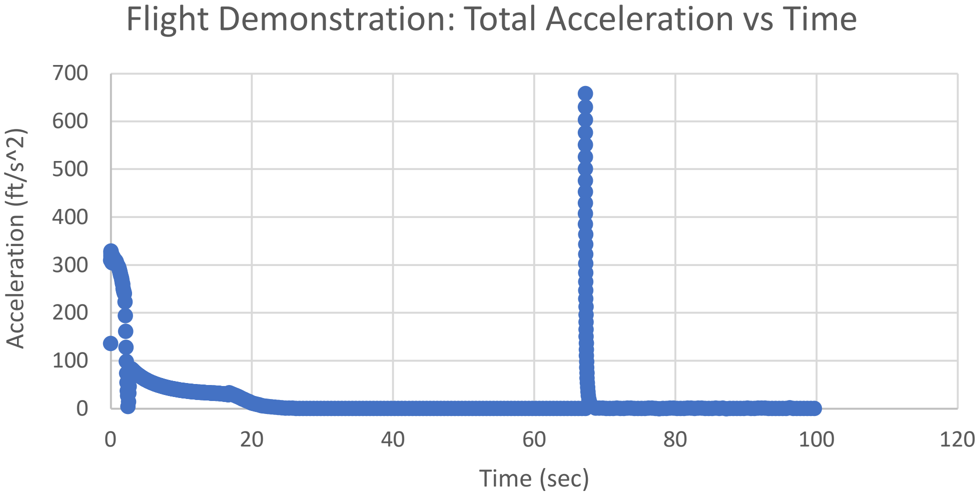


Figure 113: VDF Predicted Acceleration vs Time

5.1.3 Flight Results

The vehicle demonstration flight was successful on the first attempt. The vehicle was launched and separated successfully. All vehicle and recovery systems functioned as intended. The forward and aft sections separated at apogee allowing the drogue parachute to deploy, and the forward and nosecone sections separated at 600 ft, allowing the main parachute to deploy as well. The payload sled and camera mounts were included in and on the launch vehicle; the electronics, however, were not flown and instead the weight of the electronics was accounted for with clay ballast. The vehicle landed at the appropriate velocity and experienced no damage (Figure 114). No hardware was damaged and no off-nominal events occurred during the launch. Therefore, the vehicle was considered recoverable and reusable and thus, successful.

Figure 114: Vehicle Demonstration Flight Recovery Site

5.1.3.1 Altimeter Flight Profile Data

Altitude data was collected by the primary and secondary altimeters on board the launch vehicle. The data collected was used to find apogee, velocity, and descent time. The calculated velocity data was used to assess the launch vehicle's coefficient of drag and parachute performance. The two types of altimeters have slightly different methods of finding altitude above ground level. The Entacore AIM required manual ground level calibration (Figure 115).

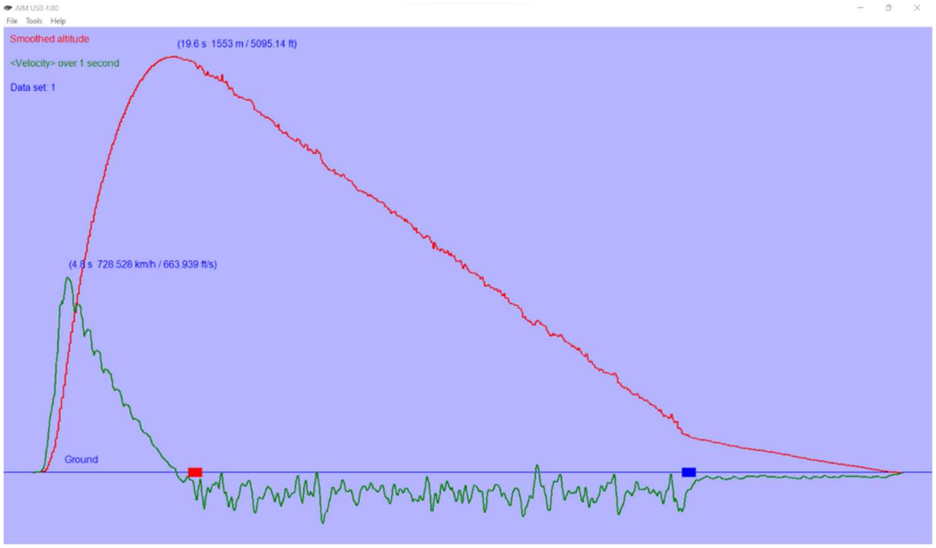
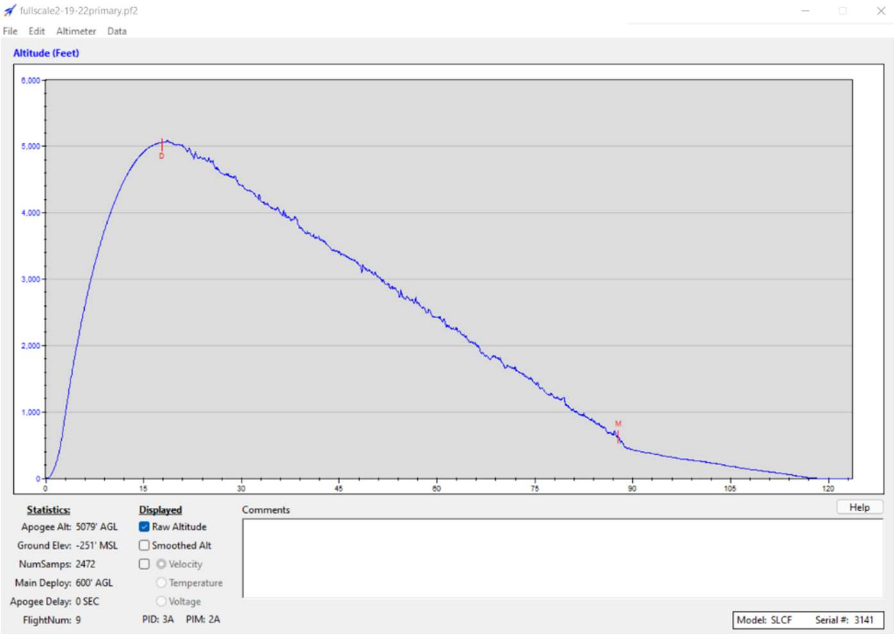


Figure 115: Entacore AIM Altitude Data

The StratologgerCF calibrates automatically during start up (Figure 116). Some oscillations are present in the data, especially during drogue parachute descent. The oscillations in the data may be due to turbulent air reaching the barometers.



Statistics:
Apogee Alt: 5079' AGL
Ground Elev: -251' MSL
NumSamps: 2472
Main Deploy: 600' AGL
Apogee Delay: 0 SEC
FlightNum: 9

☑ Raw Altitude
☐ Smoothed Alt
☐ ● Velocity
○ Temperature
○ Voltage

PID: 3A PIM: 2A

Model: SLCF Serial #: 3141

Figure 116: StratologgerCF Altitude Data

5.1.4 Analysis of Vehicle Demonstration Flight

On February 19th, 2022, the vehicle was launched in Plant City, Florida. It was deemed a successful flight meeting all mission success criteria. The flight reached apogee at 5079 ft, had successful parachute deployments, and landed safely with no damage. However, a few changes in the design, from CDR, altered the expected performance of the flight. Namely, these changes affected the drag coefficient of the vehicle and led to discrepancies in the predicted and actual profiles.

5.1.4.1 Altitude: Analysis and Error

The predicted altitude on the launch day was 4582 ft (Figure 111). The vehicle flew to an altitude of 5079 ft, as seen in the altimeter data. A failure analysis was performed assuming the failure was miscalculated parameters. The masses of the launch vehicle were confirmed, including the mass of the ballast (1 kg). The lengths were remeasured. The center of gravity was remeasured. When these parameters did not display cause for error, the coefficient of drag was considered. The estimated drag was 0.97, and the actual drag was found to be 0.78. This decrease led to the rocket travelling 497 ft higher than expected (Table 16). The coefficient of drag discrepancy is further analyzed in Section 5.1.4.6 Coefficient of Drag and Post-Flight Simulation.

Vehicle Demonstration Altitude	
Target Apogee (ft)	4578
Launch Day Simulations (ft)	4582
Vehicle Demonstration Flight (ft)	5079

Table 16: Vehicle Demonstration Altitude Results

5.1.4.2 Parachute Descent Rate: Analysis and Error

All vehicle and recovery components performed nominally during the flight. Separation events and parachutes deployed as expected during the descent of the launch vehicle. The parachutes' descent rates differed from the values predicted with the simulations (Table 17). The average drogue descent rate during the flight was 70 ft/s. The average main parachute descent rate was 17 ft/s. The drogue descent rate was 10.6 ft/s slower than the maximum descent rate predicted for the drogue parachute. The main parachute was 0.8 ft/s slower than the maximum descent rate predicted for the main parachute.

Vehicle Demonstration Parachute Descent Rates		
Parachute	**Drogue**	**Main**
OpenRocket (ft/s)	78.9	17.3
MATLAB (ft/s)	80.6	17.8
Vehicle Demonstration Flight (ft/s)	70.0	17.0

Table 17: Parachute Descent Rates

The difference in drogue descent rate may be due to the orientation of the forward section during drogue descent. The forward section was nearly parallel to the ground during drogue descent. This would increase the force of drag experienced by the launch vehicle and help slow the descent. An additional factor that was not accounted for in the simulations would be any effects of drag from the parachute protector or recovery harness (Figure 117). Thermals, hot air rising, may have also contributed to a slower descent rate when at altitude. Simulating temperature changes as altitude varies is difficult and was not possible to match to at field conditions.

Figure 117: Drogue Parachute Descent

The difference in main descent rate may be due to the drogue parachute remaining fully inflated during the entirety of the descent, or that the drag effects from the parachute protectors and recovery harness were not accounted for during simulation (Figure 118).

Figure 118: Main Parachute Descent

5.1.4.3 Descent Time: Analysis and Error

The launch vehicle took 95 s to descend from apogee to ground hit during the Vehicle Demonstration Flight. This time was 6.6 s slower than the slowest predicted descent time of 88.4 s from the OpenRocket simulation and 5 s over the 90 s descent time requirement. The parachutes having a slower descent rate than predicted and the vehicle having a significantly higher apogee than predicted caused the launch vehicle to descend for 95 s from apogee (Table 18).

Vehicle Demonstration Flight Descent Time	
OpenRocket (s)	88.4
Excel (s)	85.4
MATLAB (s)	83.4
Vehicle Demonstration Flight (s)	95.0

Table 18: Vehicle Demonstration Flight Descent Time

5.1.4.4 Kinetic Energy: Analysis and Error

The kinetic energy of each section was calculated from the ground hit velocity of the Vehicle Demonstration Flight (9). The kinetic energy during the flight was less than the predicted values due to the slower than predicted main parachute descent rate. The difference is primarily due to the differing descent rates because the final mass of each section did not change during flight. The mass did not change because no section or piece of the launch vehicle was lost during the flight. The lower than predicted kinetic energy kept the kinetic energy at ground hit well below the 75 ft-lbs maximum (Table 19).

Vehicle Demonstration Flight Kinetic Energy			
Section	**Nosecone**	**Forward**	**Aft**
Excel Prediction (ft-lbs)	5.9	31.4	50.3
MATLAB Prediction (ft-lbs)	6.3	33.3	53.5
Demonstration Flight (ft-lbs)	5.7	30.4	49.6

Table 19: Vehicle Demonstration Flight Kinetic Energy

5.1.4.5 Drift from the Launch Pad: Analysis and Error

The GPS transmitter and reciever were functional for the launch vehicle during the demonstration flight (Figure 119).

Figure 119: GPS Receiver

The launch vehicle drifted 1458 ft from the launch pad, which was well within the 2500 ft maximum drift allowed. The distance was measured using Google Maps and the coordinates found prior to launch and the cordinates found after ground hit. The Vehicle Demonstration Flight drift differs greatly from the drift predicted just prior to flight (Figure 120).

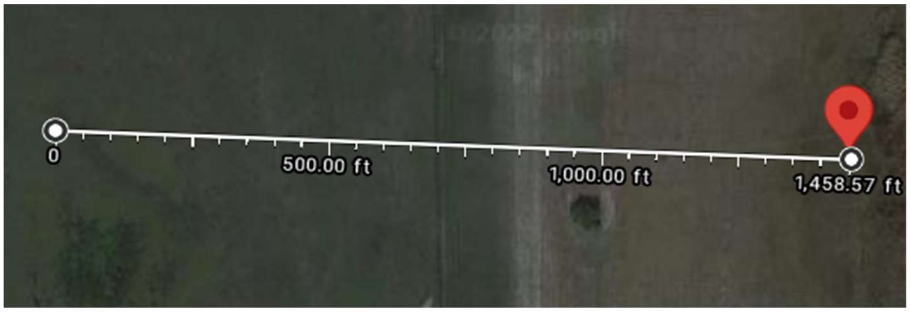


Figure 120: Drift of Vehicle Demonstration Flight

Wind speed is kept constant when predicting drift, but this is not accurate to how wind behaves at altitude. Gusts as the launch vehicle descended most likely contributed to the larger than predicted drift radius (Table 20).

Vehicle Demonstration Flight Drift From the Launch Pad	
OpenRocket (ft)	402
Excel (ft)	704
MATLAB (ft)	208
Drift (ft)	1458

Table 20: Vehicle Demonstration Flight Drift from Launch Pad

5.1.4.6 Coefficient of Drag and Post-Flight Simulation

A method of altitude backtracking was implemented to estimate the coefficient of drag of the fullscale. It was validated during the subscale launch and therefore used again. Originally, the fullscale coefficient of drag was estimated to be 0.97; however, the launch vehicle performance indicated an inaccuracy in this value. In order to determine the new coefficient of drag, the actual altitude of the rocket was considered based on the data from the altimeter. Next, a simulation using a fixed coefficient of drag of 0.97 was run. Then, the altitude that is predicted by either OpenRocket or MATLAB was compared against the altitude recorded by the altimeter. Finally, the coefficient of drag was adjusted accordingly. Since the simulation underestimated the altitude, the coefficient of drag was decreased. The method was iterated until the final coefficient of drag simulation matched the actual altitude that was recorded. This process indicated that the back-tracked coefficient of drag was about 0.78. This value was also predicted by OpenRocket (0.77) and by MATLAB (0.80). Using this calculated drag, a post-flight simulation was run to match the actual data, where the simulated apogee is 5077 ft (Figure 121). It was determined that this decrease was likely due to changes in the camera mount design, which was remodeled prior to CDR. The new design resembled a fin design and limited the protrusion that was originally designed and simulated. This design change was implemented to improve the aerodynamics but led to a significant decrease in the coefficient of drag. Other factors that may have contributed to the decrease included the surface finish due to the painting of the external body of the launch vehicle, as well as the conditions on launch day.

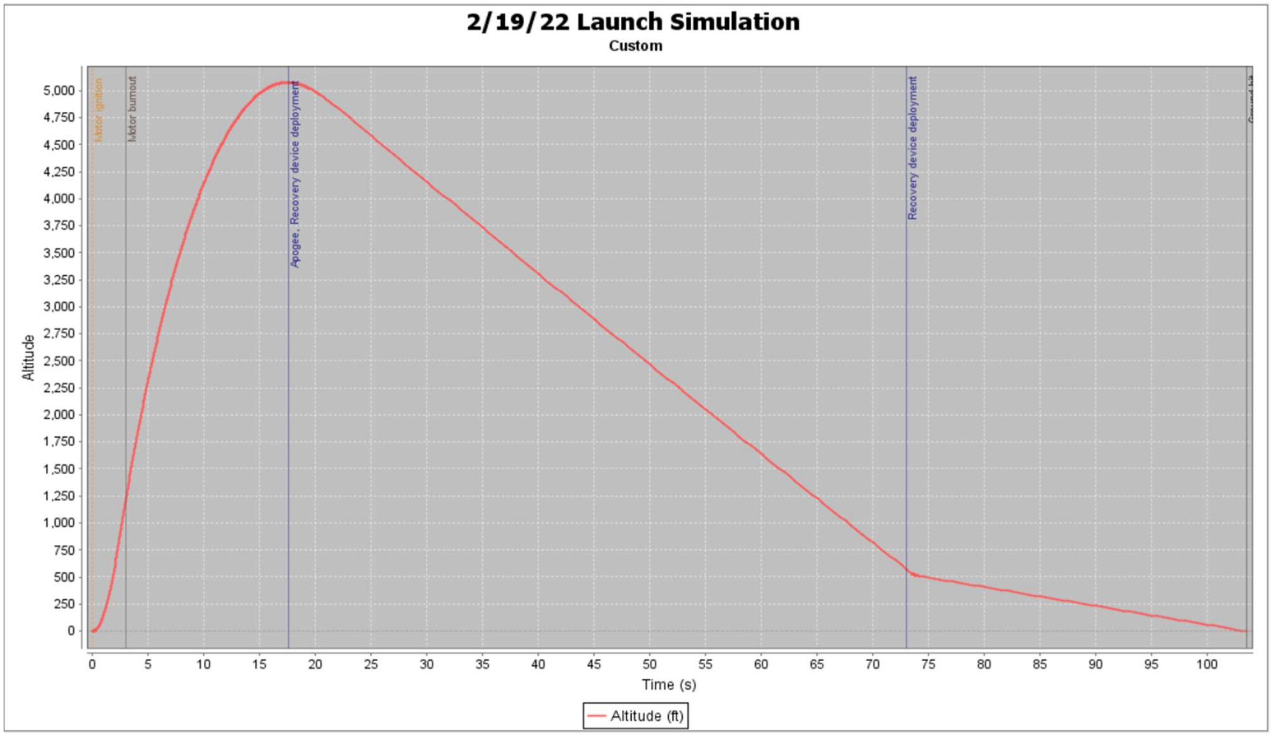


Figure 121: Post-Flight OpenRocket Simulation Altitude vs Time

5.1.4.7 Comparison to Subscale Flight Results

One major difference between the subscale flight and the fullscale vehicle demonstration flight was the fact that the subscale performed similarly to its simulation and the fullscale did not. The subscale flew within a foot of the altitude predicted just prior to launch, but the fullscale vehicle flew 497 ft over the launch day simulation (Table 21). The camera mount design change that was implemented after the subscale flight has been presented as one of the main reasons for this change in results.

Subscale Flight and Vehicle Demonstration Flight Apogee Values	
Subscale OpenRocket Altitude (ft)	2028
Subscale Flight Altitude (ft)	2027
Subscale Altitude Error (ft)	-1
Fullscale OpenRocket Altitude (ft)	4582
Vehicle Demonstration Flight Altitude (ft)	5079
Vehicle Demonstration Flight Altitude Error (ft)	+497

Table 21: Subscale Flight and Vehicle Demonstration Flight Apogees

The same drogue parachute was used on subscale as on fullscale. The descent rates of the two vehicles under drogue differed due to the subscale being smaller, but the subscale flight performed similarly to the OpenRocket simulation with an average drogue descent rate of 65 ft/s and a simulated descent rate of 65.6 ft/s. The vehicle demonstration flight did not perform similarly to the simulation. The simulation gave a descent rate of 78.8 ft/s, but during the flight the vehicle averaged a descent rate of 70 ft/s (Table 22). The descent rate results of the Vehicle Demonstration Flight are discussed in Section 5.1.4.2 Parachute Descent Rate: Analysis and Error.

Subscale Flight and Vehicle Demonstration Flight Descent Rates	
Subscale OpenRocket Drogue Descent Rate (ft/s)	65.6
Subscale Flight Drogue Descent Rate (ft/s)	65
Subscale Flight Drogue Descent Rate Error (ft/s)	-0.6
Fullscale OpenRocket Drogue Descent Rate (ft/s)	78.8
Vehicle Demonstration Flight Drogue Descent Rate (ft/s)	70
Vehicle Demonstration Flight Drogue Decent Rate Error (ft/s)	-8.8

Table 22: Subscale Flight and Vehicle Demonstration Flight Descent Rates

It was seen during the subscale flight that it may have taken the secondary ejection charge force to fully cause separation and deploy the main parachute. The fullscale flight successfully separated and deployed the main parachute at the primary ejection charge altitude. A potential reason for the fullscale performing as expected where the subscale faltered was the use of black powder on the fullscale and Pyrodex on the subscale. The mass of black powder required to separate the fullscale vehicle sections was less than the mass of the subscale Pyrodex ejection charges (Table 23). This shows the consistency and effectiveness of using black powder over other energetics.

Subscale Flight and Vehicle Demonstration Flight Ejection Charge Sizes		
Event	**Primary (g)**	**Secondary (g)**
Subscale first separation	2.00	2.50
Subscale second separation	2.50	3.13
Fullscale first separation	1.50	1.88
Fullscale second separation	2.00	2.50

Table 23: Subscale Flight and Vehicle Demonstration Flight Ejection Charge Sizes

5.1.4.8 Lessons Learned

The successful fullscale flight validated many distinct aspects of the project’s design. Understanding the precautions that were taken, such as considering the epoxy weight and accurate masses pulled from the manufacturer, has indicated value to the team. However, in the future, further testing on the drag coefficient will be performed to reduce any errors later. Design choices indicated importance in not only modeling but also manufacturing. As the nosecone used on the full-scale had to be changed due to shipping issues, it assisted in addressing potential vibrational concerns that tend to occur with long skinny rockets. In the future, the team will consider the flexibility of changing parts if there are manufacturing issues again, in a way that will be sustainable to the flight predictions. The descent of the launch vehicle taught the team that the terminal velocity during drogue descent can be impacted by more than just the size of the drogue parachute. The terminal velocity during main parachute descent was not significantly different than the simulated descent rate, even with the drogue parachute staying fully inflated. The main parachute must have contributed the most to the drag of the launch vehicle during this phase of the descent.

5.2 Payload Demonstration Flight

A payload demonstration flight is planned for March 19th, 2022, at Tampa Tripoli (Prefecture #17). The flight will be considered successful based off Requirement 2.19.2. That is, if the payload system is fully constructed and active, is fully retained throughout the flight, and is recovered without damage.

6. Safety and Procedures

6.1 Personnel Hazards

Personnel hazards were quantified using a total score given by the product between the severity and likelihood of each hazard (Table 24).

	Severity (S)	Likelihood (L)
1	No injury obtained	Extremely Unlikely
2	Very minor injury	Unlikely/low probability
3		
4	Minor injury	
5		Likely
6	Moderate injury	
7		Highly likely/high probability
8		
9	Severe injury or death of personnel	
10		Extremely likely/almost certain

Table 24: Personnel Risk Assessment

A hazard with a low severity and likelihood will receive a lower score than a hazard with a large difference between severity and likelihood. Furthermore, a hazard with a high severity and likelihood will receive a higher score than hazards with inconsistent severity and likelihood scores. Thus, quantifying scores using this method accurately shows the significance of the hazards present while completing the project. The scores have been color coded to visually represent the importance of each hazard (Table 25).

	Likelihood										
Severity		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	1	1	2	3	4	5	6	7	8	9	10
	2	2	4	6	8	10	12	14	16	18	20
	3	3	6	9	12	15	18	21	24	27	30
	4	4	8	12	16	20	24	28	32	36	40
	5	5	10	15	20	25	30	35	40	45	50
	6	6	12	18	24	30	36	42	48	54	60
	7	7	14	21	28	35	42	49	56	63	70
	8	8	16	24	32	40	48	56	64	72	80
	9	9	18	27	36	45	54	63	72	81	90
	10	10	20	30	40	50	60	70	80	90	100

Table 25: Risk Assessment Score

6.1.1 Chemical Hazards

Chemical hazards are those posed by the team's chemical inventory. The personal protective equipment (PPE) and storage requirements for mitigating each hazard were identified using the material safety data sheets (MSDS) of each chemical (Table 26).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
C.1	Irritant contacts skin	Working with epoxy	Skin redness, itching, other moderate irritation	4	6	24	Liquid-proof, chemical resistant gloves and full-body covering clothing must worn when handling epoxy resin. Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE (Epoxy work complete)
C.2	Irritant contacts eyes	Working with epoxy	Eye redness, moderate irritation	6	3	18	Epoxy work must be done in a controlled environment by safety-trained members Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE
C.3	Exposure to noxious fumes	Working with epoxy	Headache, nausea, dizziness, respiratory irritation	6	4	24	Epoxy must only be applied in well ventilated area with manufacturer-specified amounts of resin and hardener. External heat will not be applied during curing process to ensure limited fume release Verification: PPE and MSDS located in MAE-C and SDC; Multiple team members must be present when using epoxy to ensure proper use of epoxy and PPE
C.4	Uncontrolled detonation of black powder e-charge	Heat, or flame ignites black powder	Severe burns	8	2	16	Store black powder in cool, dry conditions until use. Wear metal-free and non-static producing clothes when handling. Release static buildup prior to beginning work. Verification: Ejection Charge Preparation Procedure - Checklist Verification (6.4.5.4); PPE and MSDS located in MAE-C and SDC.
C.5	Spray paint can explodes	Heat or flame causes can to explode, can is pierced	Severe burns, shrapnel injuries	8	2	16	Spray paint is stored in a cool, well-ventilated area away from sunlight. Verification: MSDS located in MAE-C and SDC.

C.6	Spray paint aerosol combusts	Heat, sparks, flames, or other ignition sources ignite aerosol	Severe burns	6	3	18	Use away from any heat sources, flames, sparks, and other ignition sources. Verification: MSDS located in MAE-C and SDC. (Painting complete)
C.7	Spray paint aerosol contacts skin	Working with spray paint	Skin irritation, allergic reaction	4	7	28	Wear protective gloves and clothing when handling. Work outdoors or in a well-ventilated area. Wash hands and other exposed areas after handling. Verification: PPE and MSDS located in MAE-C and SDC.
C.8	Spray paint aerosol contacts eyes	Working with spray paint	Serious eye irritation	6	4	24	Wear eye or face protection when handling. Verification: PPE and MSDS located in MAE-C and SDC.
C.9	Spray paint aerosol is inhaled	Working with spray paint	Respiratory irritation, drowsiness, dizziness	7	3	21	Work outdoors or in a well-ventilated area. Wear face protection and respirator when handling. Verification: PPE and MSDS located in MAE-C and SDC.

Table 26: Chemical Hazards

6.1.2 Manufacturing Hazards

Manufacturing hazards are those posed by team activities during the manufacturing process. The hazards and mitigations were identified using the operator's manuals of each machine (Table 27).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
M.1	Blade contacts skin	Improper use of bandsaw, hand saw, box cutter, or any other cutting tool.	Severe cuts, loss of extremities	8	3	24	Keep hand out of the path of the blade. Use a sacrificial handle when workpiece is too small to hold. Any member performing manufacturing work must be trained on proper machine use. Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.2	Spinning tool or workpiece contacts person	Improper use of Dremel, drill press, or any other rotating piece of machinery.	Severe skin laceration, physical trauma	8	3	24	Keep hands at least six inches away from cutting area. Any member performing manufacturing work must be trained on proper machine use. Do not wear gloves while operating powered tools. Do not wear jewelry or loose articles of clothing and tie up long hair when machining.

							Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.3	Person contacted by airborne tool or workpiece	Improper clamping of workpiece during machine work; improper grip on tool in use	Skin laceration, physical trauma	6	3	18	Ensure proper clamping of workpiece and tool in machine. At least two clamps used when clamping any workpiece for machining. When using a vise, tighten vise jaws with proper force. Any member performing manufacturing work must be trained on proper machine use. Verification: Clamps are located near each piece of manufacturing equipment. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.4	Skin contacts sharp tool	Handling sharp tools with bare hands	Skin lacerations	3	5	15	Cover sharp edges with a rag when handling. Any member performing manufacturing work must be trained on proper machine use. Verification: Rags are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.5	Skin contacts sharp edge of workpiece	Handling workpieces with burrs improperly	Skin lacerations	2	5	10	Carry newly machined parts with a rag. Deburr workpiece as soon as machining is finished. Any member performing manufacturing work must be trained on proper machine use. Verification: Rags are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.6	Skin contacted by pressurized water	Leak in waterjet system, hand too close to jet stream when cutting	Severe skin laceration	8	2	16	Stand a safe distance from the pressurization system when active. Do not put any body parts near cutting zone while waterjet is running. Any member performing manufacturing work must be trained on proper machine use. Verification: Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.7	Extended exposure to loud processes	Unprotected hearing while operating loud machinery	Hearing loss	6	5	30	Wear hearing protection when operating loud machinery. Any member performing manufacturing work must be trained on proper machine use. Verification: Ear plugs and ear muffs are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and

							the SDC. At least 2 members must be present during manufacturing work.
M.8	Non-manufacturing team member exposed to loud processes	Operation of loud machinery without warning	Hearing loss	6	4	24	Verbally warn any nearby people before making any sudden loud noises or starting manufacturing work. Any member performing manufacturing work must be trained on proper machine use (includes awareness of other individuals) Verification: Ear plugs and ear muffs are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC.
M.9	Inhalation of fibrous particles in air from manufacturing	Machining fiberglass releases fibrous particles in the air	Respiratory irritation, potential lung damage	6	7	42	Work in a well-ventilated area. Wear respirators when machining fiberglass. Verification: Respirators are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.10	Fibrous particles from manufacturing contact eyes	Machining fiberglass releases fibrous particles into the air	Eye irritation, potential blindness	6	7	42	Work in a well-ventilated area. Wear safety goggles when machining fiberglass. Verification: Safety goggles are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.11	Small particles from manufacturing contact eyes	Cutting or drilling creates chips that can go airborne	Eye irritation, potential blindness	6	7	42	Wear safety goggles or safety glasses with side shields when machining materials other than fiberglass. Verification: Safety goggles and safety glasses with side shields are located at team manufacturing sites. Documentation of trained members is located in MAE-C. Standard Operating Procedures are located in MAE-C and the SDC. At least 2 members must be present during manufacturing work.
M.12	Hot soldering iron contacts skin	Improper handling of soldering iron	Burn	5	2	10	Soldering will be performed in a controlled environment. When not in use, iron will be stored properly in stand. Soldering will only be performed by individuals trained and approved by Dylan Ogrodowski (Payload Electronics Lead). Verification: Proper soldering iron stand located in SDC and MAE-C. Dylan maintains a list of approved individuals that is shared with Safety Officers.
M.13	Inhalation of fumes from soldering	Inhalation of soldering iron fumes	Respiratory irritation	3	6	18	Work in a well-ventilated area.

							Soldering will only be performed by individuals trained and approved by Dylan Ogrodowski (Payload Electronics Lead). Verification: Dylan Ogrodowski maintains a list of approved individuals that is shared with Safety Officers.
M.14	Lead ingestion from soldering	Lead residue from hands enters mouth	Lead poisoning	9	4	36	Individuals soldering must wash hands before and after soldering. Soldering will only be performed by individuals trained and approved by Dylan Ogrodowski (Payload Electronics Lead). Verification: Signs stating that hands must be washed before and after soldering are placed near soldering stations in both MAE-C and SDC. Dylan Ogrodowski maintains a list of approved individuals that is shared with Safety Officers.

Table 27: Manufacturing Hazards

6.1.3 Launch Hazards

Launch hazards are those posed by team activities throughout launch preparation, launch, and vehicle retrieval (Table 28).

ID	Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
L.1	Falling debris	Shock cord fails Motor retainer fails	Falling debris hits person	9	1	9	Properly fold parachute and check recovery harness and motor retainer connections. Verification: Parachute Preparation Procedure - Checklist Verification 6.4.2.4
		Parachute fails to deploy properly	Vehicle hits person at high rate of speed; severe injury or death	10	2	20	Complete ejection charge testing to verify proper shearing of shear pins. Fold parachute properly and verify it will not get stuck inside airframe. Verification: Parachute Preparation Procedure - Checklist Verification 6.4.2.4
L.2	Burns from motor ignition	Ignition while loading motor or igniter	Severe Burns, hearing loss	10	3	30	No one may stand in line of motor during loading and transit to pad. No smoking, open flames, or other heat sources are allowed within 25 ft. of the motor. Verification: NAR Level 2 Certified member handles motor.
L.3	Burns from motor ignition	Person too close to launch pad during ignition	Severe Burns, hearing loss	10	2	20	No person may be within 200 ft. of the launch pad while range is active. All launch site RSO guidelines will be followed. If rocket misfires, the battery will be disconnected from the launch system and no

							one will approach the rocket for 60 s after the misfire. Verification: Launch Procedure and Troubleshooting – Checklist Verifications 6.4.11.4 and 6.4.12.4.3
L.3	Uncontrolled detonation of black powder	Heat, flame, or electrical charge ignites black powder	Severe burns	8	2	16	Wear metal-free and non-static producing clothes when handling. Release static buildup prior to beginning work. Verification: Ejection Charge Preparation Procedure - Checklist Verification 6.4.5.4; PPE and MSDS located in MAE-C and SDC; PPE carried to launches (Packing List 6.4.1).
L.4	Vehicle lands in unsafe area	Vehicle drifts from wind	Injuries from environment during recovery	4	3	12	Monitor wind on launch day and only launch in acceptable wind speeds. Angle the launch rail into the wind. Verification: Pre-Flight Simulation – Checklist Verification 6.4.8.4
L.5	Heat-Related Illness	High temperatures at launch site	Heat exhaustion	7	3	21	Bring water to launch site. Provide refreshments and shade (pop-up canopy) and check on team members' well-being throughout the day. Verification: Packing List 6.4.1

Table 28: Launch Hazards

6.2 Failure Mode and Effects Analysis

Failure mode and effects analysis (FMEA) evaluates the impact of component failure on the launch vehicle and its ability to complete the mission. The FMEAs include Structures, Payloads, Avionics and Recovery, and Flight Dynamics. Three ratings are given to each failure mode to quantify the significance of the failure: severity, occurrence, and detection. Severity is rated from 1 to 10 where a rating of 1 means that the failure has no effect while a rating of 10 is a catastrophic failure. Occurrence is rated from 1 to 10 where a rating of 1 means that the failure has little to no chance of occurring while a 10 indicated it is incredibly likely to occur. Detection is rated from 1 to 10 where a 1 is a failure that has a high likelihood of detection while a 10 is a failure that has an extremely low likelihood of detection. A risk priority number (RPN) is calculated as the product of the ratings and will be used to inform the team where mitigation strategies are needed.

6.2.1 Structures

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions & Verifications
				Local Effects	Next Higher Level	System Effects					
Airframe and coupler	Contains the payload and vehicle hardware	Breaks	Manufacturing defect or poor transportation	Fails to contain payload and other internal components	Launch vehicle assembly fails	Launch vehicle is unrecoverable and project fails.	10	3	3	90	Inspect launch vehicle immediately after manufacturing and before and after each launch (Test #1)
Fin Fillets	Epoxy keeps the fins attached to the aft airframe and motor tube assembly	Epoxy fails	Improper application	Launch vehicle loses stability	Uncontrolled flight	Launch vehicle drifts or moves uncontrollably, posing a hazard	8	2	4	64	Inspect fillets before and after each launch (Post - Flight Inspection Checklist 6.4.13)
Centering ring	Keeps the motor centered within the airframe	Epoxy fails	Improper application	Launch vehicle motor assembly fails	Uncontrolled launch	Catastrophic failure of launch vehicle, posing a hazard	10	2	5	100	Inspect launch vehicle before and after each launch (Post -Flight Inspection Checklist 6.4.13)
Centering ring	Keeps the motor centered within the airframe	Breaks	Manufacturing defects	Launch vehicle motor assembly fails	Uncontrolled launch	Catastrophic failure of launch vehicle, posing a hazard	10	2	3	60	Inspect component for defects immediately after manufacturing Verified – centering rings properly seated and without defects post-manufacturing
Bulkhead	Seals the ends of the couplers and protects internal components	Insufficient seal	Improper application	Fails to maintain sufficient seal	Ejection charges fail to separate vehicle	Parachutes not deployed properly, or internal components are damaged	8	2	2	32	Inspect component for defects immediately after manufacturing (Test 3) Verified through Flight Demonstration - Test #24
Shear pins	Keeps sections connected before separation events	Early shearing	Excessive pressure in airframe or excessive force from poor packing	Airframe and couplers separate	Premature parachute deployment	Parachutes not deployed properly, excessive drift, potential damage to vehicle	8	3	8	192	Test ejection charges and ensure that design adequately houses internal components, so shear pins do not break prematurely (Tests #11, #12)
Shear pins	Keeps sections connected before separation events	Do not shear	Insufficient ejection charge during separation event	Parachutes do not deploy	Rapid descent of launch vehicle	Launch vehicle impacts ground with high velocity	8	4	8	256	Test ejection charges to find sufficient amount of black powder for separation (Test #11, #12)
Rivets	Keeps sections connected throughout flight	Loss during flight	Improper insertion	Connection point between sections lost	Improper separation of untethered sections	Launch vehicle descends in multiple untethered sections, potential damage to vehicle	7	2	3	42	Only testing lead can insert rivets into rocket for launch, and she ensures they are fully seated (Rocket Assembly Procedure 6.4.6.4)

Rivets	Keeps sections connected throughout flight	Shear	Excessive pressure from ejection charges	Connection point between sections lost	Improper separation of untethered sections	Launch vehicle descends in multiple untethered sections, potential damage to vehicle	7	1	7	49	Test ejection charges to find sufficient amount of black powder for separation (Test #11, #12)
Nosecone	Reduce aerodynamic drag during vehicle ascent	Fracture	Heavy impact with ground	Cracks in nosecone	Inability to re-fly with same nosecone	Vehicle sustains damage, failing mission objective	8	2	6	96	Run pre-flight simulations to ensure ground-impact kinetic energy will remain below 75 ft-lb. Inspect nosecone after flight for damage, to mitigate any issues before next flight (Pre-Flight Simulation Procedure 6.4.8; Test #11, #12)

Table 29: Structures FMEA

6.2.2 Payloads

6.2.2.1 Payload Mechanical

Component	Function	Failure Mode	Failure Cause	Failure Effects			S	O	D	RPN	Corrective Actions & Verifications
				Local Effects	Next Higher Level	System Effects					
3D Printed Sled	Protect and hold all electronics on the payload	Fracture	Stresses and vibrations	Cracking/breaking of plastic	Damaged electronics on payload	Loss of payload functionality	7	2	4	56	Extensive vibrations and stress tests to ensure structural integrity (Test #32, #34, #35)
Battery Compartment	Secure batteries on payload sled	Fracture	Stresses and shearing/fastener stripping	Battery compartment breaks or strips off payload sled	Batteries lose connection to electronics on payload	Loss of electronics functionality	8	1	2	16	Ensure fastener and plastic can withstand predicted forces during flight and landing (Test #32, #34, #35)
Camera Mount	Retain cameras	Fracture	Stresses and vibrations	Camera mount is damaged	Camera cannot obtain accurate photographs	Inaccurate readings of rocket's current location	4	3	5	60	Test the strength of the camera mount and fly test subjects on all flight tests (Test #24, #37, #50)
Camera Cover	Protect camera from external forces	Fracture	Stresses and vibrations	Camera cover lost/damaged	Camera directly exposed to external forces, potential camera damage	Loss of camera functionality, inability to locate rocket	6	3	5	90	Test the strength of the camera mount and fly test subjects on all flight tests (Test #24, #37, #50)
Threaded Insert	Connects PCB to sled	Heat-staking bond fails	Improper heat setting	Raspberry Pi loosens on sled	Electrical components displaced	Loss of power, potential for short-circuited wires	3	2	5	30	Identify issues with heat-set inserts during assembly. (Payload Bay Preparation Procedure 6.4.4.4)

Threaded Insert	Connects PCB to sled	Fracture	Stresses from screw	PCB detached from sled	Electrical components displaced	Loss of power, potential for short circuited wires	6	1	4	24	Verify strength of inserts during demonstration flights (Test #24, #50)

Table 30: Payload Mechanical FMEA

6.2.2.2 Payload Electronics

Component	**Function**	**Failure Mode**	**Failure Cause**	**Failure Effects**			**S**	**O**	**D**	**RPN**	**Corrective Actions & Verifications**
				Local Effects	Next Higher Level	System Effects					
Lithium-ion Battery	Provides power to electronic payload components.	Short circuit	Unintended connection between the positive and negative battery terminals.	High current flow within the battery, generating excessive heat.	Fire within the launch vehicle.	Loss of the payload and vehicle.	9	2	2	36	Ensure no loose or exposed metallic objects are present in the payload bay. Ensure power terminals are fully insulated. (Test #50)
Radio Transceiver (XBee)	Provides communication between the payload and ground station.	Radio interference	Two or more transmitters transmitting on the same frequency simultaneously.	Data received by the ground station is altered.	The ground station is unable to correctly receive the vehicle's landing location.	The ground station is unable to display the vehicle's landing location.	5	1	1	5	Report all radio frequencies used to NASA officials to avoid overlap with other teams. (Test #42)
Payload Computer	Controls payload peripherals and calculates vehicle's grid location.	Momentary power loss	Poor connection between the battery terminals and control board and/or vehicle vibrations.	The payload computer reboots, and the program reinitiates.	The payload is momentarily unable to capture or process images.	The payload's positional estimates become less accurate, or the payload is unable to produce an estimate.	5	2	6	60	Use power connectors with strong mechanical latches and include software power-loss recovery mechanisms. (Test #33)
Ground Station SD Card Reader	Save landing location received from payload	Loss of connection	Poor connection between reader and ground station control board	Microcontroller unable to send data to SD Card	No output is saved to SD Card	Location not saved; payload functionality reduced	6	2	2	24	Inspect ground station electronics for loose connections before flight (Test #42)
Ground Station LCD	Display final grid location of rocket	Loss of connection	Poor connection between LCD and ground station control board	LCD momentary loses display	Team unable to view final	Mission failure, as location only saved and not displayed	10	2	2	40	Inspect ground station electronics for loose

					landing location						connections before flight (Test #42)
Ground Station Microcontroller	Parses data from XBee radio for output to SD Card	Momentary power loss	Poor connection between battery terminals and ground station control board	Loss of data received from rocket payload	Inability to output correct grid location	Mission failure, no location identified	10	3	2	60	Inspect ground station electronics for loose connections before flight (Test #42)

Table 31: Payload Electronics FMEA

6.2.2.3 Payload Software

Component	**Function**	**Failure Mode**	**Failure Cause**	**Failure Effects**			**S**	**O**	**D**	**RPN**	**Corrective Actions & Verifications**
				Local Effects	Next Higher Level	System Effects					
Microprocessor	Controls payload peripherals and calculates vehicle's grid location.	Software debug error	Unaccounted edge case in software, causing system to crash	The microprocessor reboots. Data may be lost/overwritten	Information regarding the vehicle's flight state and position is lost.	The payload is unable to determine its current grid location.	5	2	5	50	Run testcases preflight, by simulating effect at different altitude/terrain (Test #38)
IMU Displacement Software	Calculates displacement of vehicle	Incorrect calculation	Edge case in software, noise unaccounted for in program	Calculated displacement deviates greatly from true value	Displacement incorrectly factored into final landing calculation	The payload is unable to determine its current grid location.	5	4	5	100	Run testcases preflight. Ensure filtering algorithm is in place. (Test #38, #40)
SIFT Feature Matching Algorithm	Identifies key points to locate vehicle near apogee	Insufficient key points generated	Blurry or obstructed images, low tolerances in code	No matches found on images	Inability to identify current location	Inability to provide IMU with initial data to calculate final location	5	5	6	150	Calibrate tolerances within code using images taken from testing drone (Test #26, #27)

Table 32: Payload Software FMEA.

6.2.3 Avionics and Recovery

Component	**Function**	**Failure Mode**	**Failure Cause**	**Failure Effects**			**S**	**O**	**D**	**RPN**	**Corrective Actions & Verifications**
				Local Effects	Next Higher Level	System Effects					
Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Instant detonation of ejection charges when powered on	Polarity of battery reversed due to improper installation.	Ejection charges detonating on the launch pad	Hot gases and heavy rocket components moving near team member responsible for arming altimeter	Unable to launch, potential for burns and other injuries	10	3	1	30	Test wiring of altimeters before placing in rocket and attaching ejection charges. (Test #8 & Avionics and Recovery Preparation Checklist 6.4.2)

Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Sudden power loss	Disconnection of battery due to inflight motion	Tracking and recording of altitude halts	Ejection charges do not go off, separation does not occur, and parachutes are not deployed.	The launch vehicle goes ballistic and descends uncontrolled	10	1	5	50	Altimeters and their power sources will be secured in the avionics bay. The secondary altimeter will have its own power source. (Test #7)
Altimeter	Track and record the altitude of the rocket in order to accurately set off ejection charges to cause separation and parachute deployment for both main and drogue parachutes.	Reverse wiring of ejection charges, (main ejection plugged into drogue terminal)	Mislabeling of terminals or improper programing of altimeter	Detonation of main parachute ejection charges	Main parachute is deployed at apogee	Launch vehicle drifts out of launch field, potential for launch vehicle to be lost	6	2	4	48	Proper labeling of ejection charges and altimeter terminals. (Ejection Charge Preparation Checklist 6.4.5)
Recovery Harness	The recovery harness tethers the separated sections of the launch vehicle together during descent.	Tearing of recovery harness	Melting of the harness due to ejection charge gases, insufficient strength of recovery harness	The launch vehicle becomes two or more untethered sections	Sections disconnected from the parachutes will descend significantly faster than intended	Partial damage to the launch vehicle	6	1	5	30	Protect the recovery harness from ejection gasses using the parachute protector, ensure the recovery harness is strong enough for the mission during design and testing. (Test 13)
Parachute Protector	Protects the parachute and recovery harness from hot ejection charge gases during separation	Holes or tears in the parachute protector	Excessive use and age, ejection charges too strong	Ejection gases burn the parachute	Holes form or parts of the parachute are melted together	Faster than anticipated descent rate leading to damage to the launch vehicle	7	2	1	14	Inspection of the parachute protector before use. (Tests #11, #12)
Main parachute	Slows the launch vehicle to an acceptable landing velocity	Tangled lines	Improper storage or packing of the parachute	Parachute does not fully inflate on descent	Faster than anticipated descent rate	Minimal to mild damage to the launch vehicle or payload, failure to meet kinetic energy requirement	4	5	1	20	Inspection of parachute pre-packing and safety officer or avionics recovery lead pack the parachute for launch. (Test 21 & Avionics and Recovery Preparation 6.4.2)
Main parachute	Slows the launch vehicle to an acceptable landing velocity	Holes or tears in parachute	Parachute protector failure, exposure to sharp edges, excessive	Holes or tears could increase in size and reduce the effectiveness of the parachute	Faster than anticipated descent rate	Damage to the launch vehicle or payload, failure to meet kinetic energy	6	2	1	12	Inspection of parachute before selecting it for use. Perform regular maintenance on parachutes. (Avionics and

			velocity at deployment			requirement					Recovery Preparation 6.4.2)
Drogue Parachute	Deploys at apogee to slow the initial descent of the launch vehicle	Tangled Lines	Improper storage or packing of the parachute	Launch vehicle descends much faster than expected	Launch vehicle zippers or other components are damaged during main parachute deployment	Damage to the launch vehicle or payload, failure to meet kinetic energy requirement	7	1	4	28	Properly pack the drogue parachute and follow mitigation strategies for other potential causes of failure. (Avionics and Recovery Preparation 6.4.2)
Drogue Parachute	Deploys at apogee to slow the initial descent of the launch vehicle	Holes or tears in parachute	Parachute protector failure or exposure to sharp edges, excessive velocity at deployment	Launch vehicle descends faster than expected	Launch vehicle zippers or other components are damaged during main parachute deployment	Damage to the launch vehicle or payload , failure to meet kinetic energy requirement	6	2	1	12	Inspection of parachute before selecting it for use. Perform regular maintenance on parachutes. (Avionics and Recovery Preparation 6.4.2)

Table 33: Avionics and Recovery FMEA

6.2.4 Flight Dynamics

Component	**Function**	**Failure Mode**	**Failure Cause**	**Failure Effects**			**S**	**O**	**D**	**RPN**	**Corrective Actions & Verifications**
				Local Effects	Next Higher Level	System Effects					
Propellant grain	Generate appropriate thrust to propel the rocket.	Propellant Failure	Improper storage of motor.	Improper propellant burnout or incomplete propellant ignition.	Changes the propellant burn distribution creating abrupt changes in thrust.	Overpressure risks, unpredictable trajectory/flight, or rocket does not take off.	9	3	4	108	Ensure the structural integrity of the propellant by visually ensuring defects, or moisture is not present. Motors need to be contained in a Climate Regulated room, and ensure they are handled carefully. (Motor Preparation Checklist 6.4.7 & Safety Officers will inspect motor storage monthly)
Nozzle	Controls the mass flow rate of the propellant	Nozzle Deformation	Structural failure of nozzle.	Nozzle exit area, nozzle exhaust pressure, propellant flow rate change.	Abrupt changes in the thrust vector.	Altered trajectory of the rocket creating potential	9	3	5	135	Always handle nozzle carefully, and visually inspect ensuring

						danger to bystanders.					defects are not present. (Motor Preparation Checklist 6.4.7)
Motor Case (including forward and aft closures)	Enclose solid propellant to protect the body from ignited propellant.	Case Defect	Defect or structural failure of the motor case including the forward and aft enclosures.	Propellant burns through motor case interacting with the rocket body.	Motor assembly gets damaged.	Structural integrity of motor tube and body tube are compromised.	7	2	8	112	Always handle motor case carefully, and visually inspect ensuring defects are not present. Always have a protective cover over the casing until launch. (Motor Preparation Checklist 6.4.7)
Motor Tube	Encloses the motor assembly in the correct position.	Motor Tube Fails or Dislodges	Defect or structural failure of the motor tube	Motor case is not held in correct position.	Catastrophic failure, personnel hazard	Mission failure.	6	3	6	108	Always handle motor tube carefully, and visually inspect ensuring defects are not present. (Motor Preparation Checklist 6.4.7)
Motor Retainer	Retains the motor inside the rocket	Motor Retainer Fails	Structural failure of mount, screws improperly fastened, or failure of epoxy bonds	Motor case moves forward in the rocket	Damage to forward rocket components	Rocket integrity is compromised, and function is lost.	7	4	7	196	Visually inspect ensuring defects are not present and tighten screws. (Test #18)
Thrust Plate	Transfers thrust from centering rings to airframe	Thrust Plate Fails	Structural failure of thrust plate or screws improperly fastened	Structural integrity of centering ring becomes compromised	Improperly aligned thrust vector	Altered flight trajectory and potential damage to other components.	5	4	7	140	Visually inspect ensuring defects are not present and tighten screws. (Test #18)

Table 34: Flight Dynamics FMEA

6.3 Environmental Concerns

Environmental concerns are any hazards that the vehicle poses on the environment, or the environment poses on the vehicle. These concerns are quantified by assigning severity and likelihood values to each hazard (Table 35). This method yields a score from 1-100 in the same manner as personnel hazards (Table 25).

	Severity (S)	Likelihood (L)
1	No effect on environment or launch vehicle	Extremely Unlikely
2	Minimal effect on environment or launch vehicle	Unlikely/low probability
3		
4	Moderate but resolvable harm to environment or launch vehicle	
5		Likely
6	Moderate harm to environment or launch vehicle with lasting impact	
7		Highly likely/high probability
8		
9	Serious environmental harm requiring immediate and drastic response/Launch vehicle suffers extensive damage	
10	Catastrophic impact on launch environment, difficult to resolve with lasting damage/Total loss of launch vehicle	Extremely likely/almost certain

Table 35: Environmental Concerns Scoring

6.3.1 Effect of Vehicle on Environment

The effects of the vehicle on the environment include any hazards posed by the vehicle during testing, launch preparation, and launch (Table 36).

Hazard	Cause	Effect	S	L	Score	Mitigation & Verification
Falling debris	Recovery harness fails	Debris pollutes land around launch site	5	2	10	Properly fold parachute and check recovery harness and motor retainer connections. (Test 13, Avionics and Recovery Preparation 6.4.2)
	Parachute fails to deploy					
	Motor retainer fails					
Environment around vehicle ignites	Sparks from ejection charge testing	Uncontrolled fire	8	2	16	Follow range safety officer instructions on properly conducting ejection charge testing. Only test and launch in approved areas cleared of flammable debris.
	Motor exhaust					
Chemical leaks	Battery leaks	Ground around vehicle is polluted	6	2	12	Inspect battery for damage before loading it on the vehicle. Isolate battery from components with the potential to pierce the battery casing. (Payload Bay Preparation 6.4.4)
Black powder /motor residue in water supply	Launch vehicle lands in body of water	Increased toxicity of water supply for humans and animals	6	2	12	Monitor wind and weather conditions at the launch site. Only launch when wind is within acceptable ranges according to RSO (maximum of 20mph). Angle the launch rail into the direction of the wind. (Launch Procedure 6.4.11)
Paint in water supply	Failure to recover rocket	Increased toxicity of water supply for animals and humans	6	1	6	Launch will occur only in high visibility to enable visual tracking of rocket. Rocket will contain tested GPS (Test 19).

	Launch vehicle lands in body of water		5	2	10	Paint was properly applied and set 3 days prior to the Vehicle Demonstration Flight to ensure minimal release in the event of a water landing. (Complete)
Lead from soldered components in water supply	Launch vehicle lands in body of water	Increased toxicity of water supply for animals and humans	5	1	5	Only trace amounts of lead solder exist and are isolated in the payload. Monitor wind and weather conditions at the launch site. Only launch when wind is within acceptable ranges according to RSO (maximum of 20mph). Angle the launch rail into the direction of the wind. (Launch Procedure 6.4.11)
Toxic material in ground	Failure to recover rocket, materials degrade over time	Skin irritation hazard for future users of site Ingestion hazard for animals	5	1	5	Launch will occur only in high visibility to enable visual tracking of rocket. Rocket will contain tested GPS (Test 19).
	Ground impact breaks apart launch vehicle		5	2	10	Launch vehicle was constructed of high-strength fiberglass to prevent damage when landing (Test 2).

Table 36: Effect of Vehicle on Environment

6.3.2 Effect of Environment on Vehicle

The effects of the environment on the vehicle include any hazards present during testing, launch preparation, and launch (Table 37).

Hazard	**Cause**	**Effect**	**S**	**L**	**Score**	**Mitigation & Verification**
Vehicle exposed to moisture	Humidity	Deformation of Electronics Tubes	5	3	15	Store vehicle in a cool, dry, well-ventilated area. Check for changes in weather while vehicle is exposed to the environment. (Accessible centering rings will be inspected before and after each flight)
		Warping of plywood centering rings	6	2	12	
	Precipitation falls on vehicle	Deformation of Electronics Tubes	5	2	10	
	Vehicle lands in water	Electronics damaged and unusable	9	3	27	

Clouds obscure camera	Cloudy skies on launch day	Keypoints for mission objective cannot be identified	7	4	28	Only launch when skies are clear. Monitor weather in launch area as launch day approaches to explore alternatives. (Launch Procedure 6.4.11)
Excessive drift	Excessive windspeed during vehicle flight	Vehicle lands in unsafe area	8	5	40	Monitor wind and weather conditions at the launch site. Only launch when wind is within acceptable ranges according to RSO (maximum of 20mph). Angle the launch rail into the direction of the wind. (Launch Procedure 6.4.11)
		Vehicle lands outside of grid	6	6	36	
Vehicle lost in sky	Fog at launch site	Inability to visually track vehicle; potential vehicle loss	7	3	21	Monitor weather conditions at the launch site. Only launch when cloud ceiling is in excess of projected vehicle height and is deemed acceptable by the RSO. (Launch Procedure 6.4.11)
	Clouds at flight altitudes					
Overheated electronics	High temperatures at launch site	Unusable electronics, delayed launch, mission failure	7	5	35	Keep electronics and launch vehicle under canopy prior to launch. (Packing List 6.4.1)
Weathercocking	High winds at launch site	Unexpected flight path, lower apogee than predicted	7	5	35	Launch will not occur if winds exceed 20mph Stability at launch rod clearance is designed to be 3.2 calibers (Pre-Flight Simulation Checklist 6.4.8)
Vehicle lands in tree	High winds at launch site	Excessive drift from launch pad, leading to landing in tree	8	4	32	Launch will not occur if winds exceed 20mph. Pre-flight simulations will be utilized to ensure vehicle will not drift outside field boundaries. (Pre-Flight Simulation Checklist 6.4.8)

Table 37: Effect of Environment on Vehicle

6.4 Launch Operation Procedures

In order to promote a safe and predictable launch day, procedures have been created to standardize the process from vehicle packing to launch and post-flight inspection. If any lead responsible for the completion of a task is unable to attend a launch, their replacement must be approved by the Project Manager and the responsible lead. This change must also be communicated to Safety Officers. If the individual tasked with performing the checklist verification is unable to attend a launch, their replacement must be approved by both Safety Officers and the Project Manager.

6.4.1 Packing List

In Launch Day Storage Box:

☐ Duct Tape
☐ Sandpaper
☐ Clay
☐ Paper Towels
☐ Motor Retainer
☐ Stratologger Data Reader & Cable
☐ Additional Payload Wire
☐ Latex Gloves
☐ Fastener Bag
☐ Wipes
☐ Electrical Tape
☐ Insulation
☐ Work Gloves
☐ Large Scale
☐ Zip Ties
☐ 5-Minute Epoxy
☐ Measuring Tape
☐ Entacore AIM Data Cable
☐ Anemometer
☐ Sharpies
☐ Motor Grease
☐ Quick Links

In Ammo Can:

☐ Black Powder
☐ Gram Scale
☐ E-Matches
☐ Metal Spoon
☐ Rivets
☐ Paper Funnel
☐ Shear Pins

In Milwaukee Tool Chest:

☐ Dewalt Drill Bag
☐ Screwdriver set
☐ Box Cutter
☐ Pliers
☐ Box Cutter
☐ Wire Cutters
☐ 2x Needle-nose Pliers
☐ Batteries (in package)
☐ Adjustable Wrench
☐ Files

In Cobalt Tool Chest:

☐ Parachutes
☐ GPS Transmitter and Receiver
☐ Other Avionics Components
☐ Garbage Bags
☐ Motor Casing (With Seal Disks)
☐ Altimeters

Additional Items:

☐ Folding Table
☐ Nosecone body
☐ Avionics bay*
☐ Igniters
☐ Dremel Kit
☐ Nosecone coupler
☐ Payload bay*
☐ Motor (If not purchased on-site)
☐ Canopy
☐ Forward airframe
☐ Upper aft airframe
☐ Wooden Rod

*Including all components, as assembled at "All-Up" before launch

6.4.2 Avionics and Recovery Preparation

6.4.2.1 Relevant Personal Protective Equipment

- Closed-toed shoes and full-length pants (no rips or holes)

6.4.2.2 Authority

Responsible Lead: Collin Larke (Avionics and Recovery Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

6.4.2.3 Critical Testing Prior to Launch Date

Test 6 – Parachute Drag Analysis

Test 7 – Recovery Altimeter Resolution Test

Test 10 & 11 – Ejection Demonstrations

Test 20 – Parachute Packing Demonstration

Test 21 – Parachute Opening Demonstration

6.4.2.4 Parachute Preparation Procedure

1. Attach swivel and quick link to parachute with wrench.
2. Put slip knot in recovery harness, 1/3 of the length away from one of the ends.
3. Secure quick link on swivel to slip knot, wrench tight.
4. Attach other ends of recovery harness to their respective eye bolts, wrench tight.
5. Fold parachute from gore to gore, until all gores folded. All shroud lines should be aligned.
6. Do one Z-fold of the shroud lines inside parachute after folding from gore to gore is complete.
7. Do one Z-fold of parachute.
8. Fold the parcel in half.
9. Roll each side of the parcel as tight as possible.
10. Place in center of the parachute protector.
11. Z-fold recovery harness alongside parachute in protector.
12. Fold ends of parachute protector in and roll parachute and recovery harness inside protector.

Verify parachute properly folded; failure to do so may lead to hazard L.1.

	Responsible Lead	Checklist Verification
Drogue Parachute Folded	________________	________________
Main Parachute Folded	________________	________________

6.4.2.5 Avionics Bay Preparation Procedure

Check altimeter settings and verify deployment altitudes/delays

- ☐ Primary Drogue Deployment – At apogee
- ☐ Primary Main Deployment – At 600 ft
- ☐ Secondary Drogue Deployment – Delayed 1 s from apogee
- ☐ Secondary Main Deployment – At 550 feet

1. Plug in current elevation above sea level for the Entacore AIM to calibrate for ground level (Stratologger self-calibrates)

   Plant City: 128 ft
   Palm Bay: 20 ft
   Huntsville: 810 ft

2. Verify that batteries are connected in the correct orientation by powering on each altimeter with no charge plugged in. Expect 5-30 milliamps of current through the output terminals for each altimeter.
   - ☐ Primary Altimeter battery installed properly
   - ☐ Secondary Altimeter battery installed properly
3. Ensure altimeters and batteries are secured to the avionics bay sled.
4. Pass threaded rods through the forward bulkhead and the avionics sled.

Verify sled is oriented correctly, failure to do so will require disassembly of completed bay

    - ☐ Verify correct orientation
5. Pass wires through the wire hole in the forward bulkhead and secure to one side of the terminal block for primary and secondary charges.
6. Pass wires for the aft bulkhead ejection charges through the avionics bay coupler section.
7. Secure the wires to their respective altimeter terminals and the terminal blocks on the outside of the aft bulkhead.
8. Nest the bulkheads into the avionics bay coupler, ensuring keylock switch is accessible through switch band.
9. Secure bulkheads with hex nuts, wrench tight.
10. Place clay around wire and threaded rod holes as needed to prevent ejection gases from entering and escaping through avionics bay.

	Responsible Lead	Checklist Verification
Avionics Bay Prepared	___________________	_____________________

6.4.3 Camera Preparation

6.4.3.1 Relevant Personal Protective Equipment

- Closed-toed shoes and full-length pants (no rips or holes)

6.4.3.2 Authority

Responsible Lead: Joseph Pinkston (Payload Mechanical Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

6.4.3.3 Critical Testing Prior to Launch Date

Test 25 – Launch Rehearsal

Test 34 – Vibrational Resistance Test

Test 35 – Payload Drop Test

Test 36 – Strength of Camera Mount Test

6.4.3.4 Payload Camera Mount Preparation Procedure

1. Mount camera to the camera housing using fasteners and hex nuts, tightening hex nuts with needle-nosed pliers.
2. Place camera and camera housing onto airframe, allowing the camera to slide into the camera slot cut into the airframe. Camera housing holes must line up with the designated T-Nuts.
3. Attach camera housing to airframe using fasteners and the T-Nuts that the camera housing slides onto.
    - ☐ 1st camera housing attached
4. Attach camera cover housing using fasteners and the previously glued hex nuts, enclosing the camera housing and the camera.
    - ☐ 1st camera cover attached
5. Repeat steps 1-4 with second camera.
    - ☐ 2nd camera housing attached

☐ 2nd camera cover attached

Verify complete assembly with fully retained cameras.

	Responsible Lead	Checklist Verification
Cameras Mounted	____________	______________

6.4.4 Payload Bay Preparation

6.4.4.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.4.2 Authority

Responsible Person: Dylan Ogrodowski (Payload Electronics Lead)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

6.4.4.3 Critical Testing Prior to Launch Date

Test 25 – Launch Rehearsal

Tests 39-44, 46 – Payload Components Functionality Demonstrations

Test 45 – Wire Tube Inspection

Test 47 – Payload Data Compilation Test

Test 48 – Payload Transmission Range Test

Test 49 – IMU Drift Analysis

6.4.4.4 Payload Bay Preparation Procedure

1. Secure two lithium-ion batteries to the sled with Velcro straps.
2. Connect lithium-ion batteries to the payload power input terminal.
   Verify that the payload has established a radio connection to the ground station via the ground station's display.
   - ☐ Radio connection established
3. Connect both camera harnesses to marked terminals on PCB.
   - ☐ 1st camera harness connected
   - ☐ 2nd camera harness connected
4. Insert two mounting screws to the payload sled.
5. Insert the payload sled into the payload coupler.
6. Pass the two mounting screws through the payload bulkhead and secure with nuts.
7. Pack clay around each nut to seal the payload bay.
   Failure to seal payload bay may lead to hazard L.2.

	Responsible Lead	Checklist Verification
Payload Bay Prepared and Sealed	____________	______________

6.4.5 Ejection Charge Preparation

6.4.5.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Non-sparking spatula
- Non-sparking dish
- Non-sparking wooden dowel
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.5.2 Authority

Responsible Lead: Brida Gibbons (Testing Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

6.4.5.3 Critical Testing Prior to Launch Date

Test 11 – Fullscale Main Parachute Ejection Demonstration

Test 12 – Fullscale Drogue Parachute Ejection Demonstration

6.4.5.4 Ejection Charge Preparation Procedure

VERIFY CORRECT ENERGETIC AND AMOUNTS REQUIRED FOR ALL EJECTION CHARGES FROM CHARGE TESTS:

☐ Energetic: Black Powder
☐ Forward Avionics Bay Forward Bulkhead (Main) Primary Charge: 2.00 grams
☐ Forward Avionics Bay Forward Bulkhead (Main) Backup Charge: 2.50 grams
☐ Forward Avionics Bay Aft Bulkhead (Drogue) Primary Charge: 1.50 grams
☐ Forward Avionics Bay Aft Bulkhead (Drogue) Backup Charge: 1.875 grams

REMOVE ANY IGNITION SOURCES PRIOR TO PREPARING CHARGES. REMOVE ALL OTHER MATERIALS FROM WORK AREA. RELEASE ANY STATIC BUILDUP PRIOR TO HANDLING ENERGETIC. FAILURE TO DO SO MAY CAUSE HAZARD L.3.

Necessary Materials:

☐ Energetic (Above)
☐ 4 Premade E-Matches
☐ Fire-Resistant Insulation
☐ Electronic scale
☐ Non-sparking metal dish
☐ Non-sparking spatula
☐ Small wooden dowel
☐ Masking tape
☐ Writing Utensil

Ejection charges must be made one at a time to ensure correct amount of energetic is packed in each charge. During preparation, box for corresponding charge must be checked as work is performed.

1. Place small electronic scale on level surface.
2. Place metal dish onto scale and zero the scale.
   - ☐ Avionics Bay Forward Bulkhead Primary Charge: 2.00 grams
   - ☐ Avionics Bay Forward Bulkhead Backup Charge: 2.50 grams
   - ☐ Avionics Bay Aft Bulkhead Primary Charge: 1.50 grams
   - ☐ Avionics Bay Aft Bulkhead Backup Charge: 1.875 grams
3. Using a spatula, add energetic into metal dish until appropriate amount is measured.
4. Pour energetic into cardboard cylinder of premade e-match.
5. Insert fire-resistant insulation into cylinder and compress insulation using small wooden dowel.
   - ☐ Insulation packed in Forward Bulkhead Primary Charge
   - ☐ Insulation packed in Forward Bulkhead Backup Charge
   - ☐ Insulation packed in Aft Bulkhead Primary Charge
   - ☐ Insulation packed in Aft Bulkhead Backup Charge
6. Fold top of cylinder down and seal with masking tape.
7. Label charge with the corresponding energetic, amount, location, and primary/backup.
   - ○ Avionics Bay Forward Bulkhead Primary Charge: 2.00 grams
   - ○ Avionics Bay Forward Bulkhead Backup Charge: 2.50 grams
   - ○ Avionics Bay Aft Bulkhead Primary Charge: 1.50 grams
   - ○ Avionics Bay Aft Bulkhead Backup Charge: 1.875 grams
8. Repeat steps 1-7 for each ejection charge.

	Responsible Lead	Checklist Verification
Forward Bulkhead Primary Charge	______________	______________
Forward Bulkhead Backup Charge	______________	______________
Aft Bulkhead Primary Charge	______________	______________
Aft Bulkhead Secondary Charge	______________	______________

6.4.6 Rocket Assembly Preparation

6.4.6.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.6.2 Authority

Responsible Lead: Brida Gibbons (Testing Lead)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

6.4.6.3 Critical Testing Prior to Launch Date

Test 11 – Fullscale Main Parachute Ejection Demonstration

Test 12 – Fullscale Drogue Parachute Ejection Demonstration

Test 25 – Launch Rehearsal

6.4.6.4 Rocket Assembly Procedure

Necessary Materials:

- ☐ Nosecone body
- ☐ Nosecone coupler
- ☐ Forward airframe
- ☐ Assembled avionics bay
- ☐ Assembled payload bay
- ☐ Upper aft airframe
- ☐ Lower aft assembly (with cameras mounted)
- ☐ 6 shear pins
- ☐ 12 rivets
- ☐ Adjustable wrench
- ☐ 2 pairs of needle-nose pliers
- ☐ Flathead screwdriver
- ☐ 4 quick links
- ☐ 1 cup fire-resistant insulation

1. Assemble nosecone section by sliding nosecone body onto nosecone coupler.
   - ☐ Use 3 rivets to connect nosecone body to the nosecone coupler
2. Assemble aft section.
   - ☐ Feed recovery harness through upper aft section and connect quick link to payload bay
   - ☐ Use 3 rivets to connect upper aft airframe to payload bay
   - ☐ Use 3 rivets to connect payload bay to lower aft assembly
3. Connect avionics bay to aft section
   - ☐ Connect recovery harness in aft section to avionics bay with a quick link
   - ☐ Place drogue ejection charges in bottom of aft section

   Ensure wires of ejection charge are accessible and held apart while the lead is not touching any surface.

   - ☐ Place 1 cup fire-resistant insulation in aft section
   - ☐ Pack drogue parachute into aft section
   - ☐ Wire ejection charge to avionics bay
   - ☐ Use 3 shear pins to secure aft section to avionics bay
4. Connect forward airframe to nosecone.
   - ☐ Connect recovery harness in forward section to nosecone section eyebolt using a quick link
   - ☐ Place 1 cup fire-resistant insulation in forward section
   - ☐ Pack main parachute in forward section
   - ☐ Use 3 shear pins to secure forward section to nosecone section
5. Assemble forward section
   - ☐ Connect recovery harness to avionics bay using a quick link
   - ☐ Pack main parachute into forward airframe
   - ☐ Place 1 cup fire-resistant insulation into forward airframe

☐ Place main ejection charges in forward airframe

Ensure wires of ejection charge are accessible and shorted.

☐ Wire ejection charge to avionics bay
☐ Use 3 rivets to connect the forward airframe to the avionics bay

	Responsible Lead	Checklist Verification
Rocket Assembled (w/o motor)	____________________	____________________________

6.4.7 Motor Preparation and Installation

6.4.7.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.7.2 Authority

Responsible Person: Bilal Hassan (NAR L2 Certified Team Member)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

6.4.7.3 Critical Testing Prior to Launch Date

None

6.4.7.4 Motor Preparation Procedure

1. Grease O-rings and Threaded Sections.
2. Insert Propellant grains into Propellant Sleeve.
    a. Should be flush with end of side opposite to Aerotech logo.
3. Prepare the Delay grain.
    a. Press the inside of the delay grain cap for proper fit.
    b. Put the spacer into the delay grain cap.
    c. Slide the delay grain inside.
    d. Put the Delay Grain O-ring on the lip of the delay grain, avoiding getting grease on the grain.
4. Insert the delay grain into the forward closure.

    Verify delay grain inserted

    ☐ Delay Grain Inserted
5. Insert Aft and Forward Seal Disks to the ends of the Propellant.
    a. Use the aluminum forward seal disk for bigger motors.
6. Insert Aft O-ring (Thick) onto the aft seal disk.
7. Insert Forward O-ring (Thin) onto forward seal disk.

    Verify seal disks and O-rings inserted

    ☐ Aft Seal Disk and O-Ring Inserted

    - ☐ Forward Seal Disk and O-Ring Inserted
8. Screw on forward closure halfway.
9. Put nozzle on aft closure.
10. Screw on aft closure with nozzle in center circle halfway.
11. Screw in both closures until fully sealed.
12. Add a small diamond-shaped cut to the nozzle plug so igniter can fit through; put it on the nozzle.

Steps 13-14 may only be completed after Checklist 6.4.6 is complete and team is ready to launch

13. Insert prepared motor into rocket
    - ☐ Motor in rocket
14. Thread motor retainer fully onto retainer body
    - ☐ Motor retainer installed

IGNITER MUST NOT BE INSERTED INTO MOTOR UNTIL ON THE PAD

	Responsible Lead	Checklist Verification
Motor Installed in Rocket (w/o Igniter)	________________	________________

6.4.8 Pre-Flight Simulation

6.4.8.1 Relevant Personal Protective Equipment

- Closed-toed shoes and full-length pants (no rips or holes)

6.4.8.2 Authority

Responsible Lead: Krusha Patel (Flight Dynamics Lead)

Checklist Verification: Raymond Pace (Secondary Safety Officer)

6.4.8.3 Critical Testing Prior to Launch Date

None

6.4.8.4 Flight Simulation Procedure

Up-to-date OpenRocket file must be downloaded prior to leaving for launch. Internet connection may not be available at the launch site.

1. Load most recent OpenRocket file.
    - ☐ File is verified as most recent and loaded
2. Measure wind speed with anemometer: _____
3. Input launch day wind conditions and elevation.
   Plant City: 128 ft Palm Bay: 20 ft Huntsville: 810 ft
    - ☐ Current conditions input
4. Weigh rocket with motor installed and find center of gravity. Input into simulation.
    - ☐ Checklist 6.4.7 Complete? (Motor Preparation)

    - ☐ Weight of rocket: _______
    - ☐ Center of Gravity (from tip of nosecone): _______
    - ☐ Center of Pressure (from tip of nosecone): _______
5. Simulate to identify ballast configuration necessary for proper stability and optimal altitude.

Based on the Vehicle Demonstration flight, a maximum of 1000g of ballast may be added

6. Add ballast and repeat simulations.
    - ☐ Ballast added (and location):_______
    - ☐ Any sections disassembled for ballasting properly re-sealed
    - ☐ Mark final center of gravity on rocket
    - ☐ Mark final center of pressure on rocket

	Responsible Lead	Checklist Verification
Simulations Complete & Vehicle Ballasted	___________________	______________________

6.4.9 Setup on Launch Pad

6.4.9.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.9.2 Authority

Responsible Individuals: Bilal Hassan (NAR L2 Certified Team Member) and Collin Larke (Avionics and Recovery Lead)

Checklist Verification: Megan Wnek (Project Manager)

6.4.9.3 Critical Testing Prior to Launch Date

None

6.4.9.4 Setup on Launch Pad Procedure

VERIFY ALL SETUP CHECKLISTS ARE COMPLETE BEFORE BEGINNING LAUNCH PAD SETUP:

- ☐ Ejection charge checklist
- ☐ Payload preparation checklist
- ☐ Avionics preparation checklist
- ☐ Motor preparation checklist
- ☐ Rocket preparation checklist

Follow directions from the Range Safety Officer at all times.

1. Verify correct launch rail
    - ☐ 15-15 rail
    - ☐ 12 ft
2. Load launch vehicle on launch rail
3. Arm altimeters using keylock switch
    - ☐ Altimeter outputs correct beeps

☐ Continuity beeps sound

Responsible Leads Checklist Verification

Vehicle on Pad ____________ ____________ ________________

6.4.10 Igniter Installation

6.4.10.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.10.2 Authority

Responsible Person: Bilal Hassan (NAR L2 Certified Team Member)

Checklist Verification: Megan Wnek (Project Manager)

6.4.10.3 Critical Testing Prior to Launch Date

None

6.4.10.4 Igniter Installation Procedure

VERIFY LAUNCH PAD SETUP CHECKLIST IS COMPLETE BEFORE IGNITER INSTALLATION

☐ Launch pad setup checklist complete

1. Insert igniter all the way into the motor until the igniter touches the end of the motor.

Ensure that the wire does not lower throughout the following processes

2. Put the igniter through the small hole in the nozzle plug, and seat nozzle plug into nozzle.
3. Strike the alligator clips together to ensure they are not powered.
4. Using alligator clips, clip the wire on its tip (about 1/4 in of wire) and then wrap the remaining wire around the alligator clip

Ensure alligator clips and igniter wires are not touching the metal launch rail stand nor each other.

Responsible Lead Checklist Verification

Igniter Installed ______________ ________________

6.4.11 Launch Procedure

6.4.11.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup

6.4.11.2 Authority

Responsible Lead: Megan Wnek (Project Manager)

Checklist verification: Jason Rosenblum (Primary Safety Officer) and Raymond Pace (Secondary Safety Officer)

6.4.11.3 Critical Testing Prior to Launch Date

None

6.4.11.4 Launch Procedure

VERIFY IGNITER INSTALLATION CHECKLIST IS COMPLETE BEFORE BEGINNING LAUNCH CHECKLIST

- ☐ Igniter installation checklist completed

Follow directions from the Range Safety Officer at all times.

1. Assemble payload components
    - ☐ Payload checklist completed
2. Assemble avionics bay
    - ☐ Recovery checklist completed
3. Assemble launch vehicle
    - ☐ Rocket preparation checklist completed
4. Prepare and install motor
    - ☐ Motor preparation and installation checklist completed

Line of motor must remain clear of all persons.

5. Find rocket center of gravity
    - ☐ Balance rocket horizontally until center of gravity is found
6. Complete Pre-flight simulations
    - ☐ Pre-flight simulation checklist complete
    - ☐ Ballast added (as needed, no more than 1000g)
    - ☐ Simulations repeated (as needed)
7. Verify stability of launch vehicle with launch vehicle simulations
    - ☐ Stability is 2.0 or higher at rail exit
    - ☐ Thrust to weight ratio of 5:1 or higher
    - ☐ Velocity off rail of 52 fps or higher
8. Bring launch vehicle to launch pad
    - ☐ Launch pad checklist complete
    - ☐ Igniter installation checklist complete
9. Launch
    - ☐ Follow all Range Safety Officer instructions
    - ☐ Verify all personnel are at least 200 ft from launch pad
    - ☐ Verify pad area is cleared for 100 ft around launch pad
    - ☐ Verify windspeed is less than 20 mph
    - ☐ Verify airspace is clear
    - ☐ Verify continuity with igniter

Responsible Lead Checklist Verifications

Launch Ready ____________________ ____________________ ____________________

An immediate launch can occur once lead and verifications sign off, pending RSO final approval.

6.4.12 Troubleshooting

6.4.12.1 Relevant Personal Protective Equipment

- Non-synthetic clothing to prevent static buildup
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.12.2 Authority

Responsible Lead for Misalignment and Altimeters: Collin Larke (Avionics and Recovery Lead)

Responsible Person for Motor Issue: Bilal Hassan (NAR L2 Certified Team Member)

Checklist Verification: Either Safety Officer (Jason Rosenblum or Raymond Pace)

6.4.12.3 Critical Testing Prior to Launch Date

None

6.4.12.4 Troubleshooting Procedure

6.4.12.4.1 Avionics bay misaligned

1. Disassemble avionics bay
   - ☐ Avionics bay disassembled
2. Check for improper component placement
   - ☐ Avionics sled installed backwards or upside down
   - ☐ Wrong bulkheads used on avionics bay
   - ☐ Improper wiring of avionics components
3. Reassemble avionics bay
   - ☐ Avionics bay assembly procedure completed

Responsible Lead Checklist Verification

Avionics Bay Properly Aligned ____________________ ____________________

6.4.12.4.2 Altimeters do not have continuity or do not turn on

1. Disassemble avionics bay
   - ☐ Avionics bay disassembled
2. Check all wiring for loose connections
   - ☐ Altimeter connections
   - ☐ Terminal connections
   - ☐ Battery connections
3. Reassemble avionics bay
   - ☐ Avionics bay assembly procedure completed

Responsible Lead Checklist Verification

____________________ ____________________

Altimeter Troubleshooting Complete ______________________ ______________________

6.4.12.4.3 Motor fails to ignite

1. Wait 60 seconds before approaching launch pad
2. Disarm altimeters
   - ☐ Altimeters disarmed
3. Remove old igniter
4. Install new igniter
   - ☐ Igniter installation procedure completed

	Responsible Lead	Checklist Verification
Igniter Troubleshooting Complete	______________________	______________________

6.4.13 Post-Flight Inspection

6.4.13.1 Relevant Personal Protective Equipment

- Work Gloves – determination will be made by Safety Officers if rocket’s recovery location requires gloves
- Latex Gloves
- Closed-toed shoes and full-length pants (no rips or holes)

6.4.13.2 Authority

Responsible Leads: Megan Wnek (Project Manager)

Checklist Verification: Jason Rosenblum (Primary Safety Officer)

6.4.13.3 Critical Testing Prior to Launch Date

None

6.4.13.4 Post-Flight Inspection Procedure

Identify and make team aware of any environmental hazards in recovery area prior to approaching rocket. Only leads may approach rocket for recovery and inspection.

☐ Area safe and only necessary personnel recovering rocket

1. Locate ejection charge wiring to verify all charges properly detonated

   Note: If undetonated, wait an additional minute before approaching vehicle
2. Photograph landed rocket
3. Listen for and take audio recording of altimeter beeps (for maximum altitude)
   - ☐ Altitude recorded: _____
4. Turn off keylock switches
   - ☐ Switches off
5. Inspect launch vehicle for external damage and proper parachute deployment (Take pictures)

   Observations: ____

6. Lift rocket from ground, 1 person holding each section, ensuring that no section is stuck or recovery harness tangled. **Caution: Do not hold aft airframe by motor retainer, this may result in burns**
7. Carefully move rocket back to team preparation area.
8. Remove quick links.
9. Open avionics bay and payload bay.
10. Inspect bays and bulkheads for ejection debris.
    Observations: ____
11. Clean structural components of rocket with wet wipes.

	Responsible Lead	Checklist Verification
Post-flight inspection complete	____________________	______________________

7. Project Plan

7.1 Testing

7.1.1 Launch Vehicle Testing

7.1.1.1 Launch Vehicle – Required Testing Plan

The launch vehicle testing plan is defined (Table 38).

Test Number	Test Name	Objective	Methodology	Variable	Test Status
1	Airframe Bending and Compression Analysis	Measure bending and compressive strength of airframe material	Place material in Instron Universal Testing Machine and simulate compressive forces. Analyze data to determine the compressive strength point. Perform four-point test and analyze data to determine bending strength point.	Bending and compressive strength	Complete
2	Airframe Drop Resistance Demonstration	Measure the drop resistance of airframe material	Drop airframe material from height of 12 ft to simulate how launch vehicle would land after launch onto a similar landing	Durability of airframe material	Complete

			terrain of grass. Assess resulting behavior of fiberglass.		
3	Bulkhead Drop Resistance Demonstration	Measure the drop resistance of bulkhead material	Drop bulkhead material from height of 12 ft to simulate how launch vehicle would land after launch onto a similar landing terrain of grass. Assess resulting behavior of bulkhead.	Durability of bulkhead material	Complete
4	Rotation & Rolling Analysis	Measure potential rotation and rolling effects on rocket during launch	Using hand calculations, determine the severity of the rotation and rolling effects during launch and evaluate the results.	Pitch and yaw moment, axial rotation	Incomplete
5	Vehicle Drag Analysis	Determine drag produced by the vehicle at various orientations	Use SolidWorks simulation software to find simulated values for drag for a 5 deg angle of attack.	Coefficient of drag	Complete
6	Parachute Drag Analysis	Determine if the parachutes provide the appropriate drag to slow the launch vehicle during descent	Using the descent velocity data from the vehicle demonstration flight, calculate the coefficient of drag of the parachute using the drag equation. Repeat for each parachute.	Coefficient of drag	Complete
7	Recovery Altimeter Functionality Test	Ensure both the primary and secondary altimeters are detecting the correct altitude	Place the Stratologger altimeter at multiple heights and record altitude readings. Repeat	Altitude	Complete

			for the Entacore AIM altimeter.		
8	Barometer Functionality Test	Ensure barometer reads change in pressure	Place plastic straw over barometer, seal the edges, and provide suction on the straw to change pressure.	Pressure	Complete
9	Subscale Main Parachute Ejection Demonstration	Determine the mass of Pyrodex required to completely separate the nosecone and forward sections	Prepare Pyrodex ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Mass of Pyrodex	Complete
10	Subscale Drogue Parachute Ejection Demonstration	Determine the mass of Pyrodex required to completely separate the forward and aft sections	Prepare Pyrodex ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Mass of Pyrodex	Complete
11	Fullscale Main Parachute Ejection Demonstration	Determine the amount of black powder required to completely separate the nosecone and forward sections	Prepare black powder ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Mass of black powder	Complete
12	Fullscale Drogue Parachute Ejection Demonstration	Determine the amount of black powder required to completely separate the forward and aft sections	Prepare black powder ejection charge and assemble the launch vehicle. Place launch vehicle on test stand and ignite charge.	Mass of black powder	Complete
13	Recovery Harness Strength Analysis	Measure the strength of the recovery harness	Use a force gauge to measure force applied when pulling on the recovery harness at	Strength of recovery harness	Complete

			a force of 50 lb to simulate deployment of parachutes. Assess resulting behavior of harness.		
14	Zippering Demonstration	Ensure the launch vehicle structure will not zipper	Use a force gauge to measure force applied when pulling on the airframe with recovery harness at a force of 50 lb to simulate deployment of parachutes. Assess resulting behavior of harness.	Resistance of airframe material to zippering	Complete
15	Vibrational Resistance Test	Ensure vibrational movement during launch will not damage the launch vehicle	Simulate vibrational forces comparable to those expected during launch on the launch vehicle.	Durability of launch vehicle	Incomplete
16	RocketPoxy Density Inspection	Determine weight per inch of RocketPoxy epoxy	Weigh two pieces of fiberglass. Then, epoxy pieces together with RocketPoxy and weigh once more.	Density of epoxy	Complete
17	JB Weld Density Inspection	Determine weight per inch of JB Weld epoxy	Weight two pieces of fiberglass. Then, epoxy pieces together with JB Weld and weigh once more.	Density of epoxy	Complete
18	Epoxy Strength Analysis	Determine the operational shear strength of the epoxy utilized in the launch vehicle	Use epoxy to create fillet between two pieces of fiberglass. Load the epoxied fiberglass into the Instron Universal Testing Machine and determine the final load at failure. Observe the failed specimen to	Maximum shear strength of the epoxy	Incomplete

			determine adhesive area and calculate maximum shear stress.		
19	GPS Functionality Demonstration	Ensure GPS can transmit the correct data over one mile	Power on GPS and determine if it is detecting the correct coordinate location. Increase distance between transmitter and receiver and determine if it is transmitting data properly.	Functionality of GPS and transmission range	Complete
20	Parachute Packing Demonstration	Ensure that parachute fits in airframe and will deploy without disruption or difficulty	Fold parachute in an appropriate manner and simulate deployment. Fold in the same manner and place in the airframe.	How the parachute fits within the airframe and ability to deploy	Complete
21	Parachute Opening Demonstration	Ensure that the parachute properly opens	Attach weight to parachute and from a height of about 80 ft.	Ability of parachute to open	Incomplete
22	Center of Gravity Inspection	Determine the launch vehicle's center of gravity	Fully configure the vehicle for launch and balance the vehicle on a team member's hand.	Location of center of gravity	Complete
23	Subscale Demonstration Flight	Demonstrate the functionality of all components of the subscale launch vehicle	Design and manufacture a subscale model and conduct a launch.	Performance of subscale model during launch, descent, and landing	Complete
24	Vehicle Demonstration Flight	Demonstrate the functionality of all components of the fullscale launch vehicle	Design and manufacture a fullscale model and conduct a launch.	Performance of fullscale model during launch, descent, and landing	Complete
25	Launch Rehearsal	Ensure all preparation and assembly of launch vehicle and payload	Fully assemble the launch vehicle (without the motor) and payload	Time for full assembly	Incomplete

		can be completed within two hours	in the appropriate amount of time.		

Table 38: Launch Vehicle Testing Plan

7.1.1.2 Launch Vehicle Testing – Success Criteria and Justifications

The success criteria and justifications for the launch vehicle testing plan are defined (Table 39).

Test Number	Test Name	Success Criteria	Justification
1	Airframe Bending and Compression Analysis	The airframe material does not deform and is recoverable and reusable following landing.	The airframe and fin material must not fail during launch or landing or else the launch vehicle will not be reusable, and the launch is considered unsuccessful.
2	Airframe Drop Resistance Demonstration	The airframe material does not deform and is recoverable and reusable following landing.	The airframe material must not fail during landing or else the launch vehicle will not be reusable, and the launch is considered unsuccessful.
3	Bulkhead Drop Resistance Demonstration	The bulkhead material does not deform and is recoverable and reusable following landing.	The bulkhead material must not fail during landing, or the internal components may be damaged, and the launch vehicle will not be reusable, and the launch is considered unsuccessful.
4	Rotation & Rolling Analysis	The effects of the pitch and yaw moment, as well as the axial rotation, are not too severe on the rocket and will not greatly affect the launch vehicle's flight.	In order for stable flight, the launch vehicle should not oscillate excessively, affecting control and negatively impacting the launch vehicle's flight.
5	Vehicle Drag Analysis	The vehicle drag is appropriate so that it does not negatively impact the flight of the launch vehicle and the vehicle reaches the target apogee.	The launch vehicle must be designed such that the drag on it is not too great or too little to negatively impact the launch vehicle's flight and prevents the vehicle from reaching target altitude.
6	Parachute Drag Analysis	The parachutes adequately slow down the launch vehicle during descent to desired velocity.	Parachutes need to have a sufficient coefficient of drag, otherwise the launch vehicle will sustain significant damage during landing if the parachutes do not slow the vehicle's descent enough and will not be reusable and the launch is considered unsuccessful. Conversely, the coefficient of drag must not be too great, or the vehicle's descent time will be too great.

7	Recovery Altimeter Functionality Test	Both the primary and secondary altimeters measure the correct altitude when placed at different heights with an error of 10 ft.	In order to determine when the parachutes must be deployed, the altimeters must read the correct altitude measurements, or the parachutes may deploy incorrectly, resulting in a failed launch.
8	Barometer Functionality Test	The barometer measures correct changes in pressure.	In order to determine altitude, the barometer must detect pressure changes in the air correctly. If it does not, the parachutes may deploy incorrectly, resulting in a failed launch.
9	Subscale Main Parachute Ejection Demonstration	The subscale launch vehicle separates, and the main parachute successfully deploys.	The subscale launch vehicle must separate so the main parachute can deploy and result in the desired landing velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in damages to the vehicle and a failed launch.
10	Subscale Drogue Parachute Ejection Demonstration	The subscale launch vehicle separates, and the drogue parachute successfully deploys.	The subscale launch vehicle must separate so the drogue parachute can deploy and result in the desired descent velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in damages to the vehicle and a failed launch.
11	Fullscale Main Parachute Ejection Demonstration	The fullscale launch vehicle separates, and the main parachute successfully deploys.	The fullscale launch vehicle must separate so the main parachute can deploy and result in the desired landing velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a velocity, resulting in damages to the vehicle and a failed launch.
12	Fullscale Drogue Parachute Ejection Demonstration	The fullscale launch vehicle separates, and the drogue parachute successfully deploys.	The fullscale launch vehicle must separate so the drogue parachute can deploy and result in the desired descent velocity. If the launch vehicle does not separate, the parachute will not deploy and the launch vehicle will land at too high a

			velocity, resulting in damages to the vehicle and a failed launch.
13	Recovery Harness Strength Analysis	The recovery harness withstands the forces applied to it and does not fail.	The recovery harness must stay intact when the launch vehicle separates in order to ensure that the launch vehicle remains attached to the parachutes. If the harness fails and the launch vehicle does not remain attached to the parachutes, sections of the vehicle will land at too great of a velocity, resulting in severe damages to the vehicle and a failed launch.
14	Zippering Demonstration	The fiberglass airframe can withstand the simulated parachute deployment force without zippering.	The airframe material must not be damaged during parachute deployment or else the launch vehicle will not be reusable, and the launch is considered unsuccessful.
15	Vibrational Resistance Test	The launch vehicle is not damaged due to vibrational forces and is reusable.	The launch vehicle must not be damaged during launch or else it will not be reusable, and the launch is considered unsuccessful.
16	RocketPoxy Density Inspection	The density of RocketPoxy is determined.	The weight of epoxy must be accounted for in the launch vehicle's overall weight in order to simulate realistic results.
17	JB Weld Density Inspection	The density of JB Weld is determined.	The weight of epoxy must be accounted for in the launch vehicle's overall weight in order to simulate realistic results.
18	Epoxy Strength Analysis	The epoxy displays an adhesive shear strength large enough for operational parameters.	The adhesive joints within the airframe must be strong enough to withstand the landing forces the launch experiences, or components may break, and the launch vehicle will not be considered reusable.
19	GPS Functionality Demonstration	The GPS reads the correct coordinates and can transmit data over one mile.	The GPS must be able to transmit location data over the entire launch field radius so the team can compare the true location data with the grid location determined by the payload. The GPS data will also be used to locate the launch vehicle upon landing, thus if the GPS does not function correctly, the vehicle may not be recoverable.

20	Parachute Packing Demonstration	The parachute fits in the airframe with enough clearance so the parachute can easily slide within the airframe, allowing the parachute to properly deploy during separation.	If the parachute does not fit properly in the airframe, it may not deploy correctly during separation. This would result in the launch vehicle descending at too great of a velocity, possibly damaging the launch vehicle and causing the launch to be considered unsuccessful.
21	Parachute Opening Demonstration	The parachute opens properly during deployment.	If the parachute does not fully open, the launch vehicle will land at too great a velocity. This impact may damage the launch vehicle and the launch will be considered unsuccessful.
22	Center of Gravity Inspection	The true center of gravity is located near enough to the calculated point so that the stability margin is at least 2.0.	If the center of gravity location does not provide a stability margin of at least 2.0, the launch vehicle may not fly in the predicted manner and may be unsuccessful.
23	Subscale Demonstration Flight	The subscale launches, separates, and lands properly and all components are recoverable and reusable.	The subscale model must successfully fly in order to verify the design's functionality prior to constructing the fullscale model.
24	Vehicle Demonstration Flight	The fullscale launches, separates, and lands properly and all components are recoverable and reusable.	The fullscale model must successfully fly in order to verify the design's functionality prior to the final launch day.
25	Launch Rehearsal	The time for launch vehicle and payload assembly is within the allowed time.	The team must be prepared to prepare the launch vehicle and payload in the appropriate amount of time, or the flight may be negatively impacted.

Table 39: Launch Vehicle Testing Success Criteria and Justifications

7.1.1.3 Launch Vehicle Testing – Resultant Effects

The effects from the results of the launch vehicle testing plan are defined.

1. Airframe Bending and Compression Analysis

If the airframe fails and the material is not reusable, a new airframe material will be selected that is strong enough to withstand landing forces.

2. Airframe Drop Resistance Demonstration

If the airframe fails and the material is not reusable, a new airframe material will be selected that is strong enough to withstand landing forces.

3. Bulkhead Drop Resistance Demonstration

If the bulkhead fails and the material is not reusable, a new bulkhead material will be selected that is strong enough to withstand landing forces.

4. Rotation and Rolling Analysis

If the rocket does not adequately handle the rotational and rolling forces, the launch vehicle design must be modified to better withstand them. This modification may include altering the weight distribution with added ballast to change the stability.

5. Vehicle Drag Analysis

If the launch vehicle induces too much or too little drag that it significantly impacts the flight, the vehicle finish will be modified in order to reduce the drag. The vehicle will be covered in a rough sand paint finish if the drag must be increased and covered in a smooth glossy paint if the drag must be decreased.

6. Parachute Drag Analysis

If the parachute has an insufficient coefficient of drag and fails to slow the weight of the launch vehicle, a larger parachute will be chosen that is able to induce the desired drag effects. If the parachute has too great of a coefficient of drag and slows the weight of the launch vehicle to much, a smaller parachute will be chosen that is able to induce the desired drag effects.

7. Recovery Altimeter Functionality Test

If the altimeters fail to read the correct altitude, they will be replaced with new altimeters.

8. Barometer Functionality Test

If the barometer fails to read the correct change in pressure, it will be replaced with a new barometer.

9. Subscale Main Parachute Ejection Demonstration

If the subscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of Pyrodex in the ejection charge, respectively.

10. Subscale Drogue Parachute Ejection Demonstration

If the subscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of Pyrodex in the ejection charge, respectively.

11. Fullscale Main Parachute Ejection Demonstration

If the fullscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of black powder in the ejection charge, respectively.

12. Fullscale Drogue Parachute Ejection Demonstration

If the fullscale vehicle does not separate, the launch vehicle will be evaluated to determine if there is leaking air within the launch vehicle, if there is adequate continuity with the remote ignitor, or if the ejection charge did not provide enough separation force. The issue can be resolved by resealing possible locations of air leakage, reconnecting the charge wires, or increasing the amount of black powder in the ejection charge, respectively.

13. Recovery Harness Strength Analysis

If the recovery harness does not withstand the forces applied to it, a new harness with a higher yield strength will be used.

14. Zippering Demonstration

If the airframe material experiences zippering under simulated loads, the recovery system will be modified as fiberglass zippering is likely caused by a recovery system issue. These modifications may include utilizing a thicker recovery harness or attaching a tennis ball to the recovery harness where the harness contacts the airframe to reduce the pressure.

15. Vibrational Resistance Test

If the launch vehicle fails and becomes too damaged, the vehicle will be modified so it will be strong enough to withstand vibrational forces. These modifications may include reinforcing the coupler sections with tape to combat bending or reapplying epoxy to sections that require it.

16. RocketPoxy Density Inspection

The epoxy density measured will be the density utilized when measuring the launch vehicle's total weight.

17. JB Weld Density Inspection

The epoxy density measured will be the density utilized when measuring the launch vehicle's total weight.

18. Epoxy Strength Analysis

If the chosen epoxy does not have an acceptable shear strength to maintain structural integrity of the launch vehicle, a new epoxy with a higher strength will be chosen.

19. GPS Functionality Demonstration

If the GPS does not read the correct location data or cannot transmit data over one mile, a new GPS will be chosen.

20. Parachute Packing Demonstration

If the parachute does not fit comfortably within the airframe, the parachute will be refolded and repacked into the airframe with a different method.

21. Parachute Opening Demonstration

If the parachute does not open properly, the parachute will be refolded and repacked into the airframe in a different manner.

22. Center of Gravity Inspection

If the center of gravity is not located within the allowable range, ballast will be added to the vehicle accordingly without exceeding the limit.

23. Subscale Demonstration Flight

If the subscale flight is unsuccessful, a thorough investigation will be conducted of the launch vehicle to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

24. Vehicle Demonstration Flight

If the fullscale flight is unsuccessful, a thorough investigation will be conducted of the launch vehicle to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

25. Launch Rehearsal

If the assembly of the launch vehicle and payload takes more than the allowed time, the team will discuss and determine which components can be prepared more quickly or ahead of time.

7.1.2 Payload Testing

The payload testing plan is defined (Table 40).

Test Number	Test Name	Objective	Methodology	Variable	Test Status
26	Drone Camera Landmark Analysis	Determine how many keypoints can be captured during launch time by OV5642 cameras	Place payload camera on a testing drone and fly it to predicted altitude, then fly back to the ground. Allow camera to take photos during ascent and descent. Perform test for both the cameras.	Number of keypoints captured	Incomplete
27	Drone Camera Quality Demonstration	Determine quality of images taken by OV5642 cameras	Place payload camera on a testing drone and fly it to predicted altitude, then fly back to the ground. Allow camera to take photos during ascent and descent. Perform test for both the cameras.	Quality of images captured	Incomplete
28	Field-of-View Inspection	Determine true field-of-view (FOV) of OV5642 cameras	Place payload camera on a testing drone and measure the distance the camera can see. Confirm observations with given field-of-view from manufacturer. Perform test for both the cameras.	True FOV of cameras	Incomplete
29	Battery Life Demonstration	Verify that the battery can maintain the	Allow the battery to run for a minimum of 2	Charge of battery	Complete

		necessary charge for at least 2 hours	hours. Perform test for the payload and avionics.		
30	Accelerometer Functionality Test	Verify that the accelerometer reports accurate displacement values	Attach the accelerometer to the recovery harness and spin it to simulate launch movements, then move the spinning accelerometer a straight, measured distance and evaluate displacement readings.	Displacement readings	Incomplete
31	Heat Resistance Demonstration	Ensure the payload will not overheat if left running outside for at least 2 hours	Place payload inside the airframe and allow it to run software while leaving it outside in sunlight for at least 2 hours. Measure the temperature and assess possible resulting damage from heat.	Damage to payload	Incomplete
32	Ejection Resistance Demonstration	Ensure that the payload will not be damaged by the forces created during separation	Perform a separation ejection test with the payload inside the launch vehicle.	Damage to payload	Complete
33	Power Loss Test	Ensure that the payload can operate if it loses power	Disconnect power when the launch vehicle is configured for launch. Assess if the system's redundancies allow it to recover and continue operation.	Functionality of software and electrical components	Incomplete
34	Vibrational Resistance Test	Ensure that the payload will not be damaged by vibrations during launch	Simulate vibrational forces on the payload similar to those expected during launch.	Damage to payload	Incomplete
35	Payload Drop Test	Ensure the payload will not be damaged during landing	Drop payload in the airframe from a height of approximately 12 ft.	Damage to payload	Complete
36	Strength of Camera Mount Test	Ensure the camera mount will not detach from the launch vehicle during flight	Attach camera mounts to airframe for launch. Assess if mount is sufficiently attached to the airframe after flight.	Attachment of camera mount	Complete

37	Wire Heat Resistance Test	Ensure that the motor firing does not cause the electronic wiring of the payload to overheat	Place the wires inside the wire tubes and configure within airframe for launch. Assess if damage to the wires occurred after flight.	Damage to wires	Complete
38	Software Implementation Demonstration	Verify that the software runs as intended	Run the code written for the payload and check for errors.	Functionality of software with hardware	Incomplete
39	Raspberry Pi Functionality Demonstration	Ensure Raspberry Pi operates and responds to software	Power on the Raspberry Pi and confirm it properly responds to code instructions.	Functionality of Raspberry Pi	Incomplete
40	Inertial Measurement Unit (IMU) Functionality Demonstration	Ensure IMU gives the correct measurement of acceleration and orientation	Connect IMU with the Raspberry Pi. Orientate IMU in a controlled manner and compare the data collected with IMU to the known acceleration and orientation.	Functionality of IMU	Incomplete
41	XBee Radio Functionality Demonstration	Ensure XBee radio can send and receive data correctly	Connect XBee radio transmitter to one laptop with X-TCU opened and connect XBee radio receiver to another laptop with X-TCU opened. Send data through the transmitter and use the software to see if the receiver collects the message properly.	Communication between transmitter and receiver	Incomplete
42	Microprocessor Functionality Demonstration	Ensure microprocessor can run program correctly	Plug microprocessor into laptop and upload an example program. Determine if the example program is running properly.	Functionality of microprocessor	Incomplete
43	SD Card Functionality Demonstration	Ensure the SD card can store data	Run data to the SD card through the Raspberry Pi. Ensure the data can be accessed by reading back data and confirm that it matches the originally written data.	Functionality of SD card	Incomplete

44	Payload Altimeter Functionality Test	Ensure altimeter is detecting the correct altitude	Place the altimeter at multiple heights and record the altitude readings.	Altimeter altitude reading	Incomplete
45	Wire Tube Inspection	Ensure that wire tube is wide enough to protect wires without compromising motor position	Configure wire tube set-up and observe if tube interferes with centering rings and if tube fits within airframe.	Protection of wires	Complete
46	Payload Launch Detection Demonstration	Ensure that the payload can detect sudden acceleration changes	Induce a sudden movement on the payload from rest.	Movement detection	Incomplete
47	Payload Data Compilation Test	Ensure that the payload can compile at least 100 images within five minutes	Run the software to completion and determine the amount of time required for the payload to compile the received data.	Time for data compilation	Incomplete
48	Payload Transmission Range Test	Ensure the transmission range of the payload is at least one mile.	Evaluate the transmission capabilities of the Xbee radio over a distance of one mile.	Transmission range	Incomplete
49	IMU Drift Analysis	Ensure the drift of the IMU at rest does not exceed 100 ft over a period of 90 s	Place the IMU at rest and measure the offset error of the IMU while it is stationary. Evaluate the error over 90 s to determine the expected drift during flight.	IMU drift	Incomplete
50	Payload Demonstration Flight	Demonstrate the complete functionality of the payload	Design and assemble the payload and conduct a fullscale launch including the payload.	Performance of payload during launch, descent, and landing.	Incomplete

Table 40: Payload Testing Plan

7.1.2.1 Payload Testing – Success Criteria and Justifications

The success criteria and justifications for the payload testing plan are defined (Table 41).

Test Number	Test Name	Success Criteria	Justification
26	Drone Camera Landmark Analysis	The camera captures at least 150 keypoints during launch time in order to determine location.	The number of keypoints captured must be sufficient enough for software to determine the final grid location of the launch vehicle, or

			the launch is considered unsuccesful.
27	Drone Camera Quality Demonstration	The image quality and resolution are sufficient enough for software to determine keypoints.	The camera quality and resolution must be sufficient enough for keypoints to be identified and thus the final grid location of the launch vehicle can be determined. Insufficient camera quality may result in keypoints not being recognized.
28	Field-of-View Inspection	The field-of-view is sufficient enough for the cameras to view the entire launch field (5,000 ft by 5,000 ft) at the target altitude while also maintaining a high resolution so that the software can determine keypoints.	The camera FOV must be sufficient enough for keypoints to be identified and thus the final grid location of the launch vehicle can be determined. Insufficient FOV may result in keypoints not being identified.
29	Battery Life Demonstration	The batteries are able to maintain the charge needed for at least 2 hours. The payload battery's voltage will decrease over time but should reach a plateau of about 7.40V. The avionics battery's voltage will decrease over time but should reach a plateau of about 3.40V.	The batteries must be able to maintain the necessary charge for at least 2 hours so the launch vehicle can be launch-ready for at least 2 hours, or the payload or avionics electronics may not have enough power to function during flight.
30	Accelerometer Functionality Test	The displacement reported by the accelerometer matches the measured distance it was moved.	The values measured by the accelerometer must be accurate, so the payload can detect acceleration as the launch vehicle moves so that the payload can begin collecting data and measure the displacement between the image capture location and the landing location.
31	Heat Resistance Demonstration	The payload does not overheat and incur damage.	The payload must be able to run for at least 2 hours when it is outside so that it is launch-ready for at least 2 hours and does not overheat within this time.
32	Ejection Resistance Demonstration	The payload does not incur damage during separation.	The payload must complete its objective and therefore must not be damaged during separation, or else the launch is considered unsuccessful.
33	Power Loss Test	The payload is functional after power is momentarily lost.	If power is lost during launch, the payload must be able to recover

			and continue functioning to ensure that the launch is successful.
34	Vibrational Resistance Test	The payload does not incur damage from vibrational forces.	The payload must complete its objective and therefore must not be damaged during flight, or else the launch is considered unsuccessful.
35	Payload Drop Test	The payload does not incur damage from landing forces.	The payload must complete its objective and therefore must not be damaged during landing, or else the launch is considered unsuccessful.
36	Strength of Camera Mount Test	The camera mount remains attached to the launch vehicle during flight.	The camera mount must be attached to the launch vehicle for the entire flight so the camera can take and process images. If the camera mount fasteners fail and the cameras fall from the launch vehicle, then the keypoints will not be captured and the launch will be considered unsuccessful.
37	Wire Heat Resistance Test	The payload wiring does not incur damage after the motor has finished firing.	If the wires overheat when the motor fires, the payload will be unable to function properly, and the launch will be considered unsuccessful.
38	Software Implementation Demonstration	The payload code runs as intended without producing any errors.	The software for the payload is responsible for processing images taken by the cameras to determine the location of the rocket, thus its functionality is crucial to the payload’s success. If the software has errors and does not run correctly, the data received cannot be compiled and the launch will be considered unsuccessful.
39	Raspberry Pi Functionality Demonstration	The Raspberry Pi responds correctly to the software.	The Raspberry Pi is the basis of the electronics in the payload and its functionality is necessary to complete the mission since it extrapolates the image data and computes the launch vehicle’s location. If it does not function as intended, the launch will be considered unsuccessful.
40	Inertial Measurement	The IMU produces correct acceleration and orientation data.	The IMU must collect the acceleration and orientation data in

	Unit (IMU) Functionality Demonstration		order for the software to accurately locate keypoints and determine the payload's final grid location.
41	XBee Radio Functionality Demonstration	The XBee radio transmitter sends data and receiver collects data correctly.	The XBee radio must be able to communicate with the ground station in order to transmit the payload data and relay the payload's final grid location.
42	Microprocessor Functionality Demonstration	The microprocessor runs the programs correctly.	The microprocessor must process the images from the camera as well as use IMU data to compute the drift of the launch vehicle in order to determine the payload's final grid location.
43	SD Card Functionality Demonstration	The SD card can store the collected data and the data is able to be used and analyzed.	The images must be stored on the SD card in order for the payload to compile the data and determine its final grid location.
44	Payload Altimeter Functionality Test	Altimeter measures the correct altitude when placed at different heights.	The correct altitude measurement is required for the software to determine the scale of the collected images in order for the payload to determine its final grid location.
45	Wire Tube Inspection	The wire tube adequately protects the wires while not interfering with the position of the motor.	The wires must be protected by the tubing in order to ensure they will not be damaged during launch while also not affecting the motor alignment. If the wires are not adequately protected or the motor is misaligned, then the payload and the flight path will be respectively negatively impacted, and the launch may be considered unsuccessful.
46	Payload Launch Detection Demonstration	The payload will detect changes in acceleration due to launch initiation.	The payload must be able to recognize the presence of motion so that it will be able to detect launch initiation and begin collecting data.
47	Payload Data Compilation Test	The payload can compile image data in under 5 minutes.	If the payload can successfully compile image data under 5 minutes, it can successfully execute location processing and the final grid location will be determined. The image data should be compiled within 5 minutes so that the payload's full function can be

			completed before its battery runs out of charge.
48	Payload Transmission Range Test	The payloads transmission ranges at least one mile.	The payload must be able to send and receive signals to the ground station successfully, even from one mile away. Otherwise, the payload will not transmit data correctly and may not be able to function successfully.
49	IMU Drift Analysis	The expected drift error of IMU is within 100 ft over a period of 90 s.	The IMU measurements cannot drift more than 100 ft over 90 s so that the final estimate of location of launch vehicle does not have a significant error.
50	Payload Demonstration Flight	The payload captures images and thus significant keypoints during flight and can compile the collected data to determine its grid location when landed.	The payload must successfully determine its location in order to verify the design's functionality prior to the final launch day.

Table 41: Payload Testing Success Criteria and Justifications

6.1.2.2 Payload Testing – Resultant Effects

26. Drone Camera Landmark Analysis

If the camera does not capture enough keypoints during launch time, assess camera functionality and replace it with a camera of faster shutter speed.

27. Drone Camera Quality Demonstration

If camera quality and resolution is not high enough, a new camera will be chosen with a higher image quality.

28. Field-of-View Inspection

If FOV of camera is not large enough, a new camera will be chosen with a larger FOV.

29. Battery Life Demonstration

If the battery cannot maintain the necessary charge, a new battery will be selected with a longer battery life.

30. Accelerometer Functionality Test

If the accelerometer reports inaccurate readings, a new accurate accelerometer will be selected.

31. Heat Resistance Demonstration

If the payload overheats, insulation would be added to prevent overheating from occurring.

32. Ejection Resistance Demonstration

If the payload is damaged during separation, the bulkhead separating the payload bay and the separation point will be analyzed and reinforced to further protect the payload or the payload sled will be modified in such a way that retains the payload more securely within the payload bay.

33. Power Loss Test
If the payload is unable to recover after losing power, the redundancies in its system responsible for power recovery will be evaluated and modified.

34. Vibrational Resistance Test
If the payload is damaged due to vibrations during launch, the payload sled will be modified in such a way that allows it to more adequately resist vibrational motion.

35. Payload Drop Test
If the payload is damaged during landing, the payload sled would be modified in such a way that allows it to more adequately resist dropping motion.

36. Strength of Camera Mount Test
If the camera mount does not remain attached to the launch vehicle during flight, a new attachment method will be implemented.

37. Wire Heat Resistance Test
If the camera or wiring overheat because of the motor firing, a new design that more adequately insulates the wiring will be implemented.

38. Software Implementation Demonstration
If the software produces errors, the code will be examined and debugged. If the software fails to function properly because of connections to hardware, the design and connectivity of the hardware and software of the payload will be reevaluated.

39. Raspberry Pi Functionality Demonstration
If the Raspberry Pi does not respond to software and does not operate the other electronics, replace the Raspberry Pi with a new computer.

40. Inertial Measurement Unit (IMU) Functionality Demonstration
If the IMU does not measure the correct orientation and acceleration data, a new IMU will be chosen.

41. XBee Radio Functionality Demonstration
If the XBee does not transmit or receive data properly, a new radio will be chosen.

42. Microprocessor Functionality Demonstration
If the microprocessor does not process the data successfully, a new microprocessor will be chosen.

43. SD Card Functionality Demonstration
If the SD card does not correctly store the data or does not have the adequate space to store the data, a new SD card will be chosen.

44. Payload Altimeter Functionality Test
If the altimeter does not read the correct altitude, a new altimeter will be chosen.

45. Wire Tube Inspection
If the wire tubes do not protect the wires sufficiently or interfere with the motor position, the diameter of the tubes may be modified or the positioning of the tubes within the airframe will be adjusted.

46. Payload Launch Detection Demonstration
If the payload is unable to recognize motion, the software will be modified so that the program begins to run when the IMU accelerometer detects acceleration.

47. Payload Data Compilation Test
If the payload is unable to compile image data in under 5 minutes, the software will be modified to ensure it can process data faster by not utilizing the data from all images taken, only those that provide a keypoint match with the pre-uploaded image of the launch field.

48. Payload Transmission Range Test
If the payload is unable to transmit data over one mile, a new radio will be chosen.

49. IMU Drift Analysis
If the measured drift exceeds 100 ft in 90 s, a new IMU that does not exceed the allowed drift will be chosen.

50. Payload Demonstration Flight
If the payload demonstration flight is unsuccessful, a thorough investigation of the payload will be done to determine the failures that occurred and what components must be modified in order to resolve the failures and the model will be relaunched.

7.1.3 Completed Testing

7.1.3.1 Test #1 – Airframe Bending and Compression Analysis

The airframe bending and compression analysis was performed prior to the payload demonstration flight to measure the bending and compressive strength of the fiberglass airframe.

Variable: bending and compressive strength
Materials:

- Instron Universal Testing Machine (30 kN load cell capacity)
- 4 in diameter fiberglass airframe
- Structural FRP fiberglass rectangular specimen cut lengthwise with the fibers
- Structural FRP fiberglass rectangular specimen cut crosswise with the fibers

Procedure for bending analysis:

- Place rectangular lengthwise-fiber specimen between the four-point fatigue flexure fixtures
- Perform four-point bend test by applying force until the specimen fractures
- Repeat test for the crosswise-fiber specimen

Procedure for compressive analysis:

- Place fiberglass airframe in Instron between compression platens
- Perform compressive test by applying force

The bending analysis was performed to evaluate the strength of the fins on the launch vehicle and how the material will behave when bending forces are applied. The analysis was performed on the lengthwise-fiber specimen first (Figure 122). A rectangular specimen, 6.4 in in length and 0.5 in in width, was cut from Structural FRP fiberglass using an abrasive waterjet. The specimen broke at 690.8 N.

Figure 122: Lengthwise-Fiber Specimen Loaded in the Instron

The analysis was then performed on the crosswise-fiber specimen of the same geometry, which fractured at 298.5 N (Figure 123).

Figure 123: Crosswise-Fiber Specimen Loaded in the Instron

This analysis revealed the fiberglass utilized to manufacture the fins is significantly stronger when cut with the length of the fibers, since the lengthwise-fiber specimen fractured at a greater load than the crosswise-fiber specimen (Figure 124 and Figure 125).

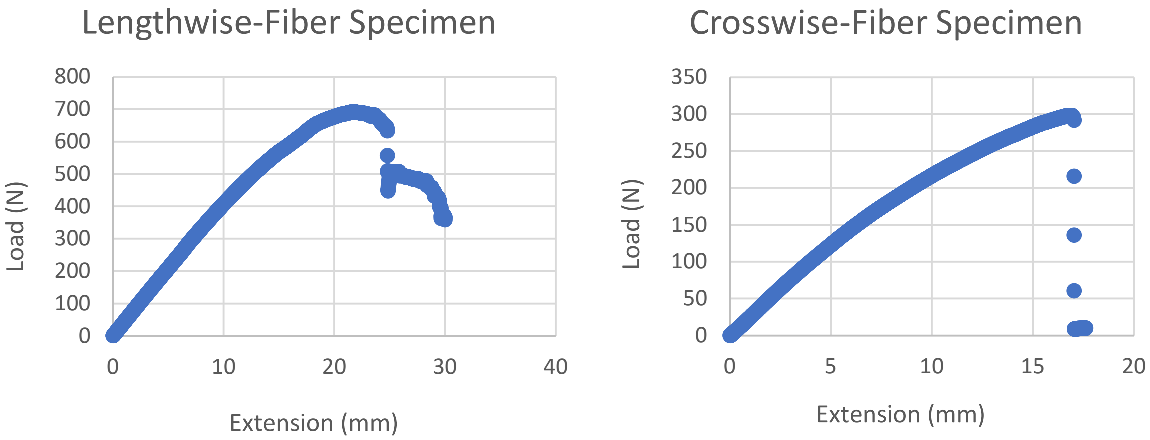


Figure 124: Lengthwise-Fiber (left) and Crosswise-Fiber Specimen (right) Load vs. Extension Data

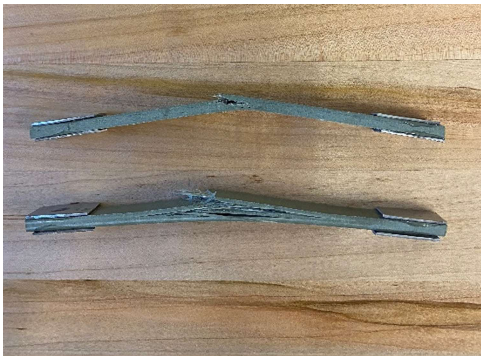


Figure 125: Crosswise-Fiber (top), Lengthwise-Fiber Specimen (bottom) After Four-Point Bending

The compression analysis was then performed to evaluate the behavior of the airframe material when it experiences compressive forces. The airframe was cut to a length of 6 in. It was not expected that the airframe would deform during this analysis because calculations performed prior to the test estimated the compressive strength of the fiberglass airframe was 120 kN while the Instron utilized had a limit of 30 kN. The team chose to compress the airframe up to 30 kN to confirm that the material would not fail under this limit since it is not expected that the airframe will be subjected to a load greater than this. The airframe was compressed in the Instron up to 30 kN and did not deform (Figure 126).

Figure 126: Airframe Specimen Loaded in Instron (left) and Specimen After Compression Test (right)

This analysis confirmed the previous calculations that the airframe would not deform at a load of 30 kN.

7.1.3.2 Test #2 – Airframe Drop Resistance Demonstration

The airframe drop resistance demonstration was performed prior to the payload demonstration flight to ensure the airframe can endure the force experienced by the vehicle during landing.

Variable: durability of airframe material

Materials Used:

- Excess piece of fiberglass airframe
- Ballast

Procedure:

- Create ballast of approximately 11 lb
- Place ballast within airframe and cover open ends with tape to prevent ballast from falling out
- Drop from a height of approximately 12 ft

The airframe drop resistance demonstration was successful on the first attempt. The airframe was assessed prior to the test to make note of its condition. Ballast was created using large metal washers and placed inside the piece of fiberglass airframe, which measured about 10 in in length. The airframe and ballast weighed 11.375 lb (Figure 127).

Figure 127: Airframe Before Drop Test (left) and Total Weight of Airframe and Ballast (right)

The total weight of the launch vehicle was estimated to be about 24 lb and the ground hit velocity of the vehicle during launch was simulated to be 17 ft/s. Using kinematics, it was calculated that the airframe must be dropped from a height of 4.5 ft to reach a ground hit velocity of 17 ft/s. However, since this demonstration utilized about 40% of the total vehicle weight, the height at which the airframe was dropped was multiplied by 2.5 to ensure that the airframe experiences the maximum possible force at landing. This ensures that the worst-case scenario is tested, in which all the weight of the launch vehicle is concentrated on one section of the airframe. Therefore, the airframe was dropped from a height of about 12 ft onto grass. The airframe did not suffer any damage from the drop (although the tape applied to ballast within the airframe broke upon landing) and was determined to be recoverable and reusable (Figure 128). Thus, the demonstration was deemed successful. It was expected that this demonstration would be successful, as the airframe was not damaged during the subscale demonstration flight.

Figure 128: Airframe on Ground After Drop (left) and Airframe After Drop Test (right)

7.1.3.3 Test #3 – Bulkhead Drop Resistance Demonstration

The bulkhead drop resistance demonstration was performed prior to the payload demonstration flight to ensure the bulkheads can endure the force experienced by the vehicle during landing. This demonstration was performed with the airframe drop resistance demonstration since the bulkhead was fitted to the airframe.

Variable: durability of bulkhead material

Materials Used:

- Excess piece of bulkhead material
- Ballast

Procedure:

- Create ballast of approximately 11 lb
- Place ballast within airframe, fit bulkhead on one end, and cover opposite open end with tape to prevent ballast from falling out
- Drop from a height of approximately 12 ft

The bulkhead drop resistance demonstration was successful on the first attempt. The bulkhead was assessed prior to the test to make note of its condition. Ballast was created using large metal washers and placed inside the piece of fiberglass airframe, which measured about 10 in in length. The bulkhead was fitted onto one end of the airframe and taped to secure in place. The airframe, bulkhead, and ballast weighed 11.375 lb (Figure 129).

Figure 129: Bulkhead Before Drop Test (left), Total Weight of Bulkhead, Airframe, and Ballast (right)

The total weight of the launch vehicle was estimated to be about 24 lb and the ground hit velocity of the vehicle during launch was simulated to be 17 ft/s. Using kinematics, it was calculated that the bulkhead must be dropped from a height of 4.5 ft to reach a ground hit velocity of 17 ft/s. However, since this demonstration utilized about 40% of the total vehicle weight, the height at which the bulkhead was dropped was multiplied by 2.5 to ensure that the bulkhead experiences the maximum possible force at landing. This ensures that the worst-case scenario is tested, in which all the weight of the launch vehicle is concentrated on one section of the bulkhead. Therefore, the bulkhead was dropped from a height of about 12 ft onto grass. The bulkhead was pointed downward when it was dropped so that it experienced the force from the ballast when landing. The bulkhead did not suffer any damage from the drop and was determined to be recoverable and reusable (Figure 130). Thus, the demonstration was deemed successful. It was expected that this demonstration would be successful, as the airframe was not damaged during the subscale demonstration flight.

Figure 130: Bulkhead on Ground After Drop (left) and Bulkhead After Drop Test (right)

7.1.3.4 Test #5 – Vehicle Drag Analysis

The vehicle drag analysis was performed prior to the vehicle demonstration flight to determine the coefficient of drag induced by the vehicle during flight.

Variable: coefficient of drag

Materials Used:

- SolidWorks simulation software

Procedure:

- Create vehicle geometry within SolidWorks
- Run CDF simulation at average ascent velocity
- Analyze forces induced during simulation and use to calculate the coefficient of drag using the drag equation

The simulation was performed using standard air temperature and pressure (72° F and 1 atm, respectively) and the average velocity of the vehicle between liftoff and apogee. The resulting forces induced by the launch vehicle were inputted into the drag equation and a coefficient of drag of 1.04 was found. This analysis was performed once more after the vehicle demonstration launch and a coefficient of drag of 0.78 was found, indicating that the first attempt at the analysis was miscalculated, possibly contributing to the performance of the vehicle in the vehicle demonstration launch. The vehicle surpassed the target apogee during the vehicle demonstration launch, indicating that the coefficient of drag expected prior to the launch was too great. Thus, the analysis was completed once more, and the new coefficient of 0.78 was determined that supports this conclusion.

7.1.3.5 Test #6 – Parachute Drag Analysis

The parachute drag analysis was performed prior to the payload demonstration flight to determine the coefficient of drag of the main and drogue parachutes.

Variable: Coefficient of drag
Materials Used:

- Main parachute descent velocity from the vehicle demonstration flight
- Drogue parachute descent velocity from the vehicle demonstration flight
- Weight of the vehicle during descent

Procedure:

- Input the flight parameters into the drag equation and solve for the coefficient of drag

The force of drag was determined to be the weight of the vehicle during descent, 21.5 lb, multiplied by the acceleration of gravity, 32 ft/s^2 and the density of air was taken to be the standard density of air, 1.225 kg/m^3. The main parachute descent velocity was 70 ft/s, and the drogue descent velocity was 17 ft/s. The surface area of the main parachute was 28.3 ft^2, and the surface area of the drogue parachute was 3.1 ft^2. These parameters were inputted into the drag equation; the coefficient of drag of the main parachute was determined to be 2.2 and the coefficient of the drogue parachute was determined to be 1.2. According to their respective manufacturers, the main parachute was to have a coefficient of drag of 2.2 and the drogue parachute was to have a coefficient of drag of 0.97. The main parachute drag was thus calculated correctly, but the drogue parachute drag was not accounted for properly during launch. The manufacturer's value for coefficient of drag was utilized in simulations prior to the vehicle demonstration launch, therefore the drag induced by the drogue parachute in reality was greater than what was estimated. This higher coefficient of drag may have contributed to the greater descent time experienced during the vehicle demonstration of flight. Conversely, the increase in drag during flight may have been caused by the parachute protectors or recovery harness acting as streamers and slowing the descent. Despite these findings, the parachutes slowed the vehicle enough to prevent the vehicle from landing at too great a speed and thus becoming damaged upon impact. This analysis is considered successful as the parachutes provided at least enough drag required and the results logically followed the results of the vehicle demonstration flight.

7.1.3.6 Test #7 – Recovery Altimeter Functionality Test

The recovery altimeter functionality test was performed prior to the vehicle demonstration flight to ensure the functionality of the primary and secondary recovery altimeter.

Variable: altimeter altitude/pressure reading
Materials Used:

- Stratologger Altimeter
- Entacore AIM Altimeter
- Stratologger software
- Entacore AIM software
- Stratologger computer cable
- Entacore AIM computer cable

Procedure:

- Power on altimeter and open altimeter software

- Record initial altimeter altitude reading
- Raise altimeter a measured distance
- Record altimeter altitude reading and compare to actual height change

The recovery altimeter functionality test was successful on the first attempt. The primary altimeter, the Stratologger, was powered on and initially read a pressure of 30.142 Hg, which was similar to the current pressure given by NOAA of 30.12 Hg (Figure 131). The altimeter was then raised about 95 ft and read 29.99 Hg. NOAA reported that the actual pressure at that altitude was 29.73 Hg The altimeter's reading had about 0.26 Hg of error, which is not large enough to result in a drastic misreading. Therefore, the test was deemed successful, and the primary altimeter was able to be used (Figure 132).

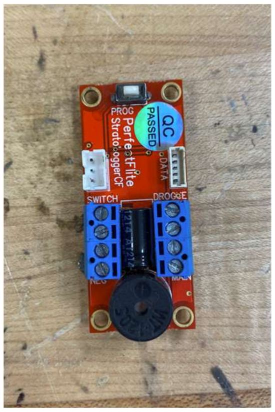


Figure 131: Stratologger Altimeter

Figure 132: Stratologger at Ground Level (left) and at 95 ft (right)

The secondary altimeter, the Entacore AIM, was powered on and initially read an altitude of 85.63 ft, which was similar to the current altitude above sea level given by NOAA of 89 ft (Figure 133). The altimeter was then raised about 95 ft and read 183.72 ft, a change of 98.10 ft. The altimeter's reading had about 3 ft of error, which is not large enough to result in a drastic misreading. Therefore, the test was deemed successful, and the secondary altimeter was able to be used (Figure 134).


Figure 133: Entacore AIM Altimeter

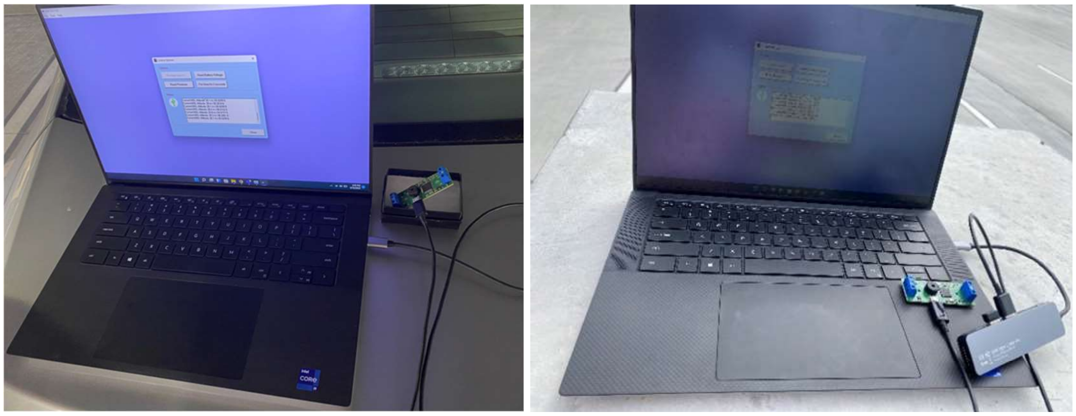


Figure 134: Entacore AIM at Ground Level (left) and at 95 ft (right)

It was expected that these tests would be successful because the electronics were in good condition and had functioned correctly when used previously.

7.1.3.7 Test #8 – Barometer Functionality Test

The barometer functionality test was performed prior to the subscale demonstration flight to ensure the functionality of the primary and secondary recovery barometer.

Variable: barometer pressure reading
Materials Used:
- Barometer on Stratologger Altimeter
- Barometer on Entacore AIM Altimeter
- Stratologger software
- Entacore AIM software
- Plastic straw

Procedure for the Stratologger:
- Power on barometer and open barometer software
- Wait for barometer to emit beeping sounds, indicating the barometer is collecting pressure data
- Place plastic straw over barometer and provide suction force
- Wait for beeping sounds to cease, indicating barometer has sensed pressure change

Procedure for the Entacore:
- Power on barometer and open barometer software

- Place plastic straw over barometer and provide suction force
- Listen for barometer to emit beeping sounds, indicating the barometer has sensed pressure change

The barometer functionality test was successful on the first attempt. The Stratologger was powered on and began to emit beeping sounds. A plastic straw was placed over the barometer and a suction force was induced to simulate a pressure change and the beeping ceased. A smooth curve was also produced on the barometer's software, indicating a pressure change. Therefore, the test was deemed successful, and the primary barometer was able to be used (Figure 135).

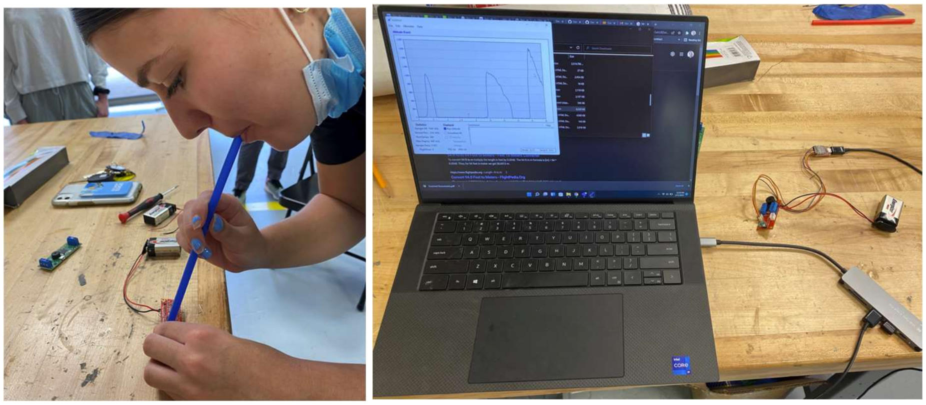


Figure 135: Stratologger Functionality Test Being Performed (left) and Curve Produced (right)

The Entacore AIM was powered on and a plastic straw was placed over the barometer. A suction force was induced to simulate a pressure change and the beeping began. A smooth curve was also produced on the barometer's software, indicating a pressure change. Therefore, the test was deemed successful, and the secondary barometer was able to be used (Figure 136).

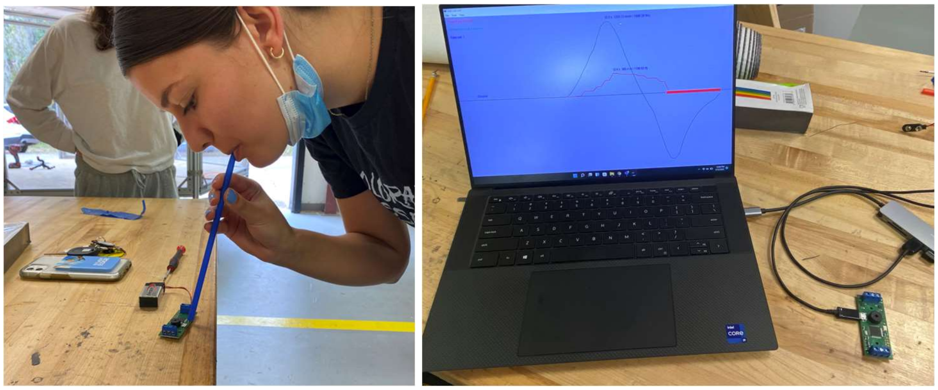


Figure 136: Entacore AIM Functionality Test Being Performed (left) and Curve Produced (right)

7.1.3.8 Test #9 – Subscale Main Parachute Ejection Demonstration

The subscale main parachute ejection demonstration was performed prior to the subscale demonstration flight.

Variable: amount of Pyrodex
Materials Used:

- Pyrodex
- Gram scale

- E-match
- Copper wire
- 9V battery
- Test stand
- Launch vehicle (including parachutes, shock cord, rivets, and shear pins)

Procedure:

- Create ejection charge using the gram scale and record mass of Pyrodex used
- Fold main parachute
- Assemble the forward and nosecone sections of the launch vehicle with floating ejection charge wired to altimeter terminals and main parachute inside
- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize Pyrodex for the ejection charges in the subscale model due to the team's short supply of black powder. The ejection charge design implemented was floating charges and the nosecone and forward sections were assembled to complete this test. The first test attempted utilized 2.0 g of Pyrodex but was unsuccessful due to leaking through the holes in the bulkhead. This issue was remedied by sealing all holes on the bulkhead with clay. The second test attempted utilized 2.25 g of Pyrodex but was again unsuccessful due to leaking through the sides of the bulkhead. The bulkhead was then remanufactured to ensure that it would fit perfectly within the airframe. The third test attempted utilized 2.50 g of Pyrodex but was again not successful because of leaking through the nosecone coupler. The coupler was covered with one strip of electrical tape to seal the gap between the nosecone and forward sections. With all the leaks identified and accounted for, the fourth attempt was successful. This attempt utilized 2.50 g of Pyrodex to completely separate the nosecone and forward sections and to fully deploy the main parachute (Figure 137). The test was deemed complete; thus 2.50 g of Pyrodex were utilized for the primary main charge with 3.125 g of Pyrodex utilized for the backup main charge. It was expected that the demonstration would not be successful on the first attempt, as the team assumed there would likely be leakage around the bulkheads.

Figure 137: Subscale Main Parachute Ejection Demonstration

7.1.3.4 Test #10 – Subscale Drogue Parachute Ejection Demonstration

The subscale drogue parachute ejection demonstration was performed prior to the subscale demonstration flight.

Variable: amount of Pyrodex

Materials Used:

- Pyrodex
- Gram scale
- E-match
- Copper wire
- 9V battery
- Test stand
- Launch vehicle (including parachutes, shock cord, rivets, and shear pins)

Procedure:

- Create ejection charge using the gram scale and record mass of Pyrodex used
- Fold drogue parachute
- Assemble all sections of the launch vehicle with floating ejection charge wired to altimeter terminals and drogue parachute inside
- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize Pyrodex for the ejection charges in the subscale model. The ejection charge design implemented was floating charges and the full launch vehicle was assembled to complete this test. The first test attempted was unsuccessful due to the fact that the ejection charge used was 1.0 g and was therefore too small to provide enough force. The second test attempted was successful when the charge was increased to 2.0 g. This test resulted in complete separation of the forward and aft sections and the drogue parachute fully deployed (Figure 138). The test was deemed complete; thus 2.0 g of Pyrodex were utilized for the primary drogue charge with 2.50 g of Pyrodex utilized for the backup drogue charge. It was expected that the demonstration would not be successful on the first attempt, as the team assumed there would likely be leakage around the bulkheads.

Figure 138: Subscale Drogue Parachute Ejection Demonstration

7.1.3.5 Test #11 – Fullscale Main Parachute Ejection Demonstration

The fullscale main parachute ejection demonstration was performed prior to the vehicle demonstration flight.

Variable: amount of black powder

Materials Used:

- Black powder
- Gram scale
- E-match
- Copper wire
- 9V battery
- Test stand
- Launch vehicle (including parachutes, shock cord, rivets, and shear pins)

Procedure:

- Create ejection charge using gram scale and record mass of black powder used
- Fold main parachute
- Assemble the forward and nosecone sections of the launch vehicle with floating ejection charge wired to altimeter terminals and main parachute inside
- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize black powder for the fullscale model because it was possible to obtain it prior to the vehicle demonstration flight. The ejection charge design implemented was floating charges and the nosecone and forward sections were assembled to complete this test. This demonstration was successful on the first attempt, which 2.0 g of black powder was utilized as the primary charge. This attempt resulted in complete separation of the nosecone and forward sections and fully deployed the main parachute

(Figure 139). The test was deemed complete; thus 2.0 g of black powder was utilized for the primary main charge with 2.50 g of black powder utilized for the backup main charge. This test revealed the strength of the black powder compared to the Pyrodex. The subscale and fullscale models used similar amounts of Pyrodex and black powder despite the fact that the fullscale is larger and thus would require greater force to separate it. Therefore, black powder is significantly more powerful than Pyrodex. It was expected that this test would not be successful on the first attempt. The team assumed that there would likely be leakage around the bulkheads, causing the separation tests to be unsuccessful. However, the vehicle experienced no leaking issues and thus did not require further testing.

Figure 139: Fullscale Main Parachute Ejection Demonstration

7.1.3.6 Test #12 – Fullscale Drogue Parachute Ejection Demonstration

The fullscale drogue parachute ejection demonstration was performed prior to the vehicle demonstration flight.

Variable: amount of black powder
Materials Used:

- Black powder
- Gram scale
- E-match
- Copper wire
- 9V battery
- Test stand
- Launch vehicle (including parachutes, shock cord, rivets, and shear pins)

Procedure:

- Create ejection charge using gram scale and record mass of black powder used
- Fold drogue parachute
- Assemble all sections of the launch vehicle with floating ejection charge wired to altimeter terminals and main parachute inside

- Attach copper wires to altimeter terminals
- Place launch vehicle on test stand
- Ignite ejection charge by touching copper wires to 9V battery

The team chose to utilize black powder for the fullscale model because it was possible to obtain it prior to the vehicle demonstration flight. The ejection charge design implemented was floating charges and the entirety of the launch vehicle was assembled to complete this test. This demonstration was successful on the first attempt, in which 1.50 g of black powder was utilized as the primary charge. This attempt resulted in complete separation of the forward and aft sections and fully deployed the drogue parachute (Figure 140). The test was deemed complete; thus 1.50 g of black powder was utilized for the primary drogue charge with 1.88 g of black powder utilized for the backup drogue charge. This test revealed the strength of the black powder compared to the Pyrodex. The subscale and fullscale models used similar amounts of Pyrodex and black powder despite the fact that the fullscale is larger and thus would require greater force to separate it. Therefore, black powder is significantly more powerful than Pyrodex. It was expected that this test would not be successful on the first attempt. The team assumed that there would likely be leakage around the bulkheads, causing the separation tests to be unsuccessful. However, the vehicle experienced no leaking issues and thus did not require further testing.

Figure 140: Fullscale Drogue Parachute Ejection Demonstration

7.1.3.7 Test #13 – Recovery Harness Strength Analysis

This test was completed prior to the vehicle demonstration flight to determine the strength of the recovery harness.

Variable: yield strength of recovery harness

Materials Used:

- Force gauge
- Recovery harness

Procedure:

- Attach recovery harness to one end of force gauge
- Pull on recovery harness until the force gauge reads maximum force that recovery harness is expected to experience (about 50 lb)

The analysis was successful on the first attempt, as the recovery harness was able to withstand the 50 lb force applied to it and did not fail (Figure 141). Thus, the test was completed, and the recovery harness was deemed acceptable to use. The recovery harness was not expected to fail at this force, as it did not fail during the subscale demonstration flight.

Figure 141: Inducing Force on the Recovery Harness (left) and Force at Which it Was Pullled (right)

7.1.3.13 Test #14 – Zippering Demonstration

The zippering demonstration was performed prior to the payload demonstration flight to ensure the launch vehicle will not zipper during separation events.

Variable: strength of airframe material
Materials Used:

- Excess piece of fiberglass airframe material
- Recovery harness
- Force gauge

Procedure:

- Attach recovery harness to one end of force gauge
- Feed recovery harness through airframe
- Pull on both ends recovery harness, being sure to pull the harness against the edge of the airframe, until the force gauge reads maximum force that recovery harness is expected to experience (about 50 lb)

The analysis was successful on the first attempt, as the airframe was able to withstand the 50 lb force applied to it and did not fail (Figure 142). Thus, the test was completed, and the airframe was deemed acceptable to use. The airframe was not expected to fail at this force, as it did not fail during the subscale demonstration flight.

Figure 142: Inducing Zippering Force on Airframe

7.1.3.14 Test #16 – RocketPoxy Density Inspection

The RocketPoxy density inspection was conducted prior to the subscale demonstration flight to determine the total weight of RocketPoxy epoxy implemented in the design.

Variable: density of RocketPoxy
Materials Used:

- 5-in fiberglass piece
- 6-in fiberglass piece
- RocketPoxy resin and hardener
- Wooden popsicle stick

Procedure:

- Weigh the two pieces of fiberglass
- Epoxy pieces together with RocketPoxy using a fillet technique: mix the epoxy with equal parts resin and hardener; create fillet by applying epoxy to the corner where the two fiberglass pieces meet; smooth out the epoxy with a 1-in wooden popsicle stick.
- Weigh the epoxied fiberglass pieces
- Determine the epoxy weight through calculation

The calculation performed to determine the total weight of RocketPoxy required for the rocket is as follows:

5-in fiberglass piece = 1 oz
6-in fiberglass piece = 3.2 oz
Epoxied pieces = 4.6 oz, thus Total Epoxy = 0.4 oz, thus Epoxy = 0.08 oz per in

RocketPoxy is utilized for external epoxy fillets. The fins implemented in the launch vehicle design are 10 in long, and therefore required 0.8 oz of epoxy per side of each fin. The fins are epoxied on both sides to the outside of the airframe so therefore, this weight was multiplied by 2 to account for both sides of the fin. There are 4 fins implemented on the launch vehicle, so the total weight of the external epoxy required for the fins is 6.4 oz (Figure 143).


Figure 143: RocketPoxy Density Inspection

7.1.3.15 Test #17 – JB Weld Density Inspection

The JB Weld density inspection was conducted prior to the subscale demonstration flight to determine the total weight of JB Weld epoxy implemented in the design.

Variable: density of JB Weld

Materials Used:

- 5-in fiberglass piece
- 6-in fiberglass piece
- JB Weld resin and hardener
- Wooden popsicle stick

Procedure:

- Weigh the two pieces of fiberglass
- Epoxy pieces together with JB Weld using a fillet technique: mix the epoxy with equal parts resin and hardener; create fillet by applying epoxy to the corner where the two fiberglass pieces meet; smooth out the epoxy with a 1-in wooden popsicle stick.
- Weigh the epoxied fiberglass pieces
- Determine the epoxy weight through calculation

The calculation performed to determine the total weight of JB Weld required for the rocket is as follows:

5-in fiberglass piece = 1 oz
6-in fiberglass piece = 3.2 oz
Epoxied pieces = 4.4 oz, thus Total Epoxy = 0.2 oz, thus Epoxy = 0.04 oz per in

JB Weld is utilized for epoxying the centering rings. The centering rings implemented in the launch vehicle design are 3 in in diameter, and therefore required about 0.12 oz of epoxy per side of each ring. The centering rings are epoxied on both sides so therefore, this weight was multiplied by 2 to account for both sides of the ring. The weight was multiplied by 3 the account for the epoxy required to account for all three centering rings implemented in the launch vehicle. The total weight of the internal epoxy required for the fins is 0.72 oz (Figure 144).

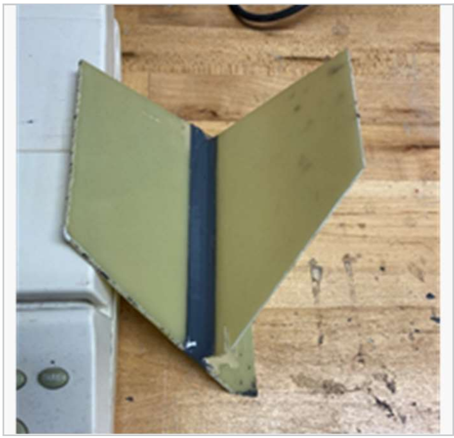


Figure 144: JB Weld Density Inspection

7.1.3.16 Test #19 – GPS Functionality Demonstration

This test was completed prior to the vehicle demonstration flight to ensure the GPS was functioning correctly.

Variable: Functionality of GPS and transmission range

Materials Used:

- GPS Transmitter
- GPS Receiver

Procedure:

- Power on the GPS transmitter and receiver and determine if it is reading the correct initial coordinates
- Transport the transmitter about one mile away from the receiver and determine if the receiver can transmit data over the distance

The GPS functionality demonstration was successful on the first attempt. The GPS was powered on and read an initial location of 29.6479 N, -82.3494 W. The actual coordinates according to Google Maps was 29.6475 N, -82.3495 W. Since the error in the GPS coordinates was less than 0.001 deg, the GPS was considered functional. The GPS transmitter was then transported about one mile away by a team member. An additional team member remained with the GPS receiver and confirmed that it was receiving data when the transmitter was one mile away. The team member ensured that the data was unobstructed throughout the demonstration. The transmission range tested was one mile because the maximum drift range of the vehicle from the launch pad is less than one mile. Therefore, it was established that if the GPS could successfully transmit data over one mile, then it would successfully transmit data over the entire expected drift. It was expected that these tests would be successful because the GPS was in good condition and had functioned correctly when used previously.

7.1.3.17 Test #20 – Parachute Packing Demonstration

This test was performed prior to the subscale demonstration flight and the vehicle demonstration flight to ensure the parachutes were packed correctly so that they will deploy and open properly during separation.

Variable: Ability to deploy

Materials Used:
- 72 in Fruity Chutes main parachute

Procedure:
- Fold parachutes using the "Z-fold" technique
- Have two team members hold onto each end of the recovery harness and a third team member support the parachute in the middle
- Have two team members pull on the recovery harness simultaneously

This test was performed before each flight. The parachute was folded, and three team members participated in the test. The two team members pulled on the recovery harness simultaneously and the parachute opened successfully prior to the subscale flight as well as the vehicle flight (Figure 145). The test was deemed successful, and the parachute was refolded in the same manner. The test was expected to be successful, as the parachutes were carefully folded in a specific manner to allow the parachute to open.

Figure 145: Parachute Folded Within Protector (left) and Parachute Deploying (right)

7.1.3.18 Test #22 – Center of Gravity Inspection

This test was performed on the day of the subscale demonstration flight as well as the day of the vehicle demonstration flight once all components of the launch vehicle were fully assembled.

Variable: Center of gravity

Materials Used:
- Launch vehicle

Procedure:
- Place the launch vehicle on a team member's hand
- Shift hand location under the launch vehicle until the launch vehicle could perfectly balance
- Mark the balance point as the center of gravity

For the subscale flight, a team member balanced the launch vehicle on their hand and the balance point was marked as the center of gravity. The test was deemed successful because the center of gravity found allowed the launch vehicle to have a stability margin of 2.3 calibers. The actual center of gravity also exactly matched the calculated center of gravity. For the vehicle demonstration flight, a team member once again balanced the launch vehicle on their hand and the balance point was marked as the center of gravity (Figure 146). The test was deemed successful because the center of gravity found allowed the launch vehicle to have a stability margin of 3.2 calibers. The actual center of gravity was 0.5 inches off from the calculated center of gravity, but since the stability margin met the competition requirements, the inspection was considered successful. The actual center of gravity may have varied from the calculated center of gravity because the vehicle was ballasted the day of the flight and the simulations may not have been properly updated with the added ballast.

Figure 146: Center of Gravity Inspection

7.1.3.19 Test #23 – Subscale Demonstration Flight

The subscale demonstration flight was performed at Tripoli Fort Myers (Prefecture #19) on December 4th, 2021.

Variable: Performance of subscale model during launch, descent, and landing
Materials Used:

- Subscale launch vehicle assembled in full
- Launch rail
- Remote igniter

Procedure:

- Fully assemble subscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter

The team chose not to use the data from the payload due to issues with the performance of the cameras but included the full payload assembly, including the sled and electronics, within the airframe to account for its weight. The camera mounts were attached to the launch vehicle to account for the drag that the mounts induced to the team could analyze the resultant effects from the drag. The payload and launch vehicle were assembled in full, and the motor was loaded into the motor casing. The vehicle was launched and successfully separated, allowing the parachutes to deploy properly (Figure 147). The forward and aft sections separated at apogee, enabling the drogue parachute to correctly deploy and open. The main parachute also successfully deployed and open, although the forward and nosecone sections may have separated when the secondary ejection charges were ignited and not the primary charges, as discussed in CDR.

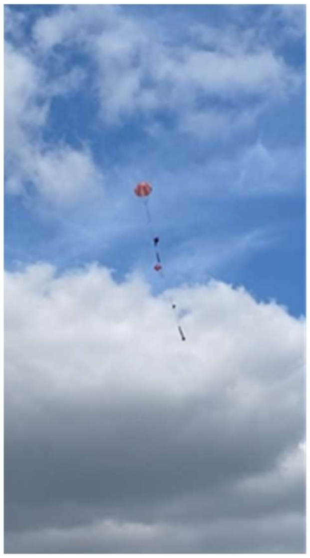


Figure 147: Subscale Model Descending With Proper Parachute Deployment

No damage was incurred on the launch vehicle during the flight or landing, resulting in a successful demonstration flight on the first attempt, as the launch vehicle is recoverable and reusable (Figure 148).

Figure 148: Subscale Model After Flight

Two small holes were burned into the main parachute (circled in blue) from the ejection charges but did not affect descent. These holes can be fixed; thus, the parachute is still reusable. The drogue parachute did not incur any damage (Figure 149). This issue will be remedied for the fullscale model by packing the main parachute in a different manner so that the parachute protector will protect it more adequately.

Figure 149: Main (left) and Drogue (right) Parachutes After Flight

7.1.3.20 Test #24 – Vehicle Demonstration Flight

The vehicle demonstration flight was performed in Tripoli Tampa (Prefecture #17) on February 19th, 2022.

Variable: Performance of subscale model during launch, descent, and landing
Materials Used:

- Fullscale launch vehicle assembled in full
- 1515 Launch rail
- Remote igniter

Procedure:

- Fully assemble fullscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter

The payload electronics were not flown in the Vehicle Demonstration Flight. The payload sled was included in the payload bay and camera mounts were mounted to the exterior of the airframe. However, the payload electronics were not flown inside the payload bay; instead, ballast was attached to the payload sled that was the same weight as all the electronics. The launch vehicle was assembled in full, and the motor was loaded into the motor casing. The vehicle was launched and successfully separated, allowing the parachutes to deploy properly (Figure 150). The forward and aft sections separated at apogee, enabling the drogue parachute to correctly deploy and open, and the forward and nosecone sections separated at 600 ft, allowing the main parachute to also successfully deploy.

Figure 150: Fullscale Model Liftoff

No damage was incurred on the launch vehicle during the flight or landing, resulting in a successful demonstration flight on the first attempt, as the launch vehicle is recoverable and reusable (Figure 151).

Figure 151: Fullscale Model After Flight

Furthermore, the parachutes did not incur any damage, indicating that the parachutes were adequately folded within the parachute protector (Figure 152).

Figure 152: Drogue (left) and Main (right) Parachute After Flight

It was expected that this test would be successful, as the ejection demonstrations were successful prior to launch and the flight was simulated with OpenRocket prior to launch. However, the vehicle exceeded the target apogee of 4,578 ft. The vehicle reached an apogee of 5,079 ft which caused the expected descent time of 85.6 s to be incorrect, as the descent time was 95 s. It was not expected that the vehicle would exceed the target apogee, as the vehicle was ballasted with 1000 g prior to flight. Further results of the vehicle demonstration flight are discussed in section 5.1.

7.1.3.21 Test #29 – Battery Life Demonstration

This test was performed prior to the subscale demonstration flight to verify the battery life of the payload battery as well as the avionics battery.

Variable: battery lifetime
Materials Used:

- Lithium-ion battery for payload
- Lithium-ion polymer (LIPO) battery for avionics
- Full payload electronic configuration
- GPS
- Voltage meter

Procedure:

- Record initial battery voltage using voltage meter
- Connect battery to payload electronics
- Let electronics run for 2 hrs, recording the battery voltage every 20 mins
- Record the final battery voltage after 2 hrs and determine if it maintained enough charge

The battery utilized for the payload was connected to the payload electronics. The starting voltage of the battery was 8.23V and the electronics were left running for 2 hrs. The voltage of the battery was checked every 20 mins. The battery lost about 0.3V of charge every 20 mins for the first hour, but then lost about 0.2V of charge every 20 mins for the second hour, indicating a plateau in voltage loss. This plateau was expected. The final voltage of the battery after running for 2 hrs was 8.10V. This demonstration was deemed successful for the payload battery since the lowest allowable charge the battery can be is 7.40V, which is significantly less than the final measured voltage (Figure 153).

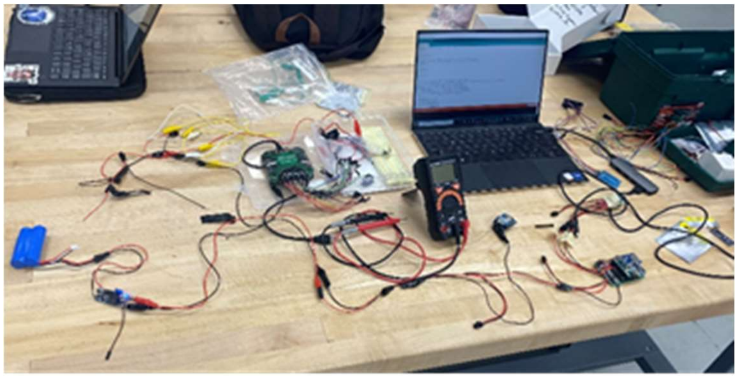


Figure 153: Payload Battery Life Demonstration

The battery utilized for the avionics was connected to the avionics GPS. The starting voltage of the battery was 4.14V and the battery was left powering the GPS for 6 hrs. The voltage of the battery was checked every 30 mins. The battery lost about 0.1V of charge per hour and the final voltage of the battery after 6 hrs was 3.50V. The shut-down voltage of the battery is stated to be 3.40V by the manufacturer, so the battery was considered dead at 3.50V since it almost reached the shut-down voltage, and the battery should ideally not be at such a low voltage when operating in the vehicle during launch. Therefore, this demonstration was deemed successful since the avionics battery could maintain enough charge to allow operation for over 2 hrs. It was expected that these demonstrations would be successful, as the batteries tested were fully charged and in good condition.

7.1.3.22 Test #32 – Ejection Resistance Demonstration

The ejection resistance demonstration was completed during the subscale demonstration flight to ensure that the payload will not be damaged by the forces created during separation.

Variable: damage to payload

Materials Used:

- Subscale launch vehicle assembled in full including payload
- Launch rail
- Remote ignitor

Procedure:

- Fully assemble fullscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter
- Assess payload after flight for any burn damage

The ejection resistance demonstration was successful on the first attempt. The subscale demonstration flight was completed, and the payload was assessed after launch. The payload did not suffer any burn damage from the separation events; therefore, the demonstration was deemed successful. It was expected that this demonstration would be successful because the bulkhead separating the payload bay and the separation point was expected to shield the payload from any damage incurred by the ejection charge.

7.1.3.23 Test #35 – Payload Drop Test

The payload drop test was performed during the subscale demonstration flight to ensure the payload will not be damaged during landing.

Variable: damage to payload

Materials Used:

- Subscale launch vehicle assembled in full including payload
- Launch rail
- Remote ignitor

Procedure:

- Fully assemble fullscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter
- Assess payload after flight for any damage

The payload drop test was successful on the first attempt. The subscale demonstration flight was completed, and the payload was assessed after launch. The payload did not suffer any damage from landing; therefore, the test was deemed successful. It was expected that this test would be successful because the payload was securely retained on the payload sled.

7.1.3.24 Test #36 – Camera Mount Strength Test

The camera mount strength test was completed during the subscale demonstration flight to ensure the camera mount will not detach from the vehicle during flight.

Variable: attachment of camera mount

Materials Used:

- Subscale launch vehicle assembled in full including payload
- Launch rail
- Remote ignitor

Procedure:

- Fully assemble fullscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter
- Assess camera mounts after flight for any separation from the vehicle

The camera mount strength test was successful on the first attempt. The subscale demonstration flight was completed, and the camera mounts were assessed after launch. The camera mounts were still fully attached to the airframe and had not loosened during flight. Therefore, the test was considered successful. This result was expected, since the fasteners utilized to attach the mounts to the airframe had four threads of engagement, which is sufficient to prevent fastener failure.

7.1.3.25 Test #37 – Wire Heat Resistance Test

The wire heat resistance test was completed during the subscale demonstration flight to ensure that the motor firing does not cause the electronic wiring of the payload to overheat.

Variable: damage to wires
Materials Used:

- Subscale launch vehicle assembled in full including payload
- Launch rail
- Remote ignitor

Procedure:

- Fully assemble fullscale launch vehicle for flight
- Place launch vehicle on launch rail
- Launch using remote igniter
- Assess wires after flight for any separation from the vehicle

The wire heat resistance test was successful on the first attempt. The subscale demonstration flight was completed, and the wires within the wire tubes were assessed after launch. The wires were not damaged by the heat from the motor; therefore, the test was considered successful. The team was unsure if the wires would be damaged prior to the test since the wires were placed directly next to the motor.

7.1.3.26 Test #45 – Wire Tube Inspection

The wire tube inspection was completed during the manufacturing of the fullscale model to ensure that wire tube is wide enough to protect the wires without compromising motor position.

Variable: protection of wires
Materials Used:

- Aft of fullscale launch vehicle including motor centering rings, wire tubes, and wires

Procedure:

- Assemble aft of fullscale launch vehicle
- Determine if the wire tubes interfere with the centering rings or motor while encasing all wires

The wire tube inspection was successful on the second attempt. The wire tubes initially did not fit within the holes created in the centering rings for the tubes to pass through because the paper used to make the tube was not rolled taut enough and thus interfered with the holes. The tubes were made once more, making sure that the paper was rolled tightly, and the tubes fit through the holes in the centering rings. All the wires fit within the tube; therefore, the inspection was complete and successful.

7.2 Requirements Compliance

7.2.1 Competition Requirements

7.2.1.1 General Requirements

The general competition requirements are defined (Table 42).

Requirement	Implementation Plan	Method of Verification	Status
1.1. Students on the team will do 100% of the project, including design, construction, written reports, presentations,	The entirety of the launch vehicle and payload will be designed, manufactured, and prepared by the students on the team. All reports will be written by the students	Inspection	Partial Verification: all work so far has been completed

and flight preparation with the exception of assembling the motors and handling black powder or any variant of ejection charges, or preparing and installing electric matches (to be done by the team's mentor). Teams will submit new work. Excessive use of past work will merit penalties.	and the work will not be plagiarized or recycled.		by students on the team.
1.2. The team will provide and maintain a project plan to include, but not limited to the following items: project milestones, budget and community support, checklists, personnel assignments, STEM engagement events, and risks and mitigations.	The team will create an outline that includes project milestones, a budget, community support, checklists, personnel assignments, STEM engagement events, risks, and mitigations. This document will be updated when new reports are generated.	Inspection	Verified: the project plan is included in this report.
1.3. Foreign National (FN) team members must be identified by the Preliminary Design Review (PDR) and may or may not have access to certain activities during Launch Week due to security restrictions. In addition, FN's may be separated from their team during certain activities on site at Marshall Space Flight Center.	Due to security restrictions, FN team members must be identified by the subteam leaders. A compiled list of all FN members will be submitted prior to PDR and may or may not have access to certain activities or be separated from their team during Launch Week at Marshall Space Flight Center.	Inspection	Verified: any FN team members were self-identified in the team's Gateway.
1.4. The team must identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR).	Team members who will attend Launch Week activities will be members with consistent engagement, a selected mentor, and a limit of 2 adult educators. A list of these active members that plan to attend will be compiled prior to CDR.	Inspection	Verified: the list of attending members has been compiled.

Team members will include: 1.4.1. Students actively engaged in the project throughout the entire year. 1.4.2. One mentor (see requirement 1.13). 1.4.3. No more than two adult educators			
1.5. The team will engage a minimum of 250 participants in direct educational, hands-on science, technology, engineering, and mathematics (STEM) activities. These activities can be conducted in-person or virtually. To satisfy this requirement, all events must occur between project acceptance and the FRR due date. A template of the STEM Engagement Activity Report can be found on pages 40-43.	At least 250 participants will engage in direct educational STEM activities offered by the team in-person or online during the time between project acceptance and the FRR due date. This requirement will be satisfied through the partnership with Alachua County Public Schools to engage with elementary and middle school students.	Inspection	Verified: the team has engaged with 327 out of 250 participants thus far, as discussed in section 1.1.7.
1.6. The team will establish and maintain a social media presence to inform the public about team activities.	An active and engaging social media presence has been established and will be maintained to publicize team activities on Instagram (@SwampLaunch), Twitter (@SwampLaunch), and Facebook (@Swamp Launch Rocket Team).	Inspection	Verified: the team has active and engaging social media platforms. The team's Instagram account has 764 followers, the team's Twitter account has 31 followers, and the team's Facebook account has 175 followers.
1.7. Teams will email all deliverables to the NASA project management team by the deadline	All email deliverable materials will be sent by the team's project manager by the deadline specified in the handbook. In the event that materials are sent in late, the	Inspection	Verified: the Project Manager, Megan Wnek, has sent and will

specified in the handbook for each milestone. In the event that a deliverable is too large to attach to an email, inclusion of a link to download the file will be sufficient. Late submissions of milestone documents will be accepted up to 72 hours after the submission deadline. Late submissions will incur an overall penalty. No milestone documents will be accepted beyond the 72-hour window. Teams that fail to submit milestone documents will be eliminated from the project.	team will only be allowed 72 hours after the specified deadline to send the deliverables with a penalty. There are no acceptations beyond this deadline.		send all deliverables via email.
1.8. All deliverables must be in PDF format.	All email deliverable materials will be in PDF format.	Inspection	Partial Verification: the deliverables for PDR, CDR, and FRR were in PDF format and all future deliverables will be as well.
1.9. In every report, teams will provide a table of contents including major sections and their respective sub-sections.	All reports will include a table of contents outlining important sections and their sub-sections.	Inspection	Partial Verification: the PDR report, CDR report, and FRR report included a table of contents with major sections and sub-sections. All future reports will include a table of contents with major sections and sub-sections as well.

1.10. In every report, the team will include the page number at the bottom of the page.	All reports will include page numbers at the bottom of each page.	Inspection	Partial Verification: the PDR report, CDR report, and FRR report included page numbers at the bottom of each page. All future reports will include page numbers at the bottom of each page as well.
1.11. The team will provide any computer equipment necessary to perform a video teleconference with the review panel. This includes, but is not limited to, a computer system, video camera, speaker telephone, and a sufficient Internet connection. Cellular phones should be used for speakerphone capability only as a last resort.	In the event of a teleconference with the review panel, all video teleconference equipment (camera, microphone, computer, Internet connection) will be provided by the team.	Inspection	Partial Verification: the team provided all video equipment for the PDR teleconference and the CDR teleconference and will continue to do so for future teleconferences.
1.12. All teams attending Launch Week will be required to use the launch pads provided by Student Launch's launch services provider. No custom pads will be permitted at the NASA Launch Complex. At launch, 8-foot 1010 rails and 12-foot 1515 rails will be provided. The launch rails will be canted 5 to 10 deg away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	At Launch Week, the team will utilize the 8-foot 1010 rails, or the 12-foot 1515 rails canted 5 to 10 deg away from the crowd provided by the launch services provider. These are the only launch pads the team will utilize.	Inspection and demonstration	Unverified: the launch has not yet been performed; however, the team plans to utilize the 12-ft 1515 rails canted 5 deg away from the crowd.

1.13. Each team must identify a “mentor.” A mentor is defined as an adult who is included as a team member, who will be supporting the team (or multiple teams) throughout the project year and may or may not be affiliated with the school, institution, or organization. The mentor must maintain a current certification, and be in good standing, through the National Association of Rocketry (NAR) or Tripoli Rocketry Association (TRA) for the motor impulse of the launch vehicle and must have flown and successfully recovered (using electronic, staged recovery) a minimum of 2 flights in this or a higher impulse class, prior to PDR. The mentor is designated as the individual owner of the rocket for liability purposes and must travel with the team to Launch Week. One travel stipend will be provided per mentor regardless of the number of teams he or she supports. The stipend will only be provided if the team passes FRR and the team and mentor attend Launch Week in April.	The team’s mentor is Jimmy Yawn, a level 3 certified NAR member. The team’s mentor is in good standing with the NAR and has launched the required number of flights. Mr. Yawn is the designated owner of the rocket and will be traveling with the team.	Inspection	Verified: the team maintains consistent contact with Mr. Yawn, and he attended the subscale demonstration flight.
1.14 Teams will track and report the number of hours spent working on each milestone.	All progress will be recorded and reported with specifications on hours spent and goals met. Each subteam will record their progress once per week.	Inspection	Verified: the hours spent working are included in this report.

Table 42: General Competition Requirements

7.2.1.2 Vehicle Requirements

The competition requirements for the vehicle are defined (Table 43).

Requirements	Implementation Plan	Method of Verification	Status
2.1. The vehicle will deliver the payload to an apogee altitude between 4,000 and 6,000 feet above ground level (AGL). Teams flying below 4,000 feet or above 6,000 feet on their competition launch will receive zero altitude points towards their overall project score and will not be eligible for the Altitude Award.	An altitude between 4,000 and 6,000 feet AGL must be met for the team's vehicle to be considered for the Altitude Award or to obtain altitude points towards overall project score. The team’s current altitude estimate is 4,578 ft.	Demonstration	Verified: Although the apogee exceeded the target apogee in the vehicle demonstration flight, the apogee did not exceed 6,000 ft and thus meets the requirement.
2.2. Teams shall identify their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team’s altitude score.	A target altitude goal will be decided at the PDR milestone through which will be used to determine the team's altitude score.	Analysis	Verified: the target altitude is 4,578 ft and was determined through OpenRocket simulations.
2.3. The vehicle will carry, at a minimum, two commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events (see Requirement 3.4). An altimeter will be marked as the official scoring altitude used in determining the Altitude Award winner. The Altitude Award winner will be given to the team with the smallest difference between the measured apogee and their official target altitude for their competition launch.	In order to measure the altitude, the team's vehicle will carry at least 2 barometric altimeters specially for rocketry recovery. This measured altitude from the barometric altimeter will be utilized to determine the team's altitude points and consideration for the Altitude Award.	Inspection	Verified: the launch vehicle carries 2 barometric altimeters: a Stratologger altimeter and an Entacore AIM altimeter.
2.4. The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on	The team’s launch vehicle will be designed with a recovery system that allows it to be able to launch again without significant modifications within the same day.	Analysis and demonstration	Verified: the Subscale Demonstration Flight (Test #23) and the

the same day without repairs or modifications.			Vehicle Demonstration Flight (Test #24) were deemed successful as the vehicle was determined to be recoverable and reusable.
2.5. The launch vehicle will have a maximum of four (4) independent sections. An independent section is defined as a section that is either tethered to the main vehicle or is recovered separately from the main vehicle using its own parachute. 2.5.1. Coupler/airframe shoulders which are located at in-flight separation points will be at least 1 body diameter in length. 2.5.2. Nosecone shoulders which are located at in-flight separation points will be at least ½ body diameter in length.	The team’s launch vehicle will have 3 sections, including the nosecone section, the forward section, and the aft section. In-flight separation points will have coupler shoulders that will be at least 4 in in length and nosecone shoulders that will be 4 in length.	Analysis	Verified: the team’s design has 3 sections, determined through analysis to decide where the separation points should be.
2.6. The launch vehicle will be capable of being prepared for flight at the launch site within 2 hours of the time the Federal Aviation Administration flight waiver opens.	The team's launch vehicle will be made ready for flight within 2 hours as outlined by Test #24.	Testing	Unverified
2.7. The launch vehicle and payload will be capable of remaining in launch-ready configuration on the pad for a minimum of 2 hours without losing the functionality of any critical on-board components, although the capability to withstand longer delays is highly encouraged.	Without losing any vital functionality or components, the launch vehicle will be able to withstand a launch ready position for at least 2 hours. This will be verified by Test #29.	Testing	Verified: Test #29 was deemed successful.

2.8. The launch vehicle will be capable of being launched by a standard 12-volt direct current firing system. The firing system will be provided by the NASA-designated launch services provider.	The team's launch vehicle will utilize a motor that is compatible with a 12-volt direct current firing system offered by NASA launch services.	Analysis	Verified: the team's design utilizes a compatible motor, an AeroTech L1090W motor, confirmed by OpenRocket simulations.
2.9. The launch vehicle will require no external circuitry or special ground support equipment to initiate launch (other than what is provided by the launch services provider).	The team's chosen motor will be capable of initiating launch without external circuitry or specific ground support.	Inspection	Verified: the team has chosen components that do not require external circuitry.
2.10. The launch vehicle will use a commercially available solid motor propulsion system using ammonium perchlorate composite propellant (APCP) which is approved and certified by the National Association of Rocketry (NAR), Tripoli Rocketry Association (TRA), and/or the Canadian Association of Rocketry (CAR). 2.10.1. Final motor choices will be declared by the Critical Design Review (CDR) milestone. 2.10.2. Any motor change after CDR must be approved by the NASA Range Safety Officer (RSO). Changes for the sole purpose of altitude adjustment will not be approved. A penalty against the team's overall score will be incurred when a motor change is made after the CDR milestone, regardless of the reason.	The team's launch vehicle will use an NAR, TRA, or CAR certified APCP motor propulsion system. Additionally, the choice of motor will be finalized before the CDR deadline. The chosen motor is an AeroTech L1090W, which satisfies the motor requirements. If changing motors is necessary after the CDR deadline, the team will be sure to attain approval from the NASA Range Safety Officer. It is understood that a penalty will be given to the team if a motor change is necessary.	Inspection and analysis	Verified: the motor, an AeroTech L1090W, was chosen using OpenRocket simulations and adheres to the certification requirements.
2.11. The launch vehicle will be limited to a single stage.	The team will utilize one motor.	Analysis	Verified: the team's

			OpenRocket simulations were designed using one motor
2.12. The total impulse provided by a College or University launch vehicle will not exceed 5,120 Newton-seconds (L-class).	The team’s chosen motor will not exceed L-class. The chosen motor is an AeroTech L1090W (L-class).	Inspection	Verified: the chosen motor is an L-class motor and thus adheres to the class requirements.
2.13. Pressure vessels on the vehicle will be approved by the RSO and will meet the following criteria: 2.13.1. The minimum factor of safety (Burst or Ultimate pressure versus Max Expected Operating Pressure) will be 4:1 with supporting design documentation included in all milestone reviews. 2.13.2. Each pressure vessel will include a pressure relief valve that sees the full pressure of the tank and is capable of withstanding the maximum pressure and flow rate of the tank. 2.13.3. The full pedigree of the tank will be described, including the application for which the tank was designed and the history of the tank. This will include the number of pressure cycles put on the tank, the dates of pressurization/depressurization, and the name of the person or entity administering each pressure event.	The team will not utilize pressure vessels in the launch vehicle.	Inspection	Verified: there are no pressure vessels implemented in the design.
2.14. The launch vehicle will have a minimum static stability margin of 2.0 at the point of rail exit. Rail exit is defined at the point where the forward rail	The team’s launch vehicle will have a static stability margin of at least 2.0. This will be ensured through OpenRocket simulations to determine the stability margin.	Analysis	Verified: the OpenRocket simulations ensure a stability

button loses contact with the rail.			margin at rail exit of 3.2 calibers.
2.15. The launch vehicle will have a minimum thrust to weight ratio of 5.0:1.0.	A minimum thrust ratio of 5.0:1.0 will be enforced on the launch vehicle.	Analysis	Verified: the OpenRocket simulations ensure a thrust-to-weight ratio of 9.27:1.0.
2.16. Any structural protuberance on the rocket will be located aft of the burnout center of gravity. Camera housings will be exempted, provided the team can show that the housing(s) causes minimal aerodynamic effect on the rocket’s stability.	The rocket will include external camera mounts that will not provide substantial aerodynamic effect.	Analysis	Verified: CFD simulations ensure that the external camera housings will not negatively impact flight.
2.17. The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	The team’s launch vehicle will reach 89.5 ft/s at the rail exit. This will be ensured through OpenRocket simulations to determine the velocity.	Analysis	Verified: the OpenRocket simulations ensure an appropriate rail exit velocity and the vehicle will reach 89.5 ft/s at the rail exit.
2.18. All teams will successfully launch and recover a subscale model of their rocket prior to CDR. The subscale flight may be conducted at any time between proposal award and the CDR submission deadline. Subscale flight data will be reported at the CDR milestone. Subscales are required to use a minimum motor impulse class of E (Mid Power motor).	The teams will launch and recover a subscale model of the rocket after the Proposal and prior to the CDR submission deadline. CDR outlines the planned schedule including this launch.	Demonstration	Verified: Test #23 was deemed successful.
2.18.1. The subscale model should resemble and perform as similarly as possible to the full-scale model; however, the	The team's subscale model will be of utmost similarity to the full-scale model in order to obtain data for the full-scale model. The team will not use the full-scale model as the subscale model	Analysis	Verified: the subscale model is geometrically similar to the

full-scale will not be used as the subscale model.	since the subscale model is smaller than the fullscale model.		fullscale and is 75% of the size of the fullscale model.
2.18.2. The subscale model will carry an altimeter capable of recording the model's apogee altitude.	The team's subscale model will carry a Stratologger and an Entacore AIM altimeter to record the model's apogee altitude.	Inspection	Verified: the launch vehicle will carry the 2 altimeters.
2.18.3. The subscale rocket shall be a newly constructed rocket, designed and built specifically for this year's project.	The team's subscale rocket will be designed and built for this year's project.	Inspection	Verified: the subscale rocket was newly designed and built on November 21-29, 2021.
2.18.4. Proof of a successful flight shall be supplied in the CDR report. Altimeter flight profile graph(s) OR a quality video showing successful launch and recovery events as deemed by the NASA management panel are acceptable methods of proof.	The team will provide successful flight data in the CDR report from altimeter flight profile graphs or a sufficient video showing all parts of launch and recovery.	Analysis and demonstration	Verified: Test #23 was deemed successful, and the required data is included in section 7.1.3.19 of this report.
2.18.5. The subscale rocket shall not exceed 75% of the dimensions (length and diameter) of your designed full-scale rocket. For example, if your full-scale rocket is a 4" diameter 100" length rocket your subscale shall not exceed 3" diameter and 75" in length.	The team's subscale model will not be larger than 75% of the full-scale model's dimensions.	Analysis	Verified: the subscale model is 75% of the size of the fullscale model. The length of the subscale is 86 in.
2.19. All teams will complete demonstration flights as outlined below.	See the guidelines specified below.	See below.	See below.
2.19.1. Vehicle Demonstration Flight - All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown shall be the same rocket to be flown for their competition launch. The purpose of the	The teams rocket will demonstrate a successful flight and recovery prior to FRR with the same rocket intended for the competition. The rocket's success will be defined by its stability, minimal changes in structure, proper recovery systems, proper preparation, and functionality of hardware.	Demonstration	Verified: Test #24 was deemed successful.

Vehicle Demonstration Flight is to validate the launch vehicle’s stability, structural integrity, recovery systems, and the team’s ability to prepare the launch vehicle for flight. A successful flight is defined as a launch in which all hardware is functioning properly (i.e. drogue chute at apogee, main chute at the intended lower altitude, functioning tracking devices, etc.). The following criteria shall be met during the full-scale demonstration flight:			
2.19.1.1. The vehicle and recovery system will have functioned as designed.	During the full-scale flight demonstration, the team’s rocket will function as intended through either the primary or redundant systems.	Demonstration	Verified: Test #24 was deemed successful since the recovery system functioned as intended.
2.19.1.2. The full-scale rocket shall be a newly constructed rocket, designed and built specifically for this year’s project.	The team's rocket will be designed and built specifically for this year’s project.	Inspection	Verified: the rocket was newly constructed for this year’s competition, as discussed in section 3.1.
2.19.1.3. The payload does not have to be flown during the full-scale Vehicle Demonstration Flight. The following requirements still apply:	The following requirements apply during the full-scale Vehicle Demonstration Flight:	See below.	See below.
2.19.1.3.1. If the payload is not flown, mass simulators will be used to simulate the payload mass.	If the payload is not flown, the mass of the payload will be simulated by mass simulators.	Demonstration	Verified: the weight of the payload was substituted with clay.
2.19.1.3.2. The mass simulators will be located in the same approximate location on the rocket as the missing payload mass.	The mass simulators will be placed in the aft section, approximately the same location as the payload.	Inspection	Verified: the mass simulation clay was placed in the aft section,

			the same location as the payload.
2.19.1.4. If the payload changes the external surfaces of the rocket (such as camera housings or external probes) or manages the total energy of the vehicle, those systems will be active during the full-scale Vehicle Demonstration Flight.	Since external camera housings are intended for the design, these features will be included in the Vehicle Demonstration Flight.	Inspection	Verified: the camera mounts were mounted to the launch vehicle and flown during the Vehicle Demonstration Flight.
2.19.1.5. Teams shall fly the competition launch motor for the Vehicle Demonstration Flight. The team may request a waiver for the use of an alternative motor in advance if the home launch field cannot support the full impulse of the competition launch motor or in other extenuating circumstances.	Teams must use the chosen competition launch motor, an AeroTech L1090W, or the Vehicle Demonstration Flight since the team's home launch field is capable of supporting its motor.	Inspection	Verified: the team utilized the L1090W motor during the Vehicle Demonstration Flight.
2.19.1.6. The vehicle shall be flown in its fully ballasted configuration during the full-scale test flight. Fully ballasted refers to the maximum amount of ballast that will be flown during the competition launch flight. Additional ballast may not be added without a re-flight of the full-scale launch vehicle.	At the full-scale test flight, the team's rocket will be prepared in a fully ballasted configuration to test how the flight will be on Launch Day.	Inspection and analysis	Partial verification: the vehicle was ballasted for the vehicle demonstration flight, although the ballast size may change prior to Launch Day.
2.19.1.7. After successfully completing the full-scale demonstration flight, the launch vehicle or any of its components will not be modified without the concurrence of the NASA Range Safety Officer (RSO).	The launch vehicle or its components will not be changed without the agreement of the NASA Range Safety Officer after a successful full-scale demonstration flight.	Inspection	Unverified
2.19.1.8. Proof of a successful flight shall be supplied in the FRR report. Altimeter flight profile data output with	The FRR report will contain proof of a successful flight. This will include altimeter flight profile data output with	Inspection	Verified: Details of the Vehicle Demonstration

accompanying altitude and velocity versus time plots is required to meet this requirement.	accompanying altitude and velocity versus time plots.		Flight are included in section 5.1.
2.19.1.9. Vehicle Demonstration flights shall be completed by the FRR submission deadline. No exceptions will be made. If the Student Launch office determines that a Vehicle Demonstration Re-flight is necessary, then an extension may be granted. THIS EXTENSION IS ONLY VALID FOR RE-FLIGHTS, NOT FIRST TIME FLIGHTS. Teams completing a required re-flight shall submit an FRR Addendum by the FRR Addendum deadline. 11 General and Proposal Requirements	Vehicle Demonstration flights must be made by the FRR submission deadline. An extension may be allowed if a Vehicle Demonstration Re-flight is necessary as determined by the Student Launch office. Teams completing a required re-flight must submit an FRR Addendum by the FRR Addendum deadline (April 4, 2021).	Inspection	Verified: Test #24 was deemed successful.
2.19.2. Payload Demonstration Flight - All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline. The rocket flown shall be the same rocket to be flown as their competition launch. The purpose of the Payload Demonstration Flight is to prove the launch vehicle's ability to safely retain the constructed payload during flight and to show that all aspects of the payload perform as designed. A successful flight is defined as a launch in which the rocket experiences stable ascent and the payload is fully retained until it is deployed (if applicable) as designed. The following criteria shall be met during the Payload Demonstration Flight:	The team must launch their full-scale rocket, including the payload, successfully by the Payload Demonstration Flight deadline. The payload will be launched in the rocket intended for competition. The payload will be fully retained, and the rocket will experience a stable ascent.	Demonstration	Unverified

2.19.2.1. The payload shall be fully retained until the intended point of deployment (if applicable), all retention mechanisms shall function as designed, and the retention mechanism shall not sustain damage requiring repair.	The team's design outlines that payload will not jettison and will be retained properly within the launch vehicle.	Analysis	Verified: the payload will not jettison.
2.19.2.2. The payload flown shall be the final, active version.	The payload will be completed and flown in its final version.	Inspection	Unverified
2.19.2.3. If the above criteria are met during the original Vehicle Demonstration Flight, occurring prior to the FRR deadline and the information is included in the FRR package, the additional flight and FRR Addendum are not required.	If the payload is successfully flown at the Vehicle Demonstration Flight, the Payload Demonstration Flight is not required and will not be performed.	Demonstration	Verified: the payload was not flown in the Vehicle Demonstration Flight; this the Payload Demonstration Flight will be performed.
2.19.2.4. Payload Demonstration Flights shall be completed by the FRR Addendum deadline. NO EXTENSIONS WILL BE GRANTED.	The Payload Demonstration Flight must be completed by the submission deadline of the FRR Addendum of April 4, 2021, with no exceptions.	Demonstration	Unverified
2.20. An FRR Addendum will be required for any team completing a Payload Demonstration Flight or NASA-required Vehicle Demonstration Re-flight after the submission of the FRR Report.	If the Payload Demonstration Flight or Vehicle Demonstration Flight is completed after the submission of the FRR report, an FRR Addendum must be completed by the team by the FRR Addendum deadline of April 4, 2021.	Inspection	Verified: the team will perform the Payload Demonstration Flight after the FRR submission and will complete an FRR Addendum.
2.20.1. Teams required to complete a Vehicle Demonstration Re-Flight and failing to submit the FRR Addendum by the deadline will not be permitted to fly a final competition launch.	If the team requires a Vehicle Demonstration Re-flight, the team will submit the FRR Addendum or will be banned from the final launch.	Inspection	Verified: the team is not required to perform a Vehicle Re-Flight.

2.20.2. Teams who successfully complete a Vehicle Demonstration Flight but fail to qualify the payload by satisfactorily completing the Payload Demonstration Flight requirement will not be permitted to fly a final competition launch.	The team will have a successful launch for both the Vehicle Demonstration Flight and the Payload Demonstration Flight.	Demonstration	Partial verification: Test #24 was deemed successful, but Test #50 was not yet performed.
2.20.3. Teams who complete a Payload Demonstration Flight which is not fully successful may petition the NASA RSO for permission to fly the payload at launch week. Permission will not be granted if the RSO or the Review Panel have any safety concerns.	If the Payload Demonstration Flight is not successful, the team may request to fly the payload during launch week, only with permission from the NASA RSO.	Demonstration	Unverified
2.21. The team's name and Launch Day contact information shall be in or on the rocket airframe as well as in or on any section of the vehicle that separates during flight and is not tethered to the main airframe. This information shall be included in a manner that allows the information to be retrieved without the need to open or separate the vehicle.	The team will include their name and contact information on each section of the launch vehicle that is not tethered to the main airframe.	Inspection	Unverified
2.22. All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.	Lithium Polymer batteries will be appropriately protected and marked using orange tape.	Inspection	Verified: safety precautions will be taken as outlined in the safety section, section 5.
2.23. Vehicle Prohibitions:	See Vehicle Prohibitions below.	See below.	See below.
2.23.1. The launch vehicle will not utilize forward firing motors.	The launch vehicle will use rear-firing motors.	Inspection	Verified: the chosen motor, an AeroTech L1090W, is a rear-firing motor.

2.23.2. The launch vehicle will not utilize motors that expel titanium sponges (Sparky, Skidmark, MetalStorm, etc.)	The launch vehicle will use an AeroTech K1090W-PS motor that does not release titanium sponges.	Inspection	Verified: the chosen motor, an AeroTech L1090W, does not release titanium sponges.
2.23.3. The launch vehicle will not utilize hybrid motors.	The motor chosen for the launch vehicle is not a hybrid motor.	Inspection	Verified: the chosen motor, an AeroTech L1090W, is not a hybrid motor.
2.23.4. The launch vehicle will not utilize a cluster of motors.	A single motor is chosen for the launch vehicle.	Inspection	Verified: the team's design includes one motor, an AeroTech L1090W.
2.23.5. The launch vehicle will not utilize friction fitting for motors.	The chosen motor will use centering rings and a thrust plate for motor retention.	Inspection	Verified: the motor has the appropriate retention system, discussed in section 3.1, involving centering rings for motor alignment and a motor retainer to keep the motor in place.
2.23.6. The launch vehicle will not exceed Mach 1 at any point during flight.	The rocket will not exceed Mach 1 during flight, ensured through utilizing OpenRocket simulations to determine the launch vehicle's velocity.	Analysis	Verified: the OpenRocket simulations ensure that the launch vehicle will not exceed Mach 1. The vehicle is expected to reach a Mach number of 0.58.

2.23.7. Vehicle ballast will not exceed 10% of the total unballasted weight of the rocket as it would sit on the pad (i.e. a rocket with an unballasted weight of 40 lbs. on the pad may contain a maximum of 4 lbs. of ballast)	Any vehicle ballast utilized will not weigh more than 10% of the rocket's total unballasted weight. The launch vehicle's expected total weight is 10.0 kg, therefore, the ballast will not exceed 1.0 kg.	Analysis	Unverified
2.23.8. Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Each transmitter will not exceed 250 mW of power.	Inspection	Verified: the onboard GPS utilizes 250 mW of power.
2.23.9. Transmitters will not create excessive interference. Teams will utilize unique frequencies, handshake/passcode systems, or other means to mitigate interference caused to or received from other teams.	Each transmitter will be equipped appropriately to minimize interference; the bulkhead that the GPS is mounted on will be covered with aluminum foil.	Analysis	Unverified
2.23.10. Excessive and/or dense metal will not be utilized in the construction of the vehicle. Use of lightweight metal will be permitted but limited to the amount necessary to ensure structural integrity of the airframe under the expected operating stresses.	The team's design will only include minimal lightweight metal primarily in the tip of the nosecone.	Inspection	Verified: the team's design does not use excessive metal.

Table 43: Vehicle Competition Requirements

7.2.1.3 Recovery System Requirements

The competition requirements for the recovery system are defined (Table 44).

Requirement	Implementation Plan	Method of Verification	Status
3.1. The full-scale launch vehicle will stage the deployment of its recovery devices, where a drogue parachute is deployed at apogee, and a main parachute is deployed at a lower altitude. Tumble or streamer recovery from apogee to main parachute deployment is also permissible, provided that	The full-scale launch vehicle will use a dual deploy system. A Rocketman 24-in C3 drogue parachute will be deployed at apogee, and a Fruity Chutes 72-in Iris Ultra main parachute will deploy at 600 feet.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.

kinetic energy during drogue stage descent is reasonable, as deemed by the RSO.			
3.1.1. The main parachute shall be deployed no lower than 500 feet.	The main parachute will be deployed at 600 feet.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.
3.1.2. The apogee event may contain a delay of no more than 2 seconds.	The primary charge for the drogue deployment will not have a delay for drogue deployment.	Analysis	Verified: Deployment time was calculated using OpenRocket and spreadsheet simulations.
3.1.3. Motor ejection is not a permissible form of primary or secondary deployment.	Motor ejection will not be used as a form of parachute deployment.	Inspection	Verified: the team's design does not utilize motor ejection.
3.2. Each team will perform a successful ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full-scale vehicles.	The testing lead and safety officers will perform ejection tests for all electronic recovery events for both the subscale and full-scale launch vehicles prior to their first flights.	Demonstration	Verified: Tests #9-#12 were deemed successful.
3.3. Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	It will be ensured that no section of the launch vehicle has a kinetic energy that equals or exceeds 75 ft-lbf at landing. This will be done using OpenRocket simulations, and the current maximum kinetic energy is estimated to be 53.5 ft-lbf.	Analysis	Verified: OpenRocket simulations ensure the appropriate kinetic energy.
3.4. The recovery system will contain redundant, commercially available altimeters. The term "altimeters" includes both simple altimeters and more	The design will include a redundant Entacore AIM altimeter.	Inspection	Verified: a secondary altimeter is implemented in the design.

sophisticated flight computers.			
3.5. Each altimeter will have a dedicated power supply, and all recovery electronics will be powered by commercially available batteries.	Each altimeter implemented will have an independent fully charged 9-volt battery power source.	Inspection	Verified: the avionics design includes an independent battery.
3.6. Each altimeter will be armed by a dedicated mechanical arming switch that is accessible from the exterior of the rocket airframe when the rocket is in the launch configuration on the launch pad.	The altimeters will have the ability to be armed through a key switch on the switch band of the avionics bay.	Inspection	Verified: the avionics design includes a key switch located on the switch band.
3.7. Each arming switch will be capable of being locked in the ON position for launch (i.e., cannot be disarmed due to flight forces).	The arming switches will be locked in the “on” position before launch by the level 2 NAR certified team member.	Inspection	Verified: the key switch has the ability to be locked in the “on” position.
3.8. The recovery system electrical circuits will be completely independent of any payload electrical circuits.	The electronics included in the payload and the recovery system will be separate and will be located in separate sections of the launch vehicle. The payload electronics will be contained within the payload bay and the recovery system electronics will be contained in the avionics bay.	Inspection	Verified: the team’s design involves the avionics system being housed in a separate coupler than the payload.
3.9. Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	The launch vehicle will be secured together through the use of shear pins at any section that will separate and rivets at any section that does not separate.	Inspection	Verified: the team’s design utilizes shear pins and rivets in the appropriate locations.
3.10. The recovery area will be limited to a 2,500 ft. radius from the launch pads.	The rocket will not drift farther than 2,500 ft from the launch pad when landing. The current estimated recovery area is 2497 ft. This value will be re-estimated throughout the project process.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure the expected drift is not too great. The current

			estimated recovery area is 2497 ft.
3.11. Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down).	The time from apogee to touch down will not exceed 90 seconds. The current estimated landing time is 85.6 sec.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure the expected descent time is within parameters.
3.12. An electronic GPS tracking device will be installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.	A GPS will be placed in the nosecone of the launch vehicle and will have the ability to communicate with the ground station.	Inspection	Verified: the team's design implements a GPS.
3.12.1. Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.	There will not be any untethered sections of the launch vehicle or payload.	Inspection	Verified: the team's design involves a fully- tethered vehicle.
3.12.2. The electronic GPS tracking device(s) will be fully functional during the official competition launch.	The Testing Lead will be responsible for ensuring the proper functionality of the GPS devices prior to launch through completing Test #19.	Demonstration	Verified: Test #19 was performed to verify the functionality of the GPS and was deemed successful.
3.13. The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Any electronic devices involved in the launch vehicle will not interfere with the recovery system electronic capabilities.	Testing	Unverified
3.13.1. The recovery system altimeters will be physically located in a separate compartment within the vehicle from any other radio frequency transmitting device	The recovery system altimeters will be located in the avionics bay, away from the devices implemented in the payload that will be located in the aft section.	Inspection	Verified: the recovery and payload electronics are housed in separate couplers.

and/or magnetic wave producing device.			
3.13.2. The recovery system electronics will be shielded from all onboard transmitting devices to avoid inadvertent excitation of the recovery system electronics.	The recovery system electronics will be shielded using aluminum foil from interference with any other transmitting devices.	Inspection	Verified: the recovery system design includes shielding.
3.13.3. The recovery system electronics will be shielded from all onboard devices which may generate magnetic waves (such as generators, solenoid valves, and Tesla coils) to avoid inadvertent excitation of the recovery system.	The recovery system electronics will be shielded using aluminum foil from magnetic waves with any other transmitting devices.	Inspection	Verified: the recovery system design includes shielding.
3.13.4. The recovery system electronics will be shielded from any other onboard devices which may adversely affect the proper operation of the recovery system electronics.	The recovery system electronics will be shielded using aluminum foil from other devices that may negatively affect the recovery system by being placed in the avionics bay.	Inspection	Verified: the recovery system design includes shielding.

Table 44: Recovery System Competition Requirements

7.2.1.4 Payload Experiment Requirements

The competition requirements for the payload are defined (Table 45).

Requirement	Implementation Plan	Method of Verification	Status
4. All payload designs shall be approved by NASA. NASA reserves the authority to require a team to modify or change a payload, as deemed necessary by the Review Panel, even after a proposal has been awarded.	The team's payload design must be approved by NASA and may be changed by NASA if necessary.	Inspection	Verified: the team's payload design was approved by NASA after submission of the proposal.
4.1. College/University Division – Teams shall design a payload capable of autonomously locating the launch vehicle upon landing by identifying the launch vehicle's grid position on an aerial image of the launch site without the use of a global positioning system (GPS). The method(s)/design(s) utilized to complete the payload mission will be at the teams' discretion and will be permitted so long as the designs are	The team's payload design will implement cameras placed on the exterior of the airframe and will be utilized to capture images and identify reference points found on the ground during flight in order to locate the grid position of the launch vehicle upon landing.	Analysis	Verified: the team's payload design adheres to the requirements.

deemed safe, obey FAA and legal requirements, and adhere to the intent of the challenge. An additional experiment (limit of 1) is allowed, and may be flown, but will not contribute to scoring. If the team chooses to fly an additional experiment, they will provide the appropriate documentation in all design reports so the experiment may be reviewed for flight safety.			
4.2.1. The dimensions of the gridded launch field shall not extend beyond 2,500 feet in any direction; i.e., the dimensions of your gridded launch field shall not exceed 5,000 feet by 5,000 feet.	The gridded launch field dimensions are 5,000 ft by 5,000 ft.	Inspection	Verified: the team's gridded launch field adheres to the requirements.
4.2.1.1. Your launch vehicle and any jettisoned components must land within the external borders of the launch field.	The entirety of the launch vehicle and its components will land within the 2,500 ft radius since the estimated drift range is 2,497 ft.	Analysis	Verified: OpenRocket and spreadsheet simulations ensure that the launch vehicle will not drift outside the field borders.
4.2.2. A legible gridded image with a scale shall be provided to the NASA management panel for approval at the CDR milestone. 4.2.2.1. The dimensions of each grid box shall not exceed 250 feet by 250 feet. 4.2.2.2. The entire launch field, not to exceed 5,000 feet by 5,000 feet, shall be gridded. 4.2.2.3. Each grid box shall be square in shape. 4.2.2.4. Each grid box shall be equal in size, it is permissible for grid boxes occurring on the perimeter of your launch field to fall outside the dimensions of the launch field. Do not alter the shape of a grid box to fit the dimension or shape of your launch field.	A gridded image of the launch field with an appropriate scale has been created and will be submitted at the CDR deadline. Each square grid is 250 ft by 250 ft and the grid box that the launch vehicle lands in will be communicated to the ground station.	Inspection	Verified: the created gridded launch field adheres to the requirements and was included in CDR.

4.2.2.5. Each grid box shall be numbered 4.2.2.6. The identified launch vehicle's grid box, upon landing, will be transmitted to your team's ground station.			
4.2.3. GPS shall not be used to aid in any part of the payload mission. 4.2.3.1. GPS coordinates of the launch vehicles landing location shall be known and used solely for the purpose of verification of payload functionality and mission success. 4.2.3.2. GPS verification data shall be included in your team's PLAR.	A GPS is not included in the payload design. The GPS located in the nosecone will be used only for verification of the payload's results.	Inspection	Verified: the payload's design does not implement a GPS.
4.2.4. The gridded image shall be of high quality, as deemed by the NASA management team, that comes from an aerial photograph or satellite image of your launch day launch field. 4.2.4.1. The location of your launch pad shall be depicted on your image and confirmed by either the NASA management panel for those flying in Huntsville or your local club's RSO. (GPS coordinates are allowed for determining your launch pad location).	The gridded image is a high-quality satellite image of the launch field, and the launch pad location will be depicted.	Inspection	Verified: the gridded launch field is of high image quality and the launch pad location is noted.
4.2.5. No external hardware or software is permitted outside the team's prep area or the launch vehicle itself prior to launch.	The hardware and software utilized is implemented only in the launch vehicle or on the ground station.	Inspection	Verified: the team's payload design does not exceed location parameters.
4.3. General Payload Requirements:	See the payload requirements below.	See below.	See below.
4.3.1. Black Powder and/or similar energetics are only permitted for deployment of in-flight recovery systems. Energetics will not be permitted for any surface operations.	Black powder and Pyrodex will be used for ejection charges only.	Inspection	Verified: the payload's design does not implement energetics.
4.3.2. Teams shall abide by all FAA and NAR rules and regulations.	The team will follow rules set forth by the FAA and NAR.	Inspection	Verified: the team is adhering to FAA and NAR guidelines, as outlined in section 5.

4.3.3. Any experiment element that is jettisoned during the recovery phase will receive real-time RSO permission prior to initiating the jettison event, unless exempted from the requirement at the CDR milestone by NASA.	No components will be jettisoned without RSO approval.	Inspection	Verified: the team will not jettison any portion of the payload.
4.3.4. Unmanned aircraft system (UAS) payloads, if designed to be deployed during descent, will be tethered to the vehicle with a remotely controlled release mechanism until the RSO has given permission to release the UAS.	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.
4.3.5. Teams flying UASs will abide by all applicable FAA regulations, including the FAA's Special Rule for Model Aircraft (Public Law 112-95 Section 336; see https://www.faa.gov/uas/faqs).	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.
4.3.6. Any UAS weighing more than .55 lbs. will be registered with the FAA and the registration number marked on the vehicle.	The team will not utilize UAS payloads.	Inspection	Verified: the team's payload design does not include a UAS payload.

Table 45: Payload Competition Requirements

7.2.1.5 Safety Requirements

The competition requirements for safety are defined (Table 46).

Requirement	Implementation Plan	Method of Verification	Status
5.1. Each team will use a launch and safety checklist. The final checklists will be included in the FRR report and used during the Launch Readiness Review (LRR) and any Launch Day operations.	The team will create a launch and safety checklist based on the launch requirements that will be included in FRR and utilized during LRR and Launch Day. This checklist will be enforced by the team's safety officers.	Analysis	Verified: the checklists are included in section 6.4.
5.2. Each team shall identify a student safety officer who will be responsible for all items in section 5.3.	Jason Rosenblum and Raymond Pace are the team's chosen safety officers and are responsible for the items listed below.	Inspection	Verified: the safety officers were declared in the Proposal.
5.3. The role and responsibilities of the safety officer will include, but are not limited to: 5.3.1. Monitor team activities with an emphasis on safety during:	The safety officers will monitor the design, construction, and assembly of the vehicle and payload. The safety officers will be present during ground	Inspection	Verified: the safety officers follow the guidelines set forth and will

5.3.1.1. Design of vehicle and payload 5.3.1.2. Construction of vehicle and payload components 5.3.1.3. Assembly of vehicle and payload 5.3.1.4. Ground testing of vehicle and payload 5.3.1.5. Subscale launch test(s) 5.3.1.6. Full-scale launch test(s) 5.3.1.7. Competition Launch 5.3.1.8. Recovery activities 5.3.1.9. STEM Engagement Activities	testing procedures and will attend both the subscale launch and full-scale launch, enforcing proper safety procedures. The safety officers will oversee recovery and ensure that team members are following safety precautions when completing recovery activities. The safety officers will also monitor any STEM engagement activities that involve safety hazards.		continue to do so.
5.3.2. Implement procedures developed by the team for construction, assembly, launch, and recovery activities.	The safety officers will review the team's manufacturing, assembly, launch, and recovery plans and enforce proper safety protocols during these processes.	Analysis	Verified: the safety officers have reviewed previous procedures and will continue to do so.
5.3.3. Manage and maintain current revisions of the team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data.	The team's hazard analyses, failure modes analyses, procedures, and MSDS/chemical inventory data is updated by the safety officers and is shared with the remaining team members through a Microsoft Teams account.	Analysis	Verified: the safety officers have included safety procedures in section 5 of this report and share the information with team members.
5.3.4. Assist in the writing and development of the team's hazard analyses, failure modes analyses, and procedures.	The safety officers will assist in creating and writing the team's hazard analyses, failure modes analyses, and procedures that will be included in reports.	Inspection	Verified: the safety officers have written the appropriate sections (section 5 of this report).
5.4. During test flights, teams will abide by the rules and guidance of the local rocketry club's RSO. The allowance of certain vehicle configurations and/or payloads at the NASA Student Launch does not give explicit or implicit authority for teams to fly those vehicle configurations and/or payloads at other club launches. Teams should	The team will abide by rules set forth by the safety officers. The team will communicate appropriately prior to attending NAR/TRA launches.	Inspection	Verified: the team abides by all rules set forth.

communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.			
5.5. Teams will abide by all rules set forth by the FAA.	The team has reviewed the rules set forth by the FAA and will abide by all regulations. The team's project plan accounts for these regulations.	Inspection	Verified: all plans designed by the team adhere to all regulations.

Table 46: Safety Competition Requirements

7.2.2 Team-Derived Requirements

The team has created requirements that are specific to the team's design. These team-derived requirements specify components of the design that go beyond the minimum competition requirements and are applied to ensure success of the team's design.

7.2.2.1 Vehicle Requirements

The team-derived requirements for the launch vehicle are defined (Table 47).

Requirement	Justification	Method of Verification	Status
1.1 The launch vehicle must not have a coefficient of drag that exceeds 2.5 due to the external camera mounts.	The external camera mounts must not induce a larger coefficient of drag or the launch vehicle's flight will be negatively impacted, and the vehicle may not reach its target altitude.	Analysis	Verified: The launch vehicle's coefficient of drag is 0.78, determined through SolidWorks analyses.
1.2 The motor centering rings' holes must be aligned sufficiently in order for electronics tubes to fit through the holes properly.	The electronics tubes cannot bend as this may compromise the wiring within and cause the payload to fail.	Inspection	Verified: Marks were made by the Structures Lead during manufacturing that indicate where the centering rings must align for the subscale launch vehicle as well as the fullscale launch vehicle.

Table 47: Vehicle Team Requirements

7.2.2.2 Recovery Requirements

The team-derived requirements for recovery are defined (Table 48).

Requirement	Justification	Method of Verification	Status
2.1 The drogue parachute will have a descent rate of 82.5 ft/s within 5 ft/s.	This descent rate ensures the vehicle is at a slow enough velocity once the main parachute must be deployed.	Testing	Verified: Test #6 was determined to be successful.

2.2 The main parachute will have a descent rate of 17.6 ft/s within 2 ft/s.	This descent rate ensures the launch vehicle will not be harmed during landing by landing at an appropriate velocity.	Testing	Verified: Test #6 was determined to be successful.
2.3 Each recovery harness will have a length of 2.5 times the total length of the vehicle.	This length is required to ensure the separate sections of the launch vehicle do not collide during descent. This length also prevents breakage of the recovery harness during separation, as a longer harness provides more slack.	Inspection	Verified: The as-designed length of the recovery harness was verified by the Avionics and Recovery Lead and the Project Manager.
2.4 There will be a delay of the secondary aft ejection charge of at least 0.5 seconds after the ejection of the primary charge.	The delay ensures that the launch vehicle does not over-pressurize, a possible occurrence during ejection that may occur if multiple charges ignite at once.	Testing	Verified: Test #8, was determined to be successful, which ensures that the barometer functions correctly, and thus ignites the ejection charge at the appropriate time.
2.5 There will be a delay of the secondary forward ejection charge to eject at an altitude of 50 ft below the altitude of primary charge, thus ejecting at an altitude of about 550 ft.	The delay ensures that the launch vehicle does not over-pressurize, a possible occurrence during ejection that may occur if multiple charges ignite at once.	Testing	Verified: Test #8, was determined to be successful, which ensures that the barometer functions correctly, and thus ignites the ejection charge at the appropriate time.
2.6 The secondary ejection charges will be 25% larger in black powder or Pyrodex weight than the primary charges.	The secondary charge must be larger than the primary in the event that the primary fails to separate the vehicle and thus the larger secondary charge can provide a greater force and result in successful separation.	Inspection	Verified: The weight of the Pyrodex was verified by the Avionics and Recovery Lead and the Project Manager prior to the subscale demonstration flight and the eight of the black powder was verified by the Avionics and Recovery Lead and the Project Manager prior to the vehicle demonstration flight.

Table 48: Recovery System Team Requirements

7.2.2.3 Payload Requirements

The team-derived requirements for the payload are defined (Table 49).

Requirement	Justification	Method of Verification	Status
3.1 The payload will be able to resume operation after a momentary power loss.	The payload must be able to continue operation without losing previously captured images or data.	Demonstration	Unverified: Test #33, Power Loss Test, ensures that the payload will continue operation correctly in a circumstance of loss of power.
3.2 The payload IMU expected positional drift must not exceed 100 ft over 90 sec.	The payload must be able detect the correct grid space the launch vehicle is located in.	Analysis	Unverified: Test #49, IMU Drift Analysis, determines the expected drift and ensures it does not exceed 100 ft.
3.3 The payload must be able to detect launch.	Launch detection allows the payload to idle in a low-power state while on the launch pad, preserving battery life, but will begin collecting data once launch is detected.	Demonstration	Unverified: Test #46, Payload Launch Detection Demonstration, ensures that the payload can detect the sudden acceleration that will occur during launch.
3.4 The payload transmitter must have a range of at least one mile.	The payload must be able to communicate its results successfully even in the event of maximum drift as well as possible obstructions.	Testing	Unverified: Test #48, Payload Transmission Range Test, ensures that the payload can transmit data over at least one mile.
3.5 The payload must be able to process at least 100 images within five minutes of landing.	The payload must be able to compile the data within five minutes in order to determine its grid location before the battery runs out of charge.	Testing	Unverified: Test #47, Payload Data Compilation Test, ensures that the data can be compiled in the appropriate amount of time.

Table 49: Payload Team Requirements

7.3 Budgeting and Funding Summary

7.3.1 Updated Overall Budget

The team's expected budget for the 2021-2022 season has been updated to equal $5,023.23 (Figure 154 and Table 50). This new, lower budget accounts for parts the team already had in inventory and takes into account budget cuts associated with the team's updated funding plan discussed in the following section.

This budget is based off a total of all estimated component and travel costs, including components needed for the full-scale rocket design and the subscale rocket build. It also accounts for changes that may occur from any necessary changes and testing or unexpected damages. The components are broken down by each subteam and listed out. Travel costs are also included in the budget accounting for road travel and hotel stays for the competition and launches.

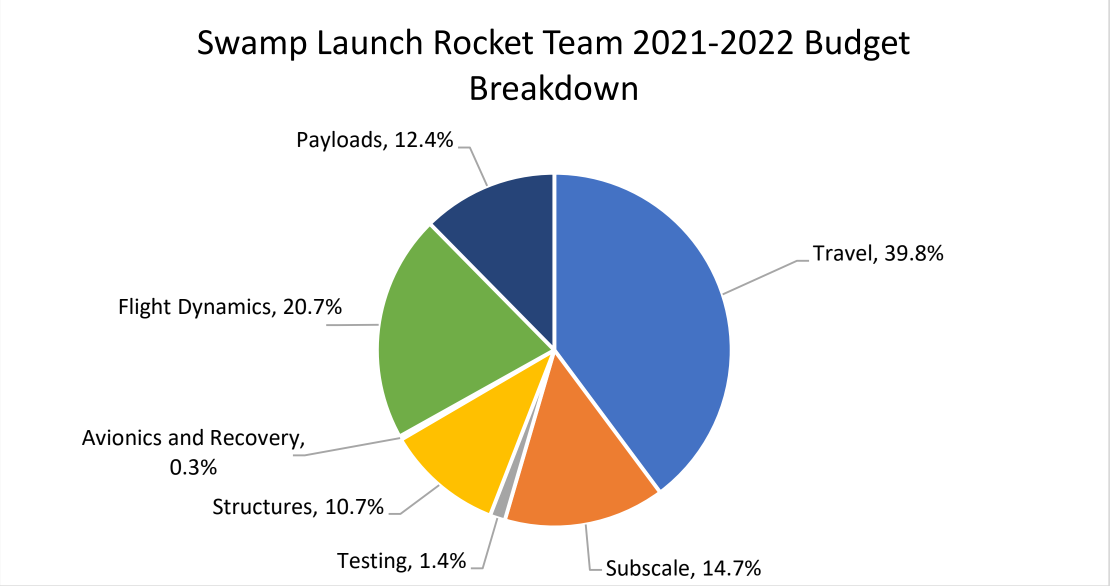


Figure 154: Budget Pie Chart

Category	**Total Cost ($)**
Full-Scale Rocket	2215.90
Travel	2000.00
Subscale	737.33
Testing	70.00
Total:	5023.23

Table 50: Project Costs by Category

7.3.2 Full Scale Line-Item Budgets

Line-item budgets for each subteam were recalculated to take inventory and need into account (Table 51 - Table 55). The team is tax-except through the University of Florida. The team limits the number of vendors it purchases and completes as many purchases as possible at the same time so as to pay minimal shipping costs.

Subgroup	Total Cost ($)
Structures	535.99
Avionics and Recovery	17.12
Flight Dynamics	1042.03
Payloads	620.76
Total:	2215.90

Table 51: Full Scale Rocket Costs by Subteam

Component	Vendor	Quantity	Unit Cost ($)	Total Cost ($)
4" 5:1 fiberglass Ogive nosecone w/ metal tip	Composite Warehouse	1	79.95	79.95
4" diameter fiberglass airframe (5 ft)	Wildman Rocketry	3	106.75	320.25
2.1" fiberglass motor tube (3 ft)	Wildman Rocketry	1	52.00	52.00
3/16" thick, 24" x 24" G10 fiberglass sheets (fins)	N/A	2	N/A	Inventory
PVC Rod 4’’ diameter (1 ft)	McMaster-Carr	1	70.54	70.54
Stainless Steel Rod 3/8’’ diameter (3 ft)	McMaster-Carr	1	13.25	13.25
1/2" thick, 24" x 24" plywood (centering rings)	N/A	2	N/A	Inventory
JBweld (10 oz)	N/A	4	N/A	Inventory
RocketPoxy (2 qt)	N/A	2	N/A	Inventory
Shear Pins	N/A	4	N/A	Inventory
Rivets	N/A	4	N/A	Inventory
Rail buttons	N/A	2	N/A	Inventory
Sandpaper	N/A	N/A	N/A	Inventory
	Total:			535.99

Table 52: Structure's Costs by Component

Component	Vendor	Quantity	Unit Cost ($)	Total Cost ($)
9 V Battery	N/A	2	N/A	Inventory
Eyebolt	McMaster-Carr	4	4.28	17.12
Main Parachute	N/A	1	N/A	Inventory
Drogue Parachute	N/A	1	N/A	Inventory
Recovery Harness	N/A	2	N/A	Inventory
Swivel	N/A	2	N/A	Inventory
Quick Link	N/A	6	N/A	Inventory
Altimeter	N/A	2	N/A	Inventory
Terminal block	N/A	4	N/A	Inventory
Key lock switch	N/A	2	N/A	Inventory
	Total:			17.12

Table 53: Avionics and Recovery's Costs by Component

Component	Vendor	Quantity	Unit Cost ($)	Total Cost ($)
Motor Retainer	N/A	1	46.66	46.66
55 mm Floating Forward Closure Plugged Set	Apogee Components	1	77.52	77.52
Motor Aft Closure	N/A	1	N/A	Inventory
Aerotech RMS 54/2800 Motor Casing	Apogee Components	1	224.88	224.88
Thrust Plate	N/A	1	N/A	Inventory
Aerotech L1090W	Apogee Components, Chris' Supplies	3	230.99	692.97
	Total:			1042.03

Table 54: Flight Dynamics' Costs by Component

Component	Vendor	Quantity	Unit Cost ($)	Total Cost ($)
Raspberry Pi 4 8GB	Amazon	1	149.99	149.99
OV5640 Camera	Amazon	3	39.99	119.97
XBee Transceiver	N/A	2	N/A	Inventory
Lithium-Ion Batteries	N/A	4	N/A	Inventory
ADIS 16470 IMU	Digikey	1	328.90	328.90
Grove Altimeter	Digikey	1	21.90	21.90
Perforated Circuit Board	N/A	1	N/A	Inventory
Wiring	N/A	1	N/A	Inventory
JST Connector Kit	N/A	1	N/A	Inventory
¼ 20 T-nuts	N/A	4	N/A	Inventory
1/4-20 Fasteners	N/A	8	N/A	Inventory
1/4-20 Hex nuts	N/A	4	N/A	Inventory
	Total:			620.76

Table 55: Payload's Costs by Component

7.3.3 Funding

7.3.3.1 Sources of Funding

The project is primarily funded by the University of Florida's Student Government. The team was allocated $5,000 in project costs for the Fall 2021 semester and $2,000 in travel costs and $500 in project costs for the Spring 2022 semester from Student Government. Budget cuts resulted from reduced project funding providing by Student Government for the Spring 2022 semester. The budget was adjusted accordingly with inventory in mind. Northrop Grumman provided $300 as a motor stipend. Additional member donations were made through out-of-pocket purchases. The team sponsor is Aerojet Rocketdyne. The team received $2,000 from Aerojet Rocketdyne for the Fall 2021 semester and an additional $2,000 for the Spring 2022 semester. The team is actively seeking more corporate sponsorships by developing a sponsorship plan and having weekly meetings specifically dedicated to reaching out to potential sponsors. The sponsorships range from $250 to $1,000, with additional monetary and material donations made optional. Funding will first be received by our advisors and will then be allocated to our team. The team has also started an alumni program to stay in touch with dedicated members who have graduated, encouraging them to stay involved and support the future (Figure 155).

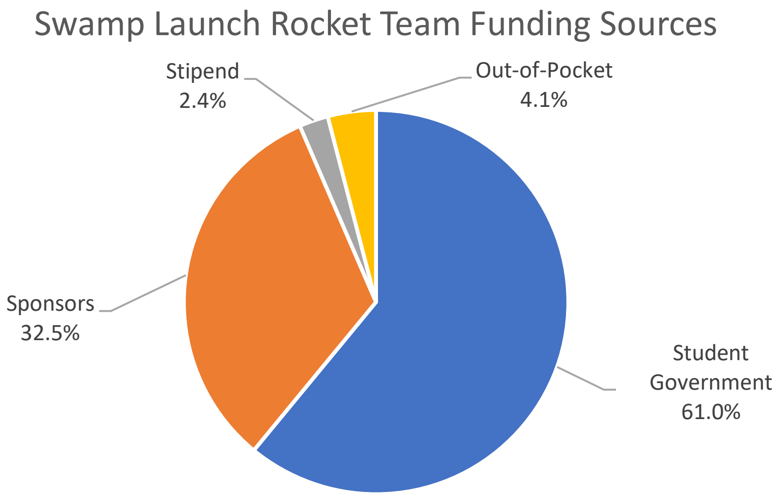


Figure 155: Funding Pie Chart

7.3.3.2 Allocation of Funds

Funding is allocated based on need and priority of components. Inventory is constantly used to ensure only necessary components were purchased. Higher priority was placed on major components needed for construction for VDF, such as the airframe. Components required for the payload received highest priority in preparation for the PDF. A set amount of funds is allocated to travel, as established by the University of Florida's Student Government.

7.3.3.3 Material Acquisition

No further materials need to be acquired except for the motor required for final launch. The team is reaching out to a vendor on site in Huntsville to purchase the motor.

8. Conclusion

In conclusion, Swamp Launch Rocket team is confident that the Gator Locator project is fully ready to complete a Payload Demonstration Flight and Competition Flight safely and successfully.