Project Hermes

2023 NASA Student Launch Initiative
Flight Readiness Review (FRR)

ResistoJets Rocketry 4-H Club of Morris County

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Glossary

4-H - Youth Organization (Our team's host administration)

FCC - Federal Communications Commission (Government Agency)
FAA - Federal Aviation Administration (Government Agency)
NASA - National Aeronautics and Space Administration (Government Agency)
SLS - The Space Launch System rocket (NASA's current rocket)

STEM - Science, Technology, Engineering, and Math

MSDS - Material Safety Data Sheet
PPE - Personal Protective Equipment

FPS - Feet per Second
TWR - Average Thrust to Weight Ratio of the Vehicle during Ascent

SLI - Student Launch Initiative
USLI - University Student Launch Initiative

NAR - National Association Of Rocketry (Rocketry Governing Body)
TRA - Tripoli (Rocketry Governing Body)
HPR - High Power Rocketry
K Motor - Using the level 2 K class of high power rocket motors

SDR - Software Defined Radio
USB - Universal Serial Bus
APRS - Automated Packet Reporting system
LIPO - Lithium-Ion Polymer Battery

CDR - Critical Design Review
FRR - Flight Readiness Review
LRR - Launch Readiness Review
PLAR - Post-Launch Assessment Review

Table of Contents:

1. Summary of FRR report

1.1 Team Summary

Name of team and mailing address:
ResistoJets Rocketry 4-H
[redacted]

Mentor: Luke McConoughey
[redacted]

<u>Our team's final launch will be in Huntsville on April 15th.</u>

Our team has spent 380 hours working on the FRR milestone.

Summary of STEM Engagement:

Our STEM Engagement program has delivered a total of 360 model rocket kits and motors to 20 different schools and youth groups across the state of New Jersey. Accompanying them are resources made by our club to educate about rocketry and physics. Through these kits and similar programs, we anticipate to have a total of 950 students engaged in a direct, educational manner by the end of the summer. The completion of this does not require intervention from our team, as all of the work and deliveries to facilitate it have been completed. We currently have confirmation of 148 students engaged, through our own events and confirmation from some recipients of our packages. In addition to direct educational engagement, we have also engaged hundreds indirectly through presentations, speeches, and social media.

1.2 Launch Vehicle Summary

Size and mass of individual sections (wet)	-	Nose - 4x24” | 3.285 LB
Payload/Upper Airframe - Fin Section	-	4x26.8”
Dry mass of launch vehicle without ballast	-	15.0925
Dry mass of launch vehicle with ballast (if applicable)	-	16.05 lb
Wet mass of launch vehicle	-	18.4 lb
Burnout mass of launch vehicle	-	16.4 lb
Landing mass of launch vehicle	-	16.35 lb
Competition Launch Motor	-	K1100T
Target altitude (ft.)	-	3800
Recovery system	-	Dual Deploy Dual Parachute
Rail size	-	1010

1.3 Payload Summary - Title: USLI Payload Challenge

Our payload is an arm mounted externally on the vehicle that extends and uses motors and servos to orient and photograph its surroundings. It uses a raspberry pi with an USB Software Defined Radio to receive and decode APRS broadcasts. Once the computer detects it has landed using a barometer, the payload operations will begin. An IMU will align the payload shroud to the top of the avionics bay, and then the arm will extend and then use computer vision to level itself to the horizon.

2. Changes made since CDR

2.1 Changes made to vehicle criteria

The main change to our vehicle is in the separation points. At the recommendation of the panel during the CDR, we've changed our main parachute separation point to the nose cone, rather than at the avionics bay. This is to achieve a "pusher" deployment which is more reliable than a"puller". This change also benefits the external payload system by giving it much more area and mass contacting the ground.

Other changes in the as-built vehicle when compared to the previously proposed vehicle are in the length and mass.

Due to a design error in OpenRocket, the vehicle is 4" shorter than previously reported. This is how the vehicle was intended.

The mass is also a bit higher than expected, about 18.4 lb compared to a previous 15.4 lb. Because of this, we will undershoot our official target altitude, as we have in both of our full scale flight tests.

From our flight tests, we've found the drogue parachute is undersized and will be replaced prior to the next flights. There is currently repairable damage to our vehicle and payload caused by this drogue parachute issue. We have an opportunity to fly these changes on April 1st if we need a payload demonstration reflight.

2.2 Changes made to payload criteria

The payload shell and camera has been optimized to reduce mass and drag. The payload will also now use computer vision to level the camera to the horizon, although it still uses an IMU to orient the payload shroud to the top of the avionics bay.

2.3 Changes made to project plan

There are no major changes to our project plan. We have updated our compliance requirements to our current standing and removed past items, such as the subscale vehicle requirements. Our STEM Expected STEM Engagement results nearly tripled since the last milestone. We also have an exceeding budget for travel reimbursements.

3. Vehicle Criteria

3.1 Design and Construction of Vehicle

3.1.1 Design Changes and Justification

Since our CDR, we have implemented few changes to the design of the vehicle.

We modified the design and construction of the fin section to better suit our manufacturing process. First, the centering ring configuration was modified. Instead of a 3-ring configuration with a thicker, stepped aft ring; we opted to go for an easier option to implement configuration where the aft centering ring is identical to the front two. Since the aft ring positioning is more flexible, this greatly simplifies the assembly of the fincan. This modification does not compromise on safety or structural integrity, because the load of the motor thrust is transferred to the airframe via the fin tabs and internal fillets rather than the centering rings. This feature turned out to give us more advantages during construction. This allowed us for more options with installing the Aeropack motor retainer.

The overall construction process of the fin section was changed as well. Our previous plan was to construct the fincan as a separate component and insert it into the airframe's extended slots as a whole. But we decided to build the fincan directly on the airframe to save time and improve mounting accuracy. Thus, our airframe slots do not extend to the base of the tube, adding strength to the airframe base. However, one drawback that we encountered with this plan was that the internal fillets were harder to apply, since we needed to reach into the airframe to apply the epoxy.

Other than these few minor modifications to the vehicle design and construction process, we followed our original plans with precision and created a vehicle that best matches the simulated structure.

3.1.2 Vehicle Features and Reliability

The vehicle separation points and energetic locations are identical to our previous plans. The vehicle is built in 3 sections: booster, payload/avionics/upper airframe, and nose cone; this configuration creates separation points between the sustainer and avionics bay, and between the upper airframe and nose cone. Each of the separation points have couplers that exceed 1 caliber, creating strength and robustness in the joint. They will also both utilize nylon shear pins to lock the joint during the flight until separation, ensuring no drag separation or other joint anomalies can occur.

Separation points as seen in flight.

Energetics are located at each end of the avionics bay on the av-bay lids. The main parachute ejection charges are located inside thick PVC charge wells. The drogue chute charges are placed in .5” copper pipe end caps. All charge wells, once filled & wired, will be packed with ‘dog barf’ wadding and taped/sealed shut during flight. This charge containment design is common in High

Power Rocketry, and we have also demonstrated its reliability by performing and optimizing the gunpowder charges for both the subscale and the full size vehicle.

Our vehicle uses fiberglass for the entire aerostructure and all structural elements that undergo large loads and stresses. This includes our lower and upper airframe, nosecone, fin can assembly (fins, motor tube, centering rings), couplers, avionics bay, avionics lids, and vent band. Our design feature is a lightweight and robust solution to our vehicle mission to be reusable multiple times and endure high flight loads and hard landings. The avionics bay uses two ¼” 20 TPI threaded rods that clamp the stepped avionics lids to the coupler, which is secured with washers and nuts.

We employ many metal attachment hardware throughout our recovery system such as u-bolts, swivels, and eyebolts. Besides being a flexible design, it reduces the amount of knot joints in the harness which improves strength and reliability. Ultimately, all structural components on the vehicle are engineered to withstand challenging flight environments, high forces, and long-term usage; our team is highly confident of its contribution to mission success.

3.1.3 Vehicle Construction Process

3.1.3.1 Vehicle Construction Instructions

All members on our team were familiar with the general build process, as we have all built high power rockets before. That said, we went into more advanced techniques than before, including precisely slotting the body tube for through-the-wall fin placement. We designed a fin jig and used a Bosch router with ⅛” milling bit to perform precise and accurate cuts.

Construction process derived from build instructions, with adjustments made to reflect adjustments in our actual build.

Sets of steps marked with “x” at the end indicate that its set of instructions don’t need to be completed in any specific order, as long as they are completed before the next numbered step.

Step	Task	Safety
1-1	Note any adjustments or mitigations needed and adapt the build plans. Ensure tools are ready for use	
1-2x	Cut and sand sustainer fin slots	Respirator, gloves, coat
1-2x	Cut and sand fins	Respirator, gloves, coat
1-2x	Cut body tubes to proper length, make cut for avionics bay switchband	Respirator, gloves, coat
1-3x	Drill hole in forward motor centering ring for sustainer eye bolt and	Respirator, gloves, coat

	install eye bolt	
1-3x	Mark and drill holes for avionics bay bulkheads and install u-bolts	Respirator, gloves, coat
1-3x	Mark and drill holes for nose cone bulkhead and install u-bolts	Respirator, gloves, coat
1-4	Dry fit parts at this time	
1-5	Sand parts that are too tight, especially in the fin can and motor tube.	Respirator, gloves, coat
1-6	Ensure all parts are ready and present before continuing	
1-7	Epoxy top two centering rings onto the motor tube and let cure. Reference design specs to space them properly.	Respirator, gloves
1-8	Apply three layers of copper RF Shielding to both sides of the nose cone bulkhead and upper avionics bay bulkhead.	

2-1	Ensure all previous steps are completed. If they are not, establish a plan to ensure they are completed properly before they're needed.	
2-2	Brief members on build plan, safety requirements, and prepare the work environment	
2-3	Rehearse a dry assembly of the fin can, look for problems and solve them before final wet assembly.	
2-4	Apply epoxy on the the top two centering rings and apply epoxy on the inside of the motor side of the body tube where the rings will slide into	Respirator, gloves
2-5	Insert the motor tube and centering rings into the aft of the airframe just to the point that the middle centering ring is at the top of the fin slots.	Respirator, gloves
2-6	Make sure the shock cord is cleared and clean	Respirator
2-7	Insert the fins into the slots	
2-8	Install fin alignment jig on the fin can	
2-9	Make internal fillets in the corner of the fins and inside of airframe, repeat for all fins	Respirator, gloves
2-10	Install the aft-most centering ring with epoxy.	Respirator, gloves
2-11	Install motor retainer onto motor tube with epoxy	Respirator, gloves

2-12	Once all fins are positioned correctly, with the fin jig still installed, lightly apply super glue and accelerator at various points of every fin to hold them in place. Once set, remove the fin jig.	Respirator, gloves
2-13	Make tape masking lines for external fillets on airframe and fins.	
2-14	Apply epoxy fillets to the corners between the fin corners and external airframe.	Respirator, gloves
2-15	Adjust fillets, including volume of applied epoxy and distribution until the fillets are smooth and clean.	Respirator, gloves
2-16	Once the epoxy is tacky, remove masking tape and make any last adjustments.	Respirator, gloves
2-17	Place the fin section vertically to cure fully.	
2-18	Epoxy nose cone bulkhead into nose cone coupler after scraping off some copper shielding from the bulkhead where epoxy is intended to be.	Respirator, gloves
2-19	Epoxy ejection charge wells and WAGO connectors on to avionics bay bulkheads, removing copper shielding where necessary.	Respirator, gloves

3-1	3-D Print and install avionics bay sled. Test fit with threaded rods and bulkheads. Make changes if necessary.	
3-2	Mark and drill holes for electronics standoffs on avionics bay sled.	
3-3	Drill holes for battery zip ties.	
3-4	3-D print and assemble pull-pin switch assembly. Epoxy onto avionics bay sled.	Respirator, gloves
3-5	Drill holes vent holes and remove before flight pin hole into the avionics bay switch band and coupler tube.	

Table 1: Assembly procedures

We made a mistake during the construction by forgetting about the rail buttons. Because of our raised rail button design, we need to use a t-nut on the inside of the airframe to ensure strength of the rail buttons. We realized this mistake after the fin section was fully assembled and cured and made a plan of action to resolve it. We marked and drilled the holes in the airframe where the rail buttons will go. One was just forward of the aft-most centering ring and the other was around the middle of the lower airframe between the CG and CP. Because the aft centering ring was already permanently affixed, we had to create a small hole in it to slide the t-nut through and into the rail button hole. We successfully completed this and repaired the hole in the centering ring with JB Weld. Beyond this, the rail extended rail buttons have held up perfectly during both flights.

3.1.3.2 Vehicle Construction Documentation

Image 1: Final, as-built picture of the vehicle

Images 2 & 3: Custom-built jig used to cut fin slots

Image 4:Body tube fin slots, cut and sanded with labels corresponding to fins that best fit in the slot.

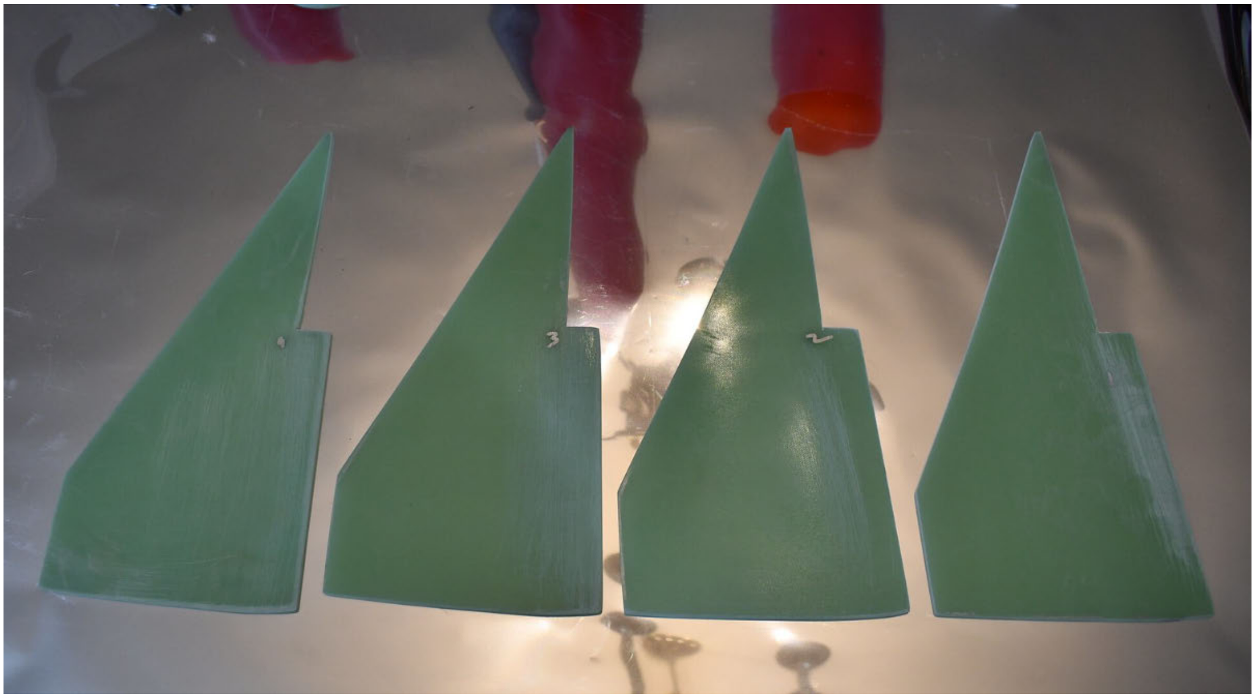


Image 5: Four Fins, sanded and labeled.


Image 6: Dry fit of slotted body tube, fins, and cut body tube.

Image 7: Motor tube with eye-bolt and top two centering rings epoxied

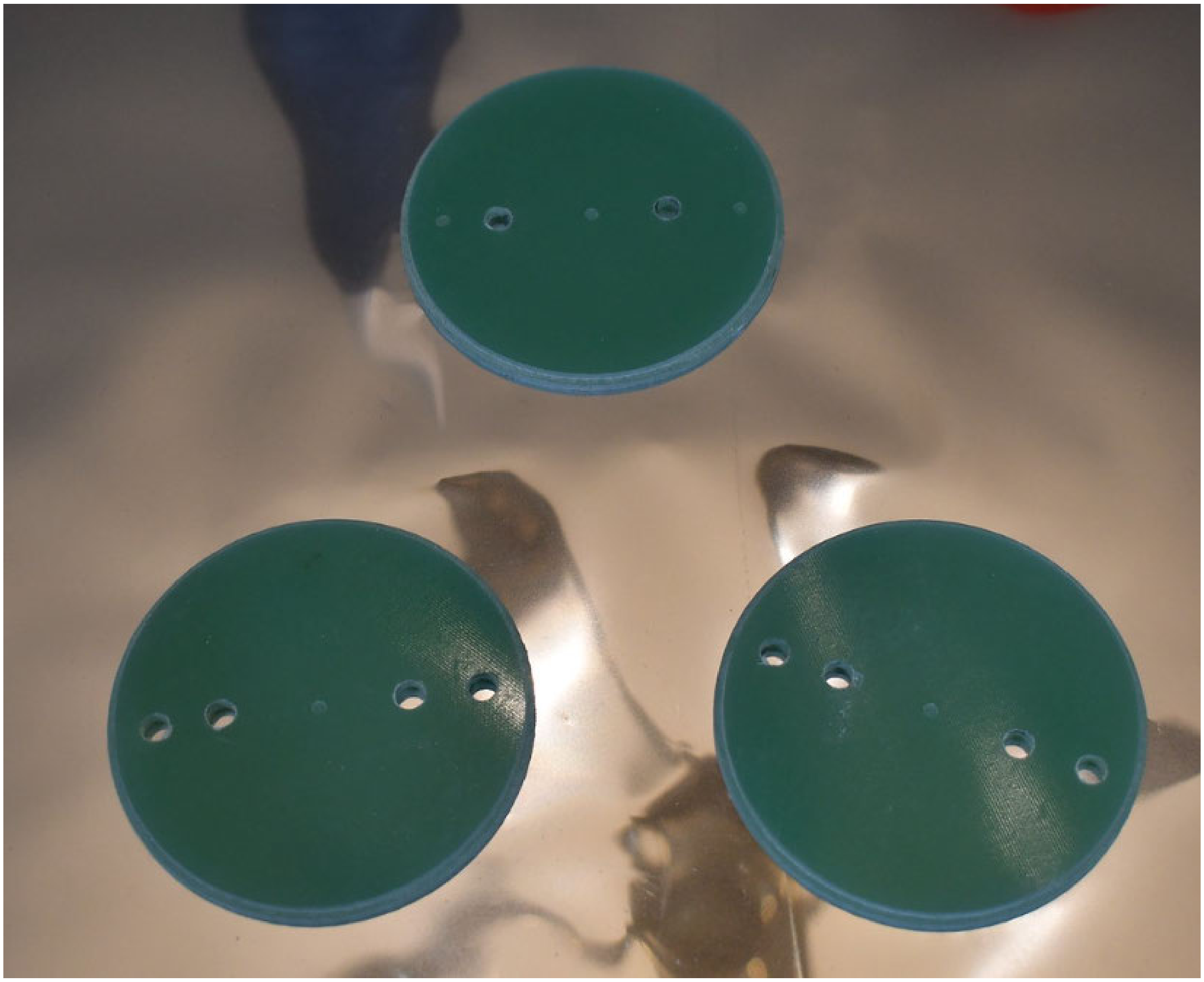


Image 8: Centering rings with holes cut for u-bolts and threaded rods.

Images 9 & 10: Copper shielding being applied to bulkheads.


Image 11: Dry fit of motor tube, with use of motor hardware.

Image 12: View of dry fit from inside the airframe.


Image 13: Epoxying centering rings before installation to the airframe.

Image 14: Installing the motor tube into the airframe.

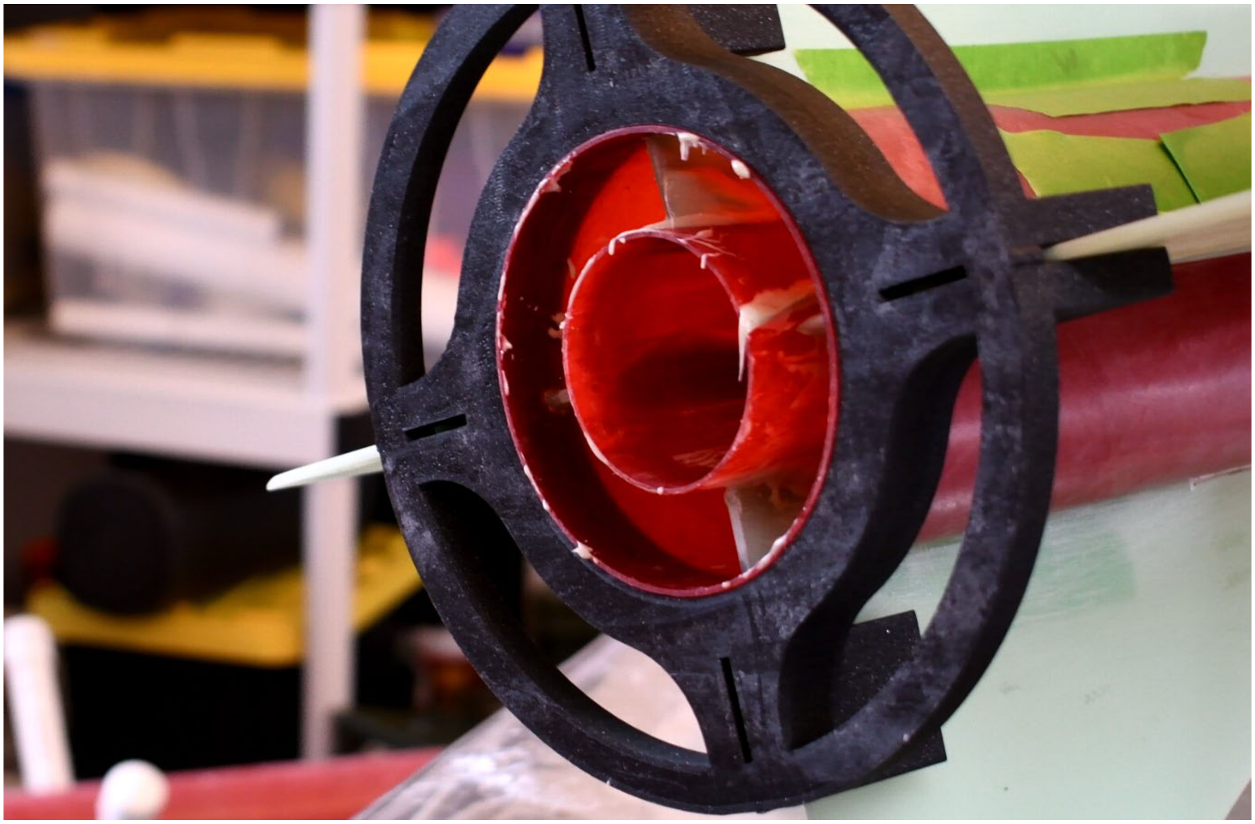


Image 15: Fins inserted and fin alignment jigs installed.

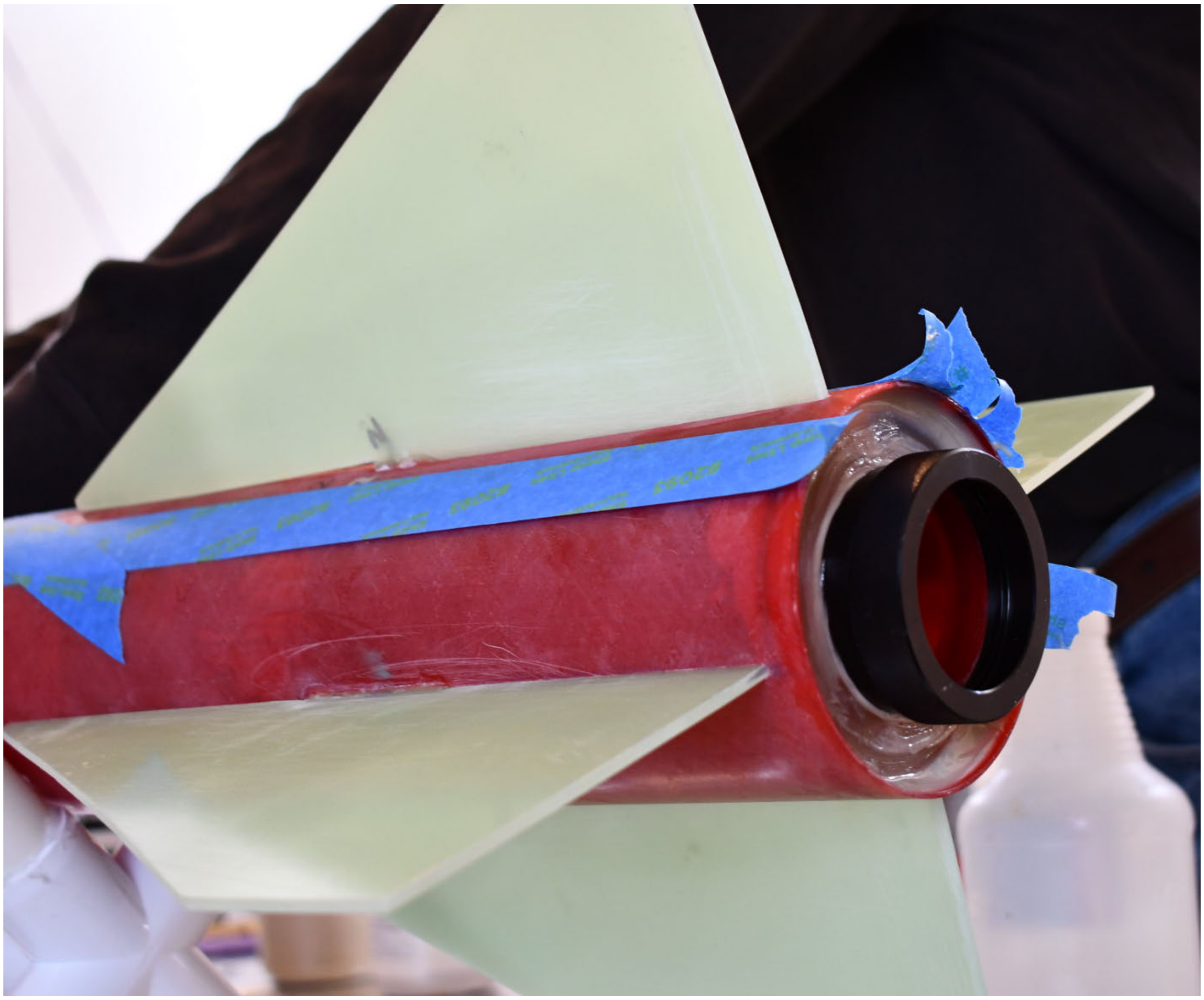


Image 16: Aft centering ring and retainer installed.

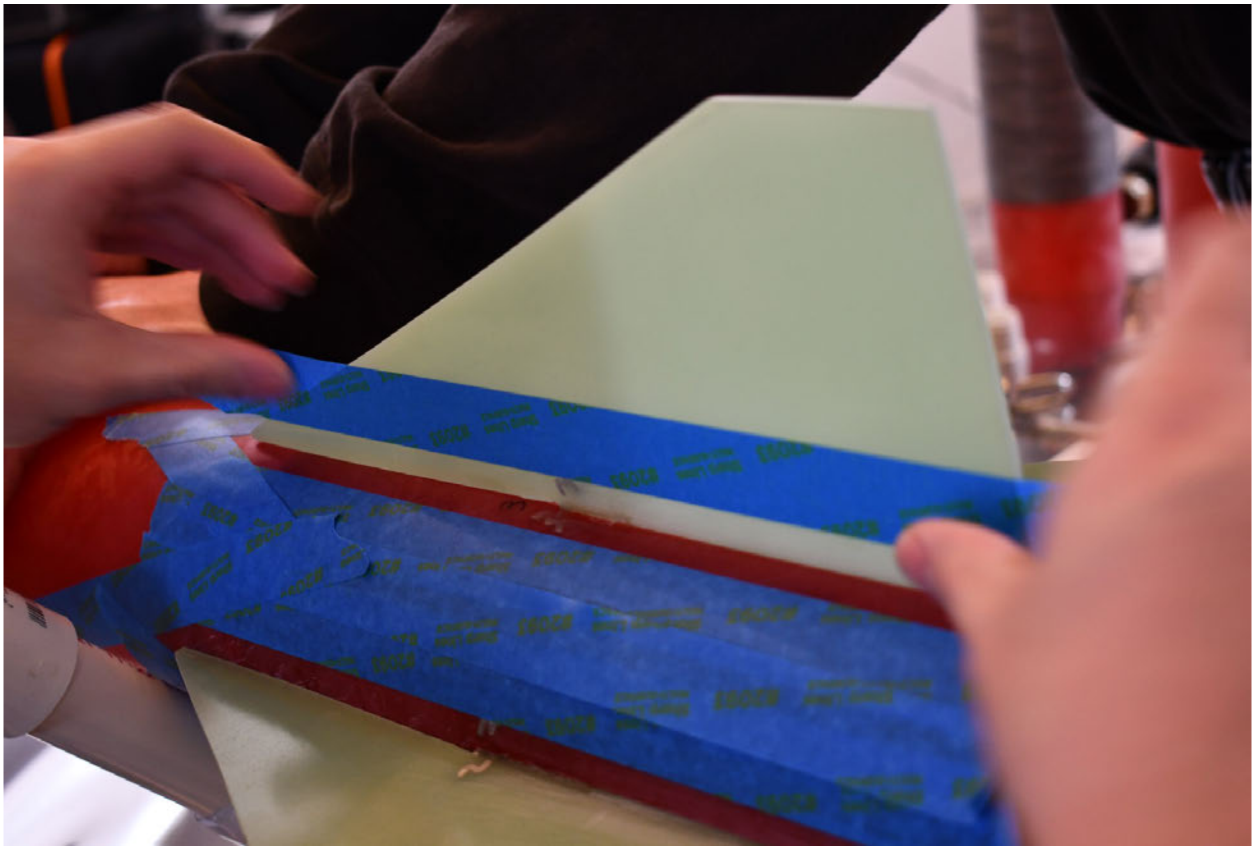


Image 17: Masking fins and airframe for fillets.

Image 18: Applying external fillets.

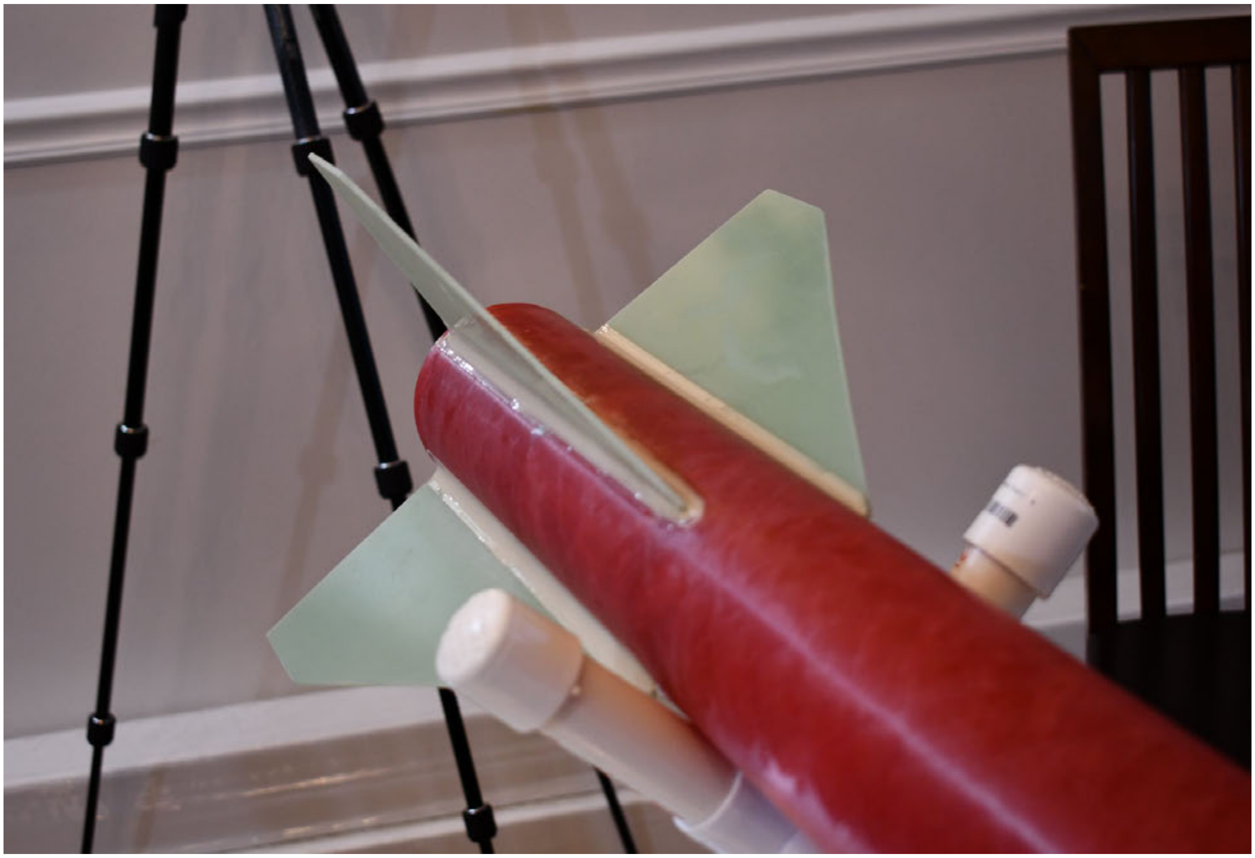


Image 19: Fillets cleaned and tape removed.

Image 20: Clearing an area on the forward avionics bay bulkhead for charge wells.

Image 20: Forward (main parachute) avionics bay bulkhead as prepared for flight.

Image 21: Aft (drogue parachute) avionics bay bulkhead as built

Image 22: Nose cone bulkhead as configured for flight.

3.1.4 As-Built Vehicle Analysis

Length

Our total length is as-designed with only a slight change due to a previous design error in OpenRocket where the payload shroud was considered its own length component which isn't how the vehicle was intended. The final vehicle is 3" shorter than in the last milestone because of this.

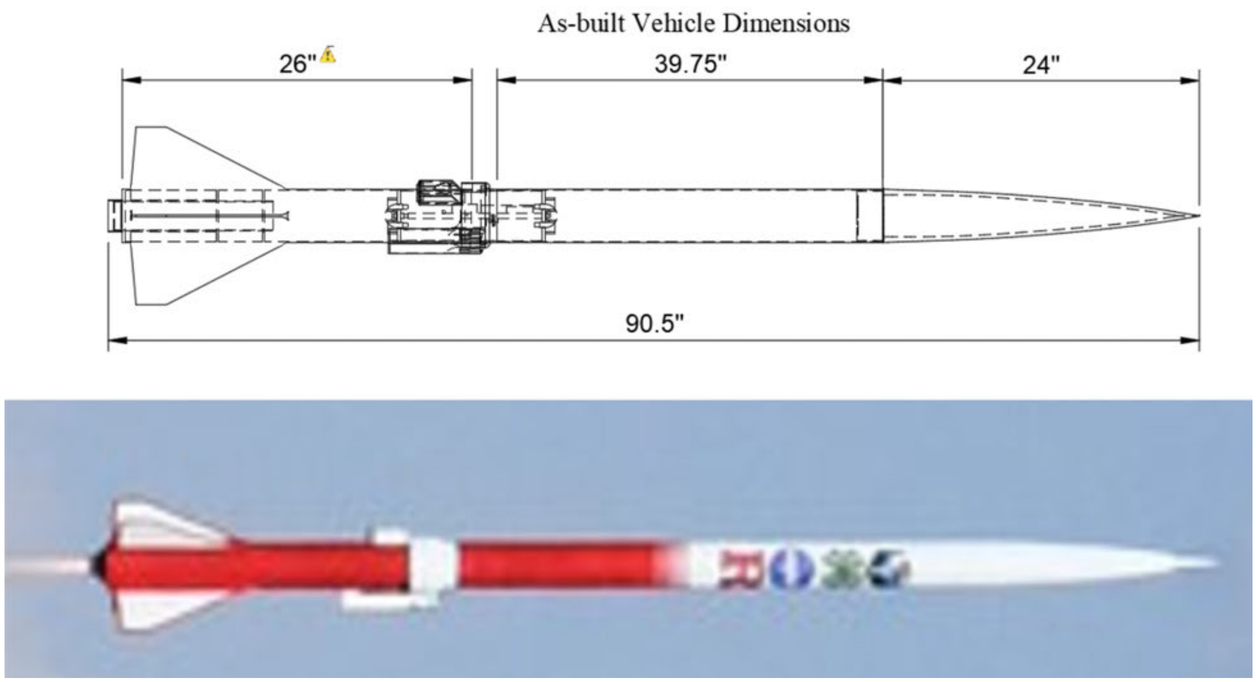


Figure 1: Vehicle schematic overridden with as-built measurements, with as-built vehicle for comparison

Fins

Our as-built fins remain extremely close to our designed vehicle. This is a result using a 3-D printed geometry of our intended fin shape in order to get cuts exactly right. After the fins were cut with saws, all four fins were sanded together to get them down to the final shape and size. There is likely a slight difference between the length or angle of some geometries of our fins, but because we were all made exactly the same this won't affect the vehicle negatively.

Avionics bay

Our avionics bay sled was cut down to the minimum length possible to still be able to house all devices in order to save weight. Nuts were added on the threaded rods in several places to ensure its structure with the bulkheads remains rigid.

Mass

Our vehicle is significantly heavier than previously planned. Our gross lift off weight is now 18.4 lb, compared to an expected 15.1 in the CDR. We haven't identified any one component causing this weight difference, however the mass of the payload sustainer are both heavier than previously expected. This has also decreased our stability but not to an unsafe degree. This increase in mass may also be responsible for the issues we've encountered with our drogue parachutes.

3.2 Recovery Subsystem

3.2.1 As-Built Recovery System Analysis

Our as-built dual-deploy recovery system has the components listed below, in order from the vehicle's aft to its forward.

Drogue Parachute System (Connected from the booster section to the avionics bay section):

- ¼"-20TPI Eye-bolt connected directly to booster forward centering ring, mounted with tightened nut and epoxied in place
- Large Quick-Link connected to the booster eyebolt
- 25 foot long kevlar harness rated to 3600 lbs of force, includes 3 loops and no knots. Bottom loop connected to bottom Quick-Link
- 13" x 13" Nomex fireproof blanket attached to drogue harness
- Large parachute swivel attached to middle loop of drogue harness
- 15 inch diameter drogue chute attached to the large swivel, mounted closer to the booster section
- Large Quick-Link connected to the top loop of the drogue harness
- Large U-bolt bolted to the bottom avionics bay lid, attached to the forward Quick-Link

Main Parachute System (Connected from the avionics bay section to the payload section):

- Large U-bolt bolted to the top avionics bay lid, attached to the aft (main) Quick-Link
- Large Quick-Link connected to the bottom loop of the main harness
- 30 foot long kevlar harness rated to 3600 lbs of force, includes 3 loops and no knots. Bottom loop connected to bottom Quick-Link
- 13" x 13" Nomex fireproof blanket attached to main harness
- Large parachute swivel attached to middle loop of main harness
- 48" inch diameter main chute (Fruity Chutes Iris Ultra) attached to the large swivel, mounted closer to the payload section
- Large U-bolt bolted to the nose cone bulkhead, connected to the top loop of the main harness

During each part of the recovery system construction, each joint was thoroughly tightened or glued, then we did a quick check of its strength by tugging on each joint and the harness making sure any simple errors will be avoided. Overall, we chose very strong attachment hardware, and our design does not include knots, therefore avoiding any weak points in the harness. Our harnesses were manufactured with three loops for attaching quick links. The strength of our vehicle recovery system is adequate and will hold up against most flight environments and long term reuse.

From our first vehicle demonstration flight our descent rates were about 65 ft/s and 20 ft/s on the drogue and the main descent, respectively. More information about the recovery flight performance is provided in section 5.1. The as-built parachute sizes are identical to the design specifications.

Image 23: As-built and flown recovery system

3.2.2 Recovery Electrical Sub-System

Our recovery system has been built using the same electrical components as discussed in previous milestones.

Dual Deploy System

We continue to use dual, fully independent and redundant, Stratologger CF flight computers for our dual deploy system. They include fully independent flight computers, batteries, and pull-pin switches. Our system consists of a designated main computer and backup computer. The main computer fires its ejection charges on time, and the backup computer fires its ejection charges slightly later. The backup charges are larger to create more energy in the event there was a failure on the primary charges. Wires come off of the flight computers ejection charge channels and run to their respective Wago connectors which connect to the ejection charge ignitors. The wires going to the main ejection charges (which face the top of the vehicle, towards the tracker) are wrapped in copper tape which provides RF shielding from the GPS tracker.

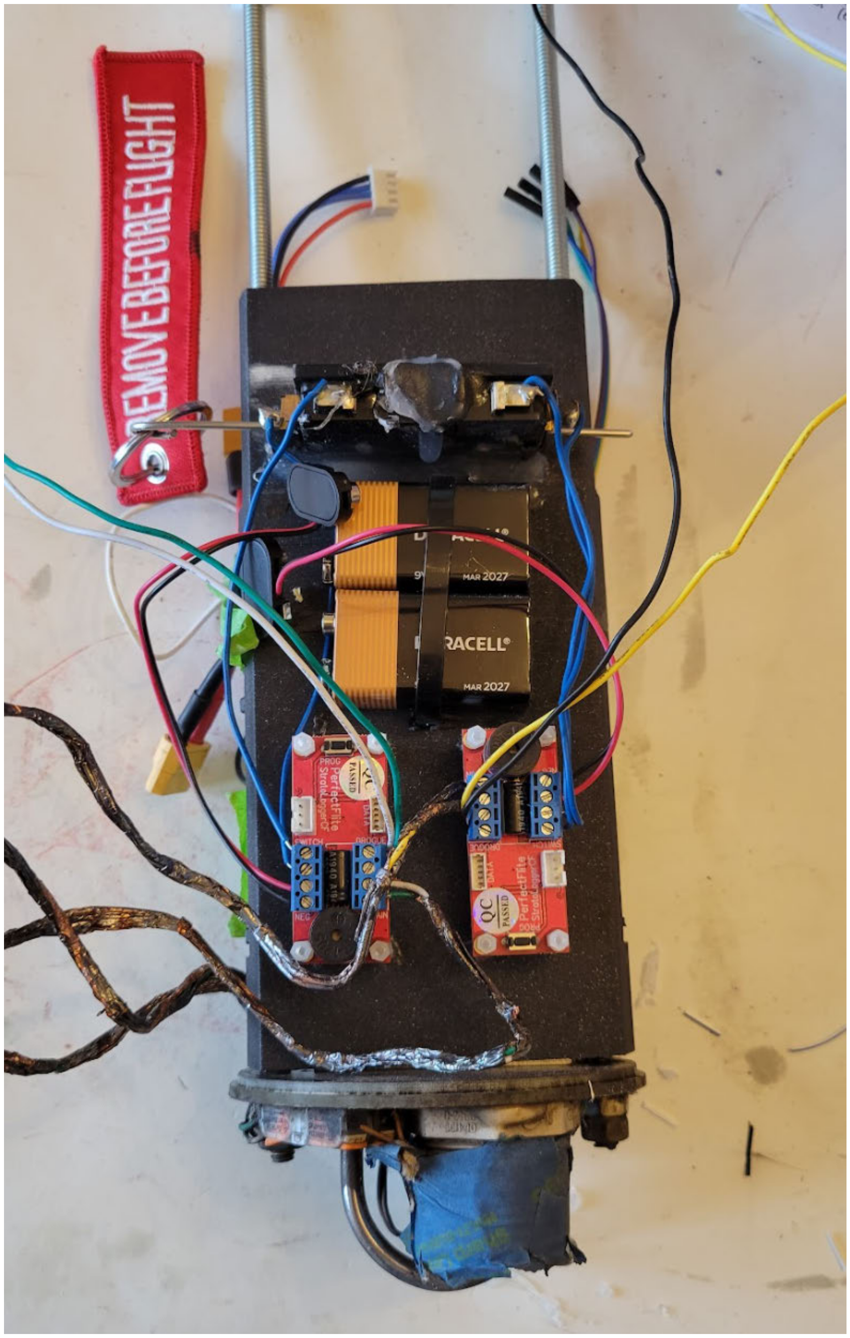


Image 24: As-built avionics bay sled

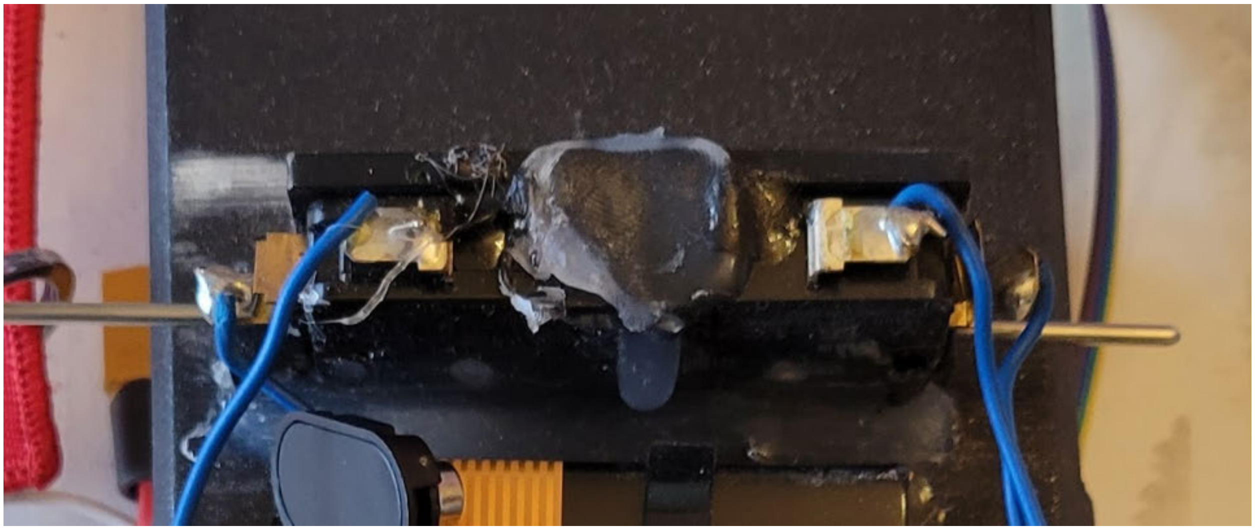


Image 25: Close up of dual pull-pin switches.

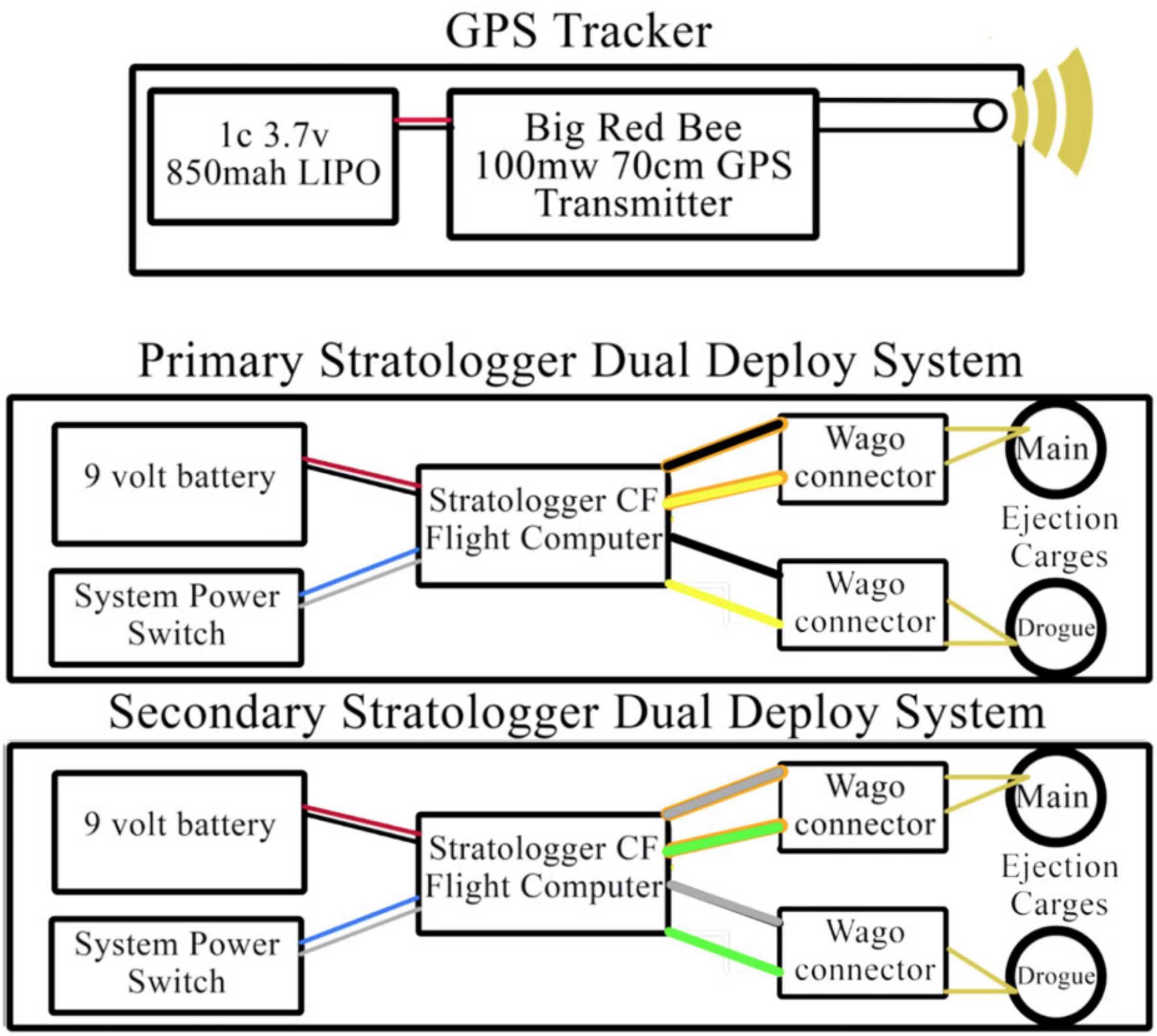


Figure 2: Recovery electronics wiring diagram

Tracker

Our vehicle uses a Big Red Bee APRS ham radio GPS tracker. It transmits on the 432.100 MHz (70cm) frequency using the team captain's ham radio technician license, KD2VGV. The tracker is placed in the base of the nose cone of the vehicle and zip tied onto a 3-D printed sled secured to the coupler using the u-bolt hardware and the screws that secure the nose cone to the coupler. The other side of the sled is used for holding ballast. The nose cone bulkhead has copper shielding to project the electronic systems aft of the tracker from interference. Additional copper shielding is on the forward bulkhead and on the wires between the flight computer and ejection charge Wago connectors.

Image 26: GPS Tracker in the nose cone sled (not in flight-ready configuration)

Image 27: The U-bolt hardware that secures the sled

Indicators that flight computers are working

The Strattologger CF computers make chirp tones that indicate their status. The primary computer makes a slightly higher pitch chirp than the back-up to help distinguish them. Each computer makes a sequence of three tones to indicate they are working nominally and have continuity with their ejection charges, They only make two chirps when they are connected to only the main ejection charge, and just one chirp when they are only connected to the drogue charge. Both computers chirping in their flight-ready status should sound like 6 chirps, however they often end up syncing with each other and it can be difficult to know the status apart from listening to the elevated volume.

3.2.3 Recovery Sensitivity

Our recovery system includes 4 e-matches, and the wires in each e-match have a potential to be affected by our radio/ GPS transmitter signals. However, the risk of this is extremely low due to a few reasons. First, all of our RF signals are low power, totalling a number far less than 1W, which is the rule-of-thumb ‘cutoff line’ where RF signals become influential to electrical components. Next, we have installed RF shielding on our avionics bay bulkheads and our nosecone bulkhead. There are 3 layers of copper tape laminated onto the surface of each bulkhead which should be adequate to block any electromagnetic radiation and radio waves to pass. The GPS tracker & transmitter is housed inside the nose cone, therefore both e-match wires/ energetic locations have either 1 or 2 walls of shielding in between i t and the radiation source. Finally, our e-match wires will be relatively short and twisted (positive and negative wires in the shape of a double helix), therefore creating a geometry less prone to electromagnetic field manipulation.

3.3 Mission Performance Predictions

3.3.1 Flight Profile Predictions

The flight simulations and predictions are conducted with the latest measurements and information gathered from our vehicle and test flights.

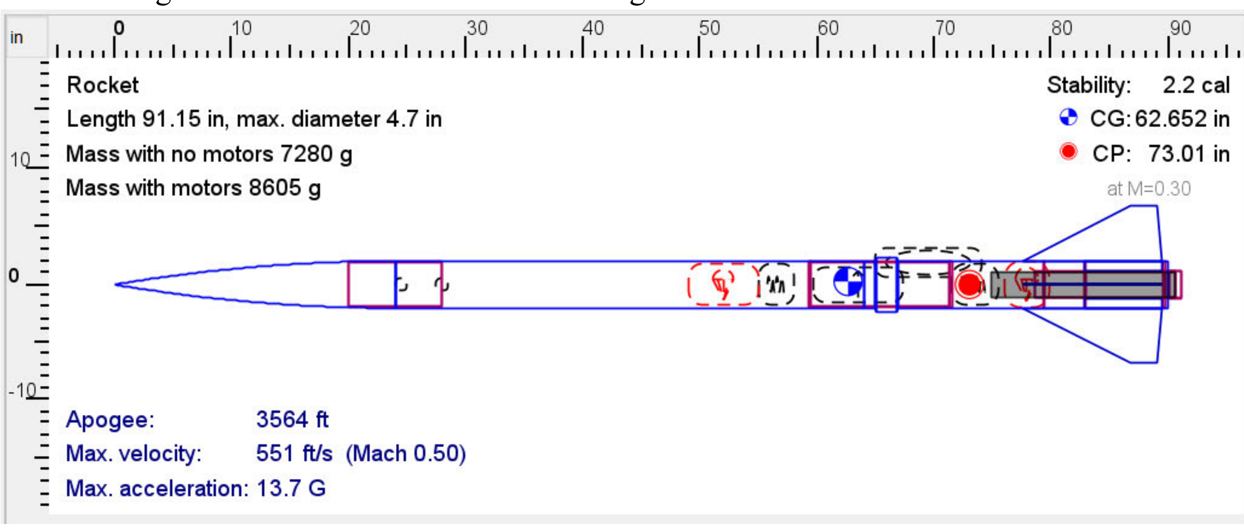


Figure 3: Simulation of vehicle as-built showing CG and CP locations.

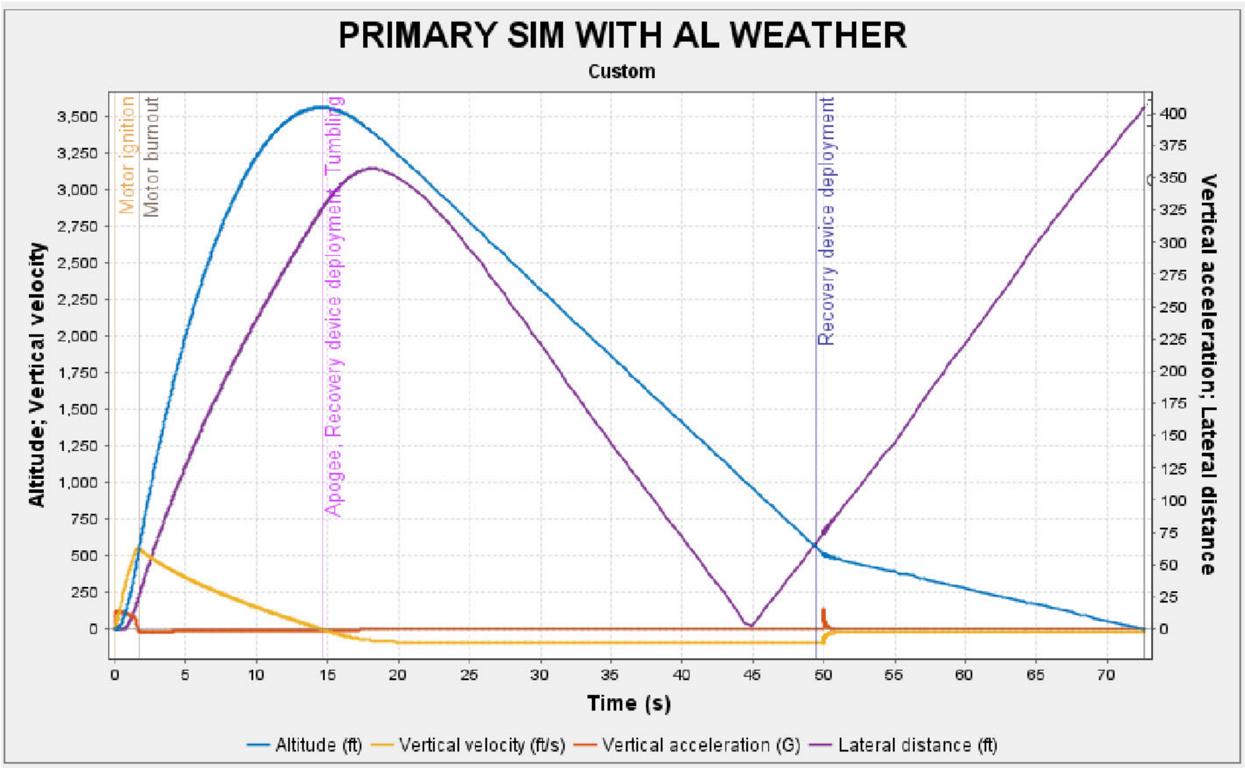


Figure 4: Primary flight simulation with expected Huntsville weather.

3.3.2 Vehicle Flight Properties

Kinetic Energy

Calculations performed using post-flight weights of components and using velocity measurements from the flight computer during the latest flight.

Under drogue parachute:
Sustainer: 315 ft-lbf
Payload/uppe airframer: 369 ft-lbf
Nose Cone: 172 ft-lb

Under main parachute:
Sustainer: 49.5 ft-lbf
Payload/uppe airframer: 58 ft-lbf
Nose Cone: 27 ft-lb

Descent Time

From our latest flight data, we expect our descent time to be 72.5 seconds from apogee to when the avionics bay section touches the ground in 15-20 mph winds.

Descent Drift

Wind	Drift Distance
0 MPH	700 ft
5 MPH	750 ft
10 MPH	879 ft
15 MPH	1021 ft
20 MPH	1235 ft

Table 2: Max simulated drift (Angled down-wind, 20 mph wind): 1425 ft

Max flight test drift: 1750 ft

We’ve understood that our real world flight drift would likely be higher than simulated due to OpenRockets basic descent simulation capabilities. We have observed that in winds 15-20 mph, our drift is about 1750, demonstrating that our drift should remain well below the 2,500 ft requirement. Our other flight in winds closer to 5-10 mph had about 750 ft of drift. We are confident in the estimations we’ve collected from our flight test and that our vehicle drift meets requirements.

4. Payload Criteria

4.1 Payload Design and Testing

4.1.1 Payload Design Changes

Payload title: 2023 NASA USLI Payload Challenge

Some changes have been made to the payload since the CDR to decrease hardware complexity and to optimize the mass of the payload.
There have been slight optimizations in the shape and size of the payload shroud and payload arm, but they still function the same.
For leveling the arm, we removed IMU’s from the arm in favor of using computer vision to level the arm. An IMU is still used to orient the payload housing upwards upon landing.
Some additional components have been added to the wiring schematic to facilitate operation, including a voltage regulator, reducing a 11.1v LIPO battery to 5.4v for the raspberry pi and motors.

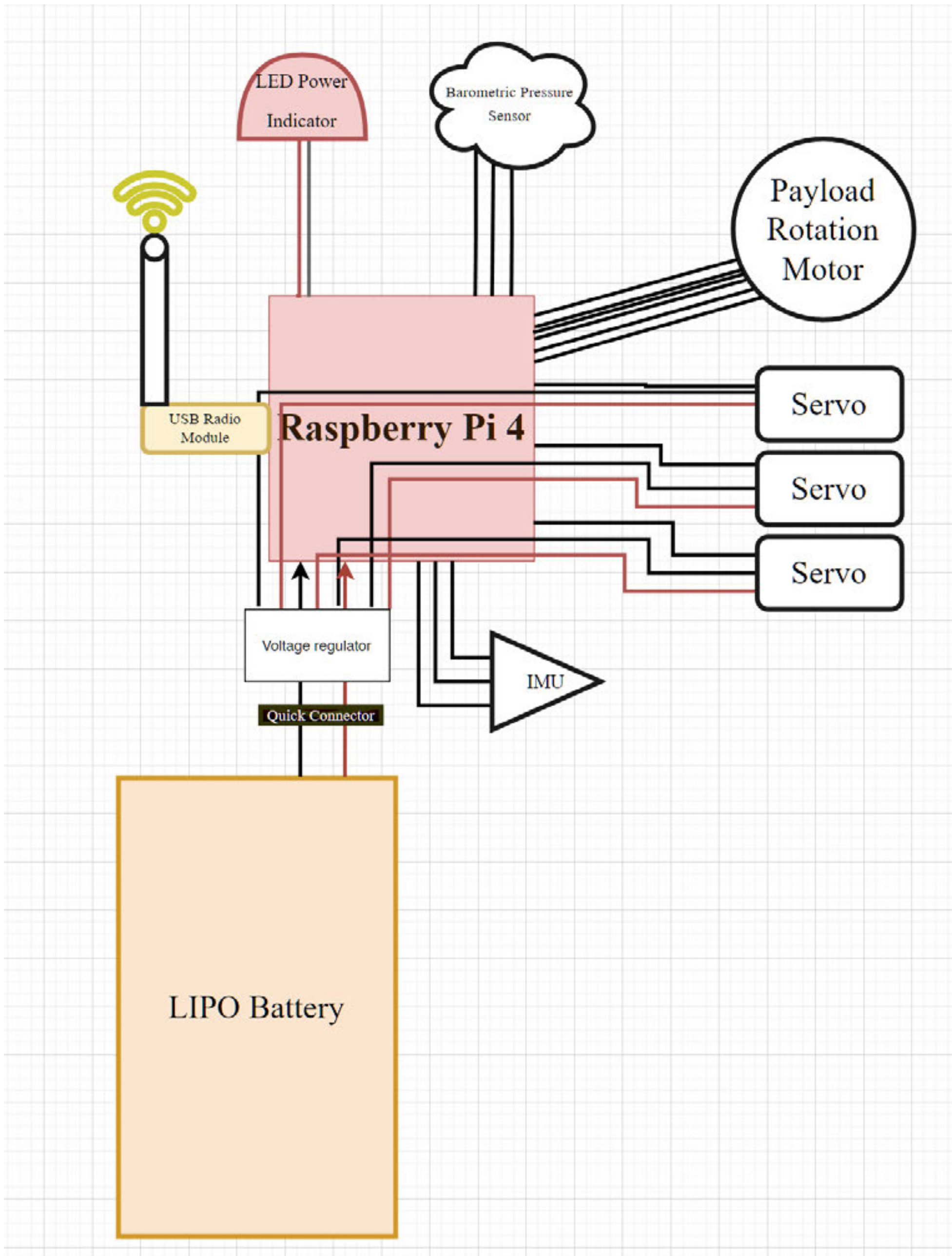

LED Power Indicator
Barometric Pressure Sensor
Payload Rotation Motor
USB Radio Module
Raspberry Pi 4
Servo
Servo
Servo
Voltage regulator
IMU
Quick Connector
LIPO Battery

Figure 4: Updated wiring diagram of the Payload

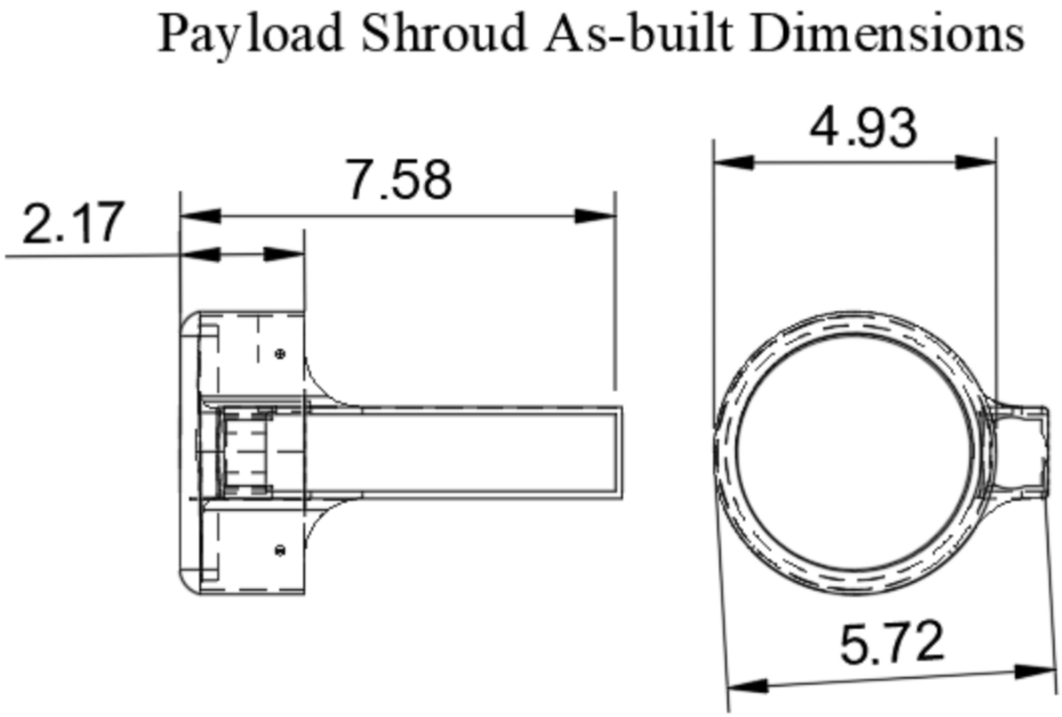


Figure 5: Payload Shroud as-built dimensions


Image 28: As-built payload deployment arm

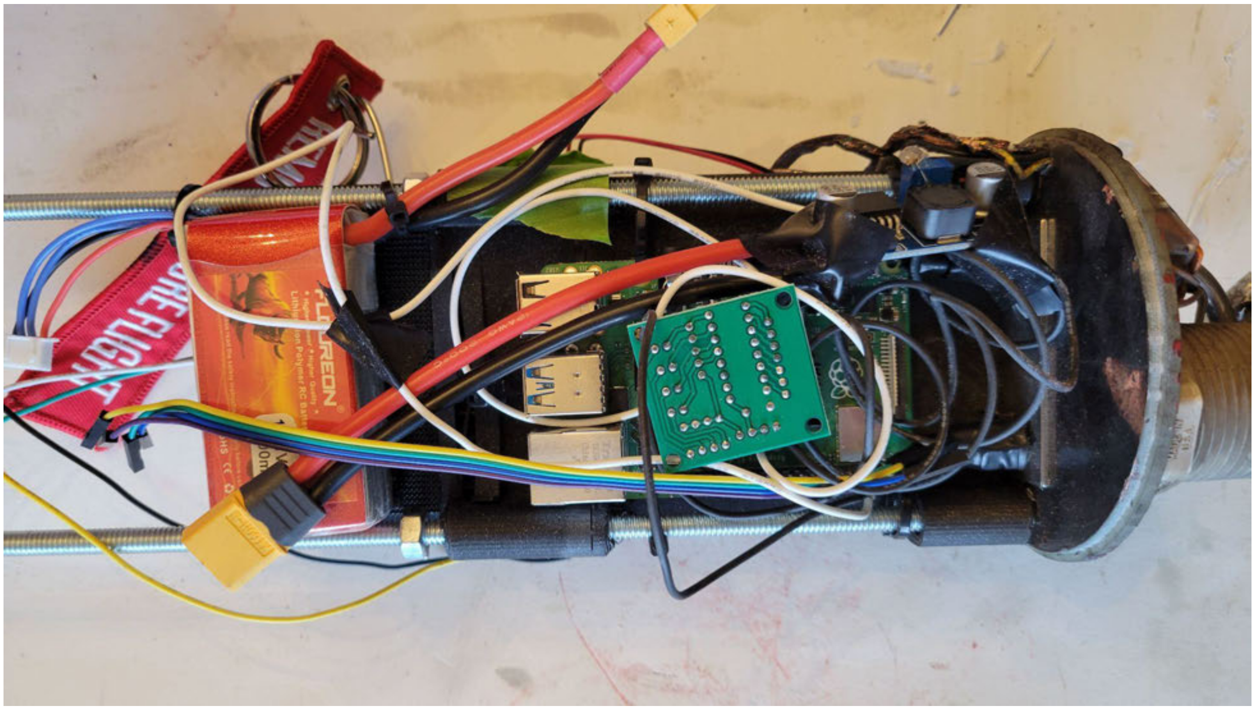


Image 29: As built payload electronics on the e-bay sled.

4.1.2 Payload Testing

While we are still developing the payload software, we have flown the final payload hardware with the launch vehicle. Unfortunately, in the last flight, the payload shroud and arm were damaged due to a problem with the drogue parachute. Despite this, we believe we have proven the safety and reliability of the payload hardware with this flight. Even in a hard landing, the payload retention system worked.

We are rebuilding the damaged payload to continue developing and testing the payload software.

If we need to complete an additional flight of the payload, we have April 1st as an opportunity to fly the final payload and demonstrate its operation. The success criteria for this flight would be achieving the following items:

- Payload remaining stowed during flight
- Payload arm orienting and deploying after landing
- Payload taking and saving images to meet the payload challenge requirements.

Image 30: Damaged payload upon landing

Image 31: Damaged payload arm upon landing

5. Demonstration Flights

5.1 Vehicle Flight Test Summary

Initially, we had planned to conduct all vehicle flights with an operational payload. However, payload progress started slipping from the efforts needed to build and test the vehicle. Our first flight was on February 4th. This was our vehicle demonstration flight, since our payload hardware was incomplete. We collected valuable information that let us refine our design prior to the next flights and more importantly proved the flight worthiness of payload attachment and shroud. In this flight we discovered an with our drogue parachute where the vehicle tumbled during drogue descent, and the drogue was found tangled after landing. We added an additional swivel on the sustainer prior to the next flight to mitigate the tumble and tangling.

We conducted a second flight on March 5th intended to achieve all vehicle demonstration goals as well as demonstrate the payload hardware readiness. The drogue parachute issues re-appeared and caused damage to the vehicle. During the entire descent the sustainer was spinning extremely rapidly, and the remaining energy was released on contact with the ground, breaking the fillets of one fin (although still being intact). Additionally, the Runcam on the sustainer broke off on landing and part of the payload shroud broke. The descent rate was nominal and in the prior flight we had proven that the vehicle is able to land safely at this velocity.
The Runcam, which died before the launch in the first due to extreme cold, provided video that showed the full extent of the tumble and spinning.

We have concluded that the drogue parachute must be replaced with a large parachute, and we should also replace the drogue-stage shock cord, as it has undergone a lot of stress. We will also re-attach the detached fin after clearing its old epoxy and inspecting for damage.

Our next flight opportunity is April 1st for a vehicle demonstration re-flight or additional payload demonstration flight attempt.

5.2 Flight Reports

Demonstration Flight Attempt 1

Pictured right: Vehicle demonstration flight

Summary of Flight

This flight was missing some mass components of the payload. However, the drag components of the payload were installed and secured for the flight. Additionally, the vehicle lacked paint. We understood these missing factors would result in altered data, however this launch was our second to last flight opportunity before the FRR milestone. Despite some payload mass missing, we believed this flight would contribute to proving the safety and reliability of our design, with hopefully a complete demonstration flight at the next opportunity. We also took this time to practice and refine our checklists.

Our flight went smoothly and we were able to collect information to contribute to the success of future flights.

Image 32: Maiden flight, Vehicle Demonstration Flight

Preflight Info

Request	Answer
Identify whether the flight was conducted to fulfill the requirements for the Vehicle Demonstration Flight, Payload Demonstration, or Both.	Vehicle Demonstration Flight.
Date of Flight	02/04/23
Location of Flight	Maryland Delaware Rocketry Association Higgs Farm
Launch Conditions	20*F, 5 MPH Wind, Clear skies,
Motor	Aerotech K1100T RMS
Ballast - sand bags in base of nose	0.925 LB
Dry Weight	17.4 LB
Final payload flown?	No
Airbake flown?	N/A
Target Apogee	3800 ft
Landing kinetic energy (Sustainer, Payload, Nose)	Sustainer: 47 | Payload/upper: 50| Nose Cone: 25.5
Black powder charge sizes	Drogue Main: 1.5g | Drogue Backup: 2g Main Main: 4g | Main Backup: 4.5g
Simulated apogee	3500 ft

Table 3: Vehicle Demonstration Flight

Flight Info

Measured Altitude: 3668 ft
Flight time: 83.5 seconds

Figure 4: Primary Altimeter Flight Profile (Stratologger CF Main Computer)

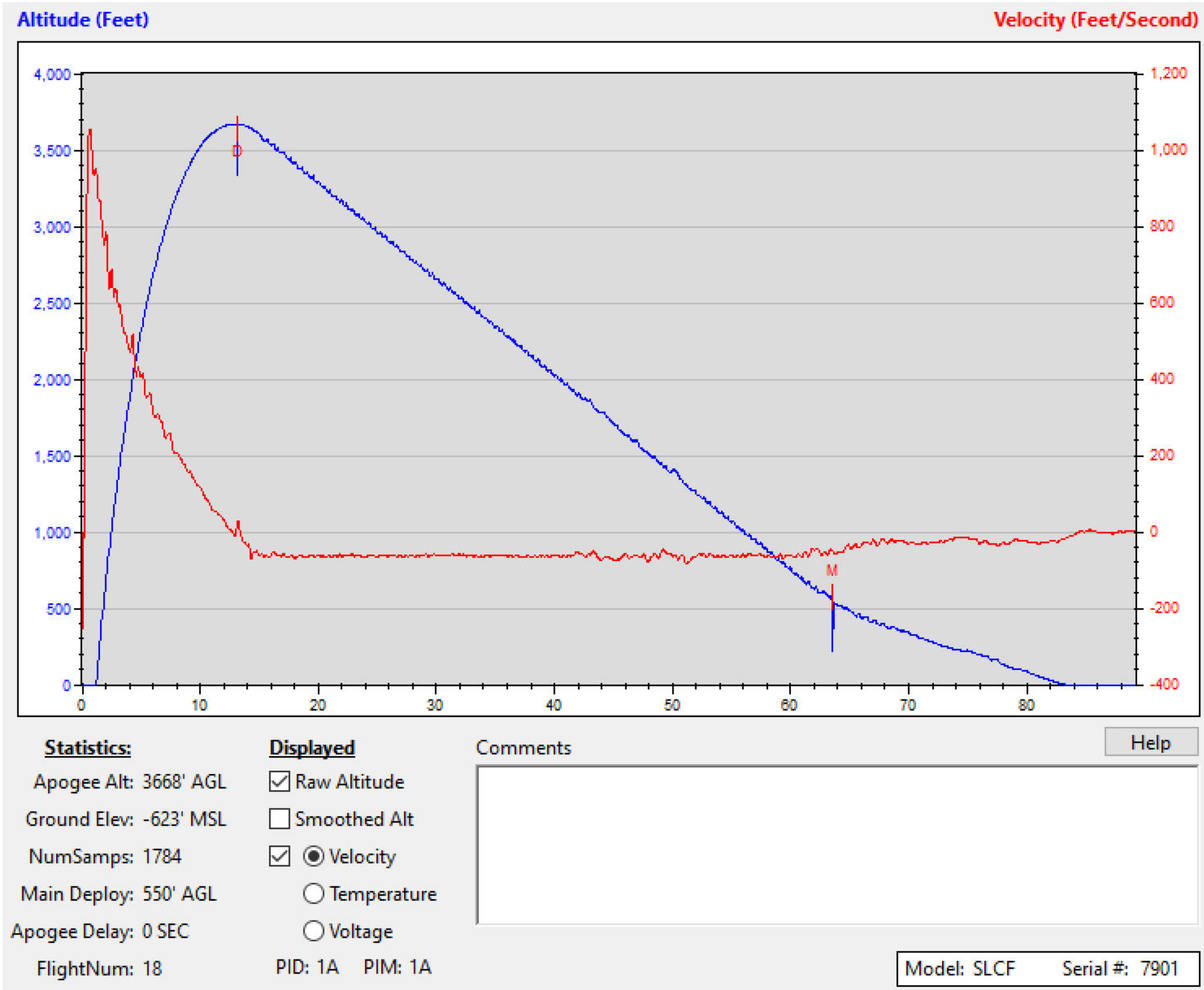
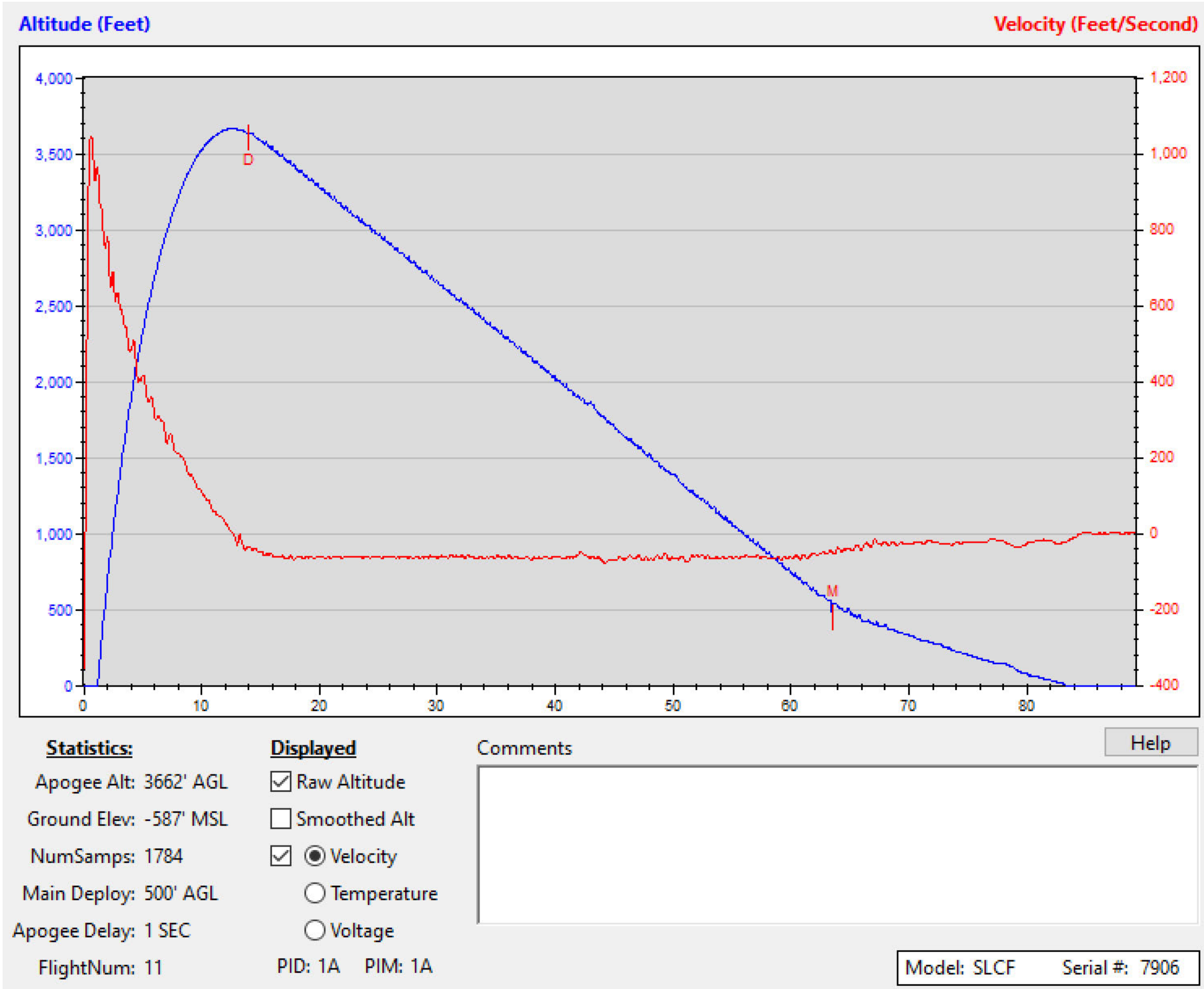


Figure 5: Backup Altimeter Flight Profile (Stratologger CF Backup Computer)



Images of Landing Configuration

Image 34: Complete configuration of landed vehicle

Image 34: Sustainer landed configuration

Image 35: Payload Landed Configuration

Image 36: Drogue ejection charges post-flight

Image 37: Tangled Drogue parachute

Image 38: Main Parachute after landing

Flight 1 Recovery System Analysis

Drogue parachute

During flight one we discovered an issue with our drogue parachute configuration. During the initial descent we observed the vehicle tumbling and twisting. Upon landing we found the drogue parachute tangled and the drogue shock parachute heavily twisted.

Image 39: Image of the drogue parachute and lines shortly after drogue parachute deployment.

Potential causes

It's likely the drogue parachute is undersized for this vehicle. Additionally, its placement along the lines may be suboptimal. The primary symptom of the rocket fin section trailing behind (above) the drogue parachute indicates that the drogue is not slowing the fin section more than natural air resistance.

The drogue parachute swivel may have been oversized for this parachute and therefore not swiveling, causing the shock cord twisting.

The fireproof nomex blanket was also attached on the quick-link on the base of the parachute, potentially stifling the parachute's effect or contributing to it becoming tangled.

Effect
This anomaly did not make the vehicle unsafe during this flight. It is possible that it decreased the potential effect that the drogue should have had, however the result was still in line with our expectations. Giving an actual descent velocity of 65 ft/s compared to our originally simulated 125 ft/s. From the CDR milestone we knew it was very likely that the descent velocity would be much lower than simulated, due to OpenRockets

Compared to how it's designed, we do not believe that this issue makes our vehicle more hazardous during drogue descent.

We do not see any significant risks to main parachute deployment from the drogue underperformance.

Mitigations
Our options for mitigation before the next flight are the following:

Adjust the location of the drogue parachute on the recovery harness to give it more authority towards the fin section.
Moving the nomex blanket off the base of the parachute.
Using a smaller parachute swivel.
Installing a swivel on the fin section recovery harness attachment point.
Use a larger drogue parachute.

The parachute is placed in its current location to ensure successful deployment by being in a location where it'll be ejected before the majority of the other shock cord. Additionally, it's attached to a loop sewn into the shock cord, so we don't need to tie the shock cord.

The current parachute configuration gives us the original expected performance, including drift, descent time, and kinetic energy. Changing to a larger parachute would impact all of these factors, and some, such as drift, may become unacceptable.

Prior to the next flight, we have made the following mitigations to make our drogue parachute performance more optimal:

Moved the nomex blanked to the quick-link at the base of the avionics bay.
Installed a swivel at the on the fin-side section of the vehicle.

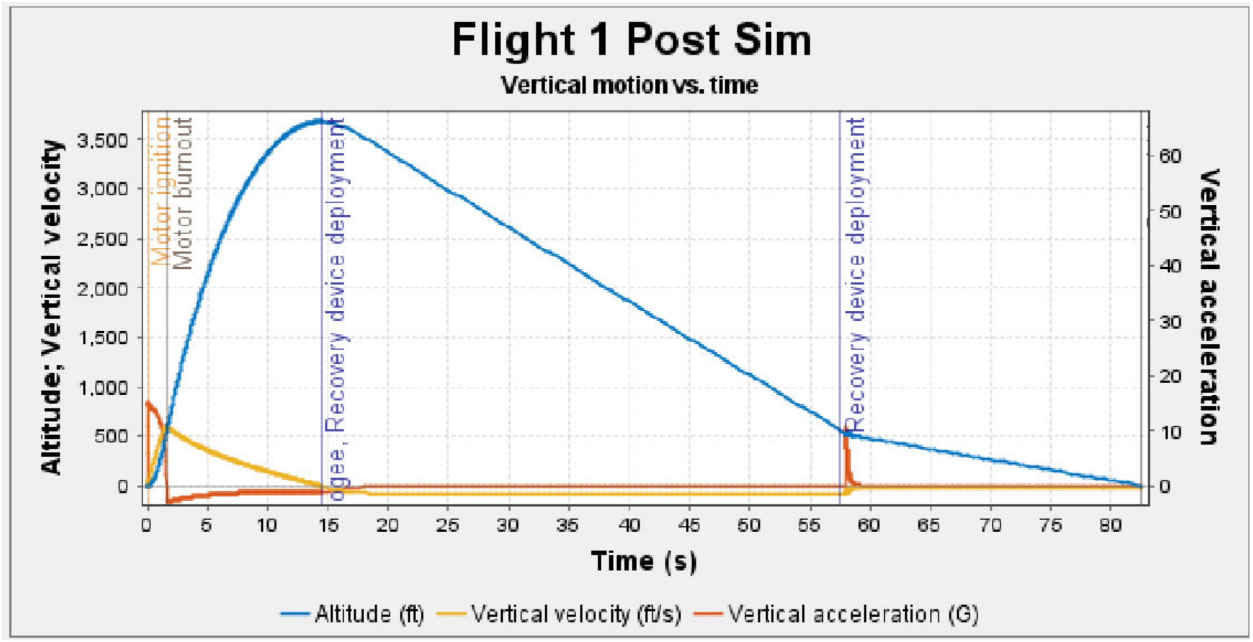
Post-Flight Simulation

We have conducted a post flight simulation to meet the flight result by making the following changes:

Drag Coefficient	0.6cd → 0.62cd
Mass override:	18.44lb → 17.4lb
Drogue Parachute size	15” → 25”

Figure 6: These adjustments resulted in the same flight time and apogee that we observed.

Velocity off rod	Apogee	Optimum delay	Max. velocity	Max. acceleration	Time to apogee	Flight time	Ground hit velocity
69.6 ft/s	3676 ft	12.8 s	597 ft/s	15 G	14.4 s	83.6 s	21.1 ft/s



Demonstration Flight Attempt 2

The purpose of this flight was to complete a demonstration with the complete payload hardware to prove the safety of the full system. We added a swivel on the sustainer eye-bolt to help mitigate the previously known tumbling during the drogue descent. We also added the final paint and stickers to our vehicle. The mass of the vehicle was 5.7% heavier than previously, but performed better than expected, leading us to believe the final finishing reduced the coefficient of drag.

The drogue parachute issues reappeared, this time resulting in damage to the vehicle caused by violent spinning. The descent rate was nominal, but due to the spinning, the first fin to contact the ground had its epoxy fillets break and became dislodged from the airframe. The fin and airframe both seem structurally sound after this, it appears we can attach the fin after cleaning up the old epoxy.

The final payload hardware was present on this flight, and apart from damage sustained from the drogue anomaly, it worked as expected. The retention system worked as expected and even with damage to the sustainer, the payload arm survived well.

Image 39: Payload Demonstration Flight

Preflight Info

Request	Answer
Identify whether the flight was conducted to fulfill the requirements for the Vehicle Demonstration Flight, Payload Demonstration, or Both.	Vehicle Demonstration Flight / Payload Demonstration Flight
Date of Flight	03/05/23
Location of Flight	Maryland Delaware Rocketry Association Higgs Farm
Launch Conditions	55*F, 15 MPH Wind, Clear skies,
Motor	Aerotech K1100T RMS
Ballast - sand bags in base of nose	0.925 LB
Dry Weight	18.4 LB
Final payload flown?	Yes
Airbake flown?	N/A
Official target altitude	3800 ft
Landing kinetic energy (ft-lb)	Sustainer: 49.5 | Payload/upper: 58 | Nose Cone: 27
Black powder charge sizes	Drogue Main: 1.5g | Drogue Backup: 2g Main Main: 4g | Main Backup: 4.5g
Predicted altitude	3350 ft

Table 4: Flight details

Flight Info

Measured Altitude: 3575ft
Flight time: 86.5 seconds

Figure 7: Primary Altimeter Flight Profile (Stratologger CF Main Computer)

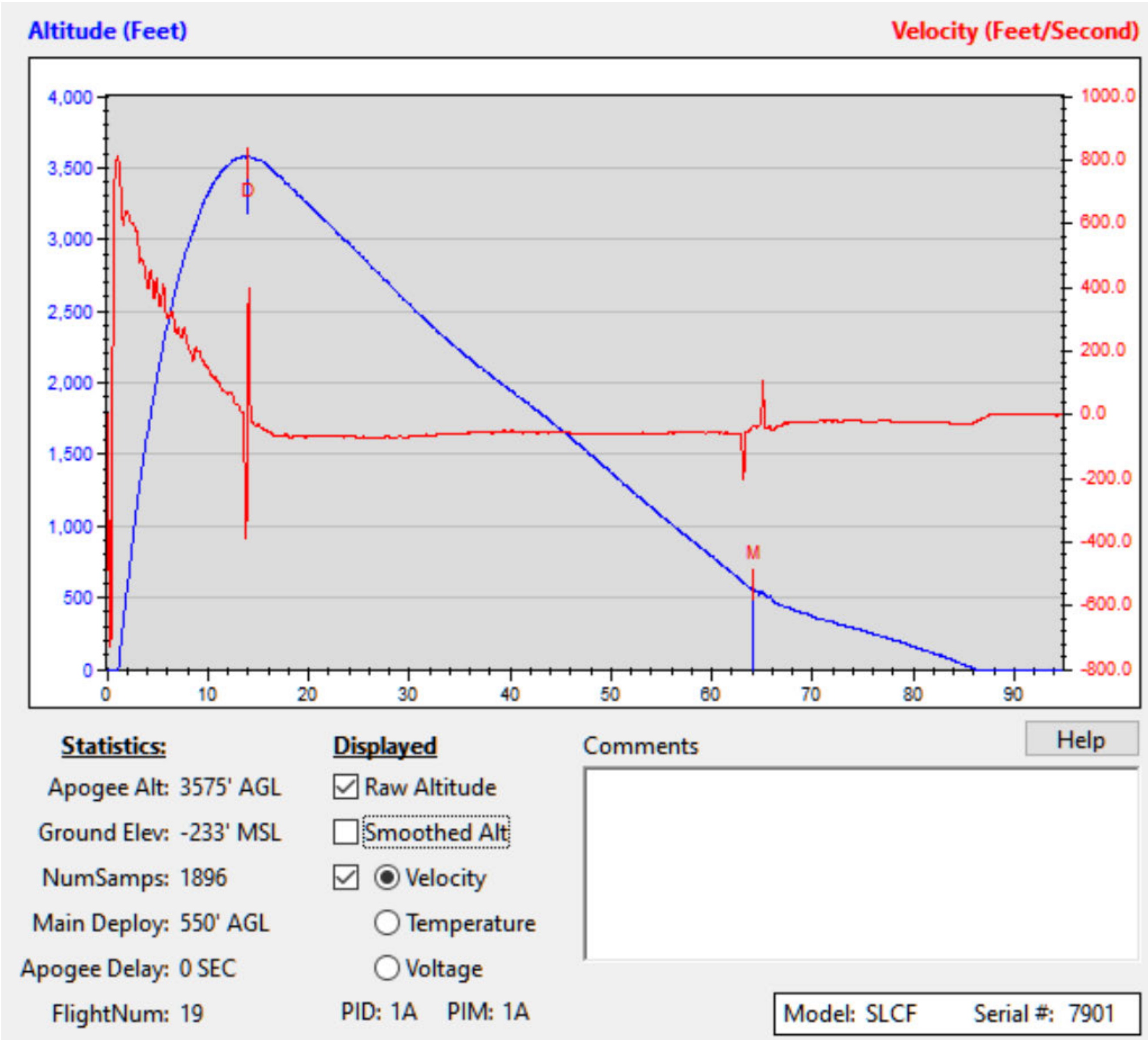
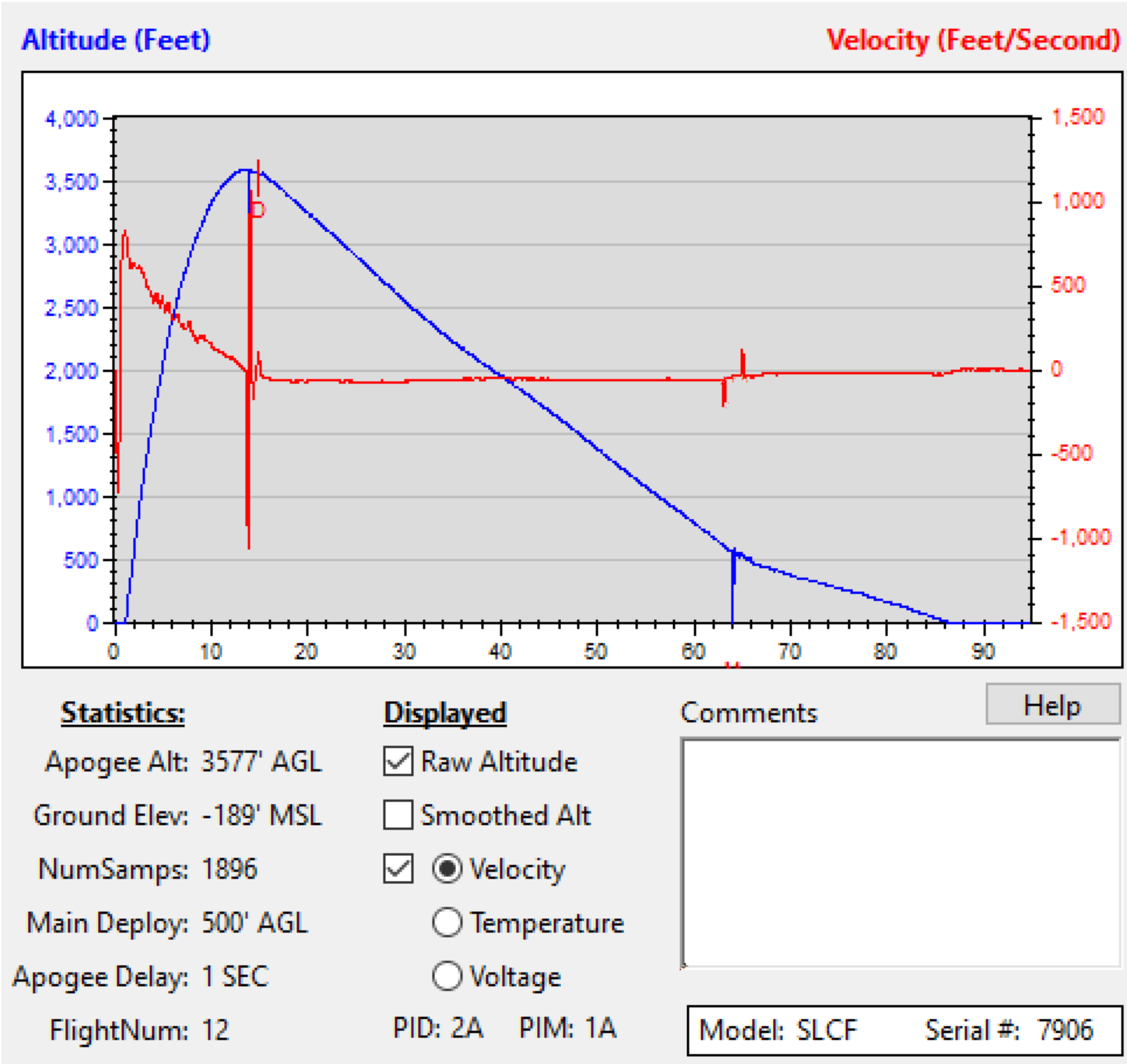


Figure 8: Backup Altimeter Flight Profile (Stratologger CF Backup Computer)



Flight 2 Recovery System Analysis

Into this flight, we were aware of potential issues with the drogue parachute and had taken steps to mitigate them. The problems occurred again and we have concluded that our drogue parachute is undersized and must be replaced prior to the next flight. We will also replace the shock cord with a new line of the same model, as the current one has undergone extreme stresses.

The symptom was the same violent tumbling as the last flight. With the assistance of on-board video we were able to understand the full extent of this issue. Additional evidence is that the fin section remains above the drogue parachute during descent, showing that it is not slowing this part of the vehicle.

Image 40: Frame from Runcam video showing the drogue parachute being below the fin section.

Image 41: Frame from Runcam video shortly before landing showing distortion in the video caused by spinning

After main parachute deployment, the tumbling fin section and lines became tangled at the base of the main parachute line. Additionally, the line was tangled around the sustainer body tube.

Image 42: Image showing the entanglement of the drogue parachute after main parachute separation.

Because of the tumbling induced by the undersized drogue, there was a lot of torque built up in the drogue shock cord, causing the fin section to continue spinning violently even after main parachute deployment. Even though our descent rate was nominal, this energy in the fin section caused damage on landing. The fin that contacted the ground first had its epoxy fillet break, but there doesn't appear to be damage to the fin component itself. The fin was retained in the can due to the internal fillet being wider than the slot. The Runcam housing also broke clean off. And the arm part of the payload shattered. All payload hardware was retained except for the parts of the housing that broke off.

Image 43: Frame from Runcam video showing the landing.

Image 44: Image showing where the Runcam housing was attached and dislodged (but retained) fin.

Image 45: Close up of fin damage as found

Image 46: Image showing the detached Runcam housing, landed about 2 feet from the fin section.

Image 47: Image showing the damaged payload arm housing and the retention of hardware components.

Image 48: Broken pieces of payload shell on the ground

Image 49: Image showing the damaged vehicle reassembled for recovery.

We also encountered a malfunction with our main parachute deployment. The parachute deployed inside-out, causing the line that nominally goes to the center spill hole of the parachute to drape over the side of the parachute. This hindered the effect of the main parachute dramatically. We can say with confidence that this was caused by improper packing.

Image 50: Image of the main parachute, the spill hole line is shown on the right side of the parachute.

Image 51: Inside-out main parachute after landing.

Once again, the dual deployment electronic system and ejection charges worked exactly as intended. Additionally, our parachute fire protection system also continues to work great, with no additional damage to any sensitive mechanic. Our GPS tracker was also used to successfully locate the vehicle.

Additional Images of Landing Configuration

Image 52: Main Parachute blowing as seen from a distance.

Image 53: Entire vehicle on the ground

Image 54: Main parachute laying on the ground


Image 55: Upper airframe and payload on the ground

Image 56: Drogue parachute tangled at base of main parachute shock cord

Image 57: Aft of vehicle

Image 58: Drogue ejection charges after flight

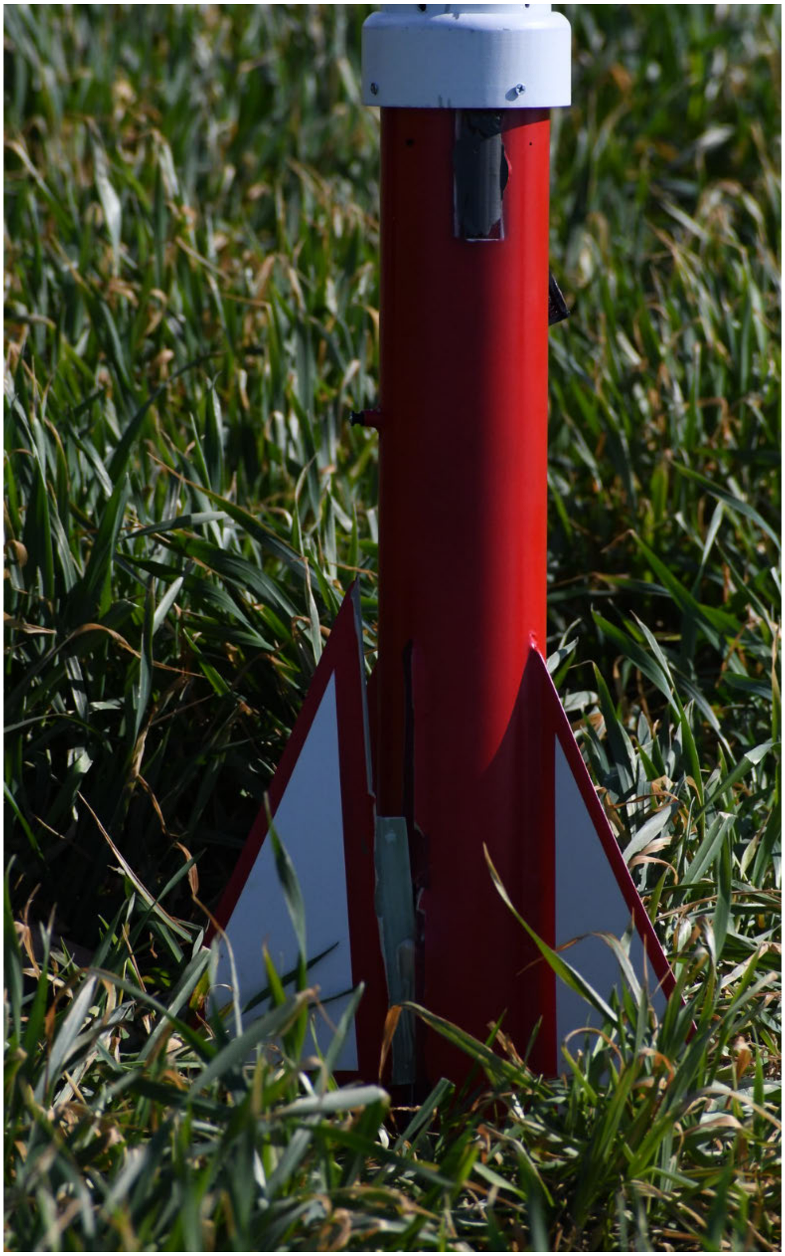


Image 59: Damage fin section, stood up.

Payload Analysis

The final payload hardware was present on this flight, however damage was sustained to it. The retention system functioned as expected and did not sustain damage.

We will rebuild the payload shroud and other damaged hardware and continue developing the software.

Post-Flight Simulation

We have made the following changes to get an accurate post-flight simulation:

Drag Coefficient 0.62cd → 0.53cd

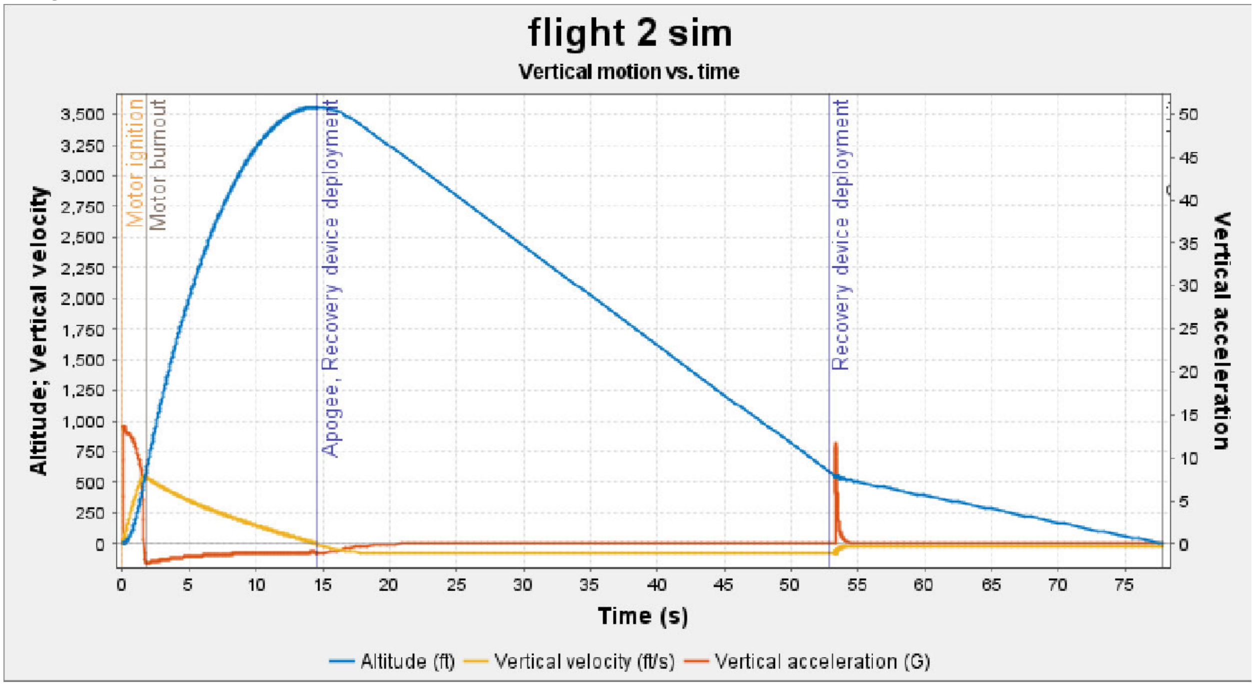


FIgure 9: This simulation is now extremely close to our final vehicle. The coefficient of drag has changed due to the addition of paint and smoothening the 3-D printed external parts, which previously had drastic 3-D print lines exposed.

6. Safety and Procedures

6.1 Safety and Environment (Vehicle and Payload)

At the moment, we have not had a 100% successful flight of our vehicle. Although neither of our flights has been catastrophic or hazardous to anything on the ground from our analysis, there are still open risk items for the vehicle. We may have a vehicle and payload reflight to demonstrate fixes for these problems, however each flight comes with its own risks to the project.

6.2 Hazard Analysis

6.2.1 Likelihood Scale

The likelihood of a hazard occurring

Value	Definition
E	Extremely Improbable
D	Extremely Remote
C	Remote
B	Probable
A	Frequent

Table 5: Likelihood Scale

6.2.2 Safety Severity Scale

The severity/damage of a hazard occurring

Value	Name	Definition of severity
5	Minimal	No risk of harm to people and/or permanent damage to equipment. Minor time or procedure setback.
4	Minor	Possible risk to personnel and/or damage to non-critical equipment. Time setback, possible cost to fix.
3	Major	Likely harm to people and/or damage to critical equipment. Time setback, cost to fix, injury.
2	Hazardous	Injury to people and/or critical damage/failures. Major project setbacks, cost impact, and injury. May result in disqualification if there is not enough time to fix critical failures.
1	Catastrophic	Major damage or injury and/or unable to continue competing.

Table 6: Safety Severity Scale

6.2.3 Total Risk Scale

The combination of both the likelihood and severity of a hazard to get an idea of the general risk (FAA Risk Matrix)

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	[Green]	[Yellow]	[Red]	[Red]	[Red]
Probable B	[Green]	[Yellow]	[Red]	[Red]	[Red]
Remote C	[Green]	[Yellow]	[Yellow]	[Red]	[Red]
Extremely Remote D	[Green]	[Green]	[Yellow]	[Yellow]	[Red]
Extremely Improbable E	[Green]	[Green]	[Green]	[Yellow]	[Red] *

High Risk [Red]

Medium Risk[Yellow]

Low Risk [Green]

* High Risk with Single Cause Failures

Figure 10: FAA 8040.4B Risk Matrix

Image Source: https://www.faa.gov/documentLibrary/media/Order/FAA_Order_8040.4B.pdf

6.2.4 Personnel Hazard Analysis

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**
Inhalation of noxious fumes (glue, paint, epoxy, etc.)	C4 Medium	Improper use or failure to use PPE	Irritation of the nose, throat, and lungs. Repetitive and high amounts of exposure can result in sensitization and asthma	Safety officer and mentor ensure the availability and use of PPE including personal respirators, and make sure the workspace is properly ventilated	Spare PPE will be on hand, everyone will be informed of what PPE is needed for a task, windows will be opened, fans will be on, some work must be done outdoors weather permitting
Glue/epoxy on skin	B5 Low	Failure to use gloves and unclean workspace	Skin tearing and burns	Make sure members wear gloves while handling glue and epoxy and keep the workspace clean	Workspace will be a clean flat surface, paper towels and other cleaning devices will always be on hand, excess gloves will be provided
Dust or debris in eyes	C4 Medium	Failure to wear eye protection during sanding, drilling, etc	Eye irritation	Ensure the availability and use of eye protection	Team members will use eye protection when doing anything where foreign objects have the potential to make contact with their eyes
Injury due to power tool misuse	D1 High	Loose clothing, untrained user, faulty equipment	Minor to severe injury, death	Regular inspection of power tools, train the member using the power tool, and proper attire, and make sure the user of the tool has read and understands the user manual	Have 2 members present while using any large or non hand held power tool, make sure everyone has PPE on, possible safety briefing before the operation
Inhalation of	C3	Failure to wear a	Irritation of the	Safety officer and mentor ensure	Fiberglass work done outside or in a

fiberglass dust	Medium	respirator/mask while working with fiberglass	airways	the use of respirator/mask, and that the space is properly ventilated	space that can be cleaned easily and is well ventilated or can be made semi open air, respirators provided when needed
Accidental ingestion of fiberglass dust	D4 Low	Failure to use gloves and wash hands after working with fiberglass	Throat and stomach irritation	Make sure members wash their hands after working with fiberglass and wear gloves during the work	Clean workspace after heavy fiberglass work, cover as much of your body as you can and wash your hands and arms afterwords
Electrocution	D1 High	Compromised power tools, power cords	Minor to major electric shock, death	Checking all power tools, cords, and outlets before use, make sure all members understand the danger of electricity	Safety officer will inspect any item with potential for serious electrocution injury before use
Collision with launch vehicle	C3 Medium	Failure of parachute or separation, vehicle stability, rail issue	Bruising or concussion	Ensure that the launch vehicle is inspected by the team safety officer, mentor, and RSO before launch, pay attention during launch, make sure heads up is given if the rocket lands near spectators	If any team member thinks the rocket is unfit to fly it will not be flown, if an unexpected mid flight event happens make sure everyone is aware of it
Motor explosion	D2 Medium	Unburned fuel, accidental ignition	Burns, asphyxiation, death	Make sure motor has fully burned out before recovering, keep potential ignition sources away from motor, motor only to be handled by the team mentor	The safety officer will be responsible for keeping the work space around motors safe.
Tripping hazard	C4 Medium	Messy workspace	Bruising, concussion	Always keep workspace tidy and clean up after each use	Safety officer will make sure there are no tripping hazards or make sure they are obvious and easily avoidable
Hypothermia, hyperthermia,	D4 Low	Improper attire, lack of water	Exhaustion, fainting,	Make sure members are properly dressed and have	Safety officer will inform team members what they need to wear/bring

dehydration				access to water	to launch the day before based off of weather forecast
Accidental black powder ignition	D2 Medium	Mishandling of black powder by improper personnel	Burns, hearing loss	Ensure black powder is kept away from potential fire/heat sources and all handling of black powder is done by team mentor	Any and all handling of black powder will be done by team mentor with PPE and in a non hazardous environment away from fire sources
Hearing damage	D4 Low	Improper distance from launch pad, failure to use hearing protection while using power equipment	Long or short term hearing loss	Make sure all team members stand the proper distance away from the launch pad during launch, ensure members wear ear protection when necessary	Spectating distance will be strictly enforced by the safety officer, ear protection will be available if needed during use of loud tools/equipment or launch
Fire	E2 Medium	Easily flammable materials at launch pad, heat sources in close proximity to flammable material	Burns, asphyxiation, death	Clear launch pad of flammable materials, make sure to separate flammable materials and heat sources in the workspace, keep a fire extinguisher nearby	Fire extinguisher will always be available at launch, depending on the launch the fire department will be notified of the launch beforehand, fire/flammable material will be kept out away from the rocket at launch

Table 7: Personnel Hazard Analysis

6.2.5 Environmental Hazards Analysis

Hazards caused by the environment:

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**
Accident caused by wind fluctuations	D5 Low	Unexpected wind fluctuation	Vehicle trajectory change to potentially cause accident	Check weather frequently before launch and if proper conditions are not met delay the launch.	The team safety officer will ensure the launch does not proceed if weather is unacceptable by referring to the weather plan.

Low cloud coverage at launchsite	D5 Low	Unsafe condition for launch due to loss of visibility	Interference or collision with aircraft, birds, humans	Follow RSO's instruction on when it's safe to launch	The launch will be prevented by the safety officer and RSO until it's safe to proceed
Landscape unconducive to safe and successful launch and recovery	C5 Low	Launch vehicle landing in trees, bushes, powerlines, across fast flowing/deep water, or on structures	Personal injury, damage to rocket, loss of rocket	Call power company if the launch vehicle lands on powerlines, call property owner to ask for help/permission to retrieve launch vehicle safely	We are very familiar with our launch sites and know who to call if we need assistance/permission retrieving a rocket
Rain	D5 Low	Rain affecting motor, trajectory, recovery of launch vehicle	Unsafe/unstable launch	Delay launch in heavy rain if necessary	Refer to the weather plan for procedures in light and heavy rain
Humidity	D5 Low	Parts swelling, parachute failure, adhesive improperly drying	Separation failure, unintended separation, recovery failure	Make sure humidity conditions are taken into account when building and launching launch vehicle	Avoid painting and similar tasks if humidity is too high, adjust part fitment if swelling occurs
Hail	E4 Low	Hail pieces damaging launch vehicle	Airframe damage, trajectory alteration, recovery failure	Postpone launch if hail storm is forecast	Check the weather forecast frequently before and during launch
Temperature	D5 Low	Air density changes with temperature	Launch vehicle trajectory change	Make sure to include the correct temperature in simulations	Input temperature data into flight simulations and act accordingly

Table 8: Environmental Hazards Analysis (Hazards caused by the environment)

Hazards to the environment:

Hazard	Risk	Cause	Effect	Mitigation	Verification
Pollution from motor	E5 Low	Fumes, smoke, and gasses from motor	Damaging local ecosystem at launch area	Choosing a launch site away from vulnerable ecosystem	None of our launches have resulted in ecological damage, we launch on primarily farm land after harvest
Pollution from vehicle parts	C5 Low	Parts unintentionally separating, launch vehicle landing in unrecoverable location	Damaging local ecosystem at launch area, unintentional littering	Make sure launch vehicle is structurally sound and assembled properly before launch, ensure enough space on the launch site for safe recovery	Team captain, team safety officer, and range safety officer will all conduct various checks that the vehicle is safe for flight, gps tracker will aid in recovery
Pollution caused directly by team members	C5 Low	Team members leave trash behind, don't clean up properly	Littering, damaging local ecosystem at launch area	Remind team members to pick up all garbage and other materials before leaving launchsite	All of our team members will pick up after themselves and other members, our goal is to leave no trace wherever we launch
Collision with property/buildings	E4 Low	Launch vehicle landing/crashing into buildings or property	Damage to property or buildings	Make sure there is enough space at the launch area for safe recovery	Conduct drift simulations to ensure the vehicle drift will not exceed the launch site recovery area.
Fire	E2 Medium	Motor not burning all the way before landing, unintended trajectory	Motor burning near flammable materials at launch or landing	Keeping flammables away from launchsite, and have a fire extinguisher ready incase of fire	Fire extinguisher will always be available at launch, depending on the launch the fire department will be notified of the launch beforehand
Wildlife damage	E4 Low	Launch vehicle striking birds during flight, colliding with other animals at lower altitudes or landing	Harm to local wildlife	Delay launch if birds are flying over launchsite, Launchpad placement away from animals/nests or burrows	It is uncommon to have large groups or regular flybys of birds at the launch sites we use, LCO will delay if there is high risk of a bird strike

Table 9: Environmental Hazards Analysis (Hazards to the environment)

6.2.6 Vehicle Failure Modes and Effects Analysis

6.2.6.1 Vehicle Failure Severity Scale

Separate severity scale for vehicle failure more focused on project setback and monetary setback
(the likelihood in this section is the same as the scale used above)

Value	**Name**	**Definition of severity**
5	Minimal	Unlikely to need much work or money to fix. Not likely to impact flight unless other problems occur.
4	Minor	Minor work or money needed to fix. Not likely to impact flight unless other problems occur.
3	Severe	Requires considerable amount of work or money to fix. Potential to negatively impact flight or fly-off.
2	Major	Major risk to program, major probability of failure to achieve mission goals. Very costly and time consuming fixes.
1	Catastrophic	Catastrophic to program or complete failure of fly-off objectives Program recovery extremely difficult or end-goal not met.

Table 10: Vehicle Failure Severity Scale

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**
Excessive landing speed	C4 Medium	Parachute torn, burned, tangled. Improper parachute size	Damage to vehicle and payload	Ensure that parachutes are properly packed, use correct parachute size Conduct extensive simulation of	Simulations and test flight demonstrate a safe landing velocity, defined in the SLI Handbook

				vehicle landing speed	
Fin damage	D3 Medium	Damage caused during previous flights, poor construction, improper materials used	Altered trajectory, unstable flight, resulting in damage or loss of vehicle	Stress test fins before flight, and ensure use of strong materials	The fins should remain structurally intact with no visible or audible damage, the fins are made of strong fiberglass and Rocketpoxy inner and outer fillets
No ejection	C1 High	Flight computer, ejection charge, or wiring malfunction	Loss of vehicle, potential damage to property, injury to humans	Use proper inspection and procedures when working on the dual deployment system	Refer to the pre launch procedures instructions for safe setup of ejection charges, black powder handled by mentor, ejection tests
Early separation	C2 High	Failure of motor, ejection charges, shear pins, or drag separation	Potential for loss of vehicle and damage to property	Conduct ejection tests, ensure ejection charges are properly prepared	Preflight shear pin test, accurate simulations, correct delay
Failure to separate	C1 High	Failure of shear pins, ejection charges, late ejection charge	Potential loss of vehicle and damage to property, injury to humans	Conduct ejection tests, ensure ejection charges are properly prepared, test separation fitment before flight	Ground ejection system testing, and proper ejection charge preparation, Refer to the recovery system preparation procedures section
Shock cord failure	D3 Medium	Shock cord improperly fastened, tangled, twisted	Unintended part separation, recovery failure,damage to or loss of vehicle, injury to humans	Double check that the shock cord can't get caught on anything, make sure the shock cord is properly secured and stress tested	Ejection ground test, preflight visual inspection and stress test, use shock cord rated for the expected forces, Make "Z" bundles wrapped in tape with the shock cords before inserting them into the rocket
Parachute damage	B4 Medium	Improperly folded, insufficient heat	Recovery failure, damage to or loss	Ensure proper folding and correct amount of heat protection	Consistency in the folding technique and folding pattern, measured and

		protection, poor quality parachute	of launch vehicle		consistent amount of cellulose housing insulation “dog barf”, and a Nomex blanket
Parachute deployment failure	C1 High	Improper fastening, tangled strings, ejection/separation failure, obstructions in deployment path	Excessive landing speed, damage to or loss of vehicle, damage to property or buildings, injury to humans	Properly fold and pack parachute, test ejection system, have a clear deployment path for the the parachute	Consistency in the folding technique and folding pattern, no obstructions for parachute by design, make sure shock cord is carefully packed
Rail button failure	C4 Low	Loose/tight rail buttons, misalignment, improper placement, Rail buttons/rail button standoffs breaking	Altered trajectory, damage to vehicle, prevention of flight	Make sure the rail buttons are in the correct position on the body of the launch vehicle and aligned correctly	Use of alignment tools and measurements during assembly, railbutton stress test, the rail buttons are screwed into a t-nut that is inside of the airframe, and raised by a 3d printed spacer. The nuts are epoxied in. We used separate, long screws for this.
Ignition failure	B5 Low	Malfunctioning motor, cheap igniter, corroded ignition cable/cable leads, no continuity	Unable to launch, late ignition, damage to vehicle	Use high quality igniters, buy motors from reliable sources, Don't use old cables	Ignitors and motors properly stored (and extras), motor purchases through verified and credible online sources (buyrocketmotors.com)
Forgotten or lost components	D2 Low	Not having all the components to successfully and safely launch the vehicle	Delays, unable to launch, unsafe launch, damage to or loss of vehicle	Have a check list of all components needed to launch	Item checklist verified and checked by safety officer and others if necessary
Motor expulsion	E2 Medium	Weak motor retainer, improperly constructed motor	Damage to or loss of vehicle, injury to humans	Use high quality motor retainers installed correctly, proper design and building of motor mount	Motor retainer stress test, test launches

		mount section			
Battery fire/hazard	D2 Medium	Catastrophic failure resulting in batteries being punctured	Battery catching on fire, exploding	Integrate batteries in a way that provides protection from potential punctures	Batteries are secure and protected from damage by design
Payload losing power	C4 Medium	Batteries disconnecting in flight, batteries dying before mission completion	Delays in project, mission failure if during launch week	Test battery connectors, battery life before first launch.	Prevent usage of old, damaged, or heavily used batteries, and use undamaged connectors
Camera failing to orient	B4 Medium	Jamming in orientation gears, failure of sensors, servos	Delays in project, mission failure if during launch week	Test all moving parts in a variety of situations before first launch.	Do a full range of motion test before launch, reliable design
Data storage failure	C4 Medium	Data storage device coming loose during launch	Failure for payload to operate, or save images	Stress test data storage retention system, use robust retention system	The use of sturdy materials and careful construction in the assembly of the retention system for the data storage

Table 11: Vehicle Failure Modes and Effects Analysis

6.2.7 Project Risk Analysis

Hazard	**Risk**	**Cause**	**Effect**	**Mitigation**	**Verification**
Lack of funding	D4 Low	Not doing enough fundraising/going over budget	Not having enough money/supplies to	Don’t leave fundraising until the last minute, be active throughout the program in finding new ways	At the FRR milestone, all expenses are covered except travel reimbursements. We are slightly over budget on STEM

			complete project and travel to launch	to fundraise	Engagement, cutting into travel reimbursements.
Part shortage	C3 Medium	Parts unavailable or taking a long time to ship	Any needed replacement parts may not be obtainable in the needed time frame.	Try to rule out / reduce the chances of needing new parts as soon as possible.	We should be finding and placing orders for replacements as soon as they are identified as necessary.
Rushed work	B3 High	Improper planning, poor management, or procrastination	Lower quality of reports, presentations, design, and hardware	Don't leave things until the last minute, follow a well thought out project plan	Delegate work and management early on, adapt plans as needed
Burnout	B5 High	Overworking for sustained amounts of time	Inability or unwillingness to complete work on time and to the quality needed.	Distribute the workload properly, take days off when needed, if possible. Keep the team motivated by taking time to enjoy the accomplishments we already have.	Identify when members are getting burnt out and remove dependencies on them, have more launches for fun (not necessarily sli project related)
Launch area issue	C3 Medium	Unable to find a suitable launch area, launch area unavailability	Inability to launch and test vehicle and payload	Make the best use of available launch windows.	We completed the VDF at the first available opportunity, and used the next opportunity to keep working on the payload and our launch procedures.
Transportation	D4 Low	Inability to find transportation for team members, materials, and launch vehicle	Delays, inability to build, test, and launch vehicle	Secure transportation and have backup if needed (or carpool)	During the FRR milestone, we have been able to get all members where they need to be.

Weather	B3 High	Weather (snow, heavy rain, storm, etc.) causing delays	Not being able to sufficiently test or fly hardware.	Leave extra time in the project timeline and schedule for delays, backup dates and locations. Identify how test objectives can still be achieved if weather is not permissible.	Have secondary launch dates or locations in case of cancellations
Members unavailable	B3 High	Poor planning, sickness, schedule conflict, or not enough members	Inability or delays to finish project deliverables	Make sure team members are reliable and have no reasons to be frequently busy when they are needed.	Schedule and confirm dates in advance for as many members as possible and have backup dates. Have back up plans to fulfill members' roles in the event they are not present.
Equipment issues	C4 Medium	Non functioning tools or a lack of the needed tools and equipment	Delays, inability to build, test, and launch vehicle	Identify tools that are needed early and make sure to keep them in functioning condition	Regular maintenance and care for equipment
Poor planning	B3 High	Poor time management, forgetting steps or deadlines in project plan	Working close to deadlines, missing deadlines, unable to finish project in time	Make sure project plan is reviewed by multiple members and is changed as needed throughout the project	All members will have an input on the schedule and timeline and changes can be made accordingly

Table 12: Project Risk Analysis

6.3 MSDS

Item Name	**Link to MSDS**
Epoxy	https://www.apogeerockets.com/downloads/MSDS/ROCKETPOXY_MSDS.pdf

Spray Paint	https://www.rustoleum.com/MSDS/ENGLISH/249114.pdf
Rocket Motor	https://www.apogeerockets.com/downloads/MSDS/Aerotech/Motors.pdf
CA Glue	https://www.highlandwoodworking.com/msds/ca-adhesives-msds.pdf
Igniter	https://www.apogeerockets.com/downloads/MSDS/Aerotech/Igniters.pdf
Black powder	https://goexpowder.com/wp-content/uploads/2018/05/sds-sheets-goex-black-powder.pdf

Table 13: MSDS

6.4 Materials / Packing list

Below are lists of the items to be brought to launches and build sessions

Most “small” tools will go in ‘Toolbox’ but bigger things like cordless drill won't fit, sandpaper, tape, etc, and bigger/yucky stuff go in ‘Black box’. Cameras and electronics equipment go in ‘Orange Box’

6.4.1 Safety Equipment

The Safety Officer is responsible for ensuring that the following items are on hand for assembly and launch.

√	**Item Name**	**Storage Location**
	Safety glasses	Shop
	Respirator	Shop
	Gloves	Shop
	Ear Protection	Shop
	First-aid kit	Shop
	Fire extinguisher	Shop

Table 14: Safety Equipment packing list

6.4.2 Tools and Parts

The Team leader is responsible for ensuring that the following items are on hand for assembly and launch.

√	**Item Name**	**Storage Location**
	Electric drill and bits	Toolbox
	Sandpaper	Black Box
	Scale	Black Box
	CA glue	Black Box

	Tape measure	Toolbox
	Masking tape	Black Box
	Duct tape	Toolbox
	Pliers	Toolbox
	Zip ties	Toolbox
	Hobby knife	Toolbox
	Screwdrivers/multi-bits	Toolbox
	Batteries	Toolbox
	Multimeter	Toolbox

Table 15: Tools and Parts packing list

6.4.3 Rocket Components

During travel, the vehicle will be assembled in an inert travel configuration. All parts should be put together to avoid misplacement.

√	**Item Name**
	Nose Cone
	Upper Airframe
	Avionics Bay & Payload
	Sustainer
	Main parachute
	Drogue parachute
	Reusable Nomex wadding
	Fireproof insulation
	Rocket motor
	Motor casing
	Motor retainer
	Recovery harness

	Shear pins
	Screws

Table 16: Rocket Components packing list

6.5 Procedures

Pre-launch procedures

1. Motor Preparation (No later than 24 hours before launch)

   PPE required: safety glasses, latex gloves

   a. Prepare motor hardware. Clean with warm soapy water. Dry.
   b. Sand cardboard of the motor reload grains with high grit sandpaper and clean surface.

c. Follow motor assembly instructions, but glue the grains into the liner with Elmer's All Purpose Glue-All Max. Do not install the ejection charge at this time.

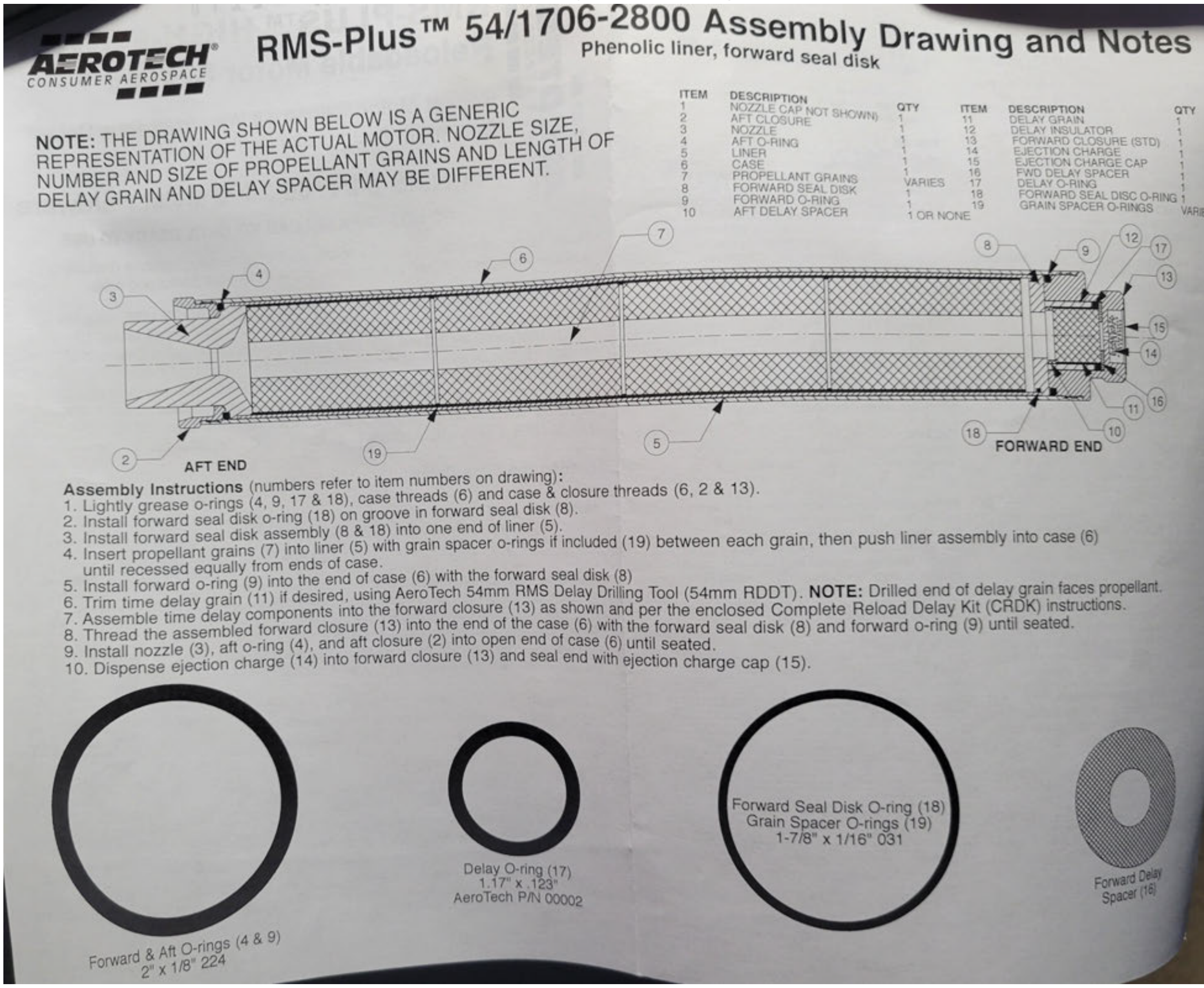


Figure 10: Motor assembly instructions

Aerotech 54/1706 RMS Checklist (to be completed by mentor and verified by team member)

1. Using dowel and paper towels, wipe the dust from inside phenolic liner
2. Grease all O-rings with Super Lube until shiny, avoid excess lube
3. Install forward seal disk O-ring to the groove in forward seal disk
4. Test fit all propellent grains in phenolic liner, avoid touching powder, peel glasine if too tight
5. Apply a thin layer of Elmer Glue All Max to the powder grains, avoid glue on grains
6. Insert powder grains in to the phenolic liner, twist as it is pushed in
7. Remove excess glue and insert nozzle

8. Rest the liner and grain on to the nozzle in vertical position, support the assembly while curing
9. Apply lube to front and back of the forward seal disk
10. Lightly grease inside liner and insert forward seal disk assembly to the phenolic liner
11. Let cure for 12 hours
12. Grease all threads (case, forward, and aft closure)
13. Apply liberal amount of lube to the outside of the phenolic liner
14. Insert phenolic liner in to the motor case
15. Chamfer one end with fingernail on delay grain sleeve in order to insert delay grain eas
16. Insert delay grain into the delay grain sleeve
17. Insert delay spacer so that the delay grain is proud
18. Attach the delay O-ring to the extended delay grain
19. Apply super lube to forward enclosure
20. Insert delay spacer seal disk in to the forward enclosure
21. Insert delay assembly in to the forward enclosure with the O-ring first
22. Verify that the cardboard delay spacer is visible in the forward enclosure
23. Insert forward O-ring
24. Insert the forward enclosure so that the delay spacer is touching the forward seal disk
25. Thread on the forward end cap
26. Insert aft nozzle
27. Insert and ensure the O-ring is seated
28. Grease the threads of the aft end cap
29. Thread on the aft end cap
30. Verify that there are no gaps with the forward and aft end caps
31. Store the assembled motor in a sealed metal container until launch day.

2. Pre-Assembly Preparation

a. Check flight computer software configurations. Ensure the parachute deployment altitudes are as they should be.
b. Install the flight computers onto their standoffs on the Avionics bay
c. Install and zip tie new flight computer 9v batteries
d. Install Payload computer
e. Install Payload Battery
f. Arm flight computers and ensure operation (ejection charges should not be connected)
g. Safe the dual deploy system and prepare for transport

h. Plug the payload arm cables into the computer
i. Mount the Arm and install the retaining screws.
j. Power on the payload and test all systems.
k. Shut off the payload and prepare the assembly for transport.

l. Test GPS tracker and reconfigure if necessary
m. Test radios and reconfigure if necessary

n. Install igniter for the ejection charge
o. Place the igniter in the charge well and insert fireproof cellulose insulation on top.
p. Have the mentor measure the black powder charges and place them in the charge case.
q. Securly tape over the charges.
r. Repeat for all four ejection charges.

s. Charge all batteries
t. Make Z Bundles with shock cord, wrapped in tape
u. Prepare rocket for transport

v. Pack for launch day according to the packing list.

3. Recovery System Preparation
    a. Install the battery into the nose cone tracker bay and power on the tracker.
    b. Close the nose cone tracker bay with 4 screws
    c. Fold the parachutes
    d. Pack the parachutes
    e. Ensure shock cord Z bundles are intact
    f. Insert the parachutes and shock cord into the airframe.
    g. Insert reusable Nomex wadding on the avionics bay side of the airframe
    h. Add fireproof insulation on the avionics bay side of the airframe
    i. Assemble the avionics bay and upper airframe with 4 screws
    j. Install 4 shear pins at the forward separation point
    k. Install 2 shear pins at the aft separation point
4. Assembly Checks
    a. Send the APRS Test command to the payload and observe if the performance is nominal.
    b. Try receiving the GPS tracker signals.
    c. Ensure airframe screws/shear pins are securely fastened.
5. Motor integration
    a. Install the motor closures.
    b. Place the motor into the rocket and screw on the motor retainer. Check good retention.
6. Pre-RSO
    a. Fill out RSO card
    b. Weigh individual rocket components
    c. Measure and document Center of gravity marker and center of pressure markers.
    d. Record ballast weight used
    e. Fill out SLI report form as needed
7. Take the rocket to the RSO table.

Launch Procedures

After all steps of pre-launch preparations are complete we are ready to begin launch operations.

1. Assign people to carry all necessary items for launch setup before the next loading cycle (where the pads are opened for rocket setup) starts.
2. When cleared to do so, walk out to the pad
3. The person on camera duty will place the cameras down
4. Inspect the pad
    a. Clean the rail if necessary
    b. Test the alligator clips for sparks
    c. Clean alligator clips with sandpaper if needed

5. Load the rocket onto the rail
6. Send the payload orientation command. This will position the payload to where it should be for flight and ensure the payload is still operational.
7. Check the GPS tracker downlink.
8. Make sure everyone except the person pulling the pin is clear of the pad and rocket for safety.
   a. Pull the remove before flight pin to arm the avionics.
9. Make the rocket vertical and lock the rail in place.
10. Install the ignitor.
11. Retest the alligator clips for sparks.
12. Connect alligator clips and t
13. If we want to take a team picture with the rocket, this is the time.
14. Leave the pad.
15. Maintain watch of visual indicators on the rocket until launch. Monitor the GPS tracker downlink until launch. If either of these stop working make sure the RSO does not send it. If permitted, do a run-out check to ensure the Stratologger altimeters are still powered up and on standby right before launch.
16. During launch, maintain visual track as well as possible, try to see where it lands.

Recovery

1. Check where it landed according to the GPS tracker.
2. Assess how many people should be sent to recover it based on the distance and weather.
   a. The team safety officer should implement the recovery safety plan at this time.
   b. This should include an assessment of temperature, humidity, distance needed to travel.
   c. Decide if it's safe for all members to go for recovery and if there are any additional precautions, such as bringing water and radios.
   d. The safety officer will deliver this report as a short briefing right after touchdown.
3. Recovery team waits for permission to recover from the range. Additionally waits for the expected payload operations to finish if this is not considered by the range.
4. Recovery team departs.
5. When the recovery team arrives, stop a distance away from the vehicle and observe the payload. If it is still operating, wait for it to finish.

Take images of: entire landing site, rocket motor retention, Runcam, Payload from all angles, aft ejection charges showing they are fired, drogue chute, drogue shock cord, main parachute, nose cone base, inside of upper airframe, upper ejection charge wells, and additional images of landing site.

6. Begin recovery process
7. Pack the parachutes and shock cords in their respective airframes.
8. Put the airframe components back together as best as can be reasonably done (there may be dirt or other debris preventing this).

9. Carry the vehicle to where instructed. This may be a recovery inspection area. Otherwise, back to our table.
10. Complete any inspections by the range if applicable, then return to our table.
11. **<u>Weigh sections of rocket for kinetic energy calculations.</u>**
12. Disassemble the vehicle. **<u>Take photographs of disassembly</u>**
    a. Ensure all ejection charges are fired. If they are not, carefully safe them by inserting the remove before flight pin disconnecting the ignitors.
    b. Disconnect the avionics bay from the recovery lines.
    c. Disconnect all batteries
    d. Remove the motor, remove liner and disposable components to trash bag.
    e. Disconnect quick links
    f. Pack vehicle into transport mode

Special Weather Procedures:

- Light Rain
    a. Continue procedures as normal with extra precautions. Have many towels nearby and take care not to get electronics or connectors wet.
    b. Take care to keep the rocket motor and black powder in a dry, sealed container as long as possible. Tape rocket motor nozzle once it's in the rocket to prevent moisture from entering.
    c. Keep the rocket covered when taking the rocket to the pad and cover for as long as possible before launch
- Heavy Rain
    a. Delay launch until rain either stops completely or turns into light rain
- Thunderstorms
    a. Follow safety instructions by launch officials
- Exceedingly High Wind
    a. Follow RSO instructions
    b. Do not launch if we believe there will be too much drift
- Bad Field Conditions (mud)
    a. Minimize team personnel walking in the field
    b. Bring towels to clean sensitive parts of rockets, mainly around electronic components.
    c. Rain boots if possible
- Cold Weather
    a. Dress warmly
    b. It’s unsafe to perform intricate and or critical tasks with cold and stiff hands, have someone take over your task momentarily while you warm up
- Hot Weather
    a. Stay hydrated
    b. Stay in the shade if possible (bring pop-up tent)
    c. Appropriate clothing
    d. Sun screen

7. Project Plan

7.1 Testing

- Prove that all testing is complete and provide test methodology and discussion of results.
- Discuss whether each test was successful or not.
- Discuss lessons learned from the tests conducted.
- Discuss any differences between predicted and actual results of the tests conducted.

7.2 Requirements Compliance

- Review and update the verification plan. Describe how each handbook requirement was verified using testing, analysis, demonstration, or inspection.
- Review and update the team derived requirements for the vehicle, recovery system, and payload. Describe how each team derived requirement was verified using testing, analysis, demonstration, or inspection.

Testing requirements

Requirement	Procedure	Verification
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	Test	All electrical components have been demonstrated to be on standby for more than 3 hours.
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.	Test	We have conducted several ejection tests to determine the size ejection charges we should use.

7.2.1 Management and Safety requirements

Item	Verification Method	Plan
Students on the team will do 100% of the project, including design, construction, written reports, presentations, 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.	Demonstration	Our team members will conduct all of the project work excluding hazardous work. Being a new team, we have no old work to reuse besides content created this year. We do not tolerate self plagiarism.
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.	Demonstration	Our team has met every goal and deadline to the best of our ability.
The team shall identify all team members who plan to attend Launch Week activities by the Critical Design Review (CDR). Team members will include:	Inspection	The travel roster was submitted on time.
Students actively engaged in the project throughout the entire year.	Demonstration	All current team members are fully engaged in the program.
One mentor/no more than two educators.	Inspection	Our team has the educators on file and the mentor identified in each report.
Teams shall engage a minimum of 250 participants in Educational Direct Engagement STEM activities in order to be eligible for STEM	Demonstration	Our team has created a program to engage a minimum of 360 students by distributing rocket kits and motors to schools and

Engagement scoring and awards. These activities can be conducted in person or virtually. To satisfy this requirement, all events shall occur between project acceptance and the FRR due date.		youth groups.
Teams will email all deliverables to the NASA project management team by the deadlines as they're specified	Demonstration	The team submits all work by deadline or by the end of deadline grace periods.
All deliverables shall be in PDF format.	Demonstration	The team captain will ensure all items are formatted properly before being submitted.
In every report, teams will provide a table of contents including major sections and their respective sub-sections.	Demonstration	We will continue including an accurate table of contents as we have in previous milestone reports.
In every report, the team will include the page number at the bottom of the page.	Demonstration	We continue to properly format the page layouts of our reports as we have in the previous milestones.
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.	Demonstration	Our team will act professional in regards to our presentation. The members giving the presentation will be dictated by their ability to attend practices, attend the final presentation, and exhibit professionalism surrounding the presentation.
Teams will track and report the number of hours spent working on each milestone.	Demonstration	We continue to track and report the number of man hours spent on each milestone.
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.	Demonstration	We compiled a draft of our checklists in the CDR and continued developing them before, during, and after both full scale flights.

Each team shall identify a student safety officer.	Inspection	The safety officer was identified in the proposal and later.
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 communicate their intentions to the local club's President or Prefect and RSO before attending any NAR or TRA launch.	Demonstration	All of our launches have been conducted with authorization from the launch site.
Teams will abide by all rules set forth by the FAA.	Inspection	The safety officer has outlined an extensive safety plan in each of the milestone reviews that include FAA rule compliance statements. Additionally, the launch site we fly at complies with all FAA requirements.

Table 17: Requirements Compliance Management and Safety requirements

7.2.2 Vehicle requirements

Item	Verification Method	Plan
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 degrees away from the crowd on Launch Day. The exact cant will depend on Launch Day wind conditions.	Inspection	The built launch vehicle has been verified to meet all requirements.
The vehicle will deliver the payload to an apogee altitude between 3,500 and 5,500 feet above ground level (AGL). Teams	Test	Our vehicle has demonstrated in flights that it complies with this rule by reaching no less than

flying below 3,000 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.		3,575 ft.
Teams shall declare their target altitude goal at the PDR milestone. The declared target altitude will be used to determine the team's altitude score.	Inspection	Our altitude target was declared in the PDR as 3,800 ft.
The launch vehicle will be designed to be recoverable and reusable. Reusable is defined as being able to launch again on the same day without repairs or modifications.	Demonstration	The vehicle is designed to comply with this rule and has been verified as nominally reflyable the same-day.
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.	Inspection	Our as-built vehicle has three parts. Sustainer, payload/avionics bay/upper airframe, and nose cone.
Coupler/airframe shoulders which are located at in-flight separation points will be at least 2 airframe diameters in length. (One body diameter of surface contact with each airframe section).	Inspection	The vehicle is designed to have over 4 inches of coupler at each separation point.
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.	Demonstration	Both of our full scale launches have taken less than 2 hours to prepare after work begins.
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.	Inspection / Demonstration	All electrical systems on our rocket have been demonstrated to last at least 3 hours.
Motor requirements	Inspection	We fly the Aerotech K1100 rocket motor which meets all motor, ignitor, and ground

		support equipment requirements.
Pressure vessel requirements	Inspection	Our team does not use any pressure vessels on our vehicle.
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 button loses contact with the rail.	Analysis	Our stability margin on both Full scale flights has been approximately 2.3 calibers.
The launch vehicle will have a minimum thrust to weight ratio of 5.0 : 1.0.	Analysis	The vehicles current TWR is 11.4:1
Any structural protuberance on the rocket will be located aft of the burnout center of gravity.	Inspection	The vehicle is built and flown with the CG above our protuberances in the wet configuration. Burnout only increases this.
The launch vehicle will accelerate to a minimum velocity of 52 fps at rail exit.	Inspection	Our most recent full scale flight had a rail exit velocity of 83.4 ft/s
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 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.).	Demonstration	The designed-final configuration of the vehicle was flown and recovered. However, an undersized drogue parachute caused problems resulting in damage. We will re-fly the vehicle with a larger drogue parachute to comply with this. All other systems of the vehicle functioned as intended.
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	Demonstration	The full scale flights were both conducted with these devices, or simulators of them, installed.

systems will be active during the full-scale Vehicle Demonstration Flight.		
Teams shall fly the competition launch motor for the Vehicle Demonstration Flight.	Demonstration	All of our flights have been conducted with the K1100T motor which we intend to fly at launch week.
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.	Demonstration	Both full scale flights have been conducted with the same ballast without issue.
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).	Demonstration	The team captain will be responsible for ensuring there are no changes without proper approval.
Proof of a successful flight shall be supplied in the FRR report.	Demonstration	We have reported on the flights we have conducted.
Quality pictures of the as landed configuration of all sections of the launch vehicle shall be included in the FRR report. This includes but not limited to nosecone, recovery system, airframe, and booster.	Demonstration	Extensive photographic documentation of the landing configurations from our flights are supplied in the FRR.
Vehicle Demonstration flights shall be completed by the FRR submission deadline.	Demonstration	We have completed two flight tests prior to the FRR.
All teams will successfully launch and recover their full-scale rocket containing the completed payload prior to the Payload Demonstration Flight deadline.	Demonstration	We have launched and recovered the final payload hardware prior to the FRR.
Payload Demonstration Flight—All teams will successfully launch and recover their full-scale rocket containing the completed	Demonstration	The payload demonstration flights will be conducted prior to the payload demonstration

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.		flight deadline.
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.	Demonstration	We have demonstrated successful payload retention on both of our current full scale flights.
The payload flown shall be the final, active version.	Demonstration	The current payload hardware has been flown. The final payload hardware will be flown and operated prior to the Payload Demonstration Flight Deadline.
Payload Demonstration Flights shall be completed by the FRR Addendum deadline.	Demonstration	Our team will ensure the payload demonstration flight is conducted.
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.	Demonstration	The team captain will ensure this requirement is met at the final competition launch.
All Lithium Polymer batteries will be sufficiently protected from impact with the ground and will be brightly	Demonstration	All Lipo batteries on the vehicle are brightly colored and sufficiently protected,

colored, clearly marked as a fire hazard, and easily distinguishable from other payload hardware.		
Vehicle Prohibitions	Inspection	The vehicle is designed to comply with all of these rules. Evidence of compliance can be found in milestone documentation.
Transmissions from onboard transmitters, which are active at any point prior to landing, will not exceed 250 mW of power (per transmitter).	Inspection	Our vehicle's only transmitter, the GPS tracker, uses 100mW of power.
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.	Inspection	Our team's transmitter uses a ham radio frequency to reduce the chances of causing or receiving interference.
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.	Inspection	The as-built vehicle complies with this rule.
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.	Inspection	The vehicle has completed ejection tests and has completed flights in this configuration.
The main parachute shall be deployed no lower than 500 feet.	Demonstration	The main parachute ejection charge fires at 550 feet, with the backup at 500 feet.
The apogee event may contain a delay of no more than 2 seconds.	Demonstration	The drogue parachute ejection charge fires at 0 seconds, with a backup at 1 second.
Motor ejection is not a permissible form of primary or secondary deployment.	Demonstration	The motor ejection charge has not been installed on either of our flights.
Each team will perform a successful	Demonstration	We have completed these

ground ejection test for all electronically initiated recovery events prior to the initial flights of the subscale and full scale vehicles.		ejection charge tests to ensure safety and to determine the ejection charge sizes needed for our vehicle.
Each independent section of the launch vehicle will have a maximum kinetic energy of 75 ft-lbf at landing.	Inspection	The vehicle sections have been verified to have a landing kinetic energy not exceeding 58 ft-lbf during our test flights.
The recovery system will contain redundant, commercially available barometric altimeters that are specifically designed for initiation of rocketry recovery events.	Inspection	The vehicle uses two fully independent Stratologger CF systems, including independent batteries and switches to control
Each arming switch will be capable of being locked in the ON position for launch (i.e. cannot be disarmed due to flight forces).	Demonstration	The switches we are using are spring loaded to be in the on position and thus are not expected to power off.
The recovery system, GPS and altimeters, electrical circuits will be completely independent of any payload electrical circuits.	Inspection	Our as-built vehicle demonstrates that all electronic components of the vehicle use fully independent power supplies.
Removable shear pins will be used for both the main parachute compartment and the drogue parachute compartment.	Demonstration	Our as-built vehicle uses two shear pins on the drogue parachute separation point of the vehicle, and four shear pins on the main parachute separation point of the vehicle.
The recovery area will be limited to a 2,500 ft. radius from the launch pads.	Inspection	In our full scale flights, the vehicle remains in-line with our expected drift figures, which do not exceed 2,500 feet.
Descent time of the launch vehicle will be limited to 90 seconds (apogee to touch down). Teams whose launch vehicle descent, as verified by vehicle demonstration flight data, stays under 80 seconds will be awarded bonus points.	Demonstration	Our full scale flights have both had a descent time under 80 seconds.
An electronic GPS tracking device will be	Inspection	Our GPS tracker has been

installed in the launch vehicle and will transmit the position of the tethered vehicle or any independent section to a ground receiver.		documented in reports and flown in both full scale vehicle flights.
Any rocket section or payload component, which lands untethered to the launch vehicle, will contain an active electronic GPS tracking device.	Inspection	The vehicle contains one tracker for the entire vehicle, which contains no untethered components.
The recovery system electronics will not be adversely affected by any other on-board electronic devices during flight (from launch until landing).	Inspection	The tracker is physically distanced from the flight control electronics. Additionally, copper shielding is installed in several places to protect against this. We have not encountered effects from interference in our full scale flights.

Table 18: Requirements Compliance Vehicle requirements

7.3 Team derived requirements

7.3.1 Vehicle Requirements

The requirements we as a team want to achieve are the following: a vehicle we can use to achieve five or more successful flights, it needs to have a center of gravity no more than 65” measured from the top of the vehicle to comply with the rules for external housings.

7.3.2 Recovery Requirements

We’re looking for two things from our recovery system: survivability and reliability. We want our recovery system to be able to survive non-catastrophic anomalies, such as slightly early or late parachute deployments.

7.3.3 Payload Requirements

Our team is participating in the USLI Payload challenge. In addition to the requirements set in the handbook section for this challenge, we aim to have a payload that accomplishes the requirements in the simplest way, while not impacting our launch vehicle drastically.

7.3.4 Team derived requirements compliance

Requirement	Verification Method	Plan
Center of gravity less than 65” from top of vehicle	Demonstration	Our as-built vehicle has its center of gravity 63” from the top of the vehicle
Vehicle reusable up to at least 5 flights.	Analysis	Our vehicle is designed and built to be extremely rugged under nominal conditions, and even after suboptimal flights can be repairable and reflown.
Durable recovery system	Analysis	The parachute and other recovery system components have been observed to have sustained minimal to no damage two flights and many ejection tests.
Payload simplicity	Analysis	The success of our payload will have to be analyzed after the end of the mission to decide if we achieved our goal of keeping it as simple as possible.

Table 19: Team derived requirements compliance

7.4 Budgeting and Funding Summary

The line item budget contains all current material expenses. As stated from the start, most of the final flight hardware will not be reimbursed as to keep ownership of it to the members after the competition ends. However, consumables and the STEM engagement are paid by the team's funding. The remaining funding we have will be used for travel reimbursements for the members going to Huntsville in April, of which we have approximately $10k for.

Fullscale:	
13" Nomex Blanket - 4" (98mm) Airframe × 2	$35.20
Iris Ultra 48" Standard Parachute - 12.5lb @ 20fps	$162.01
24" (15.28" Diameter) Hemispherical Spherachute - Heavy Duty	$32.25
FCR4.0-2.1	$20.79
G12-4.0 48" Body Tube	$92.47
G12-4.0 32" Body Tube	$58.41
4" 3/8" Tubular Kevlar Harness W/ 3 Sewn Loops 30 ft set	$75.05
FNC4.0-4.5-1-VK-FW-MT Nose Cone	$68.31
G12CT-4.0 x 12	$30.84
av-bay lid 98mm x 3	$59.40
G12-2.1 12" Coupler	$14.26
54MM U-BOLT x 4	$15.20
G10-1/8 12' x 12" Sheets for Fins	$89.10
70cm 100mw GPS/APRS Transmitter	$285.00

Consumables:	
Aerotech K1100T-14A Blue Thunder x 4	$503.96
Aerotech G80-14A New Blue Thunder 29 mm - DMS x 3	$87.72

Stem Program:	
30 Gnome Rocket Education Pack, 120 Estes 1/2A Motors	$2,400.00

Subscale:	
IRIS 2.26″ - 29 mmt	$68.56

BT-2.14 Electronics bay	$8.98

Hardware:	
Spray Paint	$176
Jig Supplies	$120
3D Printer PETG Plastic	$120
Misc Hardware	$45

Shipping Costs	$266.80

Total:	$4,835.31

Table 20: Line Item Budget