Ram Launch Initiative Team
Colorado State University

Colorado State University
Department of Mechanical Engineering
1374 Campus Delivery
Fort Collins, CO 80523-1374
April 14, 2025

Introduction

NASA University Student Launch Initiative (USLI) is a nationwide competition that challenges university students to design, build, and launch a high-powered rocket with a scientific or engineering payload. This rigorous program provides students with valuable hands-on experience in aerospace engineering, project management, and teamwork while also requiring them to meet specific NASA and team-derived requirements. The competition culminates in a launch week in Huntsville, Alabama, where teams showcase their year-long efforts. Participation in USLI fosters innovation and prepares the next generation of scientists and engineers for the challenges of space exploration and related fields.

Ram Launch Initiative (RLI) is a student team from the Colorado State University (CSU) Department of Mechanical Engineering participating in the 2025 NASA USLI competition. For this competition year, the RLI team is designing, fabricating, and testing a high-powered rocket that has a 6 in. diameter, is 12 feet tall, and uses a dual-deploy recovery system. The launch vehicle is comprised of three independent sections: a forward/payload section, an avionics bay, and a booster section. The RLI launch vehicle has the mission of meeting the requirements set forth by NASA and the team for the 2025 Student Launch competition, with a strong emphasis on safety, successful recovery, and mission reliability. The vehicle is designed to achieve a target apogee of 4,600 ft (±85 ft) and ensure the safe return of both the vehicle and its payload.

The primary mission of the RLI payload, the Rocket-borne Analytical Messenger-transmitter (RAMsmitter), is to collect and transmit key flight data and landing site conditions while also housing four LEGO STEMnauts. Specifically, it is designed to gather and relay the vehicle's maximum velocity, time of landing, apogee reached, and the temperature of the landing site.

Vehicle Mission

The mission of the RLI launch vehicle is to successfully meet the stringent requirements of the 2025 NASA USLI competition. This encompasses not only achieving specific performance targets but also prioritizing safety, ensuring successful recovery for reusability, and maintaining mission reliability. Additionally, the vehicle is designed for ease of manufacturing and assembly, allowing for launch preparations within the competition's two-hour window, and to prevent interference with payload transmissions after landing.

Requirements & Success Criteria

The launch vehicle's design and operation are guided by a set of NASA and team-derived requirements. The success of the launch vehicle will be evaluated based on several criteria, including reaching an apogee within ±2% of the target of 4,600 ft (±85 ft), achieving or exceeding a minimum exit rail velocity of 52 ft/sec, and being assembled for launch within 1.5 hours.

Furthermore, the success criteria includes the altimeters recording the complete flight profile, the drogue parachute deploying at apogee, and the main parachute deploying at 700 ft ±50 ft. The vehicle is also designed to be recoverable and reusable, with each independent section having a maximum kinetic energy of 75 ft-lbf at landing.

Forward Section Design

The forward section of the RLI vehicle is a crucial element that contributes to aerodynamic performance, structural integrity, and houses both the main recovery parachute and the payload flight capsule containing the STEMnauts. This section is comprised of the nosecone, nosecone coupler, and the forward section airframe, which are fastened together with 10-32 screws. The primary payload bulkhead within this section supports the payload and serves as the recovery point for the main parachute. The nosecone coupler and airframe have a contact length of 5 7/8 inches, meeting the requirement for non-in-flight separation points. Figure 1 displays the forward section of the RLI vehicle, including the payload integration.

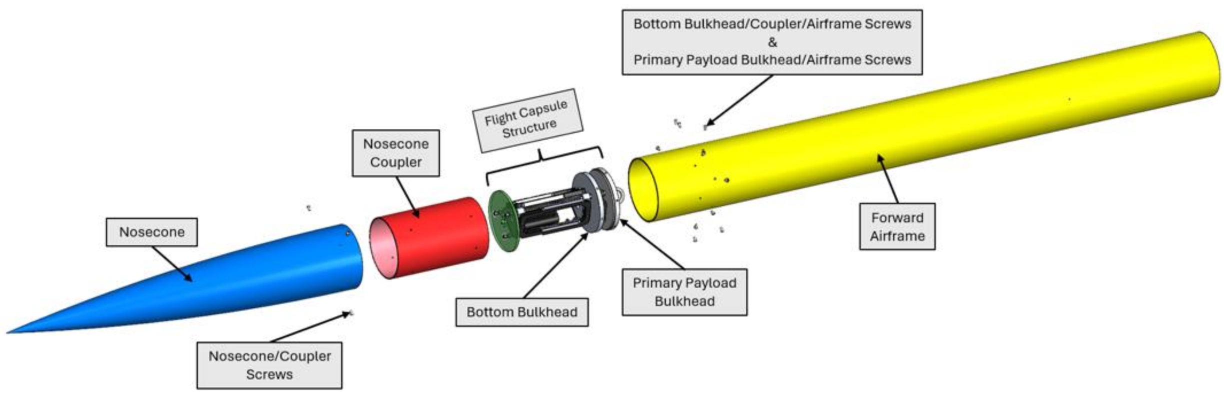


Figure 1: Forward Section Explosion with Payload

Booster Section Design

The booster section provides the primary propulsion for the vehicle through an off-the-shelf motor and is displayed in a CAD exploded view in Figure 2 below.

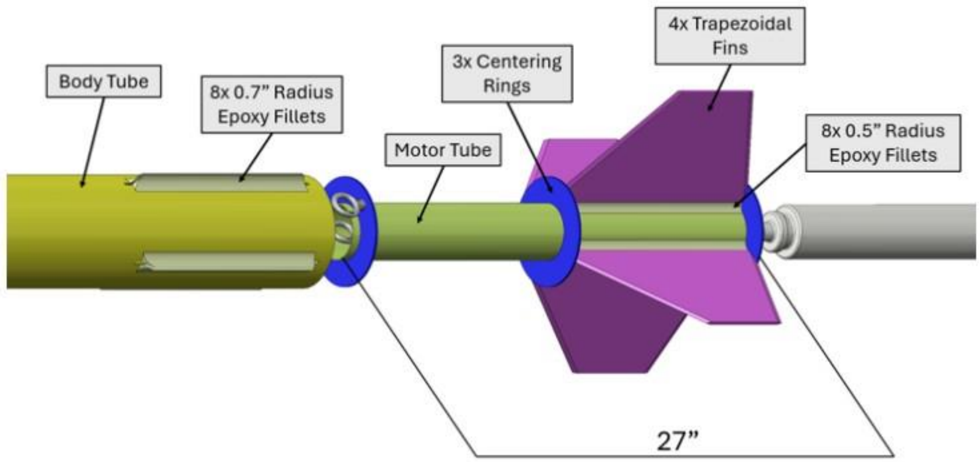


Figure 2: Booster Section CAD Exploded View

For the final launch, an AeroTech L2200G-PS Mojave Green motor with a total impulse of 5,104 N-sec is used. This section also houses the drogue parachute and associated recovery components. Stability during flight is ensured by a set of four trapezoidal G10 fiberglass fins epoxied to the aft airframe. The booster section also includes centering rings and a motor mount tube, all integrated within the airframe. The forward end of the booster section serves as one of the vehicle's separation points at the avionics bay.

Recovery System Design

The RLI vehicle employs a traditional dual deployment recovery system for safe and reusable landings. This system involves two distinct parachute deployments: a 22.92-inch hemispherical drogue parachute deployed at apogee to stabilize the vehicle and control its descent rate, and a 156-inch custom hemispherical main parachute deployed at 700 ft Above Ground Level to further slow the descent for a gentle landing. Within 90 seconds from apogee, all sections of the rocket will land with less than 75 ft-lbf of kinetic energy and within a 2,500 ft. radius of the launch pad. The concept of operations (CONOPS) of the recovery system can be seen in Figure 3.

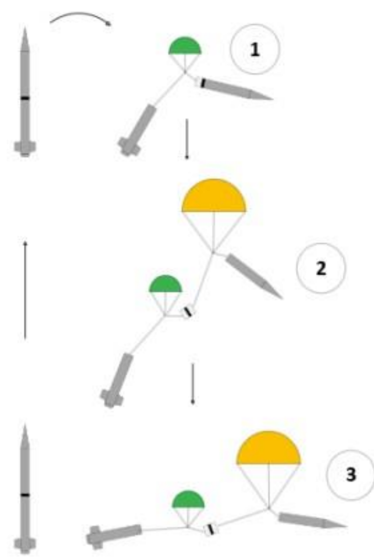


Figure 3: Recovery CONOPS

The drogue parachute is housed in the booster section, tethering it to the avionics bay via a shock cord and a 3-point harness on the forward most centering ring. The main parachute is located in the forward section and is connected to the avionics bay by its own shock cord. Both parachutes are packed in Nomex blankets for protection from ejection charges. Removable shear pins are used at the separation points for both the main and drogue parachute compartments to prevent premature deployment.

Avionics System Design

The recovery avionics subsystem is critical for initiating the dual deployment sequence and providing GPS tracking. The avionics bay, located between the forward and booster sections, houses two redundant Missile Works RRC3+ barometric altimeters with independent power circuits for reliability. The primary altimeter is programmed to deploy the drogue parachute at apogee and the main parachute at 700 ft, with the secondary altimeter providing a one-second delay for redundancy. A Featherweight GPS tracker, mounted outside the avionics bay in a 3D-printed capsule on the booster shock cord, transmits real-time flight data to a ground station. The avionics bay is enclosed in copper mesh shielding to mitigate radio frequency interference. The separation events for parachute deployment are triggered by ejection charges located in wells on the forward and aft bulkheads of the avionics bay. The avionics bay is shown as a section view in Figure 4.

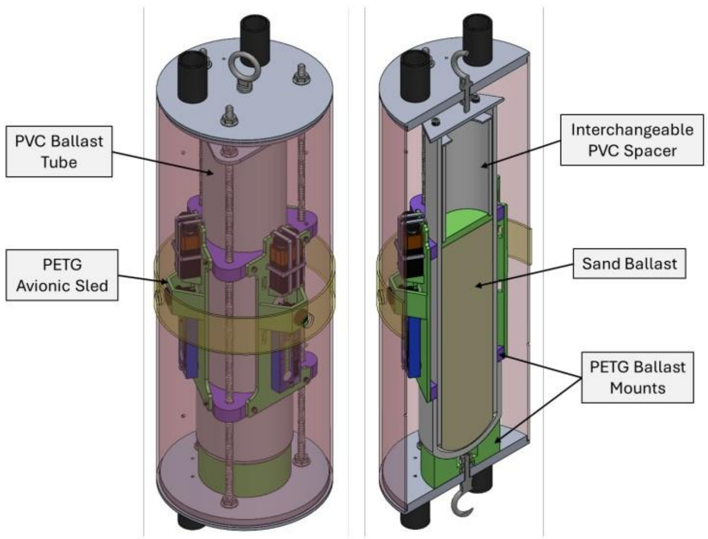


Figure 4: Avionics Bay Section View

Payload Mission

The mission of the RAMsmitter, the payload for the RLI team's rocket, is to collect critical in-flight data and landing site information during the 2025 NASA USLI competition while also safely housing four STEMnauts. The payload is designed to gather data on the vehicle's maximum velocity, apogee reached, time of landing, and the temperature of the landing site. This collected data is then intended to be transmitted to a ground station.

Requirements & Success Criteria

The success of the payload mission is judged against several criteria. The recorded maximum velocity must be within 10% of the maximum velocity recorded by the vehicle's altimeters, and the apogee recorded by the payload must be within ±50 ft of the altimeter's reading. The time of landing reported by the payload must be within 5 seconds of the observed landing time, and the landing site temperature measured by the payload should be within ±5°F of the reported temperature at the launch site. Furthermore, all transmitted data points must be legibly received by the RLI team's receiver at the launch site on the 144.39 MHz frequency using Frequency Shift Keying (FSK) modulation. Finally, the four STEMnauts must remain safely retained within the flight capsule throughout the entire duration of the flight.

Flight Capsule Design

The flight capsule serves as the primary housing for all payload electronics and the four STEMnauts during flight. The design prioritizes accessibility, robustness, and adaptability. It consists of two aluminum bulkheads (primary and secondary) fastened to the forward airframe and nosecone coupler with twelve 10-32 screws, providing structural integrity to the vehicle. Three steel threaded rods act as the main structural elements, supporting the bulkheads and two triangular mounting brackets that hold the electronics sleds. Components are secured to the threaded rods with hex nuts and to the sleds with M3 screws. The STEMnauts are housed within a dedicated STEMnaut capsule located between the two bulkheads. The full-scale flight capsule CAD model is shown in Figure 5.

Figure 5: Full-Scale Exploded Payload CAD Model

Sensors Design

The payload's sensors array is responsible for collecting the required flight data. It includes a BMP384 barometer to measure altitude and, consequently, determine apogee and maximum velocity. A PCF8523 Real Time Clock (RTC) is used to record the time of landing. Three negative temperature coefficient (NTC) thermistors measure the average temperature of the landing site. These sensors are controlled and managed by a Teensy 4.1 microcontroller, which also handles data logging to an onboard micro-SD card. Shown in Figure 6 is the sensor design.

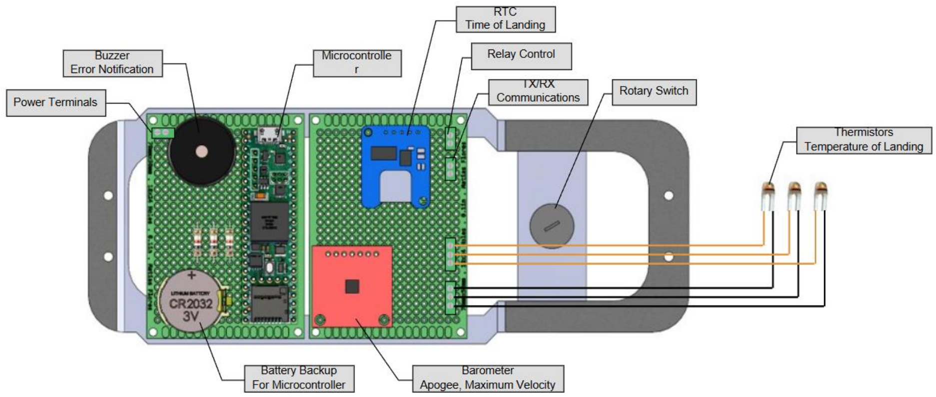


Figure 6: Sensor Design

Transmission System Design

The transmission system is designed to relay the collected data to the RLI team's ground station after landing. The core component is a Semtech SX1276MB1MAS transceiver, which operates on the 144.39 MHz frequency. Data is transmitted using FSK modulation. A 15-inch smooth gooseneck antenna is used for transmitting the collected data. A STMicroelectronics NUCLEO F446RE microcontroller controls the transmission process and is connected to the Teensy 4.1 microcontroller to receive the data that was collected from the sensors. The antenna is mounted on the top payload bulkhead which was 3D printed from a nonconductive material. The transmitted data is formatted using the AX.25 encoding protocol and includes the team's call sign. Transmissions are programmed to occur only after landing and will be shut off after five minutes by a relay. The transmission sled is shown in Figure 7, and Figure 8 shows the flow chart for the transmission system.

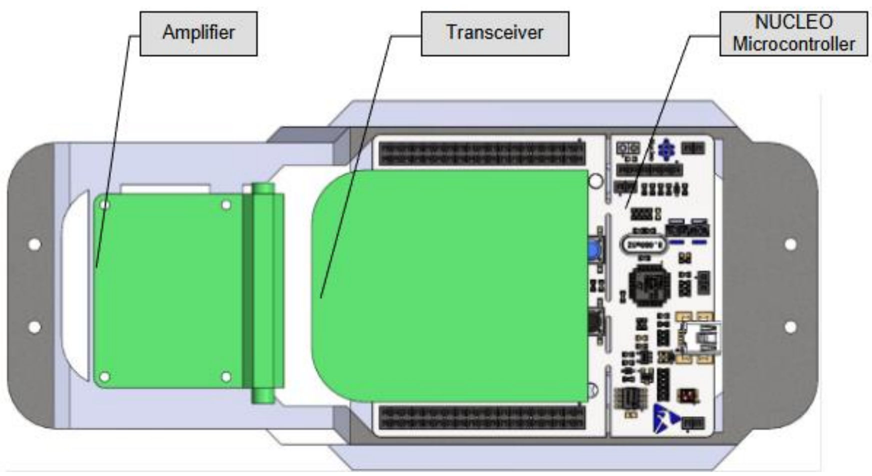


Figure 7: Transmission Sled

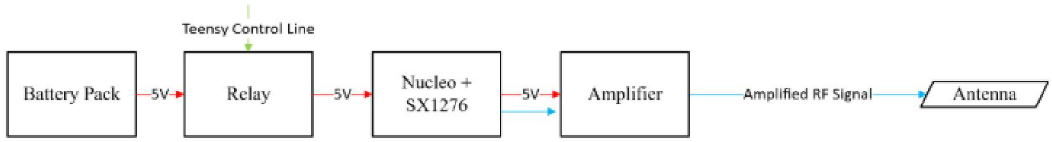


Figure 8: Transmission Component Flow Chart

Power System Design

The payload is equipped with an independent power system to ensure functionality throughout the mission. Power components, including the battery back, are mounted on a dedicated power sled within the flight capsule for easy connection and management. A relay will be used to shut off the power after five minutes of transmission. The relay and battery pack are mounted to allow the payload to remain powered on for the duration of being on the launch pad, during launch, and after launch. Wiring connections are shown in Figure 9 for the sensors, power, and transmission system integration.

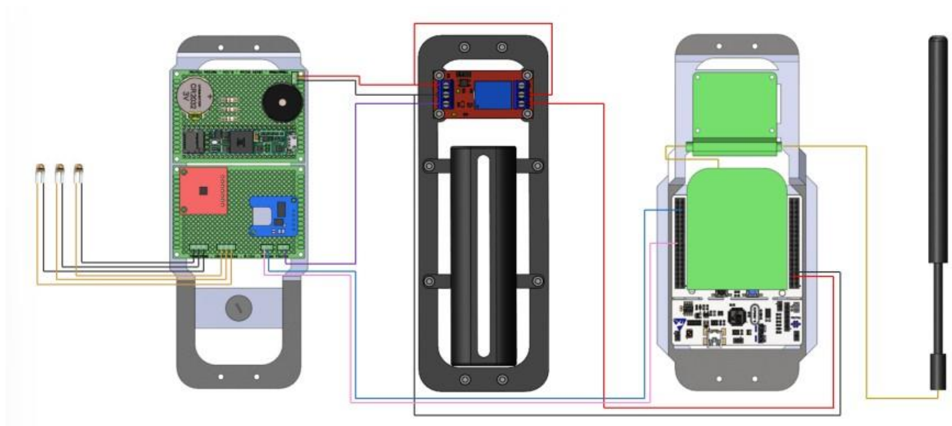


Figure 9: Payload Inter-Sled Wiring

Systems Integration

The RAMsmitter comprises of these subsystems: the flight capsule, the sensors array, the power system, and the transmission system. The full design is shown in Figure 10. The flight capsule provides the physical structure and housing for the sensor, power, and transmission subsystems with four STEMnauts. The sensors array, mounted on its own sled, collects the necessary flight data and communicates with the Teensy microcontroller within the flight capsule. The transmission system, also mounted on a sled, receives the processed data from the microcontroller and transmits it via the antenna, which is mounted to the top bulkhead. The power system provides the necessary electrical energy for all payload components to operate throughout the mission, with wiring connections between the sleds and components from the battery pack and relay. Ground testing is conducted to verify the functionality of the integrated system before launch with testing of each electronic component to verify accuracy.

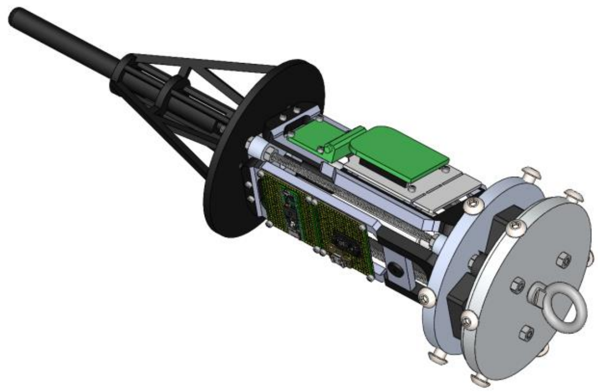


Figure 10: Full Payload Design

Flight Results

Subscale Flight 1

Subscale Flight 1 (SSF1) was conducted on October 20, 2024, at the SCORE launch site in Pueblo, Colorado. The primary aim of this flight was to provide the RLI team with hands-on experience designing and constructing a high-powered rocket while testing initial design concepts, specifically the dual deployment recovery systems, RRC3+ altimeters, and Featherweight GPS hardware. The 1/2 scale vehicle, measuring 3 inches in diameter and 5 feet in length, was powered by an Aerotech J-415W motor and successfully achieved an apogee of 5,811 ft. The rocket experienced a safe, non-destructive recovery after 84 seconds of flight, although it drifted approximately 3,300 ft and landed in a tree, which complicated data collection. Overall, SSF1 provided valuable insights into the team's design and operational processes.

Subscale Flight 2

Subscale Flight 2 (SSF2) was intended to replicate the full-scale vehicle more closely and included the integration of a scaled-down flight capsule to test components and software. This 4-inch diameter, 93-inch-long vehicle utilized a more traditional through-the-wall fin assembly, replacing the end-slot method used in SSF1. Launched on December 7, 2024, SSF2 took approximately 1 hour and 20 minutes to assemble, integrate, and arm at the launch site. The flight demonstrated no visual malfunctions and maintained a relatively straight trajectory. The full recovery subsystem was successfully demonstrated, with the drogue parachute deploying at apogee and the main parachute deploying at 900 ft, resulting in all vehicle sections landing safely with no damage. Data collected from the RRC3+ altimeters was compared with OpenRocket simulations, providing valuable information on aerodynamic and recovery performance, and contributing to the estimation of the full-scale drag coefficient. The successful flight of SSF2 confirmed the vehicle design's ability to retain a payload and validated the scaling approach for the full-scale vehicle.

Vehicle Demonstration Flight

The first full-scale flight, the Vehicle Demonstration Flight (VDF), took place on February 1st. During this flight, the vehicle reached an apogee of 4,465 ft. The vehicle employed a dual deployment recovery system, with the drogue parachute deploying at apogee and the main parachute deploying at 1,000 ft. Post-flight analysis compared the recorded altitude and velocity data with OpenRocket simulations, revealing some discrepancies in descent rates potentially due to the larger full-scale rocket producing more drag than the subscale model.

An issue encountered during recovery was that the main shock cord became partially wrapped around the canopy of the main parachute as it was inflating, which caused the Nomex blanket to become separated from the shock cord. The VDF served as a crucial step in validating the full-scale vehicle's design and performance. Figure 11 shows the flight profile graph using data from the primary and second altimeters that were onboard during the flight. These profiles were overlaid with simulation flight data obtained through OpenRocket.

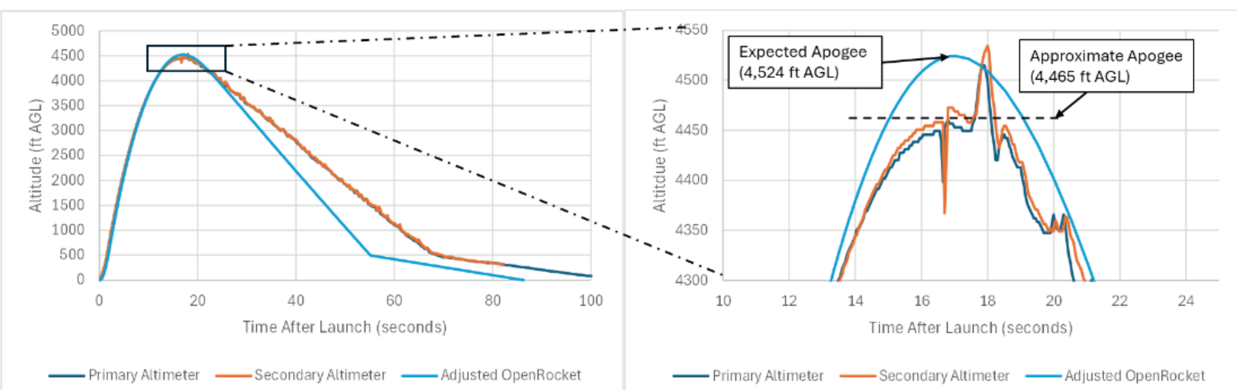


Figure 11. VDF1 Flight Profiles

Payload Demonstration Flight

The Payload Demonstration Flight (PDF) was conducted on Saturday, April 5th, at the NCR North Launch Site that is North of Briggsdale, Colorado. This launch was conducted to fly the complete and functional payload to verify the functionality of the sensors, transmission system, and the safety of the retention system with the integration within the vehicle. The payload during the PDF was able to collect the time of landing, temperature of the landing site, maximum velocity of the vehicle, and apogee reached. For data collected, see Figures 12 to 14.

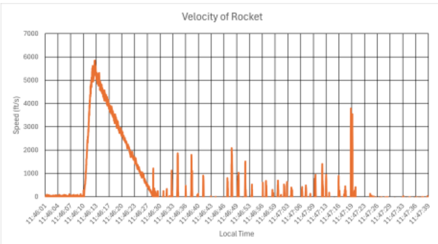
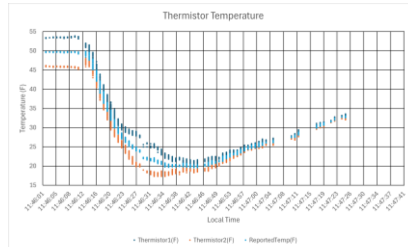


Figure 12: Velocity of the Rocket

Figure 13: Temperature Collected



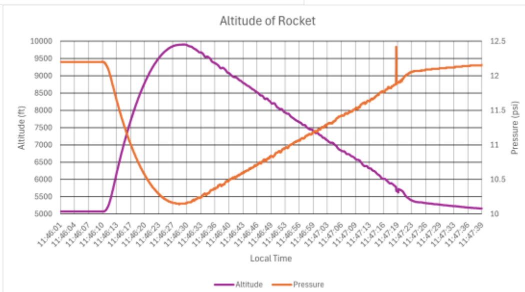


Figure 14: Apogee Reached

The data from the payload's sensors at the PDF was collected but contained errors in calculating maximum velocity due to time sampling issues, as indicated in Figure 12. The RLI team will test to optimize sampling rates. Before the PDF flight, the payload successfully transmitted sensor data, verified by transmissions received on the ground computer, with raw data shown in Figure 15.

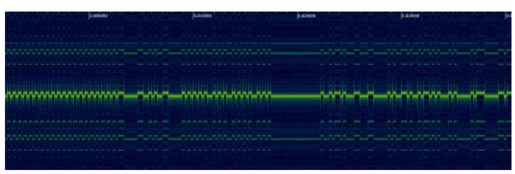


Figure 15: Data Collected by RLI Ground Computer

After the vehicle landed at the PDF, the RLI team confirmed the payload retention system was effective with all hardware securely attached. However, the ground computer didn't receive a transmission post-landing. Troubleshooting revealed excessive input gain in the amplifier as the issue, which was bypassed to restore signal transmission. The team will adjust the amplifier's gain settings in the microcontroller software for the upcoming Huntsville, AL competition and will conduct thorough tests on all systems under simulated flight conditions.

Competition

The RLI team will be traveling to Huntsville, Alabama on the 29th of April and will launch on the 3rd of May with a backup date of the 4th. The RLI team is excited to present their development process and the struggles and successes that have occurred over the last several months. Additionally, the RLI team is looking forward to interacting with their peers from colleges across the country to learn more about their rockets, design processes, and the components they decided to go with to accomplish the mission. There is a wealth of knowledge that can be gathered by the RLI team this year that can be passed to next year's team to provide valuable insight into how to succeed in this competition.

Budget and Funding

The RLI team has developed a comprehensive budget encompassing the launch vehicle, payload, travel, and miscellaneous expenses. The total projected budget is $26,734, with $20,853.12 spent at this point. The budget includes $13,000 allocated for the launch vehicle, with $9,981.24 spent currently. The payload budget is projected at $4,500, with $1,665.85 spent on the FRR. Travel for 12 senior members to the competition is budgeted at $7,869.47. Miscellaneous costs, including outreach, team polos, and shipping, are budgeted at $1,336.56. The team's funding plan involves various sources, including the ASCSU Travel Grant ($1,200) and crowdfunding ($7,500). Several project risks related to the budget have been identified, such as being over budget or not having enough money for miscellaneous or vehicle sub-team expenses, with mitigation strategies including tracking spending and enforcing fundraising.

Scheduling and Planning

The project schedule was created with the intention of maximizing launch opportunities available to the team and providing ample cushion for delays. The schedule had to balance design and testing with preparing the in-depth design reviews that take place throughout the competition. Table 1 lists all major project deliverables, and the amount of time spent on them.

Table 1: Project Deliverables

Deliverable	Date	Time Allocated (hours)
Proposal	September 11th, 2024	593.6
SSF1	October 20th, 2024	228
Preliminary Design Review	October 28th, 2024	826.2
SSF2	December 7th, 2024	162.8
Critical Design Review	January 8th, 2025	510.3
VDF	February 1st, 2025	349.3
Flight Readiness Review	March 17th, 2025	456.4
PDF	April 5th, 2025	249

STEM Engagement

The RLI team places significant importance on STEM Outreach, aiming to promote an interest in science and technology within the greater Fort Collins area by visiting local schools and institutions. Their approach involves teaching and demonstrating rocketry and related scientific concepts to pique the interest of future scientists and engineers. The team tailors these STEM engagement events to different skill levels based on the age of the participants. For adult participants, they plan to conduct surveys to assess learning objective achievement and identify areas for improvement, alongside educational briefings. For younger participants, RLI members will use hands-on activities and verbal quizzing to gauge understanding. The team also intends to promote their social media platforms at the end of each event to encourage follow-up questions and continued interaction. Fulfilling the requirement to engage a minimum of 250 participants in Educational Direct Engagement STEM activities is a key objective. The team successfully completed educational direct engagement for 505 participants.

Safety

Safety is a paramount concern for the RLI team, with a designated safety officer responsible for overseeing all safety-related aspects of the project. The safety officer maintains hazard analyses, failure modes and effects analyses (FMEA), checklists, procedures, and safety data sheet inventories, as well as ensuring that the team adheres to regulations set forth by the CSU Engineering Manufacturing Education Center, the National Association of Rocketry High Powered Rocket Safety Code, Code of Federal Regulations (CFR) 27 Part 55: Commerce in Explosives, Federal Aviation Regulations 14 CFR, Subchapter F, Part 101, Subpart C; Amateur Rockets, and National Fire Protection Association Code 1127, "Code for High Power Rocketry." Comprehensive assembly and launch procedures were documented, with steps checked off and approved by responsible personnel and the safety officer. Risk assessment tables were used to evaluate the probability and severity of potential hazards, with mitigation strategies identified. The categorization designations of risks are shown in Table 2.

Table 2: Risk Assessment Designations

Probability	**Severity**			
	Catastrophic	Critical	Marginal	Negligible
Frequent	1A	1B	1C	1D
Probable	2A	2B	2C	2D
Occasional	3A	3B	3C	3D
Remote	4A	4B	4C	4D
Improbable	5A	5B	5C	5D

Hazard analysis was conducted for personnel and environmental effects associated with the launch. FMEA was conducted for various aspects of the project, including energetics, vehicle design, recovery, avionics, payload, and launch operations. The team mentor is responsible for handling all energetics and plays a crucial role in overseeing launch activities.

Conclusion

In conclusion, the RLI project is a comprehensive endeavor by Colorado State University students to meet the requirements of the 2025 NASA University Student Launch Initiative. The team has diligently progressed through the design, manufacturing, and testing phases, demonstrating their commitment to building a recoverable and reusable launch vehicle with a functional payload. The successful completion of two subscale flights (SSF1 and SSF2) provided critical data and validation for the full-scale design, particularly regarding the dual deployment recovery system and payload integration. The first full-scale flight (VDF) marked a significant milestone, validating the vehicle's ascent and recovery systems, while also identifying areas for refinement, such as the main parachute deployment altitude. The PDF showcases the functionality of the integrated payload, including the safe housing of the STEMnauts and the successful collection of flight data. Throughout the project, the RLI team has maintained a strong focus on budget management, detailed scheduling and planning, and, most importantly, stringent safety protocols. The iterative process of testing and refining, combined with thorough documentation and a proactive approach to potential challenges, positions the RLI team for successful participation in the NASA Student Launch competition.