Final Design Report

EGEE-4820: Senior Design II

Kenneth Lee III, Rebekah Porter, & Arkin Solomon

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1. Abstract

The purpose of this project was to develop a payload for NASA's Student Launch competition, in conjunction with Cedarville's mechanical engineering senior design project for NASA's Student Launch. It involved developing an independent electrical system to fit within the rocket and developing software for a microcontroller to gather data from sensors and communicate that data via a radio transmitter and antenna.

2. Introduction and Background

For the past three years, Cedarville University has participated in the NASA Student Launch competition. Within the competition, several universities compete to design a rocket containing a payload to accomplish a set of goals set by NASA. Teams are scored based on how well they achieve each goal, their implementation, and their documentation and presentations given to NASA. Historically, the payload team has also developed the avionics systems onboard the rocket; this year, however, the team focused solely on making the payload, which was self-sufficient and independent of rocket systems, and aiding the mechanical engineering team with the electrical and software components of the airbrake system as needed.

This year's payload objective was to take several different measurements, either in flight or on the ground after landing, and transmit them over radio to a NASA receiver. NASA required the team to pick at least three measurements from eight different options; the team chose five. The payload was also required to contain four human-like figures, called STEMnauts, which may be used fictionally to determine astronaut survivability and other rocket conditions which can be broadcast to NASA.

3. Objectives, Specifications, and Requirements

NASA provided several objectives and constraints for this year's payload, but they also incorporated much freedom in the design of the payload, provided it meets governmental regulations and adheres to the intent of the challenge. As the team is split by role rather than objective, all team members are responsible for all objectives. The requirements outlined by NASA in their 2024-2025 Student Launch Handbook (SLH) are summarized below:

- A minimum of three of the following, and a maximum of eight, must be transmitted to NASA upon landing:
    - Temperature of Landing Site
    - Apogee Reached
    - Orientation of On-Board STEMnauts
    - Time of Landing
    - Battery Check/Power Status Report
    - Calculated STEMnaut Crew Survivability

    - Landing Velocity and G-Forces Sustained
    - Maximum Velocity

The team chose to transmit the following five objectives out of these eight options:

    - Temperature of Landing Site
    - Apogee Reached
    - Orientation of On-Board STEMnauts
    - Time of Landing
    - Battery Check/Power Status Report

4. Constraints

NASA provided constraints in the SLH for the design of the payload, and they are as follows:

- The data to be transmitted to NASA shall be communicated no later than March 17, 2025.
- The payload may not protrude more than a quarter inch before apogee.
- The payload shall transmit on the 2-meter band at the NASA-provided frequency at the time of landing, and at a maximum of 5 watts.
- The payload's transmission shall not occur prior to landing.
- The payload shall have sufficient power to function after idling on the launch pad for three hours.

The mechanical engineering team also provided constraints for the payload to ensure that it fit within the rocket and worked well with their design. These are the constraints provided by the mechanical engineering team:

- The payload shall not exceed 3.9 inches in diameter.
- The payload shall not exceed eight inches in length.
    - Some extra components may be placed above the payload, extending into the nosecone. This will not count towards the eight-inch maximum length; however, they must be fully contained in the nosecone.
- The payload shall not exceed three-fourths of a kilogram.
- The payload shall not interface nor interfere with the avionics system.
- The payload's radial center of mass shall be within one-half inch of the center of the rocket.
- The payload should be as close to the given weight and length constraints as possible.
- The payload shall be easily removable from the rocket.

The team shall also keep the project cost under $1,000 for all parts, including the parts already owned by the university.

5. Engineering Design

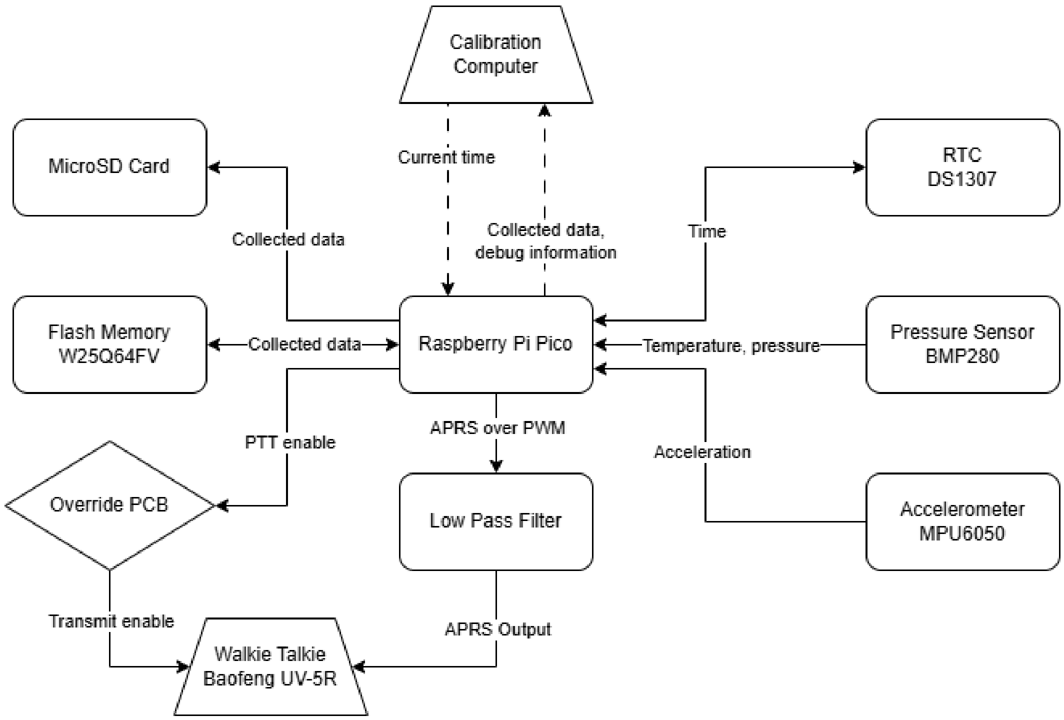

Figure 1: Full System Diagram

5.1 Software Design

The operation of the payload can be seen in Figure 1 and is as follows: First, the Raspberry Pi Pico 2 microcontroller collects data from the three sensors. The microcontroller then processes the data and sends it to the encoder formatted in Automatic Packet Reporting System (APRS) packets. The encoder turns the digital bits into APRS tones, which are then sent to the radio transceiver for transmission to the receiver at the launch site. After landing, the microcontroller stores the launch data to an SD card.

The code is written using C++ and the official Raspberry Pi Pico software development kit (SDK). The three systems that the team was responsible for coding were the primary and override systems on the primary payload and the airbrakes system. All three systems (payload, override, and airbrakes) share the underlying code for flight phase detection, data collection and storage, tone management, and some other processes. The first core of all three systems is responsible for collecting and writing data. In the case of the airbrakes, the first core also calculates the ideal target angle. The second core on the primary board is responsible for encoding and transmitting data after landing; on the override board, the second core enables the Push-to-Talk (PTT) button and then disables it after 4.5 minutes. On the airbrakes, the second core is responsible for continuously maintaining the target airbrake angle.

The payload also required the creation of an auxiliary computer program used to calibrate it with the current time and current air pressure. This calibration computer is a simple terminal program which uses a custom packet-based serial protocol and is written in Python. It is also designed for debugging and self-testing.

The results from the final launch included successful recovery and landing of the rocket. At the location of receiver (next to the launch site), the team observed that the radio audibly heard the transmissions sent by the payload, just as expected. However, the distance between the transmitter and receiver was great enough that the APRS packets were distorted to the point that they could not be decoded. The team confirmed that the packets continued to be sent for only five minutes after landing, but that zero of these packets could be successfully decoded. This means that the payload operated as intended for both the primary and override systems, but because the rocket landed farther away than permitted by NASA's requirements, the transmission could not be successfully received.

The team was able to successfully simulate and test all systems in lab. The logs recovered from the payload after the final launch indicate that it restarted after landing. This error was observed during the previous full-scale launch, but was never reproduced in lab, nor was it ever observed during simulations. Code changes were made which fixed the root cause of the issue, but since the issue could not be reproduced, the fix was unable to be verified. Steps had previously been taken to ensure that some data could be restored after a restart. The likely cause is that saving the time caused a deadlock or exception which was caught by the watchdog, causing a restart. Earlier logs indicate that it tried to restore the landing time, and the payload assumed it did successfully, which led to the incorrect landing time being sent. The data that successfully transmitted was the apogee reached, temperature, orientation, and battery voltage. The team was unable to successfully transmit the landing date and time.

The airbrakes also failed to function entirely as intended due to a calibration error. They caused the rocket to reach what the airbrakes thought was 4,024 feet, which was close to the desired apogee of 4,100 feet. However, the calibration error meant that what the airbrakes thought was 4,024 feet was actually 3,719 feet; this was not close to the intended apogee. The reason for this discrepancy was later discovered during post-flight analysis. The system attempts to recalibrate itself when it detects launch; however, during the competition launch, the pressure sensor initially read a very large pressure. This caused the ground pressure to be calculated to be extremely high when the pressure samples were averaged upon launch, leading to the airbrakes thinking that the rocket's altitude was much higher than it truly was.

5.2 Electrical Design

The payload incorporated two PCBs for each rocket launch. The primary PCB collected data, stored it in memory, and sent out APRS data to be broadcast by the transmitter. The secondary PCB acted as an override for the primary PCB, only allowing transmissions to be broadcast during the particular transmission window immediately after landing. This fulfilled a

NASA constraint which required the payload to have redundancy for disabling the transmitter before, during, and after the rocket's flight.

The designs for both printed circuit boards were created using EasyEDA software. The primary PCB is shown with its major iterations below in Figure 2. The left image depicts the rendered PCB, the middle image shows the board after manufacturing and assembly at the end of the fall semester, and the right image displays the primary PCB as it is now. The board features numerous small improvements which were added during the semester to make it capable of reliable operation during six flights. The secondary PCB, shown below in Figure 3, was designed during the fall semester to be used for both the override PCB and the airbrakes PCB. This implementation was carried out during the spring semester, as both circuit boards were manufactured, assembled, tested, and upgraded as needed.

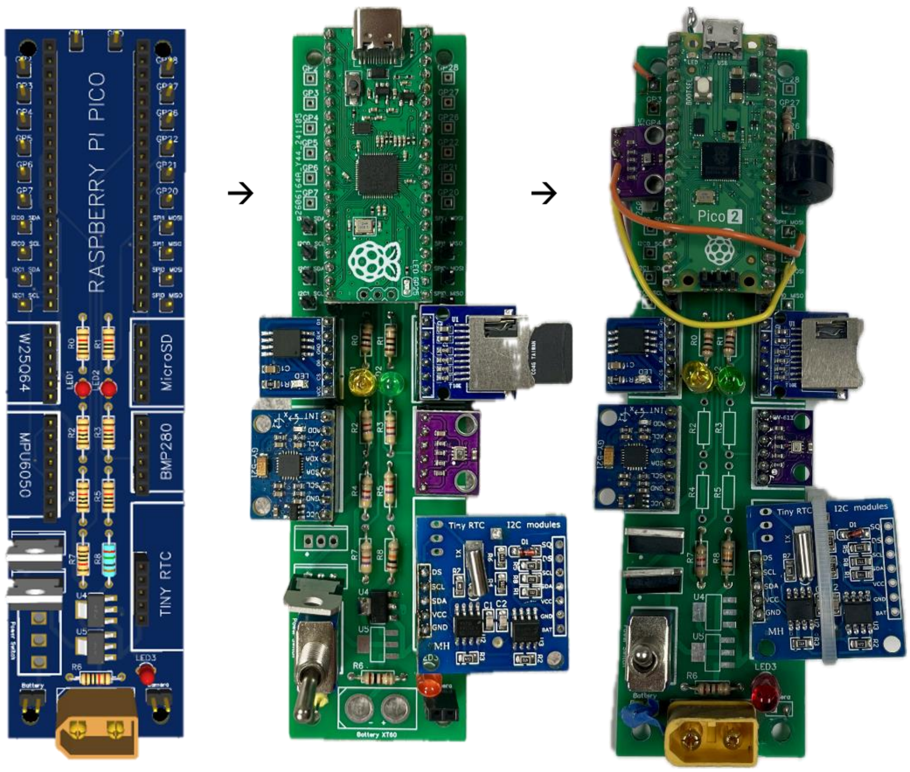

Figure 2: Primary PCB Iterations

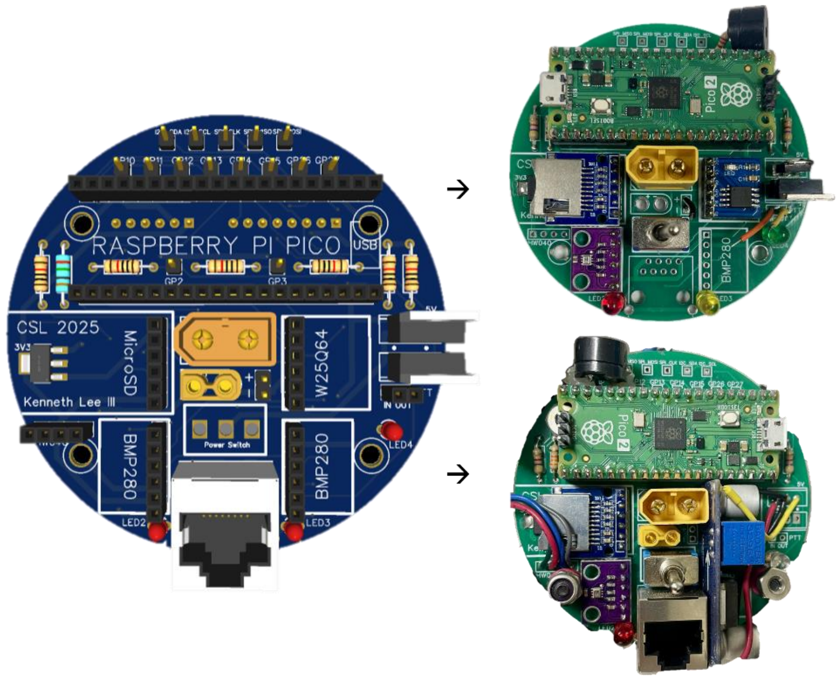

Figure 3: Override and Airbrakes PCBs

Once the microcontroller on the primary PCB has received the data from the sensors and formatted it into APRS packets, it sends the data to the APRS encoder, which converts the digital bits to APRS tones and sends them to the Baofeng UV-5R HAM radio. The radio then transmits the tones on the 2-meter band.

The final design of the APRS encoder consists of just two resistors and two capacitors, and the diagram is shown below in Figure 4. The circuit takes in the APRS signal and uses a voltage divider to scale the voltage input; it then applies a low pass filter via the RC circuit before finally removing the DC bias with the capacitor in series.

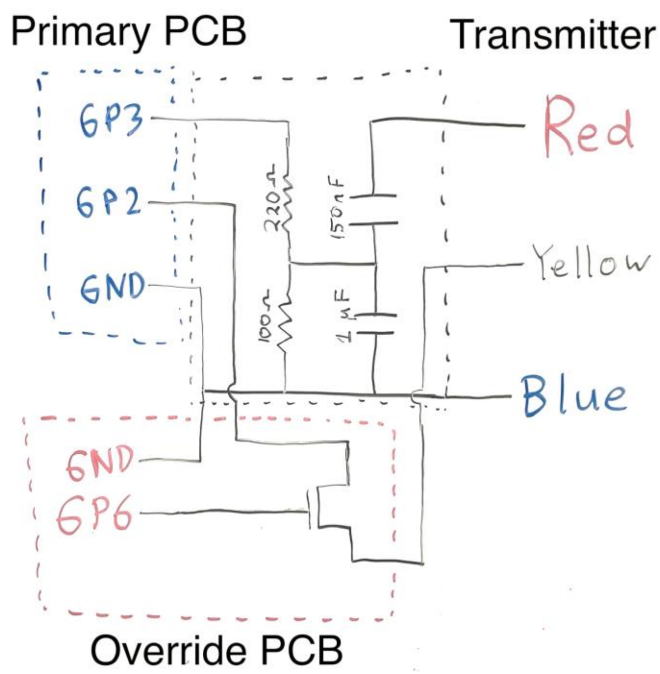

Figure 4: APRS Encoder Circuit

The Baofeng UV-5R has its own battery pack, so the power requirements for this year's payload were much smaller than they have been for previous years. The team used two 1000mAh 7.4V LiPo battery packs because of their compact size and secure connectors. One battery pack was used for each of the two printed circuit boards (PCBs). Research and testing were both conducted to ensure that the battery life would be sufficient for the project, and the results of both are shown below in Table 1.

Table 1: Estimated Versus Tested Battery Life

Circuit	Estimated (mA)	Tested (mA)	Battery	Estimated (mAh)	Tested (mAh)	Estimated Battery Life (h)	Tested Battery Life (h)
Primary	114.0	68.0	Ovonic	1000	930	8.8	13.7
Override	97.1	110.0	Ovonic	1000	930	10.3	8.5
Airbrakes	112.5	212.0	Liperior	850	738	7.6	3.5
Minimum Battery Life						**7.6**	**3.5**

5.3 Mechanical Design

The final payload design can be seen below in Figure 5. The top section of the payload, which extends into the nosecone, holds the primary PCB on one side and the batteries on the other. The lower section of the payload holds the radio transmitter on one side and the APRS encoder circuit, the override PCB, and the STEMnauts in their individual compartments on the other side. Both PCBs are attached to the housing via standoffs bolted into embedded heat-set inserts. The batteries fit into their holding tabs and are secured to the payload with cable ties, and the radio transmitter is attached via screws in its back panel and further secured with another cable tie. The STEMnauts, which are LEGO astronaut figurines, are fastened to the payload housing via LEGO shield parts. These shields are attached to the housing with super glue, and the STEMnauts hold onto the shield handles. This has allowed the STEMnauts to be securely fastened to the payload without the need to permanently attach them, allowing their reuse in several payload iterations with no damage to the STEMnauts themselves.

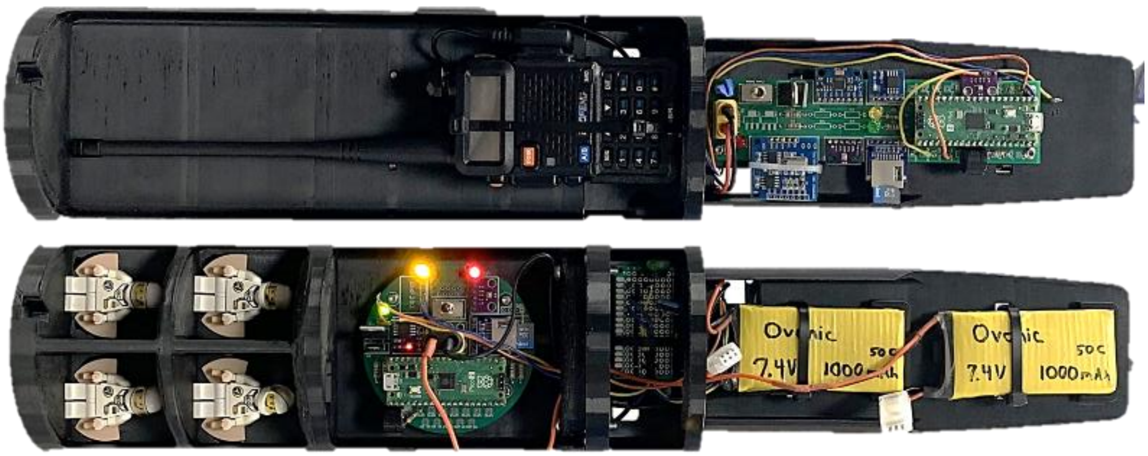

Figure 5: Final Payload Design

The main body of the payload is 3D printed to allow for rapid prototyping, which allowed the team to be able to make design changes quickly over the course of this year. Some of these design changes can be seen in Figure 6, which shows the major iterations of the payload. At the end of the fall semester, the team had the design on the left, which had the radio transmitter antenna extending into the nosecone. The mechanical engineering team decided that steel ballast must be added to the tip of the nosecone to improve rocket stability, so the ECE team switched to the second design shown. While the top of the payload still extends into the nosecone, the transmitter antenna does not, which prevents any potential electromagnetic interference from the ballast and ensures that the payload fits within the remaining space. The team then improved the resiliency of the housing, including adding sides to the compartments, crossbeams between the STEMnauts, and many fillets. The result was the third design shown, which the team then 3D printed and assembled. The payload was printed in two sections because of its height; these two sections were bolted together after printing. The final payload, shown on the far right, has been successfully flown in multiple launches.

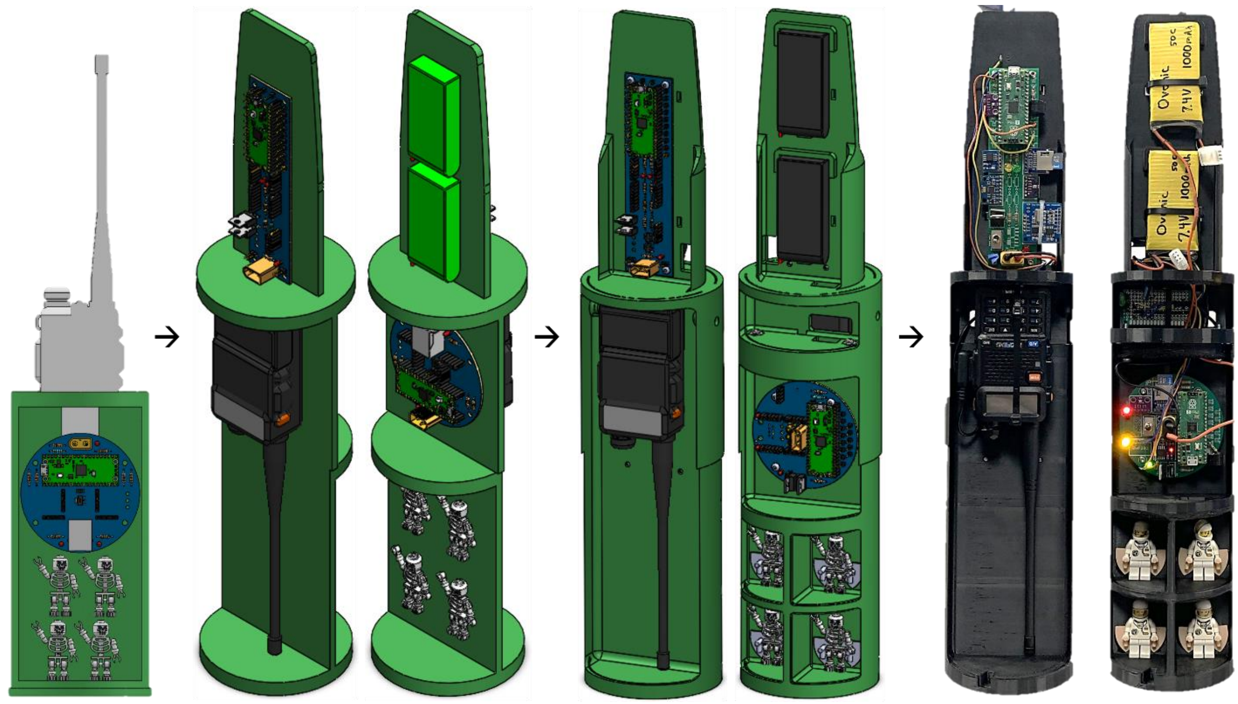

Figure 6: Payload Housing Design Iterations

Figure 7 shows the payload as it fits inside the rocket body. The lower section is enclosed by the translucent covers, while the upper section is encircled by the nosecone. The payload's largest diameter only allows it to slide into the airframe as far as the airframe overlap, and the nosecone retains it from above. Two bolts are used to further secure it from the outside of the airframe, and the bulkhead below seals off the payload compartment. This fulfills the payload's requirement to be completely self-contained. Figure 7 also clearly shows the area at the top of the nosecone that is reserved for ballast, which was the main driver of the payload's mid-year redesign. The eye bolt that screws into the bulkhead below the payload is for attachment of the rocket's payload section to the main parachute.

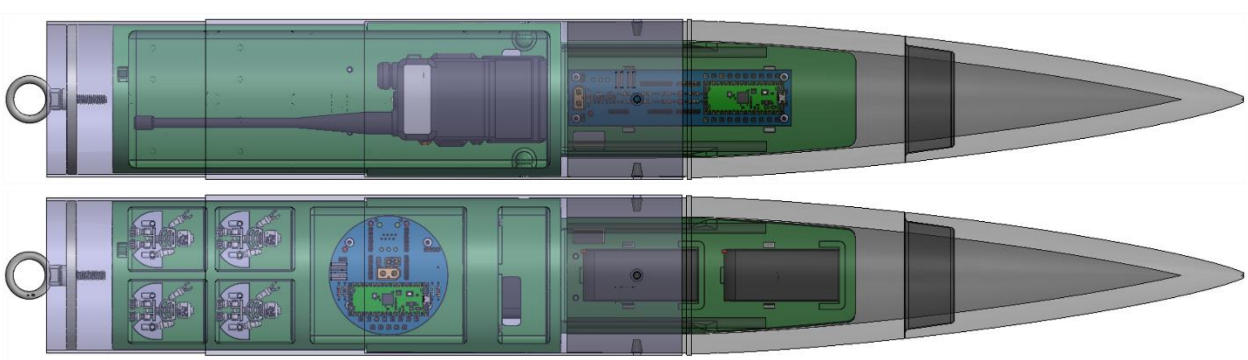

Figure 7: Payload Inside Rocket Section

The payload has flown in nine launches, including the final competition launch that took place on April 28, 2025. The fully assembled and launch-ready payload, including the installment of the translucent covers to seal off the payload, is shown below in Figure 8. The hole in the translucent cover, seen on the far right of Figure 8, is to allow the altimeter to get an accurate pressure reading; a similar hole is present in the rocket airframe. The housing has proved to be robust and has survived all but one rocket landing (April 17, 2025, due to a failed parachute deployment). A launch on April 26, 2025 also had a partially failed parachute, but the housing survived intact with no damage to either the 3D printed structure or to the components it held. The payload housing has been validated by its survival of these launches.

Figure 8: Final Payload Assembled and Ready for Launch

6. Summary and Conclusion

In conclusion, the team has successfully designed, manufactured, tested, validated, and launched the primary payload for NASA’s Student Launch Competition. The team collaborated with their mechanical engineering counterparts to ensure the payload interfaced seamlessly with the rest of the rocket and assisted with all reports and presentations given to NASA. Extensive engineering design work has been done by all team members, resulting in a payload that has been well-designed programmatically, electrically, and mechanically.

7. Appendix

7.1 Personal Contributions

CEO: Rebekah Porter

Responsibilities included circuit design, CAD design, electronics assembly, and all NASA presentations. Specific accomplishments during the fall semester include design of the radio transmission circuitry, design of the voltage divider and analog multiplexer circuity, and presentation of the Preliminary Design Review (PDR) to NASA as the electrical engineering lead (alongside the mechanical engineering lead and overall team lead). Specific accomplishments during the spring semester include a full redesign of the payload housing, PCB and GPS system assembly, and presentation of the Critical Design Review (CDR) and Flight Readiness Review (FRR) to NASA.

CFO: Kenneth Lee III

Responsibilities included project budget management, early CAD design, PCB and circuit design, and APRS transmission testing. Specific accomplishments during the fall semester include 3D printing the first payload prototype as well as designing, soldering, and testing the primary PCB. Specific accomplishments during the spring semester include override PCB assembly and testing, APRS encoding and decoding setup, payload systems testing, and airbrakes systems testing.

CTO: Arkin Solomon

Responsibilities included software design and development. Specific accomplishments during the fall semester include implementing multicore processing and achieving communication and control between the sensors, microcontroller, and flash memory. Specific accomplishments during the spring semester include developing a shareable fault-tolerant framework, successfully collecting and storing data allowing full flight reconstruction, and successfully actuating airbrakes in flight.

7.2 Bill of Materials

Table 2: Cedarville Student Launch Payload Team Final Budget

Item Type	Part	Quantity	Unit Cost	Total Cost	Already Owned	Already Purchased
Radio	FCC Ham Radio License	2	$ 35.00	$ 70.00	No	$ 70.00
Radio	BTECH APRS-K1 PRO	1	$ 34.49	$ 34.49	No	$ 34.49
Radio	BTECH APRS-K2	1	$ 22.49	$ 22.49	No	$ 22.49
Radio	UV-5R Ham Radio Transceiver	2	$ 31.69	$ 63.38	No	$ 63.38
Radio	Diamond Antenna Dual-Band HT Antennas RH707	3	$ 29.99	$ 89.97	No	$ -
Microcontroller	Raspberry Pi Pico	3	$ 5.00	$ 15.00	Yes	$ 24.00
Sensor	DS1307 Real Time Clock (3-pack)	1	$ 7.99	$ 7.99	Yes	$ -
Sensor	BMP280 Barometer & Thermometer (10-pack)	1	$ 7.99	$ 7.99	Yes	$ 7.99
Sensor	MPU6050 Gyroscope & Accelerometer (3-pack)	1	$ 9.99	$ 9.99	Yes	$ -
Battery	1000mAh 2S Li-Po Battery (2-pack)	2	$ 22.99	$ 45.98	Yes	$ -
Memory	W25Q64 Flash Memory Module (5-pack)	1	$ 7.99	$ 7.99	No	$ 7.99
Memory	Micro SD-Card Reader (10-pack)	1	$ 8.89	$ 8.89	No	$ 8.89
Memory	Micro SD-Card 32GB (5-pack)	1	$ 29.94	$ 29.94	Yes	$ 25.60
PCB	PCB Manufacturing per Version	2	$ 40.00	$ 80.00	No	$ 43.00
Materials	PLA Filament (1 kg)	2	$ 25.00	$ 50.00	Yes	$ -
Miscellaneous	LEGO STEMnauts	4	$ 5.00	$ 20.00	No	$ 20.00
Miscellaneous	Wires, Connectors, etc.	1	$ 20.00	$ 20.00	Yes	$ -
			Total:	**$ 584.10**		
			Actual:	**$ 397.21**		**$ 327.83**

8. Bibliography

[1] “2025 Student Launch Handbook,” NASA, https://www.nasa.gov/wp-content/uploads/2024/08/2025-nasa-sl-handbook.pdf?emrc=f8a406?emrc%3Df8a406.