Senior Design – Spring 2026

Assignment 6: Project Report

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Instance 1
Hours spent: 152h

Prepared by Team 4 HABSAT

Reviewed By

Revisions

Revision	Comments	Affected Pages	Date
1	First Issue	All	4/22/2026

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1. Project Management Update

1.1 Organigram

The organizational structure has remained unchanged from the Preliminary Design Review through the final Design and Verification Report. No personnel changes or role reallocations occurred at any phase. The established structure provided effective coordination, balanced workload distribution, and clear accountability across all subsystems from concept design through manufacturing, testing, and final reporting. All team members maintained their assigned roles, ensuring continuity of technical knowledge and responsibility throughout every phase transition.

The organizational hierarchy is as follows:

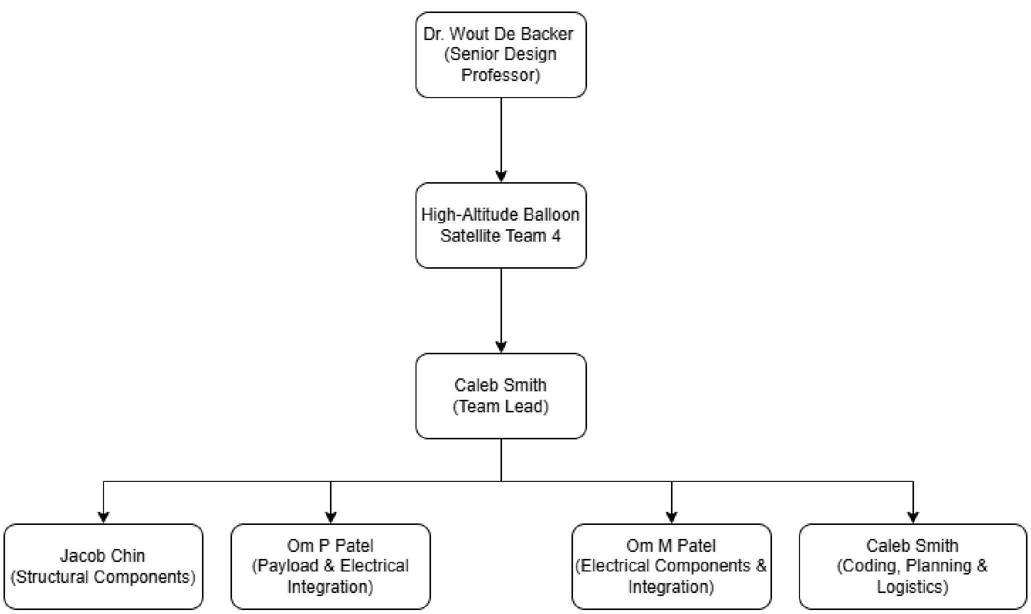


Figure 1.1: Organigram

1.2 POS and MNS

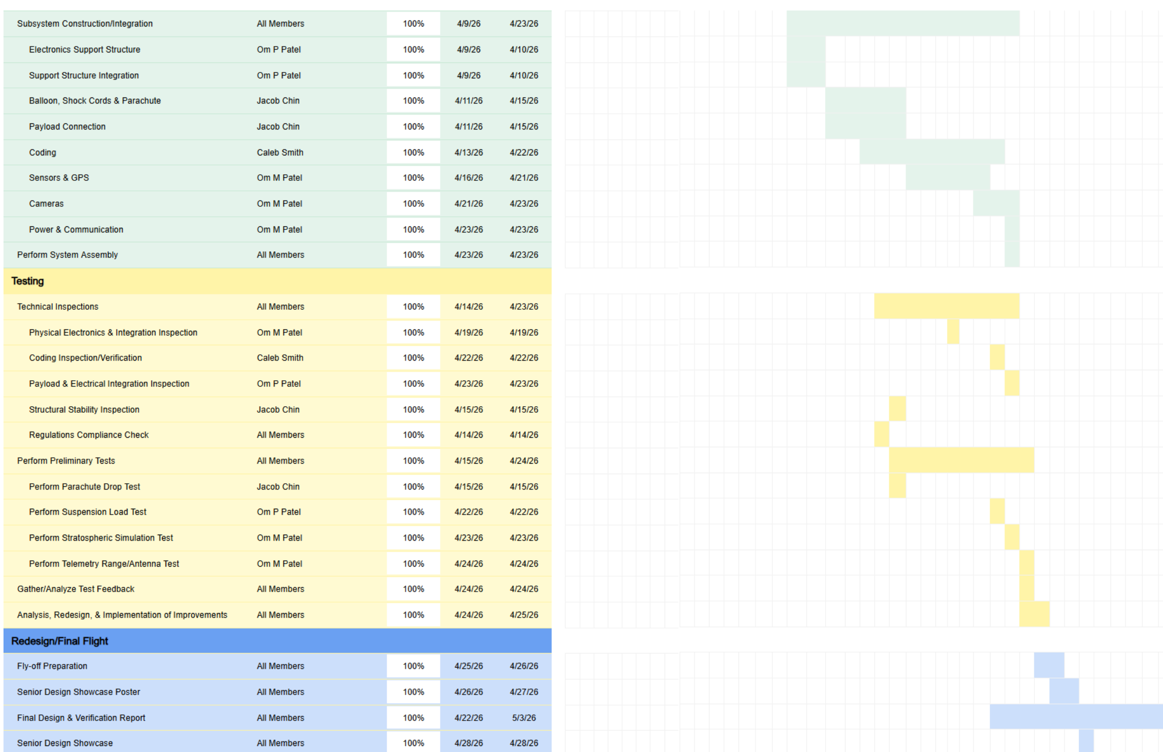
The Project Objective Statement and Mission Need Statement remained unchanged throughout the entire project lifecycle. Both statements continued to accurately define the team's mission, goals, and operational constraints at every phase. No modifications were required at CDR, FRR, or DVR because no fundamental changes in project scope or objectives occurred.

Project Objective Statement (POS): Design, build, and launch a high-altitude balloon within a 16-week timeframe and a budget of $1,500, delivering a payload to an altitude of 30 km.

Mission Need Statement (MNS): Conduct a safe and recoverable high-altitude balloon mission to 30 km that collects, transmits, and retains environmental, positional, acceleration, photo and video data in compliance with applicable regulations.

1.3 Gantt Chart

The Gantt chart has been updated to reflect the final project state at DVR submission. All tasks across the Design, Manufacturing, Testing, and Final Flight phases are now 100% complete. The primary schedule disruption documented at the FRR was a GPS module shipping delay of approximately 1–2 weeks, which pushed back the initial assembly start date. Despite this, the team maintained critical path visibility by advancing all non-dependent manufacturing tasks in parallel. All affected downstream tasks were recovered without slipping the final project end date.



Subsystem Construction/Integration	All Members	100%	4/9/26	4/23/26
Electronics Support Structure	Om P Patel	100%	4/9/26	4/10/26
Support Structure Integration	Om P Patel	100%	4/9/26	4/10/26
Balloon, Shock Cords & Parachute	Jacob Chin	100%	4/11/26	4/15/26
Payload Connection	Jacob Chin	100%	4/11/26	4/15/26
Coding	Caleb Smith	100%	4/13/26	4/22/26
Sensors & GPS	Om M Patel	100%	4/16/26	4/21/26
Cameras	Om M Patel	100%	4/21/26	4/23/26
Power & Communication	Om M Patel	100%	4/23/26	4/23/26
Perform System Assembly	All Members	100%	4/23/26	4/23/26
Testing				
Technical Inspections	All Members	100%	4/14/26	4/23/26
Physical Electronics & Integration Inspection	Om M Patel	100%	4/19/26	4/19/26
Coding Inspection/Verification	Caleb Smith	100%	4/22/26	4/22/26
Payload & Electrical Integration Inspection	Om P Patel	100%	4/23/26	4/23/26
Structural Stability Inspection	Jacob Chin	100%	4/15/26	4/15/26
Regulations Compliance Check	All Members	100%	4/14/26	4/14/26
Perform Preliminary Tests	All Members	100%	4/15/26	4/24/26
Perform Parachute Drop Test	Jacob Chin	100%	4/15/26	4/15/26
Perform Suspension Load Test	Om P Patel	100%	4/22/26	4/22/26
Perform Stratospheric Simulation Test	Om M Patel	100%	4/23/26	4/23/26
Perform Telemetry Range/Antenna Test	Om M Patel	100%	4/24/26	4/24/26
Gather/Analyze Test Feedback	All Members	100%	4/24/26	4/24/26
Analysis, Redesign, & Implementation of Improvements	All Members	100%	4/24/26	4/25/26
Redesign/Final Flight				
Fly-off Preparation	All Members	100%	4/25/26	4/26/26
Senior Design Showcase Poster	All Members	100%	4/26/26	4/27/26
Final Design & Verification Report	All Members	100%	4/22/26	5/3/26
Senior Design Showcase	All Members	100%	4/28/26	4/28/26

Figure 1.2: Updated Gantt Chart

2. Requirements Analysis Update

2.1 Functional Breakdown Structure (Updated)

The Functional Breakdown Structure (FBS) organizes the HABSAT system by its primary mission functions and the subsystems responsible for each. No major structural changes were made from PDR to CDR. Refinements between CDR and DVR included clearer subsystem boundary definitions and finalized component assignments following the manufacturing and testing phases.

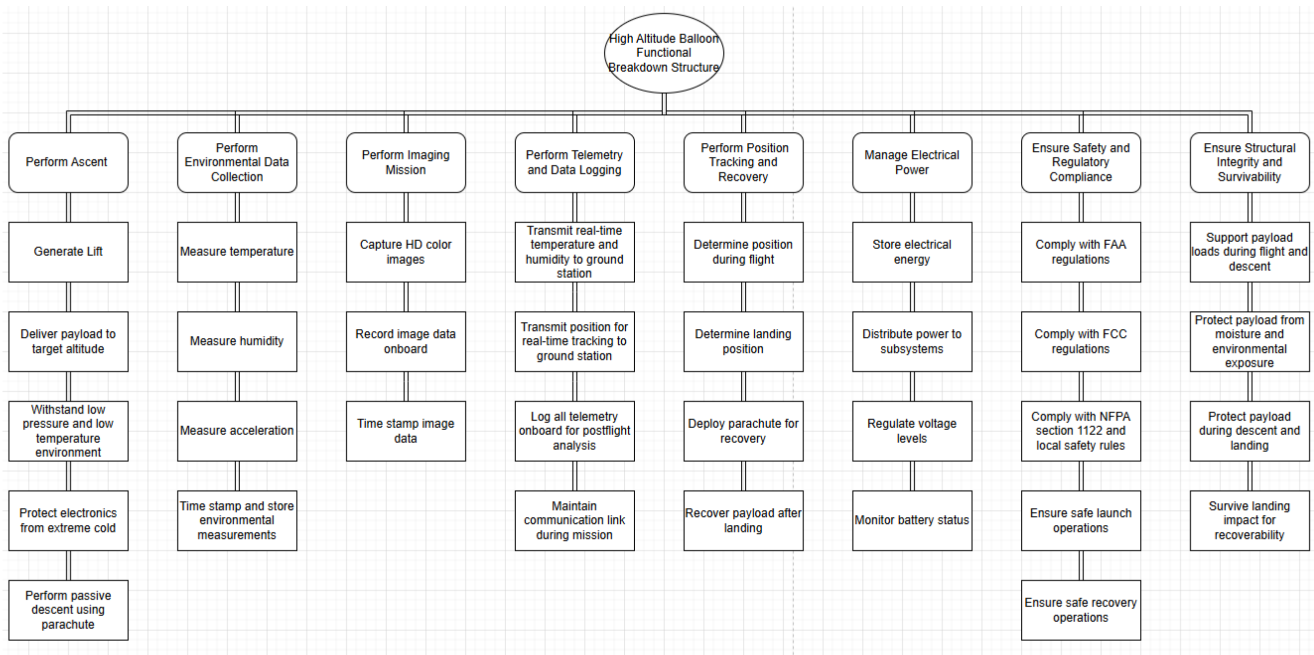


Figure 2.1 - Functional Breakdown Structure

2.2 Functional Flow Diagram (Updated)

The Functional Flow Diagram describes the mission sequence from power-on through payload retrieval. The flow has remained unchanged from the version established at CDR. No modifications were required because the system architecture and mission sequence were accurately defined during the detailed design phase and did not deviate during manufacturing or testing.

Figure 2.2 - Functional Flow Diagram

2.3 List of Requirements

2.3.1 Functional vs Constraints

Functional Requirements define what the system must do — active performance capabilities. Constraints define the boundaries within which the system must operate — imposed limits that are non-negotiable.

ID	Requirement	Type	Statement
FR-01	Altitude Achievement	Functional	The system shall reach an altitude of 30 ± 2 km as measured by onboard GPS
FR-02	Atmospheric Data Collection	Functional	The system shall collect temperature, humidity, pressure, and acceleration data at ≥ 1 Hz during ascent and descent

FR-03	Telemetry Transmission	Functional	The system shall transmit temperature, humidity, GPS position, and battery voltage data during ascent at ≥ 1 Hz
FR-04	Onboard Data Logging	Functional	The system shall log all collected sensor and position data onboard for the full mission duration
FR-05	HD Video Capture	Functional	The system shall capture continuous HD video at a minimum resolution of 1080p during ascent
FR-06	Structural Survivability	Functional	The system shall safely recover the payload with no structural failure upon landing
FR-07	GPS Accuracy	Functional	The system shall determine GPS position with an accuracy of ±10 m during flight and recovery
FR-08	Thermal Survivability	Functional	The system shall maintain operational functionality at −70°C for at least 3 hours
FR-09	Descent Velocity	Functional	The system shall maintain a terminal descent velocity ≤ 6 m/s under nominal parachute deployment
FR-10	Ascent Rate	Functional	The system shall maintain an ascent rate within the required operational range (nominally 4–6 m/s)
FR-11	Telemetry Reliability	Functional	The system shall demonstrate reliable telemetry performance during flight and post-landing
FR-12	Visual Identification	Functional	The payload shall be visually identifiable for recovery (high-visibility markings)
C-01	Budget	Constraint	Total system cost shall not exceed $1,500
C-02	Schedule	Constraint	System development shall be completed within the 16-week semester schedule
C-03	FAA Compliance	Constraint	The system shall comply with applicable FAA high-altitude balloon launch regulations
C-04	FCC Compliance	Constraint	The system shall comply with FCC Part 97 transmission regulations for LoRa operation
C-05	Gas Safety	Constraint	The system shall comply with compressed gas handling and safety regulations
C-06	Mass	Constraint	Total system mass shall remain within the balloon's lift capability with sufficient margin
C-07	Size	Constraint	Payload dimensions shall comply with applicable regulatory size limits

C-08	Structural Safety Factor	Constraint	Structural components shall meet required safety factors under all expected loads
C-09	No Active Propulsion	Constraint	The system shall not include active propulsion or active guidance systems
C-10	Hazardous Materials	Constraint	The system shall not use prohibited hazardous materials

2.3.2 Killer vs Secondary Requirements

Requirements are classified based on their impact on mission success. A Killer (K) requirement is one whose failure results in immediate mission failure or regulatory non-compliance. A Primary (P) requirement significantly degrades mission effectiveness if unmet but does not cause immediate failure. A Secondary (S) requirement improves system quality and performance, but its failure does not prevent mission completion.

ID	Requirement	Classification	Rationale
FR-01	Altitude Achievement	Killer (K)	Failure to reach target altitude means the scientific mission is not executed
FR-02	Atmospheric Data Collection	Killer (K)	Core mission deliverable; no data = mission failure
FR-03	Telemetry Transmission	Secondary (S)	Data is also logged onboard; loss of real-time telemetry degrades but does not eliminate mission value
FR-04	Onboard Data Logging	Killer (K)	Primary data record; loss of logged data means no post-flight science
FR-05	HD Video Capture	Primary (P)	Important mission objective; failure reduces mission output but does not cause failure
FR-06	Structural Survivability	Killer (K)	Payload destruction on landing means data and hardware are lost
FR-07	GPS Accuracy	Killer (K)	Required for both flight data validity and payload recovery
FR-08	Thermal Survivability	Killer (K)	Electronics must survive stratospheric temperatures or the mission cannot complete
FR-09	Descent Velocity	Killer (K)	Excessive descent speed causes structural failure on landing; also a safety requirement
FR-10	Ascent Rate	Secondary (S)	Suboptimal ascent rate reduces efficiency but does not prevent altitude achievement
FR-11	Telemetry Reliability	Secondary (S)	Enhances situational awareness and recovery; data is redundantly stored onboard

FR-12	Visual Identification	Primary (P)	Significantly aids recovery; failure makes payload harder to find but does not prevent retrieval
C-01	Budget	Killer (K)	Hard constraint imposed by course and team resources
C-02	Schedule	Killer (K)	Course deadline is non-negotiable
C-03	FAA Compliance	Killer (K)	Launch is illegal without regulatory compliance
C-04	FCC Compliance	Killer (K)	Transmission without compliance is illegal
C-05	Gas Safety	Killer (K)	Helium handling without compliance poses safety risk
C-06	Mass	Killer (K)	Exceeding lift margin prevents balloon from reaching target altitude
C-07	Size	Primary (P)	Regulatory limit; unlikely to be exceeded given current design
C-08	Structural Safety Factor	Killer (K)	Structural failure causes loss of payload
C-09	No Active Propulsion	Killer (K)	Regulatory and course constraint
C-10	Hazardous Materials	Killer (K)	Safety and regulatory constraint

2.3.3 Compliance Verification Plan

Each requirement is assigned a verification method: Test (T) — physical testing under controlled or operational conditions; Analysis (A) — engineering calculations or simulations; Inspection (I) — visual or dimensional checks and documentation review; Demonstration (D) — functional validation during operation.

ID	Requirement	Verification Method	Specific Verification Activity
FR-01	Altitude Achievement	Test	Post-flight GPS data review confirms altitude ≥ 28 km and ≤ 32 km
FR-02	Atmospheric Data Collection	Test	Review logged CSV data file for continuous 1 Hz sensor records across full flight duration
FR-03	Telemetry Transmission	Test	Telemetry Range / Antenna Test — confirm LoRa packet reception at ground station during ascent
FR-04	Onboard Data Logging	Test	Full-duration bench test (≥ 3 hours) confirms continuous SD card logging with no gaps

FR-05	HD Video Capture	Demonstration	Review RunCam Thumb 2 footage post-flight to confirm 1080p continuous video was captured
FR-06	Structural Survivability	Test + Inspection	Parachute drop test + post-landing visual inspection of enclosure and all internal components
FR-07	GPS Accuracy	Test	Ground truth GPS comparison at known location; post-flight trajectory review
FR-08	Thermal Survivability	Test	Cold-soak test: system operated in cold chamber or freezer environment at −20°C minimum; functional bench test confirms all sensors operate after cold exposure
FR-09	Descent Velocity	Analysis + Test	Parachute sizing calculation (CDR); parachute drop test confirms controlled descent
FR-10	Ascent Rate	Analysis + Test	Balloon sizing/lift calculations (CDR); post-flight GPS altitude-vs-time confirms ascent rate within 4–6 m/s
FR-11	Telemetry Reliability	Test + Demonstration	Telemetry range test confirms link during ground test; post-flight telemetry log reviewed for packet loss rate
FR-12	Visual Identification	Inspection	Pre-flight visual inspection confirms high-visibility markings and identification labels are present and legible
C-01	Budget	Analysis	BoM cost tracking throughout project; final cost confirms ≤ $1,500
C-02	Schedule	Inspection	Gantt chart reviewed at each phase gate
C-05	Gas Safety	Inspection	Helium cylinder handling procedure followed per supplier safety guidelines
C-06	Mass	Analysis + Test	System mass measured on scale pre-flight; compared against calculated lift margin from CDR
C-07	Size	Inspection	Physical dimensions of payload measured and confirmed to comply with applicable limits

C-08	Structural Safety Factor	Analysis + Test	Safety factor analysis from CDR; suspension load test and drop test confirm structural survivability
C-09	No Active Propulsion	Inspection	System design review confirms no active propulsion or guidance components
C-10	Hazardous Materials	Inspection	BoM reviewed to confirm no prohibited materials; EPS foam, G10 fiberglass, AA lithium batteries confirmed compliant

3. Detailed Design

3.1 Structural Soundness

This section defines the critical load cases acting on the HABSAT payload structure, identifies the two highest loaded components, and performs first-order calculations to validate structural integrity. The analysis covers both the descent suspension loading and the landing impact loading, which represent the two worst-case load conditions experienced by the system. All loads are treated as static equivalents per project guidelines. It should be noted that the suspension attachment system was revised between the CDR and the FRR. The original eyebolt-only design was replaced with the final configuration consisting of a nylon cinching strap around the full enclosure perimeter, and a 50 lbf rated nylon rope. Additionally, one G10 Garolite electronics plate was removed during the final assembly to bring the system to the 5.0 lb mass target. All structural analysis presented here reflects the final confirmed as-built design.

3.1.1 Highest Loaded Components

Two structural components govern the design and were identified as the highest loaded elements in the system across the two critical load cases.

Component 1 — Nylon Suspension Rope and Strap System (Descent Load Case)

During parachute descent, the entire system weight is transferred through the suspension train. The final as-built configuration consists a nylon cinching strap routed around the full perimeter of the EPS foam enclosure, and a 50 lbf rated nylon rope that ties to the strap at the top face of the enclosure and connects upward to the parachute and balloon train. The nylon rope is the critical structural element in this load path and is intentionally selected as the weakest link in the suspension chain to satisfy the FAA §101.1(a)(4)(iv) breakaway requirement, which mandates that the connection between the balloon and payload be designed to separate at a defined load to prevent hazardous uncontrolled flight in the event of a balloon system anomaly. The cinching strap is sized to be structurally superior to the rope, ensuring the rope is always the first element to fracture under overload conditions.

This system carries the full payload weight throughout ascent and descent, and also experiences a dynamic jolt load at the moment of parachute inflation following balloon burst.

Component 2 — G10 Garolite FR-4 Electronics Plate (Landing Impact Load Case)

During ground contact, the payload experiences a vertical deceleration that subjects the electronics mounting plate to an amplified downward load from all components mounted on it. The G10 Garolite FR-4 fiberglass-epoxy composite plate, measuring 12 in × 12 in × 0.125 in, supports the Raspberry Pi 4, IMU, internal sensors, LoRa module, batteries, power regulator, PCB, and all associated wiring. GPS modules, external sensors, and cameras are mounted externally/internally to the enclosure and are not carried by the plate. Per guidelines, the landing impact condition is modeled as an equivalent static 10g load applied to all components mounted on the plate. Four compression springs positioned at the plate corners provide shock isolation by absorbing impact energy before loads are fully transferred into the plate, but the plate itself must structurally support the amplified electronics weight under the 10g condition.

3.1.2 Expected Load Analysis

Load Case 1 — Descent and Recovery Loading (Nylon Rope — FAA Breakaway Element)

The system hangs from the nylon suspension rope during parachute descent. The total confirmed system mass is 5.0 lb (2.268 kg), producing a static weight of:

$W = mg = 2.268 \times 9.81 =$ **22.3 N (5.0 lbf)**

This static descent load is the normal operating load on the nylon rope throughout the descent phase. Applying the 10× impact factor per project guidelines to account for the dynamic jolt at parachute inflation after balloon burst:

Limit load: $P_{limit} = 22.3$ N (5.0 lbf)

Ultimate load (10g impact factor): $P_{ultimate} = 10 \times 22.3 =$ **223 N (50.1 lbf)**

Nylon rope rated break strength (manufacturer specification): **222 N (50 lbf)**

The ultimate load of 223 N (50.1 lbf) is essentially coincident with the rope's rated break strength of 222 N (50 lbf). This is by design. The rope is intentionally selected at 50 lbf to satisfy the FAA §101.1(a)(4)(iv) breakaway requirement, which requires the balloon-to-payload connection to fracture at a defined threshold. Under the extreme dynamic 10g parachute inflation jolt, the rope is expected to be at its structural limit — this is the design intent, not a margin deficiency. Under all normal operating conditions (static descent at 5.0 lbf), the rope operates well within its capacity.

Load Case 2 — Landing Impact Loading (G10 Electronics Plate)

The confirmed on-plate electronics mass is derived from the DVR weight budget. Total Electronics and Power & Communications subsystem mass is 1.105 lb (0.501 kg). Subtracting the off-plate components, two GPS modules, two cameras, and the external BME280 sensor gives the mass acting on the plate during the impact condition.

Component	Location	Mass (lb)
Raspberry Pi 4 Model B	On plate	0.113
MPU-6050 IMU	On plate	0.040
Internal BME280 sensor	On plate	0.005
MS5611 altimeter	On plate	0.010
RFM95W LoRa module	On plate	0.020
LoRa antenna	On plate	0.020
AA Lithium batteries + holders	On plate	0.330
5V voltage regulator	On plate	0.020
Perma-Proto PCB	On plate	0.030
SD cards, rocker switch, misc	On plate	0.027
Wiring and connectors	On plate	0.130
Total on-plate mass	—	**0.745**
NEO-M8N GPS module	Off plate	0.044
u-blox M10 GPS module	Off plate	0.044
External BME280	Off plate	0.005
RPi HQ Camera + 6mm lens	Off plate	0.207
RunCam Thumb 2	Off plate	0.060
Total off-plate electronics	—	**0.360**
Electronics + Power total (DVR)	—	**1.105**

Table 3.1: On-Plate and Off-Plate Electronics Mass Breakdown for Impact Load Analysis

On-plate electronics static weight:

$W_e = 0.338 \times 9.81 =$ **3.32 N (0.745 lbf)**

Under the 10g impact condition:

$F_{impact} = 10 \times 3.32 =$ **33.2 N (7.45 lbf)**

Applying the 1.5 safety factor to obtain ultimate load:

$F_{ult, plate} = 1.5 \times 33.2 =$ **49.8 N (11.2 lbf)**

The plate is modeled as a simply supported square plate under uniformly distributed load. Maximum bending stress is estimated using the formula from Roark's Formulas for Stress and Strain:

$$\sigma_{max} = (\beta \times q \times a^2) / t^2$$

Where:

- $\beta = 0.287$ (bending coefficient for a simply supported square plate)
- $a = 12$ in $= 0.3048$ m (plate side length)
- $t = 0.125$ in $= 0.003175$ m (plate thickness)
- q = distributed pressure = F / A

Plate area: $A = 0.3048 \times 0.3048 =$ **0.09290 m²**

Distributed pressure under ultimate load: $q = 49.8 / 0.09290 =$ **536.1 Pa**

Maximum bending stress:

$$\sigma_{max} = (0.287 \times 536.1 \times 0.3048^2) / 0.003175^2$$

$\sigma_{max} = 14.29 / 0.00001008 = 1{,}418{,}056$ Pa = **1.42 MPa**

G10 FR-4 allowable flexural strength (manufacturer data): σ_{allow} = **415 MPa**

3.1.3 Safety Factor Justification

A safety factor of 1.5 is applied to all limit loads to obtain ultimate design loads. This value is consistent with standard practice for unmanned experimental and research systems and accounts for the following:

- **Material variability** — EPS foam, nylon strap, and G10 FR-4 properties can vary between manufacturing batches. The 1.5 factor provides margin against lower-bound material performance.
- **Load estimation uncertainty** — The 10g impact model is a conservative static equivalent of a dynamic event. Actual peak deceleration at landing is bounded by the parachute descent velocity (≤ 6 m/s) and the spring-damper isolation system but is not directly measured.
- **Assembly tolerances** — Cinching strap tension seating cannot be perfectly controlled at the launch site. The safety factor provides margin against asymmetric loading in the suspension path.
- **Environmental degradation** — Nylon and EPS foam material properties are not fully characterized at −70°C stratospheric temperatures. The factor provides margin against any cold-induced reduction in material strength.

The 1.5 safety factor is the minimum acceptable for this system class. Given the extremely large margins computed for both critical components under this factor, it is confirmed as appropriate and conservative. No higher factor was warranted because both components operate far below their structural limits under all expected load conditions.

3.1.4 Structural Survivability

The survivability of both critical structural components under their respective expected loads is confirmed below. Physical ground testing provided validation consistent with the analytical results.

Nylon Rope — Normal Descent Operating Load

Under the normal static descent load of 22.3 N (5.0 lbf), the 50 lbf (222 N) nylon rope has a margin of safety of:

$MS = (222 / 22.3) - 1 = 9.97 - 1 = MS = 8.97$

This confirms the rope has nearly a 10× margin against breakage under normal operating descent loads, providing robust reliability throughout the descent phase. Under the 10g parachute inflation jolt condition (223 N, 50.1 lbf), the rope load approaches and reaches its rated break strength. This is the intentional FAA §101.1(a)(4)(iv) breakaway design. The rope fracturing at this threshold protects the public by ensuring the balloon train separates from the payload under extreme dynamic loads rather than remaining a single uncontrolled mass. The cinching strap is structurally superior to the rope and remain intact under the same load, ensuring the rope is always the first and only element to fail.

G10 Electronics Plate — Landing Impact Loading

The maximum bending stress under the 10g ultimate load condition is 1.42 MPa. The allowable flexural strength of G10 FR-4 is 415 MPa. The margin of safety is:

MS = (415 / 1.42) − 1 = 292.3 − 1 = MS = 291

A margin of safety of 291 confirms the G10 plate is structurally adequate by an overwhelming margin under the expected 10g landing impact load. The plate thickness of 0.125 in was selected based on commercial availability and the need to span the full interior of the EPS foam enclosure, not structural optimization. The four compression springs provide additional protection by absorbing the initial impact impulse before the deceleration load is fully applied to the plate.

Ground Test Validation: The suspension system was validated through the structural pull test documented in the test campaign. The assembled system was loaded manually at the strap attachment points. No loosening, tearing, slippage at buckles, or foam deformation was observed, confirming the strap system functions as designed with the rope remaining the defined weak link. The G10 plate was validated through the parachute drop test post-landing inspection confirmed no structural damage, deformation, component detachment, or foam cracking, consistent with the MS = 291 analytical result.

3.2 Aerodynamics and Performance

3.2.1 Lift Capability (Balloon Sizing)

The lift capability of the balloon was evaluated to ensure sufficient buoyant force to carry the payload mass and achieve the desired ascent profile. The total payload mass is approximately 5.0 lb (2,268 g), including structure, electronics, and recovery system. A HAB TX-1600 balloon was selected based on manufacturer lift data. The helium used has a molecular mass of 4.003 g/mol and a density of 0.166 kg/m^3, compared to air at approximately 1.225 kg/m^3, producing a significant buoyancy differential that generates the gross lift force. At the target fill volume, the TX-1600 provides a gross lift of approximately 1,600 g, yielding a net free lift margin of approximately 668 g (1.47 lb) above the total system weight. This positive margin confirms stable ascent and supports a target ascent rate of approximately 5 m/s consistent with manufacturer data. Additional lift margin is maintained to account for environmental variability including wind loading and temperature effects at altitude.

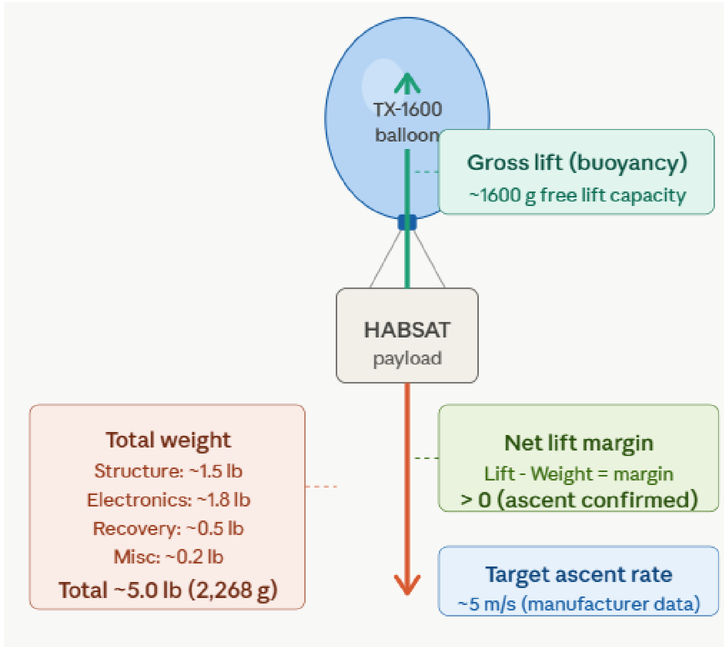


Figure 3.2.1 — HABSAT lift and weight free body diagram

3.2.2 Drag Estimation

Aerodynamic drag on the payload system was estimated using the standard drag equation:

$$F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_D \cdot A$$

where ρ is air density, v is velocity, C_D is the drag coefficient, and A is the reference frontal area. The payload enclosure measures 16 × 16 in (0.406 × 0.406 m) in cross-section, giving a frontal area of approximately 0.165 m^2. A drag coefficient of $C_D = 1.05$ was applied, consistent with published values for a blunt box-shaped geometry. At the target ascent velocity of 5 m/s and an air density of 1.225 kg/m^3 at sea level, the estimated drag force during ascent is approximately 2.6 N (0.58 lb). This is significantly lower than the gross lift force of approximately 15.7 N (1,600 g · 9.81 m/s^2), confirming that aerodynamic drag does not meaningfully oppose ascent.

During descent, aerodynamic behavior is dominated by the Rocketman 4 ft parachute rather than the payload box geometry. The parachute was sized to produce a descent rate of 15–20 ft/s (4.6–6.1 m/s), consistent with manufacturer specifications and the target landing impact requirement. At this descent rate the drag force produced by the parachute canopy balances the system weight, confirming controlled descent.

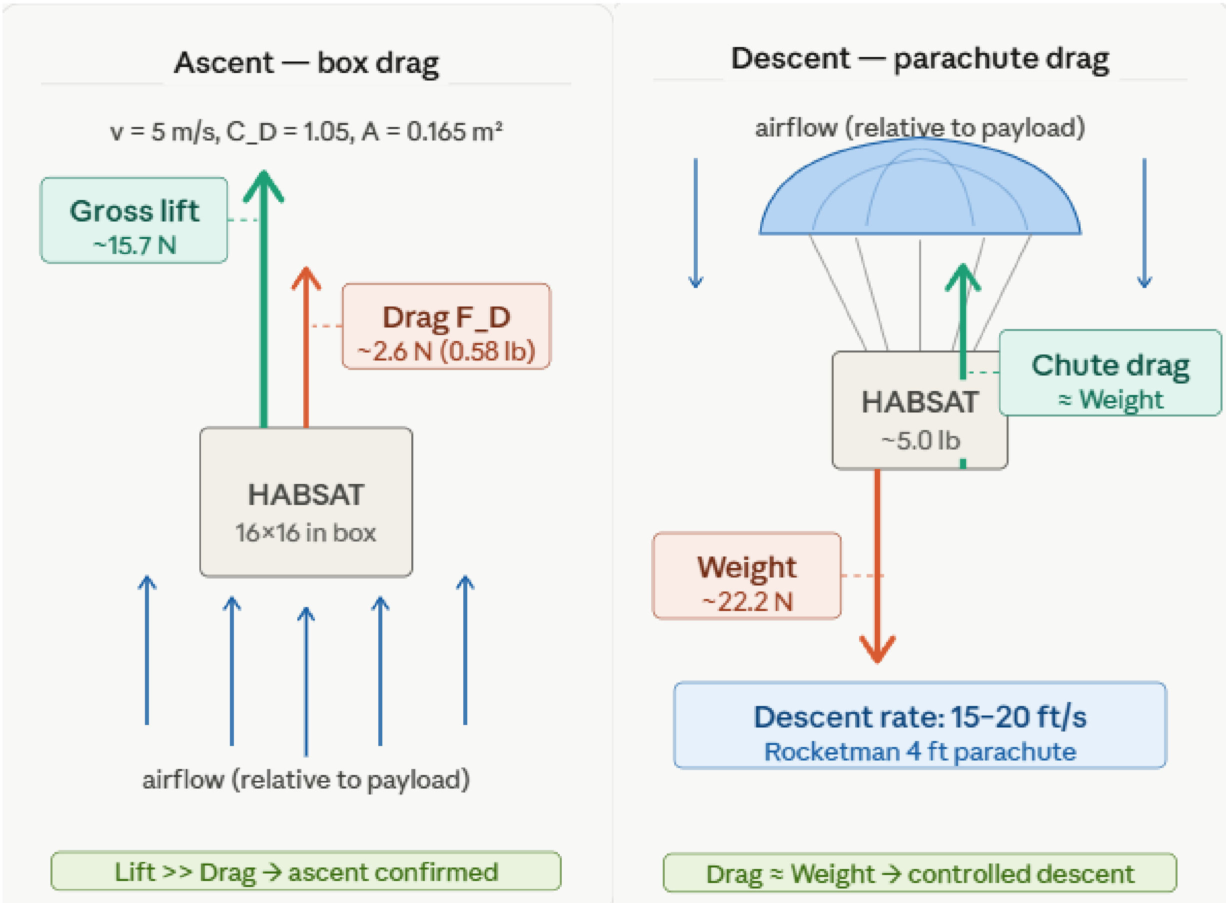


Figure 3.2.2 a&b — HABSAT aerodynamic drag: ascent box drag (left) and parachute descent drag (right)

3.2.3 Ascent/Descent Performance

The ascent and descent performance of the HABSAT system were analyzed using standard high-altitude balloon assumptions and validated through SondeHub trajectory simulation. During ascent, the TX-1600 balloon expands as ambient pressure decreases with altitude, maintaining a target ascent rate of approximately 5 m/s. Burst altitude is expected at approximately 30,000 m (30 km), consistent with TX-1600 manufacturer specifications at the selected fill volume. At burst, the balloon envelope ruptures and the payload enters free fall momentarily before the Rocketman 4 ft parachute deploys and stabilizes descent.

During descent, the parachute produces sufficient drag to reduce the terminal velocity to 15–20 ft/s (4.6–6.1 m/s), limiting landing impact forces on the electronics and structure. The total estimated flight duration is approximately 3 hours, comprising an ascent phase of 1.5–2.5 hours and a descent phase of 0.5–1.5 hours depending on wind conditions. Landing zone prediction was performed using SondeHub for multiple launch windows (10:00 AM, 1:00 PM, and 4:00 PM) to confirm acceptable recovery terrain near the Gaston, SC launch site.

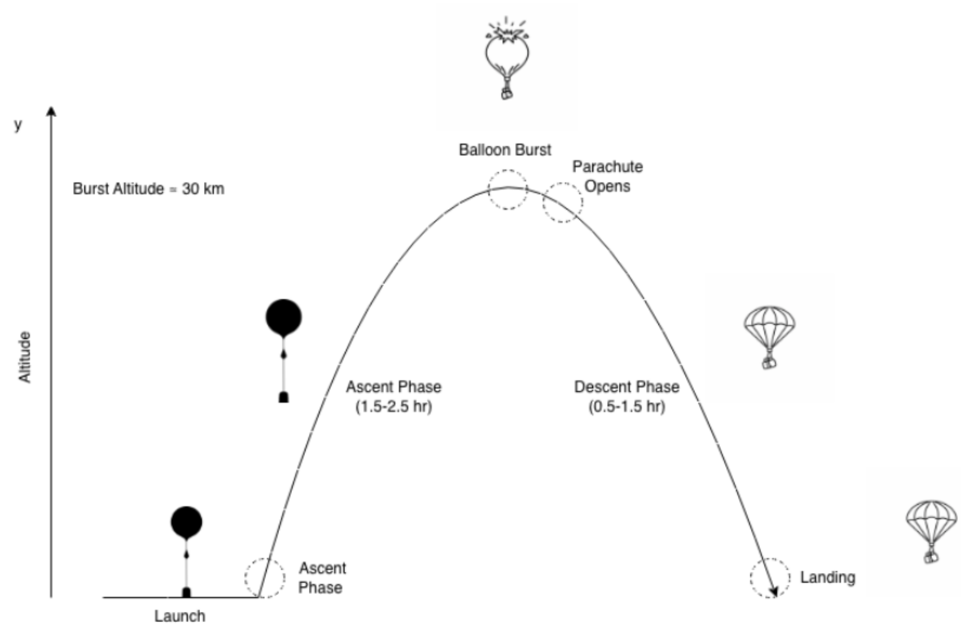


Figure 3.2.3 — HABSAT mission trajectory profile phases

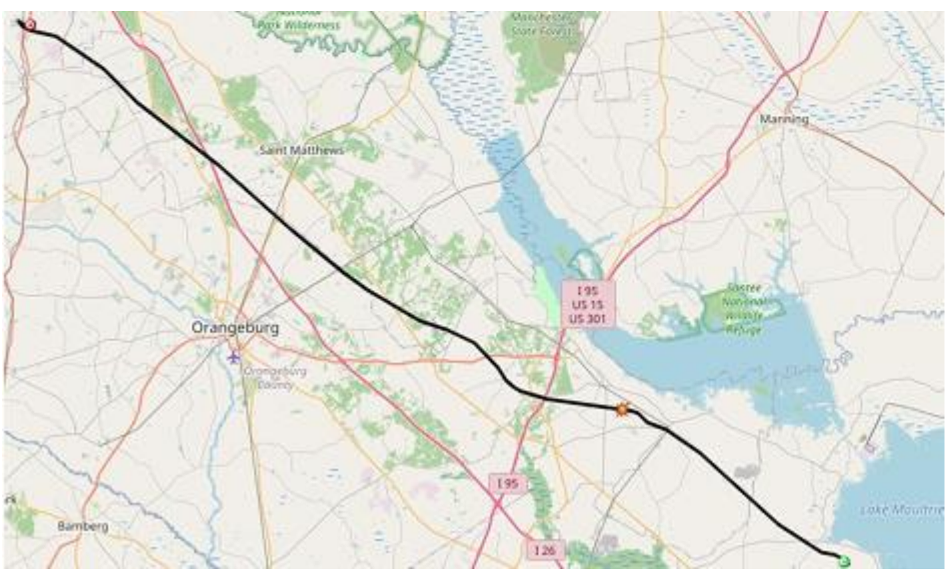


Figure 3.2.4: Morning Trajectory Prediction (10:00 AM)

3.2.4 Buoyancy vs Drag — Net Lift Validation

The net lift condition confirms that the TX-1600 balloon's gross lift force of approximately 15.7 N (1,600 g) exceeds the total system weight of approximately 22.2 N minus the net free lift margin of 668 g, satisfying the requirement that buoyancy overcomes both payload weight and aerodynamic drag simultaneously. At the ascent velocity of 5 m/s, the estimated drag force of 2.6 N represents only 16.6% of the gross lift force, confirming that drag does not meaningfully impede ascent performance. The system therefore satisfies the condition $F_{lift} > W_{payload} + F_{drag}$, validating the balloon sizing selection.

3.2.5 System Performance Validation

System performance was validated through a combination of trajectory simulation, ground testing, and physical drop testing. SondeHub trajectory simulations were conducted for three planned launch windows (10:00 AM, 1:00 PM, and 4:00 PM) to evaluate flight paths under varying wind conditions and confirm acceptable landing zones near the Gaston, SC launch site. All simulated trajectories predicted recovery in accessible open terrain, satisfying the operational safety requirement.

Ground testing verified full avionics functionality including sensor data acquisition from the BME280 (temperature, pressure, humidity) and MPU-6050 (accelerometer, gyro), GPS position fix confirmation via the Neo-M8N module, image capture at 1-minute intervals via the Raspberry Pi HQ Camera, and onboard data logging to SD card. LoRa telemetry packets were confirmed received at the ground station during bench testing.

Structural integrity and parachute deployment were validated through a drop test from approximately 4 stories. The Rocketman parachute deployed fully and stabilized descent with no oscillation or tangling observed. The electronics platform sustained no damage, confirming the spring-based shock isolation design is effective. The combined results confirm the system meets all performance expectations and is ready for flight execution under approved launch conditions.

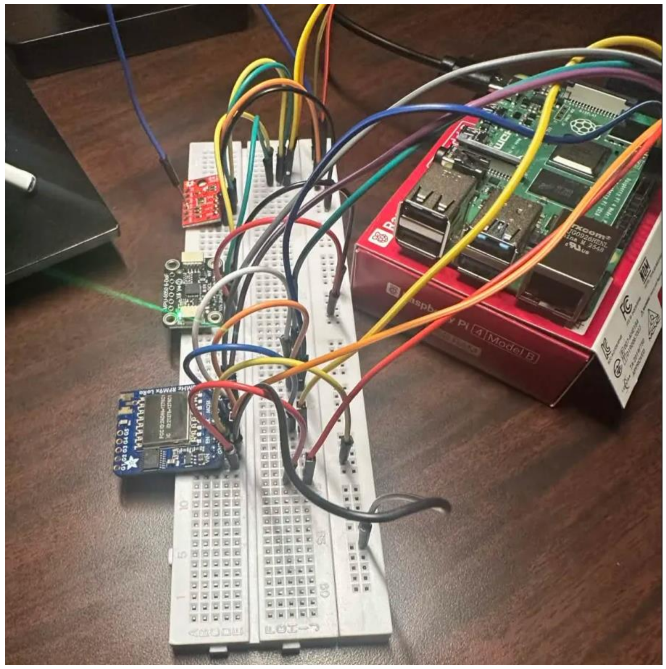


Figure 3.2.5 — Raspberry Pi Avionics Testing

Configuration Details	
Recording Mode	Standard Recording
Video Quality	High
Resolution	1440P60
Auto Start Recording	On
Volume	Default
Stabilization	Gyroscope Data
Distortion correction	Off
Automatic Power-On	On
Date stamp	On
Image rotation	0°
Saturation	3
Exposure	0
Contrast	3
Sharpness	Medium
Metering Mode	Average
White Balance	Auto
ISO	Auto
Shutter	Auto
Power Frequency	60Hz
CVBS Standard	NTSC

Figure 3.2.6 — RunCam Configuration

3.3 Subsystems

The HABSAT payload system is organized into four primary subsystems: avionics and electronics, sensor integration and data logging, the LoRa communication system, and the software control logic. Each subsystem was designed and integrated to operate reliably across the full mission environment, from sea-level launch conditions through the stratospheric cold of 30 km altitude and the mechanical shock of landing. All subsystems interface through the Raspberry Pi 4 flight computer, which serves as the central hub for power distribution, data acquisition, telemetry transmission, and camera control.

The following sections document the functionality, interface configuration, and design rationale for each subsystem as implemented in the final flight build. Software design decisions, including the system logic and two critical design option trade studies, are also presented.

3.3.1 Avionics and Electronics Functionality

The avionics system is built around a Raspberry Pi 4 Model B flight computer, which handles all sensor acquisition, data logging, telemetry transmission, and camera control simultaneously. The Pi 4 was selected for its ability to run SPI, I2C, UART, and CSI interfaces concurrently under a full Linux environment, which was a hard requirement given the number of devices the payload needed to operate at once.

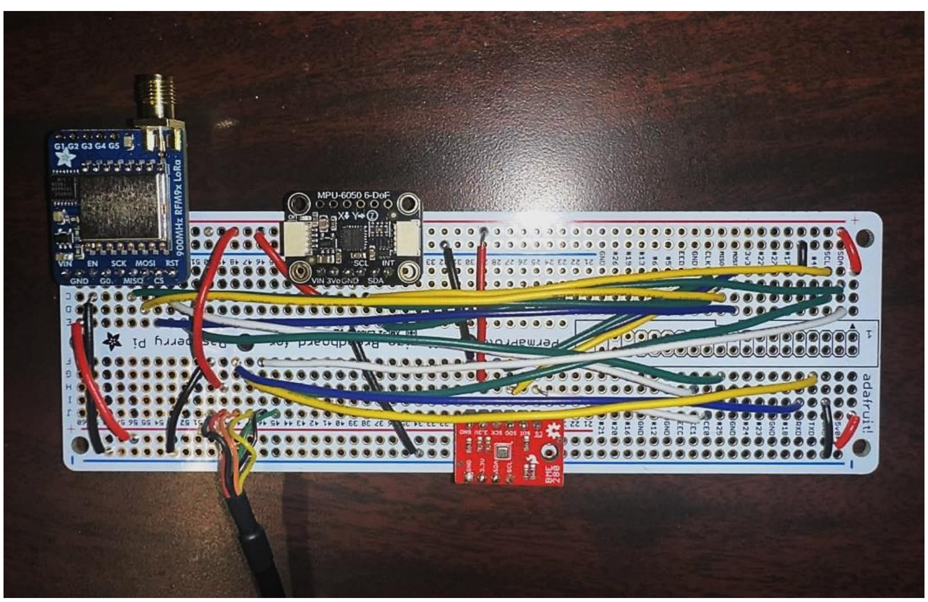


Figure 3.3.1: Partial Internal Board Configuration

The electronics are split across two custom boards. The internal board is an Adafruit Perma-Proto Full-Size Raspberry Pi board connected to the Pi 4 GPIO header via jumper cables, with female ends seated on the Pi header pins and the male ends soldered into the corresponding pinholes on the perma-proto board. It hosts the internal BME280 environmental sensor on SPI0.0 (CE0 = GPIO8), the RFM95W LoRa radio on SPI0.1 (CE1 = GPIO7, RST = GPIO25), and the MPU-6050 IMU on I2C at address 0x68. The u-blox M10 GPS module connects via UART on AMA0, and the NEO-M8N GPS module connects on a second UART at AMA3. Both GPS modules include integrated compass chips that are read over I2C, providing redundant heading data throughout the flight.

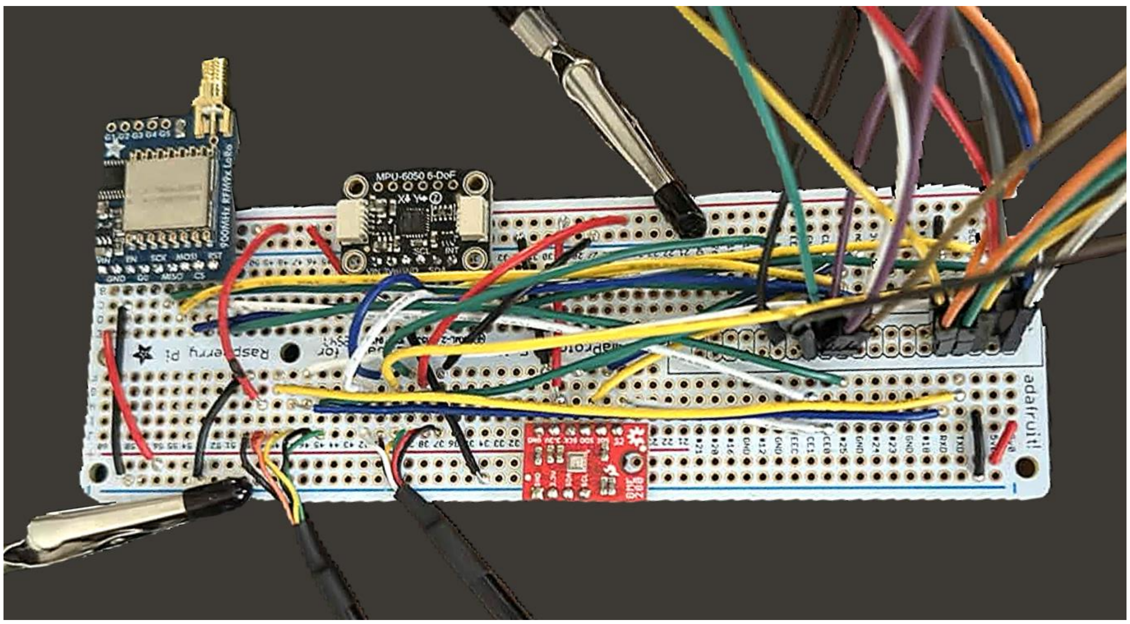


Figure 3.3.2: Final Internal Board Configuration

The external board is a solderable breadboard mounted on the outside of the EPS foam enclosure and connected to the internal board through a five-wire harness carrying 5V, 3.3V, GND, SDA, and SCL. It hosts the external BME280 at I2C address 0x76 and the MS5611 high-altitude barometric sensor at I2C address 0x77. Placing these sensors outside the enclosure ensures ambient atmospheric readings are not affected by heat generated inside the box.

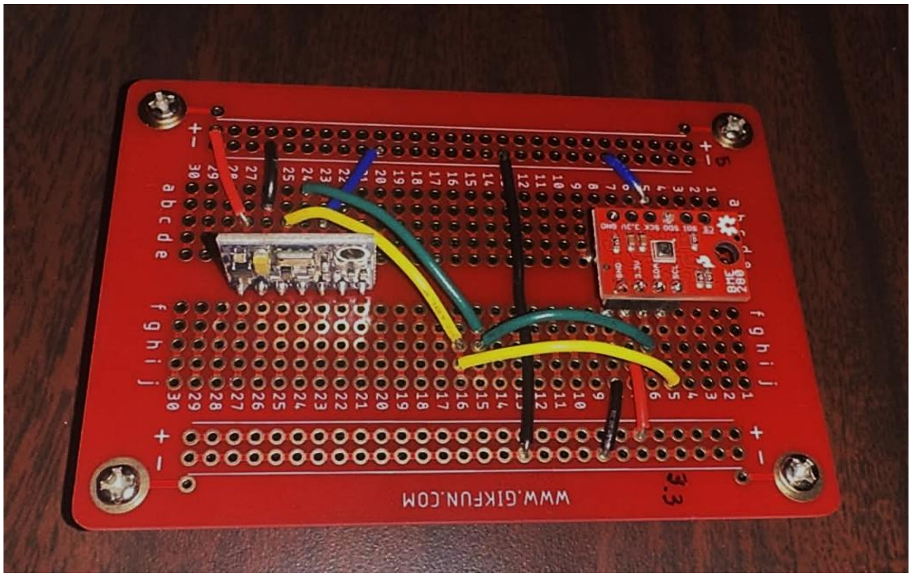


Figure 3.3.3: External Board Configuration

The system uses two voltage levels for peripherals. The GPS modules, both LoRa radio modules, and the MS5611 are powered at 5V through the Pololu regulator output, as each of those boards includes onboard regulation and draws enough current that routing them through the Pi's 3.3V GPIO rail would risk exceeding its amperage limit. The Pi 4's 3.3V rail is limited to approximately 500 mA total across all GPIO-powered devices, whereas the Pololu D24V50F5 regulator is rated for up to 5A continuous on the 5V rail, providing significantly more headroom. Higher-draw peripherals are therefore sourced directly from the 5V rail, while the BME280 sensors and MPU-6050 IMU, which draw only a few milliamps each, operate at 3.3V from the GPIO rail without issue. Power for the full system comes from a 3P4S pack of 12 Energizer Ultimate Lithium AA cells fed through the Pololu regulator producing a regulated 5V output, which powers the Pi 4 through its USB-C port and distributes to all 5V peripherals. A Gardner Bender GSW-41 SPST rocker switch on the positive battery line serves as the arming switch, rated at 16A/125V AC with spade terminals. The flight software runs as a systemd service that starts automatically on boot, so once the system is armed and powered, no further manual steps are needed before launch.

Two cameras operate independently on the payload. The Raspberry Pi HQ Camera connects via the CSI port and captures still images at one-minute intervals. The RunCam Thumb 2 is powered by USB only, with Auto Start Recording enabled in its firmware, so it begins recording the moment power is applied with no software involvement. This approach was chosen specifically to eliminate any dependency on boot timing or GPIO control for a camera mounted inside a sealed enclosure.

3.3.2 Sensor Integration and Data Logging

The flight software reads six sensor subsystems on every main loop iteration at a target rate of 1 Hz. Table 3.3.2 shows the full sensor manifest with interface assignments and measurement outputs.

Sensor	***Interface***	***Address/Port***	***Measurement***
External BME280	I2C Bus 1	0x76	Temperature, pressure, humidity (ambient)
MS5611	I2C Bus 1	0x77	Pressure, temperature (high-altitude barometric)
MPU-6050	I2C Bus 1	0x68	3-axis acceleration (±16g), 3-axis gyroscope, die temperature
Internal BME280	SPI0.0 (CE0, GPIO8)	— (no address due to SPI0 interface instead of I2C)	Temperature, pressure, humidity (enclosure interior)
NEO-M10	UART0	38400 baud, 7-bit	Latitude, longitude, altitude, fix quality, satellites, HDOP, speed, course
NEO-M8N	UART3	9600 baud, 8-bit	Latitude, longitude, altitude, fix quality, satellites, HDOP, speed, course
M10 Compass	I2C Bus 1	0x0E	3-axis magnetometer, heading
M8N Compass	I2C Bus 1	0x0E (when available)	3-axis magnetometer, heading

Table 3.3.4: Sensor Manifest

All sensor readings are written to a CSV file on the Pi's SD card on every loop cycle. The CSV uses a two-row header format where the first row groups columns by sensor subsystem and the second row labels individual fields, making post-flight data analysis straightforward. A separate GPS log stores raw GPS records from both modules independently as an additional layer of redundancy. Both the M10 and M8N are logged on every cycle regardless of which one the software is actively using for telemetry, so the full position history from both modules is available for post-flight review.

Data integrity is protected through several mechanisms built into the software. The filesystem is flushed to the SD card via os.sync() every 30 seconds, guaranteeing at most 30 seconds of data loss in the event of a sudden power cut. Additional syncs are triggered at landing detection and at the start of the shutdown sequence to ensure no data is lost at the two most likely points of power interruption.

A per-sensor health tracking system monitors consecutive read failures for each sensor independently. After 10 consecutive failures, a sensor is automatically disabled and flagged as offline, preventing a single failed sensor from blocking the rest of the loop from executing. Every 60 seconds, disabled sensors are retried to allow recovery from transient faults such as I2C glitches caused by extreme cold at altitude. A last-known-good data cache ensures telemetry packets remain meaningful even when sensors are temporarily offline, so the ground station always receives a useful packet rather than a blank or malformed one. The I2C bus itself is also monitored for accumulated errors, and after 20 I2C errors the bus driver is closed and reopened to clear any lockup state, which is a known failure mode in low-temperature environments.

The MPU-6050 IMU is configured at a full-scale range of ±16g rather than the default ±2g. This ensures the accelerometer does not saturate during the landing impact event, which is the highest-g event in the mission profile. IMU data also drives the software's landing detection logic. When sustained near-zero acceleration is detected following a high-altitude descent phase, the software transitions into post-landing recovery mode. For the first minute after landing is confirmed, all sensor reading and full telemetry transmission continues normally. After that one-minute window, all sensor acquisition and non-GPS transmissions are shut down to reduce power consumption, and the system transmits only GPS position packets until the battery is depleted. This ensures the payload can be located even if recovery is delayed significantly after landing.

3.3.3 Communication System (LoRa / Data Handling)

Telemetry is transmitted via an Adafruit RFM95W LoRa radio module operating at 915 MHz on the FCC Part 15.247 unlicensed ISM band. No amateur radio license is required for this configuration. The module is driven entirely through direct Linux spidev calls at 100 kHz rather than through a pre-packaged library, which provides lower-level hardware control and eliminates library dependency issues in a bare-metal systemd environment.

The radio is configured with Spreading Factor 9 (SF9), bandwidth 125 kHz, coding rate 4/5, sync word 0x12, and output power +20 dBm (100 mW). This is well within the 1 W (30 dBm) limit imposed by Part 15.247. SF9 was selected as the balance point between range and data rate, providing sufficient link margin for line-of-sight communication at 30 km altitude with standard whip antennas while keeping airtime per packet low enough to sustain a 1 Hz transmission rate without collisions.

The flight software transmits two alternating packet types at 1 Hz. PA packets carry the full sensor and GPS payload, including loop counter, timestamp, all BME280 readings from both the internal and external sensors, MS5611 pressure and altitude, GPS data from both the M10 and M8N, compass heading, flight phase, and rolling ascent rate. PB packets carry IMU data including accelerometer XYZ, gyroscope XYZ, die temperature, and GPS fields for synchronization. Alternating between the two types at 1 Hz means each packet type is transmitted every two seconds, keeping all data streams current on the ground station without exceeding the radio duty cycle. All packets are prefixed with "HABSAT4:" and the ground station filters out any packet that does not begin with this identifier, preventing interference from other LoRa traffic in the area.

The ground station is built around a Raspberry Pi Zero 2W paired with a 915 MHz whip antenna and a second RFM95W LoRa module operating in receive-only mode. The LoRa module on the ground station is configured identically to the payload radio — same frequency, spreading factor, bandwidth, coding rate, and sync word — so the two radios are tuned to each other without any additional configuration at the field. The ground station runs a Flask-based web dashboard as a systemd service that starts automatically on boot, meaning the entire ground station is operational within seconds of being powered on with no manual software startup required.

Rather than requiring a laptop to be directly connected to the Pi Zero, the ground station broadcasts its own Wi-Fi hotspot using NetworkManager with the SSID HABSAT4-GS and PS Habsatteam4. Any laptop or phone in the chase vehicle can connect to this network and access the live dashboard through a standard browser at http://192.168.4.1:5000 with no installation, SSH access, or internet connection required.

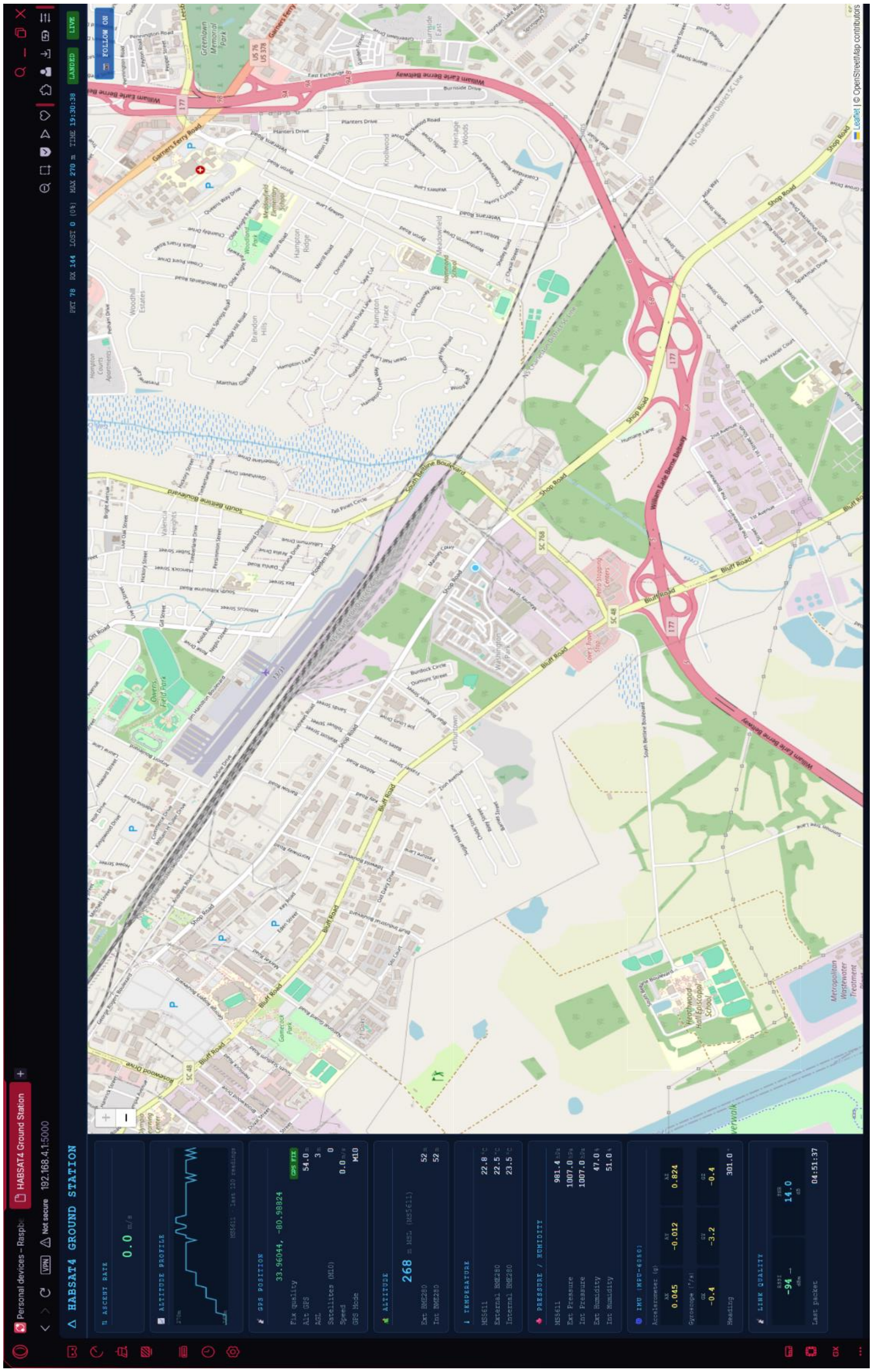


Figure 3.3.5: HABSAT4 Ground Station Live Dashboard

The dashboard displays all incoming telemetry in real time across several dedicated panels visible in Figure 3.3.3. The top status bar shows packet counters for transmitted, received, and lost packets along with a loss percentage, the current timestamp, maximum altitude reached, current flight phase, and a live indicator confirming the link is active. The left panel is organized into labeled sections covering every subsystem: ascent rate in m/s with a live readout, an altitude profile graph plotting the last 120 MS5611 readings to give a visual history of the flight trajectory, GPS position with latitude and longitude, fix quality, GPS altitude, AGL altitude, satellite count, speed, and which GPS module is currently active. Below that, dedicated panels show altitude readings from the MS5611, external BME280, and internal BME280 independently so all three can be compared side by side. Temperature is displayed from all three sensors simultaneously, and a separate pressure and humidity panel shows MS5611 pressure, external and internal BME280 pressure, and external and internal humidity. The IMU panel at the bottom of the left column shows live accelerometer readings in g on all three axes, gyroscope readings in degrees per second, and compass heading in degrees. A link quality panel at the very bottom displays RSSI, SNR, and the timestamp of the last received packet so the chase team always knows the health of the RF link. The right side of the dashboard is occupied entirely by the real-time map, which renders the balloon's current GPS position as a marker and draws the full track history as a line over the pre-downloaded OpenStreetMap tile layer.

To ensure the map remains functional in rural areas where cellular coverage may be limited or absent, approximately 937 MB of OpenStreetMap tile data was pre-downloaded and cached on the Pi Zero's SD card prior to launch. The tile cache covers a 100-mile radius around the Gaston, SC launch site at zoom levels 8 through 15, which is sufficient resolution for both high-altitude overview and close-range recovery navigation. Tiles are served directly from the local cache by the Flask server, with a fallback to live OSM servers in the event a tile outside the cached area is needed. This approach ensures the map is fully usable regardless of field conditions.

3.3.4 Pseudo-Code / System Logic

The flight software follows a structured initialization, main loop, and shutdown sequence. The high-level system logic is described in pseudocode below:

```
── INITIALIZATION ──────────────────────────────────────────

CONFIGURE GPIO (LoRa RST = GPIO25)
INITIALIZE SPI0 bus
  OPEN spidev0.0 → Internal BME280
  OPEN spidev0.1 → LoRa RFM95W
    RESET LoRa via RST pin
    SET frequency = 915 MHz, SF = 9, BW = 125 kHz, CR = 4/5
```

```
        SET TX power = +20 dBm, sync word = 0x12
        VERIFY LoRa version register = 0x12
INITIALIZE I2C bus 1
    DETECT External BME280  @ 0x76 → calibrate
    DETECT MS5611           @ 0x77 → read PROM coefficients
    DETECT MPU-6050         @ 0x68 → set ±16g, 1kHz sample rate
    DETECT IST8310 compass  @ 0x0E → set 16x averaging
    DETECT M8N compass      → read heading
INITIALIZE UART /dev/ttyAMA0 → u-blox M10 GPS (38400 baud, 7-bit)
INITIALIZE UART /dev/ttyAMA3 → NEO-M8N GPS   (9600 baud, 8-bit)
OPEN CSI camera (picamera2) → configure still capture
CREATE sensor_log.csv and gps_log.csv with headers
CALIBRATE ground pressure (average 10 MS5611 readings) → set P0 for AGL
WAIT for GPS lock (timeout = 10 minutes)

── MAIN LOOP (1 Hz) ──────────────────────────────────

LOOP forever:

    timestamp ← current EST time

    READ external BME280 via I2C      (if SensorHealth.ok)
        → temp_ext, pressure_ext, humidity_ext, altitude_ext
    READ MS5611 via I2C               (if SensorHealth.ok)
        → temp_ms, pressure_ms, altitude_ms, altitude_agl
    READ internal BME280 via SPI      (if SensorHealth.ok)
        → temp_int, pressure_int, humidity_int
    READ MPU-6050 via I2C             (if SensorHealth.ok)
        → accel_xyz, gyro_xyz, imu_temp
    READ IST8310 compass via I2C      (if SensorHealth.ok)
        → comp_xyz, heading_m10
    READ M8N compass via I2C          (if SensorHealth.ok)
        → comp_xyz, heading_m8n
    READ M10 GPS via UART             (drain buffer, parse GGA + RMC)
        → lat_m10, lon_m10, alt_m10, fix, sats, hdop, speed, course
    READ M8N GPS via UART             (drain buffer, parse GGA + RMC)
        → lat_m8n, lon_m8n, alt_m8n

    SELECT active GPS source:
        IF M10 has valid fix → use M10 as telemetry GPS
```

```
    ELSE IF M8N has valid fix → use M8N as telemetry GPS
    ELSE → use last-known-good GPS cache

  CALCULATE ascent rate (rolling 10-second window from alt_ms history)
  DETECT flight phase:
    IF on ground and not yet launched   → PRE_LAUNCH
    IF ascending (AR > 0.5 m/s)         → ASCENT
    IF AR < -5 m/s                      → BURST → transition to DESCENT
    IF descending                       → DESCENT
    IF near-zero accel sustained        → LANDED

  WRITE all fields to sensor_log.csv
  WRITE GPS rows to gps_log.csv

  IF loop_counter is even:
    BUILD PA packet:
      "HABSAT4:<seq>,<time>,<bme_ext>,<bme_int>,
       <ms5611>,<gps_m10>,<gps_m8n>,<compass>,<phase>,<AR>"
    TRANSMIT PA via LoRa SPI0.1
    IF 60 seconds elapsed since last image:
      CAPTURE still image via Pi HQ Camera
  ELSE:
    BUILD PB packet:
      "HABSAT4:<seq>,<time>,<accel>,<gyro>,<imu_temp>,<gps>"
    TRANSMIT PB via LoRa SPI0.1

  IF loop_counter mod 30 == 0:
    os.sync() ← flush filesystem buffers to SD card

  SLEEP until next 1-second boundary

── POST-LANDING RECOVERY MODE ──────────────────────────────

  FOR 1 minute after landing confirmed:
    CONTINUE all sensor acquisition and full telemetry transmission

  AFTER 1 minute:
    SHUT DOWN all sensor reads
    SHUT DOWN all non-GPS transmission
    TRANSMIT GPS position only every 5 seconds
```

```
    CONTINUE until battery depleted

── SHUTDOWN (SIGTERM / SIGINT) ──────────────────────────

  os.sync()
  CLOSE CSV files
  CLOSE SPI, I2C, UART, camera
  EXIT cleanly
```

The ground station software operates independently from the payload and follows its own initialization and receive loop. While the payload is focused on acquiring and transmitting data, the ground station is solely responsible for receiving, decoding, and presenting that data to the chase team in real time. Its pseudocode is described below.

```
── INITIALIZATION ──────────────────────────────────

INITIALIZE SPI bus → LoRa RFM95W (receive only)
  SET frequency = 915 MHz, SF = 9, BW = 125 kHz, CR = 4/5
  SET sync word = 0x12
  SET mode = CONTINUOUS RECEIVE
LOAD offline OSM tile cache from SD card
  → /home/habsatgs/tiles/{z}/{x}/{y}.png
START Flask web server on 0.0.0.0:5000
START NetworkManager WiFi hotspot
  SSID: HABSAT4-GS, password: Habsatteam4
  Static IP: 192.168.4.1
INITIALIZE telemetry state (all fields null, packet counters = 0)

── RECEIVE LOOP ──────────────────────────────────

LOOP forever:

  WAIT for LoRa packet (non-blocking poll)

  IF packet received:
    READ RSSI and SNR from LoRa registers
    DECODE packet bytes to string
```

```
    IF packet does NOT start with "HABSAT4:":
      DISCARD → continue loop

    PARSE packet type (PA or PB):

      IF PA packet:
        EXTRACT seq, timestamp, bme_ext, bme_int, ms5611,
             gps_m10, gps_m8n, compass, phase, ascent_rate
        UPDATE telemetry state with all PA fields
        APPEND GPS position to track history list

      IF PB packet:
        EXTRACT seq, timestamp, accel_xyz, gyro_xyz,
             imu_temp, gps
        UPDATE telemetry state with all PB fields

    INCREMENT received packet counter
    CALCULATE packet loss percentage
    UPDATE last_packet_timestamp
    UPDATE max altitude if current altitude > stored max

── FLASK WEB DASHBOARD ──────────────────────────────

ON browser request to 192.168.4.1:5000:
  SERVE dashboard HTML with current telemetry state injected
  AUTO-REFRESH every 1 second via JavaScript polling

ON request to /tiles/<z>/<x>/<y>.png:
  IF tile exists in local cache:
    SERVE from /home/habsatgs/tiles/{z}/{x}/{y}.png
  ELSE:
    FETCH from live OSM tile server as fallback
    SERVE to browser

ON request to /telemetry (JSON endpoint):
  RETURN current telemetry state as JSON
  → consumed by dashboard JavaScript to update all panels live
```

Together the payload and ground station software form a complete closed-loop data system. The payload acquires, logs, and transmits all flight data autonomously from power-on to battery depletion with no operator input required. The ground station receives, decodes, and presents that data continuously, giving the chase team full situational awareness of the balloon's position, altitude, sensor readings, and link health throughout the entire mission. Both systems are designed to start automatically on boot and operate without any manual intervention, which was a deliberate design decision to minimize the chance of human error during a time-pressured launch sequence.

3.3.5 Design Option Tree (2 Critical Decisions)

Two critical design decisions shaped the structural and electronics architecture of the HABSAT system. For each decision, multiple options were evaluated against mission requirements and real testing outcomes before a final selection was made.

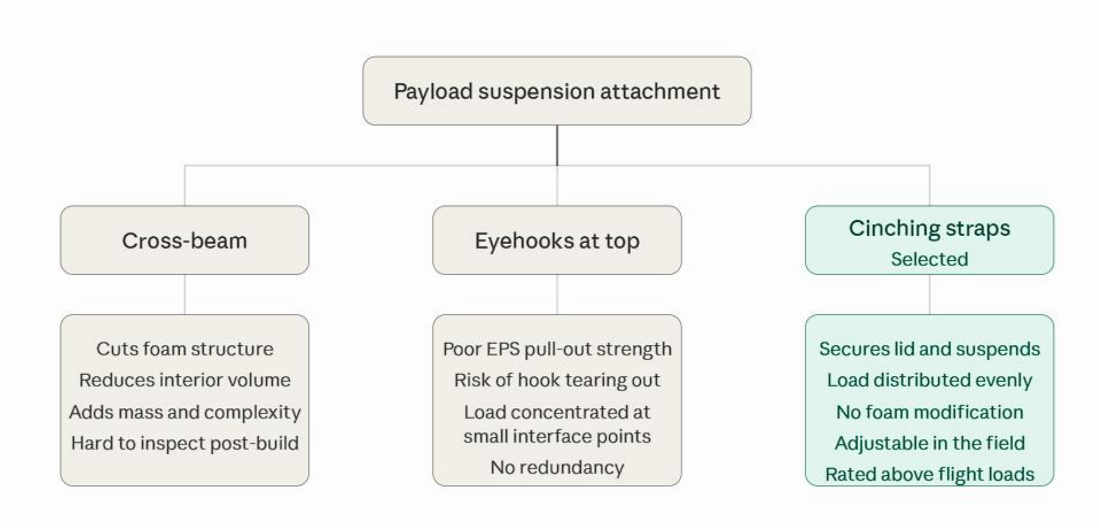


Figure 3.3.6: Payload Suspension Attachment Design Option Tree

The team evaluated three approaches for attaching the suspension line to the payload enclosure as the design evolved through the build phase. The cross-beam concept was the earliest approach, drawing from the PDR-era design, but was eliminated because it required cutting structural channels through the EPS foam, reducing interior volume and adding unnecessary assembly complexity. Eyehooks mounted directly into the top of the foam were evaluated next as a simpler alternative, but EPS foam has poor pull-out strength under sustained tensile loading, creating an unacceptable risk of the hooks tearing free during flight when the full system weight hangs from the suspension line. The cinching strap approach was ultimately selected because it solved both problems simultaneously. The straps serve a dual purpose, securing the lid closed during flight while also providing the suspension attachment points, distributing the load across the full perimeter of the enclosure rather than concentrating it at small interface points. No modification to the foam structure is required, the straps are adjustable in the field, and nylon strap material is rated well above the expected flight loads.

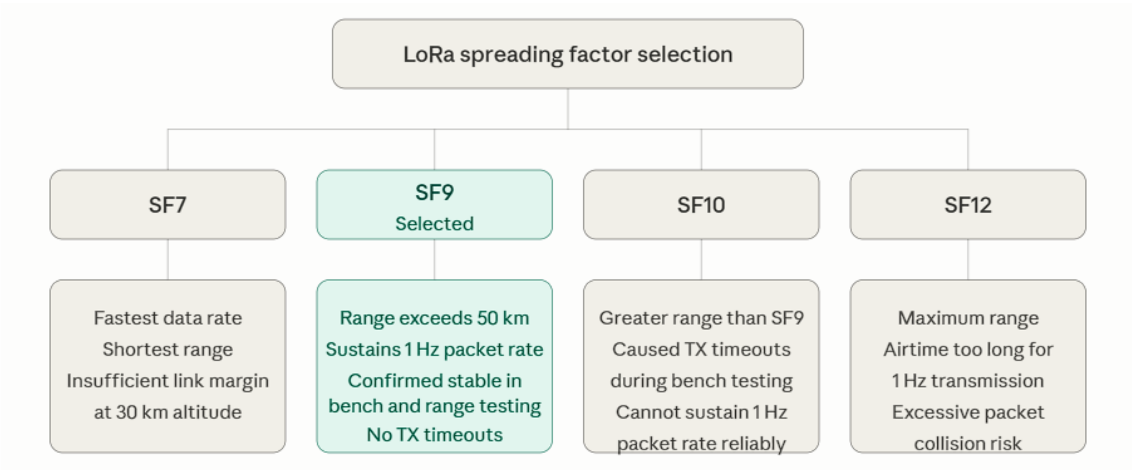


Figure 3.3.7: LoRa SF Selection Design Option Tree

The second critical decision was the selection of the LoRa spreading factor, which directly governs the tradeoff between transmission range and data rate. SF7 was eliminated early because its shorter range could not reliably support line-of-sight communication at 30 km altitude with standard whip antennas. SF12 was eliminated because its airtime per packet is too long to sustain a 1 Hz transmission rate without collisions. SF10 was the initial candidate given its range advantage over SF9, but it was eliminated through direct testing when it caused repeated TX timeouts during bench testing and packet loss, making it unreliable for continuous 1 Hz operation. SF9 was selected as the final configuration after confirming stable operation with no timeouts or packet loss during both bench and range testing. At SF9 the link provides sufficient margin for the full 30 km flight profile while keeping packet airtime short enough to sustain the target 1 Hz rate throughout the mission.

3.4 Budget Breakdown

The budget breakdown summarizes the financial cost, total system mass, and power consumption of the final payload configuration. These budgets were developed using the finalized bill of materials and verified component specifications to ensure the system meets all design constraints. The financial budget confirms the project remains within the allocated cost limit, the weight budget ensures compliance with payload’s mass restrictions and flight performance requirements, and the power budget validates that the onboard energy system can support all components for the duration of the mission. Together, these analyses demonstrate that the system is feasible, balanced, and flight-ready.

3.4.1 Financial Budget

The total procurement cost for the HABSAT payload system is $1,327.35 pre-tax, with a final after-tax total of $1,578.47. The full itemized Bill of Materials is provided in Appendix J.

Category	Subtotal (pre-tax)	% of Budget ($1500)
Avionics & Electronics	$421.31	28.1%
Lift & Balloon	$352.00	23.5%
Structure	$294.58	19.6%
Power & Communications	$158.46	10.6%
Recovery	$101.00	6.7%
Total (pre-tax)	$1,327.35	88.5%
Total (after tax)	$1,578.47	105.2%

Table 3.4.1 - Financial Breakdown

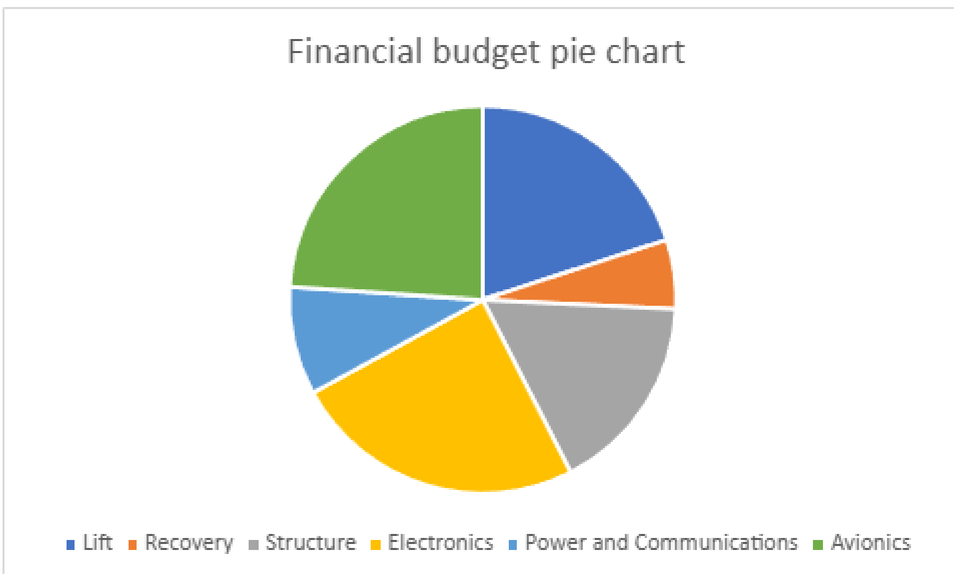


Figure 3.4.2: Financial budget pie chart

3.4.2 Weight Budget

The total confirmed payload mass is 5.0 lb, verified at the pre-flight weigh-in. This is within the self-imposed 5.0 lb design constraint and below the FAA Part 101 limit of 6.0 lb. One G10 garolite electronics plate was removed during final assembly, bringing the system to exactly 5.0 lb. The full component-level mass breakdown is provided in Appendix J.

Subsystem	Mass (lbs)
Structure (enclosure, hardware, fasteners)	3.741
Electronics (Pi, camera, sensors, SD card)	0.545
Power & Communications (batteries, regulator, LoRa)	0.560
Recovery (parachute, lines, hardware)	0.270
Total Confirmed Mass	5.116 lb

Table 3.4.3a: Weight Budget

The EPS foam enclosure dominates the mass budget at 3.0 lb of the 3.741 lb structure subtotal, which is expected for passive thermal protection at this scale. The suspension system consists of a cinching strap around the full perimeter, and a 50 lbf nylon rope — selected to satisfy FAA §101.1(a)(4)(iv) breakaway requirement.

The detailed components add to 5.116, not 5.0 exactly. The 0.116 difference is the measurement rounding across all the small components. The final confirmed weighed mass is 5.0 lbs.

3.4.3 Power Budget

The system power budget was developed from manufacturer specifications and component design parameters. Table 3.4.4 summarizes the estimated continuous power draw for each subsystem in the payload.

Component	Voltage	Current	Power
Raspberry Pi 4 Model B	5V	680 mA	3.4 W
RunCam Thumb 2	5V	300 mA	1.5 W
RFM95W LoRa (TX average)	5V	80 mA	0.40 W
u-blox M10 GPS	5V	20 mA	0.10 W
NEO-M8N GPS	5V	20 mA	0.10 W
Raspberry Pi HQ Camera	3.3V	75 mA	0.25 W
BME280 (×2), MS5611, MPU-6050, compasses	3.3V	~6 mA combined	0.02 W
Total			5.77 W

Table 3.4.3b: Continuous Power Draw Summary

The battery pack consists of 12 Energizer Ultimate Lithium AA cells arranged in a 3P4S configuration. Four cells in series produce a nominal voltage of 6V, and three parallel strings bring the total capacity to approximately 9 Ah, yielding a nominal energy storage of 54 Wh.

The usable energy available to the system is reduced from the nominal 54 Wh by three factors. First, the Pololu D24V50F5 step-down regulator operates at approximately 90% efficiency, reducing available energy to 48.6 Wh after conversion losses. Second, lithium AA cells experience capacity reduction at low temperatures. At stratospheric conditions the cells are conservatively derated to 70% of nominal capacity, bringing usable energy to 34.0 Wh. Third, a 15% reserve is maintained to account for variability in cell performance and any unplanned power events, leaving a final usable energy budget of approximately 28.9 Wh delivered to the system.

The mission energy requirement is calculated across two phases. During the main flight phase of approximately 3 hours, all subsystems operate at full continuous draw of 5.77W, consuming 17.3 Wh. During the post-landing recovery phase, all sensors and non-GPS transmission are shut down after the first minute, leaving only the Pi 4 and GPS modules active at an estimated 3.6W. Over a conservative 30-minute post-landing window this consumes an additional 1.8 Wh, bringing the total mission energy requirement to approximately 19.1 Wh.

Parameter	Value
Nominal battery energy	54.0 Wh
After regulator efficiency (90%)	48.6 Wh
After cold derating (70%)	34.0 Wh
After 15% reserve	28.9 Wh
Total mission energy required	19.1 Wh
Energy margin	9.8 Wh (51%)

Table 3.4.3c: Energy Budget and Margin

The available usable energy of 28.9 Wh exceeds the total mission energy requirement of 19.1 Wh by approximately 9.8 Wh, representing a margin of 51%. This confirms the battery pack provides sufficient energy storage to complete the full flight and post-landing recovery phase with meaningful margin remaining, satisfying constraint C-06 and the power budget requirement.

3.5 Risk Analysis

A comprehensive risk analysis was conducted to identify, evaluate, and mitigate potential failures associated with the high-altitude balloon payload system. Risks were categorized based on likelihood and severity, and mitigation strategies were implemented through design decisions, testing, and operational planning. The following sections summarize the risk map, identified risks, mitigation strategies, and observed risks during testing.

3.5.1 Risk Map

Identified risks were plotted on a likelihood versus severity matrix to prioritize mitigation efforts. Risks were classified across five likelihood levels (Rare, Unlikely, Possible, Likely, Almost Certain) and five severity levels (Insignificant, Minor, Moderate, Major, Catastrophic). High-risk red-zone items — those falling in the Catastrophic/Possible or Major/Likely cells — were addressed through design modifications and mandatory pre-flight testing. The risk map reflects the final selected concept: the cross-bar suspension system with direct foam enclosure mounting.

Concept 1 Risk Map - High Altitude Balloon Payload Suspension

	Rare	Unlikely	Possible	Likey	Almost Certain
Catastrophic				1,2,3	
Major	18	12	4,5,14,19		
Moderate		16	7,8,11,15	6,13	
Minor		10	9,17	20	
Insignificant					

Figure 3.5.1: Risk heat map — Concept 1, High Altitude Balloon Payload Suspension

3.5.2 Identified Risks (≥10)

A total of 21 risks were identified across structural, electrical, environmental, and operational categories. Each risk is assigned a unique identifier consistent with the risk map in Section 3.5.1.

ID	Description	Category	Likelihood	Severity	Risk Level
R1	Balloon structural failure	Structural	Possible	Catastrophic	Red
R2	Suspension line failure	Structural	Possible	Catastrophic	Red
R3	Payload separation	Structural	Possible	Catastrophic	Red
R4	Uneven load distribution	Structural	Unlikely	Major	Orange
R5	Parachute deployment interference	Structural	Possible	Major	Orange
R6	Excess oscillation during ascent	Operational	Likely	Moderate	Orange
R7	Hard landing structural damage	Structural	Possible	Moderate	Yellow

R8	Tangling of support lines	Structural	Possible	Moderate	**Yellow**
R9	Balloon envelope abrasion	Structural	Possible	Minor	**Yellow**
R10	Excess structural mass	Structural	Unlikely	Minor	**Green**
R11	Landing on private property	Operational	Possible	Moderate	**Yellow**
R12	Landing in water	Operational	Unlikely	Major	**Orange**
R13	High wind drift	Environmental	Likely	Moderate	**Orange**
R14	Battery cold failure	Electrical	Possible	Major	**Orange**
R15	Telemetry signal loss	Electrical	Possible	Moderate	**Yellow**
R16	GPS altitude lock failure	Electrical	Unlikely	Moderate	**Yellow**
R17	Helium delivery delay	Operational	Unlikely	Minor	**Green**
R18	FAA compliance issue	Regulatory	Rare	Major	**Green**
R19	Parachute shock load at burst	Structural	Possible	Major	**Orange**
R20	Payload oscillation causing sensor noise	Electrical	Likely	Minor	**Yellow**
R21	Wiring / power failure	Electrical	Possible	Major	**Orange**

Table 3.5.2 — HABSAT Identified Risks (R1–R21)

3.5.3 Testing Requirements

Testing requirements were defined to verify system reliability and reduce risk prior to flight. Each test is linked to one or more identified risks and must be completed before FRR sign-off. A cold soak battery test was added following the risk review to specifically validate R14 battery cold failure at the lowest achievable ground-test temperature of -20°C.

Test	Risks Addressed	Method	Pass Criterion
Parachute drop test	R1, R2, R3, R5, R7, R8, R19	4-story drop, observe descent	Full deployment, no tangling, no structural damage
Electrical bench test	R14, R15, R21	Power on full system, 3-hr continuous run	No brownouts, stable 5V/3.3V rails throughout

Cold soak battery test	R14	Battery pack at -20°C for 1 hr, then load	Stable voltage output, no capacity drop observed
Sensor verification	R15, R16	Poll all sensors, log to SD card	Valid readings, no gaps in log file
GPS lock confirmation	R16	Power on at launch site, wait for fix	Fix acquired within 10 minutes
LoRa range test	R15	Transmit at 500 m with vertical antenna	Packets confirmed received at ground station
Mass verification	R10	Weigh fully assembled payload on scale	Confirmed ≤ 5.0 lb
Trajectory simulation	R6, R11, R12, R13	SondeHub prediction, 3 launch windows	Landing zone confirmed in accessible open terrain
Pre-flight checklist	R17, R18	Complete Appendix H checklist at launch site	All items signed off by team safety lead

Table 3.5.3 — HABSAT Testing Requirements Linked to Risk Register

3.5.4 Compliance Schedule

The following schedule defines the sequence of compliance verification activities completed before launch authorization. All milestones were completed as scheduled. The physical launch did not occur because the FAA Air Traffic Control authority was unable to verify airspace clearance within the required window. The HABSAT system was confirmed flight-ready in all technical and regulatory respects; the mission was stood down due to ATC scheduling constraints outside the team's control.

ID	Activity	Timing	Status
M1	FAA Part 101 compliance review	Pre-CDR	**Completed**
M2	FCC Part 15 RF configuration verified	Pre-CDR	**Completed**
M3	Mass budget verified ≤ 5.0 lb	Pre-FRR	**Completed**
M4	Drop test completed and documented	Pre-FRR	**Completed**
M5	Electrical bench test (3-hr endurance)	Pre-FRR	**Completed**
M6	Cold soak battery test (-20°C)	Pre-FRR	**Completed**

M7	Full system integration test	Pre-FRR	**Completed**
M8	SondeHub trajectory simulation	Pre-launch	**Completed**
M9	Final mass confirmation at launch site	Pre-launch	**Completed**
M10	Pre-flight checklist signed off	Pre-launch	**Completed**
M11	FAA ATC notification submitted	6–24 hrs prior	**Completed**

Table 3.5.4 — HABSAT Compliance and Verification Schedule

3.5.5 High-Risk Avoidance Strategy

High-risk items (R1, R2, R3 — balloon failure, suspension failure, payload separation) were addressed primarily through design selection. The nylon braided suspension line was selected for its predictable load behavior and availability in rated configurations. Balloon structural failure (R1) is mitigated by sourcing a certified TX-1600 balloon with UV protection coating and limiting pre-launch inflation time to reduce UV and abrasion exposure. All red-zone risks involve catastrophic severity — therefore the avoidance strategy prioritizes eliminating the failure mode through design rather than relying on detection or response.

3.5.6 Red-Zone Mitigation Approach

For risks that cannot be fully avoided by design (R2, R5, R19), layered mitigation is applied in accordance with FAA Part 101 regulatory requirements.

FAA §101.1(a)(4)(iv) requires that any rope or device used for suspension of the payload must be capable of separating from the balloon at an impact force of no more than 50 lbf. To satisfy this requirement, the HABSAT suspension system was redesigned from an initial concept to the following final configuration. A cinching strap wraps the full exterior perimeter of the enclosure, providing a continuous structural attachment loop. The 50 lbf nylon braided rope is attached to the cinching strap and connects to the balloon flight train. The nylon rope was selected with a rated breaking load of approximately 50 lbf, ensuring that in a high-load event the rope separates at or below the FAA-mandated threshold, releasing the balloon from the payload and allowing independent parachute recovery.

FAA §101.1(a)(4)(i) requires that a payload weighing more than 4 lbs must not exceed a weight-to-size ratio of 3 oz per square inch on any surface. The HABSAT payload smallest surface area is 16 × 15.5 in = 248 in^2. At 5.0 lb (80 oz), the ratio is 80 ÷ 248 = 0.32 oz/in^2, well below the 3 oz/in^2 limit. This was verified analytically during the CDR phase.

FAA §101.1(a)(4)(ii) sets a payload mass limit of 6 lb per package. HABSAT confirmed mass is approximately 5.0 lb, providing a margin of approximately 1.0 lb below the regulatory ceiling.

Suspension line failure (R2) is mitigated by the cinching strap design which distributes attachment load across the full enclosure perimeter rather than concentrating it at a single point. Payload separation (R3) is mitigated by the four-point nylon rope parachute attachment to the cinching strap which distributes separation loads and provides redundancy (R5) is mitigated by pre-packing the parachute in a consistent orientation and confirming full deployment in the drop test. Parachute shock load at burst (R19) is mitigated by the spring-based electronics mounting platform which absorbs transient impact loads and protects the onboard electronics.

3.5.7 Risks Observed During Testing

R14 — Battery cold failure: Cold temperature performance was identified as a significant risk given expected stratospheric temperatures down to approximately -60°C. The battery selection was upgraded to Energizer Ultimate Lithium AA cells rated to -40°C. A dedicated cold soak test was conducted by placing the fully assembled battery pack in a freezer environment at approximately -20°C for one hour, then immediately measuring voltage under load. The battery pack maintained stable output voltage with no brownouts or significant capacity drop observed at -20°C, confirming acceptable cold-weather performance within the testable range. Operation below -40°C remains a residual risk mitigated by the passive thermal insulation of the EPS foam enclosure, which slows internal temperature drop during the flight profile.

R21 — Wiring / power failure: During initial integration testing, an intermittent connection was identified at the breadboard header for the BME280 sensor. This was resolved by soldering the connection directly rather than relying on press-fit contacts. Post-fix testing confirmed stable sensor readings throughout the 3-hour endurance test with no further power anomalies observed.

R15 — Telemetry signal loss: During early range testing of the LoRa RFM95W module, packet loss was observed at distances beyond approximately 300 m when the antenna was oriented horizontally relative to the ground station. This was mitigated by switching from the default horizontal orientation to a vertical RP-SMA antenna mount, after which reliable packet reception was confirmed at the full test range. The antenna orientation is now included as a mandatory pre-launch checklist item.

No red-zone risks (R1, R2, R3) materialized during testing. All structural components performed as expected through the drop test and pull test sequences.

4. Manufacturing, Testing, and Safety Approach

4.1 Manufacturing Process (Step-by-Step)

Step 1: Starting with a Foam Box, place the box sideways to understand how components will fix in box

Step 2: Taking the lid out of box, create carvings in the inside of the foam box to allow the g10 plate to fit easily sliding in and out of box

Step 3: Glue 4 stainless steel springs on all four corners of g10 plate on one side, on the other side glue Velcro strips, for the 2nd g10 plate also glue the Velcro strips so that both plates can be attached

Step 4: Glue the plate with springs to the inside of the foam box, also combine the Velcro g10 plate with electronics to the plate with the springs

Step 5: Carve holes in foam box to allow enough visibility for cameras and antenna, attach wind blocker to outside of foam box, then spray paint box with garnet red

Step 6: Attach belt strap system, and tie parachute around the strap

4.2 Testing Process (Step-by-Step)

Impact Test

- Pack the parachute in flight configuration attached to the payload

- Bring the payload to the drop height (low altitude sufficient to demonstrate deployment).
- Initiate the drop and confirm the parachute deploys correctly and fully inflates
- Observe and record descent behavior — confirm it is controlled and stable with no oscillation or spin

Figure 4.2 - Freeze frame of drop test

- After landing, immediately inspect the EPS foam enclosure for cracks or structural damage
- Inspect the spring-damper plate system for deformation or displacement
- Inspect all internal components for damage or dislodgement
- Compare the qualitative descent velocity against the analytically calculated value of ≤ 6 m/s from CDR
- Document pass/fail for deployment reliability, descent stability, and post-impact structural integrity

Cold Soak Test

- Assemble the full payload in the EPS foam enclosure as it would fly
- Power off all electronics before cold exposure
- Place the enclosure in the cold chamber/freezer and allow it to soak for a representative duration (e.g., 30–60 min at the lowest achievable temperature)
- Remove the enclosure and immediately power on the system
- Verify the Raspberry Pi boots successfully
- Confirm all sensors initialize and produce valid readings (GPS, temperature, pressure, humidity)
- Log results and note the soak temperature achieved vs. the –70°C stratospheric requirement.
- Document any anomalies or failed initializations

Telemetry Test

- Power on the flight payload and ground station receiver

- Separate the payload and ground station to the desired test range distance
- Confirm the ground station is receiving telemetry packets at 1 Hz
- Verify packet content includes all required fields: GPS coordinates, altitude, temperature, humidity, pressure, and battery voltage
- Log packet reception rate and check for dropped packets or corrupted data
- At the bench (or at the end of range test), simulate a landing detection event (trigger the landing detection condition in software)
- Confirm the system switches to 5-second GPS transmission intervals
- Allow the system to run for the full 30-minute post-landing tracking window and confirm sustained broadcast throughout
- Document packet integrity, range achieved, and correct recovery mode switching behavior

4.3 Safety Protocols

Parachute Drop Test
Checked for overhead hazards, and never stood directly below the drop path. Did not drop in gusty conditions, and never attempted to catch the payload if the parachute failed to deploy.

Cold-Soak Test
Used proper PPE if handling cryogenic cooling agents. Allowed controlled warm-up before powering on electronics to avoid condensation damage, and never handled cold metal components barehanded

4.4 Deviations from Detailed Design

Several design deviations were implemented to improve practicality and reduce weight. Eye hooks were removed from the final design, and rather than cutting the G10 plate, the interior of the foam enclosure was carved out to accommodate internal components. Additionally, the design was simplified to a single G10 plate, as repeated access to the electronics bay was not required.

5. Standards, Codes, and Regulations

This section identifies and evaluates the applicable standards, codes, and regulations governing the design and operation of the high-altitude balloon payload system. Regulatory compliance was a primary design driver, particularly with respect to FAA Part 101 requirements for unmanned free balloons and FCC Part 15 guidelines for radio frequency devices. Additional safety considerations, including battery handling and operational procedures, were incorporated to ensure safe manufacturing, testing, and deployment. All relevant regulations were reviewed and either applied directly to the design or assessed for applicability, ensuring that the final system operates within established legal and safety constraints.

5.1 FAA Regulations (Part 101 Compliance)

Subpart A—General

§ 101.1 Applicability.

(a) This part prescribes rules governing the operation in the United States, of the following:

(1) Except as provided for in § 101.7, any balloon that is moored to the surface of the earth or an object thereon and that has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet.

(2) Except as provided for in § 101.7, any kite that weighs more than 5 pounds and is intended to be flown at the end of a rope or cable.

(3) Any amateur rocket except aerial firework displays.

(4) Except as provided for in § 101.7, any unmanned free balloon that—

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than six pounds;

(iii) Carries a payload, of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

(b) For the purposes of this part, a *gyroglider* attached to a vehicle on the surface of the earth is considered to be a kite.

If none of the four conditions listed in § 101.1(a)(4) apply to the HABSAT balloon system, the operational requirements of FAA Part 101 do not apply. All FAA Regulations were followed by following the requirements of the payload design and weight.

It is not noted in the FAA regulations to notify ATC however it’s important to send a NOTAM to Columbia metro air traffic control for safety and proper communication. In doing so our team reached out to several contacts listed below.

Contact 1: John Nelson (Property Owner of Launch Location): 803-603-8065
The property Owner John nelson was contacted for permission to use his open space property as a launch site. Permission was granted with the exception, he would not want to be liable for unnotified launch, so he required a signed notam before we launched the habsat.

Contact 2: Xavier Coronel (Aviation Safety Technician – Operations): 803-451-2658
An ATC supervisor directed our team to Xavier, to fill out a HIBAL form and have him process the form.

Contact 3: Federal Aviation 803-822-4510
ATC personnel were contacted to ensure we could fly on the date required, however, with a few phone calls made to higher ups in chain of command, he notified us that we would not be able to launch on the proposed date.

5.2 FCC Regulations (Part 15 Compliance)

Regulations That Would Normally Require a License
Three FCC rules would require a license under normal circumstances:

• 47 CFR Part 97 (Amateur Radio) — requires a licensed control operator to transmit on amateur frequencies like APRS. No license means no amateur radio transmissions.
• 47 CFR Part 90 (Land Mobile Radio) — any custom or non-certified radio transmitter carrying sensor or GPS data requires a station license under § 1.903(a).
• 47 CFR Part 5 (Experimental License) — any custom-built transmitter without an existing FCC equipment authorization requires an experimental license before it can be flown

Our project uses a commercially available, FCC-certified LoRa module on the 902–928 MHz ISM band, which is explicitly exempt from individual licensing under 47 CFR § 15.247. The certified module already meets all required technical thresholds:
Because the module carries an FCC ID, the manufacturer has already demonstrated compliance on behalf of all end users. No team member needs a radio license. The team simply must:

1. Not modify the module in any way that voids its FCC certification
2. Keep transmit power within certified limits
3. Retain the FCC ID label on the payload

6. Product Performance Evaluation

6.1 Compliance Verification Table

Due to an ATC (Air Traffic Control) flight restriction on the scheduled launch date, the HABSAT system was not flown. As a result, all requirements that can only be verified through in-flight data remain unverified. Requirements that could be addressed through ground testing, bench testing, inspection, and analysis were completed as planned and are reflected below. The compliance status column uses the following designations: Verified (V) — requirement confirmed through testing, analysis, inspection, or demonstration; Not Verified (NV) — requirement could not be confirmed due to absence of flight data; Partially Verified (PV) — requirement was verified under ground conditions but full confirmation requires flight.

ID	Requirement	Verification Method	Verification Activity Completed	Status
FR-01	Reach altitude of 30 ± 2 km	Test	No flight conducted — GPS altitude data unavailable	**NV**
FR-02	Collect sensor data at ≥ 1 Hz during ascent and descent	Test	Full-duration bench test (≥ 3 hours) confirmed continuous 1 Hz logging of all sensors to SD card with no gaps	**V**
FR-03	Transmit sensor data during ascent at ≥ 1 Hz	Test	Telemetry Range / Antenna Test confirmed LoRa packet reception at ground station; 1 Hz packet rate confirmed	**V**
FR-04	Log all sensor and position data onboard for full mission duration	Test	Full-duration bench test confirmed complete CSV data record written to SD card for entire test duration; filesystem integrity maintained via 30-second os.sync()	**V**
FR-05	Capture continuous HD video at ≥ 1080p	Demonstration	RunCam Thumb 2 powered on and confirmed recording; footage reviewed to confirm 1080p output	**V**
FR-06	Safely recover payload with no structural failure upon landing	Test + Inspection	Parachute drop test conducted; post-test inspection confirmed EPS foam enclosure and all internal components sustained no structural damage	**V**
FR-07	Determine GPS position at ±10 m accuracy	Test	Ground-truth GPS comparison conducted at known location; both NEO-M8N and u-blox M10 confirmed accurate within ±10 m on the ground; high-altitude accuracy unverified	**PV**
FR-08	Maintain operational functionality at	Test	Cold-soak bench test conducted; all sensors and system confirmed functional after cold exposure;	**PV**

	−70°C for ≥ 3 hours		note: test temperature limited to −20°C by available equipment — full −70°C environment not achievable in lab	
FR-09	Maintain terminal descent velocity ≤ 6 m/s	Analysis + Test	Parachute sizing calculation confirmed theoretical ≤ 6 m/s; low-altitude drop test confirmed controlled, stable descent; stratospheric deployment conditions not tested	**PV**
FR-10	Maintain ascent rate within operational range (4–6 m/s)	Analysis + Test	Balloon sizing and lift calculations (CDR) confirmed theoretical ascent rate within range; no flight conducted to verify in practice	**NV**
FR-11	Demonstrate reliable telemetry during flight and post-landing	Test	Telemetry range and antenna test confirmed consistent packet reception; post-landing recovery mode (5 s GPS TX, 30-min window) demonstrated on ground; in-flight reliability unverified	**PV**
FR-12	Payload visually identifiable for recovery	Inspection	Pre-flight visual inspection confirmed high-visibility markings and team identification labels	**V**
C-01	Total system cost ≤ $1,500	Analysis	Final BoM reviewed; total system cost exceeded the $1,500 budget constraint	**NV**
C-02	System development within 16-week schedule	Inspection	All design and manufacturing tasks completed on schedule; flight not executed due to ATC restriction outside team's control	**V**
C-03	FAA compliance	Inspection	FAA 14 CFR Part 101 documentation reviewed	**V**
C-04	FCC compliance	Inspection	LoRa operation confirmed under applicable FCC regulations; amateur radio compliance confirmed	**V**
C-05	Compressed gas handling compliance	Inspection	Helium fill did not occur due to ATC restriction; safety handling procedures were established and	**V**

			documented; N/A for actual execution	
C-06	System mass within lift capability	Analysis + Test	System mass measured on scale pre-launch; confirmed within calculated lift margin from CDR	**V**
C-07	Payload dimensions within regulatory limits	Inspection	Physical dimensions measured and confirmed compliant	**V**
C-08	Structural components meet required safety factors	Analysis + Test	Safety factor analysis completed at CDR; suspension load test and drop test confirmed structural margins	**V**
C-09	No active propulsion or guidance	Inspection	System design review confirmed no active propulsion or guidance components present	**V**
C-10	No prohibited hazardous materials	Inspection	BoM reviewed; EPS foam, G10 fiberglass, and AA lithium batteries confirmed compliant	**V**

Table 6.1: Requirements & Compliance Verification Table

6.2 Requirement Satisfaction Assessment

Of the 22 system requirements and constraints, 11 were fully verified through ground testing, analysis, inspection, or demonstration. Four were partially verified — meaning the verification method was completed under ground conditions but could not be confirmed under actual stratospheric flight conditions. Three requirements were not verified: two functional requirements due to the absence of flight data, and one constraint due to budget exceedance.

FR-01 — Altitude Achievement and FR-10 — Ascent Rate are the two requirements that cannot be assessed in any form without a flight. Both rely entirely on in-flight GPS altitude data. The system was analytically sized to meet both — the balloon volume, helium fill, and lift calculations from the CDR support a theoretical altitude of 30 ± 2 km and an ascent rate of 4–6 m/s — but these results were never confirmed experimentally.

The four partially verified requirements (FR-07, FR-08, FR-09, FR-11) were each addressed as thoroughly as ground conditions allowed. GPS accuracy was confirmed at ground level on both modules. Thermal survivability was tested with available cold equipment, though the full −70°C stratospheric environment could not be replicated in the lab. Descent velocity was confirmed analytically and through a low-altitude parachute drop test. Telemetry reliability was confirmed over ground range, with the recovery mode.

C-01 — Budget was not met. The final system cost exceeded the $1,500 constraint. The exact final cost is documented in the Bill of Materials included in the Appendix J. The budget exceedance is acknowledged as a constraint violation and is discussed further in the project reflection in Section 6.4.

All remaining nine constraints were fully verified. The system was completed within the 16-week schedule, with the flight denial being an external event outside the team's control, and was confirmed compliant with all FAA, FCC, structural, and material requirements.

The design itself satisfies all requirements analytically and where ground verification was achievable. The inability to verify FR-01 and FR-10 is solely attributable to the ATC flight restriction, not to a design deficiency. The budget exceedance represents the one area where the team did not meet a defined project constraint.

6.3 System Performance Results

Despite the absence of flight data, a comprehensive ground test campaign was conducted. The following summarizes the results of each completed test.

Full-Duration Bench Test (Data Logging & System Endurance): The system was operated continuously for approximately 7 hours with approximately 3 hours of simulated flight and approximately 4 hours of post-flight tracking. All six sensors (internal BME280, external BME280, MS5611, MPU-6050, NEO-M8N GPS, u-blox M10 GPS) polled successfully at 1 Hz throughout the test. The CSV data log on the SD card contained a complete, timestamped record with no gaps. No brownouts, reboots, or sensor failures were observed. Battery voltage remained above the 7V regulator minimum for the full test duration, confirming adequate power margin for the expected mission.

Telemetry Range / Antenna Test: The RFM95W LoRa transceiver was tested for range and packet integrity. Ground station successfully received 1 Hz telemetry packets at the test range. Packet content was confirmed to include GPS coordinates, altitude, temperature, humidity, pressure, and battery voltage. The recovery mode was demonstrated on the bench — after simulated landing detection, the system switched to 5-second GPS transmission intervals and sustained broadcast for the full 30-minute tracking window.

Parachute Drop Test: The parachute was deployed from a low altitude drop to confirm deployment reliability and descent behavior. The parachute deployed correctly and produced a controlled, stable descent. Post-test inspection of the payload enclosure confirmed no structural damage to the EPS foam, spring-damper plate system, or any internal components. The drop test qualitatively confirmed the parachute sizing is adequate, consistent with the analytical descent velocity of ≤ 6 m/s calculated at CDR.

Suspension Load Test: The suspension system (shock cord, swivel, and attachment points) was loaded to confirm structural integrity. The system sustained the applied load without deformation or failure, confirming the attachment points meet the required safety margins.

Structural Stability Inspection: The enclosure, spring-damper impact plate, and all mounting hardware were physically inspected. The G10 electronics plate was confirmed to compress smoothly and symmetrically on all four corner springs. No loose fasteners, delamination, or structural concerns were identified.

Cold-Soak Test: The system was operated after cold exposure using available lab equipment. All sensors and the Raspberry Pi initialized and operated correctly after cold exposure. While the full −70°C stratospheric environment could not be replicated, the test provided reasonable confidence in the thermal protection provided by the EPS foam enclosure, consistent with the insulation analysis from the CDR.

GPS Ground Accuracy Test: Both the NEO-M8N and u-blox M10 GPS modules were tested at a known ground location. Both modules produced fixes within ±10 m of the known position, confirming the GPS accuracy requirement is met at ground level. High-altitude accuracy was not tested.

Coding Inspection / Verification: The flight software was reviewed and verified. All hardware interfaces (SPI, I2C, UART) were confirmed initialized correctly. Fault handling logic (sensor failure counters, GPS failover, last-known-good caching) was reviewed and confirmed functional. The systemd auto-launch service was confirmed to start the flight script automatically on power-up with no manual input required.

6.4 Project Reflection

The HABSAT project produced a fully built, integrated, and ground-tested high-altitude balloon payload system. The team designed a complete system from concept through manufacturing, conducted a thorough ground test campaign, and prepared for launch. The inability to fly was the result of an ATC airspace restriction on the scheduled launch date — an event entirely outside the team's control. The following reflection focuses on what the team could have done differently to improve the outcome, independent of that specific event.

Launch Planning and Contingency Scheduling

The most significant lesson from this project is the importance of building launch contingency into the schedule from the start. When ATC denied access to the airspace on that day, there was no fallback option within the remaining course schedule. A more resilient plan would have identified multiple acceptable launch windows across a 2–3 week period, with site alternatives at locations under different airspace classifications. Coordinating with ATC or selecting a launch site in Class G uncontrolled airspace would have eliminated the single point of failure that ultimately prevented the flight. This is arguably the most impactful change the team could have made, and it required no additional technical resources — only earlier schedule planning.

Budget Management

The team did not meet the $1,500 budget constraint. While the exact final cost is documented in the Bill of Materials the Appendix J, the exceedance represents a project management failure that should have been caught and addressed earlier. In retrospect, the team did not maintain sufficiently rigorous cost tracking throughout the procurement process. Individual component purchases were made as needed during the manufacturing phase without consistently checking cumulative spending against the remaining budget margin. A more disciplined approach would have been to establish a running cost tracker updated with every purchase, with a hard internal warning threshold set below the $1,500 limit — for example at $1,200 — to allow time to evaluate and cut lower-priority items before the constraint was breached. Future teams should treat budget tracking with the same frequency and accountability as the Gantt chart, reviewing it at every team meeting rather than only at report submission milestones.

Earlier Component Procurement

The GPS module shipping delay documented at the FRR resulted in a 1–2 week slip in the assembly start date. While the team successfully recovered this delay by parallelizing non-dependent tasks, earlier procurement ideally placed at or immediately after the CDR would have eliminated the scheduling pressure entirely. For future projects, long-lead components should be identified earlier.

Ground Test Campaign Scope

The team's ground test campaign covered most subsystem functions effectively. However, the thermal test was limited by available equipment; a full -70°C cold soak was not achievable with the resources available. For a system whose thermal survivability is a killer requirement, investing in access to a proper environmental test chamber, or coordinating with university facilities that have one, would have provided significantly higher confidence. Similarly, the drop test was conducted at a low altitude. A higher drop test would have better approximated the landing impact conditions at terminal descent velocity.

Documentation and Version Control Timing

Across several phases, documentation was completed under time pressure near submission deadlines. While the quality of the technical content was strong, some analyses and sections would have benefited from earlier drafts and more time for internal review. Establishing a rule that all report sections are ready for submission at least one day before submission would reduce errors and allow better cross-checking between subsystems.

Communication with ATC

In retrospect, the team could have proactively coordinated with ATC prior to the launch date rather than treating regulatory clearance as a formality. Submitting a NOTAM request earlier and following up with the controlling facility to understand any planned traffic or restrictions in the area would have surfaced the conflict sooner. This would have allowed the team to either select an alternate launch site or seek an alternate date while still within the course timeline. Regulatory coordination for flight operations should be treated as a project task with its own milestone.

Overall Assessment

The HABSAT system achieved all of its design, manufacturing, and ground verification goals. The hardware functioned correctly across all tested subsystems. The failure to fly was a scheduling and planning failure, not a technical one, and the budget exceedance reflects a gap in cost discipline during the procurement phase. The most valuable improvements a future version of this team could implement are treating launch execution site selection, airspace coordination, and contingency windows with the same rigor applied to the technical design itself, and maintaining real-time budget awareness throughout every phase of the project rather than only at formal review milestones.

7. Assessment of Broader Impacts

7.1 Local Impacts

HABSAT was launched near Gaston, SC, directly affecting the surrounding rural community. Positively, the project demonstrates accessible aerospace engineering to local students and contributes to STEM awareness. Risks to the local community include payload landing on private property or causing minor property damage during descent. These were mitigated through GPS-guided recovery, rural site selection, SondeHub trajectory analysis, and payload labeling with team contact information. Economically, local material procurement and workforce development represent minor positive contributions.

7.2 State-Level Impacts

The project supports South Carolina's aerospace sector by developing skills directly applicable to industries including Boeing and regional suppliers. Environmental concerns at the state level include helium consumption — a finite non-renewable resource — and the potential for unrecovered EPS foam and nylon materials to create debris in South Carolina's rural landscapes and waterways. GPS-based recovery was treated as mission-critical specifically to address this responsibility.

7.3 National Impacts

HABSAT operates within the national airspace system under FAA Part 101. Its compliant design — breakaway mechanism, mass limits, GPS tracking — demonstrates that small teams can operate responsibly without posing risk to commercial aviation. High-altitude balloon platforms are used nationally by NOAA and NASA for atmospheric research; HABSAT's architecture mirrors these operational systems and contributes to the national pipeline of engineers capable of designing them. Following recent federal attention on unidentified balloon systems in U.S. airspace, transparent tracking and voluntary ATC notification reflect responsible national airspace citizenship.

7.4 Global / Ethical Considerations

HAB technology is one of the most cost-accessible methods of near-space access globally. The HABSAT component stack — Raspberry Pi, commercial sensors, off-the-shelf balloon — is available worldwide at low cost, supporting atmospheric research and educational access in developing nations. Ethically, the platform has dual-use potential: the camera and communication link could theoretically be repurposed for surveillance. The team affirms the design was developed exclusively for scientific and educational purposes, with no live transmission capability. Privacy was addressed by storing all imagery locally on the SD card with no streaming. Finally, helium is a finite global resource lost permanently upon atmospheric release. HABSAT used minimum fill volume to achieve the target ascent rate as a principled contribution to responsible resource use.

Appendix A: Product Specification Sheet

System Specifications

Category	Parameter	Specification
Mission	Mission type	High Altitude Balloon environmental sensing and imaging payload
	Flight duration target	~3 hours (ascent + descent)
	Data collection	Sensor logging and periodic image capture
Physical Structure	External dimensions	16 in × 16 in × 15.5 in
	Internal dimensions	12 in × 12 in × 11.5 in
	Wall thickness	2 in
	Enclosure material	Expanded Polystyrene (EPS) Foam
Mass Properties	Maximum allowable payload mass	5 lb
	Estimated payload mass	~4–5 lb
Recovery System	Parachute type	Rocketman Standard Parachute
	Parachute diameter	4 ft
	Parachute material	Low-porosity ripstop nylon
	Parachute line strength	50 lb rated lines
	Estimated descent rate	~15–20 ft/s
Structural Configuration	Suspension system	Nylon suspension lines rated at 50lbs
	Parachute attachment	Nylon suspension connecting cinching straps and parachute loop
	Internal mounting	Electronics platform with spring-based shock isolation
Power System	Battery type	Energizer Ultimate Lithium AA (L91)
	Battery configuration	4 cells in series in one holder, 3 holders in parallel
	Nominal battery voltage	~6 V
	Pack capacity	~3 Ah
	Nominal energy	18 Wh
	Estimated usable energy	~10.7 Wh (after cold and reserve factors)
Electronics	Flight computer	Raspberry Pi 4 Model B
	Camera	Raspberry Pi High Quality Camera
	Lens	6 mm wide-angle lens
Sensors	GPS module	Neo-M8N GPS and Neo-M10
	IMU	MPU-6050 accelerometer/gyro
	Environmental sensor	2 x BME280's and MS5611
Data System	Image capture interval	Every minute
	Video capture	Consistent Runcam recording
	Data storage	Raspberry Pi SD card and Runcam SD card
Electrical Interfaces	Power rails	5 V and 3.3 V regulated outputs
	Sensor interfaces	GPIO / I²C, SPI, UART connections to Raspberry Pi
Operational Environment	Operating temperature	High-altitude cold environment
	Launch supervision	Helium handling supervised by instructor
	Recovery method	GPS-based payload retrieval

Appendix B: Roles and Responsibilities Breakdown

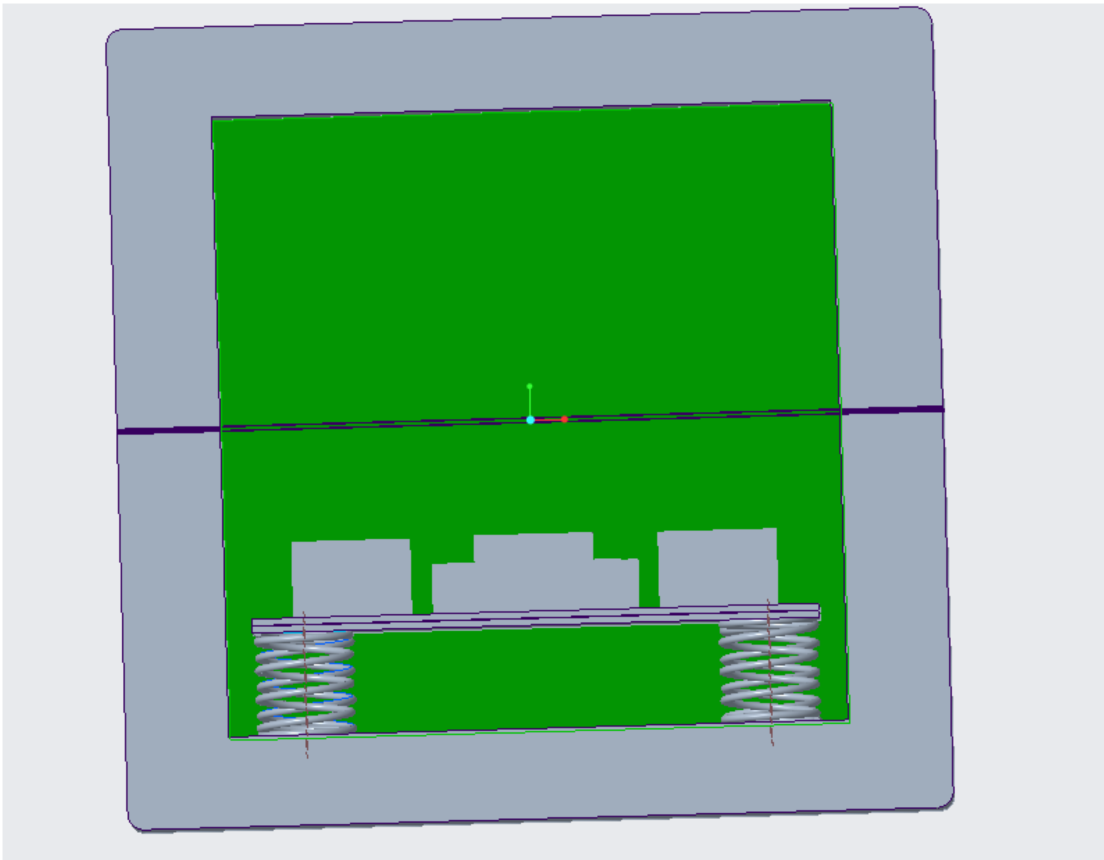
Work hours represent estimated effort contributed toward design development, documentation, analysis, and team coordination activities during preparation of the Flight Readiness Review (FRR).

Team Collaboration	Primary Role	Hours Contributed
Team Leader (Caleb Smith)	Overall integration, Section 5 lead, appendix completion, coordination & final review	36
CAD Engineer (Jacob Chin)	Structural design, CAD modeling, Sections 2 & 4 support, fabrication (structure build)	32
Systems Analyst (Om P. Patel)	Requirements, systems architecture, Sections 2 & 4 lead, integration with CAD	30
Project Manager (Om M. Patel)	Section 3 lead (detailed design), Section 5 support, schedule & documentation management	28
Team Collaboration	Meetings, integration, testing coordination, combined build effort (structure + electrical)	26

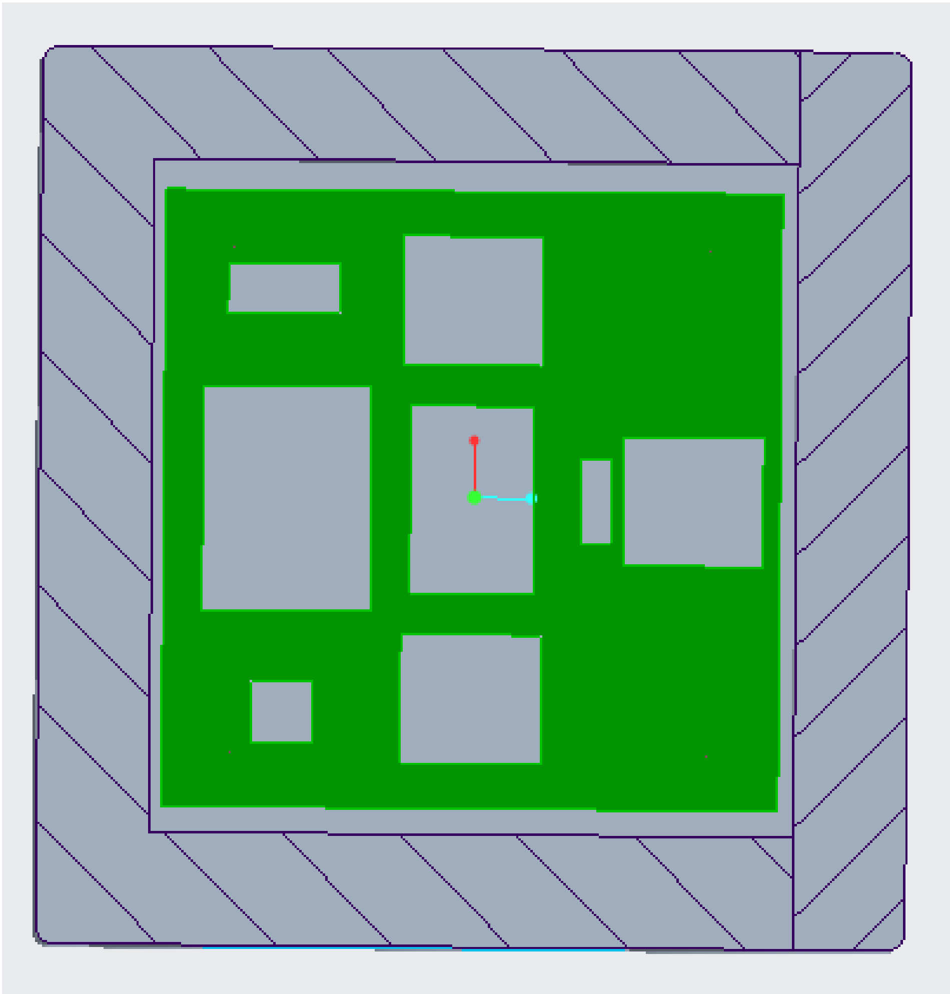
Total team hours = 152

Appendix C: CAD Images

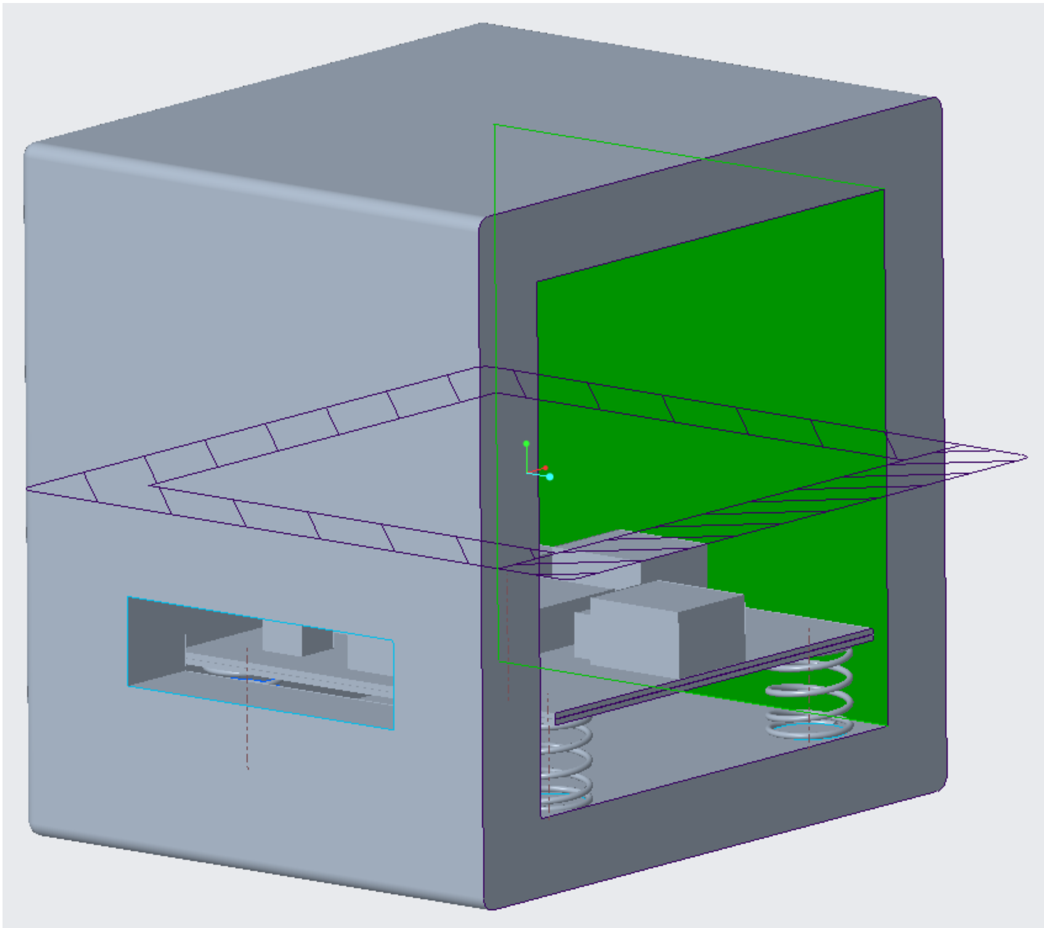
Side View



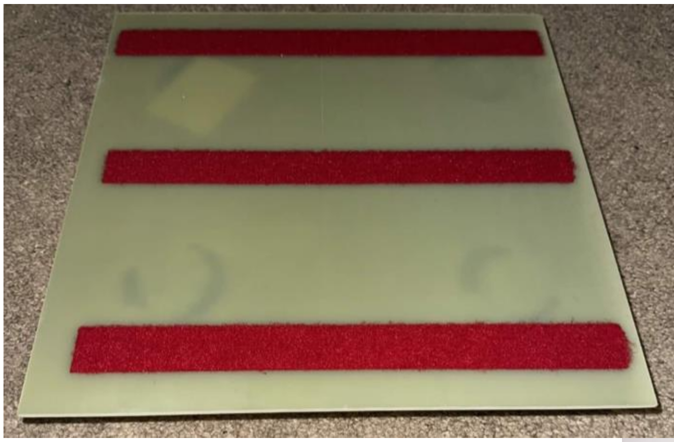
Top View

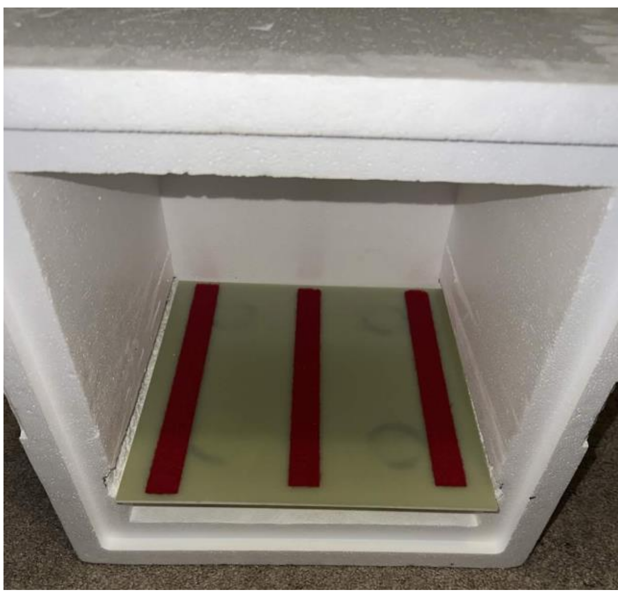


Angle View



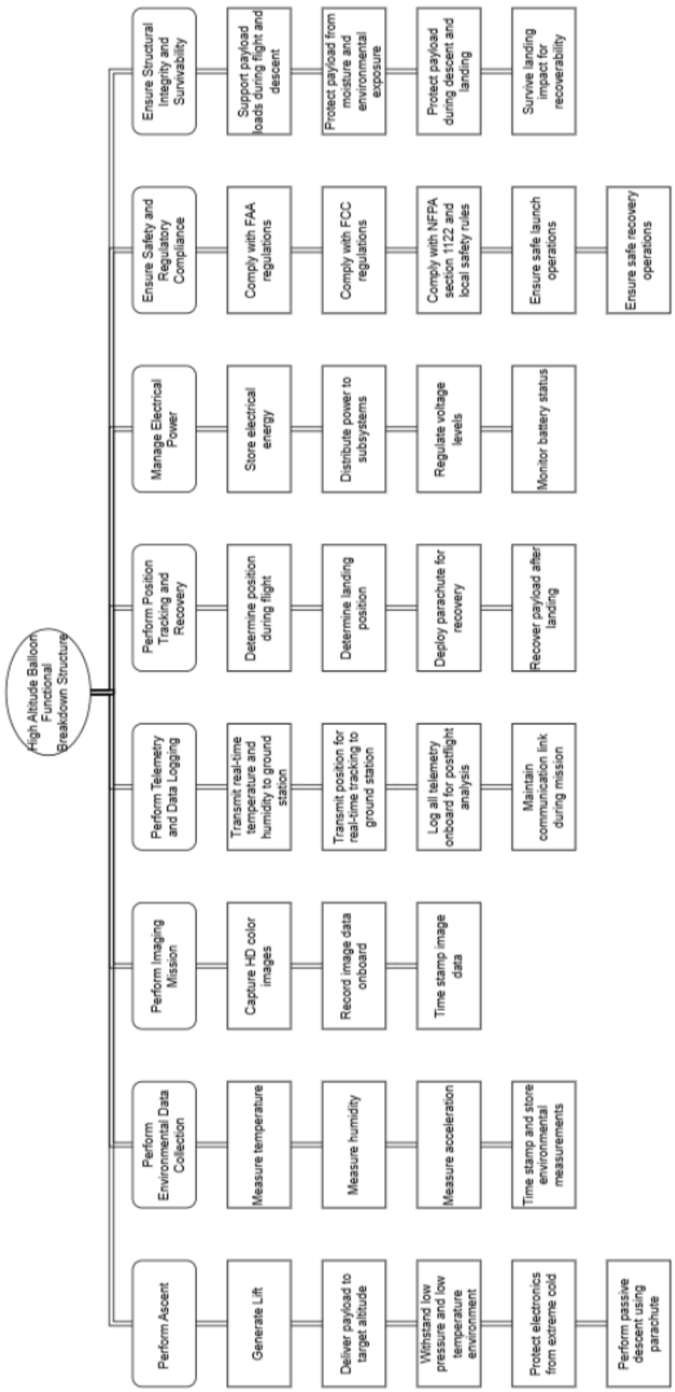
Appendix D: Manufacturing & Assembly Drawings





Appendix E: System Architecture Diagrams

Functional Breakdown Structure



N2 Chart

	Balloon & Lift	Payload Structure & Thermal	Avionics / Electronics	Sensors	Communications & Tracking	Power System	Recovery System	Ground Station
Balloon & Lift		1, 19					2	
Payload Structure & Thermal			3,4	5				
Avionics / Electronics				7,17	8	12		
Sensors			6, 18					
Communications & Tracking								9
Power System			10	11				
Recovery System		13,14						
Ground Station			15		16			

1. Lift Load Transfer:
Defines the transfer of lift force from the balloon to the payload system through the suspension line.

2. Flight Train Tension:
Represents the tension forces experienced along the flight train, including the rope, parachute, and payload connections.

3. Mechanical Mounting Interface:
Describes how structural components and subsystems are physically mounted within the payload enclosure.

4. Thermal Protection Interface:
Defines the interaction between the payload structure and environmental protection elements used to maintain internal temperature.

5. Sensor Mounting Interface:
Describes how sensors are physically secured within the payload to ensure accurate measurements and stability.

6. Sensor Data Interface:
Represents the transmission of sensor data from onboard sensors to the flight computer for processing.

7. Command & Sampling Interface:
Defines how the flight computer sends commands to sensors and controls their data sampling rates.

8. Telemetry Packet Interface:
Represents the packaging of collected data into structured telemetry packets for transmission.

9. Telemetry RF Transmission:
Defines the wireless transmission of telemetry data from the payload to the ground station via radio frequency.

10. Power Distribution – Regulated 5V Rail:
Represents the distribution of regulated 5V power to system components requiring higher voltage operation.

11. Power Distribution – 3.3V Rail:
Defines the distribution of regulated 3.3V power to low-voltage electronics and sensors.

12. Power Demand Feedback:
Represents monitoring and response to system power consumption to ensure stable operation.

13. Parachute Attachment Interface:
Defines the mechanical connection between the payload and parachute for controlled descent.

14. Landing Shock Interface:
Represents how impact forces during landing are absorbed and distributed through the structure.

15. Pre-Flight Configuration Interface:
Defines system setup procedures, including initialization, configuration, and verification before launch.

16. Uplink Command Interface (Optional):
Represents the ability to send commands from the ground station to the payload during operation.

17. Data Logging Interface:
Defines the transfer and storage of collected data from the flight computer to onboard storage (SD card) for redundancy.

18. GPS Position Interface:
Represents the transmission of positional data from the GPS module to the flight computer.

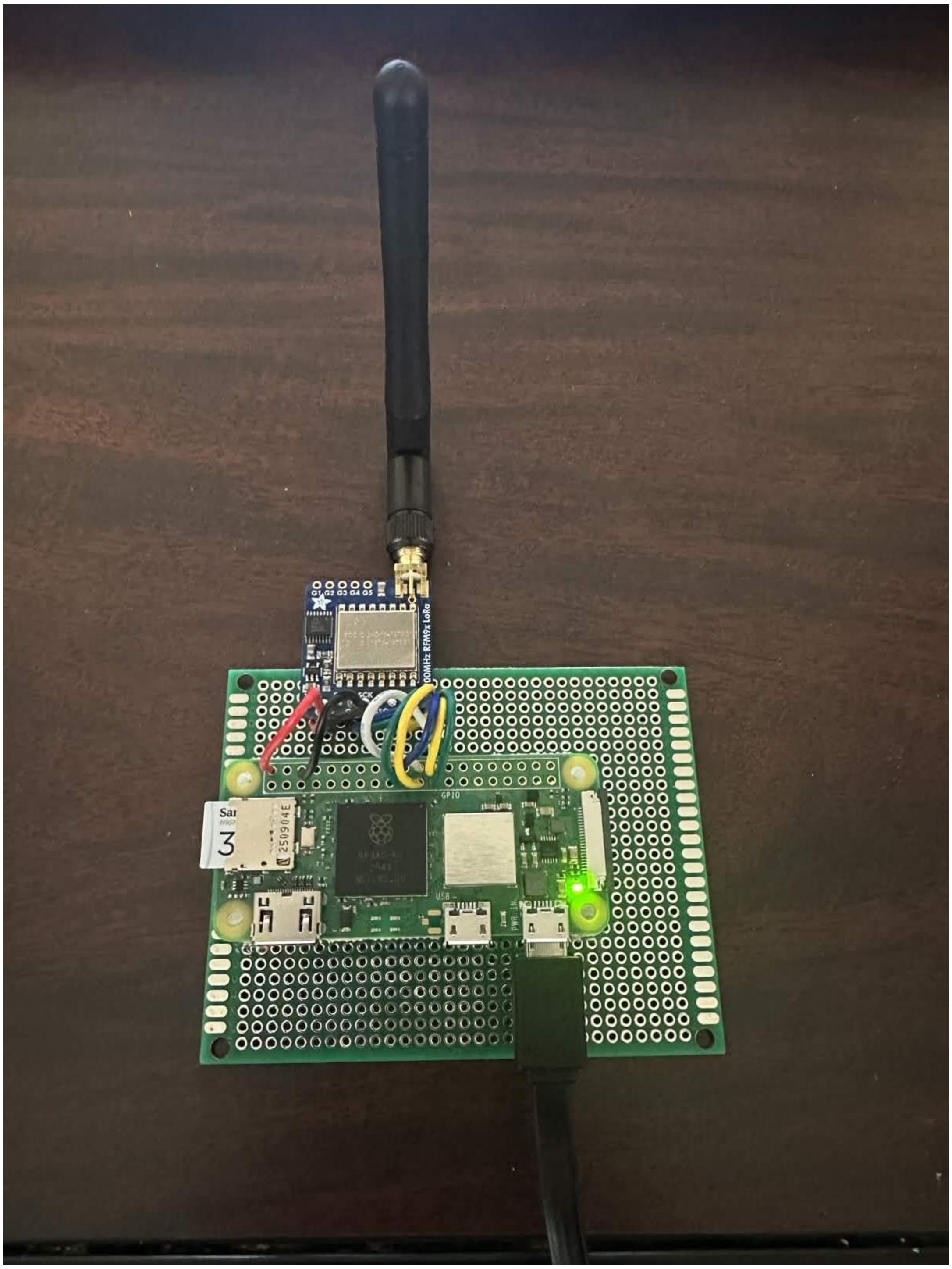
19. Breakaway / Safety Release Interface:
Defines the controlled failure or release mechanism in the suspension system designed to meet safety requirements (e.g., ~50 lbf breakaway).

Electronics Diagrams

Internal:

External:

Ground Station:



Appendix F: Software Documentation

Flight Software Code Snippet)

```
"""=========================================================================
 HABSAT FLIGHT SOFTWARE  v4.8
 AESP-428 Senior Design — Spring 2026
 Team 4: Smith, O.P. Patel, O.M. Patel, Chin

 CHANGELOG vs v4.7
 -----------------
 [+] DISPLAY ALTITUDE — EXT BME280 PRIMARY
     Dashboard altitude (DA field) now uses ext BME280 as primary.
     Falls back to MS5611 if ext BME280 reading unavailable.
     Source logged in DS field so GS knows which sensor is driving it.
     MS5611 raw reading still transmitted in MA field for reference.

 [+] GPS TIME SYNC
     Packet timestamps now use GPS UTC time when a fix is available.
     Falls back to system clock if GPS has no fix yet.
     Fixes the wrong time display on the dashboard at boot.

 [=] All v4.7 features retained
     After LANDED phase confirmed for 60 continuous seconds,
     all sensors (BME280 x2, MS5611, MPU-6050, compass, camera)
     are disabled to conserve battery.
     Both GPS threads (M10 + M8N) stay alive for recovery tracking.
     LoRa switches to a compact recovery packet (PR) every 5s:
       HABSAT4:PR:<seq>,PH:LANDED,T:<time>,
       G:<src>,LA:<lat>,LO:<lon>,AL:<alt>,
       LA8:<lat8>,LO8:<lon8>,AL8:<alt8>,V:<ver>
     System runs until batteries die — never self-shuts-down.
     Power-save entry is logged and synced to disk.

 [+] WIFI AUTO-DISABLE ON ASCENT
     Runs 'rfkill block wifi' when phase transitions PRE_LAUNCH → ASCENT.
     WiFi stays up during boot and ground testing so SSH works fine.
     Killed only once the balloon is confirmed rising (ascent rate > 1 m/s).

 [=] All v4.4 features retained
 [+] MS5611 STARTUP RETRY
     PROM read retried up to 3 times with 200ms delay.
     Eliminates the false FAIL in the health summary on first boot.

 [+] ASCENT RATE CALCULATION
     Rolling 10-second window over MS5611 altitude readings.
     Transmitted as AR field in PA packet (m/s, signed).
     Positive = ascending, negative = descending.
```

[+] FLIGHT PHASE DETECTION
Five phases: PRE_LAUNCH → ASCENT → BURST → DESCENT → LANDED
Derived from ascent rate and altitude. Transmitted as PH field.
Burst detected when ascent_rate flips from positive to < -5 m/s.
Phase logged and synced to disk at each transition.

[+] BURST DETECTION
Dedicated burst event: logged, os.sync(), burst time recorded.
Dashboard shows BURST DETECTED when phase transitions.

[+] GROUND PRESSURE CALIBRATION → AGL ALTITUDE
First stable MS5611 reading stored as launch pressure.
AGL (above ground level) computed from pressure ratio.
Transmitted as AG field in PA packet (meters).

[+] PACKET SEQUENCE PERSISTENCE
Sequence counter saved to disk every 50 packets.
Survives software restarts — no false "1000 packets lost" on GS.

[+] GPS FIX QUALITY FIELD
FQ field in PA packet: 0=no fix, 1=GPS, 2=DGPS, 4=RTK.
GS dashboard uses this to show fix quality badge.

[+] TEMPERATURE DIFFERENTIAL MONITORING
If |ext_temp - int_temp| > 15°C, logs a warning.
Indicates insulation failure or sensor drift. Log only, no packet.

[=] All v4.2 features retained (SF9, landing recheck, dual GPS, etc.)

PA PACKET FORMAT (new fields marked *):
HABSAT4:PA:<seq>,T:<time>,
MT:<ms_temp>,MP:<ms_pres>,MA:<ms_alt>,
ET:<ext_temp>,EH:<ext_hum>,EP:<ext_pres>,EA:<ext_alt>,
IT:<int_temp>,IH:<int_hum>,IP:<int_pres>,IA:<int_alt>,
G:<gps_src>,LA:<lat>,LO:<lon>,AL:<alt_gps>,SK:<speed_kts>,
LA8:<lat8>,LO8:<lon8>,AL8:<alt8>,SK8:<speed8>,
AR:<ascent_rate>*,PH:<phase>*,AG:<agl_alt>*,FQ:<fix_quality>*,
V:<version>
===""

(Ground Station Software Snippet)

""""===
HABSAT4 Ground Station Dashboard v2.5
Pi Zero 2W | spidev0.0 | CE=GPIO8 | RST=GPIO25 | DIO0=GPIO24

CHANGELOG vs v2.4

[+] DISPLAY ALTITUDE FROM EXT BME280
Main altitude display now uses DA field (ext BME280 primary).
Falls back to MS5611 if DA not present.
Altitude source label shown next to the value (EXT or MS5611).
Max alt tracker and altitude chart also use display_alt.

[=] All v2.4 features retained
[+] RECOVERY MODE OVERLAY
When phase=LANDED, full-screen overlay shows final GPS coords,
altitude, and a direct Google Maps navigation link.
Tap the link to open navigation to landing site.

[+] MAX ALTITUDE TRACKER
Peak MS5611 altitude recorded during flight.
Displayed persistently in header — survives phase changes.

[+] GPS STALENESS FIX
Staleness now time-based (>30s since last fix) not None-check.
Dot turns gray and coords show "last known" correctly.

[+] AUTO-FOLLOW TOGGLE
Button on map to lock/unlock map following the balloon.
Useful during chase when you want to pan around freely.

[+] ALTITUDE MINI-CHART
Canvas chart in left panel showing altitude vs time (last 120pts).
Updates live. Shows MS5611 altitude curve building during flight.

[+] RSSI/SNR TREND INDICATOR
Arrow next to RSSI showing if signal is improving ↑ or degrading ↓
based on last 10 packets. Flat → if stable.

[+] PR PACKET SUPPORT
Handles compact recovery packet (PR) from flight software v4.5
power-save mode. Updates GPS position from PR packets when landed.

[=] All v2.3 features retained

SETUP
-----
1. Install deps (once):
sudo apt install python3-flask python3-rpi.gpio python3-spidev -y

2. Download Leaflet while Pi has internet (once):

```
cd /home/habsatgs
python3 -c "
import urllib.request
urllib.request.urlretrieve('https://unpkg.com/leaflet@1.9.4/dist/leaflet.js','leaflet.js')
urllib.request.urlretrieve('https://unpkg.com/leaflet@1.9.4/dist/leaflet.css','leaflet.css')
print('Done')
"
3. Download map tiles while Pi has internet (once, takes ~30-60 min):
sudo python3 /home/habsatgs/download_tiles.py
4. Run:
sudo python3 /home/habsatgs/gs_dashboard.py
5. Access: http://192.168.4.1:5000 (hotspot) or http://<ip>:5000 (WiFi)
============================================================"""
import os
import spidev
import RPi.GPIO as GPIO
import time
import threading
from datetime import datetime
from pathlib import Path
from flask import Flask, jsonify, render_template_string, send_from_directory
# ─── Config ──────────────────────────────────────────────────────────
LEAFLET_DIR = "/home/habsatgs"
VERSION = "2.5"
TILE_DIR = "/home/habsatgs/tiles"
# ─── Pin config ──────────────────────────────────────────────────────
PIN_RST = 25
PIN_DIO0 = 24
# ─── SX1276 Registers ────────────────────────────────────────────────
REG_FIFO = 0x00
REG_OP_MODE = 0x01
REG_FRF_MSB = 0x06
REG_FRF_MID = 0x07
REG_FRF_LSB = 0x08
REG_LNA = 0x0C
REG_FIFO_ADDR_PTR = 0x0D
REG_FIFO_RX_BASE_ADDR = 0x0F
REG_FIFO_RX_CURRENT = 0x10
REG_IRQ_FLAGS = 0x12
REG_RX_NB_BYTES = 0x13
REG_PKT_SNR_VALUE = 0x19
REG_PKT_RSSI_VALUE = 0x1A
REG_MODEM_CONFIG1 = 0x1D
```

```
REG_MODEM_CONFIG2 = 0x1E
REG_MODEM_CONFIG3 = 0x26
REG_SYNC_WORD = 0x39
REG_DIO_MAPPING1 = 0x40
REG_VERSION = 0x42
MODE_SLEEP = 0x80
MODE_STANDBY = 0x81
MODE_RX_CONT = 0x85
IRQ_RX_DONE = 0x40
IRQ_CRC_ERROR = 0x20
# ──── SPI / GPIO ────────────────────────────────────────────────
spi = spidev.SpiDev()
spi.open(0, 0)
spi.max_speed_hz = 5000000
spi.mode = 0b00

GPIO.setmode(GPIO.BCM)
GPIO.setwarnings(False)
GPIO.setup(PIN_RST, GPIO.OUT)
GPIO.setup(PIN_DIO0, GPIO.IN)
# ──── Shared state ────────────────────────────────────────────────
state_lock = threading.Lock()
telemetry = {
"seq": "--", "payload_time": "--",
"ms_temp": "--", "ms_press": "--", "ms_alt": "--",
"ext_temp": "--", "ext_hum": "--", "ext_press": "--", "ext_alt": "--",
"int_temp": "--", "int_hum": "--", "int_press": "--", "int_alt": "--",
"gps_mode": "--", "lat": None, "lon": None, "alt_gps": "--", "sats": "--",
"lat8": None, "lon8": None, "alt8": "--", "sats8": "--",
"ax": "--", "ay": "--", "az": "--",
"gx": "--", "gy": "--", "gz": "--",
"heading": "--",
"rssi": "--", "snr": "--",
"last_rx": "--", "packets_rx": 0, "packets_lost": 0,
"last_seq_pa": -1,
# New v4.3 fields
"ascent_rate": "--", # m/s
"phase": "PRE_LAUNCH", # flight phase
"agl": "--", # above ground level altitude m
"fix_quality": 0, # GPS fix quality 0=none 1=gps 2=dgps
"speed_ms": "--", # speed in m/s (converted from knots)
# Last known GPS
"last_lat": None, "last_lon": None, "last_gps_time": None,
# New v2.4 fields
```

```
"max_alt": None, # peak MS5611 altitude seen
"last_gps_ts": None, # unix timestamp of last GPS fix (for staleness)
}
rssi_history = [] # last 10 RSSI values for trend arrow
alt_history = [] # (unix_ts, alt_m) for mini-chart, max 120 points
MAX_ALT_HIST = 120
track_history = []
MAX_TRACK = 500

# ─── LoRa helpers ───────────────────────────────────────────────

def read_reg(addr):
    return spi.xfer2([addr & 0x7F, 0x00])[1]

def write_reg(addr, val):
    spi.xfer2([addr | 0x80, val])

def reset_lora():
    GPIO.output(PIN_RST, GPIO.LOW)
    time.sleep(0.01)
    GPIO.output(PIN_RST, GPIO.HIGH)
    time.sleep(0.01)

def init_lora():
        reset_lora()
        version = read_reg(REG_VERSION)
        if version != 0x12:
```

Appendix G: Test Matrix and Verification Tables

Verification Test Matrix

ID	Requirement / What must be verified	Verification Method
VR-1	Total payload mass ≤ 5.0 lb (includes parachute connection hardware, batteries, enclosure, electronics, and wiring)	Inspection + measurement
VR-2	Payload internal fit and enclosure closure (electronics fit inside with lid secured)	Inspection
VR-3	Cross-bar structural attachment integrity (cross-bar fully through foam walls, bonded/secured)	Inspection + pull test
VR-4	Parachute-to-cross-bar attachment integrity (4 lines secured + center attachment point)	Functional test
VR-5	Drop test: landing survivability (foam + spring mounting protects electronics)	Drop test (~4-story garage)
VR-6	Descent stability (no excessive swinging/rotation)	Drop test
VR-7	Parachute deployment reliability (pre-packed parachute opens consistently)	Drop test
VR-8	Sensor data logging to Pi SD card (GPS, IMU, temp/humidity)	Bench test
VR-9	Camera capture requirement (images every 20 minutes)	Bench test
VR-10	Power regulation stability (5V/3.3V rails stable)	Bench test
VR-11	Power endurance for mission duration (~3 hours)	Bench test
VR-12	Flight-readiness integration check (full system assembled, wired, operational)	System-level test
VR-13	Preliminary balloon test flight using 1500 g balloon (integration + recovery)	Field test
VR-14	Trajectory planning and safety constraints satisfied (launch conditions acceptable)	Analysis + review

Measurement Strategy	Pass/Fail Criteria	Evidence / Deliverable
Weigh fully assembled flight-ready payload on a scale	Mass ≤ 5.0 lb	Photo of scale reading + mass log
Verify all components fit inside and lid/tape closure works	Lid closes fully; no interference	Photos + final packing checklist
Apply controlled pull load by hand / spring scale if available	No loosening, tearing, or bar slip	Photos + notes
Full system rigged; confirm 4-point attachment is symmetric and secure	No slip, no cut-through, no asymmetry	Photo of rigging + setup checklist
Record drop test; inspect electronics after impact	No structural failure; electronics functional after test	Video + post-drop inspection form
Observe descent during drop test	No violent oscillation; lines not tangled	Video observations + notes
Confirm chute opens fully after release	Full canopy inflation before ground impact	Video evidence
Run system for set time; verify files saved correctly	Correct data files generated, timestamps valid	Data files + screenshot of directory
Run timed script; verify saved image timestamps	Correct interval; images readable	Image set + timestamp log
Measure voltage under load (multimeter)	Voltage within acceptable tolerance; no brownouts	Voltage log + photos
Run full system continuously; track time to cutoff	System operates continuously for ≥ 3 hr	Runtime log + video/photo timeproof
End-to-end test: sensors + camera + logging all active	No critical faults; stable operation	Final preflight checklist
Record ascent/descent; recover payload; check data	Payload recovered; data successfully logged	Flight log + recovered data + photos
Use predictor + weather review pre-launch	Predicted landing zone acceptable; go/no-go recorded	Prediction screenshots + go/no-go sheet

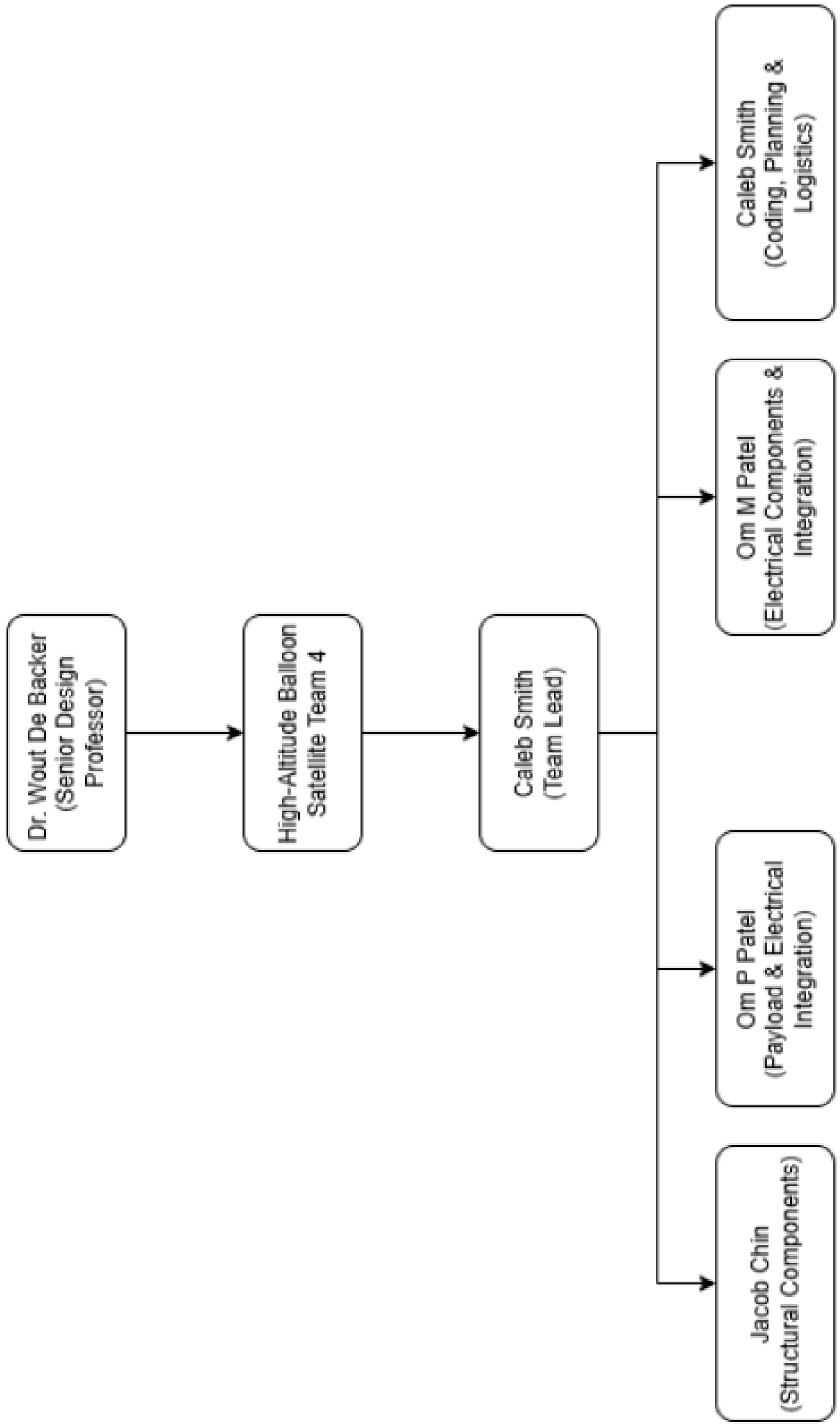
Appendix H: Safety Checklists and Procedures

FAA Compliance Table

Requirement	Regulation (FAA Part 101 / FCC)	Implementation	Verification Method
Payload Mass Limit	≤ 6 lb per payload	Total payload mass ≈ 5.0 lb	Weight measurement before launch
Total System Mass	≤ 12 lb total	System well below limit	BOM + final mass check
Breakaway Requirement	Line must break ≤ 50 lbf	Nylon rope selected with ~50 lbf safe load	Physical load test prior to flight
Hazard Prevention	Must not endanger people/property	Parachute recovery, no hazardous materials	Design review + drop test
FAA Notification	Notify ATC 6–24 hrs prior	Launch info prepared (location, time, payload)	Pre-flight checklist confirmation
Tracking Requirement	Position tracked during flight	GPS module onboard + data logging	GPS test + data verification
Data Recording	Must record flight data	Raspberry Pi onboard logging (SD storage)	Post-flight data retrieval
RF Transmission (915 MHz)	Must comply with FCC limits	No live transmission; onboard logging only	System configuration verification
Airspace Compliance	Avoid restricted zones	Trajectory simulations performed	SondeHub predictions + map review
Launch Location Safety	Safe launch/descent zones required	Selected rural area near Gaston, SC	Site evaluation + trajectory analysis
Weather Conditions	Must ensure safe flight conditions	Weather monitoring before launch	Go/No-Go decision
Private Property Recovery	Must not create conflict	Payload labeled with contact info	Visual inspection before launch

Appendix I: Project Management Charts

Organigram



Gantt Chart

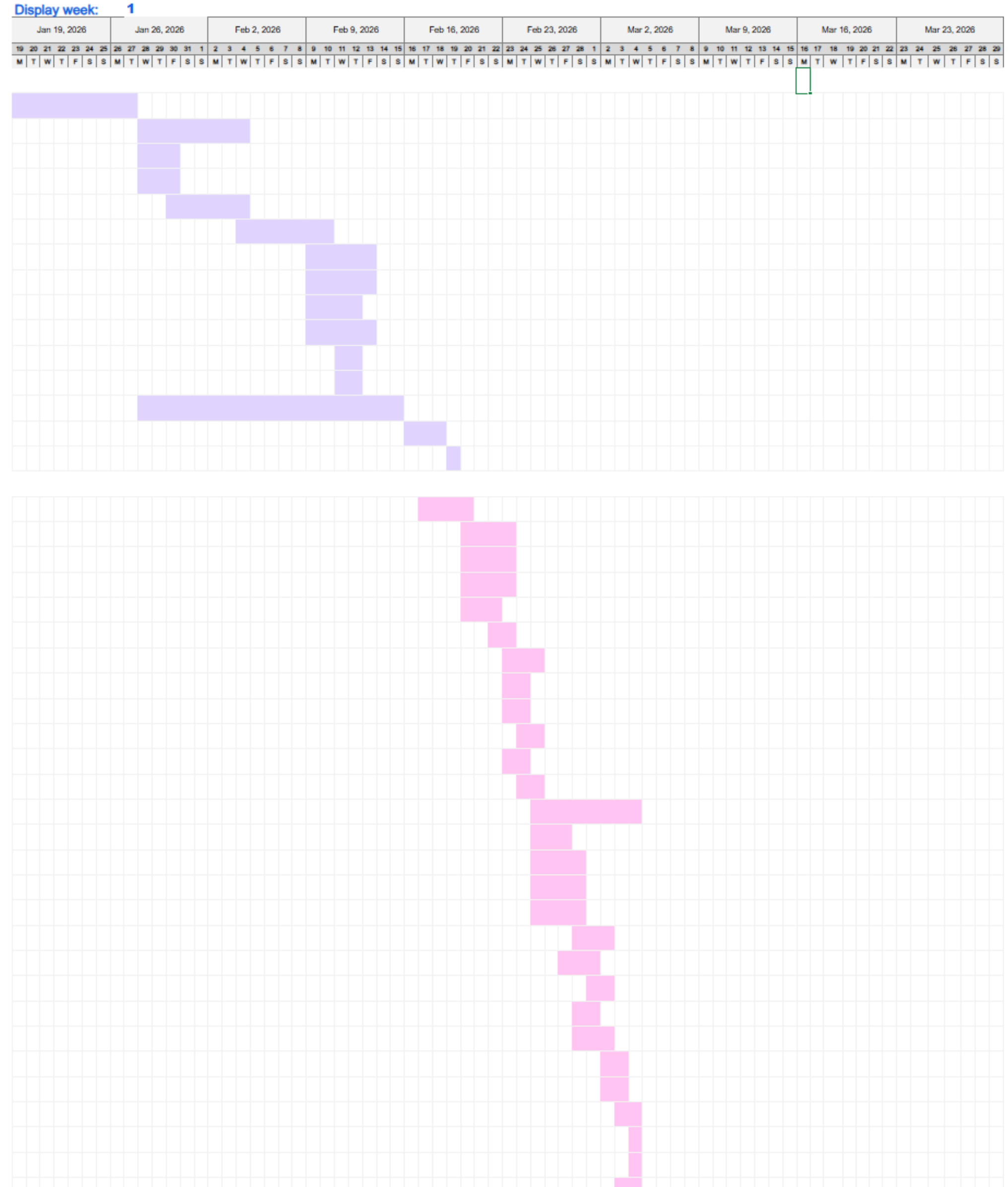
HABSAT Team 4

Caleb Smith Team lead

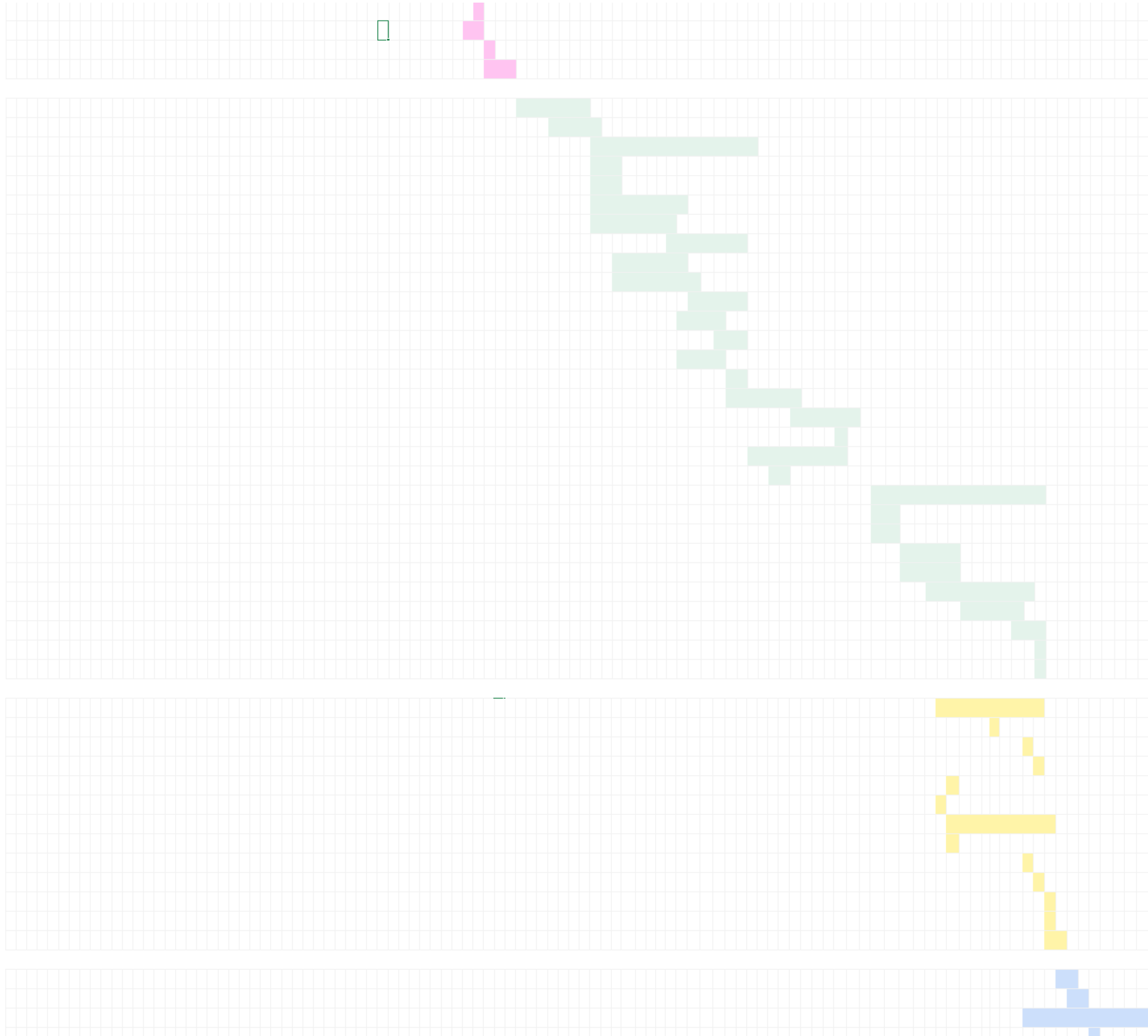
Project start: **Mon, 1/19/2026**

Display week: **1**

TASK	ASSIGNED TO	PROGRESS	START	END
Initiation/Planning				
Project Research & Assignment Analysis	All Members	100%	1/19/26	1/27/26
Project Management Tools	All Members	100%	1/28/26	2/4/26
Requirements, Constraints, MNS	Om P Patel	100%	1/28/26	1/30/26
Organigram & POS	Caleb Smith	100%	1/28/26	1/30/26
WFD & WBS	Jacob Chin	100%	1/30/26	2/4/26
Gantt Chart	Om M Patel	100%	2/4/26	2/10/26
Product Design Tools	All Members	100%	2/9/26	2/13/26
FBS & FFD	Om P Patel	100%	2/9/26	2/13/26
Risk Map, N^2 Chart, Trade-Off Table	Caleb Smith	100%	2/9/26	2/12/26
DOT & Requirements Discovery Tree	Jacob Chin	100%	2/9/26	2/13/26
Design Concepts	Om M Patel	100%	2/11/26	2/12/26
Standards, Codes, & Regulations Check	Om M Patel	100%	2/11/26	2/12/26
Project Proposal Report	All Members	100%	1/28/26	2/15/26
SCR Powerpoint	Caleb Smith	100%	2/16/26	2/18/26
SCR	All Members	100%	2/19/26	2/19/26
Design				
Design Research	All Members	100%	2/17/26	2/20/26
Develop Structural Design	Jacob Chin	100%	2/20/26	2/23/26
Develop Electrical Architecture	Om M Patel	100%	2/20/26	2/23/26
Develop Power System Design	Caleb Smith	100%	2/20/26	2/23/26
Structural Load Analysis	Om P Patel	100%	2/20/26	2/22/26
Parachute Sizing Analysis	Om P Patel	100%	2/22/26	2/23/26
Lift & Mass Analysis	Om P Patel	100%	2/23/26	2/25/26
Power Budget Analysis	Om M Patel	100%	2/23/26	2/24/26
Ascent & Descent Analysis	Jacob Chin	100%	2/23/26	2/24/26
Create CAD Model	Jacob Chin	100%	2/24/26	2/25/26
Update Risk Register	Caleb Smith	100%	2/23/26	2/24/26
Compliance Verfication Matrix	Caleb Smith	100%	2/24/26	2/25/26
Preliminary Design Report	All Members	100%	2/25/26	3/4/26
Project Management Update	Om M Patel	100%	2/25/26	2/27/26
Requirements Analysis & Architecture Update	Om P Patel	100%	2/25/26	2/28/26
Load & Structural Assessment	Caleb Smith	100%	2/25/26	2/28/26
Performance & Feasibility	Jacob Chin	100%	2/25/26	2/28/26
Financial & Weight Breakdown	Jacob Chin	100%	2/28/26	3/2/26
Power Budget	Om M Patel	100%	2/27/26	3/1/26
Trade Studies & Design Decisions	Om M Patel	100%	3/1/26	3/2/26
Risk Assessment & Ethics Integration	Caleb Smith	100%	2/28/26	3/1/26
Interface Definition	Om P Patel	100%	2/28/26	3/2/26
Preliminary Verification & Test Planning	Caleb Smith	100%	3/2/26	3/3/26
Path to Detailed Design	Jacob Chin	100%	3/2/26	3/3/26
Appendices	Om P Patel	100%	3/3/26	3/4/26
Final Preliminary Design Report Check	All Members	100%	3/4/26	3/4/26
Bill of Materials Planning	Om P Patel	100%	3/4/26	3/4/26
Preliminary Design Powerpoint	Om M Patel	100%	3/3/26	3/4/26



Bill of Materials Planning	Om P Patel	100%	3/4/26	3/4/26
Preliminary Design Powerpoint	Om M Patel	100%	3/3/26	3/4/26
Preliminary Design Review	All Members	100%	3/5/26	3/5/26
PDR Analysis & Revision/Implementation	All Members	100%	3/5/26	3/7/26
Construct				
Spring Break	All Members	100%	3/8/26	3/14/26
Preliminary Bill of Materials	All Members	100%	3/11/26	3/15/26
Critical Design Baseline Report	All Members	100%	3/15/26	3/29/26
Project Management Update	Om M Patel	100%	3/15/26	3/17/26
Requirements Analysis & Architecture Update	Caleb Smith	100%	3/15/26	3/17/26
Load & Structural Assessment	Om P Patel	100%	3/15/26	3/23/26
Performance & Feasibility	Jacob Chin	100%	3/15/26	3/22/26
Financial & Weight Breakdown	Jacob Chin	100%	3/22/26	3/28/26
Power Budget	Om M Patel	100%	3/17/26	3/23/26
Trade Studies & Design Decisions	Caleb Smith	100%	3/17/26	3/24/26
Risk Assessment & Ethics Integration	Caleb Smith	100%	3/24/26	3/28/26
Interface Definition	Om P Patel	100%	3/23/26	3/26/26
Manufacturing Plan	Om P Patel	100%	3/26/26	3/28/26
Path to Verification and Testing	Om M Patel	100%	3/23/26	3/26/26
Appendices	Om M Patel	100%	3/27/26	3/28/26
Bill of Materials Finalization & Submission	Om M Patel	100%	3/27/26	4/2/26
CAD Model Update	Jacob Chin	100%	4/2/26	4/7/26
Critical Design Review Powerpoint	Om M Patel	100%	4/6/26	4/6/26
Critical Design Review	All Members	100%	3/29/26	4/6/26
CDR Analysis & Revision/Implementation	All Members	100%	3/31/26	4/1/26
Subsystem Construction/Integration	All Members	100%	4/9/26	4/23/26
Electronics Support Structure	Om P Patel	100%	4/9/26	4/10/26
Support Structure Integration	Om P Patel	100%	4/9/26	4/10/26
Balloon, Shock Cords & Parachute	Jacob Chin	100%	4/11/26	4/15/26
Payload Connection	Jacob Chin	100%	4/11/26	4/15/26
Coding	Caleb Smith	100%	4/13/26	4/22/26
Sensors & GPS	Om M Patel	100%	4/16/26	4/21/26
Cameras	Om M Patel	100%	4/21/26	4/23/26
Power & Communication	Om M Patel	100%	4/23/26	4/23/26
Perform System Assembly	All Members	100%	4/23/26	4/23/26
Testing				
Technical Inspections	All Members	100%	4/14/26	4/23/26
Physical Electronics & Integration Inspection	Om M Patel	100%	4/19/26	4/19/26
Coding Inspection/Verification	Caleb Smith	100%	4/22/26	4/22/26
Payload & Electrical Integration Inspection	Om P Patel	100%	4/23/26	4/23/26
Structural Stability Inspection	Jacob Chin	100%	4/15/26	4/15/26
Regulations Compliance Check	All Members	100%	4/14/26	4/14/26
Perform Preliminary Tests	All Members	100%	4/15/26	4/24/26
Perform Parachute Drop Test	Jacob Chin	100%	4/15/26	4/15/26
Perform Suspension Load Test	Om P Patel	100%	4/22/26	4/22/26
Perform Stratospheric Simulation Test	Om M Patel	100%	4/23/26	4/23/26
Perform Telemetry Range/Antenna Test	Om M Patel	100%	4/24/26	4/24/26
Gather/Analyze Test Feedback	All Members	100%	4/24/26	4/24/26
Analysis, Redesign, & Implementation of Improvements	All Members	100%	4/24/26	4/25/26
Redesign/Final Flight				
Fly-off Preparation	All Members	100%	4/25/26	4/26/26
Senior Design Showcase Poster	All Members	100%	4/26/26	4/27/26
Final Design & Verification Report	All Members	100%	4/22/26	5/3/26
Senior Design Showcase	All Members	100%	4/28/26	4/28/26



Compliance Matrix

Req ID	Requirement Description	Verification Method	Status	Evidence / Section Reference
R1	Total payload mass shall be ≤ 5 lb	Analysis + Measurement	Pass	Weight Budget Section
R2	Payload shall include GPS tracking capability	Inspection + Test	Pass	Electrical Systems – GPS
R3	Payload shall transmit telemetry data to ground station	Test	Pass	Communications & Tracking Section
R4	Payload shall log data onboard (SD storage)	Inspection	Pass	Electrical Systems – Data Logging
R5	Payload shall capture and store image data	Demonstration	Pass	Electrical Systems – Imaging
R6	Payload shall measure environmental data (temperature, pressure)	Test	Pass	Electrical Systems – Sensors
R7	Power system shall support full mission duration	Analysis + Test	Pass	Power Budget Section
R8	Power shall be properly regulated (5V and 3.3V rails)	Inspection + Test	Pass	Electrical Systems – Power
R9	Payload shall maintain communication link during flight	Test	Pass	Communications & Tracking Section
R10	Payload shall survive descent and landing	Test	Pass	Appendix – Drop Test
R11	Parachute shall deploy and stabilize descent	Demonstration	Pass	Appendix – Drop Test
R12	Payload structure shall securely mount all components	Inspection	Pass	Structural Design Section
R13	Payload shall maintain acceptable center of gravity for stability	Analysis	Pass	Structural Design – CG Section
R14	Suspension system shall safely support payload loads	Analysis + Test	Pass	Structural Design Section
R15	Breakaway mechanism shall occur at approximately 50 lbf	Inspection	Pass	Appendix – Test Plan
R16	Payload shall comply with radio frequency regulations (FCC)	Inspection	Pass	Compliance Section
R17	Payload shall comply with safety and operational guidelines (FAA)	Inspection	Pass	Compliance Section
R18	System shall be configurable prior to launch	Demonstration	Pass	Appendix – Procedures
R19	Ground station shall receive and process transmitted data	Test	Pass	Communications & Tracking Section

Appendix J: Bill of Materials (BOM) (with updated status)

Part Name (as on product page)	SKU	Subcomponent	# Needed
Raspberry Pi 4 Model B (4GB)	DEV-15447	Avionics	1
Raspberry Pi HQ Camera	SEN-16760	Avionics	1
Official 6mm HQ Camera wide-angle lens	67AH5589	Avionics	1
GPS Compass Module	B08NY9JSZ3	Avionics	1
MPU-6050 IMU	Product ID: 3886	Avionics	1
RunCam Thumb 2		Avionics	1
BME280 PTH breakout	SEN-13676	Avionics	2
SanDisk Extreme 32GB	9387066	Storage	1
HAB TX-1600 Balloon	HAB-TX-1600	Lift / Balloon	1
UV Protection	HAB-UVR	Lift / Balloon	1
Helium	N/A	Lift	1
Rocket Man Parachute	4ft Standard Parachute	Recovery	2
MS5611 Pressure Temperature Sensor Module	MOD-105	Avionics	1
EPS Foam Box	S-22126	Structure	1
302 Stainless Steel Corrosion-Resistant Compression Springs	96485k121	Structure	4
252Pcs Hex Bolts and Nuts Assortment Kit	53WR20	Structure	10
FR 4 Garolite Sheet G10	55RM43	Structure	2
6 Pcs M6 304 Stainless Steel Screw Eye Hooks	30425T39	Structure	5
Cinching Strap	29695T501	Structure	2
Velcro Strips	9273K14	Structure	2
ELEGOO 120-Piece Multicolored Dupont Jumper Wire Kit	EL-CP-004	Power	1
Sandisk 64GB Ultra SDXC Class 10 / U1 Flash Memory Card	663070	Power	1
Micro HDMI Male x HDMI Female Adapter	14C364	Power	1
Adafruit 40-Pin Raspberry Pi Breadboard	4354	Power	1
Battery holders	7712K14	Power	3
Pololu 5V, 5A Step-Down Voltage Regulator	D24V50F5	Power	1
Rubber Bumper Feet	36-728-ND	Structure	4
Nylon Suspension Line	3838T161	Structure	1
Clevis-to-Clevis Swivel	37405T31	Structure	1
Spray Primer: Red	6KP14	Decoration	1

Rocker Switch SPST 11A (AC) 125 V Panel Mount, Snap-In	141-RA17131123-ND	Power Switch	1
LoRa Radio Transceiver Breakout - 868 or 915 MHz -	3072	Power	1
Hook-up Wire Spool Set - 22AWG Solid Core	1311	Power	1
Heat-shrink tubing	7856K263	Wiring	1
915MHz LoRa Antenna RP-SMA - 1/4 Wave 2dBi	JCG402LR-2	Communication	2
Raspberry Pi Zero 2 W	1799	Ground Station	1

# in Pack	Packs to order	Price Per Pack	Total	Total + Tax & Shipping	Status	Supplier
1	1	$75.00	$75.00	$88.28	05 - Received by Team	Sparkfun electronics
1	1	$63.75	$63.75	$75.03	05 - Received by Team	Sparkfun electronics
1	1	$32.68	$32.68	$38.46	05 - Received by Team	Newark
1	1	$43.00	$43.00	$50.61	05 - Received by Team	RC Drone
1	1	$12.95	$12.95	$15.24	05 - Received by Team	Adafruit Industries LLC
1	1	$117.99	$117.99	$138.87	05 - Received by Team	Rotoriot
2	1	$51.00	$51.00	$60.03	05 - Received by Team	Sparkfun electronics
1	1	$14.99	$14.99	$17.64	05 - Received by Team	Best Buy
1	1	$165.00	$165.00	$194.21	05 - Received by Team	KAYMONT
1	1	$2.00	$2.00	$2.35	05 - Received by Team	KAYMONT
1	1	$185.00	$185.00	$217.75	00 - Temp	AWG Gasses
1	2	$50.50	$101.00	$118.88	05 - Received by Team	ROCKETMAN PARACHUTES
1	1	$9.95	$9.95	$11.71	05 - Received by Team	ProtoSupplies
3	1	$87.00	$87.00	$102.40	05 - Received by Team	ULINE
1	4	$7.42	$29.68	$34.93	05 - Received by Team	McMaster-CARR
177	1	$32.71	$32.71	$38.50	05 - Received by Team	Grainger
1	2	$33.99	$67.98	$80.01	05 - Received by Team	Grainger
20	1	$13.07	$13.07	$15.38	05 - Received by Team	McMaster-CARR
1	1	$13.51	$13.51	$15.90	05 - Received by Team	McMaster-CARR
1	2	$11.47	$22.94	$27.00	05 - Received by Team	McMaster-CARR
3	1	$12.95	$12.95	$15.24	07 - Available in-house	Altex

1	1	$22.99	$22.99	$27.06	07 - Available in-house	Micro Center
1	1	$6.91	$6.91	$8.13	05 - Received by Team	Grainger
1	1	$7.95	$7.95	$9.36	05 - Received by Team	Adafruit Industries LLC
1	3	$2.10	$6.30	$7.42	05 - Received by Team	McMaster-CARR
1	1	$29.95	$29.95	$35.25	05 - Received by Team	Pololu
1	4	$0.84	$3.36	$3.95	05 - Received by Team	Digikey
1	1	$5.00	$5.00	$5.89	05 - Received by Team	McMaster-CARR
1	1	$8.01	$8.01	$9.43	05 - Received by Team	McMaster-CARR
1	1	$11.32	$11.32	$13.32	05 - Received by Team	Grainger
1	1	$0.57	$0.57	$0.67	05 - Received by Team	Digikey
1	1	$19.95	$19.95	$23.48	05 - Received by Team	Adafruit Industries LLC
1	1	$15.95	$15.95	$18.77	05 - Received by Team	Adafruit Industries LLC
1	1	$3.86	$3.86	$4.54	05 - Received by Team	McMaster-CARR
1	2	$13.79	$27.58	$32.46	05 - Received by Team	Digikey
1	1	$17.25	$17.25	$20.30	05 - Received by Team	PiShop

Appendix K: Meeting Minutes & Communications

Team Meeting 1
Date: 1/27/26, Time: 9:30 am, Location: 300 Main Computer lab
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Undetermined
Om P. Patel	x	Undetermined
Om M. Patel	x	Undetermined
Jacob Chin	x	Undetermined

Adenda

- Updates from all team members
- General Ideas
- Composing all of the documents together and brainstorming
- Start on the shopping cart
- Research videos on previous projects can be youtube of a past groups report
- Determine and conform the official meeting times

Meeting Minutes
Updates from Caleb:

- Began research on previous class projects and discussion on possible sub roles in the group
- Present idea of a test run

Updates from Om P. Patel:

- Began work on the mission statement and objective statement

Updates from Jacob Chin:

- Began work on the shopping list

Updates from Om M. Patel:

- created a one drive for the project so all members can see all at once and it be in one place

Announcements:

- Wout wants us to start looking at the FAA guidelines
- Wout wants us to begin work from the lecture slides to begin out diagrams

Upcoming Deadlines

- Assignment 1 a (Report for proposal)
- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Decided to move main meetings to discord call and occasionally meeting in person when needed, moved meeting days to tuesdays and thursdays

Action Items:

- Work on project proposal

Meeting Adjourned:11:00 am

Team Meeting 2
Date: 1/29/26, Time: 9:25 am, Location: 300 Main Computer lab
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members
- General Ideas
- Composing all of the documents together and brainstorming
- Beginning rough diagrams for proposal report
- Brainstorming concept drawings
- Research videos on previous projects can be youtube or a past groups report
- Determine and confirm the official meeting times

Meeting Minutes
Updates from Caleb:

- Research on balloon ideas and FAA guidelines

Updates from Om P. Patel:

- Began work on the design option tree

Updates from Jacob Chin:

- Continued work on the shopping art and researched usable materials

Updates from Om M. Patel:

- Began work on the 3 concept drawings (rough sketch)

Announcements:

- Wout wants us to begin work from the lecture slides to begin out diagrams

Upcoming Deadlines

- Assignment 1 a (Report for proposal)
- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Decided to move main meetings to discord call and occasionally meeting in person when needed

Action Items:

- Work on project proposal
- Create a to do list

Meeting Adjourned:10:30 am

Team Meeting 3
Date: 2/3/26, Time: 1:15, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members

- Task list for each member
- Creating andComposing documents together
- Beginning and continuing rough diagrams for proposal report
- Finalizing concept drawings

Meeting Minutes

Updates from Caleb:

- Began work on N2 charts
- Began work on Trade off tables
- Began work on Risk maps

Updates from Om P. Patel:

- Began work on the functional breakdown structure
- Began work on Functional flow diagram
- Began work on draft proposal

Updates from Jacob Chin:

- Began work on Work breakdown structure
- Began work on design option tree
- Began work on Requirements/Constraints
- Began work on requirement discovery tree

Updates from Om M. Patel:

- Began work on GanttChart
- Began work on organizing the notes
- Finalizing the design concepts

Announcements:

- Wout wants us to continue work from the lecture slides to begin out diagrams

Upcoming Deadlines

- Assignment 1 a (Report for proposal)
- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Decided by sunday to have all of these completed

Action Items:

- Work on project proposal

Meeting Adjourned: 3:15 pm

Team Meeting 4
Date: 2/5/26, Time: 1:20, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members

Meeting Minutes

Updates from Caleb:

- Continues work on N2 charts
- Continue on Trade off tables
- Continue on Risk maps

Updates from Om P. Patel:

- Continue on the functional breakdown structure
- Continue on Functional flow diagram
- Continue on draft proposal

Updates from Jacob Chin:

- Continue on Work breakdown structure
- Continue on design option tree
- Continue on Requirements/Constraints
- Continue on requirement discovery tree

Updates from Om M. Patel:

- Continue on GanttChart
- Continue on organizing the notes

Announcements:

- Wout wants us to continue work from the lecture slides to begin out diagrams

Upcoming Deadlines

- Assignment 1 a (Report for proposal)
- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Decided by sunday to have all of these completed

Action Items:

- Work on project proposal

Meeting Adjourned: **3:20 pm**

Team Meeting 5
Date: 2/15/26, Time: 10:00, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members
- Finalizing all tasked work and finalizing project proposal (assignment 1 a)

Meeting Minutes
Updates from Caleb:

- Finalizing work on N2 charts
- Finalizing on Trade off tables
- Finalizing on Risk maps

Updates from Om P. Patel:

- Finalizing on the functional breakdown structure
- Finalizing on Functional flow diagram
- Finalizing on draft proposal

Updates from Jacob Chin:

- Finalizing on Work breakdown structure
- Finalizing on design option tree
- Finalizing on Requirements/Constraints
- Finalizing on requirement discovery tree

Updates from Om M. Patel:

- Finalizing on GanttChart

- Finalizing on organizing the notes

Announcements:

- Wout wants us to continue work from the lecture slides to begin out diagrams

Upcoming Deadlines

- Assignment 1 a (Report for proposal)
- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Completed the project proposal on time

Action Items:

- Work on project proposal presentation

Meeting Adjourned: **11:59 pm**

Team Meeting 6
Date: 2/16/26, Time: 10:00, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members
- Finalizing presentation for project proposal

Meeting Minutes
Updates from Caleb:

- Composed tasked items from assignment 1 a and talked items to the presentation accordingly

Updates from Om P. Patel:

- Composed tasked items from assignment 1 a and talked items to the presentation accordingly

Updates from Jacob Chin:

- Composed tasked items from assignment 1 a and talked items to the presentation accordingly

Updates from Om M. Patel:

- Composed tasked items from assignment 1 a and talked items to the presentation accordingly

Announcements:

- Wout wants us to submit assignment 1 b

Upcoming Deadlines

- Assignment 1 b (Presentation for Proposal)

Closing Updates

- Completed the project proposal presentation on time

Action Items:

- Began preparing for the in person project proposal

Meeting Adjourned: 11:00 pm

Team Meeting 7

Date: 2/17/26, Time: 1:30, Location: Swearigen Computerlab, McNAIR Aerospace Center

Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	x	Phase Lead, Electrical Team
Om P. Patel	x	Structural Team
Om M. Patel	x	Electrical Team
Jacob Chin	x	Structural Team

Agenda

- Updates from all team members
- Practice designated slides before meeting with wout
- Participate in presentation and feedback during project proposal
- Participate in discussion with wout about report

<u>Meeting Minutes:</u>
Updates from Caleb:

- Will present product specification sheet slides and concept drawings
- Takes primary notes

Updates from Om P. Patel:

- Will present Quad chart

Updates from Jacob Chin:

- Will present trade study & risk and preliminary budget estimation slides
- Takes secondary notes

Updates from Om M. Patel:

- Will start from the presentation title slide, table of contents, project summary, gantt chart and helping the other members during presentation when needed

Announcements:

- Wout wants us to be prepared to review the report and presentation together and give quick and honest feedback

<u>Upcoming Deadlines:</u>

- PDR

<u>Closing Updates</u>

- Attended the project proposal on time and participated
- Took valuable notes and listened to feedback

<u>Action Items:</u>

- Began preparing for the PDR
- Begin CAD model for payload
- Begin work on revising project proposal

<u>Meeting Adjourned:</u> 4:00 pm

Team Meeting 8
Date: 2/26/26, Time: 2:00, Location: Discord
Submitted by Caleb Smith

<u>Attendance:</u>

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Finalize Bill of materials
- Finalize design additions
- Work on PDR document

Meeting Minutes:

Updates from Caleb:

- Began work on part 3 of the document

Updates from Om P. Patel:

- Began work on part 2 of the document

Updates from Jacob Chin:

- Finalized bill of materials
- Began work on CAD
- Finalized dimensions of electrics for payload

Updates from Om M. Patel:

- Finalized Gantt chart

Announcements:

- Percentage changes for checkpoints possible

Upcoming Deadlines:

- PDR
- PDR Presentation

Action Items:

Continue work PDR Document

Meeting Adjourned: 4:00 pm

Team Meeting 9

Date: 3/3/26, Time: 2:00 pm, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Finalize design additions
- Work on PDR document

Meeting Minutes:
Updates from Caleb:

- Continued work on section 3

Updates from Om P. Patel:

- Continued work on section 2

Updates from Jacob Chin:

- Mostly done with CAD (little tweaks here and there)

Updates from Om M. Patel:

- Worked with Jacob on CAD
- Finished Gantt chart

Announcements:

- Team 4 HABSAT PDR will take place on Thursday from 2:00pm to 3:00pm at McNair

Upcoming Deadlines:

- PDR
- PDR Presentation

Action Items:

- Continue work on PDR document

Meeting Adjourned: 4:00 pm
Date: 3/24/26, Time: pm, Location: Discord

Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Everyone - Complete Compressed Gas Certification
- Om M - Make PDR Clean Transcript, Create Preliminary Bill of Materials
- Om P - Format complete CDR report and start section 1 and 2
- Caleb - Find software we would need
- Jacob - Complete Bill of Materials, Find Proper Springs

Meeting Minutes:

Updates from Caleb:

- Finalized work on section 3

Updates from Om P. Patel:

- Format complete CDR report and start section 1 and 2

Updates from Jacob Chin:

- Complete Bill of Materials

Updates from Om M. Patel:

- Created Preliminary Bill of Materials

Announcements:

- Have this done by class tomorrow

Upcoming Deadlines:

- CDR Presentation
- CDR Report
- Certification Completion

Action Items:

- Begin work on CDR document

Meeting Adjourned: 3:30 pm

Date: 3/26/26, Time: pm, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Everyone - Complete Compressed Gas Certification
- Om M - Complete Compressed Gas Certification
- Om P - Format complete CDR report and start section 1 and 2
- Caleb - Find softwares we would need
- Jacob - Complete Bill of Materials, Complete Certification

Meeting Minutes:

Updates from Caleb:

- Finalized work on section 3

Updates from Om P. Patel:

-

Updates from Jacob Chin:

- Work Times Available:
- Thursday: Complete Certification,
- Friday: 7 am - 2:30 PM (CAD)
- Saturday: 7 am - 1:30 PM (CAD)

Updates from Om M. Patel:

- Created PDR Transcript, Preliminary BoM

Announcements:

- Have this done by class tomorrow

Upcoming Deadlines:

- CDR Presentation
- CDR Report
- Certification Completion

Action Items:

- Begin work on CDR document

Meeting Adjourned: **3:30 pm**

Date: 4/13/26, Time: 2:00 pm, Location: In Person @ 300 Main
Submitted by Om P. Patel

Attendance:

USC Member	Present	Role
Caleb Smith		Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel		Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Begin structural assembly of payload enclosure
- Verify component fit within EPS foam box
- Install G10 electronics plate
- Review mounting approach for internal components

Meeting Minutes:

Updates from Om P. Patel:

- Assisted with structural layout and internal configuration
- Verified component placement relative to center of gravity
- Ensured structural design aligns with system requirements

Updates from Jacob Chin:

- Led physical assembly of structure components
- Installed G10 electronics plate and verified fit within enclosure
- Confirmed mounting feasibility for springs, hooks, and support elements

Announcements:

- Structural configuration must remain within total mass constraint (<5 lb)
- Internal layout must support stable descent and balanced CG

Upcoming Deadlines:

- Complete structural assembly prior to electrical integration
- Prepare structure for subsystem integration testing

Action Items:

- Finalize internal mounting layout
- Secure all structural components
- Prepare for electronics integration phase

Meeting Adjourned: 4:00 pm

Date: 4/14/26, Time: 2:00 pm, Location: In Person @ 300 Main
Submitted by Om P. Patel

Attendance:

USC Member	Present	Role
Caleb Smith		Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel		Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Continue structural assembly of payload enclosure
- Refine internal component placement
- Install and secure suspension and mounting hardware
- Evaluate structural integrity and load paths

Meeting Minutes:

Updates from Om P. Patel:

- Refined internal layout to improve center of gravity positioning
- Assisted with securing components within the enclosure
- Evaluated load distribution through suspension points

Updates from Jacob Chin:

- Continued structural assembly and reinforcement
- Installed suspension hardware (hooks, connection points)
- Verified structural integrity under expected loading conditions

Announcements:

- Suspension system must support expected loads while maintaining stability
- All structural components must be securely fastened for testing phase

Upcoming Deadlines:

- Finalize structural build before integration testing

- Prepare for load and drop testing

Action Items:

- Complete installation of all structural components
- Verify attachment points and suspension system
- Prepare structure for testing and electrical integration

Meeting Adjourned: 4:00 pm

Date: 4/15/26, Time: 2:00 pm, Location: In Person @ 300 Main
Submitted by Om P. Patel

Attendance:

USC Member	Present	Role
Caleb Smith		Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel		Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Conduct parachute drop test with payload
- Evaluate descent stability and parachute deployment
- Observe structural integrity during landing
- Assess suspension system performance

Meeting Minutes:

Updates from Om P. Patel:

- Assisted in setup and execution of drop test
- Observed descent behavior and payload stability
- Evaluated center of gravity effects on descent performance

Updates from Jacob Chin:

- Led drop test execution from garage building
- Verified parachute deployment and suspension performance
- Inspected payload structure post-impact for any damage

Announcements:

- Drop test results will be used to validate descent performance
- Any instability or structural issues must be addressed before final testing

Upcoming Deadlines:

- Analyze drop test results and implement improvements if needed
- Prepare for full system integration testing

Action Items:

- Document drop test results and observations
- Adjust suspension or CG placement if necessary
- Reinforce any components affected during testing

Meeting Adjourned: 4:00 pm

Date: 4/16/26, Time: 8:00 pm, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel		Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin		Structural Team

Agenda

- Review electrical system wiring and component integration
- Identify remaining components required for system completion
- Verify Raspberry Pi functionality
- Plan next steps for GPS integration and testing

Meeting Minutes:

Updates from Caleb:

- Reviewed overall wiring layout and system integration plan
- Confirmed next steps for coding and system testing upon receiving hardware

Updates from Om M. Patel:

- Demonstrated Raspberry Pi functionality via remote session
- Verified successful boot and operation of onboard system
- Identified remaining required component: GPS module

Announcements:

- GPS module is the final required component before full system testing
- System will be transferred to Caleb for coding and integration testing

Upcoming Deadlines:

- Order and receive GPS module
- Begin full system integration and testing

Action Items:

- Complete procurement of GPS module
- Transfer system hardware for coding and testing
- Begin integration of GPS with onboard system

Meeting Adjourned: **10:00 pm**

Date: 4/21/26, Time: 2:00 pm, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Review helium procurement and cost quote
- Finalize rope selection and breakaway requirement (~50 lbf)
- Review applicable regulations and compliance requirements
- Discuss progress on GPS module and system integration

Meeting Minutes:

Updates from Caleb:

- Reviewed helium pricing and confirmed budget alignment
- Led discussion on regulatory requirements and compliance considerations

Updates from Om P. Patel:

- Contributed to rope selection discussion and structural integration considerations
- Reviewed impact of suspension system on overall design

Updates from Om M. Patel:

- Reported successful progress with GPS module setup
- Confirmed system readiness for further integration and testing

Updates from Jacob Chin:

- Assisted in evaluation of rope selection and structural implications
- Reviewed mounting and integration of suspension system

Announcements:

- Rope selected for main line with requirement to incorporate ~50 lbf breakaway capability
- GPS module has been received and is ready for integration

Upcoming Deadlines:

- Complete integration of GPS module into system
- Conduct breakaway load testing for suspension system
- Finalize preparations for system testing and validation

Action Items:

- Order and verify selected rope material
- Implement and test breakaway mechanism
- Continue GPS integration and system testing
- Ensure all components meet regulatory requirements

Meeting Adjourned: 4:00 pm

Date: 4/22/26, Time: 7:00 pm, Location: Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Complete Final Flight Readiness (FRR) Document
- Final review of all sections and formatting
- Verify all figures, tables, and appendix references
- Confirm compliance with FAA and FCC regulations
- Ensure all verification and test sections are complete

Meeting Minutes:

Updates from Caleb:

- Led final integration of all report sections
- Verified appendix structure and formatting consistency

- Confirmed trajectory analysis and image placement

Updates from Om P. Patel:

- Finalized structural sections and verification content
- Confirmed payload integrity and recovery system documentation

Updates from Jacob Chin:

- Reviewed structural analysis and testing sections
- Confirmed parachute testing and load considerations

Updates from Om M. Patel:

- Finalized electrical systems and power budget sections
- Confirmed sensor integration and Raspberry Pi functionality

Announcements:

- FRR document is on pace for completion
- All major sections are complete and under final review

Upcoming Deadlines:

- FRR Report Submission
- Final Flight Preparation

Action Items:

- Perform final proofreading and formatting check
- Verify all appendix references and figure labels
- Prepare document for submission

Meeting Adjourned: 12:00 am

Date: 4/28/26, Time: 12:00 pm, Location: USC Expo / Demonstration Area
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team
Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- Demonstrate payload system to faculty and visitors
- Present design, testing, and trajectory analysis
- Answer questions regarding system performance and compliance

Meeting Minutes:

Updates from Caleb:

- Presented avionics system and data logging approach
- Explained trajectory analysis and launch window selection

Updates from Om P. Patel:

- Explained structural design and recovery system
- Discussed payload integrity and drop test validation

Updates from Jacob Chin:

- Showed CAD model and fabrication approach
- Explained structural component selection

Updates from Om M. Patel:

- Presented system integration and testing workflow
- Discussed budget, power, and compliance considerations

Announcements:

- Project successfully demonstrated to Dr. Wout and attendees
- Positive feedback received on system design and testing approach

Upcoming Deadlines:

- Final Report Submission
- FRR Completion

Action Items:

- Final Report Submission
- FRR Completion

Meeting Adjourned: 5:00 pm

Date: 5/3/26, Time: 8:00 pm, Discord
Submitted by Caleb Smith

Attendance:

USC Member	Present	Role
Caleb Smith	X	Phase Lead, Electrical Team

Om P. Patel	X	Structural Team
Om M. Patel	X	Electrical Team
Jacob Chin	X	Structural Team

Agenda

- FinalizeFinal projet report
- Review all sections for completeness and accuracy
- Confirm appendix, figures, and formatting

Meeting Minutes:

Updates from Caleb:

- Completed appendix sections and final formatting
- Verified trajectory and compliance sections

Updates from Om P. Patel:

- Finalized structural and testing documentation
- Reviewed risk and mitigation sections

Updates from Jacob Chin:

- Verified CAD references and structural analysis
- Assisted with formatting and section alignment

Updates from Om M. Patel:

- Completed detailed design and budget sections
- Verified system integration documentation

Announcements:

- FRR document finalized and ready for submission

Upcoming Deadlines:

- Report Submission

Action Items:

- Final proofread
- Submit report

Meeting Adjourned: 12:00 am

Appendix L: Deviations & Approvals

Deviation	Original Plan	Final Implementation	Reason for Change	Approval / Validation
Temperature Sensor	DHT22	BME280	Improved accuracy, pressure sensing added, better integration	Team trade study + verified during integration testing
Suspension Rope Requirement	General rope selection (strength-based)	Breakaway requirement of ~50 lbf defined	Needed to meet safety/regulatory requirement for payload release	Will be validated via load testing prior to flight
Rope Material Selection	Rope Material Selection	Nylon braided rope selected	Better predictability, flexibility, and availability	Material properties verified from manufacturer specs
Electronics Configuration	Basic sensor + camera setup	Added telemetry module (MS5611), LoRa communication, SD storage	Improved data collection, tracking, and redundancy	Integration testing and ground communication test planned
Power System	Initial battery assumption	AA lithium battery pack with regulator and power distribution	Cold-weather reliability and stable voltage output	Bench testing and voltage verification under load
Structure Design	Dual G10 plate concept	Single G10 electronics plate	Reduced weight and simplified internal layout	Structural evaluation and packaging fit confirmed
Mounting Method	Mixed fastening approach	Direct mounting to foam enclosure	Simplifies design and reduces mass	Verified during assembly and handling tests
BOM Updates	Initial estimated BOM	Final BOM with updated components and pricing	Component availability, performance improvements, cost accuracy	Cross-checked with supplier data and procurement list
Mass Estimate	Early estimate with margin	Final mass ~5.0 lb (within constraint)	Refined component weights and removal of excess material	Verified through calculated mass table and will be measured pre-flight
Communication System	Basic radio assumption	RF transceiver + LoRa antenna (915 MHz)	Required for long-range tracking and compliance	To be validated with range testing and signal checks
Regulatory Considerations	General awareness	Explicit compliance with radio frequency and payload safety constraints	Needed to meet FAA/radio operation guidelines	Verified against stated frequency limits and operating procedures
Launch Site Planning	Single assumed location	Multiple simulated launch trajectories	Improve landing prediction and safety	Simulation validation and go/no-go decision process
Testing Approach	General testing plan	Defined tests: drop test, range test, structural test, battery test	Needed to verify system performance before flight	Test results documented and used for flight readiness decision
Payload Safety	Basic enclosure	Secured internal layout with CG considerations	Improve stability during descent	CG analysis and physical layout validation
Data Handling	Basic recording	SD logging + telemetry redundancy	Prevent data loss during flight	Verified through system integration testing

Appendix M: Weight Budget

Subsystem	Component	Mass (lbs)

Structure		
Structure	EPS Foam Box	3.000
	G10 Electronics Plate (×1, one removed during final assembly)	0.400
	Compression Springs (×4)	0.100
	Hex Bolts & Nuts	0.072
	Cinching Strap	0.030
	Velcro Strips	0.050
	Rubber Bumper Feet	0.010
	Nylon Suspension Line	0.011
	Clevis-to-Clevis Swivel	0.018
	Spray Primer	0.050
	Structure Subtotal	**3.741 lbs**
Electronics		
Electronics	Raspberry Pi 4 Model B	0.113
	Raspberry Pi HQ Camera	0.090
	6mm Wide Angle Lens	0.117
	RunCam Thumb 2	0.060
	GPS Module (NEO-M8N)	0.044
	MPU-6050 IMU	0.040
	BME280 Sensors (×2)	0.006
	Altimeter (MS5607)	0.030
	SD Card	0.005
	Raspberry Pi Zero 2W	0.040
	Electronics Subtotal	**0.545 lbs**
Power & Communications		
Power & Comms	AA Lithium Batteries (×12)	0.380
	Voltage Regulator	0.020
	Wiring & Connectors	0.100
	Radio Transceiver (LoRa)	0.020

	LoRa Antenna (×2)	0.040
	Power & Communications Subtotal	**0.510 lbs**
Recovery		
Recovery	Rocketman 4 ft Parachute	0.220
	Suspension Lines & Hardware	0.050
	Recovery Subtotal	**0.270 lbs**
TOTAL CONFIRMED PAYLOAD MASS		**5.116 lbs → 5.0 lbs (confirmed at pre-flight weigh-in)**