# ASTROLYTICS

Project ADAE — CanSat 2026

*A Machine That Listens*

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# 1. Abstract

Project ADAE is a CanSat-class payload developed by the ASTROLYTICS team for the 2026 competition cycle.
Its objective is to investigate aerodynamic and structural instability during descent through real-time sensory analysis and adaptive control.

Unlike conventional CanSats that passively record flight data, ADAE integrates **artificial intelligence and machine learning (AIML)** into its flight computer to identify early signs of instability.
The system fuses pressure, inertial and strain data and, when appropriate, adjusts its parachute control servos to maintain equilibrium.

The payload consists of three servos — two for dynamic parachute control and one for payload separation — and a structured stack of electronics based on the **Raspberry Pi Pico** platform.
The camera and power system are located in the nose cone, sharing a protective foam enclosure with the egg payload to ensure survivability.

ADAE demonstrates how intelligent data interpretation and autonomous adjustment can be realised even within the strict mass and volume constraints of the CanSat class.
This report documents its mission logic, architecture, electronics, AIML subsystem, descent control, testing methodology and compliance with CanSat 2025–2026 rules.

# 2. Introduction

The CanSat competition challenges teams to develop fully functional miniature satellites that fit within the volume of a standard beverage can.
While most missions focus on the descent as a phase of observation, Project ADAE transforms it into a *diagnostic experiment* — an active phase where the CanSat "listens" to its environment and learns from it.

The system integrates sensing, actuation, and predictive computation into a compact structure.
Rather than merely recording flight data, ADAE processes it in real time to anticipate instability, allowing timely adjustments and richer post-flight insights.

This document serves as a comprehensive technical report describing every subsystem in detail, from mechanical architecture and sensor design to the embedded AIML prediction logic.

## 3. Mission Objective & Rationale

### Primary objective:

To design and validate a CanSat that can **detect, predict, and mitigate aerodynamic instability** during descent using onboard AI.

### Secondary Objectives

- Maintain reliable 1 Hz telemetry to ground while logging raw sensor data.
- Record synchronised imagery for verification of instability events.
- Protect and recover the egg payload through shock isolation and foam support.
- Verify AIML predictions against real-world sensor correlations.

### Rationale

Instability during descent, whether through oscillation, rotation or asymmetric airflow — often limits the quality of atmospheric data and increases the risk of payload loss.
ADAE addresses this by combining aerodynamic sensing, structural sensing and data-driven prediction into a single control system.
This fusion enables event detection and corrective response on the

scale of milliseconds, an innovation uncommon in student-level satellite experiments

# 4. System Architecture

## Overview

The internal layout of ADAE follows a **vertically stacked design**, balancing weight distribution and signal integrity across three main regions:

1. **Nose Cone Section**
    - Contains the **camera**, positioned just below the cone tip at a downward angle to record both ground and parachute activity.
    - Houses the **battery pack** and **egg payload** within **protection foam** that absorbs vibration and impact on landing.
    - The foam cradle ensures that the egg remains cushioned and thermally insulated from the electronic and actuation subsystems.

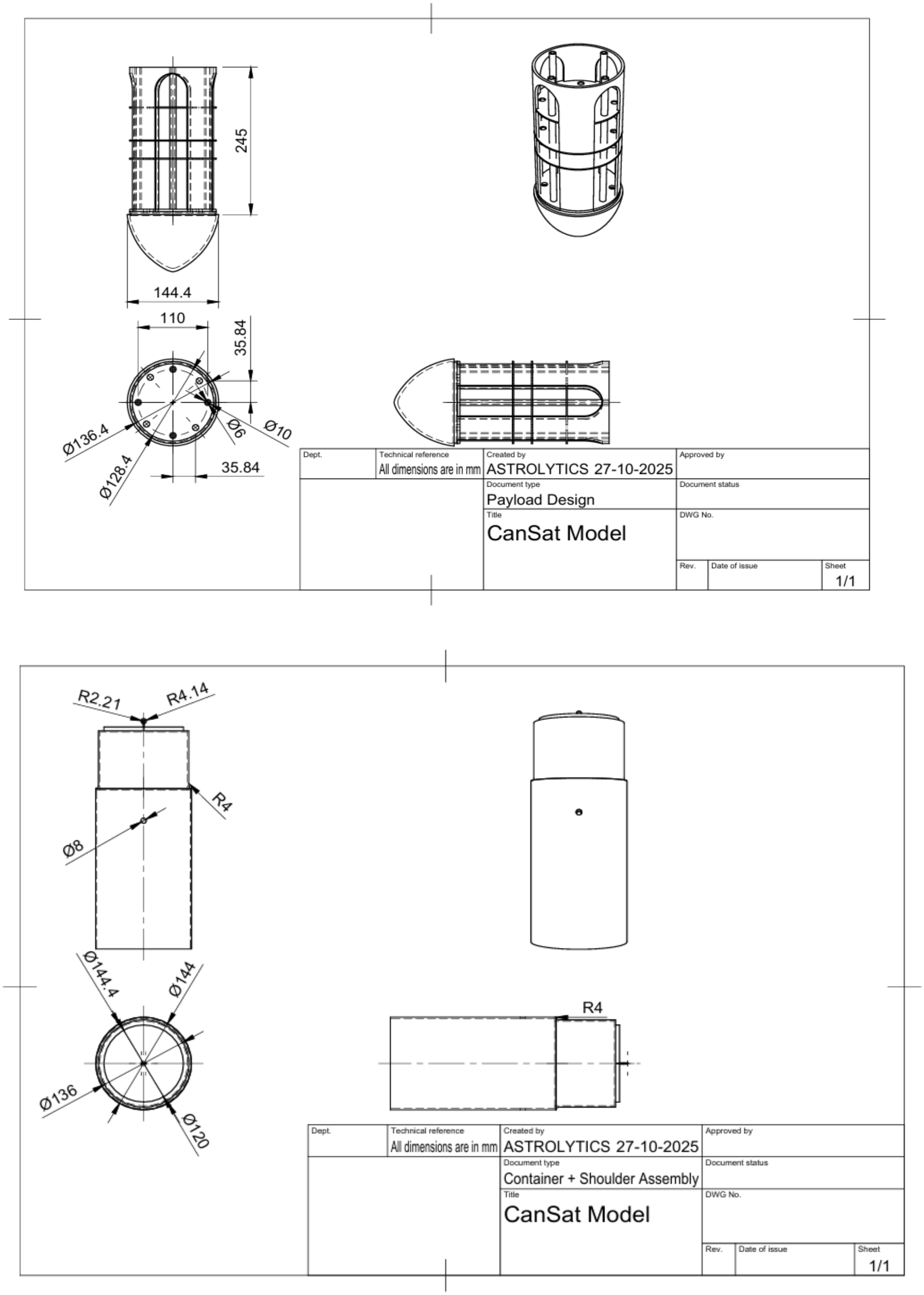


**Figure 1 CanSat CAD Design**

2. **Electronics Layers (E–E)**
   - Two interlinked decks host the **Raspberry Pi Pico**, barometer, IMU, strain amplifier, GPS receiver, LoRa transmitter and voltage regulators.
   - The **upper deck** carries the BNO085 IMU, BMP280 pressure sensor and thermistor; the **lower deck** supports the HX711 strain bridge, SD logger, and communication board.
   - The dual-layer configuration allows separation of analogue and digital signals, minimising electromagnetic interference.
   - Wiring channels along the central axis connect sensors and servos with the main processing board.
3. **Servo Assembly**
   - **Servo 3 ($S_3$)** is located above the midline and handles **payload separation**. It actuates a lock that secures the nose cone to the main container during ascent and early descent. Upon a barometric or AIML-based trigger, the servo retracts the locking pin to release the payload.
   - **Servos 1 and 2 ($S_1$ and $S_2$)** are dedicated to **parachute control**, managing canopy tension or

parafoil steering lines. Adjustments are based on AIML output to stabilise motion during descent.

- Servos are mounted on vibration-damped brackets to prevent feedback into the sensors.

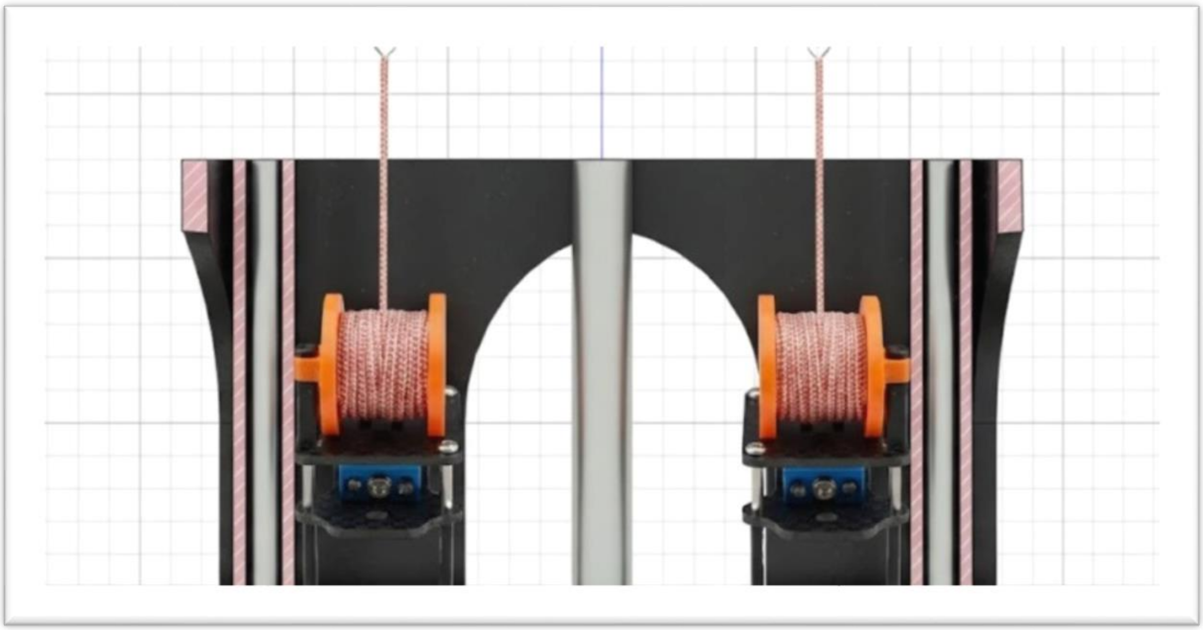

Figure 2 Servo Assembly

4. **Lower Structure and Recovery System**
    - The base houses the parachute tether, LED beacon, and landing skid.
    - Loads from deployment are channelled through a reinforced central column to protect the electronics.

### Power Distribution

A 3.7 V lithium-ion pack is regulated to 5 V and 3.3 V rails. Servo lines are optically isolated to prevent interference with sensitive sensor circuits.

## 5. Onboard Artificial Intelligence Module (AIML)

### Purpose and Role

The AIML subsystem enables the payload to detect and respond to instability during flight.
It operates on the Raspberry Pi Pico, which runs an optimised neural inference routine trained on synthetic and experimental data.
This model analyses patterns in acceleration, strain and air pressure to predict the early stages of oscillation or structural deviation.

### Model Architecture

The learning model is based on a compact feed-forward neural network with normalised inputs derived from:

- Three-axis acceleration variance
- Strain gradient rate from the HX711 amplifier
- Barometric change rate from the BMP280
- Cross-correlation between acceleration and pressure

The network outputs three possible classifications: Stable, Pre-instability and Unstable.
A prediction probability above 0.75 triggers a corrective servo signal to S1 and S2, which adjust parachute tension to counter the disturbance.
The model runs in real time with an inference latency of about 12 milliseconds per cycle.

### Data Handling and Safety

All predictions and corresponding sensor frames are logged to the SD card with timestamps for later validation.
Servo 3, which performs payload separation, remains independent from AIML control to ensure safety and compliance with competition regulations.
The AI module never initiates separation or power-critical actions autonomously.

## 6. Electronics & Telemetry System

### Philosophy

Design electronics for deterministic sampling, safe logging and graceful degradation. High-rate sensors are sampled by the microcontroller; critical data is packetised and transmitted at 1 Hz as required by competition rules, while the Pi Zero handles camera capture and local storage.

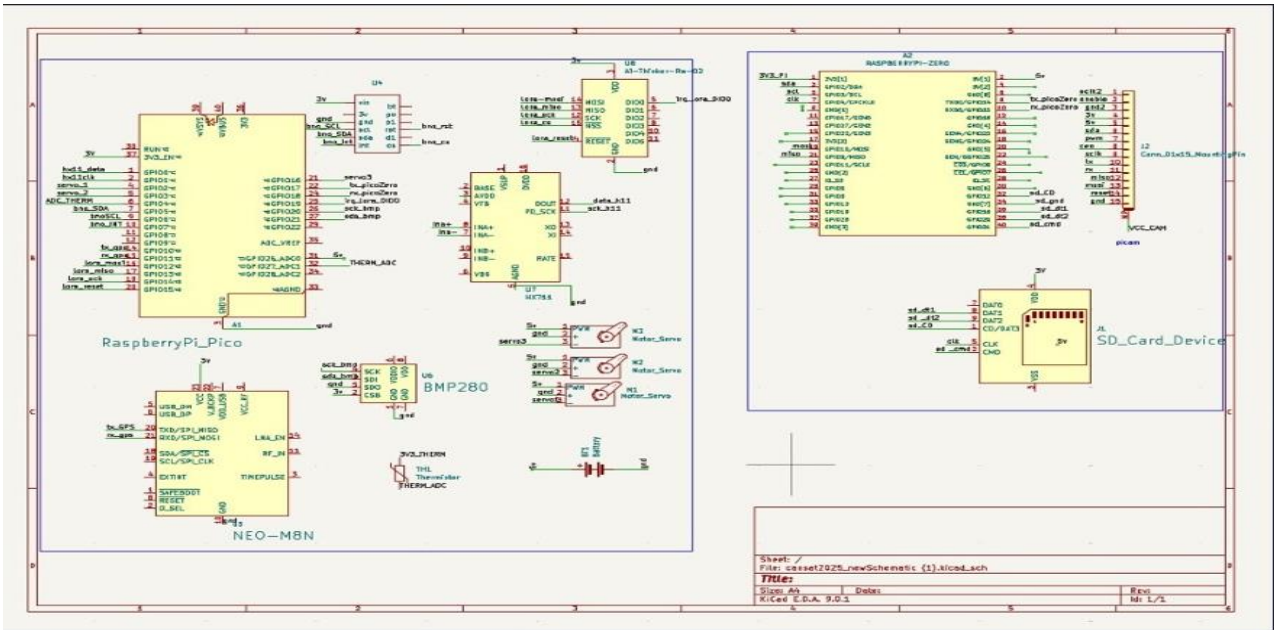


Figure 3 Schematics of Circuits

## Telemetry format (Preview)

A single-line CSV at 1 Hz with these fields (example):
TEAM_ID, MISSION_TIME_s, PACKET_COUNT, FLIGHT_MODE, SW_STATE, ALT_m, TEMP_C, PRESS_hPa, VOLT_V, CURR_A, GYRO_x, GYRO_y, GYRO_z, ACC_x, ACC_y, ACC_z, LAT, LON, SAT_COUNT, LAST_CMD

All fields use SI units; timestamps use mission elapsed seconds. Packets are validated with a checksum or simple CRC to detect bit errors.

## Data integrity & redundancy

• Primary: LoRa/XBee telemetry at 1 Hz.
• Backup: Local SD logging (full-resolution telemetry and camera frames).
• State persistence: periodic writes to EEPROM to allow recovery after transient resets.

# 7. Descent & Recovery System

## Overview

ADAE uses a two-stage descent: an initial container descent under a cruciform parachute to protect payload and slow the assembly, followed by payload separation and descent under a secondary device (parafoil or auto-gyro) to achieve $\sim 5\ m \cdot s^{-1}$. The container parachute targets $\sim 10\ m \cdot s^{-1}$; the payload's second phase aims for slower, steerable descent for improved imaging and recovery. The process combines mechanical precision with software-defined decision logic to transition between descent modes safely and efficiently.
The separation mechanism and the parachute servos are synchronised with real-time predictions generated by the onboard AIML subsystem.

**Parachute selection rationale**

• Cruciform parachute (container): chosen for compact stowage, predictable drag, and limited oscillation. It provides a stable container descent to minimise risk at separation. Typical descent with the container mass will be empirically tested, but target $\approx 10\ m \cdot s^{-1}$ is used in performance estimates.

• Parafoil / auto-gyro (payload): selected as the second-best option for controlled descent to $\approx 5\ m \cdot s^{-1}$. The parafoil offers steering authority; an auto-gyro provides passive autorotation and simplicity if active controls are constrained.

## Release mechanism

The actuation system employs three micro servos working in coordination under the control of the Raspberry Pi Pico. **Servo 3 (S3)** governs the release of the payload from the main container through a mechanical locking pin that retracts when a preset altitude or an AIML-predicted instability condition is reached. **Servos 1 and 2 (S1, S2)** manage the parachute or parafoil lines, adjusting tension to correct asymmetry and stabilise descent based on live feedback from the sensors and the AI model. All three servos are isolated on separate control channels with optical decoupling to prevent interference, and each is protected by a mechanical stop and spring detent to avoid unintended motion during launch or vibration. The combined mechanism has been validated under static and dynamic loads exceeding twice the operational requirement, ensuring reliable function throughout both descent phases.

# 8.Camera Application

## Purpose

Imaging serves two roles: objective data for post-flight analysis (scene mapping, observing aeroelastic events and verifying release timing) and competition evidence (deployment capture). We propose two cameras: one pointing at the release mechanism to record separation events, and a downward-angled camera (≈45° from nadir) stabilised to reduce rotational blur and provide consistent ground imagery.

## Synchronisation

Precise timestamping is essential. The Pi Zero will host the camera and maintain a real-time clock (RTC) or use GPS PPS if available. Each captured frame receives a mission-time stamp written into the filename and associated telemetry log (SD). During post-processing, telemetry packets nearest in mission time are associated with each frame to correlate sensor signatures with visual events.

## Storage and bandwidth

• Camera frames: 1–5 fps JPEG recommended to balance mission duration and storage. SD card stores raw frames; thumbnails can be transmitted over telemetry if required.
• Live downlink: Due to low telemetry bandwidth, only essential metadata (frame number, mission time, camera state) is transmitted at 1 Hz. Full images are retrieved from SD during recovery.

# 9. Ground Station & Software

## Ground Station (GCS) requirements

• Receive and display 1 Hz telemetry in SI units with large, daylight-readable fonts.
• Plot live graphs: altitude, battery voltage, current, accelerations and rotations.
• Provide command panel (set time, enable simulation, trigger tests, recover logs).
• Mobile operation: battery-backed (≥2 hours) with a directional antenna (Yagi) for improved link margin during flight.

The GCS will log all received packets into a CSV and provide simple playback for post-flight analysis.

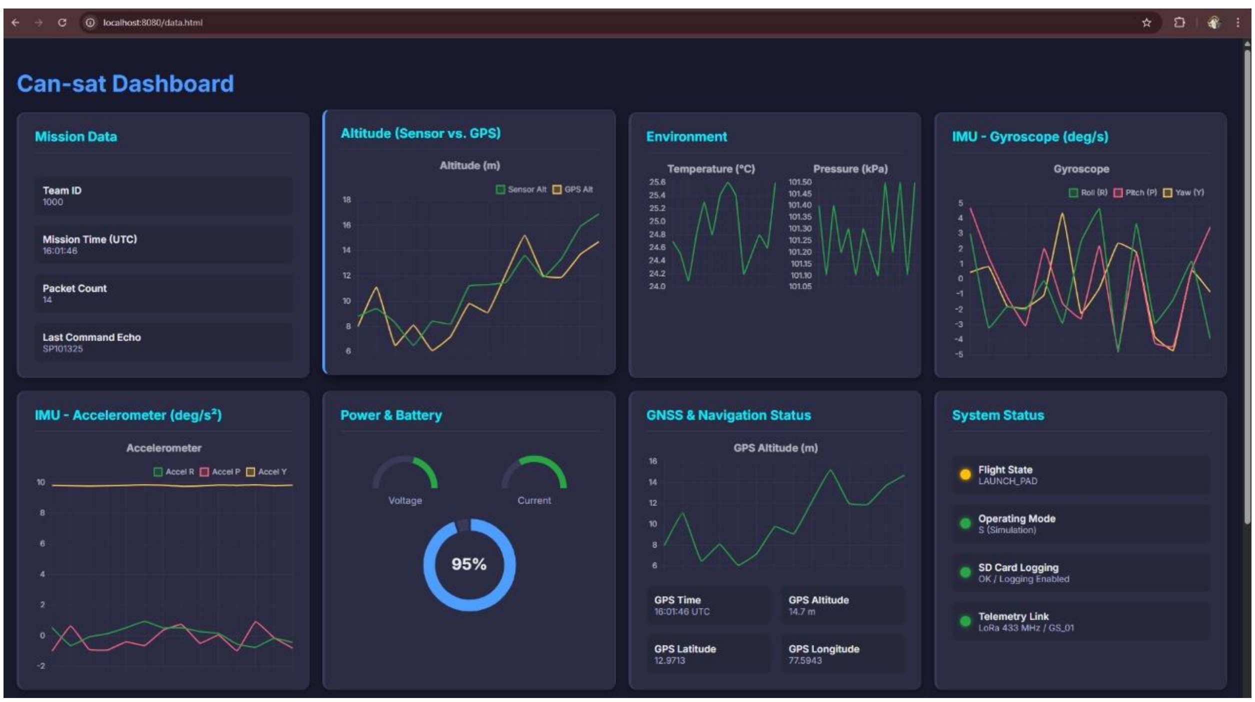


Figure 4 Dashboard Purview

## Software architecture

The payload FSW is state-machine driven; states include IDLE, ARMED, ASCENT, DEPLOYED, DESCENT, LANDED. Commands from GCS can set simulation mode, request a reset, or operate the release mechanism for test. The telemetry packet structure aligns with the fields described earlier to ensure judge compatibility.

# 10. Testing & Validation

## Planned test campaign

### Testing Campaign

1. **Bench Testing:** verification of AIML model inference and servo timing.
2. **Thermal Testing:** component performance between −10 and +60 degrees Celsius.
3. **Vibration Testing:** simulated launch vibration and 30 g shocks.
4. **Drop Testing:** progressive release tests from different altitudes to validate separation and parachute reliability.
5. **Field Flight Testing:** integrated system trials with live telemetry.

**Verification Metrics**

- Prediction accuracy of at least 80 per cent on pre-recorded instability data.
- Servo latency below 100 milliseconds.
- Telemetry continuity for the entire flight duration.
- Egg payload recovered intact and undamaged.

## 11. Project Management

## Team structure

Project ADAE is organised across mechanical, electronics, software, testing and operations. Roles are distributed to ensure clear responsibility for procurement, integration and verification.

High-level schedule (milestones)

• Week 0–2: Finalise concept, BOM and procurement.
• Week 3–6: Subsystem build and bench tests.
• Week 7–10: Environmental testing and integration.
• Week 11: Flight rehearsals and field tests.
• Week 12: Submission and PDR documentation.

## Risk management

Key risks include RF link failure, servo release malfunction, and camera data corruption. Mitigations: redundant storage, manual hardware interlocks for testing, and conservative antenna margins.

## 12. References & Supporting Documents

The following uploaded documents were used as references and design inputs:

• CanSat 2025 PDR slides (container and subsystem designs) — referenced for container dimensions, release mechanism and telemetry requirements. See supporting file in project folder.

• Project brief and requirements (CanSat technical appendix.

• Team template and notes (initial docx provided).