Applications of Systems Engineering Methodologies to an Undergraduate Student Volunteer-Led CubeSat Constellation

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Banner Photo Credit: NASA

Introduction and Motivation

The Northern Space Program for Innovative Research and Integrated Training (Northern SPIRIT) satellite consortium launched in March 2023 and consists of three CubeSats designed, assembled, and operated by AlbertaSat, a University of Alberta student group:

- **Ex-Alta 2:** a 3U CubeSat containing an open-source, multispectral imager designed for wildfire prediction, detection, and prevention.
- **YukonSat and AuroraSat:** 2U CubeSats developed in collaboration with Yukon University and the Aurora Research Institute, each with an educational outreach payload that can receive, display, and photograph community submitted artwork and messages.
- All three satellites have digital fluxgate magnetometer payloads, and nearly identical buses composed of both commercial off-the-shelf (COTS) and designed-in-house components.

Common aerospace systems engineering methodologies were applied throughout all mission phases in a lean manner to mitigate technical and programmatic risk.

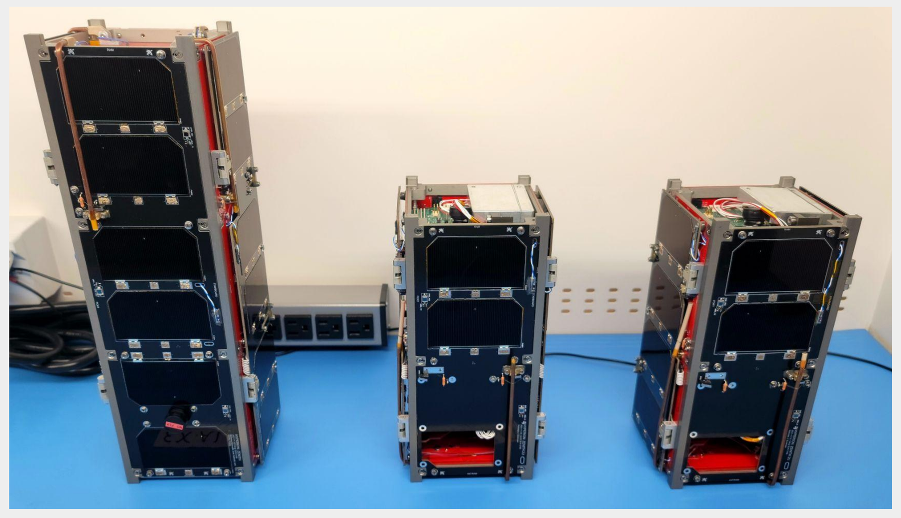

Figure 1: From left to right: Ex-Alta 2, YukonSat, and AuroraSat.

Team Structure and Membership Model

- **Motivation: to lower barriers to entry to the aerospace industry**
  - Primarily undergraduate students
  - Volunteer-based group
  - All applicants accepted to the team
- Challenging to maintain body of committed and experienced members
- Strong leadership hierarchy (see Figure 2), all leadership roles held by student volunteers
- Student interns hired full-time, year-round for last two years of mission
  - Accelerated training, development of in-house designs, and AI&T
  - Reduced membership turnover
  - Increased resources towards strategic management, such as implementation of Agile Scrum methodology

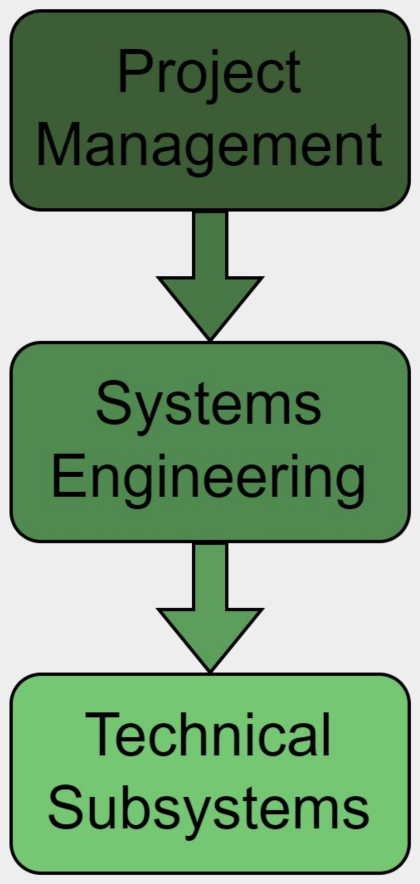

Figure 2: AlbertaSat organizational flowgraph.

Figure 3: The AlbertaSat team in Winter 2022.

System Requirements Management

- Definition guided by NASA Systems Engineering Handbook
- Split into functional and performance requirements for each subsystem
- Bimonthly reviews conducted by the systems team with each subsystem to track compliance

During AI&T, **ambiguous or unattainable requirement verification methods** led to requirements being non-compliant or out of scope given the project's limited resources.

ID	Design Consideration	Design Specification	Design Authority
ASX2-DAT-1 .010	Spatial Resolution	Images shall have a spatial ground resolution no larger than 500 m.	Systems Engineering

Verification Method	Compliance Verification Method	Phase by which should be compliant	Compliant?
Inspection	First order approximation using focal length, pixel size, spacecraft altitude.	Critical Design Review	Compliant (Ex-Alta 2)

Figure 4: Sample system requirement. Compliance was assessed separately for each of the three spacecraft.

Prototype and Protoflight FlatSats

- One prototype FlatSat used for all three satellites
  - Prototype models of all electronic components common between all three satellites
  - Ability to switch between Ex-Alta 2 payload and YukonSat/AuroraSat payload
  - Remained in use after integration of flight models, for further software development, operator training, and anomaly troubleshooting during the operations phase
- Three protoflight FlatSats (one for each satellite) (see Figure 5)
  - Allowed end-to-end verification of flight model hardware
  - Lean approach to flight model testing required, due to limited project resources
- Each FlatSat began by validating the critical subsystems (power, two-way communications, and main computer system) (see Figure 6), then adding and testing other subsystems individually.

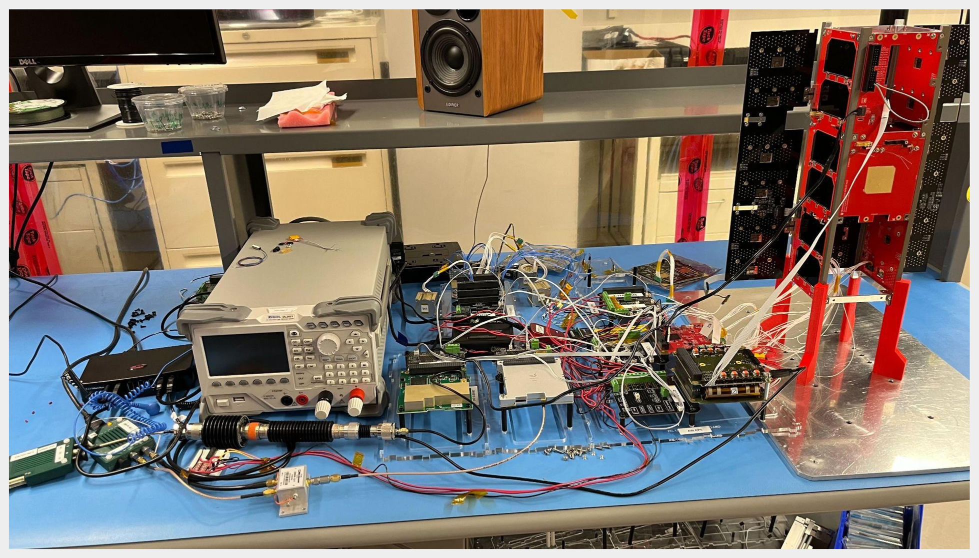

Figure 5: Ex-Alta 2 Protoflight FlatSat undergoing deployables testing as part of the system-wide FlatSat testing plan.

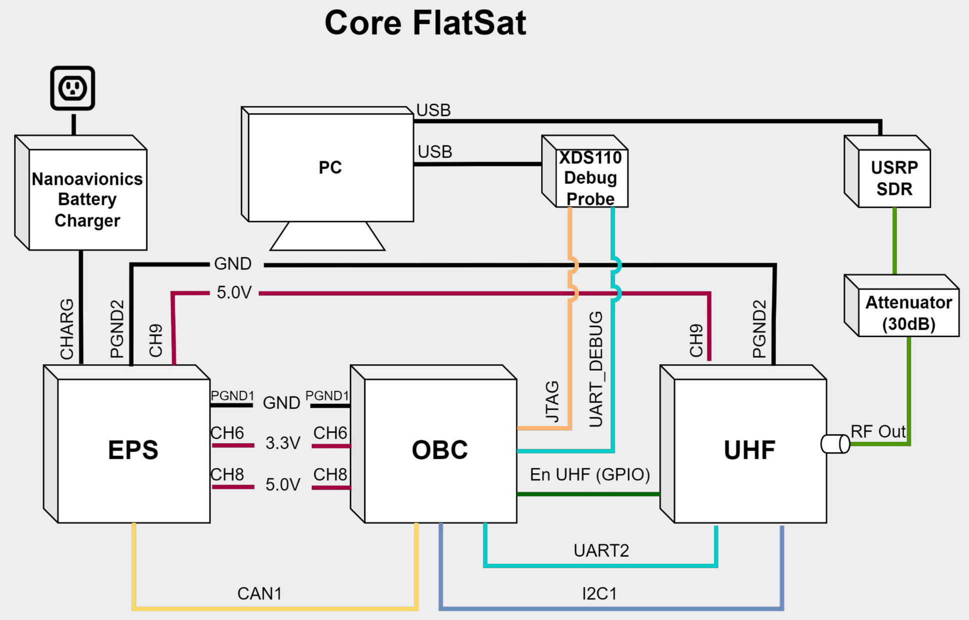

Figure 6: The "core" FlatSat was validated first, consisting of the power, two-way communications, and main computer systems only.

Assembly, Integration, and Testing

- AI&T done in parallel across three satellites (see Figure 7)
  - Lower technical and scheduling risk
  - Fit check and final assembly performed concurrently by three teams of two members each
- Version-controlled documents for all testing and assembly procedures
  - Authored by student members and approved by key stakeholders, project management, systems engineering, and faculty advisors
  - Configuration management system developed by project management and applied to all AlbertaSat projects

However, late maturation of system design and high member turnover rate caused ambiguities in AI&T implementation. Scope of testing was reduced due to procurement delays, major last-minute design changes, damage to critical components, and requirement non-compliance.

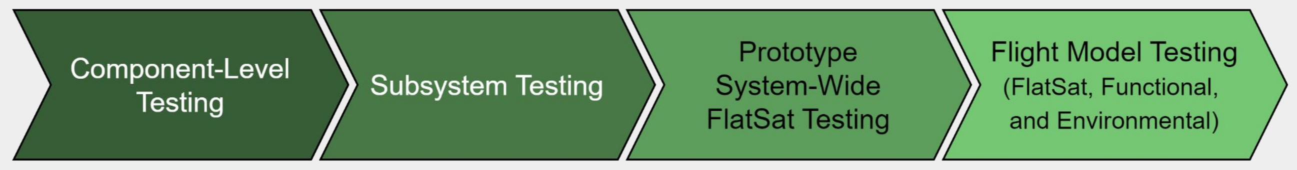

Figure 7: AI&T workflow, used in parallel for all three spacecraft.

Mission Retrospective

- Procurement and COTS suppliers:
  - **Lack of internal procurement strategy** resulted in schedule changes
  - **Critical COTS components** were damaged during testing or found to have manufacturing defects–this reduced time for testing flight models
- Turnover of members and volunteer commitment levels:
  - Schedule delays exacerbated by **semesterly personnel changes**.
  - Steep learning curve emerged at the end of the mission– AI&T limited by **experienced personnel** available
- Requirements:
  - Should be written with clear and attainable **verification methods**
  - Requirements **traceability** necessary to prevent scope creep
- Assembly, Integration, and Testing:
  - Significant **configuring** (software and hardware) was completed directly before final integration, adding unnecessary risk
  - **Design software and hardware for validation** to mitigate ambiguity in flight model testing
- Program outcomes:
  - **Length and complexity** of mission provided ample opportunities for a large body of undergraduate students across Alberta.
  - Many Northern SPIRIT alumni have gone on to work in the **Canadian aerospace industry**, and lessons learned from Northern SPIRIT will be applied to **future AlbertaSat missions**.

Conclusion

The Northern SPIRIT systems engineering methodology provides a model adaptable for student-led CubeSat missions. The volunteer-intern membership model, requirements management, FlatSat infrastructure, and AI&T flow present a significant technical challenge, similar to what is encountered in industry, while remaining an appropriate level of complexity for a student group.

Thank you to our supporters:

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- Our members who contributed to Northern SPIRIT over the past six years.
- Donors, industry supporters, and community members, without whom Northern SPIRIT would not be possible.