ADVANCED ELECTRICAL BUS (ALBUS) CUBESAT: FROM BUILD TO FLIGHT

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SmallSat 2020 – A Look Back: Lessons Learned

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Project Overview

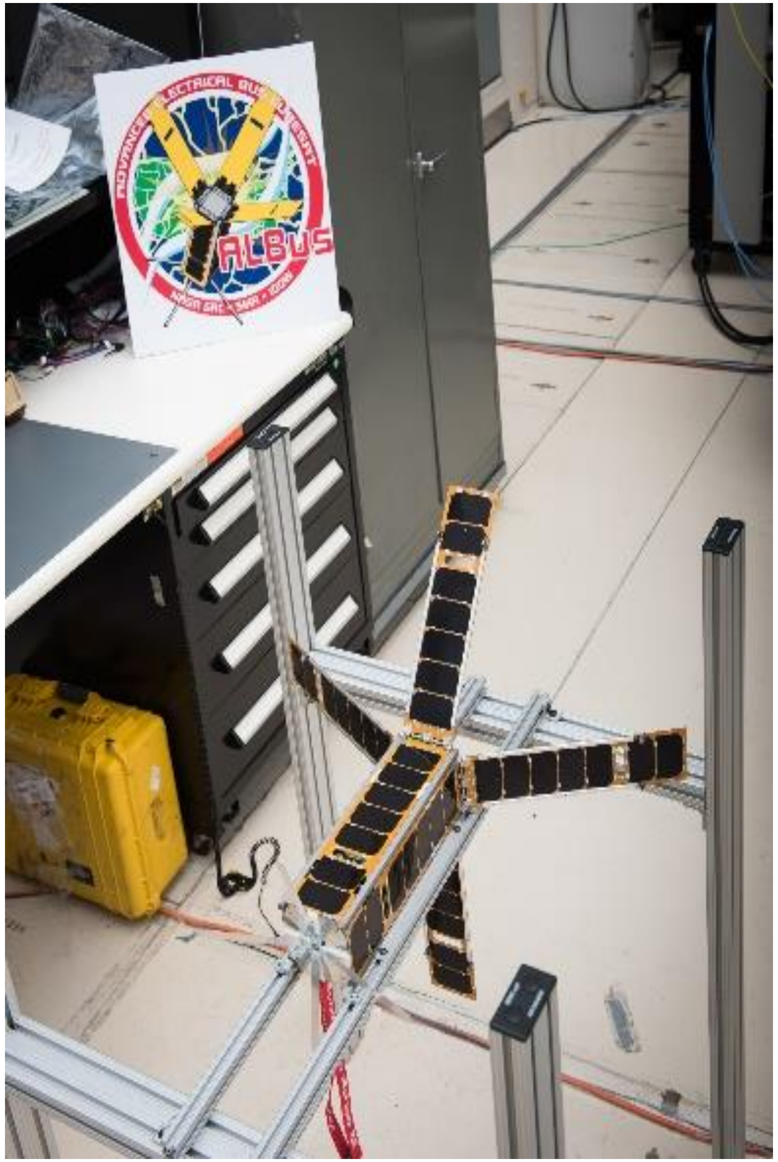
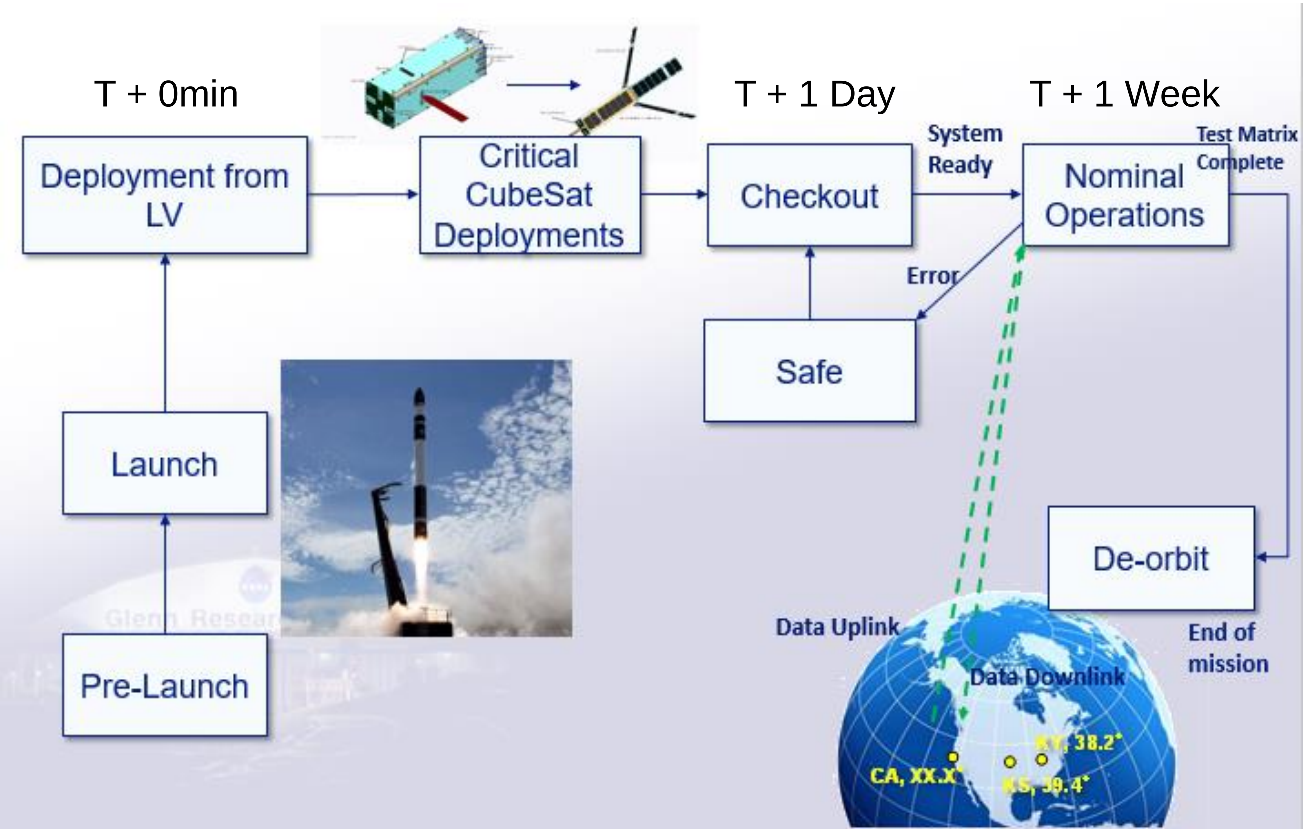


Photo Credit: NASA

- Contribute to the advancement of the CubeSat platform as a vehicle for expeditious and cost-effective technology demonstration for science and exploration missions
- Leverage Glenn Research Center’s (GRC) core competencies in power management and distribution (PMAD) systems and shape memory alloy (SMA)
- Expose the early career team to hands-on hardware design as well as developmental, technical, and project management practices
- Two Primary Objectives:
  - Demonstrate the functionality of the novel SMA activated retention and release mechanism, and SMA deployable array hinges, in an on-orbit environment.
  - Assess system-level capability to charge a high capacity battery, distribute 100W of power, and thermally control the system in a low earth orbit environment
- ALBus launched in December 2018 as part of CubeSat Launch Initiative (CLI) Educational Launch of Nanosatellites (ELaNa) XIX mission on Rocket Lab’s Electron.

Mission Operations



T = Deployment	Event
T + 0min	Deployment from launch service provider. Spacecraft power ON, deployment timer begins.
T + 1min	Spacecraft boot sequence completes and begins calculating payload data.
T + 15min	Solar array and antenna deployment sequence executes
T + 16min	Beacon begins (every 15 seconds)
T + 1 Day (estimated)	Communication link established and 1st set of data received. Beacon changes every 60 seconds. CubeSat collects and transmits data to validate thermal control and battery charging algorithm predictions.
T + 1 Week	CubeSat commanded to being nominal operations with demonstration of 100W discharge cycles
Note:	The system remains in this mode and continues to take payload data until commanded otherwise

- Calls for a 4-6 month mission duration
- Utilized the NASA Wallops Flight Facility (WFF) ground station for communications
- Conducts ground operations at NASA Glenn Research Center via an interface to WFF network

- ALBus Nominal Orbital Parameters:
  - 85 degree inclination
  - Perigee: 471 km, Apogee: 501 km
  - RAAN: 178.9 degrees

ALBUS MILESTONE SCHEDULE

2013

April
Announcement of CubeSat Launch Initiative (CLI)

2014

November
Project Technical Review 1

CLI Proposal Submission

2015

February
HEOMD Acceptance Letter

August
Project Technical Review 2

2016

April
Project Technical Review 3

December
System CDR

2017

November
Random Vibration Testing

Thermal Bake-Out

December
Mission Readiness Review

2018

February
Pre-Ship Review

April
Delivery to Rocket Lab USA

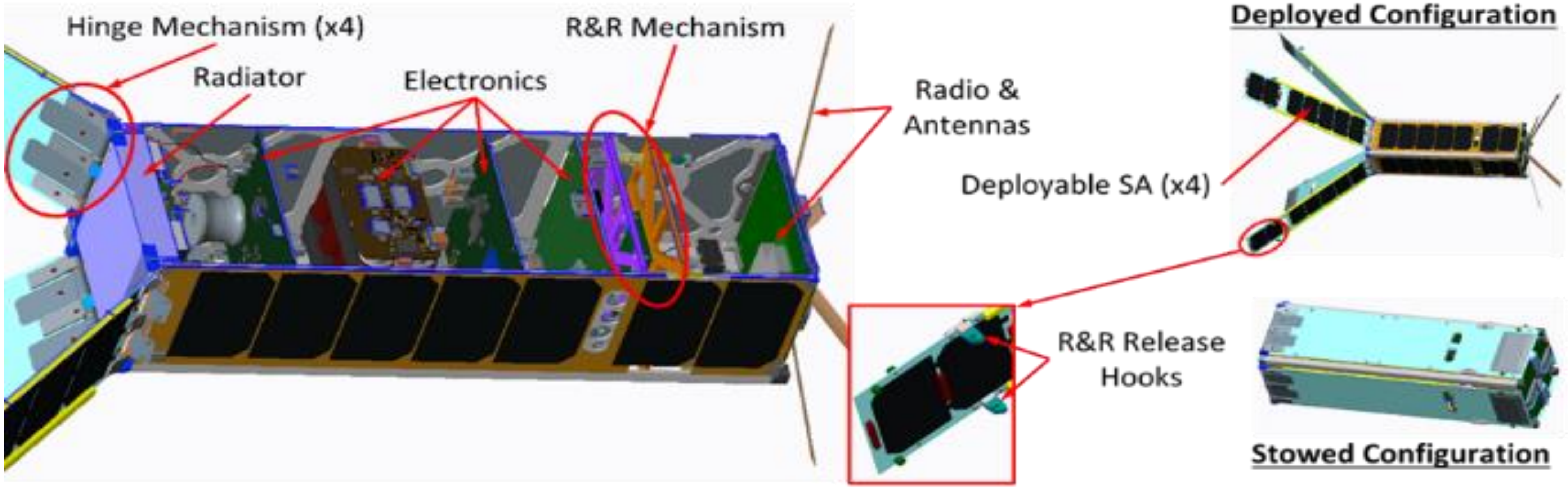
December
Launch

2019

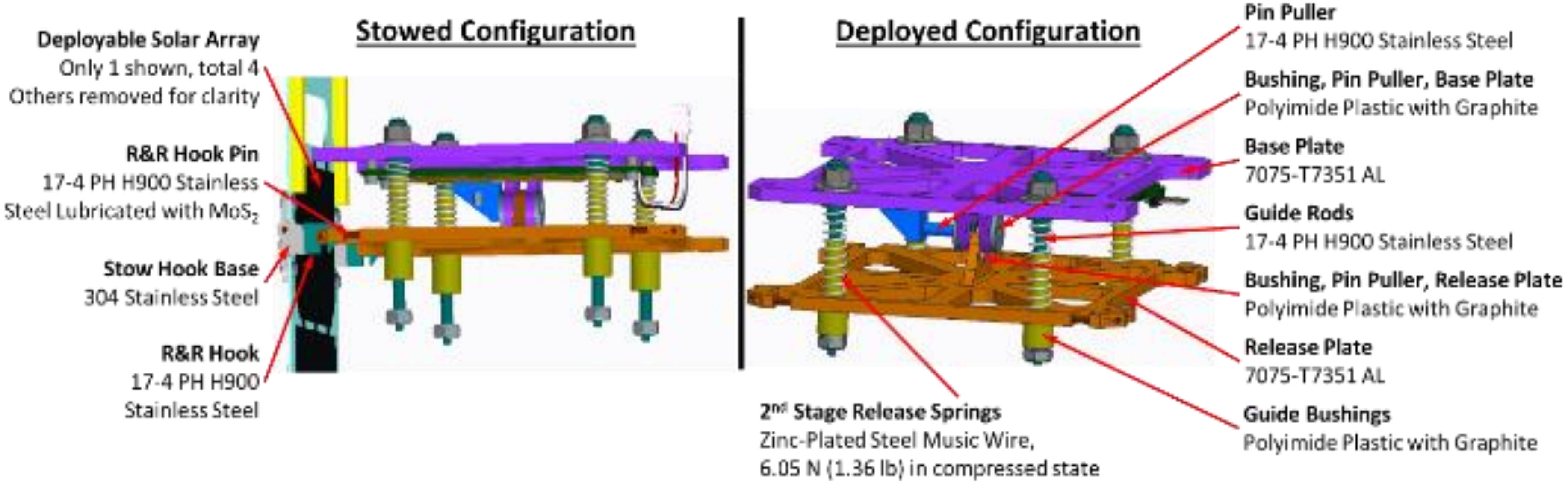
February
ALBus Deactivation

ALBus CubeSat Architecture

Main Internal and External Components



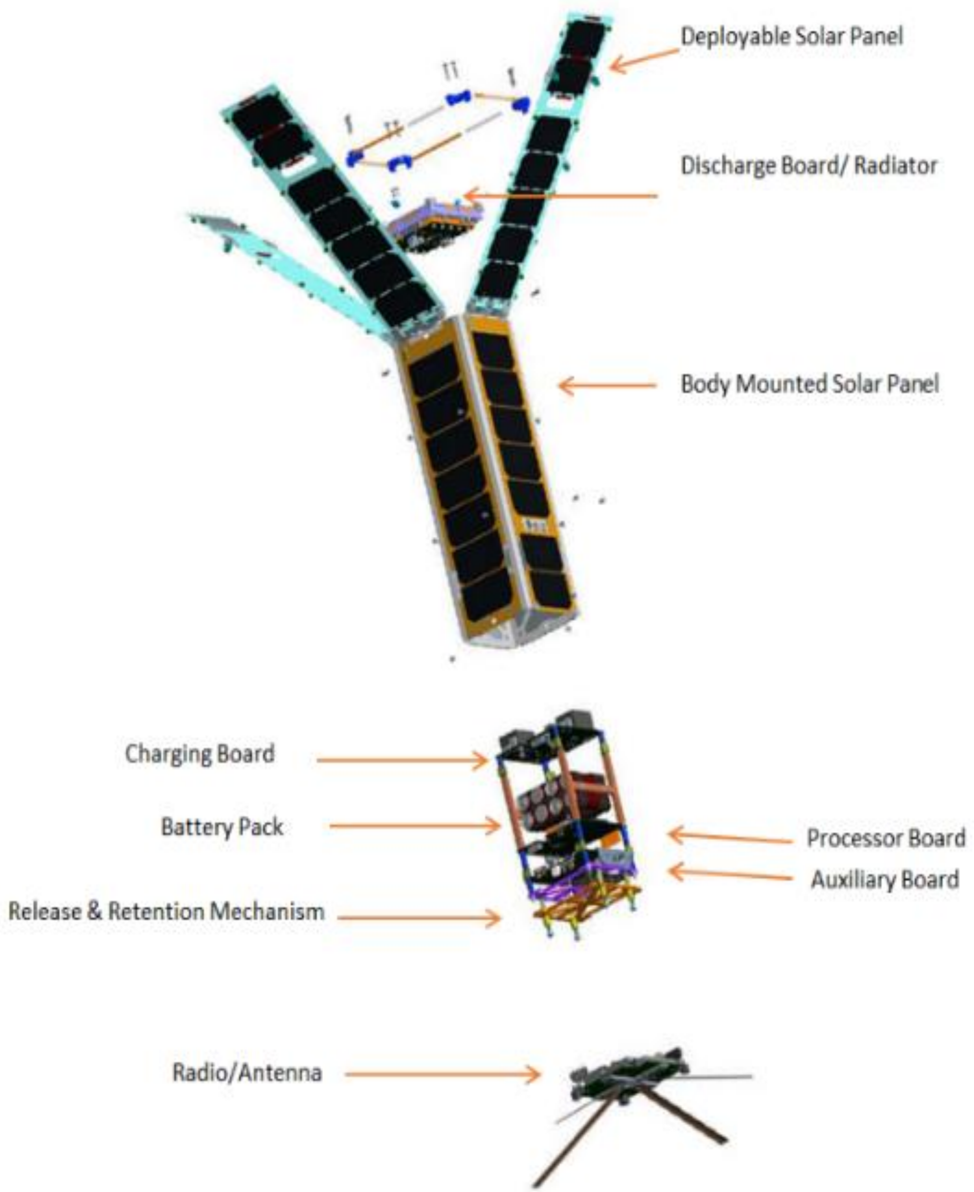
Retention and Release (R&R) Mechanism



Retention and Release (R&R) Mechanism

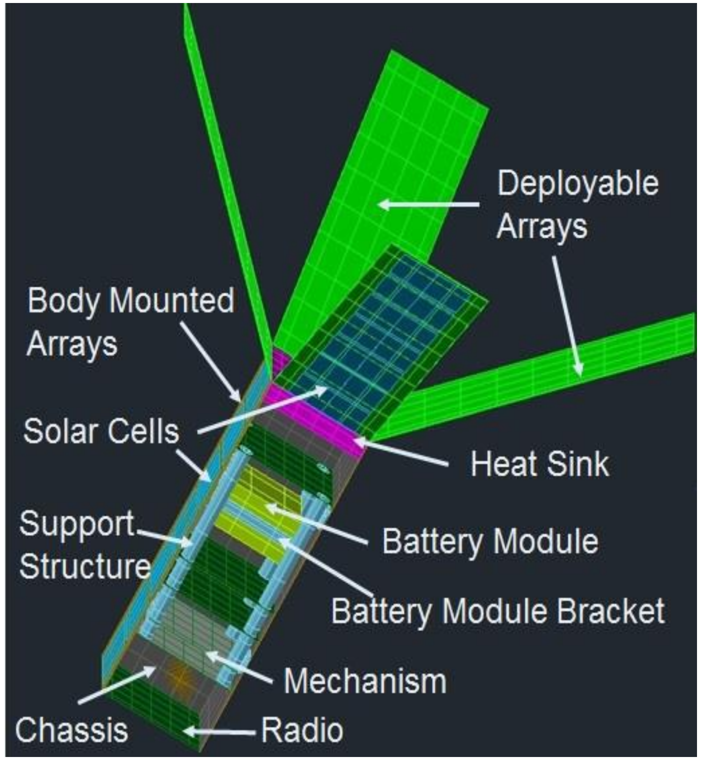
- A two-stage Shape Memory Alloy (SMA) actively driven pin-puller type mechanism used to retain the arrays during ascent and release in orbit (R&R mechanism)
- The first stage is a pin-puller device driven by an SMA linear actuator (designed by Miga Motor Co using GRC's alloy).
- The second stage is a hook and pin design that is released by a compression spring loaded plate on plain bearings.
- Once released, a passively driven SMA hinge mechanism, one for each of the four arrays, deploys each array to the desired deployment angle.

Electrical Power System



- **Auxiliary**
  - Power Distribution and Regulation
  - SMA R&R Mechanism enable circuitry
  - Discharge enable and current sense circuitry
- **Charging**
  - Solar arrays input to diode of the high side switch of a boost converter which can be controlled for maximum power point tracking control algorithm for efficient battery charging
  - By default, ALBus charges with constant current transitioning to constant voltage scheme.
- **Discharge**
  - 100W output bank of 10 high-power FET resistors in parallel
- **Processor**
  - Flight computer is a Texas Instruments MSP430
- **Battery**
  - Four series, two parallel configuration of 18650 Lithium-Ion cells with 5.2Ah with a nominal voltage of 14.8V.
- **Solar Arrays**
  - Four body-mounted and four deployed solar panels
  - The deployable solar arrays utilize SMAs instead of wires.
  - All cells were ultra-triple-junction (UTJ) type solar cells with a nominal efficiency of 28.3%

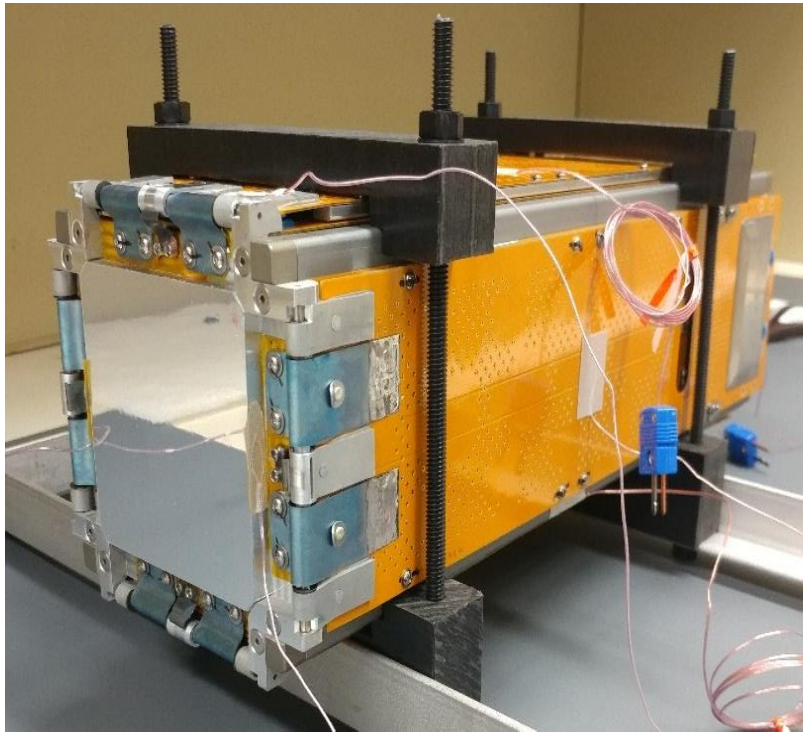
Thermal Analysis



Thermal Desktop Model (Cutaway)

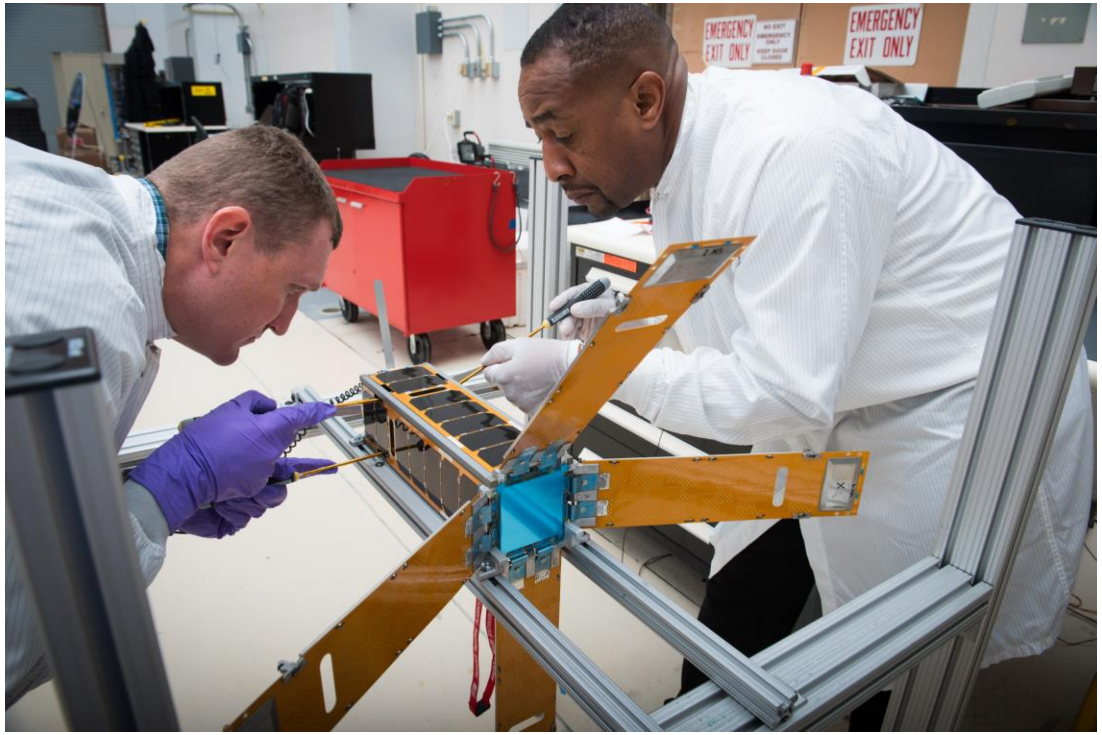
- ALBus relies entirely on passive thermal control.
- Primary Challenges:
  - Limited external surface area for radiators to reject waste heat into space.
  - Limited thermal mass due to the small size of the spacecraft
  - The high-power thermal transients (while exercising the 100W PMAD system to the internal dummy load) requires iterative analysis to predict hardware temperatures and ensure they are within component limits.
  - The lack of active attitude control adds additional challenges to providing adequate thermal control.
- The PMAD subsystem waste heat was managed primarily by providing conductive pathways to the CubeSat frame and utilizing the solar array body panel as effective radiators.
- For the 100W transients, an aluminum mass was mounted at the end of the CubeSat adjacent to the deployable arrays.
- The exterior, or radiating surface, was covered with low solar absorptivity, high infrared emissivity silver Teflon tape.

System Ground Testing



ALBus Flight Unit Prepared for TVAC Testing

VF-10 Facility for TVAC

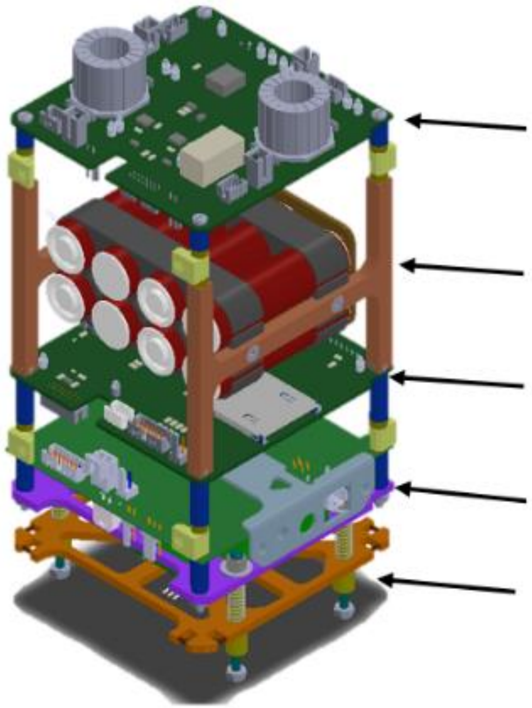


Team members preparing flight unit

- Environmental testing and system functional testing were completed to verify the specified requirements.
- The CubeSat project followed guidance for Protoflight testing.
- Thermal vacuum testing was performed at the NASA Glenn Vacuum Facility 10 (VF-10).
- The vibration test was performed at Glenn Research Center’s Structural Dynamics Laboratory (SDL) facility.

Photo Credit: NASA

Battery Pack Anomaly



Failure Summary

- During a functional test of the flight system, the CubeSat remained in an "ON" state even with the footswitches and RBF pin engaged (non-compliance with ICD requirement).

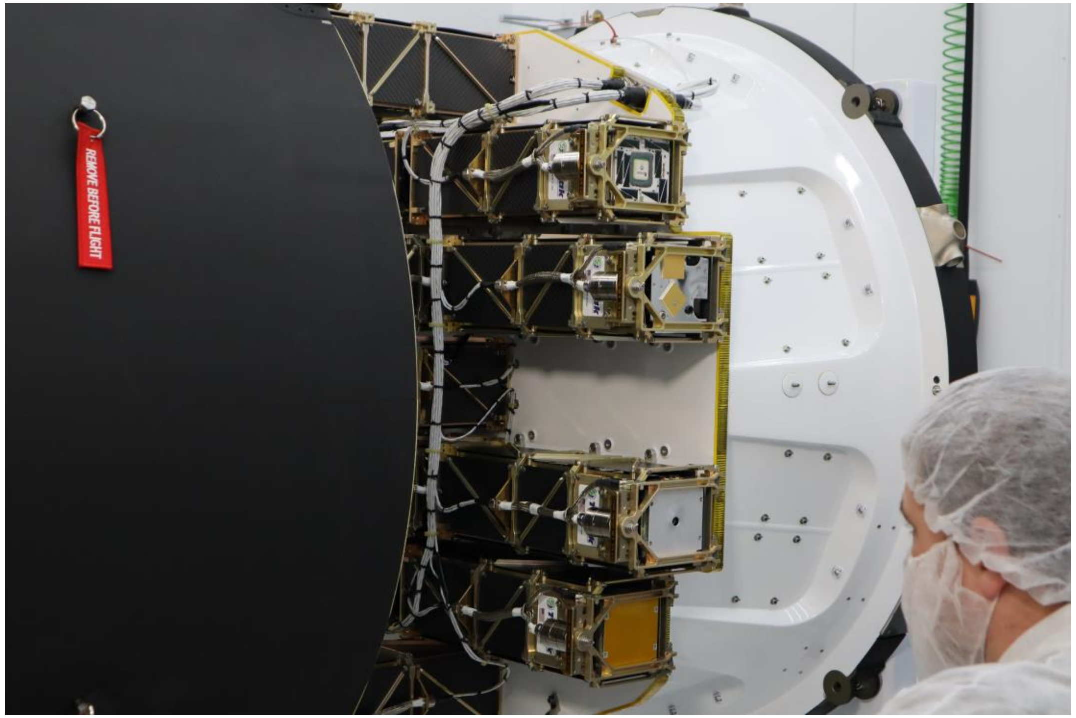
Root Cause

- The failed component was a MOSFET that enables/disables the battery pack when commanded through a pin on the battery connector by the CubeSat footswitch or the Remove-before-Flight Pin (RBFP). The MOSFET failed during a battery charging cycle when the MOSFET was in the 'on' state. Testing confirmed that the footswitches and RBF pin switch were fully functional and sending the correct enable/disable signals through Pin 14 to the battery pack.
- Improper charging procedure.

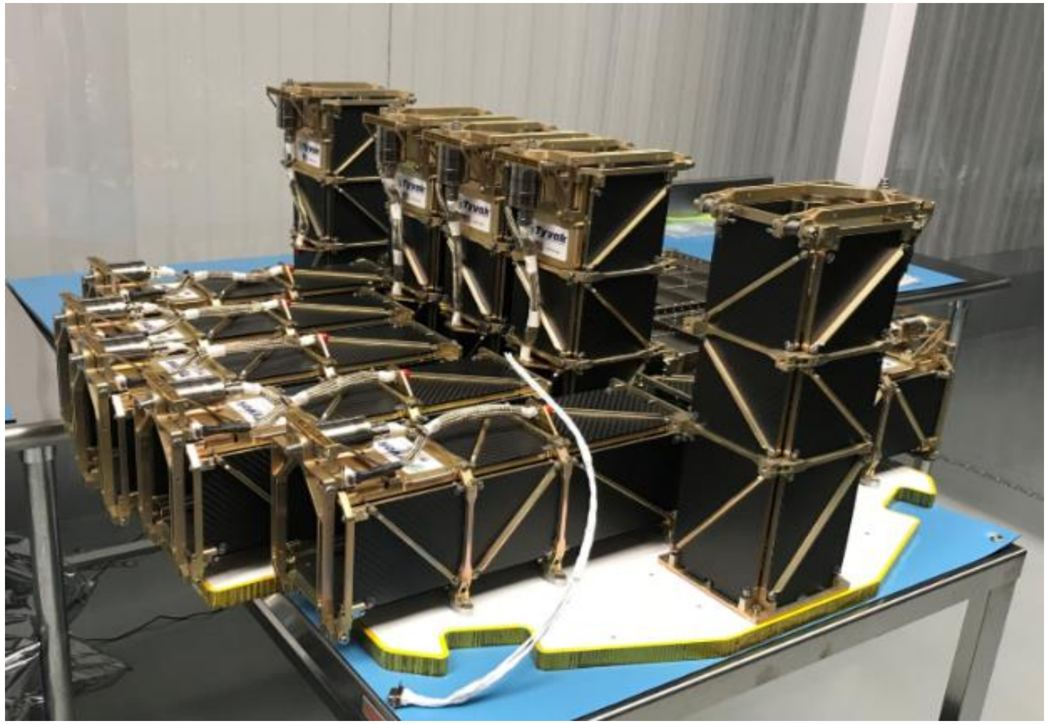
Corrective Action

- Additional rigor added to the step-by-step charging procedure. Using a better power supply with better control circuitry for battery charging to avoid transient voltage spikes. Charging at a slower rate than the charge rate during the failure.

Integration into Spacecraft



NASA ELaNa-19 Mission Fairing Encapsulation
Photo Credit: Rocket Lab



Rocket Lab completes fit check for NASA VCLS ELaNa XIX mission
Photo Credit: Rocket Lab USA

- A CubeSat Acceptance Checklist (CAC) was completed and the fully assembled ALBus CubeSat was packaged into a hard case, foam filled container and delivered by hand from NASA GRC to the LSP's integration facility.
- Team reviewed the CAC with the integrator and performed final integration preparations such as charging up the batteries to ensure they were full. The GRC team ended up returning two more times to the LSP's integration facility. The first time, due to launch delays, the ALBus batteries needed to be charged up. The second return was to correct a radio issue that was discovered last minute. Both returns to the LSP required removing the ALBus from the dispenser and reintegrating it.

Launch

ELaNa-19 Lift-Off
Photo Credit: Trevor Mahlmann, Rocket Lab

ELaNa-19 Lift-Off from Launch Complex 1
Photo Credit: Kieran Fanning and Sam Toms, Rocket Lab

Successfully launched on Saturday, December 15, 2018 at 11:00 PM EST (4:00 UTC) from Mahia Peninsula, New Zealand via Rocket Lab on Electron.

Flight Operations

Deployment

- The CubeSat solar panels deployed on Sunday, December 16, 2018 at 2:42am Eastern and Wallops Flight Facility (WFF) picked up the satellite's beacon signal at 7:00am via their spectrum analyzer.

Beacon

- The Wallops team saw the ALBus beacon signal coming in very strong at the exact beacon period of 15 seconds on the exact frequency of 400.4 MHz.

Confirmation

- This signal reception immediately validated the success criteria for a successful deployment of solar panels and antennas. Had the antennas failed to deploy, the radio would have most likely destroyed itself as the antennas, when stowed, are touching the CubeSat’s metal chassis.

Flight Operations

Next Pass

- Unfortunately, that series of beacons that were received four hours after ALBus deployed was the first and last time a signal was heard from it.
- ALBus was not able to get a first pass scheduled to begin the search until Monday, December 17, 2018.

Government Shutdown

- Several attempts were made until the government shutdown on December 26, 2018, at which point the ALBus team was unable to continue searching.
- During the government shutdown, WFF ground station technicians continued to look for the ALBus 400.4 MHz beacon while they supported other missions. A few more search attempts were made after the shutdown, but eventually the search was called off early February 2019.

Lessons Learned

1. It is important to start mechanical and electrical integration early in the design to make sure harness routing cutouts and important component placement is established as keep-out zones.

2. Building an EDU or 3D printing hardware to test is key in any new development to quickly uncover assembly issues and evaluate actual functional performance. Do not rely on analysis alone.

3. Keep as many aspects of your design as simple as possible. No matter how simple you think it is it will balloon in complexity just with the passage of time.

Lessons Learned

4

Start writing your test plan as soon as possible. It is a living document. It will change and grow as you learn. Share it with the rest of the team and get feedback. Share it with more experienced engineers and get advice.

5

Once you have a reviewed test plan, do as many dry runs with the engineering unit as possible. It will pay off and give you confidence when it comes time to test the flight unit. It is also the best way to refine your test plan.

6

Include testing scenarios when designing. The ALBus design would not allow disabling the radio through the USB-C connector. ALBus decided not to perform the TVAC due to the risk of damaging the radio while in a small metal chamber.

Lessons Learned

7 Start analysis early. Use spreadsheet modeling to establish your design envelope for parameters that have the most influence on your design/performance. Use these calculations to establish what is reasonable for a certain concept or approach

8 Do your best to define your potential environment. You can limit your options by having to over constrain your design to fly in every possible environment. At the same time, do not go too far in the other direction.

9 Having an ability to disassemble the CubeSat in case anomalies arise is important. Design with ease of integration/disassembly/repair in mind.

Thank You