Assembly Integration and Test of the Lunar Flashlight Propulsion System

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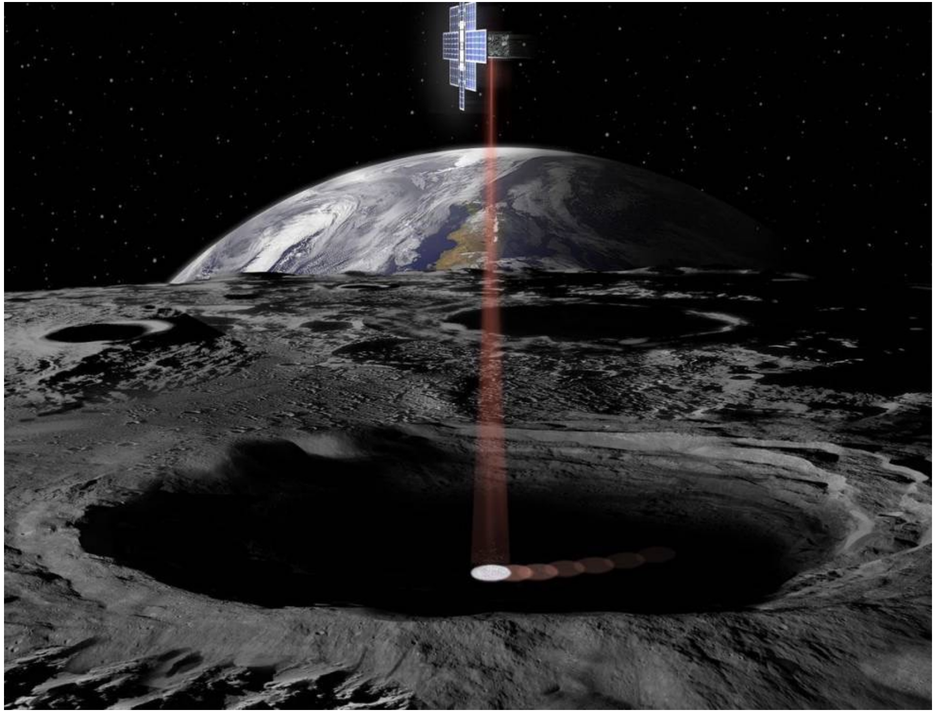
Lunar Flashlight Mission Background

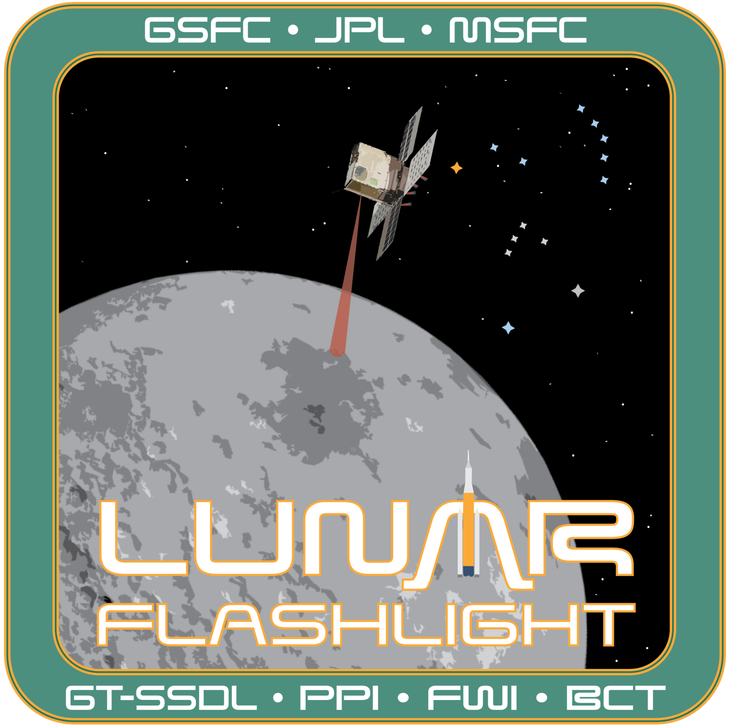
- 6U CubeSat
- Originally a secondary payload on Artemis 1 (SLS)
  - Now launching in early Spring 2022
- LF will perform a Lunar Orbital Insertion
- Uses ASCENT (Advanced Spacecraft Energetic Non-Toxic) monopropellant
- Map lunar ice deposits using infrared laser reflectance



Source: Jet Propulsion Laboratory

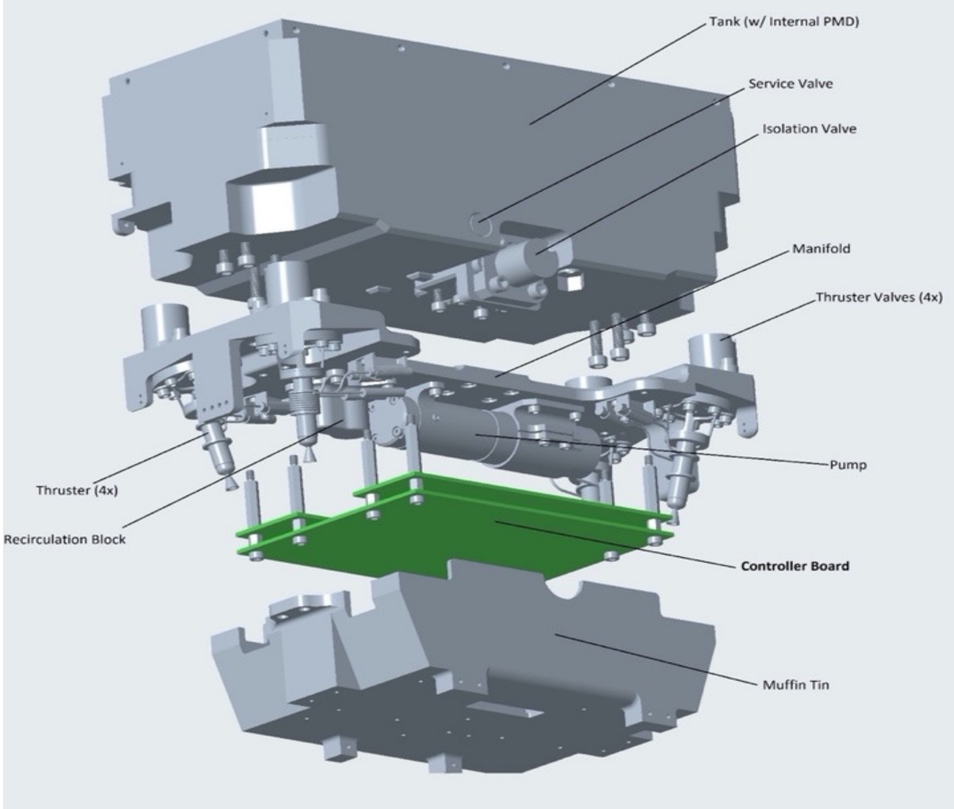
Outline

- System Overview
- System Integration
- System Level Verifications
- Controller Testing
- Full Flat-Sat Testing



Unofficial Logo

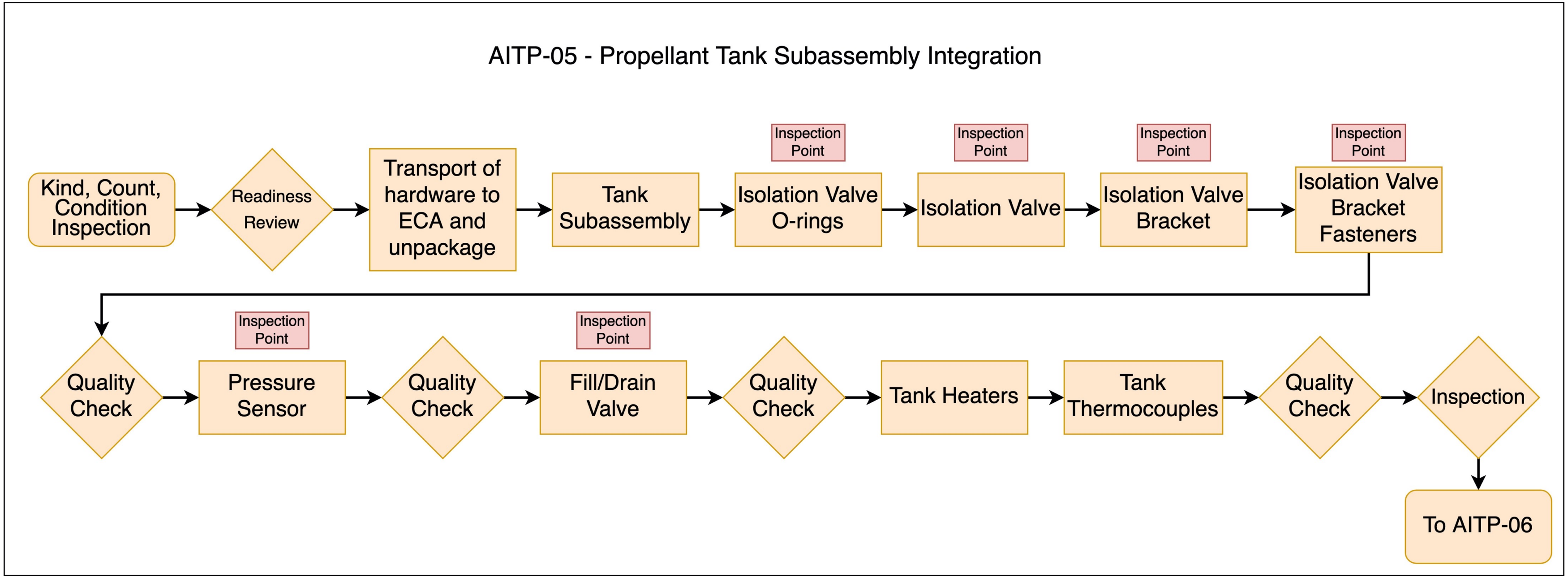
System Overview: Expanded View



System Integration

System Integration: Assembly, Integration, and Test Procedures (AITPs)

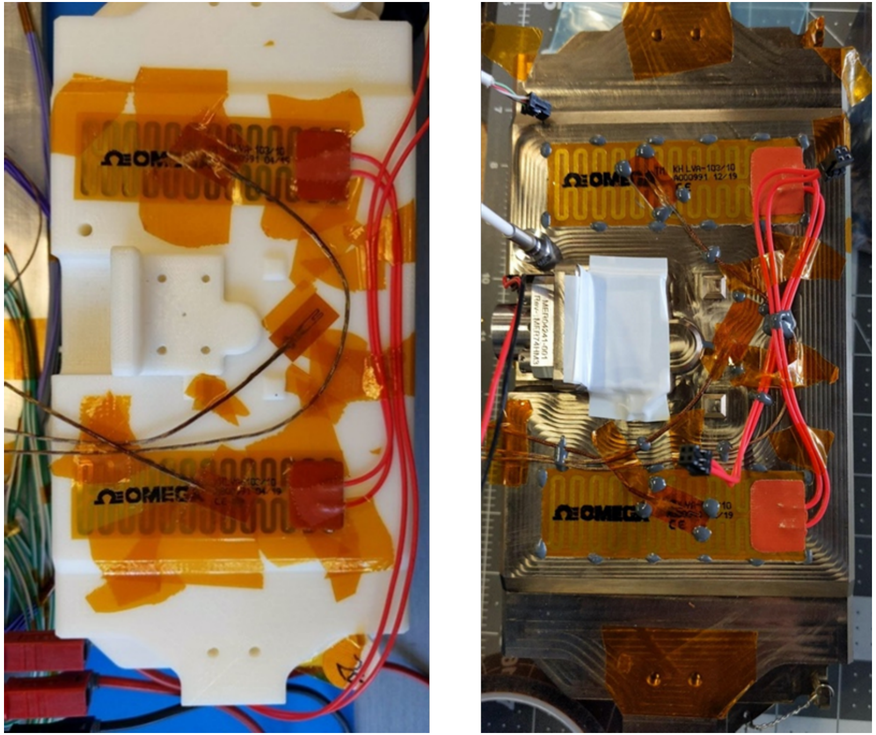
- Product Breakdown Structure used to break down assembly



SHAPING THE FUTURE OF AEROSPACE

System Integration: Wire Routing

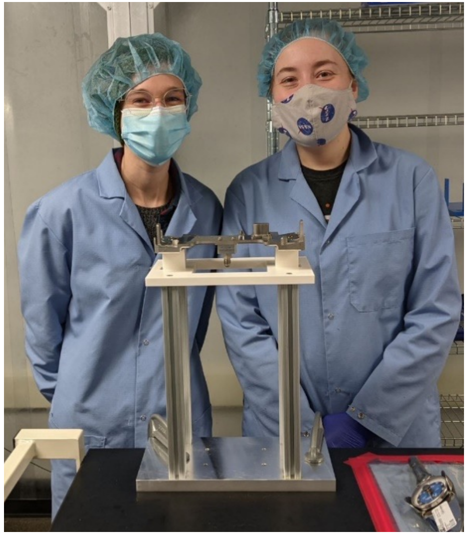
- Full scale 3D printed model
  - Used to lay out wires before integration
  - Wire measurements too conservative
- Wiring diagrams included as deliverable

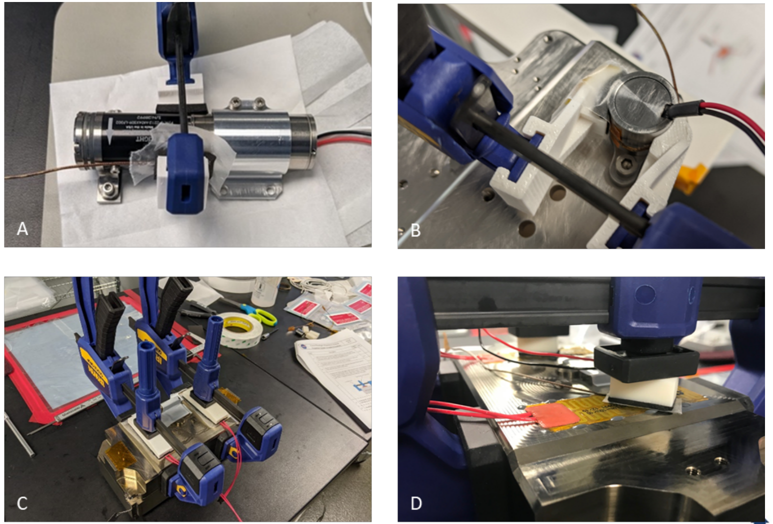


Tank Heater and Thermocouple Example Routing (left), and Flight Routing (right)

System Integration: Assembly Aids and Techniques

- 3D printed fixtures for each assembly procedure
- ‘Fixators’ printed for epoxy adhesion





System Level Verifications

'Hybrid' Protoflight Qualification Approach

	Testing Campaigns	Flight Qualification					Flight Acceptance				
		Radiation Testing	Random Vibration	Thermal Vacuum	Performance Life	Proof & Burst	Random Vibration	Thermal Vacuum	Proof & Leak	Hot Fire	End – End Functional
Components	100mN Thrusters	--	Qual Levels & Durations	--	Per Test Plan	--	Acceptance Levels & Durations	--	MDP X 1.5	Per Test Plan	FlatSat
	Pump	--	Qual Levels & Durations	Qual Margins (4 Cycles)	Per Test Plan	MDP X 2.5	Acceptance Levels & Durations	Acceptance Margins (4 Cycles)	MDP X 1.5	--	FlatSat
	Solenoid Valve	--	Qual Levels & Durations	Qual Margins (4 Cycles)	Per Test Plan	MDP X 2.5	Acceptance Levels & Durations	Acceptance Margins (4 Cycles)	MDP X 1.5	--	FlatSat
	Fill/Drain Valve	--	Qual Levels & Durations	Qual Margins (4 Cycles)	Per Test Plan	MDP X 2.5	Acceptance Levels & Durations	Acceptance Margins (4 Cycles)	MDP X 1.5	--	--
	Controller	TID & SEE (Prototype)	Qual Levels & Durations	Qual Margins (4 Cycles)	Per Test Plan	--	Acceptance Levels & Durations	Acceptance Margins (2 Cycles)	--	--	--
	Propellant Tank	--	--	--	Per Test Plan	MDP X 2.5	--	--	MDP X 1.5	--	--
	Manifold	--	--	--	--	MDP X 2.5	--	--	MDP X 1.5	--	--
	LFPS System	--	--	--	--	--	SC Protoflight Levels & Durations	SC Protoflight Levels & Durations	MDP X 1.1	--	AITP-09

Vendor

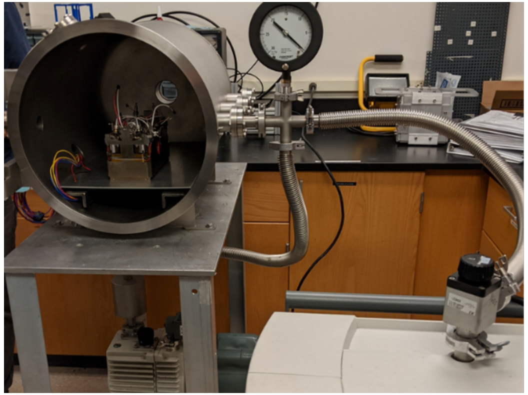
MSFC

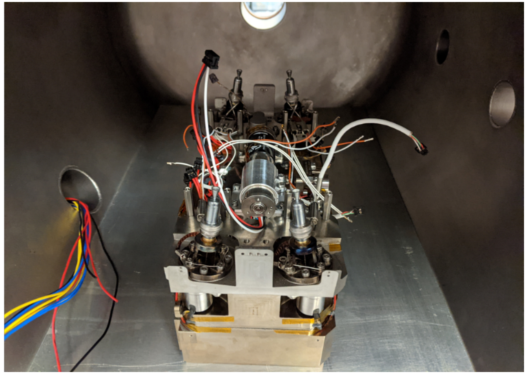
GT

JPL

System Level Verifications: System Flow and Leak Rate

- Flow Test
  - With tank pressurized
    - Open thruster valve
    - Measure flow through rotameter connected to nozzle
  - Ensure system met expected mass flow rate
- Leak Test
  - With tank pressurized
    - Place in vacuum with mass spectrometer attached
    - Used mass spectrometer measure any leakage
  - Ensure system leak rate was below requirement



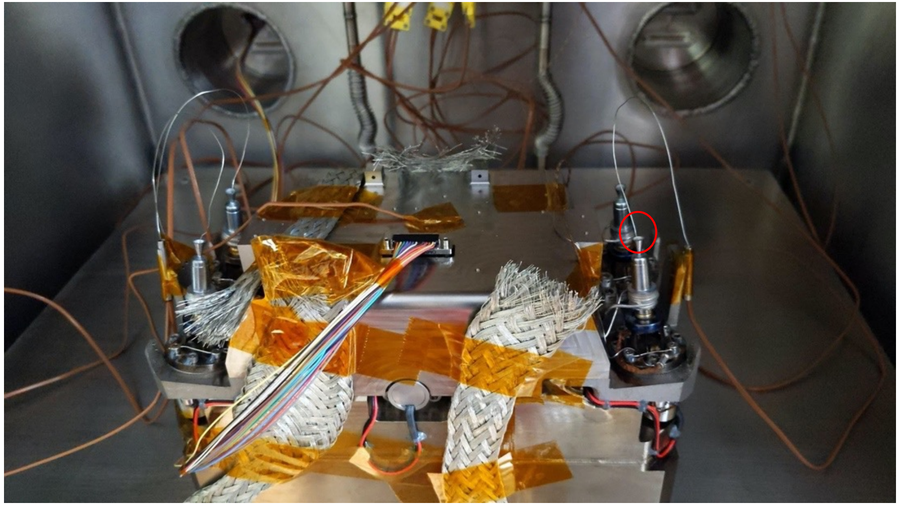


System Level Verifications: Mass and Dimensional Verifications

- Dry mass effects amount of fuel loaded
- Followed AIAA S-120 ‘Mass Properties Control for Space Systems’ and applied appropriate mass growth allowances
- Final mass very close to baseline mass without mass growth allowances
- May recommend reassessing application of standard mass growth allowances for CubeSats

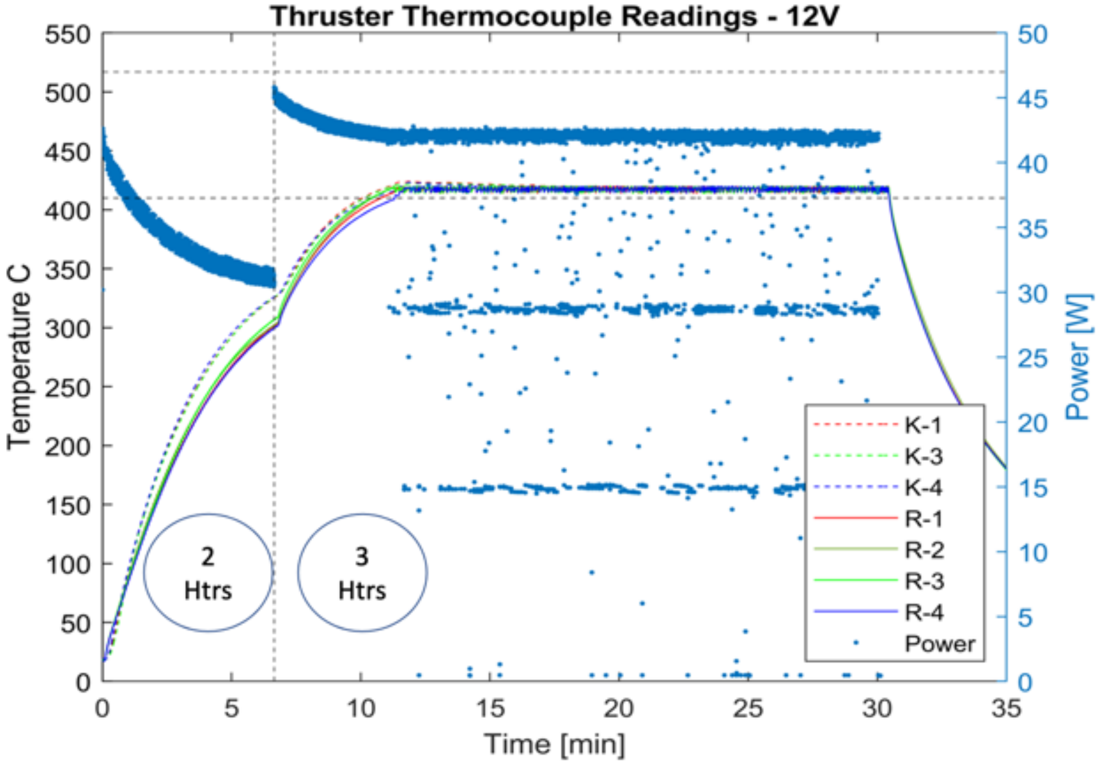
System Level Verifications: System Power Verifications

- Day in the life TVAC testing
- Exercised each component in vacuum
  - Valves
  - Heaters
  - Pump
  - Thermocouples
  - Pressure sensors



System Level Verifications: System Power Verifications

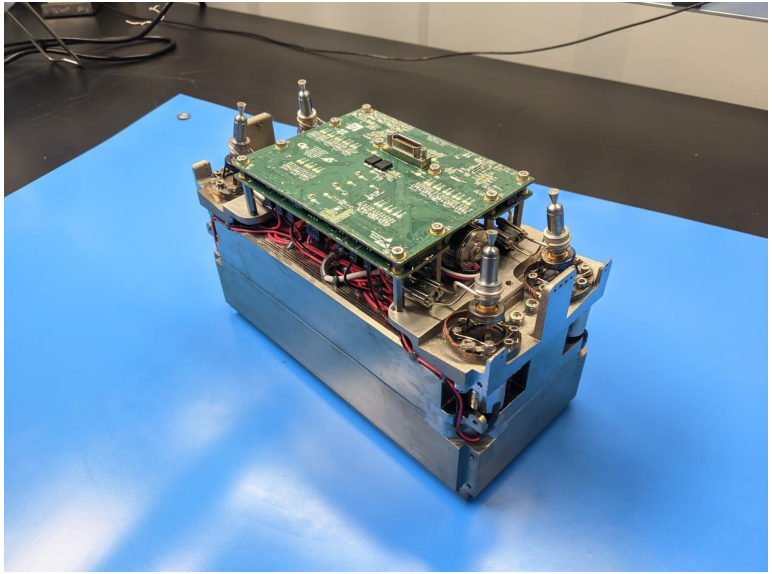
- Thruster preheat testing
  - Preheat using less than 47W instantaneously
  - Test thermocouple issue



Controller Acceptance Testing

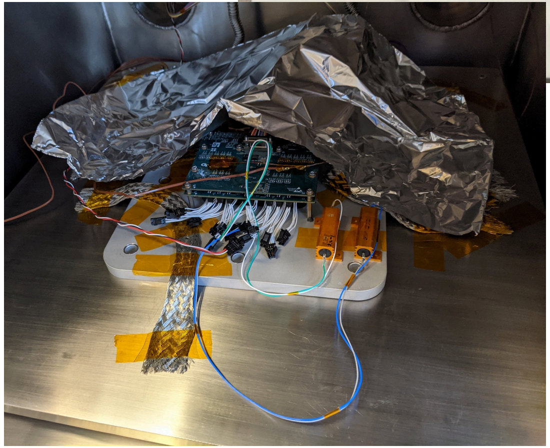
Controller

- 3 PCBs
- Implement control loops, accept commands, and send telemetry
- Uses JPL's FPrime flight software framework



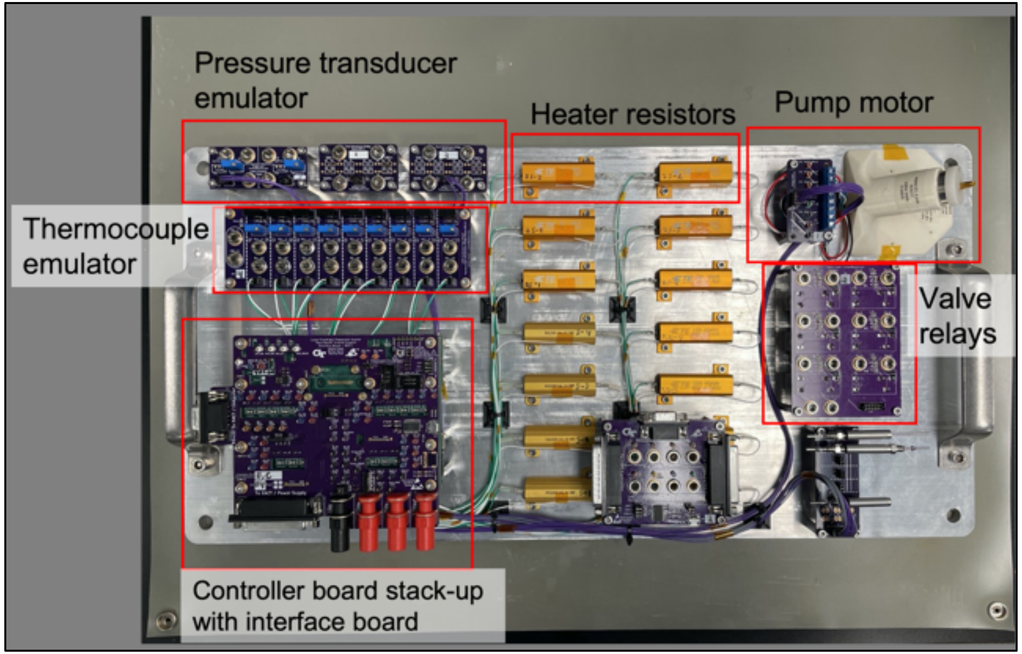
Controller: Environmental Acceptance Testing

- Random Vibration
  - Stacked according to flight design
  - Short functional test between each axis
- Thermal Vacuum Cycling
  - 4 cycles done during qualification
    - Project opted to do 2 during acceptance
  - Techniques applied to reach target temperature:
    - Copper thermal straps, thermal grease, aluminum foil



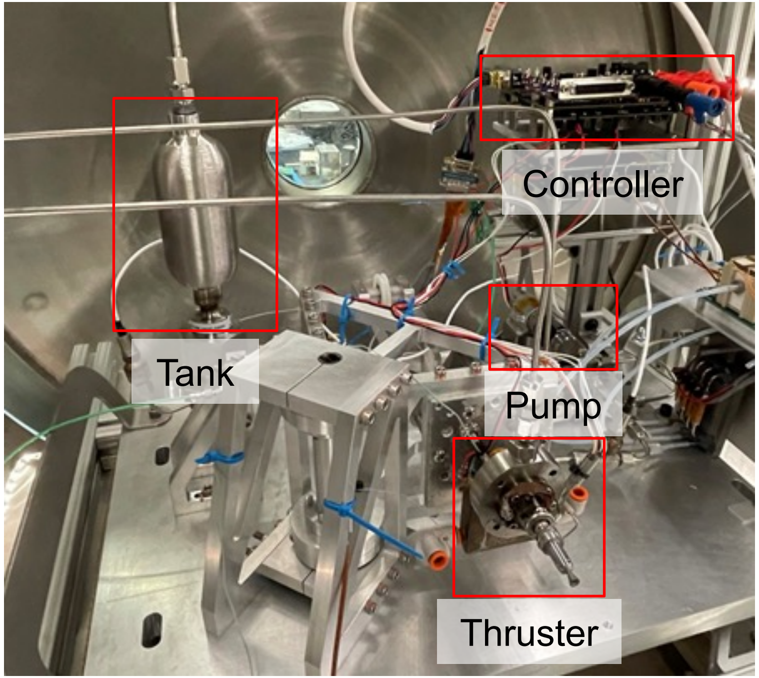
Controller: Firmware Testing

- Electrical Flat-Sat mimicked each component on the LFPS
- Python scripted test could run for many hours
- Interactive test required adjustment of the thermocouple and pressure transducer emulators
- Further integrated Flat-Sat testing occurred at JPL



Full Flat-Sat Testing

- Mechanical Flat-Sat using spare:
  - Pump
  - Thruster Valve
  - ISO Valve
  - Thruster
  - LFPS Controller
- Pump proportional-integrator calibration
- Successful Hot Fire Testing

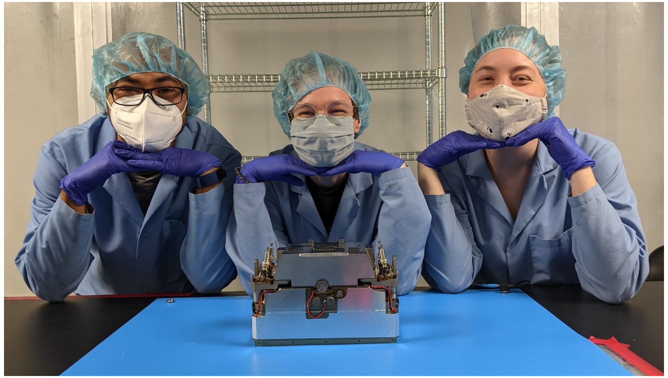


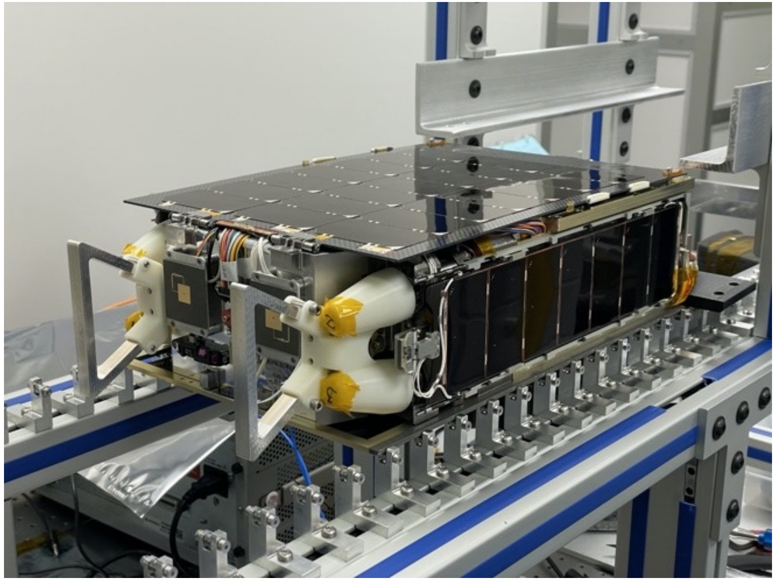
Summation

- Processes, procedures, techniques, and tools were developed to:
  - Speed integration and test
  - Document and control the build process
  - Mitigate rework or non-conformities
- LFPS accepted by LF (JPL) in May 2021
- The LF Spacecraft will be fueled at MSFC in February 2022, then transported to KSC for launch (scheduled in March).

Continuing Work

- LF integration and test support
- LF operations support
- A second LFPS Unit to be delivered in April 2022
- Using heritage on new projects





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