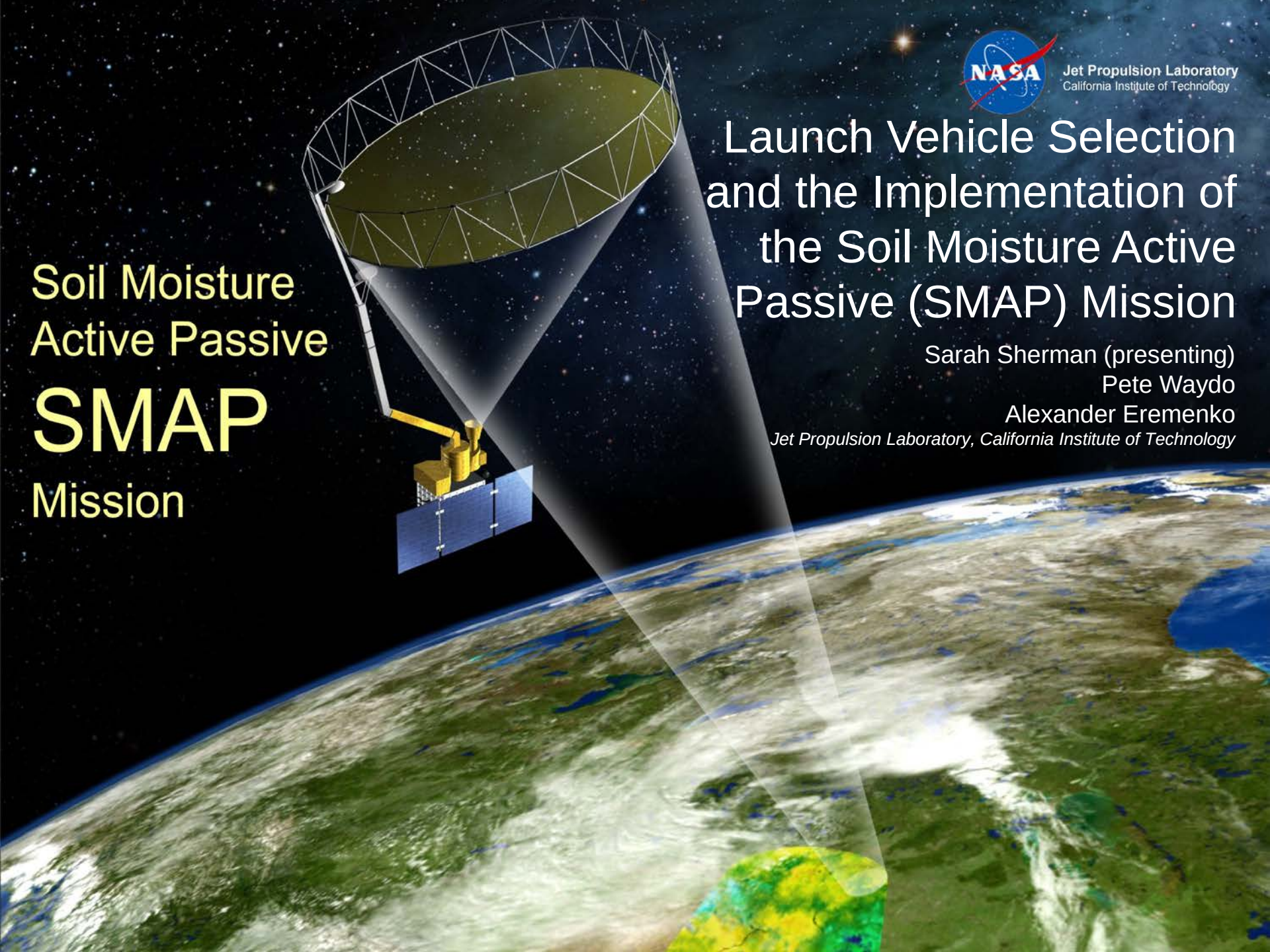

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Launch Vehicle Selection and the Implementation of the Soil Moisture Active Passive (SMAP) Mission

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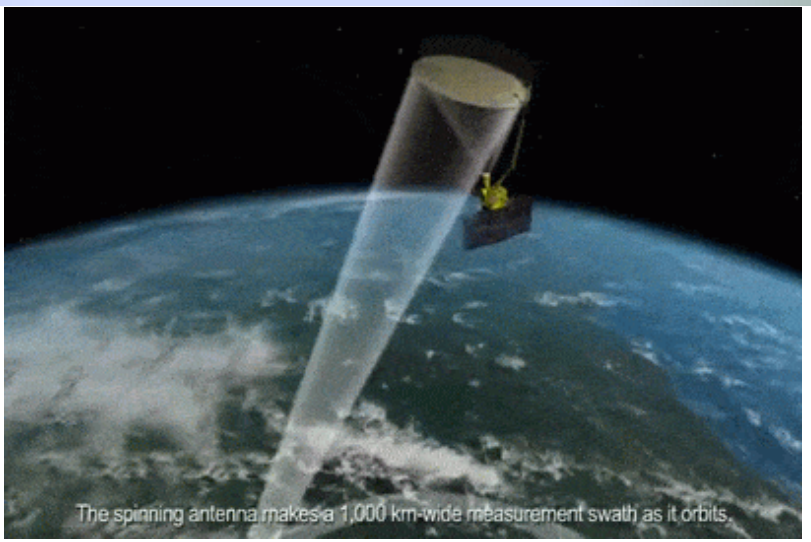
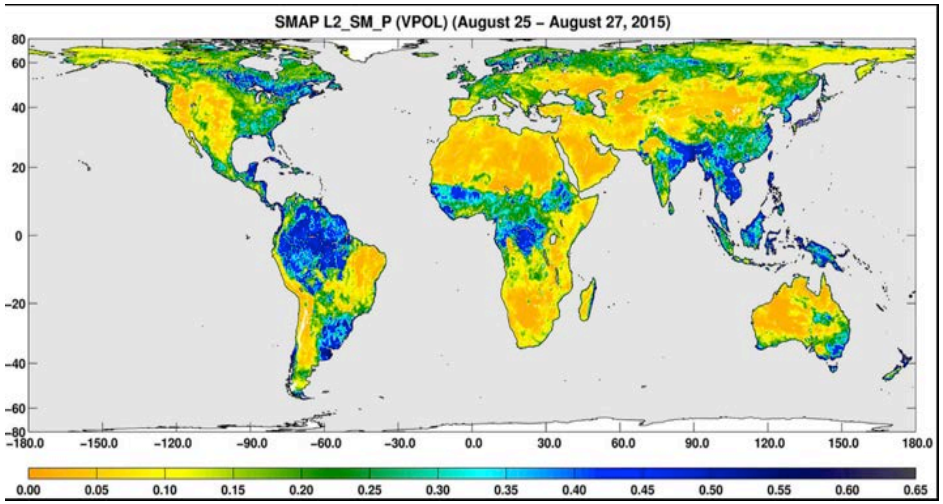
SMAP Overview

- Science
  - NASA-developed Earth science satellite
  - Maps the **soil moisture** content and **freeze/thaw** state of Earth's land mass
  - Contributes to our understanding of Earth's water, carbon and energy cycles, climate and weather forecasting, as well as providing accurate flood and drought prediction.
- Mission
  - Launched on **January 31, 2015** from Vandenberg AFB on a Delta II rocket
  - 685km, near-polar, sun-synchronous orbit
- Spacecraft
  - Shared spinning feed horn and antenna for **radar** and **radiometer**
  - 3-axis reaction wheel stabilized with hydrazine attitude control
  - Passive thermal control
  - 863 kg dry mass





Composite soil moisture data of the top 5 centimeters of soil for August 25-27, 2015.

SMAP Launch Vehicle Selection

- NASA directed SMAP to maintain compatibility with three launch vehicles until the project's Critical Design Review (CDR) in July 2012:
  - **Minotaur IV+** (Orbital), **Falcon 9** (SpaceX), **Delta II** (ULA
- Successfully incorporated the chosen launch vehicle (Delta II) without impact to the launch date:
  - Designed spacecraft to accommodate all launch vehicles, where possible and
  - Minimized post-selection changes in the design

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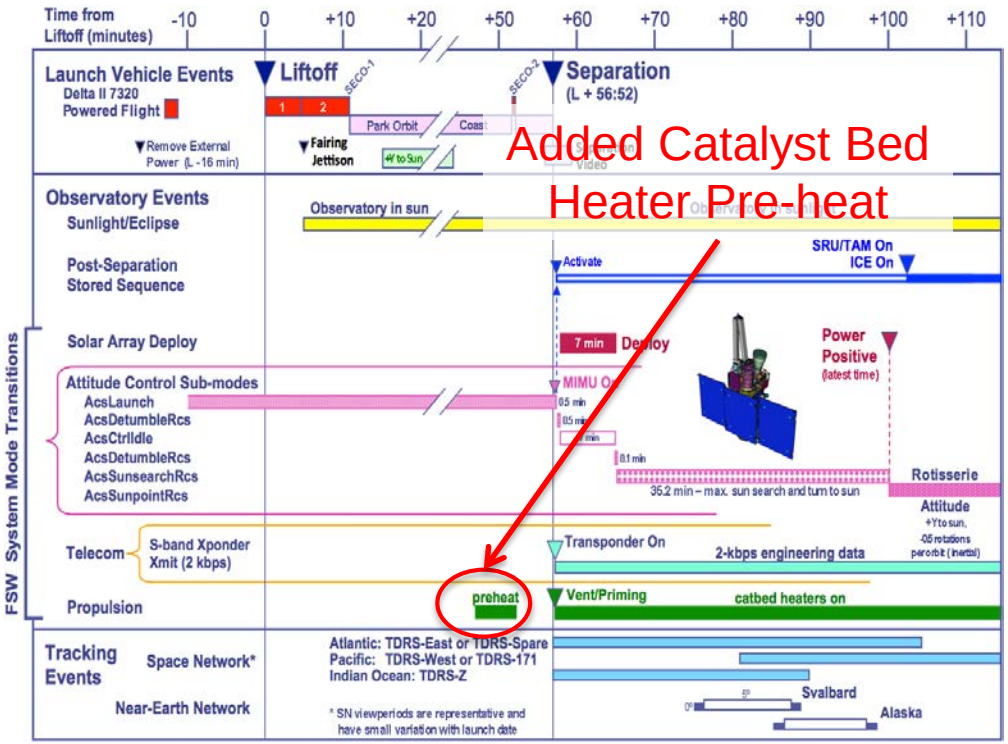
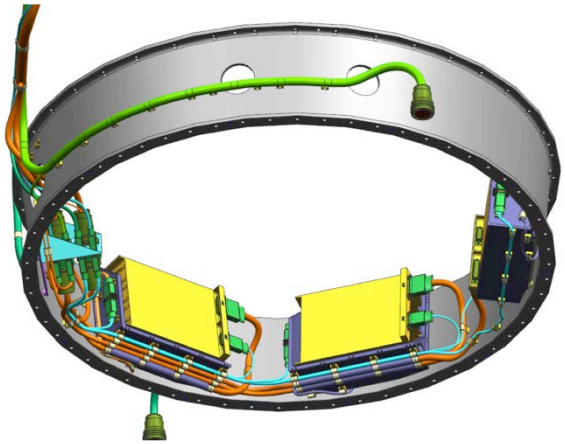
LV Ascent Timeline: Thermal Effects

- Baseline **14 minute** ascent time increased to **57 minutes** before in thermally safe attitude
- Thrusters could cool too much to create a potentially damaging "frozen start"
  - Added **pre-heat sequence** during ascent to guarantee catalyst beds reached a minimum temperature of 8°C at the time of the first detumble
- Launch-stowed reflector-boom assembly (RBA) and the Command and Data Handling (CDH) assembly could overheat with the ascent's solar incidence angle
  - Added **longitudinal roll** of LV second stage during ascent to more evenly distribute solar radiative heating

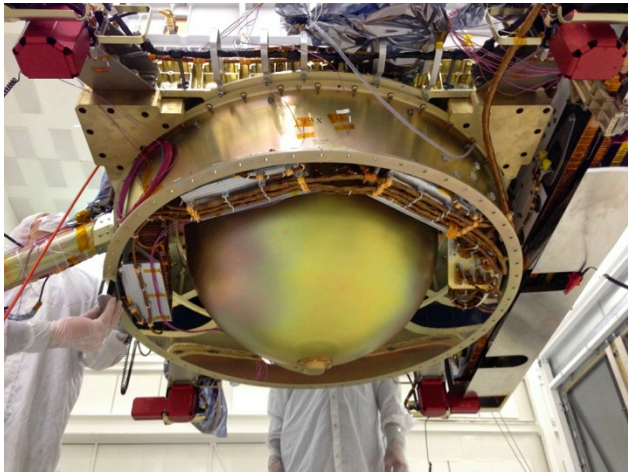


LV Ascent Timeline: Energy Effects

- Early design included one **8S52P 78Ah** Lithium-ion battery
  - Supported **14 minute** Minotaur IV+ launch ascent through solar array deployment and sun-pointed attitude
  - Mounted on the outside of the spacecraft bus
  - Design, procurement, structural and thermal accommodations, and mass properties were well-established by Critical Design Review
- Rather than increasing size or exiting battery, added three new 8S10P 15Ah batteries to the Delta-II-specific Launch Vehicle Adapter (LVA) ring to support **57 minute** ascent
  - Increased battery capacity by 45Ah or about 58%
  - Appeared to the power bus as a single **8S82P 123Ah** battery
  - Lowest predicted state of charge following launch vehicle ascent was about 75%
- New location minimally perturbed the baseline configuration

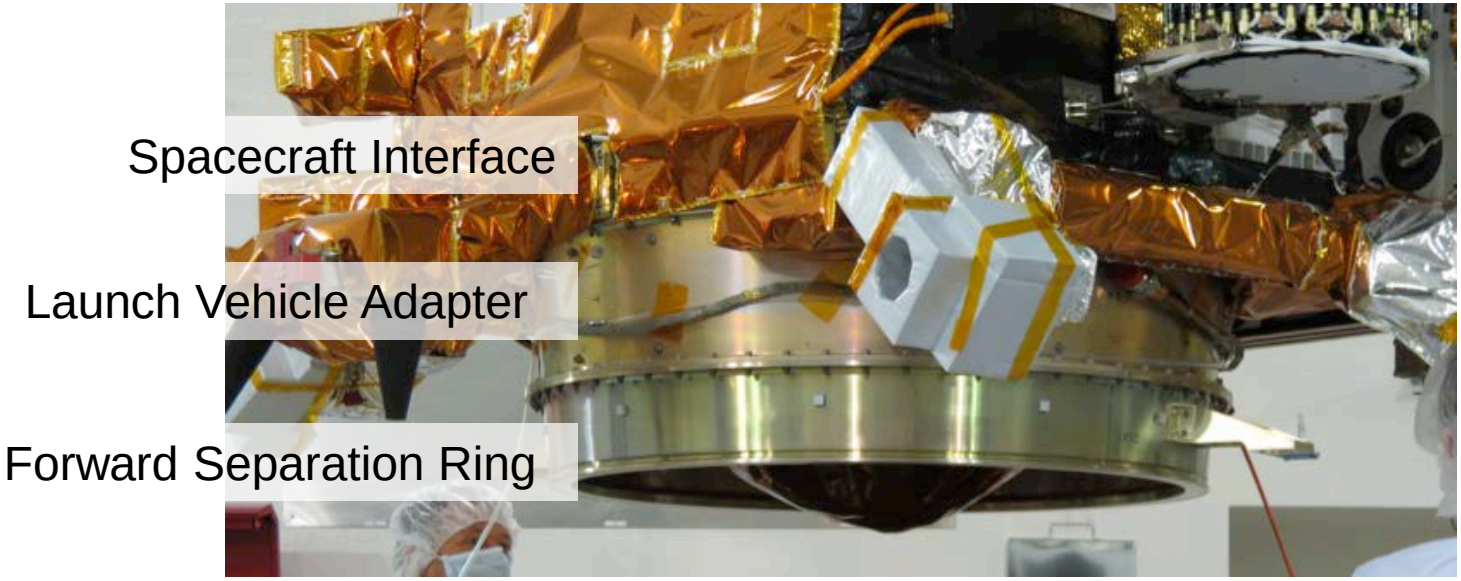


Add'l batteries mounted on LVA



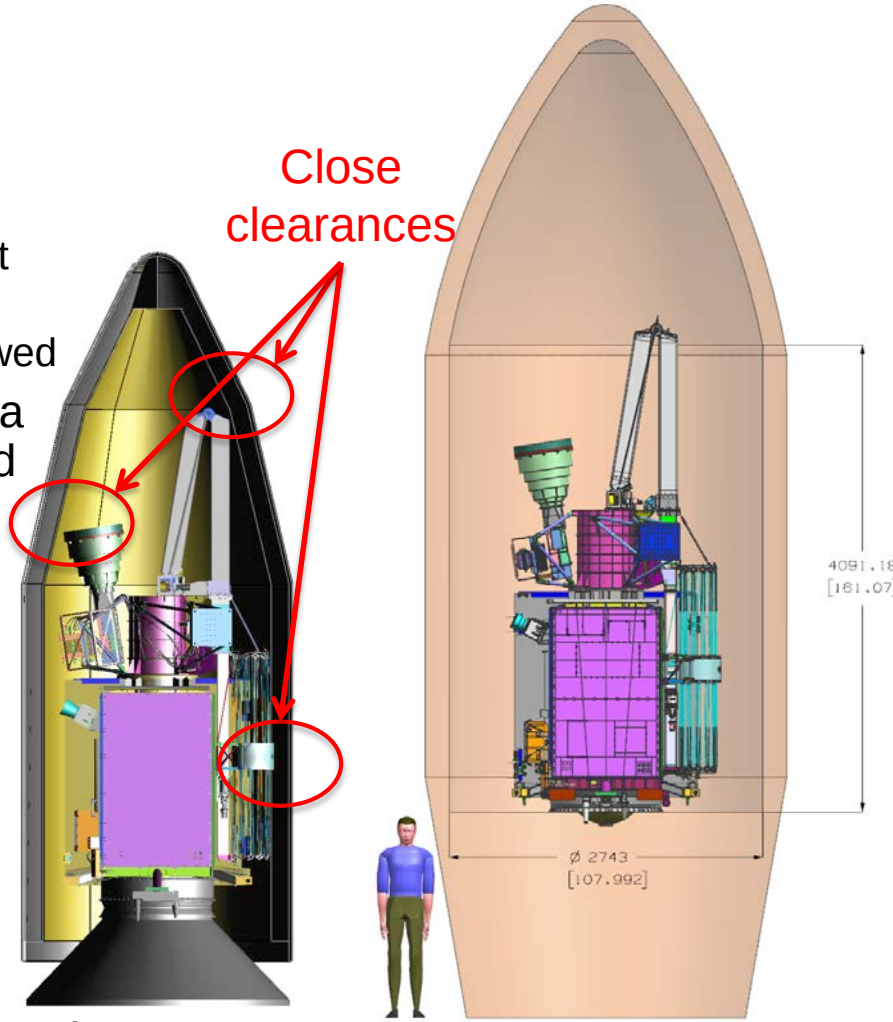
Spacecraft/Launch Vehicle Interface

- Launch Vehicle Adapter (LVA) from spacecraft to separation ring was one of the few components to be intentionally finalized after launch vehicle selection
- Caused additional bolted joint scar mass
- Decoupled design of separation system from the rest of the spacecraft



Fairing Envelope

- Restrictive Minotaur IV+ fairing drove early spacecraft bus and reflector configuration
  - Ultra-compact reflector-boom design
  - Complex Reaction Wheel Assembly (RWA) installation process
  - Many deeply-buried components within spacecraft bus
  - Solar array with no outward-facing cells while stowed
- Spacious Delta II fairing provided relief, but at a stage in development when extra volume could not be realized



Fairing Access

Co-author demonstrating access through simulated fairing door

- Spacecraft designed to fit snugly within Minotaur IV+ fairing
- Post-fairing-encapsulation access required for:
  - Installation of the flight battery enable plug
  - Installation of the flight arming plug for propulsion and pyrotechnic systems
  - Gas and liquid service valves
- Larger Delta II fairing created significant reach from the fairing door to the plugs and valves
- Located plugs and valves in close proximity to allow access through one door
- Required to demonstrate feasibility in Self Contained Atmospheric Protective Ensemble (SCAPE) suit

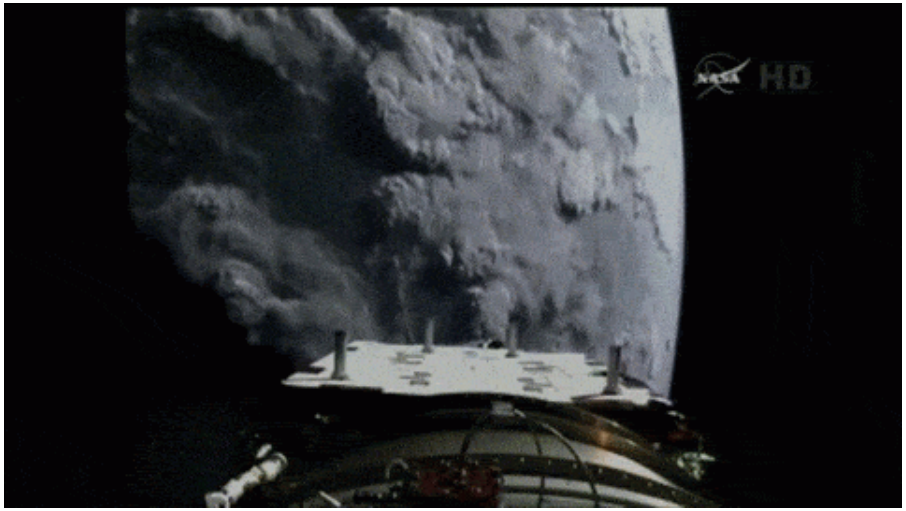
Lift Capability & Fuel Budget

- Lift capability driven by Minotaur IV+
  - Minotaur IV+ lift capability of 1156 kg was driving for SMAP spacecraft
    - Project eliminated some redundancy to meet requirement
  - Delta II had much larger lift capability
    - Good mass margin to accommodate late-breaking problems
    - Did not reincorporate redundancy after CDR
- Fuel budget driven by Minotaur IV+
  - Minotaur IV+
    - ±18.5 km perigee altitude injection error, ±0.5 °/sec per axis tip-off rates
    - **80 kg** capacity fuel tank needed
  - Delta II
    - ±9.3 km perigee altitude injection error, <1°/sec per axis axis tip-off rates
    - **66 kg** capacity fuel tank needed
  - Did not reduce tank size
  - Used extra propellant margin for lifetime station-keeping, collision avoidance maneuvers, and fault recovery maneuvers

Launch Vehicle Environments

- Dynamic environments envelope was established that **bounded worst-case load cases** from each of the candidate launch vehicles
- Falcon 9 was not driving in any case, although it had more uncertainty.
- Final design that had positive structural margin against all load cases encountered on the selected Delta II
  - Some margins appear large because SMAP was a stiffness-driven design

	SMAP Envelope	Minotaur IV+ User's Guide 2006	Delta 2 7320-10C Payload Planner's Guide 2007	Falcon 9 User's Guide 2009
Axial Frequency	> 35 Hz	> 35 Hz	> 35 Hz	> 25 Hz
Lateral Frequency	> 15 Hz	> 15 Hz	> 12 Hz	> 10 Hz
Space Vehicle (SV) CG Limit Load				
Axial	+10.6/-2.0 G's	+9.5/-0.03 G's	+8.3/-0.2 G's	+6/-2 G's
Lateral	+/- 3.7 G's	'+/-2.89 G's	+/-3.5 G's	+/-3.5 G's
Acoustic Env (Qual/PF)	144.2 dB	139.2 dB	142.7 dB	142.6 dB
Sep Shock Environment	4100 G's	2000 G's RUAG 937S	4100 G's for 3715 PAF	3000 G's
SV CG location (lateral)	< 1"	< 1"	< 2"	< 5"

Conclusion

- Design, operation, and performance were affected by LV selection
- Two key strategies:
  - Stay as agnostic to launch vehicle selection as possible
  - Leave some components unfinalized until after selection
- No effects of the timing of launch vehicle selection became critical-path items on SMAP's development schedule.