On the Maneuvers Operational Response for NASA's Soil Moisture Active-Passive (SMAP) Mission

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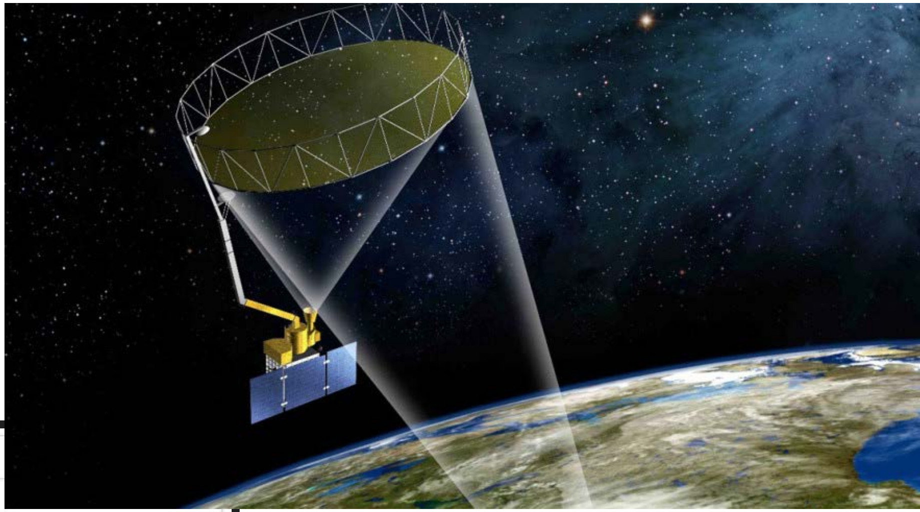
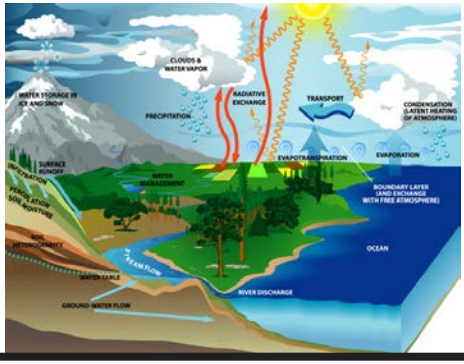
Outline

- An Overview of SMAP and its Planned Maneuvers
- Three-Pronged Operational Approach
- Lessons Learned:
  - Bettering Response Times Through Practice
  - Lack of High-Fidelity Simulators Highlighted by Maneuvers
  - Automation, Automation, Automation
- Concluding Remarks

SMAP Overview



Launch vehicle	Delta II 7320-10C
Launch site	Vandenberg Air Force Base, California
Launch date/time	**Jan. 31, 2015**
Orbit type	Circular polar orbit, 8-day repeating ground track
Orbit altitude	685 km (426 miles)
Orbit period	98.5 minutes
Spacecraft type	3-axis stabilized
Spacecraft mass	944 kg
Spacecraft downlink	Via NASA Near-Earth Network Stations, supplemented by Tracking and Data Relay Satellite (TDRS) support
Antenna size	6 meters (20 feet); offset-fed mesh refle
Antenna mass	65.5 kg (144 lbs)
Radar mass	50.8 kg (112 lbs)
Radar frequency	1.26 GHz; non-imaging (unfocused) sy
Radar transmit power	550 Watts (peak)
Radar real-aperture footprint	29 km x 35 km (18 miles x 22 miles)
Radar ground resolution	1-3 km (0.62-1.86 miles) after unfocuse
Radiometer mass	30 kg (electronics only)
Radiometer frequency	1.41 GHz
Radiometer footprint	39 km x 47 km
Radiometer ground resolution	30 km (18.6 miles)
Mapping scheme	Antenna spins at 14.6 revolutions per minute, sweeping out overlapping loops 1000 km (621 miles) in diameter. Overlapping loops are combined to make wide ribbons which overlap each other. Mapping Earth's surface takes 2 days near the poles and 3 days near the equator.

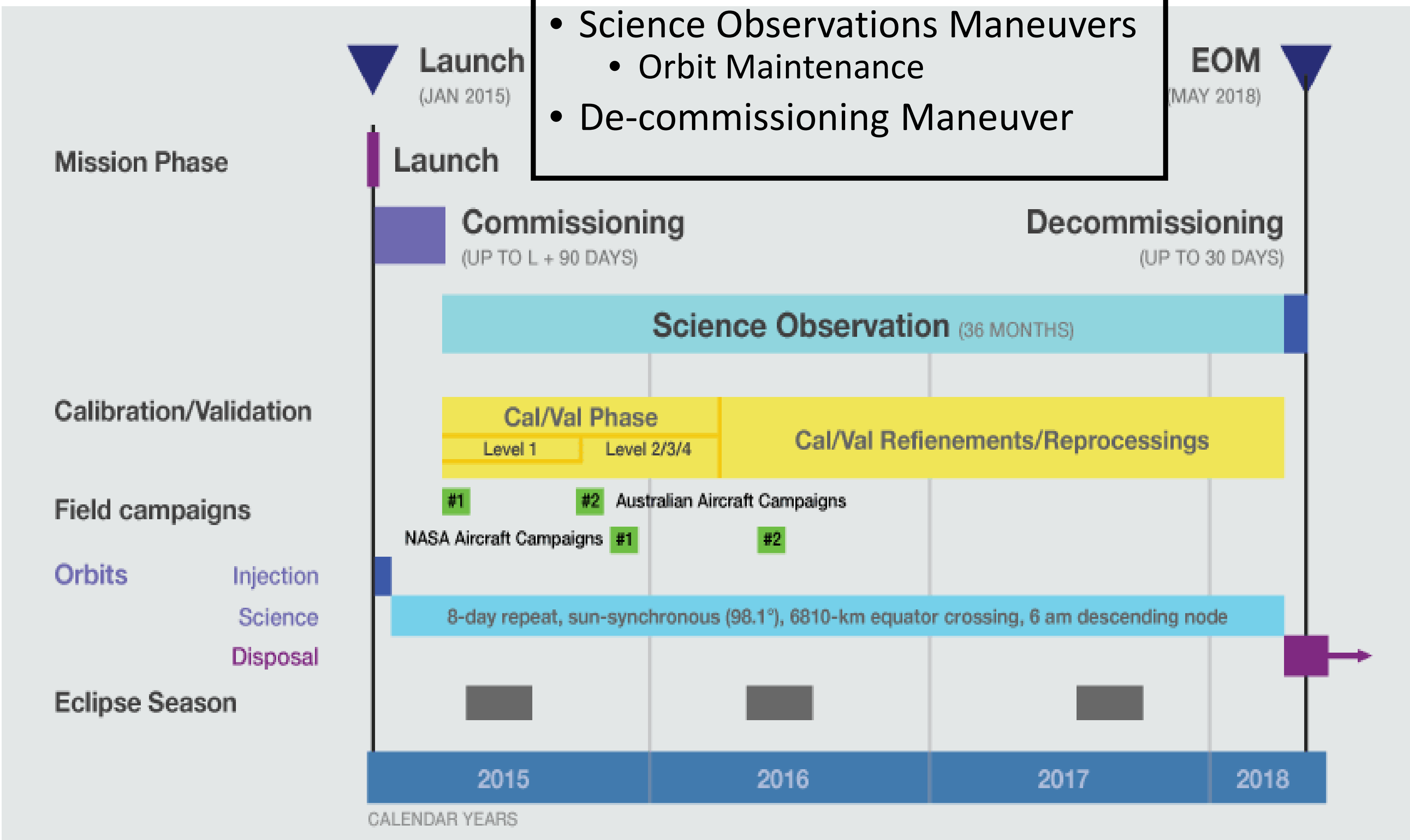


SMAP will provide a capability for global mapping of soil moisture and freeze/thaw state with unprecedented accuracy, resolution, and coverage. SMAP science objectives are to acquire space-based hydrosphere state measurements over a three-year period to:

- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capabilities

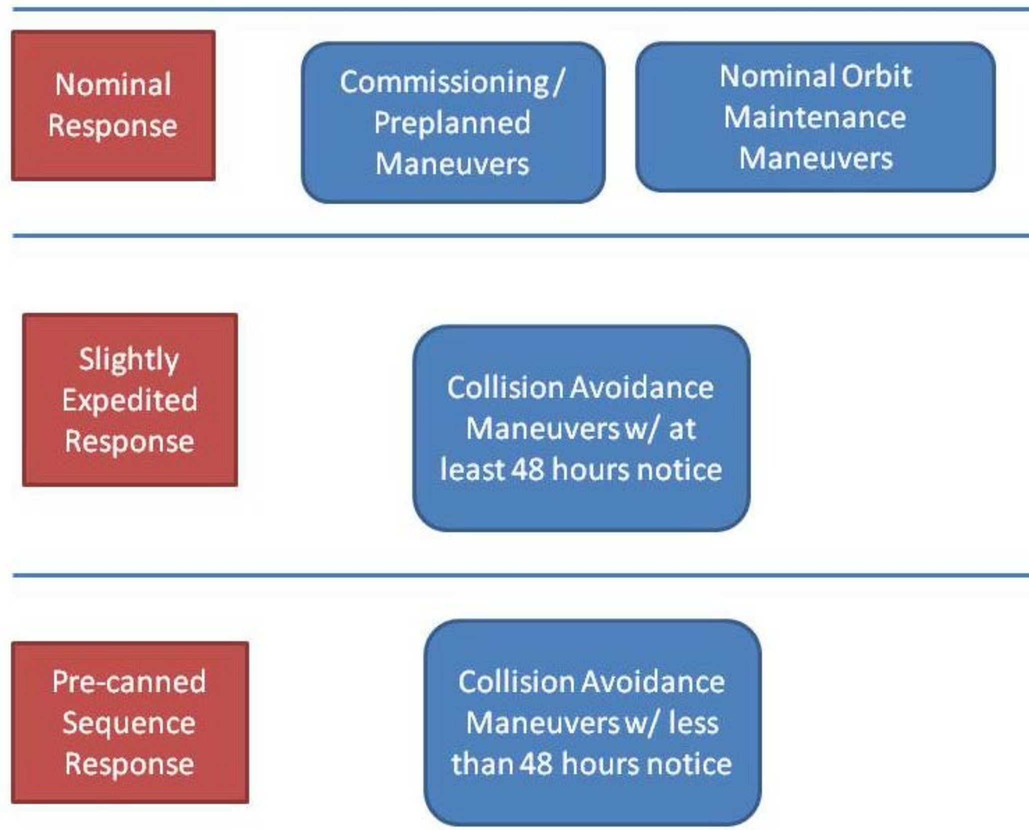
SMAP Maneuver Overview

- Commissioning Maneuvers
  - Calibration
  - In-Plane
  - Inclination
- Collision Avoidance Maneuvers
- Science Observations Maneuvers
  - Orbit Maintenance
- De-commissioning Maneuver

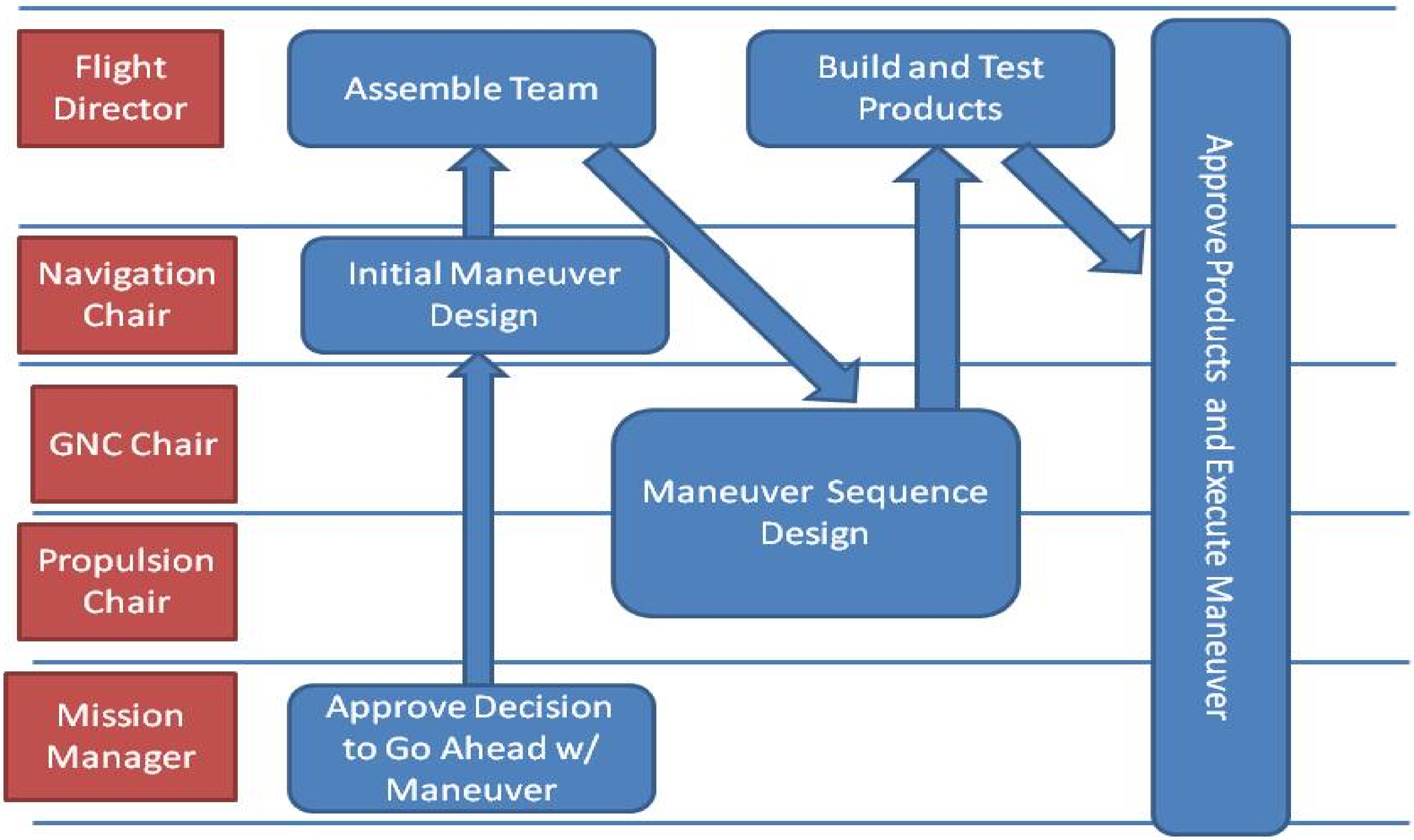


Three-Pronged Operational Approach to Maneuvers

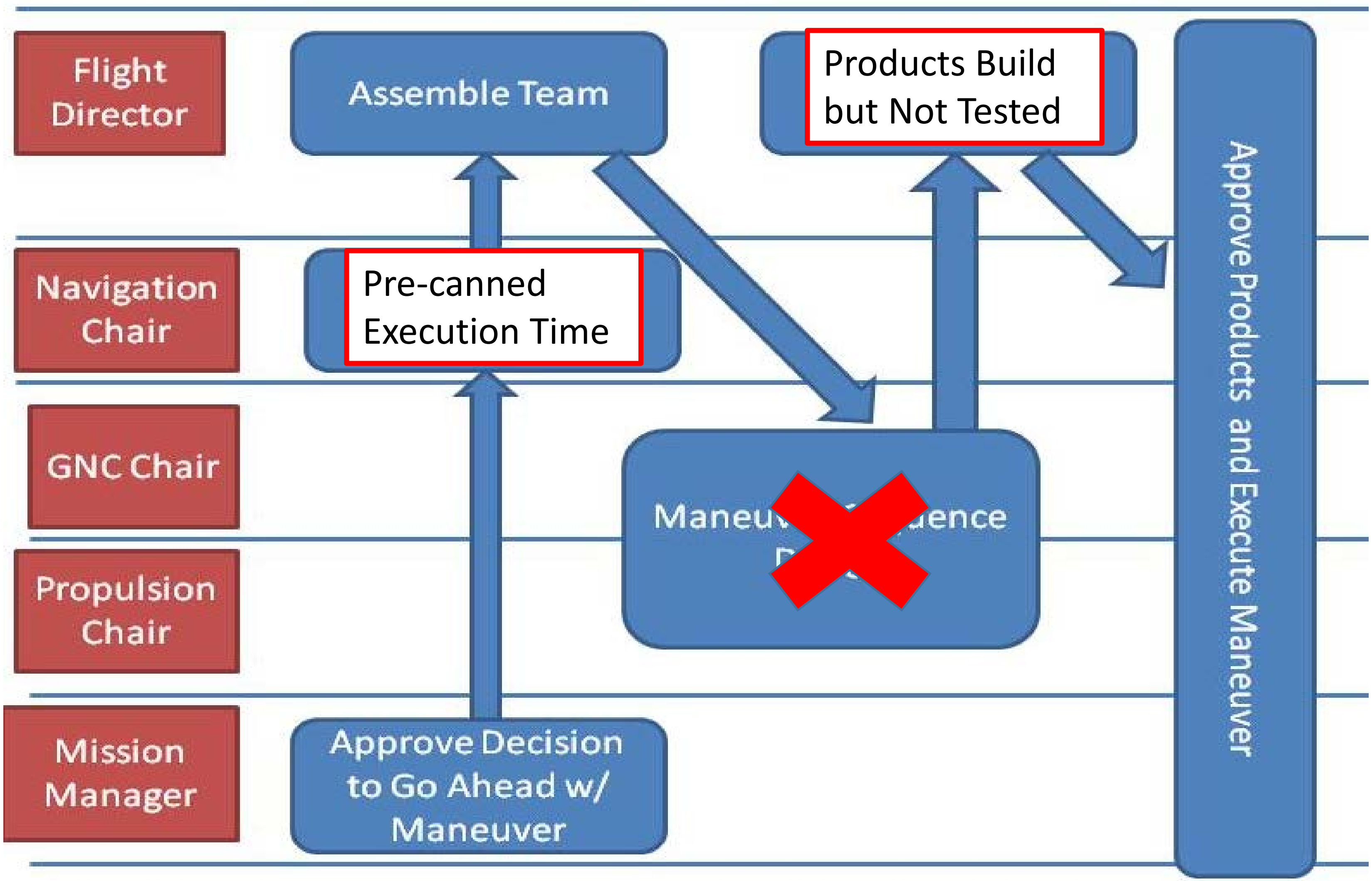
- Drivers:
  - Limited staffing during science operations
  - Triggering of maneuver sequences at absolute times
  - Interaction with Near Earth Network (NEN) and Space Network (SN) telecommunications passes
  - Flexibility in choosing a response based on staffing availability



A "Nominal" Operations Maneuver Response



Pre-canned Maneuver Response



Bettering Response Times Through Practice

- Planned Practices:
  - Mission Scenario Tests (MSTs):
    - Primarily a test of the flight hardware and hardware simulators
    - Frist chance to test out architecture of maneuver sequences and verify correctness
  - ORTs
    - Primarily a test of the operations team and their ability to respond within the allocated timelines
    - Refinement of which steps to be included / left out based on timelines and the amount of automation introduced during development
    - Refinement of "three-pronged" architecture and role definition
- Initial maneuvers
    - Continued refinement of steps, timelines, architecture, and role definition based on ever-changing staffing
    - Introduction of new anomalies that were not captured in "practice" tests led to iteration of operations approach to maneuvers
- Lesson learned:
  - Ironing out as many of the "controllable" wrinkles with tests of the hardware and operations personnel allows the team to be ready for "unknown unknowns" during flight

Lessons Learned: Lack of High Fidelity Simulators

- What happened:
  - Decisions regarding the level of fidelity of testbed simulators (and how much to spend on these simulators) were made well before SMAP's maneuver operations strategy was cemented
  - During practice, the maneuver operations strategy was refined to the best of the team's ability given its knowledge of the NEN and SN networks and SMAP's telecommunications subsystem, as well as the level of fidelity in the testbed's hardware simulators
- Lessons Learned:
  - The lack of fidelity in (and the lack of knowledge about) the modeling of both NEN/SN ground stations and of SMAP's telecommunications subsystem, as well as the interactions between them, led to some surprises during SMAP's commissioning maneuvers
    - Example: the first large maneuver that changed SMAP's inclination highlighted an issue in the timing and implementation of ground station pointing files
  - Cross training of personnel allowed knowledge of the testbed, the fidelity of its simulators, and the operations teams' automation tools to be more easily transferred amongst team members. Widespread knowledge allowed more rigorous troubleshooting when anomalies arose

Lessons Learned: Automation, Automation, Automation

- History:
  - Knowledge of SMAP's operational staffing profile during the science observation phase placed a premium on automation during the mission's development.
- Lessons learned:
  - Specifically, automation facilitated cross-training of personnel and decreased the reaction time of the operations team in responding to maneuver decisions
  - The tools might have increased the amount of learning at the onset of cross-training (by adding additional learning), but it greatly limited the realm of mistakes that could have been introduced through human error
    - Tools have been updated by those cross-trained as the needs of the operations team had adapted over time
  - These are not newfangled concepts – but are nonetheless true

Concluding Remarks

- The specific implementation of this maneuver strategy may not be applicable to other missions or applications – but it is the hope of the author that the general approach of maintaining flexibility and increasing automation (both of which allow teams to react to and counter unpleasant surprises along the way) are properly conveyed. This paper documents the strategy, the lessons learned along the way (both those that contributed to the creation of this strategy and those that were especially memorable in the implementation of this strategy), and the methodology behind the decisions described.
- The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.
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