Dynamic Control System Performance During Commissioning of the Space Technology 7 – Disturbance Reduction System Experiment on LISA Pathfinder

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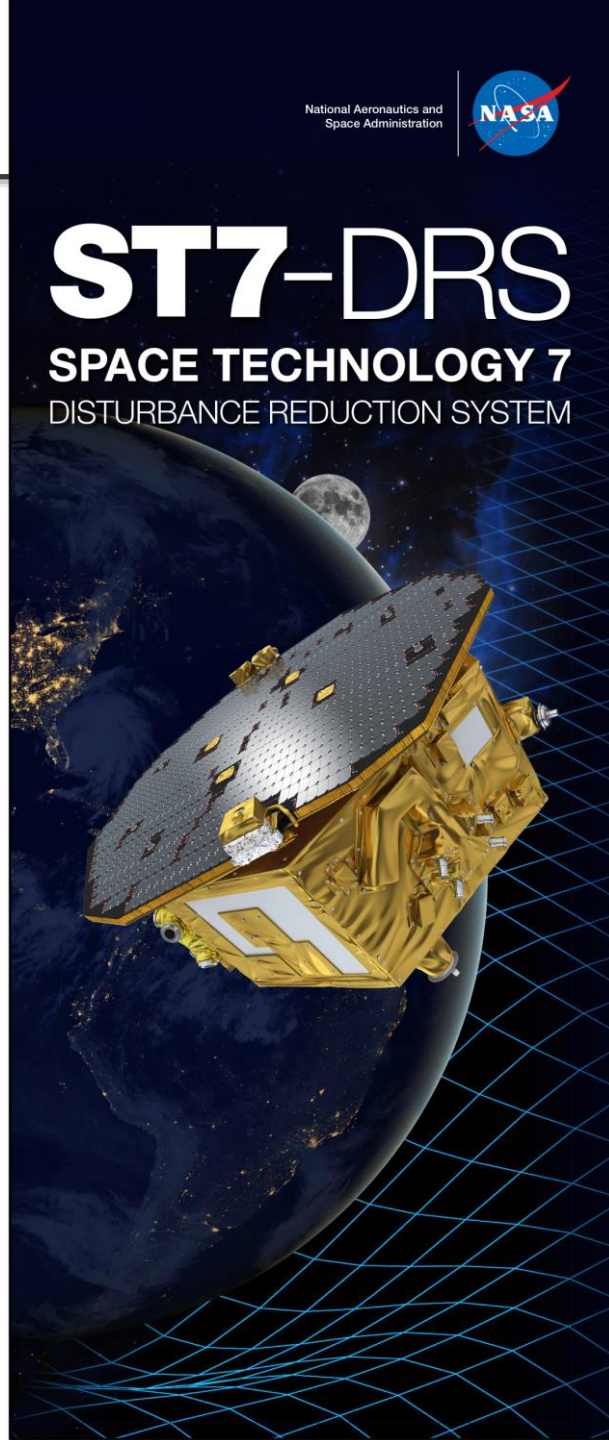
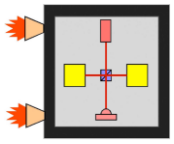
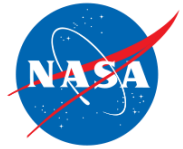




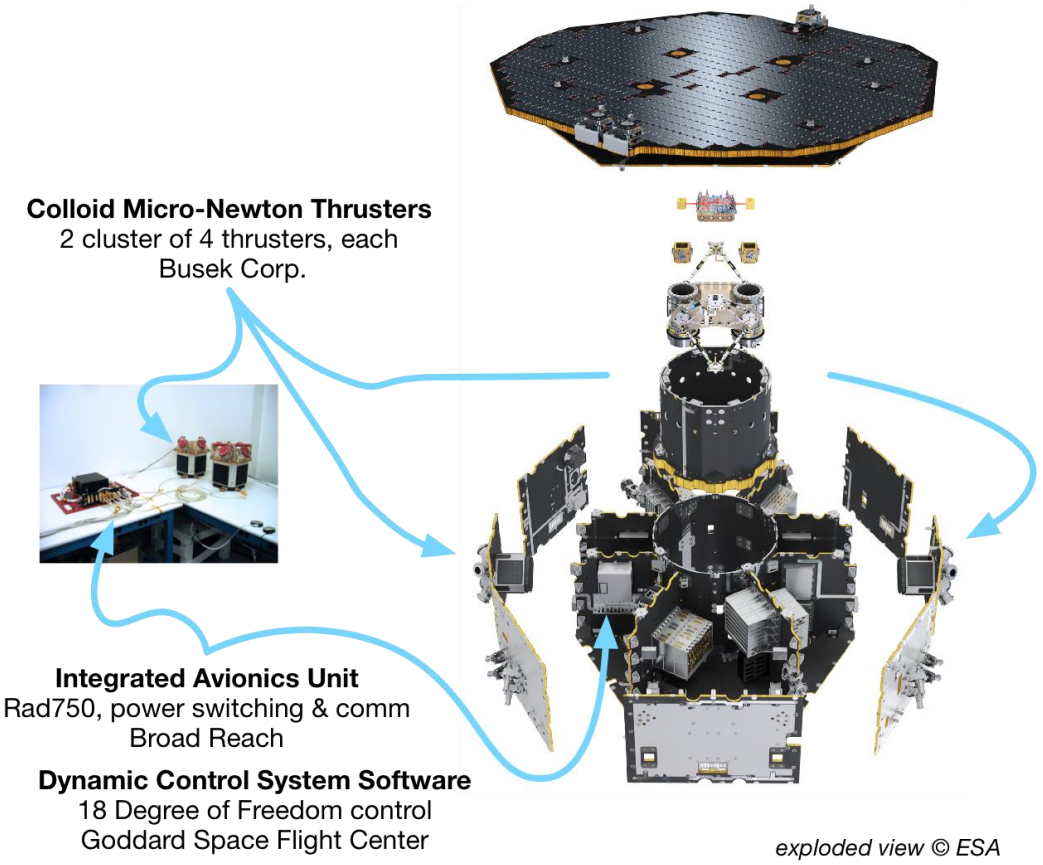
Outline

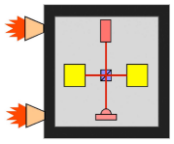


- LISA Pathfinder & DRS
- DRS Mission Timeline Highlights
- DRS Mission Modes
- Thruster Checkout
- Handover/Handback
- Zero-G Mode
- Drag-Free Low Force
- Thruster Anomaly & Resolution
- Acknowledgements
- Conclusion

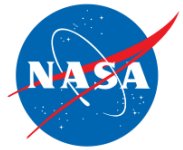
LISA Pathfinder & DRS

- DRS is a NASA Contribution to the ESA LISA Pathfinder Mission
- Three Components:
  - Integrated Avionics Unit
  - Colloid Micro-Newton Thrusters
  - Dynamic Control System Software

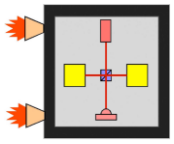




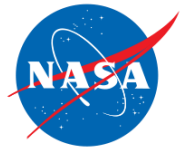
DRS Mission Timeline Highlights



- 2002 – DRS Project Started
- 2006 – DCS Control Design Completed
- 2008 – DRS Technology Package Delivered to LISA Pathfinder
- 2015 – DCS algorithms updated.
- December 3, 2015 at 04:04 UTC – Launch of LISA Pathfinder
- December 12, 2015 – Transfer to Sun-Earth L1 Point Begins
- **January 2-10, 2016 – DRS Thruster Checkout**
- January 22, 2016 – Arrive at L1 Point/Propulsion Module Separation
- March 1, 2016 – LISA Pathfinder Science Mission Starts
- June 24, 2016 – LISA Pathfinder Completes first operations Phase
- **June 27-July 7,2016 – DRS Instrument Checkout**
- **July 8, 2016 – DRS Thruster Anomaly**
- **August 8, 2016 – DRS Recommissioning Begins**
- August 12, 2016 – Final day of recommissioning, 18-DOF Control Achieved
- **August 13, 2016- DRS Experiment Phase Begins!!**



DRS Mission Modes



DRS Mission Mode	Spacecraft Control Mode	Reference Test Mass Control Mode	Reference Test Mass Force Mode	Non-Reference Test Mass Control Mode	Non-Reference Test Mass Force Mode
Standby	Standby	DFS Standby	N/A	DFS Standby	N/A
Attitude Control	Attitude-Only	DFS Accelerometer	High Force	DFS Accelerometer	High Force
Zero-G	Accelerometer				
Drag Free Low Force	Drag Free 1	DFS Drag Free 1	Low Force		
18-DOF Transitional				Suspended Drag Free 1	Low Force
18-DOF	Science	DFS Drag Free 2		Suspended Drag Free 2	

Thruster Checkout

- Two periods for Thruster Checkout
  - January 2-10, 2016
    - Propulsion Module still attached
  - June 27 – July 1, 2016
- Activities:
  - Thruster Impedance
  - Thruster Bubble & Dissipation Test
  - Thruster Functional Test
  - Thruster Characterization Tests

Image Credit: ESA/NASA/JPL-Caltech

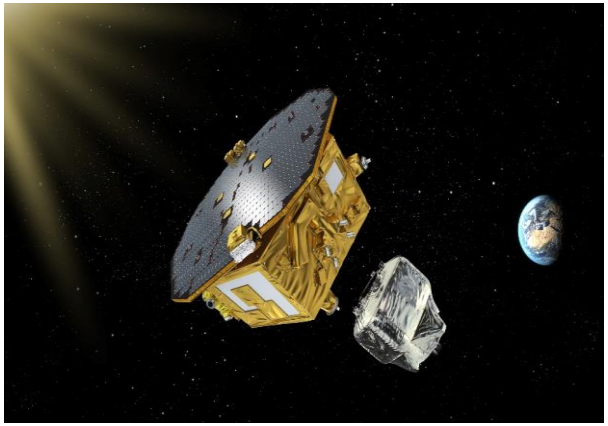
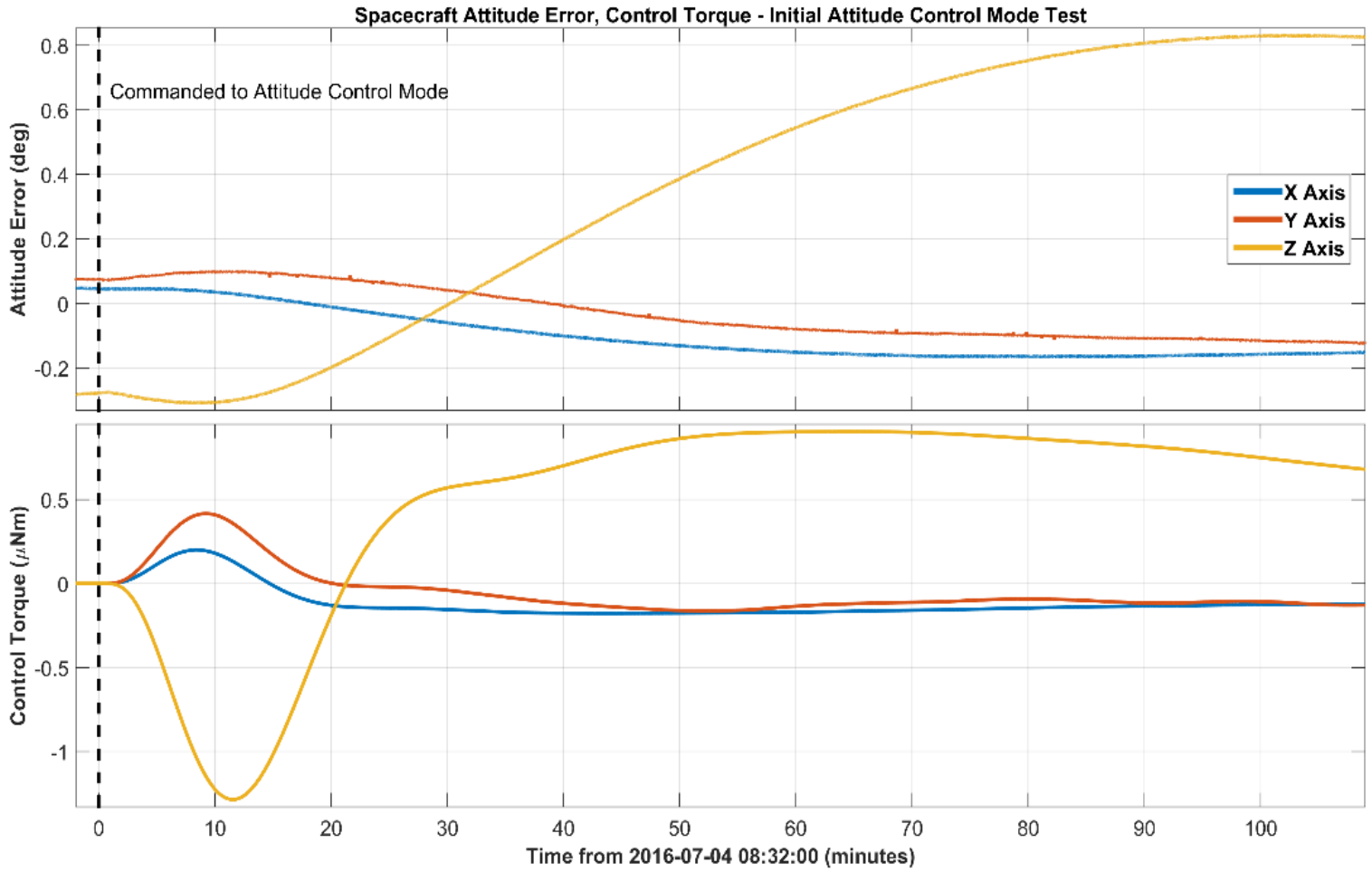


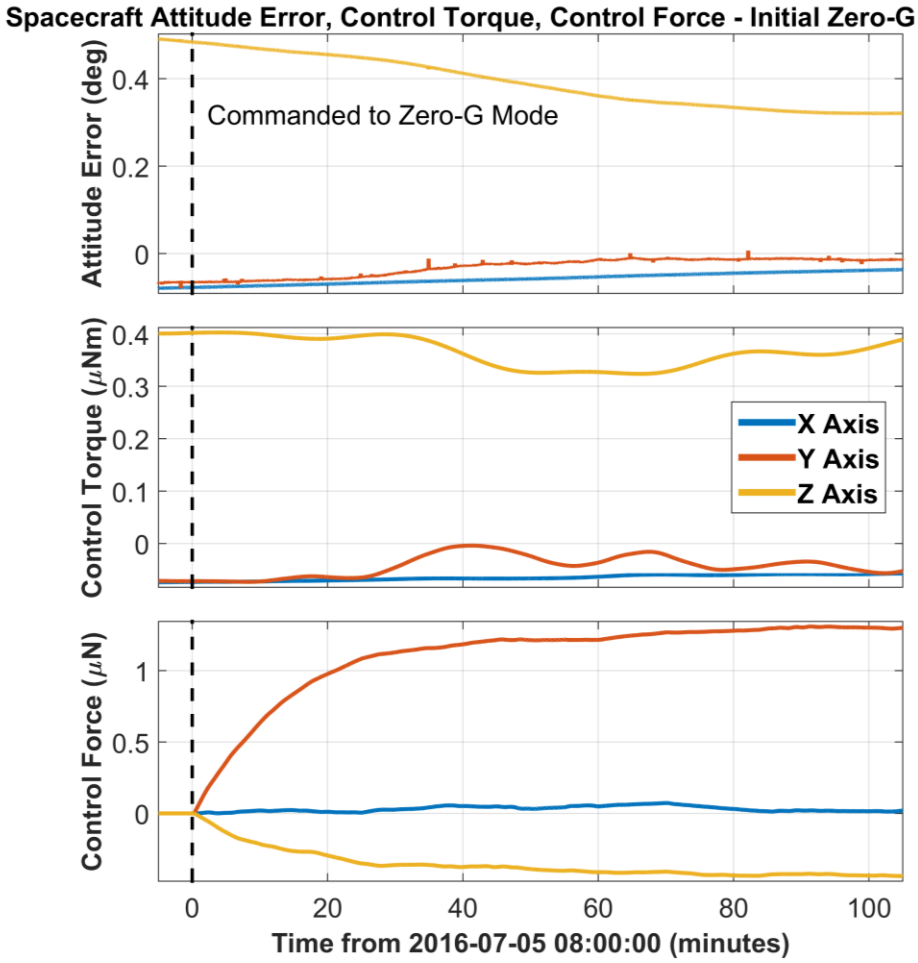
Image Credit: ESA/C. Carreau

Handover/Handback Test



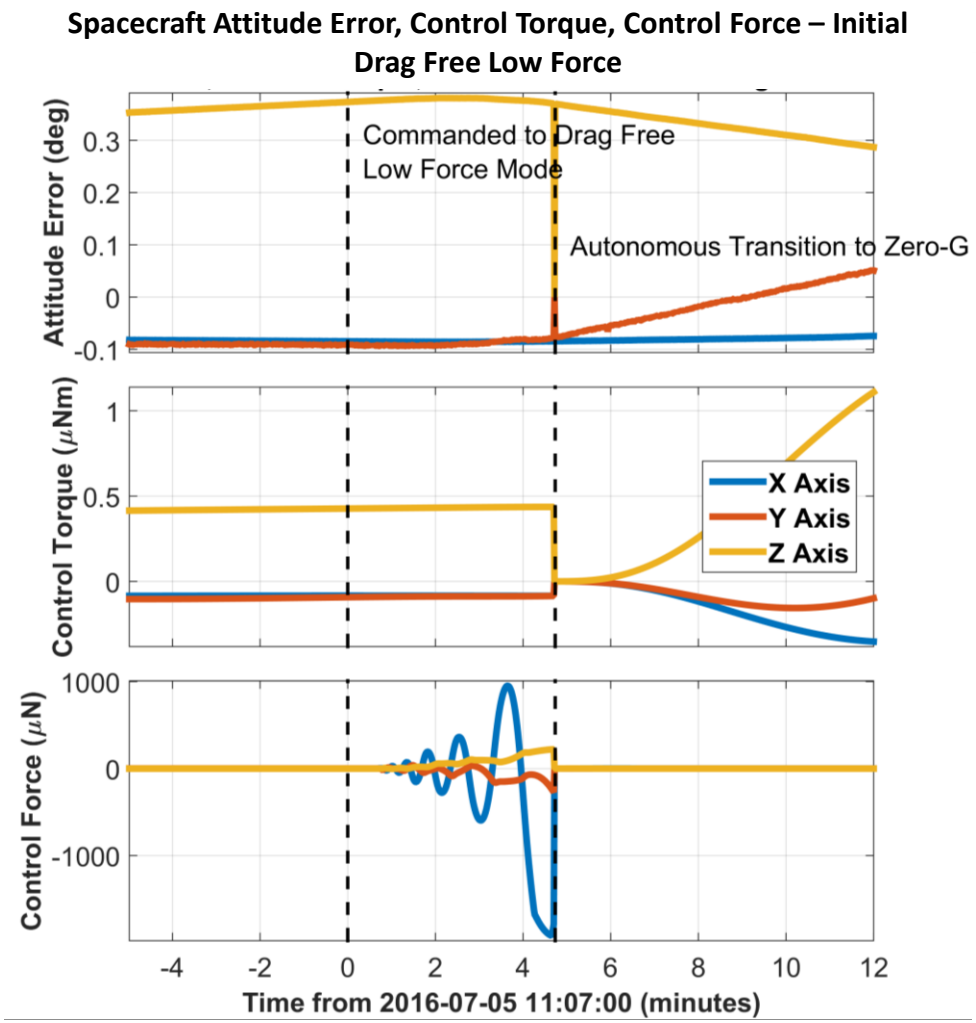
DRS given control on July 4, 2016 at 08:32 UTC

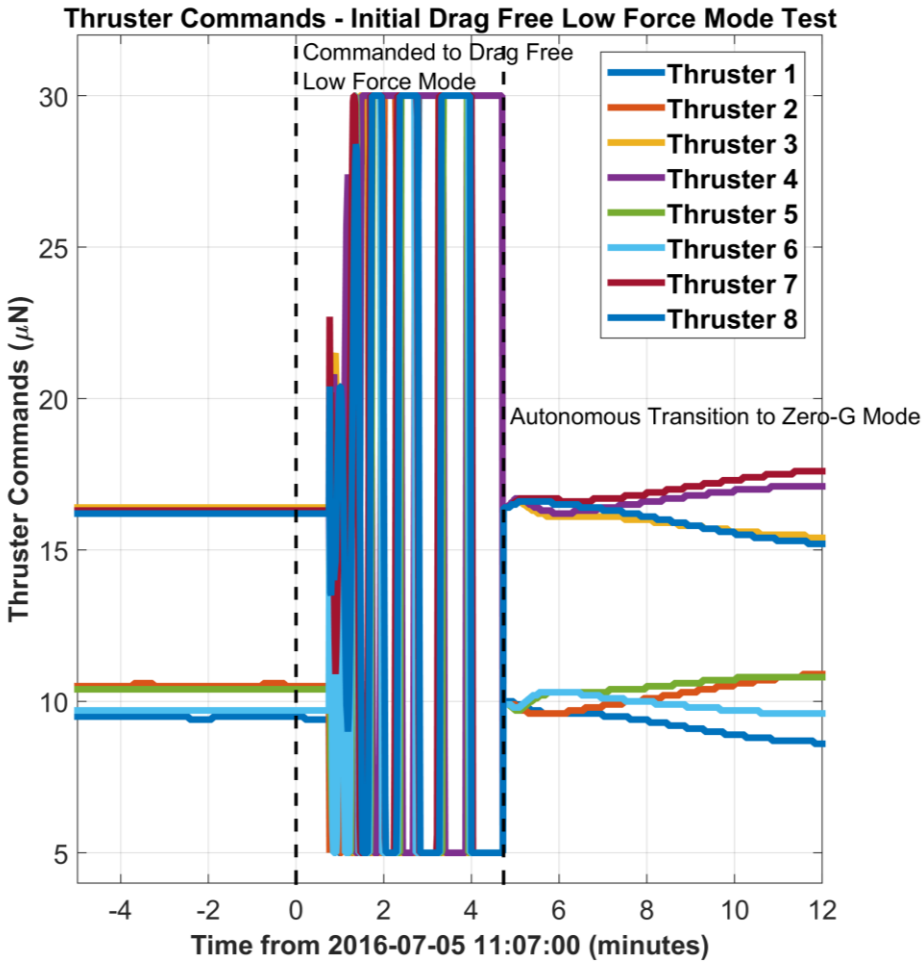
Zero-G



Zero-G Mode commanded on July 5, 2016 at 08:00 UTC

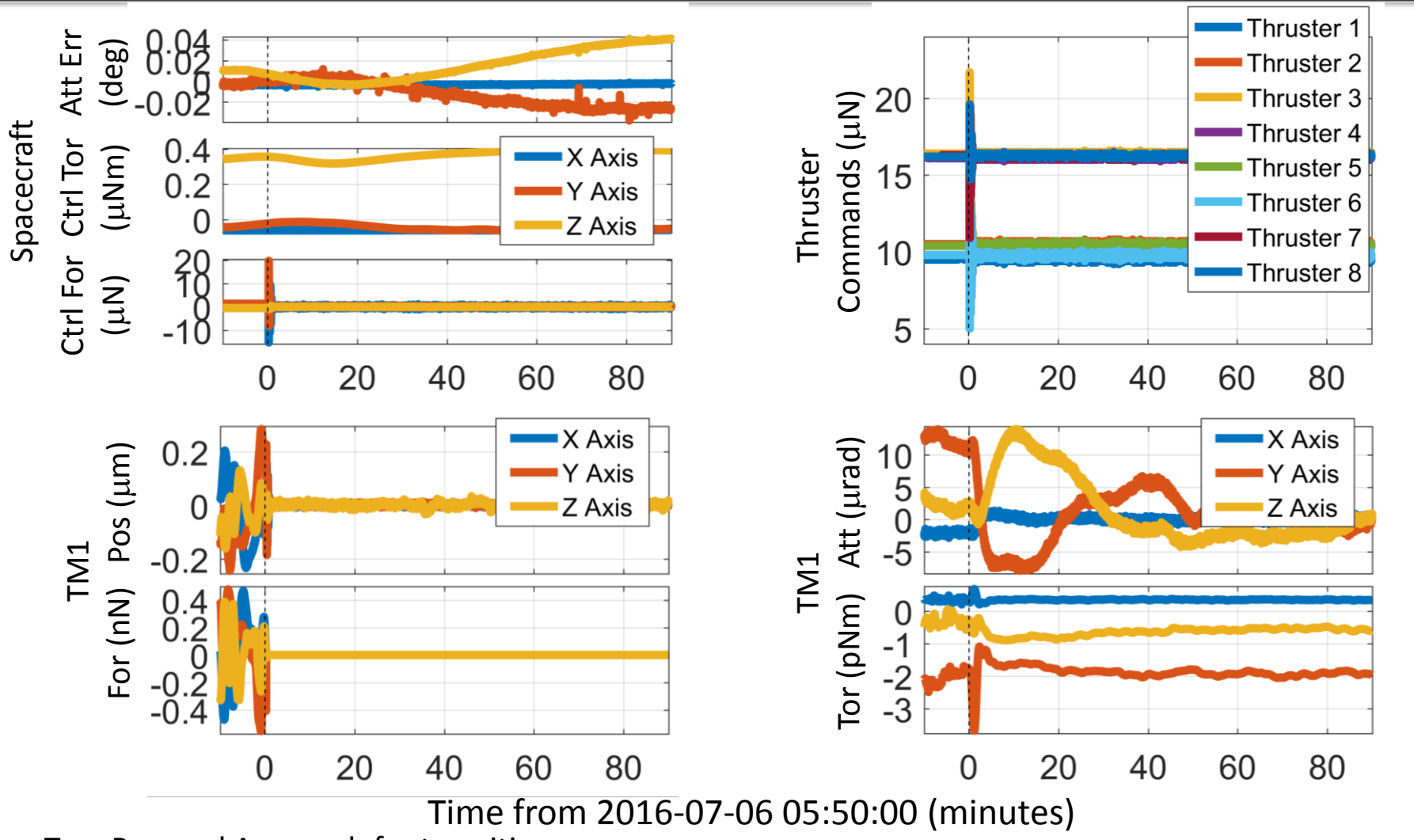
Drag-Free Low Force: 1st Attempt





Drag-Free Low Force Commanded on July 5, 2016 at 11:07 UTC
Transition Aborted at 11:12 UTC

Drag-Free Low Force: 2nd Attempt



Two-Pronged Approach for transition:

- Transition RTM to Low-Force earlier (July 6, 2016 at 05:30 UTC)
- Limit Spacecraft Force Command to 5 micron per axis. (July 6, 2016 at 11:00 UTC)

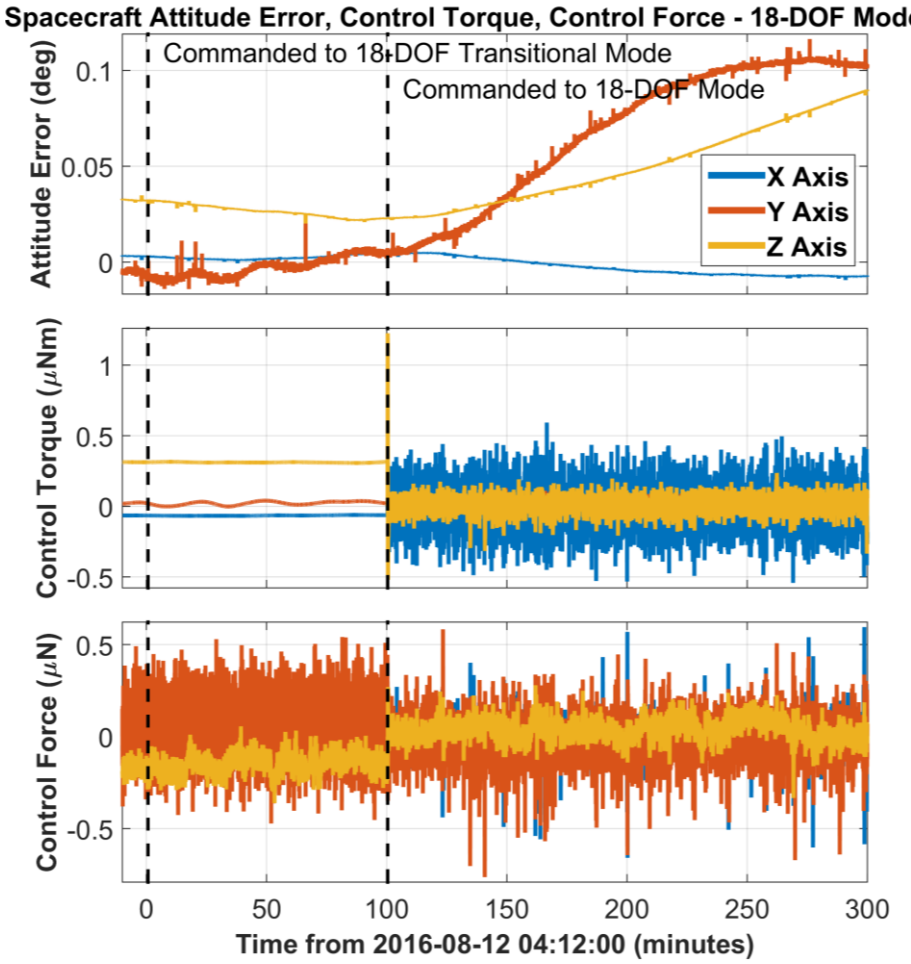
Final Commissioning Tests and Bonus Activities

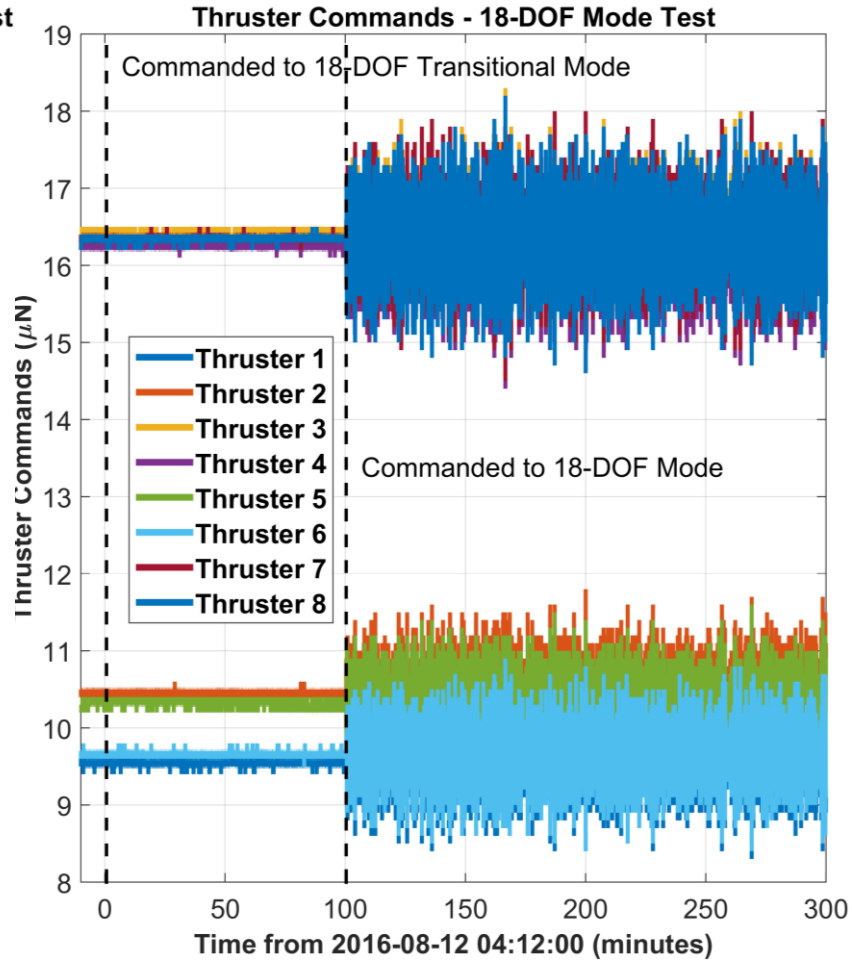
- Final Commissioning Tests executed on July 7-8, 2016
  - Purpose: Verify remaining command sequences needed for the experiment phase:
  - Activities:
    - Test Mass Signal Injection
    - Single Thruster Open Loop Test
    - Freeze Thruster Open Loop Test
    - System Level Delay Measurements
    - DRS use Optical Measurement System Data for Control
    - Change Reference Test Mass to the 2nd test mass.
- All Tests were successful with the exception of the system level delay test.
- Following week will be transitioning to 18-DOF Mode

Thruster Command Anomaly

- July 9, 2016 – Acquisition of Signal showed that DRS was no longer in control of LISA Pathfinder.
- Upon Investigation, Reset of Thruster Cluster 2 occurred due to single event effect. The Single Event Effect caused the HW Logic to reset the cluster upon receipt of thruster commands (Thruster Command Mode).
- DRS FSW and Thrusters include a second a method to command thrusters (Thruster Diagnostic Mode).
  - Used during thruster commissioning.
  - Never used for close-loop control.
- Needed changes tested over 3 week period by JPL and GSFC engineers.

Recommissioning and 18-DOF

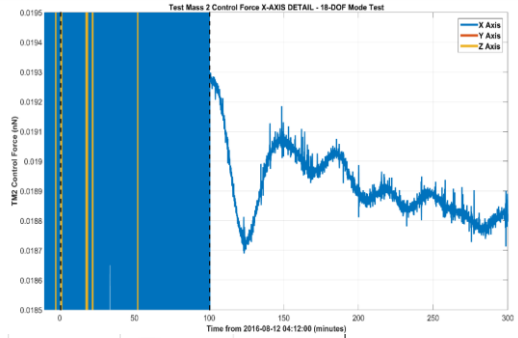


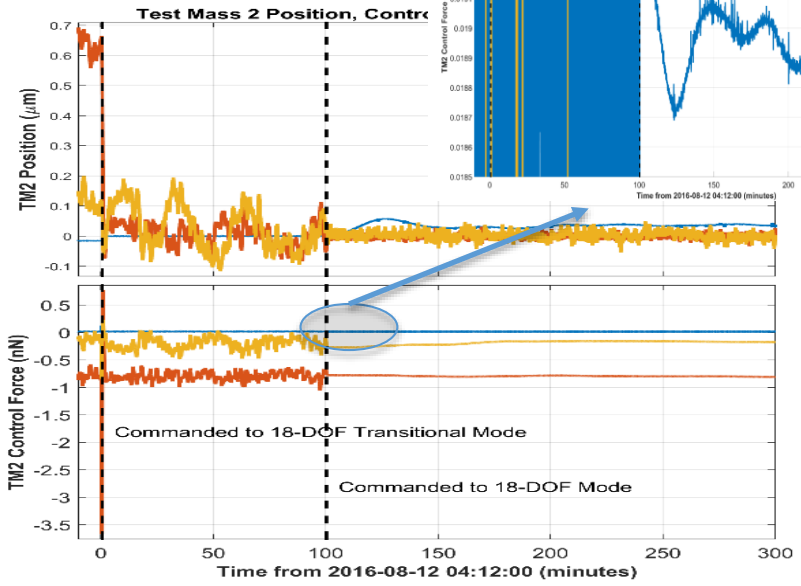


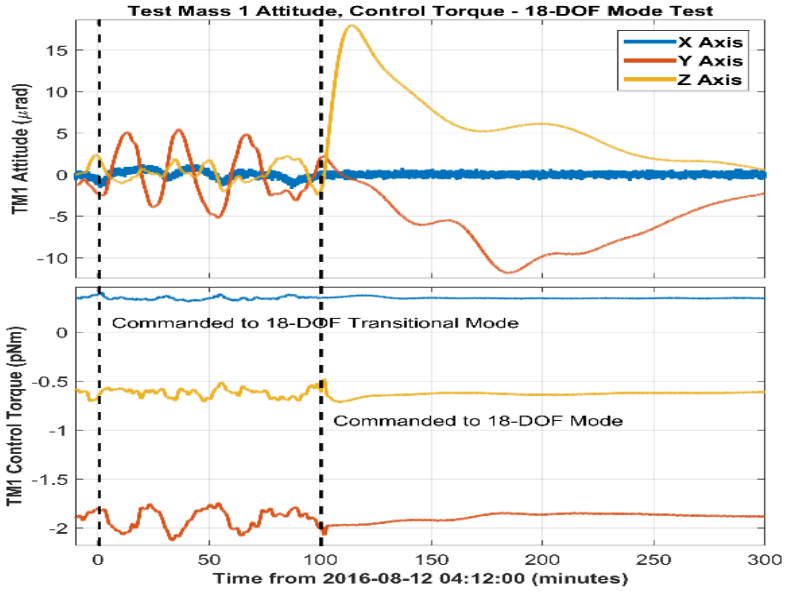
Recommissioning Activities – August 8-12, 2016

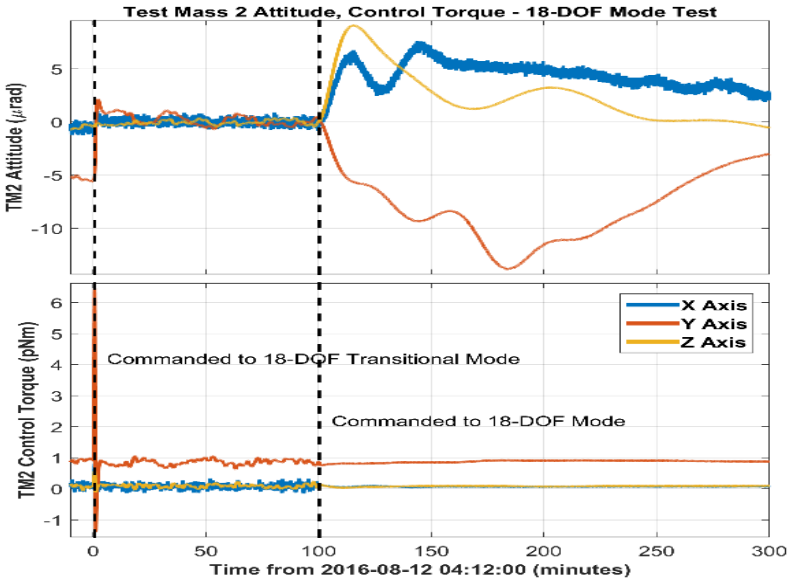
Completed with successful transition to 18-DOF Mode on August 12, 2016 at 05:52 UTC

18-DOF Test Masses



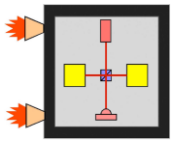




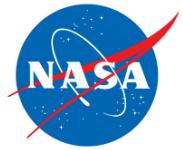


Acknowledgements

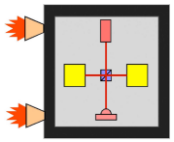
- the Hammers Company
- Busek Co.
- Airbus Defense and Space in Stevenage, UK
- European Space Operations Centre in Darmstadt, Germany
- LISA Pathfinder Spacecraft and Science Team

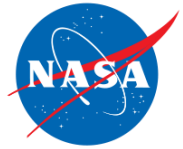


Conclusion



- DRS launched aboard LISA Pathfinder on December 3, 2015.
- Three highly successful commissioning periods with two originally planned a third added after thruster anomaly.
- DCS Modes and Mode Transitions successfully verified.





Questions?