ST7-DRS on LISA Pathfinder: Initial Status

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Project Overview

Space Technology 7 - Disturbance Reduction System (ST7-DRS)

Salient Features
• Project Category: 3  Risk Class: C
• DRS flies on the ESA LISA Pathfinder spacecraft
• Sun-Earth L1 halo orbit
• Drag-free satellite to offset solar pressure
• Payload delivery: July 2009 – COMPLETE
• Launch date: November 2015
• Operational life: 2 months
• Data Analysis: 12 months

Technologies
• The Disturbance Reduction System (DRS) will validate system-level technologies required for use on future gravity and formation flying missions.
• The key new technologies are gravitational reference sensors and microthrusters.
  - DRS will validate spacecraft position control to an accuracy of $\leq 10 \text{ nm}/\sqrt{\text{Hz}}$ over frequency range of 1 mHz to 30 mHz (Precision Flight Validation Experiment)
  - With LISA Pathfinder GRS, DRS will validate that a test mass follows trajectory determined by gravitational forces only within $3 \times 10^{-14} \text{ m/s}^2/\sqrt{\text{Hz}}$ over frequency range 1 mHz to 30 mHz
What is Disturbance Reduction?

- Microthrusters
- Secondary Test Mass
- Laser
- Photodetector
- Capacitive Measurement
- Spacecraft Body
- Primary Test Mass

~ 0.1 μN

H 30 μN
• Colloid Thrusters emit charged droplets that are electrostatically accelerated to produce thrust

\[
\text{Thrust} \propto I_B^{1.5} \oplus V_B^{0.5}
\]

• Current and voltage are controlled independently by adjusting the flow rate and beam voltage

• Precise control of \(I_B\) (\(\sim 1\ A\)) and \(V_B\) (\(\sim \text{kV}\)) facilitates the delivery of micronewton level thrust with better than 0.1 \(\text{nN}\) precision

• The exhaust beam is positively charged, well-defined (all charged particles), and neutralized by a cathode/electron source if needed

Images courtesy of Busek Co.
ESA LPF Launch Date History

Feb. 2010: Shelf-life Recertification was approved by HQ. Launch date was April 2012.

ST7/DRS Delivery to ESA – June 2008
Overall Mission Profile

**LTP**
Commissioning and Experiment
(Launch + 57 to 165 days)

**DRS Experiment Phase**
Commissioning – Instrument Check-out
(Launch + 165 days, 10 days long)

**DRS Experiment**
(Launch + 175 to 265 days)

- **LEO Orbit Raising**
  (15 days)

- **Propulsion Module Separation**
  (Launch +50 days)

- **DRS Transfer Phase**
  Commissioning – Thruster Check-out
  (Launch + 25 days)

- **LEO to L1 Transfer**
  (23 days)
LISA PATHFINDER

• LISA Pathfinder is a technology verification mission for Gravitational Wave Telescopes

• LPF will test:
  – Inertial sensors
  – Interferometry between free floating test masses
  – Drag free and attitude control systems
  – Micronewton propulsion technologies

• All subsystem integrations and ATLO tests are complete

• LPF is on its way to launch site for a November 26th/27th Launch
DRS Installed on LPF Spacecraft

- DRS Colloid Micro-Newton Thruster (CMNT) Clusters (2)
- DRS Integrated Avionics Unit (IAU)
The DRS Commissioning has two phases:

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Phase</th>
<th>Purpose</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 days</td>
<td>Transfer</td>
<td>Thruster Checkout</td>
<td>• Occurs between orbit insertion and separation of the spacecraft propulsion module.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The objective is to have the CMNT thrusters available as a backup to the cold gas thrusters.</td>
</tr>
<tr>
<td>90 days</td>
<td>LTP Experiments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 days</td>
<td>Experiment</td>
<td>Instrument Checkout</td>
<td>• Occurs after ESA's LPF experiments.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The objective is to prepare the CMNT for DRS experiments.</td>
</tr>
<tr>
<td>90 days</td>
<td>DRS Experiments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thruster Checkout:
All DRS Success Criteria Passed

- IAU Check-out
- Thruster Power Cycle
- Thruster Impedance Test
- Thruster Start-up
- Bubble Dissipation
- Thruster Full Functional Test (all 8 thrusters)
- A / B Side Power Check-Out
- ESA Thrust Command Mode Demonstration
- Thruster Safe Shutdown
- A / B Side Communications Check-Out
DRS Experimental Plan

- C1 - DRS Control Mode and Noise Performance
- C2 - Measure TM Actuation Response
- C3 - Test Mass Working Point Optimization for Interferometer
- C5 - Spacecraft Attitude Working Point
- P1 - Thruster Performance as a Function of Temperature
- P2 - Thruster Performance as a Function of Beam Voltage
- P3 - Thruster Crosstalk
- P5 - Measure Maximum Thrust
- P6 - Thruster Current Control Parameters
- T1 - Thruster Performance Characterization Using In-loop Injections
- T3 - Open Loop Thruster Performance Characterization
- T6 - Thruster Performance Functional Tests in Commissioning
- T7 - Closed Loop Control on Seven Thrusters
- T9 - DFACS Performance with Colloid Thrusters
- D3 - Recovery to Attitude or Accelerometer Mode
- D4 - System Level Delays
1. The plans for each commissioning activity are coded into DRS sequences validated in the JPL testbed.

2. Sequences are uploaded to the spacecraft and validated by their checksums and executed.

3. Telemetry data is analyzed as it arrives and the behavior of the system is compared to expected outcomes.

4. Unexpected behavior results review of DRS sequences. If needed, sequences are updated and steps 1-3 are repeated.
# Instrument Check-Out (1 of 4)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCS Table Updates</td>
<td>1. Update the DCS control parameters prior to IAU and Thruster Checkout.</td>
</tr>
</tbody>
</table>
| IAU and Thruster Safety Checkout | 1. Verify that the IAU can receive commands, send telemetry, change telemetry modes.   
                                        2. Verify the initial state of the thruster safety flags and the versions of the thruster power-on sequence 077 loaded in flash memory.  
                                        3. Verify the correct version of the flight software is loaded in RAM and FLASH slots 1 and 2.  
                                        4. Verify the DRS C&DH RTI  
                                        5. Verify the memory addresses of core DCS tables and capiBase Address.  
                                        6. Verify correct FSW sequences are loaded in flash  
                                        7. Verify functionality of warm and cold reset commands |

Same as DRS & Colloidal Check-out
## Instrument Check-Out (2 of 4)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Objectives</th>
</tr>
</thead>
</table>
| CMNT Cluster 1 & 2 Cycle Test | 1. Verify that each cluster can receive commands, and send telemetry.  
2. Verify that the heaters run to warm them up to >10C before enabling (in case they are <10C).  
3. Verify that the thrusters can be enabled  
4. Verify that each thruster head does not have any impedances <10 GOhm between electrodes (including the cluster chassis) at 2 kV beam voltage during enable command (2 kV is the minimum operating voltage, and the default condition on enabling the clusters)  
5. Verify that the thrusters can be disabled and power off safely |
## Instrument Check-Out (3 of 4)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CMNT Impedance Test</strong></td>
<td>1. Verify each thruster head does not have any impedances &lt;10 GOhm between electrodes at 6 kV beam voltage and 1.6 kV extraction voltage (default condition for providing thrust).</td>
</tr>
</tbody>
</table>
| **Start up CMNT**               | 1. Bring all thruster voltages to their default values  
                                    2. Bring all thruster currents to 2.5 µA (minimum thrust)                                      |
| **Bubble Test and Dissipation** | 1. Measure thruster and beam current response time to estimate potential bubble size in each thruster.  
                                    2. Run all thrusters at maximum thrust to clear any bubbles out of the thrusters in the shortest possible time. |
| **Functional Test**             | 1. Apply various beam voltage and beam current set points to verify expected response.  
                                    2. Validate that thrust commands produce the expected beam voltage and current levels.                                |
| **Cathode Neutralizer Test**    | 1. Test the functionality of the cathode neutralizer.                                                                                     |
# Instrument Check-Out (4 of 4)

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</table>
| Handover, DCS Control in Attitude Mode, and Handback | 1. Verify handover procedure.  
2. Verify stabilization of the s/c with the drs.  
3. Verify handback procedure. |
| Drag Free Low Force Test with Test Mass 1 as Reference | 1. Demonstrate DRS control in Drag-Free Low Force mode using test mass 1 as the reference. |
| Drag Free Low Force Test with Test Mass 2 as Reference | 1. Demonstrate DRS control in Drag-Free Low Force mode using test mass 2 as the reference. |
| 18 DOF Test | 1. Demonstrate DRS control in 18-DOF mode using test mass 1 as the reference |
Requirements & Priorities

Level 1 Requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Full Success Criteria</th>
<th>Minimum Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position control; 1-30 mHz</td>
<td>10 nm/√Hz</td>
<td>100 nm/√Hz</td>
</tr>
<tr>
<td>Drag-free sensor*</td>
<td>5 nm/√Hz</td>
<td>50 nm/√Hz</td>
</tr>
<tr>
<td>Propulsion system noise; 1-30 mHz</td>
<td>0.1 μN/√Hz</td>
<td>0.5 μN/√Hz</td>
</tr>
<tr>
<td>Performance demonstration: duration</td>
<td>60 days</td>
<td>10 days</td>
</tr>
</tbody>
</table>

* DRS is required to use the LTP as its drag free sensor; Stated performance is assumed in setting the other DRS requirements.

Priorities:

1. Verify minimum mission success criteria
2. Verify full mission success criteria
3. Provide system demonstration of NASA technology investment which results in use by future missions