Deep Space 1: Testing New Technologies for Future Small Bodies Missions

Marc D. Rayman
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

52 International Astronautical Congress
October 1 - 5, 2001
New Millennium Program

Objective:
- Flight validate advanced technologies to help enable NASA’s future space and Earth science programs.

Technology selection criteria:
- Present a high risk to the first user,
- Require in-flight validation,
- Reduce cost and risk of future programs, and
- Represent a significant improvement over state of the art.

Technology validation:
- Assess the applicability of the technology product to those programs.
  - Elucidating the limitations of an advanced technology is valuable.
  - Diagnose in-flight anomalies.
**Deep Space 1 Mission**

- **Launch:** October 24, 1998.
  - 39 months from initiation of concept
  - 24 months from formulation of level-1 requirements
- **Objective:** Assess payload of advanced, high-risk technologies to reduce cost and risk of future space science missions.
- **Result:** Met or exceeded all mission success criteria.
- **Primary mission concluded on September 18, 1999.**
**Mission Success Criteria**

1) Demonstrate the in-space flight operations and quantify the performance of the following 5 advanced technologies:
   - Solar Electric Propulsion
   - Scarlet Solar Concentrator Arrays
   - Small Deep Space Transponder
   - Miniature Camera and Imaging Spectrometer
   - Autonomous Navigation

   and 3 of the 6 following advanced technologies:
   - Beacon Monitor Operations
   - Autonomous Remote Agent
   - Ka-band Solid State Power Amplifier
   - Low Power Electronics
   - Multifunctional Structure
   - Power Actuation and Switching Module

   [ + Plasma Experiment for Planetary Exploration (PEPE) ]

2) Acquire the data necessary to quantify the performance of these advanced technologies by September 30, 1999. Analyze these data and disseminate the results to interested organizations/parties by March 1, 2000.

3) Utilize the on-board Solar Electric Propulsion (SEP) to propel the DS1 spacecraft on a trajectory that will encounter a near-Earth asteroid in FY 1999.

4) Assess the interaction of the SEP system operations with the spacecraft and its potential impact on charged particle, radio waves and plasma, and other science investigations on future SEP propelled deep space missions.
Stowed Configuration

- MICAS Sun shade
- Plasma Experiment for Planetary Exploration
- Power processing unit
- High gain antenna
- Low gain antennas
- Ka band antenna
- Waveguide transfer switches
- Diplexer
- Xe feed system panel
- Service boom
- Low gain antenna
- Ion propulsion system digital control interface unit
- Battery
- Sun sensor electronics
- Sun sensor head

Deep Space 1  Page 7  Marc D. Rayman - Oct 2001
New Millennium Program Deep Space 1
Successful Validation of 12 Breakthrough Technologies

- Ion Propulsion System: enables rapid access to deep space
- AutoNav: first totally autonomous on-board navigation system; first deep-space low-thrust Nav
- Small Deep Space Transponder: currently baselined for all follow-on deep space missions
- Remote Agent: NASA software of the year award
DS1 Technology Payload

- Solar electric propulsion
  - Provided by NSTAR (NASA SEP Technology Applications and Readiness) Program
  - 2.5 kW ↔ \( I_{sp} = 3100 \) s; throttle in discrete steps to 0.5 kW ↔ \( I_{sp} = 1900 \) s
  - Diagnostics sensors for E and B, energy and density of electrons and ions, and surface contamination
- Solar concentrator array
  - Provided by BMDO
  - Arrays of cylindrical Fresnel lenses over strips of GaInP\(_2\)/GaAs/Ge
  - 2.5 kW at 1 AU BOL
- Miniature integrated ion and electron spectrometer
  - Energy and angle analysis for electrons and ions
  - Ion mass analysis
  - Microcalorimeter
- Miniature integrated camera and imaging spectrometer
  - 2 visible imaging channels
  - IR and UV imaging spectrometers
    - UV channel never functioned correctly
  - Shared 10-cm primary mirror
DS1 Technology Payload - Cont’d.

- Autonomous optical navigation system
  - Acquisition and processing of images of asteroids against stellar background
  - Orbit determination
  - Maneuver design and execution
  - Direct commanding of IPS, MICAS, and ACS
- Remote agent
  - Planner/scheduler to generate a set of activities
  - Executive to expand that to a sequence of commands and to monitor their execution
  - Mode identification and reconfiguration
- Beacon monitor operations
  - Summarize spacecraft health and transmit 1 of 4 tones to indicate urgency of request for ground intervention. For example
    - No tracking required
    - Track when convenient
    - Track soon
    - Track as soon as possible
- Small deep-space transponder
  - X-band receiver, X-band and K_a-band exciters, CDU, TMU, and beacon tone generator
  - K_a-band solid state power amplifier
    - 2.3 W RF, 13% efficiency
- Power actuation and switching module
  - Power switch using high-density interconnects with mixed signal ASIC controller
- Low power electronics
  - 0.9 V logic, 0.25 μm feature size
- Multifunctional structure
  - Electronics integrated into load-bearing structural element
Extended Mission Concept

- Borrelly encounter: 9/22/01
- Launch: 10/24/98
- Earth
- Comet Borrelly
- Braille encounter: 7/29/99
- Comet Wilson-Harrington
- Wilson-Harrington encounter: 1/12/01

Asteroid Braille
Technology Benefit Example

- Mission concept:
  - Same encounter targets as DS1 for primary and possible extended missions
  - Standard technologies with similar functionality:
    - $N_2O_4/MMH$ propulsion system
    - Scaled solar array
    - Mars '98-class telecommunications system
    - Cassini-class plasma spectrometer
    - Separate visible imager and IR push-broom spectrometer

<table>
<thead>
<tr>
<th>&quot;Standard&quot; DS1 Technology</th>
<th>Actual DS1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injected Mass</td>
<td>~1300 kg</td>
</tr>
<tr>
<td>Launch Vehicle</td>
<td>Shared Atlas IIA</td>
</tr>
</tbody>
</table>
RESULTS FROM THE DEEP SPACE 1 TECHNOLOGY VALIDATION MISSION

Marc D. Rayman, Philip Varghese, David H. Lehman, and Leslie L. Livesay
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109 USA

Launched on October 24, 1998, Deep Space 1 (DS1) is the first mission of NASA's New Millennium program, chartered to validate in space high-risk, new technologies important for future space and Earth science programs. The advanced technology payload that was tested on DS1 comprises solar electric propulsion, solar concentrator arrays, autonomous on-board navigation and other autonomous systems, several telecommunications and microelectronics devices, and two low-mass integrated science instrument packages. The technologies were rigorously exercised so that subsequent flight projects would not have to incur the cost and risk of being the first users of these new capabilities. The performances of the technologies are described as are the general execution of the mission and plans for future operations, including a possible extended mission that would be devoted to science.

Published in Acta Astronautica 47, p. 475 (2000)