SPACE-FLIGHT VALIDATION OPPORTUNITIES FOR LOW-TEMPERATURE TECHNOLOGIES

Martin Buehler, NMP Staff Technologist, JPL
Peter Mason, Low-Temperature Physicist, Caltech

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Introduction

- New Millennium Program (NMP) is a flight test program providing:
  - Flight validation of new technologies
  - Reduced risk and cost to NASA's Earth and Space Science missions in the use of new technology.

- This talk will:
  - Describe NMP
  - Solicit suggestions for flight validating low-temperature technologies.
Outline

☐ New Millennium Program Overview
  ☐ Launch Schedule and Activity Triad
  ☐ Current NMP Technologies

☐ Technology Selection Process
  ☐ User Needs
  ☐ Technology Readiness Levels (TRL)
  ☐ Flight Justification

☐ Flight Validation
  ☐ Cryogenic Technology Examples
  ☐ Candidate Technologies for Flight Validation
NMP Overview
## Validation Flight Launch Schedule

<table>
<thead>
<tr>
<th>Year</th>
<th>98</th>
<th>99</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
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<tbody>
<tr>
<td>DS1</td>
<td><img src="image1.png" alt="Image" /> 10/98</td>
<td><img src="image2.png" alt="Image" /></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DS2</td>
<td><img src="image3.png" alt="Image" /> 01/99</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>EO1</td>
<td><img src="image4.png" alt="Image" /></td>
<td></td>
<td><img src="image5.png" alt="Image" /> 11/00</td>
<td></td>
<td></td>
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<tr>
<td>ST5</td>
<td><img src="image6.png" alt="Image" /> One Flight Per Year</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>EO3</td>
<td><img src="image7.png" alt="Image" /></td>
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</tr>
<tr>
<td>ST6</td>
<td><img src="image8.png" alt="Image" /></td>
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</tr>
<tr>
<td>ST7</td>
<td><img src="image9.png" alt="Image" /></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **DS1**: Launch in 10/98
- **DS2**: Launch in 01/99
- **EO1**: Launch in 11/00
- **ST5**: Launches one flight per year
- **EO3**: Additional information not provided
- **ST6**: Additional information not provided
- **ST7**: Additional information not provided

*Note: Images of satellites or space vehicles are used to illustrate the launch schedule.*
NMP Flight Validation Activity Triad

**IMPLEMENTATION**
- partnerships
- access-to-space carrier options
- validation infusion project

**FORMULATION**
- maturing technologies offering
- technology selection and project formulation
- significant improvements
- users/NASA theme needs

**FLIGHT**
- technology infusion report workshop
- validation flight/subsystem
# NMP Technologies for Flight Validation

<table>
<thead>
<tr>
<th></th>
<th>EO3</th>
<th>ST5</th>
<th>ST6</th>
<th>ST7</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPLEMENTATION</td>
<td>FT Spectrometer</td>
<td>Satellite Constellation</td>
<td>SUBSYSTEM</td>
<td>SYSTEM</td>
</tr>
<tr>
<td>LAUNCH</td>
<td>2004 LAUNCH</td>
<td>2003 LAUNCH</td>
<td>SELECT: ~Three tech.</td>
<td>SELECT: One system</td>
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<tr>
<td>INTERFERENCE</td>
<td>Interferometer</td>
<td>SYSTEM</td>
<td>Sail/Sunshade Deploy.</td>
<td>DISTURB. REDUCT. SYS</td>
</tr>
<tr>
<td>Focal Plane Array</td>
<td>MicroSat Fabrication</td>
<td>LW High Volt. Solar Array</td>
<td>Gravitational Sensor</td>
<td>MicroNewton Thuster</td>
</tr>
<tr>
<td>MINI-COOLER</td>
<td>Research Quality S/C</td>
<td>Deployable Inflat. Booms</td>
<td>SOLAR SAILS</td>
<td></td>
</tr>
<tr>
<td>RH-A/D Converter</td>
<td>Constellation Operation</td>
<td>Membrane Optics Deploy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RH-VECTOR Processor</td>
<td>SUBSYSTEM</td>
<td>Ultra-Low Power Avionics</td>
<td>Sail Subsystem</td>
<td></td>
</tr>
<tr>
<td>Active Pixel Sensor</td>
<td>Micro-Thruster</td>
<td>Optical Communication</td>
<td>Attitude Control</td>
<td></td>
</tr>
<tr>
<td>LW-OPTICS &amp; STRUCT.</td>
<td>Ultra-Low Power Logic</td>
<td>Dilution Cryocooler</td>
<td>AEREO-ENTRY/MAEUVER</td>
<td></td>
</tr>
<tr>
<td>POWER PC</td>
<td>Flexible Harness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STACKED MEMORY</td>
<td>Emmisivity Tech.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULTRA-LOW POWER LOGIC</td>
<td>Constell. Transceiver</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RADIATION SHIELDING</td>
<td>SatTrack Constel. Tools</td>
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<td></td>
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</tr>
<tr>
<td>ADVANCED INSTRUMENTATION</td>
<td>AUTONOMY</td>
<td></td>
<td></td>
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<tr>
<td>ON-BOARD SCI. PROCESS.</td>
<td>Sys.-Level Auto. Software</td>
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</tr>
<tr>
<td>ADVANCED AUTONOMOUS ENABLER</td>
<td>Hardware Concepts</td>
<td></td>
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</tbody>
</table>
Technology Selection Process
NASA Technology Readiness Levels

TRL 9 Actual system flight proven through successful mission operations.

TRL 8 Flight System completed and qualified through test and demonstration.

TRL 7 System prototype demonstrated in a space environment.

TRL 6 System prototype demonstrated in a relevant environment.

TRL 5 Component and/or breadboard validated in relevant environment.

TRL 4 Component and/or breadboard validated in laboratory environment.

TRL 3 Critical function or characteristic demonstrated (proof-of-concept).

TRL 2 Technology concept and/or application formulated.

TRL 1 Basic principles observed and reported.

NMP flight validates technologies that have matured to TRL 4.
## Flight Validation Justification Factors

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>EFFECTS</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Persistent Effects</strong> are steady space/planetary environments acting on the technology.</td>
<td>Zero Gravity, Radiation Effects, Temperature Cycling.</td>
<td>Large, light-weight deployable structures need zero g flight validation because accurate ground tests are impossible.</td>
</tr>
<tr>
<td>2. <strong>Transient Effects</strong> are impulse space/planetary environments acting on technology.</td>
<td>Cosmic Rays, Temperature Spike, Dust Devils, Vibration, Coronal Mass Ejection.</td>
<td>System level faults, such as cosmic-ray induced single-event upsets in integrated circuits. Validation flight needed to demonstrate performance of fault management software and planning agents.</td>
</tr>
<tr>
<td>3. <strong>External Interactions</strong> are environments used by the technology to accomplish something.</td>
<td>Planetary Atmospheres, Solar Wind, Magnetic Fields.</td>
<td>Aeroassist technologies using planetary atmospheres and solar sails using solar wind for propulsion. Both require flight validation to build an experience base and to determine the performance envelope and safe operating zones.</td>
</tr>
<tr>
<td>4. <strong>Reliability Hazards</strong> are space/planetary environments that degrade performance.</td>
<td>Micrometeorite, Dust Accumulation, Atomic Oxygen, Radiation Effects.</td>
<td>Micrometeorite, orbital debris, dust accumulation, atomic oxygen, and radiation effects are difficult to predict and simulate.</td>
</tr>
</tbody>
</table>

Justification based on space environmental effects where ground tests are difficult or impossible.
NMP Flight Validation Selection Target

TRL:
1. Principle
2. Concept
3. Proof
4. Lab Demo
5. Relevant Environment
6. System Demo
7. Flight
8. Demo
9. Operation

User Needs
1. NASA Theme
2. NASA Enterprises

Flight

Technology Readiness Level

Access to Space:
1. Standalone Spacecraft
2. Secondary Payload
3. NMCarrier

Cost:
1. System: $50M
2. Subsystem: $5M

FitVal Justification:
-Space Environmental Effects
Flight Validation
## NMP System/Subsystem Flight Opportunities

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>SYSTEM</th>
<th>SUBSYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>Several higher-TRL technologies tested in a system context.</td>
<td>Lower-TRL new technologies tested individually.</td>
</tr>
<tr>
<td><strong>Normal Project Class</strong></td>
<td>Flight: Shared with partner(s)</td>
<td>Flight: Shared with partner(s)</td>
</tr>
<tr>
<td></td>
<td>Cost: $50M</td>
<td>Cost: $25M supporting several new technologies</td>
</tr>
<tr>
<td><strong>Occasional Project Class</strong></td>
<td>Flight: Stand-alone</td>
<td>Flight: Hosted by the NASA technology carrier</td>
</tr>
<tr>
<td></td>
<td>Cost: $100-$150M</td>
<td>Cost: $25M supporting several new technologies.</td>
</tr>
<tr>
<td><strong>Launch</strong></td>
<td>Annual</td>
<td>Annual</td>
</tr>
</tbody>
</table>

NMP has two approaches to flight validation.
Subsystem-Level Validation: Dilution Cryocoolers

**Technology Description:**
Cryocoolers enable the use of low temperature detectors that measure photons with energies ranging between X-rays through IR. The dilution cryocooler uses liquid helium to achieve temperatures between 50 and 300 mK. Cooling occurs without the use of stored cryogens, with no moving parts, no vibration and no magnetic fields. The size is 25 cm dia. X 40 cm long. The mass is < 2 kg and requires 25 mW peak electrical power and a 2 K heat sink with a < 3 mW capability.

**Flight Validation Justification:**
- Dilution cryocoolers are difficult or impossible to test on the ground due to gravity sensitive of the He-3 and He-4 and require flight validation to demonstrate their performance in space.

**Customers:**
- Missions with X-ray or IR requirements.
- FIRST, Constellation-X, SOFIA, Plank (ESA), SPECS, HIRLODLS; NGST; SUVO

**Validation Measurements:**
- Measure the temperature of the dilution cryocooler in space to determine its stability and dynamic behavior.
- Measure the power required to reach lowest temperatures.

**Technology Status:**
- A single-cycle prototype with necessary porous material for controlling the liquid has been demonstrated on the ground. It is being modified to operate continuously. The technology is expected to reach TRL 4 by FY02.
Flight Validation Elements

Space Tests are Greatly Constrained

1 1 0 1 TECHNOLOGY 0 SPECIFIC 1 DATA

EARTH AND SPACE SCIENCE MISSIONS

SPACE RESULTS FLIGHT VALIDATION RESULTS GROUND RESULTS SIMULATORS MODELS

Ground Tests are More Comprehensive
System-Level Validation: Miniaturized Pulse-Tube Cryocooler

**Flight Validation Justification:**
- The space steady state and dynamic temperature response is difficult to predict based on ground tests.
- The space cooler vibration performance is difficult to predict based on ground tests.

**Customers:**
- Enabling technology for NOAA, ONR, FAA, and NASA's Earth and Science Enterprises.

**Validation Measurements:**
- Measure the input power and cooler temperature sensors to determine the power efficiency
- Measure the cooler temperature sensor to determine the temperature stability
- Measure the cooler accelerometer to gather vibrational and perhaps mechanical reliability statistics.

**Technology Description:**
The two-stage pulse-tube cooler will provide a stable 55K (2-W load), 90K, and 120K for FPA cooling and for zonal cooling of the instrument. The cooler provides second-stage cooling at ~140 K, 7-W load, allowing the interferometer to be cooled for lower background noise operation. Mass is 17 kg, power is 170 W, and rejection temperature is 300 K.

**Technology Status:**
Bench model of the cooler currently under test has demonstrated a factor of four improvement in mass per unit power over coolers of similar capacity (3.9 kg for GIFTS versus 11 kg for AIRS/TES). The technology is expected to reach TRL 4 by FY02.
Validating technology at the system-level is challenging because the technology is embedded in the system and so requires extensive operations and instrumentation planning.
NMP Events

- TECHNOLOGY INFUSION:
  - DS1 Workshop: January 2000
  - DS1 CDROM: January 2001
  - EO1 Workshop: August 2001
  - DS2 Report: August 2001

- FLIGHT:
  - ST5 Launch: 2003
  - EO3 Launch 2004

- TECHNOLOGY SELECTION:
  - ST6 Selection August 2001
  - ST7 Selection December 2001

- TECHNOLOGY FORMULATION:
  - ST8 Subsystem Workshop January 2002
Low-Temperature Technologies

- CRYOCOOLERS
  - Cooling Mechanisms
  - Reliability

- HEAT TRANSFER AND COMPONENTS
  - Heat Exchangers
  - Fluid Flow Valves

- SPACE TRANSPORTATION
  - Propellants and Storage
  - Liquid Measures

- FACILITIES
  - Test Capabilities
  - Simulators and Modeling

- OTHER
  - Microelectronic Cooling
  - Contamination
Flight Validation Assessment

- **Identify Needs:**
  - Identify Mission application
  - Determine if a NASA Theme(s) is interested

- **Determine the Viability of the Technology:**
  - Determine if the technology is ready (TRL)
  - Decide on the Flight Justification
  - Determine if the Cost is reasonable
  - Identify the Access-to-Space options

- **Advertise:**
  - Inform the NASA Theme(s) of the technology
  - Participate in an NMP Workshop
  - Respond to an NMP TA (Technology Announcement)