The New Millennium Program: Validating Advanced Technologies for Future Space Missions

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Abstract

NASA's New Millennium Program (NMP) was created to accelerate the insertion of advanced space-related technologies into future science missions using deep-space and Earth-orbiting technology validation spacecraft. This paper describes objectives and current status of the New Millennium space exploration and Earth orbiting validation missions, introduces the government/industry/academia Integrated Product Development Teams (IPDTs) formed to support the program, and provides a summary of the microelectronics flight hardware these teams have developed for the validation missions.

New Millennium Program Objectives

In 1995 the National Aeronautics and Space Administration (NASA) created the New Millennium Program. The objective of this program is to conduct space flight validation of breakthrough technologies that will significantly benefit future space- and Earth-science missions. The breakthrough technologies selected for validation are focused on 1) enabling new science capabilities to fulfill NASA's Space and Earth Science Enterprises' objectives and 2) reducing the costs of future space and earth science missions. A secondary objective is to return high priority science data to the extent possible within mission and cost constraints. The Jet Propulsion Laboratory (JPL) serves as the lead center for management of the Program.

The goal of space flight validation of these technologies is to mitigate the risks to the first users and to promote the rapid infusion of these technologies into future science missions. Investments made by the NMP will accelerate the insertion of these high-value, breakthrough technologies into the Space and Earth Science programs, leading to significant leap-ahead scientific capabilities and improvements in program cost effectiveness.

Technology Selection: The Role of Integrated Product Development Teams

The technology development and validation efforts of the NMP are focused around six technology thrust areas: Autonomy, Telecommunications, Multifunctional and Modular Systems, Microelectronics, In-Situ Instrument and Microelectromechanical Systems, and Instrument Technologies and Architecture. For each thrust area, teams consisting of representatives from government, academia and industry have been formed. These teams, referred to as Integrated Product Development Teams (IPDTs), operate as consortia to identify breakthrough technologies and to develop flight hardware to validate these new enabling space-related technologies in a cooperative and collaborative fashion. Non-NASA members were selected through a formal source selection process. The organizational membership of these IPDTs is shown in Table 1. Representative Technology validation activities (indicated by bold type) of four of these IPDTs are summarized in the following sections and described in detail in other papers presented at this conference. Specific activities of the Microelectronics Systems IPDT are summarized in reference 1.

Current Missions

At the present time there are four approved (2 deep-space and 2 Earth-orbiting) New Millennium missions. Another earth-orbiting and three deep-space missions are in early planning states. The four approved missions will be briefly described below, and the microelectronics technologies validated in three of these missions will be described in the other papers presented at this conference.

Deep Space 1

Deep Space 1, the first of the New Millennium missions, was launched from the Kennedy Space Center on 24 October 1998. This spacecraft, depicted in Figure 1, carries a complement of 10 technologies for validation during the next eleven months. These technologies are: 1) ion propulsion system, 2) solar concentrator arrays, 3) autonomous optical navigation, 4) miniature integrated camera spectrometer, 5) plasma experiment for planetary exploration, 6) small deep space transponder, 7) **K_a-band solid-state power amplifier (sspa)**, 8) **silicon-on-insulator low-power electronics experiment**, 9) **multifunctional structure,** and 10) **power activation and switching module**. The K_a-band sspa serves as a secondary downlink to earth and is the highest power device of this type ever used for deep space communications. The low-power electronics experiment was developed to characterize the effects of the space

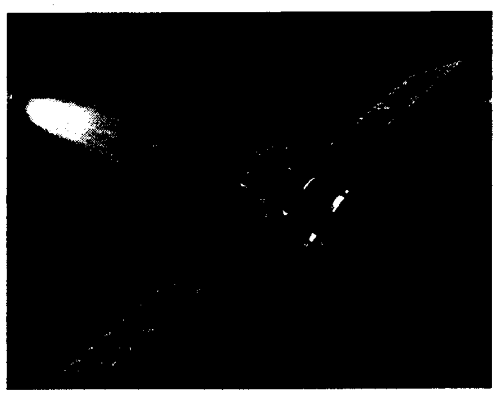

Figure 1. Deep Space 1 contains 11 technologies for space flight validation. The mission will end after the spacecraft rendezvous with Asteroid Wilson-Harrington in September 1999.

Table 1. Organizational Membership of NMP Integrated Product Development Teams

IPDT	Member Organizations
Microelectronics	USAF Research Lab, Boeing, Georgia Tech, GSFC[1], Hughes, Honeywell, Irvine Sensors, JPL[2], APL[3], LERC[4], Lockheed-Martin, MIT/LL[5], Optivision, Sandia National Lab, Space Computer Corp., Space Electronics Inc., TRW, UC/San Diego, Univ. of New Mexico, USC
Telecommunications	Boeing, GSFC, JPL, APL, Lockheed-Martin, Raytheon
Multifunctional Structures and Modular Systems	GSFC, Honeybee Robotics, JPL, LRC[6], L'Garde, MIT, ARC[7], NOOA[8], Primex, SGG, Univ. of Arizona, Univ. of Colorado, USAF Research Labs, Yardney
In-Situ Instrument and Micro Electro-mechanical Systems	DARPA, USAF Research Labs, Ball Aerospace, JPL, APL, LANL[9], NSF, U. S. Navy Postgraduate School, Sandia National Lab, Southwest Research Institute, Stanford Univ., Univ. of So. Calif./ISI
Autonomy	ARC, Carnegie-Mellon Univ., GSFC, ISX Corp., APL, JPL, Lockheed-Martin, Stanford Univ.,TRW, USAF Research Lab.
Instrument Technologies and Architecture	Ball Aerospace, GSFC, ITT Aerospace, JPL, APL, Lockheed-Martin, MSFC, MIT/LL, LRC[10], NRL[11], NOAA, Orbital Sciences Corp., Raytheon, SGG Corp., TRW, Univ. of Wisconsin

[1] NASA Goddard Space Flight Center
[2] CalTech Jet Propulsion Laboratory
[3] Johns Hopkins University Applied Physics Laboratory
[4] NASA Lewis Research Center
[5] Massachussetts Institute of Technology/Lincoln Labs
[6] NASA Langley Research Center
[7] NASA Ames Research Center
[8] National Oceanic and Atmospheric Administration
[9] Los Alamos National Laboratory
[10] NASA Langley Research Center
[11] Naval Research Laboratory

environment on sub 0.25 μm fully depleted silicon-on-insulator CMOS test devices that operate at supply voltages less than two volts. The multifunctional structure is a experiment to evaluate the concept of folding spacecraft electronics into the walls of the spacecraft, thereby saving weight and space by eliminating chassis, cables and connectors. The power activation and switching module enables significant miniaturization of spacecraft electrical load and switching functions by eliminating bulky relays and fuses that have been used in the past. A **3-D computer stack,** which included a number of advanced component and packaging technologies, was also scheduled for validation, but, due to unforeseen technical problems and schedule delays, was replaced with a flight computer similar to that used on the Mars Pathfinder mission. However, many features of the 3-D computer stack are being incorporated into future deep space missions.

Deep Space 2

Deep Space 2, the second of the New Millennium missions, will be launched from the Kennedy Space Center in early January 1999 with a complement of eight advanced technologies. The objective of this mission is to demonstrate: 1) key technologies that enable future network science missions (such as multiple landers, penetrators or spacecraft), 2) a passive reentry system, 3) highly integrated microelectronics capable of surviving high-g impact and operating at extremely low temperatures, and 4) in-situ subsurface science data acquisition. The primary science objectives are to determine if ice is present below the Martian surface and to characterize the thermal properties of the Martian subsurface soil.

This mission consists of two microprobes, one of which is shown in Figure 2, attached to the Mars 98 Polar Lander spacecraft. Approximately 10 minutes prior to landing, the probes will separate from the mother spacecraft, descend through the atmosphere without the benefit of either parachutes or airbags, and survive a high-g impact on the Martian surface. At impact, the probes will separate into two parts, one part (the aft body) remaining on the surface and the other part (the fore body) penetrating up to 2 meters into the Martian soil. Instruments in the part that penetrates the soil will attempt to determine the presence of water ice and to measure the vertical temperature gradient in the soil. Data from these instruments is transmitted via a multi-layer flex cable to a radio beacon in the part that remains on the surface. The beacon relays the data to the Mars Global Surveyor spacecraft, which, in turn, relays the data back to earth.

Microelectronics play a key role in the Deep Space 2, and the microelectronics technologies to be validated on this mission are 1) an **advanced microcontroller, 2) a power microelectronics unit** and 3) the **evolved water experiment** with its associated electronics. All of these technologies are located in the fore body mentioned previously. The evolved water experiment uses a novel drill mechanism to acquire sub-surface soil samples that are then heated in a small crucible to release water if present. A tunable diode laser is used to detect the presence of water vapor. The advanced microcontroller controls operation of and stores data produced by the evolved water experiment and the temperature sensors, and sends the data to the radio beacon for transmission to the Mars Global Surveyor,

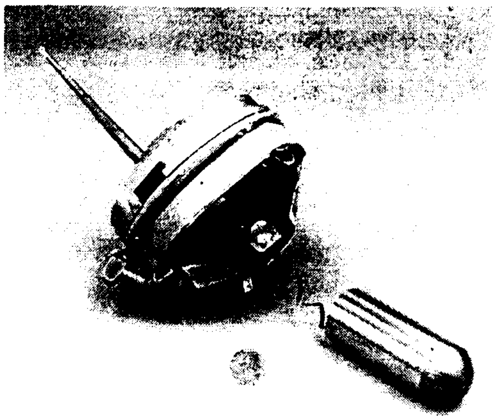

Figure 2. Deep Space 2 Microprobe. At impact, the aftbody (left) will remain on the Martian surface, and the forebody (right) will penetrate into subsurface soil to detect the presence of water. A multilayer flex cable connects the two sections electrically.

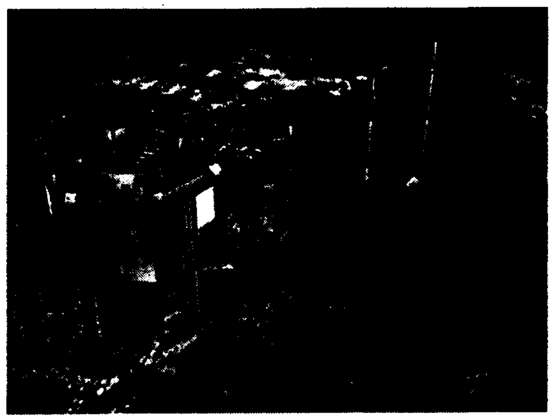

Figure 3. Earth Orbiting 1. This spacecraft will validate technologies contributing to the reduction in cost of future Landsat missions.

which was launched in 1996. The power microelectronics unit provides power management (power is provided by lithium/thionyl chloride primary batteries located in the aft body), distribution and conversion for the evolved water experiment, temperature sensors and the advanced microcontroller. Some of the unique electronics packaging aspects of the electronics in both the fore body and the aft body are described in reference 2.

Earth Orbiting 1

Earth Orbiting 1, the third of the New Millennium missions, is scheduled for launch in December 1999 with three advanced land imaging instruments and a complement of eight advanced spacecraft technologies. The three advanced imaging instruments, the Advanced Land Imager, the Atmospheric Corrector, and the Hyperspectral Imager will lead to a new generation of light weight, higher performance and lower cost Landsat type instruments for the Earth Science Enterprise. The advanced spacecraft technologies, which include a X-band phased array antenna, a carbon-carbon composite radiator, a lightweight flexible solar array, a pulsed plasma thruster, and enhanced formation flying capability will enable smaller, lower weight and reduced power spacecraft buses. A **wide band advanced recorder processor** receives, stores and processes high-rate science data from the instruments and then transmits the data via X-band transmitter to the ground. A **fiber-optic data bus** with a 1000-fold higher data rate capability than the flight proven 1773 fiber optic protocol recently completed successful ground tests and was originally scheduled for this mission. However, due to technical problems and delays, this technology will be rescheduled for validation on a future New Millennium mission. The Earth Orbiting 1, illustrated in Figure 3, will fly in formation with the Landsat 7 and provide 100-200 paired scene comparisons with the ETM+ instrument on the Landsat 7.

Earth Orbiting 2

Earth Orbiting 2, the fourth of the New Millenium missions is scheduled for launch in March 2001. This mission, illustrated in Figure 4, will evaluate the Space Readiness Coherent Lidar Experiment (SPARCLE), a test model of a large-scale, space-based (infrared) laser to measure winds across the planet . EO-2 hardware will be contained in three Getaway Special canisters on the Space Shuttle. One canister will contain the pulsed, eyesafe, coherent detection doppler wind lidar, the second canister will contain a transceiver, and the third canister will contain a off-the-shelf computer. No microelectronics technologies are scheduled for validation on this mission.

Figure 4. Earth Orbiting 2. This mission will fly on the Space Shuttle and will validate a pulsed, eyesafe, coherent detection doppler wind Lidar to measure winds from space.

Future Missions

There are currently three deep-space missions and one Earth-orbiting mission in the planning stages.

The Deep Space 3 will consist of two spacecraft that will perform as a single, long baseline space-based optical interferometer. These spacecraft will fly in precise formation with separation distances ranging from 50 m to 1 km for observation of 8^{th} magnitude stellar targets. This mission is scheduled for launch in late 2003.

The Deep Space 4 will be launched in April 2003, rendevous with and orbit comet Tempel 1 in 2005 and send a lander to the comet surface in 2006. The orbiter will demonstrate technologies for multi-engine solar-electric (ion) propulsion and propellant feed, advanced inflatable solar arrays, advanced microelectronics and software, autonomous navigation and operations, and a spacecraft transponding modem. The advanced microelectronics for this mission will incorporate a number of the technologies used in the DS-1 3D computer stack mentioned previously. The lander will demonstrate a scanning laser radar and autonomous precision guidance for hazard avoidance and landing.

The Deep Space 5 is in the early project concept development phase. This mission is scheduled for launch in late 2003 and will validate technologies that will enable future science missions associated with the Sun/Earth Connection and Structure/Evolution of the Universe Enterprises of the NASA Office of Space Science.

The Earth Orbiting 3 is also in the early project concept development phase . This mission is scheduled for launch in mid 2002 and will focus on validating technologies for future Earth study at high altitude orbits (>1000 km).

Summary

NASA's New Millennium Program has embarked on a bold initiative to accelerate the insertion of advanced technologies into future deep-space and earth-science missions. With the expertise provided by integrated product development teams composed of members from NASA, industry, academia and other government agencies, technologies have been selected and flight validation hardware developed for four missions to date. The first of these missions, Deep Space 1, was successfully launched in October 1998, and both the solar concentrator arrays and the ion propulsion have been successfully demonstrated and characterized. Two more missions will be launched in 1999, and one will be launched in 2001. In addition, 3 deep-space missions and 1 earth-orbiting mission are in the early planning stages and are scheduled for launch in 2002-2003 time frame.

Acknowledgments

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3). Additional information on New Millennium flight projects can be found on the NMP web page (http://nmp.jpl.nasa.gov)