New Millennium Program

Outlook

- FY11 plans called for closeout activities and completion of ST-8 development
- ST-7 launch expected in 2014 on ESA's LISA Pathfinder spacecraft as part of Physics of the Cosmos program; no longer part of NMP
- NASA NMP terminated in FY12
- This report will be archived in December 2013

Orientation

Description. New Millennium was a program to develop and validate advanced space technologies.

Sponsor. The Jet Propulsion Laboratory (JPL), Pasadena, CA, managed the New Millennium Program, while NASA's Earth-Sun System Division Headquarters – located at the Goddard Space Flight Center, MD – had program oversight responsibility.

Status. Technology developed under ST-7 launched on board ESA LISA Pathfinder mission.

Total Produced. Five NMP missions have flown. EO-1, DS-1, and ST-5 were dedicated satellites, while DS-2 rode as a piggyback payload on the Mars Polar Lander and ST-6 rode on Tacsat-2.

Application. The New Millennium Program encouraged the development of new technologies for small, cost-efficient spacecraft missions. Flight-proven technologies were used in future NASA Earth or Space Science programs.

Price Range. Deep Space-1 cost a total of \$162 million. EO-3 cost NASA approximately \$105 million to design, produce, and launch. The ST-5 mission was budgeted at approximately \$55 million. ST-6 is expected to cost \$24.8 million. NASA allocated \$62.6 million for ST-7 development.

Contractors

Prime

General Dynamics C4 Systems, Gilbert Factory	http://www.gdc4s.com, 1721 W Elliot Rd, Gilbert, AZ 85233 United States, Tel: + 1 (480) 892-8200, Prime
Goddard Space Flight Center, GSFC	http://www.nasa.gov/centers/goddard/home/index.html, NASA Bldg 03 Rm S22 M/S 6, , Greenbelt, MD 20771-0001 United States, Tel: + 1 (301) 286-8955, Prime
Swales Aerospace Inc	http://www.swales.com, 5050 Powder Mill Rd, Beltsville, MD 20705 United States,

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	Tel: + 1 (301) 595-5500, Fax: + 1 (301) 902-4114, Email: achomas@swales.com, Prime

Subcontractor

Jet Propulsion Laboratory	http://www.jpl.nasa.gov, 4800 Oak Grove Dr, Pasadena, CA 91109 United States, Tel: + 1 (818) 354-4321 (Propulsion; Power Activation and Switching Module)
Los Alamos National Laboratory	http://www.lanl.gov, Bikini Atoll Rd, SM 30, PO Box 1663, Los Alamos, NM 87545 United States, Tel: + 1 (505) 667-7000 (Plasma Experiment for Planetary Exploration/PEPE)
MIT Lincoln Laboratory	http://www.ll.mit.edu, 244 Wood St, Lexington, MA 02420-9108 United States, Tel: + 1 (718) 981-5000, Fax: + 1 (781) 981-7086 (Advanced Land Imager)
Northrop Grumman Aerospace Systems, Space Systems	http://www.as.northropgrumman.com, 1 Space Park, Redondo Beach, CA 90278 United States, Tel: + 1 (310) 812-4321, Fax: + 1 (310) 813-7548 (Hyperion Hyperspectral Remote Sensing Instrument)
Southwest Research Institute	http://www.swri.org, 6220 Culebra Rd, PO Drawer 28510, San Antonio, TX 78228-0510 United States, Tel: + 1 (210) 648-5111 (Plasma Experiment for Planetary Exploration/PEPE)
University of New Mexico, Institute for Space and Nuclear Power Studies	http://www.unm.edu, Farris Engineering Center, Rm 239, Albuquerque, NM 87131-0001 United States, Tel: + 1 (505) 277-0446, Fax: + 1 (505) 277-2814 (Microelectronic Devices)
Yardney Technical Products Inc	http://www.yardney.com, 82 Mechanic St, Pawcatuck, CT 06379-2154 United States, Tel: + 1 (860) 599-1100, Fax: + 1 (860) 599-3903, Email: mktgmgr@yardney.com (Lithium Ion Power System)

Technical Data

Design Features

The Deep Space-1 (DS-1) validated advanced instrument and spacecraft systems technologies required for low-cost space science missions.

DS-1's primary science goals included detailed studies of the characteristics of the solar wind and the stream of charged particles emitted by the Sun. Another priority was to learn more about the physical properties of the asteroid 9969 Braille and Comets Wilson-Harrington and Borrelly.

The 12 advanced systems technologies validated by DS-1 include solar electric propulsion, high-power solar concentrator arrays, autonomous onboard optical navigation, and several telecommunications and microelectronics devices.

The spacecraft used a xenon-ion solar electric propulsion system rather than a conventional rocket engine. It proved to be the longest-running propulsion system in the history of NASA's space program.

Space Technology-4/Champollion (formerly Deep Space-4) was to deploy a 100-kilogram spacecraft in the first landing on the surface of a comet. This program was canceled in 1999. NASA opted to take part in ESA's Rosetta mission instead.

Space Technology-5/Nanosat Constellation Trailblazer will validate methods of operating several spacecraft as a system and test eight technologies in the harsh space environment near the boundary of Earth's protective magnetic field, or magnetosphere.

Results from the Trailblazer mission will be used to design future missions using constellations of lightweight (about 20 kg), highly miniaturized autonomous spacecraft. One proposed constellation of up to 100 spacecraft positioned around the Earth could monitor the effects of solar activity on spacecraft, electrical power, and communications systems. Another could study global precipitation and the atmosphere of other planets.

Each Trailblazer spacecraft is an octagon 40 centimeters across and about 20 centimeters high, featuring booms and antennas that will extend after launch. The mission was launched as a secondary payload on an Orbital

Sciences Pegasus XL launch vehicle in March 2006 (originally slated for 2003).

Earth Observing-1's key objective during its one-year mission was to demonstrate new remote sensing spacecraft and operations technologies (both hardware and software). The mission would also validate technologies that will help lower the costs of Landsat follow-on missions.

EO-1's two primary instruments were the Hyperion hyperspectral satellite sensor that utilized 220 bands of the spectrum at approximately 30-meter (98.4-ft) spatial resolution, and the Advanced Land Imager (ALI), a lightweight, high-performance, multispectral sensor. Both proved invaluable in monitoring the Earth's surfaces. ALI had a panchromatic sharpening band that produces 10-meter (32.8-ft) imagery. In its other spectral bands, it offered 30-meter ground resolution using a four-chip multispectral focal plane array that covered seven of the eight bands of the current Landsat. Hyperspectral capabilities, which further split these bands into highly differentiated images, were tested to show that they could be combined into traditional Landsat-equivalent data sets. An Atmospheric Corrector was a bolt-on accessory and provided simultaneous atmospheric correction for the images being gathered by the ALI instrument.

Associated with the propulsion system was a small, self-contained electromagnetic propulsion unit – new at the time – that used solid Teflon as a propellant. It produced an ISP of 1,000-2,000 seconds and was used experimentally to intermittently replace one of the reaction wheels that maintained attitude control.

Earth Observing-2 (EO-2)/SPARCLE. EO-2 was a payload slated for launch on the Space Shuttle orbiter. It was designed to take direct measurements of the tropospheric winds. The program was canceled in 1999.

Earth Observing-3 (EO-3). The main instrument on this spacecraft was to be the Geostationary Imaging Fourier Transform Spectrometer (GIFTS). The 100-kilogram (220.5-lb) GIFTS instrument would have tested seven new technologies, including an advanced interferometer; high-speed signal processing; advanced cryogenic cooling; data compression; autonomous pointing and control; low-power, radiation-tolerant microelectronics; and lightweight structures and optics. It would also have demonstrated the usefulness of geostationary satellites for studying gases in the atmosphere.

The total weight of the satellite was approximately 1,805 kilograms (3,980 lb). Launch was planned for October 2006 on a Delta II from Kennedy Space Center, but was canceled. Still, this sensor may be used on other spacecraft in the future.

Space Technology-6. The Charles Stark Draper Laboratory Inc, located in Cambridge, Massachusetts, is building the Inertial Stellar Compass, consisting of a mini star camera and microscopic gyro that will allow a satellite to determine its own position and orientation.

NASA's Jet Propulsion Laboratory, Pasadena, California, is creating the Autonomous Sciencecraft Constellation software, which will allow a spacecraft to process data and make autonomous intelligent decisions to choose interesting observations and downlink the data it deems scientifically important.

Space Technology-7. This mission, formerly a partnership between NASA's New Millennium Program and the European Space Agency (ESA), will place a satellite into a Lagrangian orbit around the Sun, where the pull of the Earth's and Sun's gravities balance. However, even the minute outside forces that remain – such as pressure from sunlight – could interfere with a search for gravitational waves. To make the satellite virtually disturbance-free, ST-7 will test an experimental technology that counteracts outside forces. This system, called the Disturbance Reduction System (DRS), is so sensitive that it can maintain the satellite's path within about a nanometer (a millionth of a millimeter) of an undisturbed elliptical orbit.

DRS works by letting two small (4-cm) cubes float freely in the belly of the satellite. The satellite itself shields the cubes from outside forces so they can naturally follow an undisturbed orbit. The satellite can then adjust its own flight path to match that of the cubes using high-precision ion thrusters. Making the masses cube-shaped lets DRS sense deviations in all six directions (three linear, three angular). ST-7 is scheduled to fly in 2014 on the LISA Pathfinder, but it is a test mission; it will not search for gravitational waves. That final goal will be achieved by the NASA/ESA LISA mission (Laser Interferometer Space Antenna), which is expected to launch later. LISA will use the DRS technology tested by ST-7 to create the ultra-stable satellite platforms it needs to successfully detect gravitational waves.

Ultraflex Next Generation Solar Array System (NGU) from AEC-Able Engineering Inc, Goleta, California, is an ultra-lightweight flexible-blanket solar array that deploys to provide a significant advancement in performance over existing stateof-the-art for high-power arrays. The proposed experiment cost for the NGU is $6.9 million.

SAILMAST Ultra Lightweight Boom from AEC-Able Engineering Inc is an ultra-light graphite mast intended

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for solar sail propulsion systems. The proposed experiment cost for the SAILMAST is $4 million.

Miniature Loop Heat Pipe (MLHP) Small Spacecraft Thermal Management System from NASA's Goddard Space Flight Center, Greenbelt, Maryland, can transport large heat loads over long distances with small temperature differences and without external pumping powers to provide precise temperature control and reduce the need for supplemental heaters. The proposed experiment cost for the MLHP is $9.8 million.

Environmentally Adaptive Fault Tolerant Computing (EAFTC) System from Honeywell International Inc, Clearwater, Florida, will provide high-rate onboard processing for science data and autonomous control functions. The proposed experiment cost for the EAFTC is $10 million.

Note: *Portions of the technical data text above were extracted from New Millennium material supplied by NASA.*

Artist's depiction of ESA's LISA, which will host ST-7.

Source: ESA

Variants/Upgrades

Deep Space-1 (DS-1). The first New Millennium mission. Launched in 1998; flew near an asteroid and several comets. Mission concluded in December 2001.

Deep Space-2 (DS-2). The spacecraft piggybacked a ride to Mars on the Mars Polar Lander in 1999. After an 11-month journey, communication was lost.

Space Technology-3 (ST-3). Formerly Deep Space-3. Two separate spacecraft designed to test interferometry and formation flying in space (canceled).

Space Technology-4 (ST-4). Comet rendezvous mission (canceled).

Space Technology-5 (ST-5). Also called Nanosat Constellation Trailblazer, this mission involves three very small satellites that are tasked with validating methods of operating several spacecraft as one system and testing eight technologies in space. Launched in March 2006.

ST-6. A two-spacecraft mission to test two separate technologies that will enable a spacecraft to operate with more autonomy. Launched in 2006.

ST-7. A mission to demonstrate sensors and thrusters that can note and counteract non-gravitational drag on a spacecraft to create a drag-free orbit. Disturbance Reduction System launch planned for 2014 aboard the ESA spacecraft LISA Pathfinder.

Space Technology-8 (ST-8). A mission to validate a deployable, lightweight solar array as well as a thermal management subsystem and high-performance computer.

Future Space Technology Missions. NASA plans to fund ST missions through ST-10.

Earth Observing-1 (EO-1). Land imagery spacecraft to supplement Landsat-7.

Earth Observing-2 (EO-2)/SPARCLE. Space Shuttle payload to measure wind velocities worldwide. The program was terminated due to cost growth; however, the progress made in lidar technology will be useful for future lidar remote systems.

Earth Observing-3 (EO-3)/GIFTS. The spacecraft will measure water vapor, temperature, wind, and chemical composition in high-velocity space and time. The spacecraft will also test advanced technologies such as a large-area focal plane array, new data readout and signal processing electronics, and passive thermal switching.

New Millennium Carrier-1 (NMC-1). NASA initiated feasibility studies for the NMC Space Technology Carrier in FY01. The studies explored access-to-space options for stand-alone subsystem technology validation. NMC was expected to move into formulation and refinement (Phase B) in FY05.

Program Review

Background. Proposed for initiation in FY96, the New Millennium Program was geared toward development and in-space validation of advanced technologies needed for a fleet of small spacecraft that will explore the solar system, monitor Earth, and observe the cosmos. Constellations, or networks of spacecraft carrying instruments sometimes as small as a dime, were designed to study phenomena in the Earth's atmosphere, oceans, and landmasses, as well as astronomical events in the solar system and beyond.

Although NASA said that the primary purpose of the New Millennium missions was to validate the high-priority technologies needed to enable future science missions, the demonstration flights also featured a modest science payload to exploit scientific targets of opportunity. Simultaneously, much of the technology developed – by some estimates as much as 50 percent – would eventually become commercially usable. Lightweight computer systems and antennas, for example, might find uses in commercial communications satellites.

The New Millennium Program's annual goals were as follows:

1. Mature at least three technologies to the point where they could be validated in space or incorporated directly into a science and/or operational project.
2. Infuse at least one technology development into a commercial entity, a remote sensing or in-situ project, or the Earth Science information systems infrastructure.
3. Establish at least one joint agreement with a program external to NASA's Earth Science Enterprise (ESE) that results in the inclusion of at least one new ESE technology requirement.

<u>ST-4 and EO-2 Scrapped</u>. Funding overruns forced NASA to cancel the over-budget Space Technology-4 / Champollion and Earth Observing-2 missions in 1999. A last-minute agreement to scale back the ST-4 mission had saved it from cancellation once before, but the mission to return cometary material to Earth was ultimately dropped. EO-2 followed suit shortly thereafter, although the progress made in its lidar technology should be useful for future lidar remote systems.

Deep Space-1 Meets Asteroid

DS-1 flew within an estimated 26 kilometers (16 mi) of asteroid 9969 Braille in July 1999. An apparent target-tracking problem prevented the spacecraft from taking black-and-white photos during the flyby. The spacecraft's infrared sensor, however, confirmed that the small asteroid is similar to Vesta, a rare type of asteroid and one of the largest bodies in the main asteroid belt, which lies between Mars and Jupiter.

In September 2001, the spacecraft flew within 2,200 kilometers (1,400 mi) of the rocky, icy nucleus of the 10-kilometer-long (6-mi-long) comet Borrelly. Deep Space-1 produced high-resolution imagery of the comet and measured the gases and infrared waves around it, as well as how the gases interacted with the solar wind. The mission concluded on December 18, 2001. The spacecraft lasted three times its expected lifespan.

Communication with Deep Space-2 Lost

Eleven months into the mission, communication with the Mars Polar Lander, which carried the DS-2, was lost just before the pair reached the Martian surface in late 1999. NASA tried unsuccessfully to regain contact with the spacecraft, and ultimately called off the mission.

New Millennium Program

NASA Restructures NMP through ST-6. In an effort to cut costs without jeopardizing science, NASA decided that candidates involved with the New Millennium Program would receive NASA funding for technology development only. It is now the responsibility of the manufacturer to find a ride into space. According to NASA, this will be the first time the agency validates technology items as stand-alone subsystems. The first program affected was ST-6.

NMC-1. The New Millennium Carrier-1 (NMC-1) was being developed to ensure that ST-8 technology experiments would each have an equal opportunity for being hosted on a carrier spacecraft. The New Millennium Carrier project also sought to develop low-cost access-to-space approaches to accommodate subsystem-level technologies (e.g., ST-6, ST-8) for flight validation. Approaches included providing a means of accommodating the flight validations via existing host spacecraft or utilizing a small, dedicated free-flying platform to host multiple subsystem technology experiments.

ST-6 Teams and Technologies Chosen. Total NASA funding for the ST-6 flight-validation opportunity is $24.8 million. This includes the cost of all three technologies and all phases of the project. NASA chose eight candidate teams and technologies in January 2001 for the ST-6 mission, and downselected three that October. After a Critical Design Review in 2003, the two technology finalists were chosen:

- *The Charles Stark Draper Laboratory Inc, Cambridge, Massachusetts*. The Inertial Stellar Compass (ISC) consists of a mini star camera and microscopic gyro that allow a satellite to determine its own position and orientation. This lightweight technology is expected to advance nanosatellite development and create room for science instrument payloads on large- or medium-class spacecraft. The ISC was slated to fly on the Team Encounter spacecraft, but delays with Team Encounter mean that the ISC will need to find access to space elsewhere.
- *NASA's Jet Propulsion Laboratory, Pasadena, California*. JPL's Autonomous Sciencecraft Constellation software will allow a spacecraft to process data and make autonomous intelligent decisions to choose interesting observations and downlink the data it deems scientifically important. In 2008, testing of ASC software began.

ST-7 Contractors Chosen. Of the 13 prospective teams named in November 2001, NASA tapped Stanford University (Stanford, California) and the Busek Company (Natick, Massachusetts) to lead work on the Disturbance Reduction System technology which will constitute the ST-7 mission. The mission used sensor and thrust-producing technologies to sense and counteract any non-gravitational drag on the spacecraft, controlling its flight path so that the payload responds only to true gravitational forces.

NASA has allocated $62.6 million for ST-7 development. Stanford University will provide a highly sensitive gravitational reference sensor that will measure the position of a spacecraft with respect to an internal free-floating mass. Busek will provide a set of mini ion "MicroNewton" thrusters, which will control ST-7's position with extreme precision.

Launch is planned for 2014 on a European Space Agency spacecraft known as the Laser Interferometer Space Antenna (LISA) Pathfinder. The ST-7 is now part of the Physics of the Cosmos program.

Joint Development of EO-3 No More

NASA and the U.S. Navy's Office of Naval Research (ONR) were jointly developing the Earth Observing-3 spacecraft to validate technologies for weather-observation missions. ONR was funding the Indian Ocean Meteorological Imager, which would image the Indian Ocean region to collect meteorological data.

Program costs were to run about $160 million, excluding launch. The Navy was contributing approximately $60 million to the program for satellite modifications and wanted to extend the mission for five years. EO-3 was slated to fly as a primary payload (instrument/experiments) in October 2005.

Forecast International spoke with the EO-3 program's mission manager, Kim Leschly, who stated that the Navy was no longer participating with NASA and the National Oceanic and Atmospheric Administration (NOAA) and that consequently, no funding was identified for the spacecraft bus. EO-3/GIFTS was also demanifested from its 2005 launch. The GIFTS instrument development continued with NASA funding and was delivered in 2006.

On the Wings of a Pegasus

The ST-5 microsatellites successfully launched on March 22, 2006, aboard an Orbital Sciences Pegasus rocket from Vandenberg Air Force Base, California. The official launch time was 9:03:45 a.m.

Funding

Funding for New Millennium was provided under NASA's Heliophysics theme. The following funding figures are from NASA's FY12 budget request. The program received no funding after FY11.

U.S. FUNDING

	FY09 AMT	FY10 AMT	FY11 AMT	FY12 AMT	FY13 AMT	FY14 AMT	FY15 AMT	FY16 AMT
New Millennium	2.7	1.2	0.1	0.0	0.0	0.0	0.0	0.0

All $ are in millions.

Timetable

Month	Year	Major Development
Aug	1994	Science working group established
Sep	1995	DS-1 contractor selected
Oct	1998	DS-1 launched on Delta Med-Lite
Jan	1999	DS-2 launched on Delta Med-Lite; mission fails late in the year
Jul	1999	DS-1 rendezvous with asteroid 9969 Braille
	1999	ST-4 mission canceled
	2000	EO-2/SPARCLE mission terminated due to cost growth
Nov	2000	EO-1 launched
Sep	2001	EO-1 mission extended through September 2002
Sep	2001	Deep Space-1 rendezvous with Comet Borrelly
Dec	2001	Deep Space-1 mission concludes
Mar	2006	ST-5 launched on Pegasus XL
Dec	2006	ST-6 ISC launched with Tacsat-2
	2011	Planned launch of ST-7 DRS on ESA LISA Pathfinder spacecraft; date pushed back to 2014 under Physics of the Cosmos program
FY	2012	NMP program likely to end

Forecast Rationale

In 2009, NASA began the process of phasing out the New Millennium Program. In its FY09 budget request, NASA reduced the NMP's budget to accommodate reprioritization of programs within the Heliophysics Division. As a result, budgets were increased for sounding rockets as well as for research and analysis to achieve a more robust level of small payload opportunities.

In FY11, New Millennium Program funding primarily covered closeout activities, as well as continuation of Space Technology 8, a program to develop new space technology. No plans for launching ST-8 equipment were announced. Most likely, technology developed under Space Technology 8 will be used for other programs. All work taking place within the program was completed by FY12. No funding will be available to the program after that time.

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