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# Exploration in the New Millennium

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## Abstract

*The National Aeronautics and Space Administration (NASA) envisions a 21st-century program of space and Earth science missions that will use revolutionary new technologies and architectures to reduce costs and enhance the capabilities of missions. Needed will be advanced miniaturized instruments, microspacecraft, and "intelligent" flight systems to reduce the costs and personnel involved in operations monitoring. The goal of NASA's New Millennium Program (NMP) is to enable frequent, affordable, capable missions of the future by identifying, developing, and flight validating key technologies. Targeting technologies in development by NASA's field centers, government agencies, nonprofit organizations, and academia — and establishing partnerships among these entities to develop the technologies and implement the flights — NMP will enable future missions to avoid the risk of "first use," and at the same time take advantage of advanced capabilities. Teaming approaches and new management structures are also a part of NMP, with the aim of demonstrating effective operations methods for high-technology organizations in the post-2000 environment. The accelerated infusion of advanced, enabling technologies and the application of new ways of doing business will encourage development and open the way to the 21st century.*



## The New Millennium Concept

NASA's vision for its space and Earth science programs of the 21st century is bold: Exciting, affordable scientific missions with highly focused objectives will be launched frequently, with numerous "microspacecraft" carrying advanced miniaturized instruments returning a continuous flow of information from space to Earth. Using revolutionary new technologies and architectures to reduce the costs and enhance the capabilities of these missions, the United States will gain important data about Earth, the solar system, and the universe; new insights reaped from the programs will stimulate public interest and provide new learning opportunities for students at all levels. The wealth of new scientific information and its widespread dissemination — combined with the rapid development, deployment, and transfer of new technology — will maintain the United States' global leadership in space science and technology.

The goal of NASA's New Millennium Program (NMP) is to enable frequent, affordable, capable scientific missions in the 21st century by identifying, developing, and flight validating key technologies that can significantly contribute to lowering lifc-cycle costs while increasing scientific returns. Breakthrough technologies selected from the existing "pipeline" that is formed by and flows through current technology programs of NASA, other government agencies, nonprofit institutions, and academia will be developed in partnership among these organizations. Critical technologies will be validated through Icdic-sled spaceflights so that future science missions can take advantage of these technologies without having to assume the risks inherent in their first use.

In addition to developing and validating key enabling technologies, NMP will pioneer new ways of partnering among industry, nonprofit organizations, academic institutions, and NASA and other government agencies by developing and implementing illlm'alive management practices. '1 his will advance the competitive edge of the nation's high-technology organizations as wc move into the 21st century.

NMP is being implemented in partnership among NASA's Office of Space Science, Office of Mission to Planet Earth, and Office of Space Access and "1 echnology, and is managed by the Jet Propulsion 1 aboratory (]}'1 ) of the California Institute of '1 echnology. Several other NASA field centers are participating in the program as validation-flight implementers and/or as technology providers. Goddard Space Flight Center in particular will contribute significantly in the development and execution of the Earth science technology-validation flights.

## SCIENTIFIC EXPLORATION IN THE NEXT CENTURY

An essential element of the NMP technology-validation process is a clear understanding of the envisioned mode of carrying out scientific exploration in the next century. During the 20th century, specifically in the 1960s and 1970s, NASA's space science program focused primarily on developing and implementing solitary robotic explorers in which electronics were mainly discrete-composed based. As a spacecraft's functionality increased, so did its number of components. Since discrete-component reliability was limited, redundancy was used to allow the multiyear flights to last their required lifetime. Size, weight, power, design, development, and cost all grew accordingly with the spacecraft's increasing capabilities. Round-trip communications times dictated the nature and expansion of onboard autonomy and the types of fault protection and correction. Since launch-vehicle capability was very high, launching these spacecraft - which weighed thousands of kilograms - was well within our means. With transportation ability to visit other planets well irr hand, it became cost effective to try to maximize the science return from each mission, since spacecraft were launched infrequently. This, in turn, led to the development of spacecraft with capabilities of executing 20 or more science experiments. For example, the planetary exploration program, with its initial focus on reconnaissance and preliminary characterization of the solar system, has sent out single or dual spacecraft with complex complements of itl-s1111111('111s to gather fundamental information about planetary surfaces, atmospheres, magnetospheres, satellites, rings, and the interplanetary environment.

Continued use of individual or dual spacecraft to expand our exploration frontiers is still expected to be an important element of the space science program of the future. Astronomers will usc individual spacecraft to continue observations in all regions of the electromagnetic spectrum; space physicists will employ individual spacecraft to study the response of the Earth's atmosphere to solar radiative output; planetary scientists will use individual spacecraft to explore Pluto, the Kuiper Belt, and the universe beyond. Individual spacecraft can also be used to characterize the surface of Mercury and to study and monitor the outer planets and their satellites. Through a series of individual launches, individual spacecraft can also be used to survey multiple asteroids and comets and to provide samples from a range of possible objects targeted for study.

As we approach the 21st century, however, the nation's fiscal environment, our technological capabilities, and our relative maturity in terms of understanding Earth and the solar system all point to a new paradigm: one that capitalizes on new technologies to enable frequent launches of low-mass, low-cost spacecraft, each of which addresses a focused set of scientific questions.

NASA envisions the deployment of multiple spacecraft to analyze the more dynamic systems and processes in our solar system and beyond. Single-point measurements will be insufficient to address questions concerning complex, dynamic systems; these questions would best be answered through time-correlated measurements at multiple locations. For example, in using just a single spacecraft, it is impossible to discern with sufficient accuracy the extent to which solar tidal activity affects changes in planetary atmospheric structures. The science community has for some time supported the concept of using networks of landers to examine interior planetary dynamics and structures as a means of determining the size and nature of planetary cores and geologic activities. Constellations of spacecraft may prove to be the most cost-effective way to get the comprehensive information needed to determine solar variability and its effects on Earth, in order to further investigate global change and natural hazards.

Two examples of exciting 21st-century missions that will be enabled by NMP's technology-validation flights are comet sample return missions and extrasolar planetary imaging missions. Comet sample return missions form a category of high-priority missions that are focused on our solar system, grouped within the unifying theme of "Our Planetary Neighbors." Characterization of the primitive materials of which comets are composed will shed light on the origin and evolution of the solar system. The envisioned mission implementation includes the selection of an appropriate landing site following an orbital survey, in situ study, selection and collection of local samples, and return of samples to Earth through direct atmospheric entry. The second type of mission — an extrasolar planetary imaging mission — will explore the universe using a free-flying interferometer: a constellation of spacecraft capable of imaging extrasolar planets. Such a constellation could detect Earth-like planets and should provide information clarifying the origin and evolution of planetary systems in general.

## THE NEW MILLENNIUM [illegible]

Fulfilling this vision for the future will require new capabilities to reduce the costs of development, launch, and operations; to increase mission frequency; and to enhance scientific-observing and data-gathering capabilities. Capable microspacecraft with miniaturized instruments will be called for, with a move toward use of smaller, less costly launch vehicles. Also, shorter flight times and "intelligent" flight systems will be required in order to reduce the number of people needed to operate our spacecraft. Through a series of technology-driven missions, NMP will provide an orderly transition to this new paradigm by flight validating, those technologies that contribute most significantly to establishment of the paradigm.

The basic plan is relatively simple and straightforward: NMP will first identify shortcomings in current technology that prevent us from immediately carrying out our vision of scientific exploration. Breakthrough technologies providing affordable solutions will then be sought from the technology community, and [hose that are found to most significantly contribute to achieving our goal of frequent launches of exciting, affordable space and Earth science missions will be selected as high-priority candidates for development and validation.

## THE NEW MILLENNIUM SCIENCE WORKING GROUP

A New Millennium Science Working Group (SWG) has been chartered to help the program both in developing a vision of scientific exploration in the next century and in identifying the capabilities required to fulfill this vision. The SWG has listed the key scientific challenges facing the space and Earth sciences community as we enter the next century, emphasizing those challenges that are particularly amenable to solutions using small, capable spacecraft. The SWG has also helped in cataloging the kinds of missions we can expect to fly in the post-2000 era that might address these scientific challenges, while working closely with the NMP team to evaluate which capabilities these missions require, and using this information to identify and evaluate advanced-technology candidates that can provide these capabilities.

The SWG is expected to remain active through the duration of the New Millennium Program to ensure that the program stays focused on achieving our scientific vision of exploration for the next century.

## SELECTING TECHNOLOGIES FOR FLIGHTS

NMP will emphasize technologies that significantly contribute to reducing the costs, increasing the frequency, and enhancing the scientific capability of future science missions. It will sponsor revolutionary technology advances that offer significant new opportunities for future missions but which have traditionally been difficult to incorporate into science missions because of the inherently high risk associated with developing, qualifying, and validating new technologies.

Initial evaluation of the capabilities required to achieve our scientific vision has indicated a need to focus on several key technology areas. These are:

*Autonomy*: Technologies supporting revolutionary advances in autonomous spacecraft operations.

*Microelectronic Systems*: Technologies supporting revolutionary advances in microelectronics in flight computing, command and data handling, guidance and navigation, and power subsystems

*Instruments and Microelectromechanical Systems (MEMS)*: Technologies supporting revolutionary advances in [illegible], miniaturized instruments, novel instrument designs, and interferometric systems, using MEMS advances where appropriate.

*Communications Systems*: Technologies supporting revolutionary advances in transmitters, amplifiers, receivers, antennas, switches, and transmission lines, with frequencies ranging from traditional RF bands (S, X, Ka) and beyond, to optical wavelengths.

*Modular and Multifunctional Systems*: Technologies supporting revolutionary advance in a number of areas including, but not limited to, structural, mechanisms, thermal control, and propulsion.

Integrated Product Development Teams (IPDTs) have been formed to identify advanced-technology candidates currently under development in these key areas. Initially, the IPDTs are being co-led by a technology expert from JPL and an expert from another NASA center. Industry, academia, NASA and other government agencies, and nonprofit organizations arc all expected to participate as IPDT members. Solicitations for team participation will be issued periodically throughout the duration of the program.

"1 he IPDTs will establish and maintain "road maps" - phased technology-development plans needed to achieve required capabilities - for each key technology area. The teams will determine costs associated with advancing each technology to the point where it can be flight validated. The IPDTs (or certain subsets of these teams) are expected to facilitate the final development of the technologies determined to be of most benefit toward achieving NM]' objectives, and infuse them into the validation flights.

## IDENTIFICATION OF CANDIDATE NMP MISSION SETS

The NMP Architecture Development Team, using JPL's Project Design Center, is beginning to evaluate candidate mission sets. Each mission set is composed of three to four technology-validation flights expected to take place between 1997 and 2000; each flight is structured to validate a selected suite of advanced technologies. The Architecture Development Team, using technology-development plan inputs from the 11'1>"1"s, will evaluate a range of mission set options to determine the extent to which they meet NMP objectives.

While the primary purpose of each flight will be to validate a given suite of advanced technologies, the mission itself will be designed to be of scientific value and of sufficient complexity so as to fully exercise the technologies to perform as they would in future scientific missions. 1 inking the primary technology objectives with a secondary scientific objective will assure close and continued interaction between the technology developers and the scientific community throughout the design, development, and operations phases of the missions. This is critical to ensuring that, once validated, the technologies will be readily incorporated into future scientific missions.

NASA Headquarters will make the decision to proceed with the development of a specific mission set, applying a number of metrics in [heir evaluation. These metrics include assessing the overall technology richness of the mission and its scientific value, as well as the future commercialization potential of the technologies. Additionally, life-cycle cost comparisons - i.e., comparing the cost of missions employing new technologies versus those that do not - will be established to clearly illustrate the long-term benefits of the program

It should be noted that not all technologies will require flight validation, since in some cases ground validation will suffice, Also, an NMP technology validation may take advantage of non-NMP flight opportunities when an appropriate opportunity exists.

## VALIDATION FLIGHT TEAMS

After NASA Headquarters decides to proceed with a given mission set, Flight Teams will be established to implement each technology-vali(lation flight. Each Flight Team will include members from industry, academia, and govern -

ment - with industry and academia participation being formally solicited - and will work closely with the IPDTs and the NMP Architecture Development Team to design the technology-validation flights in a manner compatible with the technology-readiness dates, launch-schedule, and funding.

JPL will use its Flight System Testbed (FST) to support mission development as required. The FST allows the Flight Teams to rapidly evaluate and test new technologies by creating a virtual (simulated) spacecraft in which system-level evaluation of components can be carried out very early in the development cycle. In addition to spacecraft hardware and software validation, the FST also accommodates ground data system development and end-to-end project simulation and testing. During spacecraft development, designers can bring one or several subsystems, or even an entire small spacecraft, to the FST for testing.

## New Millennium Partnerships

innovative partnerships among industry, nonprofit organizations, academic institutions, and NASA and other government agencies are integral to NMP's success. Partners will be involved in every aspect of the program. They will participate as IPDT members, identifying and providing breakthrough technologies appropriate for NMP technology-validation flights, and as Flight Team members, assuming a major role in developing and fabricating components, subsystems, systems, and spacecraft for the flight. They will also participate through the duration of mission operations and support data processing. These partnerships will create an environment conducive to the transfer of technologies and expertise to those expected to be the primary spacecraft providers of the future.

NMP expects to capitalize on the existing NASA Small Business Innovative Research (SBIR) program to focus small business technology-development efforts in support of NMP objectives. Consequently, members of the SBIR program are also expected to form partnerships within NMP.

NMP partnerships are expected to evolve over the course of the program. New team members will be brought on board as new technologies are identified and new validation missions are implemented. A "Council" will be instituted to recommend strategies and activities to NMP that will maximize the benefits and competitive advantages of these partnerships.

## Summary

Investing in the New Millennium Program is investing in the future. fulfilling the vision of future scientific exploration depends on new capabilities to reduce costs of development, launch, and operations; to increase mission frequency; and to enhance scientific-observing and data-gathering capabilities. Smaller launch vehicles and capable microspacecraft and microinstruments will be required, and fewer people will be needed for operations because of shorter flight times and the use of "intelligent" flight systems having increased autonomy.

NASA's vision for the 21st century is a compelling one, incorporating access to new frontiers and greatly expanding our scientific understanding. With networks of landers on Mars and Venus, clusters of probes mapping planetary ionospheres and magnetospheres, spacecraft returning samples from asteroids and comets, and constellations of spacecraft peering into neighboring solar systems, we will truly be able to create a virtual human presence in space. The concepts of fleets of individual spacecraft, constellations, and networks of spacecraft arc allowing new mission approaches for the future to evolve. We need multiple spacecraft to go beyond our initial solar system reconnaissance and to more completely characterize dynamic systems in the way wc ate able to do on the surface of Earth.

An accelerated infusion of new, enabling technologies and new ways of doing business are integral to achieving these goals. The Ncw Millennium Program, with its emphasis on strong partnerships among government, academia, and industry, and between the science and technology communities, will provide an environment conducive to rapid technology development and flight validation. These benefits, along with the substantial benefits to the science community, herald new ways of doing business in the 21st century.

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