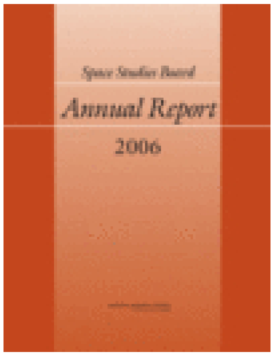
Space Studies Board Annual Report 2006



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Space Studies Board

Annual Report

2006

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

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The Space Studies Board is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical questions of national importance. The National Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear through its volunteer advisory committees.

Support for the work of the Space Studies Board and its committees and task groups was provided by National Aeronautics and Space Administration contracts NASW-01001 and NNH06CE15B, National Oceanic and Atmospheric Administration Contract DG133R04CQ0009, and National Science Foundation Grants ATM-0109283 and AST-0075757.

From the Chair

The foreword to this 2006 Annual Report of the Space Studies Board provides an opportunity to comment not only on our activities for the past year but also on the environment that has shaped those activities. As has been true for the past several years, and may well be for years to come, we live in an environment that is continually changing. NASA has continued to pursue the Vision for Space Exploration laid down by President George W. Bush in 2004, but it has obtained only limited resources to do so, requiring continuing adjustments in other NASA programs and reconsideration of our plans for the future.

In this environment, the activities of the Space Studies Board are of particular importance. We can, through the National Research Council reports that we charter, provide advice on the issues most important to the execution and planning of the space program. Through our Congressional testimony and public statements, we call attention to the concerns and dilemmas that confront NASA and the science community that it supports.

The Space Studies Board itself is also in transition. The year 2006 marked the arrival of a new Director, Marcia Smith, who is the permanent replacement for the long-serving and much admired Joe Alexander. As is evident in this Annual Report, Marcia has had to experience a year that has been among the busiest for the Space Studies Board. And that level of activity appears only to be increasing, as we attempt to help navigate the space program through the technical challenges and political turbulence that are expected in the years ahead.

L.A. Fisk
Chair
Space Studies Board

Contents

Space Studies Board Chairs

Lloyd V. Berkner (deceased), Graduate Research Center, Dallas, Texas, 1958–1962

Harry H. Hess (deceased), Princeton University, 1962–1969

Charles H. Townes, University of California at Berkeley, 1970–1973

Richard M. Goody, Harvard University, 1974–1976

A.G.W. Cameron (deceased), Harvard College Observatory, 1977–1981

Thomas M. Donahue (deceased), University of Michigan, 1982–1988

Louis J. Lanzerotti, American Telephone & Telegraph Co., Bell Laboratories, 1989–1994

Claude R. Canizares, Massachusetts Institute of Technology, 1994–2000

John H. McElroy (deceased), University of Texas at Arlington, 2000–2003

Lennard A. Fisk, University of Michigan, 2003–

Space Studies Board Vice Chairs

George A. Paulikas, The Aerospace Corporation (retired), 2003–2006

A. Thomas Young, Lockheed Martin Corporation (retired), 2006–

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Charter and Organization of the Board

THE ORIGINS OF THE SPACE SCIENCE BOARD

The National Academy of Sciences (NAS) was created in 1863 by an Act of Congress, signed by President Abraham Lincoln, to provide scientific and technical advice to the government of the United States. Over the years, the breadth of the institution has expanded, leading to the establishment of the National Academy of Engineering (NAE) in 1964 and the Institute of Medicine (IOM) in 1970. The National Research Council (NRC), the operational arm of the National Academies, was founded in 1916. The NAS, NAE, IOM, and NRC are collectively referred to as "The National Academies." More information is available at http://nationalacademies.org.

The original charter of the Space Science Board was established in June 1958, three months before the National Aeronautics and Space Administration (NASA) opened its doors. The Space Science Board and its successor, the Space Studies Board (SSB), have provided expert external and independent scientific and programmatic advice to NASA on a continuous basis from NASA's inception until the present. The Board has also provided such advice to other executive branch agencies, including the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the U.S. Geological Survey, and the Department of Defense, as well as to Congress.

The fundamental charter of the Board today remains that defined by National Academy of Sciences' president Detlev W. Bronk in a letter to Lloyd V. Berkner, first chair of the Board, on June 26, 1958, which established the SSB:

> We have talked of the main task of the Board in three parts—the immediate program, the long-range program, and the international aspects of both. In all three we shall look to the Board to be the focus of the interests and responsibilities of the Academy-Research Council in space science; to establish necessary relationships with civilian science and with governmental science activities, particularly the proposed new space agency, the National Science Foundation, and the Advanced Research Projects Agency; to represent the Academy-Research Council complex in our international relations in this field on behalf of American science and scientists; to seek ways to stimulate needed research; to promote necessary coordination of scientific effort; and to provide such advice and recommendations to appropriate individuals and agencies with regard to space science as may in the Board's judgment be desirable.
>
> As we have already agreed, the Board is intended to be an advisory, consultative, correlating, evaluating body and not an operating agency in the field of space science. It should avoid responsibility as a Board for the conduct of any programs of space research and for the formulation of budgets relative thereto. Advice to agencies properly responsible for these matters, on the other hand, would be within its purview to provide.

The Space Science Board changed its name to the Space Studies Board in 1989 to reflect its expanded scope, which now includes space applications and other topics. Today, the Space Studies Board exists to provide an independent, authoritative forum for information and advice on all aspects of space science and applications, and it serves as the focal point within the National Academies for activities on space research. It oversees advisory studies and program assessments, facilitates international research coordination, and promotes communications on space science and science policy among the research community, the federal government, and the interested public. The SSB also serves as the U.S. National Committee for the Committee on Space Research (COSPAR) of the International Council for Science (ICSU).

THE SPACE STUDIES BOARD TODAY

The Space Studies Board is a unit of the NRC's Division on Engineering and Physical Sciences (DEPS). DEPS is one of six major program units of the NRC through which the institution conducts its operations on behalf of NAS, NAE, and IOM. Within DEPS there are a total of 13 boards that cover a broad range of physical science and engineering disciplines and mission areas.

Members of the DEPS Committee on Engineering and Physical Sciences (DEPSCOM) provide advice on Board membership and on proposed new projects to be undertaken by ad hoc study committees formed under the SSB's auspices. Every 3 years, DEPSCOM reviews the overall operations of each of the DEPS Boards. The next review of the SSB will take place in 2007.

The "Space Studies Board" encompasses the Board itself, its standing committees (see Chapter 2), and ad hoc study committees (see Chapter 3), and its staff. The Board is composed of prominent scientists, engineers, industrialists, scholars, and policy experts in space research appointed for 2-year staggered terms. They represent seven space research disciplines: space-based astrophysics, heliophysics (also referred to as solar and space physics), Earth science, solar system exploration, microgravity life and physical sciences, space systems and technology, and science and technology policy. In 2006, there were 23 Board members. The chairs of the SSB's standing committees are members of the Board, and of its Executive Committee. The chair of the NRC's Aeronautics and Space Engineering Board (ASEB) and the U.S. representative to COSPAR are ex officio members. A standing liaison arrangement also has been established with the European Space Science Committee (ESSC), part of the European Science Foundation, and the NRC's Ocean Studies Board.

Organization

The organization of the SSB in 2006 is illustrated in Figure 1.1. Taken together, the Board and its standing and ad hoc study committees generally hold as many as 40 meetings during the year.

Major Functions of the Space Studies Board

The Board provides an independent, authoritative forum for information and advice on all aspects of space science and applications and serves as the focal point within the National Academies for activities on space research. The Board itself does not conduct studies, but it oversees advisory studies and program assessments conducted by ad hoc study committees (see Chapter 3) formed in response to a request from a sponsor. All projects proposed to be conducted by ad hoc study committees under the auspices of the SSB must be reviewed and approved by the chair and vice-chair of the Board (as well as other NRC officials).

Decadal surveys are a signature product of the Board, providing strategic direction to NASA, NOAA, and other agencies on the top priorities over the next 10 years in astronomy and astrophysics, solar system exploration, solar and space physics, and Earth science. (The astronomy and astrophysics decadal survey is a joint effort with the NRC's Board on Physics and Astronomy.)

The Board serves as a communications bridge on space research and science policy among the scientific research community, the federal government, and the interested public.

The Board ordinarily meets three times per year (March, June, and November) to review the activities of its committees and to be briefed on and discuss major space policy issues. The November Board meeting typically involves a workshop on a topic of current interest and results in a workshop report. In 2006, that topic was a review of how the Board conducts its "decadal surveys" of specific space research disciplines. The goal of the workshop was to review how the decadal surveys are conducted and to recommend methods to ensure that the decadal surveys remain credible and resilient during the 10-year period they cover. The report of the workshop, which was published in 2007, is available at http://books.nap.edu/catalog.php?record_id=11894.

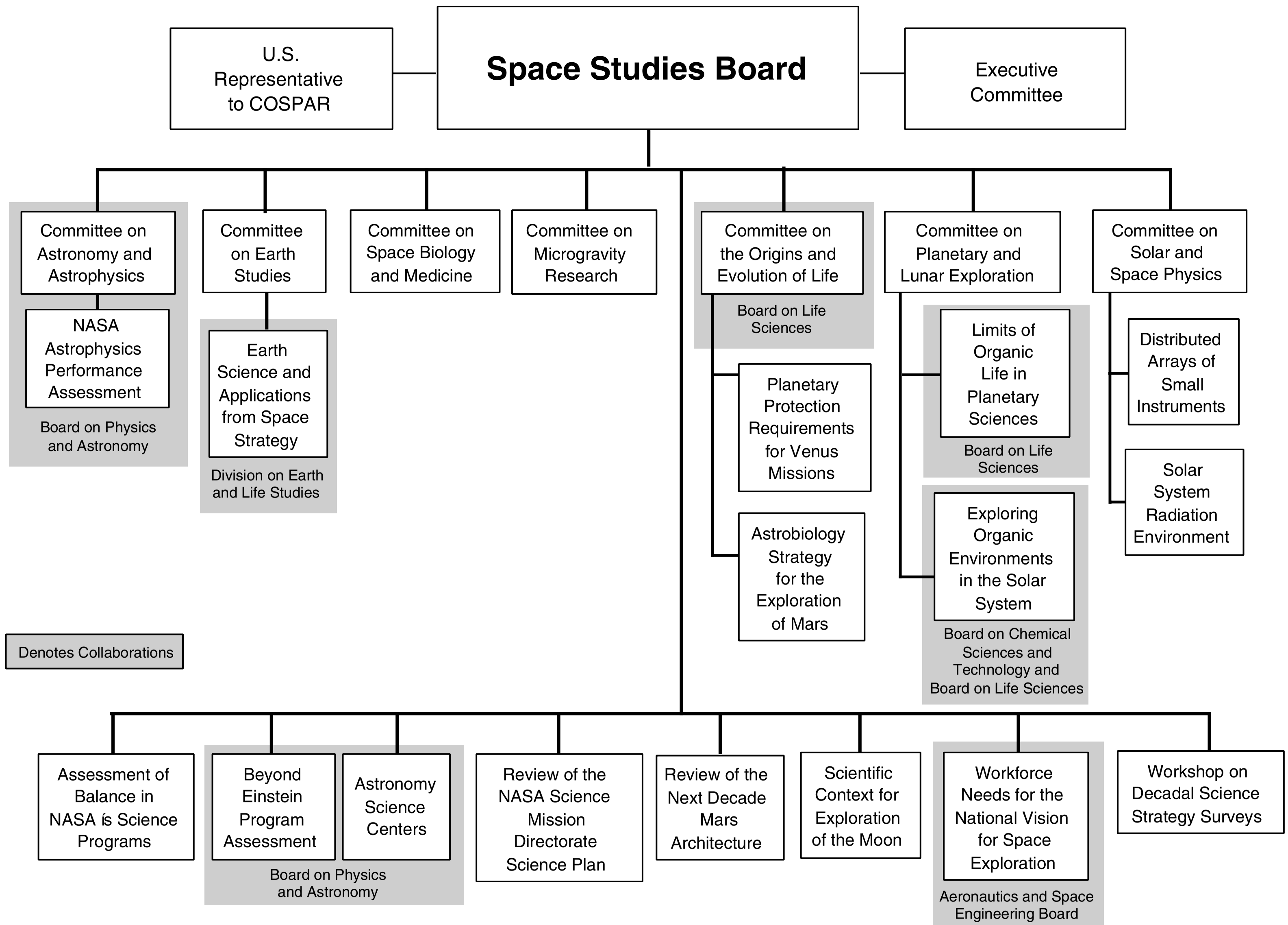

FIGURE 1.1 Organization of the Space Studies Board, its standing committees, and ad hoc study committees in 2006. Shaded boxes denote activities performed in cooperation with other National Research Council units.

International Representation and Cooperation

The Board serves as the U.S. National Committee for COSPAR, an international, multidisciplinary forum for exchanging space science research. Board members may individually participate in COSPAR scientific sessions to present their research or, occasionally, present the results of an SSB report to the international community, or conduct informal information exchange sessions with national entities within COSPAR scientific assemblies.

The Board also has a regular practice of exchanging observers with the European Space Science Committee, which is part of the European Science Foundation (see http://www.esf.org/).

Space Studies Board Committees

Executive Committee

The Executive Committee (XCOM), composed entirely of Board members, facilitates the conduct of the Board's business, permits the Board to move rapidly to lay the groundwork for new study activities, and provides strategic planning advice. XCOM meets annually for a session on the assessment of SSB operations and future planning. Its membership includes the chair and vice-chair of the Board, the chairs of the standing committees, and one Board member for each discipline that does not have a standing committee.

Standing Committees

Discipline-based standing committees are the means by which the Board conducts its oversight of specific space research disciplines. Each standing committee is composed of about a dozen specialists, appointed to represent the broad sweep of research areas within the discipline. Like the Board itself, each standing committee serves as a communications bridge with its associated research community and participates in identifying new projects and prospective members of ad hoc study committees. Standing committees do not, themselves, write reports, but oversee reports written by ad hoc study committees created under their auspices.

At the beginning of 2006, SSB had seven standing committees:

- Committee on Astronomy and Astrophysics (CAA)
- Committee on Earth Studies (CES)
- Committee on Microgravity Research (CMGR)
- Committee on the Origins and Evolution of Life (COEL)
- Committee on Planetary and Lunar Exploration (COMPLEX)
- Committee on Solar and Space Physics (CSSP)
- Committee on Space Biology and Medicine (CSBM)

On August 18, 2006, a new 5-year contract with NASA's Science Mission Directorate (SMD) came into effect to support the operations of the Board and its standing committees. Due to a reorganization within NASA, the disciplines of microgravity life and physical sciences were moved out of SMD and into the Exploration Systems Mission Directorate. Consequently, the new contract with SMD did not support the continuation of CSBM or CMGR and those committees were abolished.

Ad Hoc Study Committees

Ad hoc study committees are created by NRC action to conduct specific studies at the request of sponsors. These committees typically produce NRC reports that provide advice to the government and therefore are governed by Section 15 of the Federal Advisory Committee Act (FACA). Ad hoc study committees usually write their reports after holding two or three information-gathering meetings, although in some cases they may hold a workshop in addition to or instead of information gathering meetings.

In other cases, workshops are organized by ad hoc study committees that serve as organizers only, and the workshop report is written by a rapporteur and does not contain findings or recommendations. In those cases, the study committee is not governed by FACA Section 15 since no NRC advice results from the workshop.

The ad hoc study committees that were in place during 2006 are summarized in Chapter 3.

COLLABORATION WITH OTHER NATIONAL RESEARCH COUNCIL UNITS

Much of the work of the Board involves topics that fall entirely within its principal areas of responsibility and can be addressed readily by its members and committees. However, there are other situations in which the need for breadth of expertise, alternative points of view, or synergy with other NRC projects leads to collaboration with other units of the NRC.

The Space Studies Board has engaged in many such multi-unit collaborations. Among the NRC Boards with which the SSB works most often are the Aeronautics and Space Engineering Board, the Board on Physics and Astronomy, the Board on Atmospheric Sciences and Climate, the Board on Life Sciences, and the Ocean Studies Board. This approach to projects has the potential to bring more of the full capability of the National Academies to bear in preparing advice for the federal government and the public. Multi-unit collaborative projects also present new challenges—namely, to manage the projects in a way that achieves economies of scale and true synergy rather than just adding cost or complexity. Collaborative relationships between the SSB and other NRC units during 2006 are illustrated in Figure 1.1.

ASSURING THE QUALITY OF SSB REPORTS

A summary listing of all Space Studies Board reports released during 2006 is presented in Table 1.1. Included are reports of interest to NASA's Science Mission Directorate, NASA's Exploration Systems Directorate, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Department of Defense.

A major contributor to the quality of these reports is the requirement that NRC reports are peer-reviewed. Except for the *Space Studies Board Annual Report—2005,* all of the reports were subjected to extensive peer review, which is overseen by the NRC's Report Review Committee (RRC). Typically 4 to 7 reviewers (occasionally as many as 15 or more) are selected on the basis of recommendations by NAS and NAE section liaisons, SSB members, and staff. The reviewers are subject to approval by the NRC. The identities of external reviewers are not known to a report's authors until after the review has been completed and the report has been approved by the RRC. The report's authors, with the assistance of SSB staff, must provide some response to every specific comment from every external reviewer. To ensure that appropriate technical revisions are made to the report and that the revised report complies with NRC policy and standards, the response-to-review process is overseen and refereed by an independent monitor, or in some cases, also by a coordinator. Monitors are appointed by the RRC and are members of the NAS, NAE, or IOM. Coordinators are appointed by DEPS and typically have specific subject area knowledge of the topic of the report. All of the reviews emphasize the need for scientific and technical clarity and accuracy and for proper substantiation of the findings and recommendations presented in the report. Names of the external reviewers, including the monitor (and coordinator if one was appointed), are published in the final report, but their individual comments are not released.

Another important method to ensure high-quality work derives from the size, breadth, and depth of the cadre of experts who serve on SSB and its committees or participate in other ways in the activities of the Board. Some highlights of the demographics of the SSB in 2006 are presented in Tables 1.2 and 1.3. During 2006, a total of 355 individuals from 99 colleges and universities and 87 other public or private organizations served as formally-appointed members of the Board and its committees. Over 220 individuals participated in SSB activities either as presenters or as invited workshop participants. The report review process is as important as the writing of reports, and during 2006, 52 different external reviewers contributed to critiques of draft reports. Overall, more than 600 individuals from 105 academic institutions, 69 industry or nonprofit organizations, and 35 government agencies or offices participated in SSB activities. That number included 48 members of NAS, NAE, or IOM. Being able to draw on such a broad base of expertise is a unique strength of the NRC advisory process.

TABLE 1.1 Space Studies Board Reports Released in 2006

Report Title	Oversight Committee or Board[a]	Principal Agency Audience[b]				
		SMD	ESMD	NOAA	NSF	OTHER
"A Review of NASA's 2006 Draft Science Plan" [short report]	SSB	X				
An Assessment of Balance in NASA's Science Programs	SSB	X				
"Assessment of Planetary Protection Requirements for Venus Missions" [short report]	COEL		X			
Distributed Arrays of Small Instruments for Solar-Terrestrial Research: Report of a Workshop	CSSP	X			X	
Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report	SSB	X			X	
Review of the Next Decade Mars Architecture[c]	COMPLEX	X				
The Scientific Context for Exploration of the Moon: Interim Report	COMPLEX	X	X	X		
Space Radiation Hazards and the Vision for Space Exploration: Report of a Workshop	CSSP	X		X		DOD
Space Studies Board Annual Report—2005	SSB					All

[a]Oversight committee or board
- CSSP Committee on Solar and Space Physics
- COMPLEX Committee on Planetary and Lunar Exploration
- SSB Space Studies Board

[b]Principal agency audience
- SMD NASA Science Mission Directorate
- ESMD NASA Exploration Systems Mission Directorate
- NOAA National Oceanic and Atmospheric Administration
- NSF National Science Foundation
- DOD Department of Defense

[c]An earlier, edited version of this report, formatted as a letter, was sent to NASA on June 30, 2006.

TABLE 1.2 Experts Involved in the Space Studies Board and Its Subunits, January 1, 2006, to December 31, 2006

	Number of Board and Committee Members	Number of Institutions or Agencies Represented
Academia	232	99
Government and national facilities[a]	38	23
Private industry	43	31
Nonprofit and other[b]	42	33
Total[c,d]	355	186

[a]Includes NASA and other U.S. agencies and national facilities (e.g., Los Alamos National Laboratory (LANL), U.S. Geological Survey (USGS), NOAA).
[b]Other includes foreign institutions and entities not classified elsewhere.
[c]Includes 36 NAS, NAE, IOM members.
[d]Thirty-two SSB members, 323 committee members.

TABLE 1.3 Summary of Participation in Space Studies Board Activities, January 1, 2006, to December 31, 2006

	Academia	Government and National Facilities[a]	Private Industry	Nonprofit and Others	Total Individuals
Board/committee members	232	38	43	42	355
Guest experts	63	71	10	19	165
Reviewers	37	6	6	3	52
Workshop participants	23	24	12	7	66
Total	355	139	71	71	638

NOTE: Counts of individuals are subject to an uncertainty of ±3 due to possible miscategorization.
[a]Includes government agencies and national facilities (e.g., National Optical Astronomy Observatory (NOAO), LANL, National Radio Astronomy Observatory, Space Telescope Science Institute, Applied Physics Laboratory, Lawrence Berkeley National Laboratory, Naval Research Laboratory).

Total number of NAS, NAE, and/or IOM members	48
Total number of non-U.S. participants	13
Total number of countries represented, including United States	6
Total number of participants by gender	378(M); 93(F)
Total number of different institutions represented	
Academia	105
Government and national facilities	35
Industry	34
Nonprofit and other	35

U.S. government agencies represented: NASA, NOAA, National Science Foundation, NIST, USGS, Environmental Protection Agency (EPA), Office of Science and Technology Policy, Office of Management and Budget, Smithsonian Institution, U.S. Congress.

PERFORMANCE MEASURES

One way to assess the performance of the SSB is to examine the extent to which the Board's efforts have been relevant to the full range of government interests in civilian space research. Figure 1.2 summarizes the principal federal agency audiences to which SSB reports were directed from 2000 through 2006. Reports on NASA-wide issues were addressed to multiple NASA offices or the whole agency; reports on SMD issues, to the Science Mission Directorate; and reports on ESMD issues, to the Exploration Systems Mission Directorate. Within NASA, SMD has been the leading sponsor of SSB reports. The "multiple government agencies" category covers reports that were directed to one or more agencies besides NASA—for example, NOAA, NSF, the Department of Energy, and/or DOD.

SSB OUTREACH AND DISSEMINATION

Enhancing outreach to a variety of interested communities and improving dissemination of Board reports remains a high priority for the SSB. In 2006, the SSB moved to distribution of the quarterly newsletter entirely by electronic means to its approximately 1,400 subscribers, except for a very small group of individuals (less than 10) who request hard copies. Several kinds of report announcements, fliers, and mailing list sign-up cards were designed and used at SSB committee meetings and national and international scientific society meetings.

The Board teamed with other NRC units (including the Division on Earth and Life Studies, the Board on Physics and Astronomy, the National Academies Press, the Office of News and Public Information, and the Proceedings of the National Academy of Sciences) to take exhibits to national meetings of the American Geophysical Union and the American Astronomical Society. Popular versions of the three decadal surveys (*Astronomy and Astrophysics in the New Millennium*, *New Frontiers in the Solar System*, and *The Sun to the Earth—and Beyond*) continue to be widely distributed to the science community and the general public. Over, 1,000 copies of the popularized version of the solar and space physics decadal survey, *Understanding the Sun and Solar System Plasma*, were distributed through the NASA-sponsored "Living with a Star" education seminar. As a consequence of these activities, roughly 3,100 additional copies SSB reports were distributed.

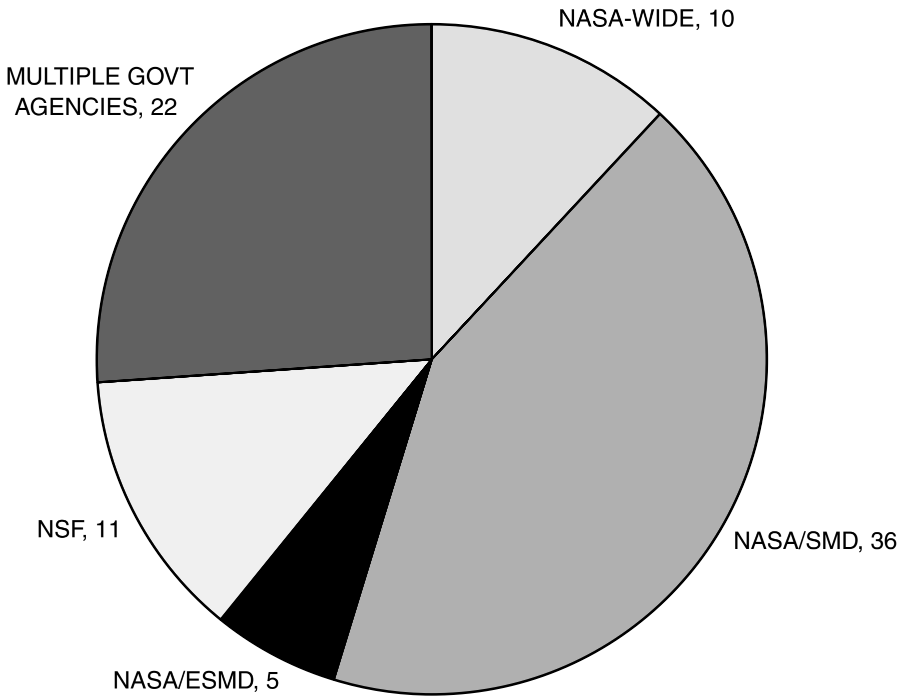

FIGURE 1.2 Principal federal agency audiences for Space Studies Board reports published from 2000 through 2006. Totals are inclusive of more than one agency audience per report.

Formal reports delivered to government sponsors constitute one of the primary products of the work of the SSB, but the dissemination process has a number of other important elements. The Board is always seeking ways to ensure that its work reaches the broadest possible appropriate audience and that it has the largest beneficial impact. Copies of reports are routinely provided to key executive branch officials, members and staffs of relevant congressional committees, and members of other interested NRC and federal advisory bodies. Members of the press are notified about the release of each new report, and the Board maintains a substantial mailing list for distribution of reports to members of the space research community. The SSB publishes summaries of all new reports in its quarterly newsletter. The Board also offers briefings by committee chairs and members or SSB staff to officials in Congress, the executive branch, and scientific societies. Reports are posted on the SSB Web home page at http://www7.nationalacademies.org/ssb and linked to the National Academies Press Web site for reports at http://www.nap.edu.

INTERNSHIP PROGRAM

The SSB has operated a very successful competitive summer internship program since 1992. The general goal of each internship is to provide a promising undergraduate student an opportunity to work in civil space research policy in the nation's capital, under the aegis of the National Academies. Interns work with the Board, its committees, and staff on one or more of the advisory projects currently underway. Other interns, paid or unpaid, also join the Board staff on an ad hoc basis. For intern opportunities at the SSB, and a list of past SSB interns, visit the SSB Web site at http://www7.nationalacademies.org/ssb/SSB_SpacePolicyInternship.html.

2
Board and Standing Committees: Activities and Membership

At the end of 2006, the Space Studies Board (SSB) had five standing committees representing various disciplines: the Committee on Astronomy and Astrophysics (jointly with the Board on Physics and Astronomy), the Committee on Earth Studies, the Committee on the Origins and Evolution of Life (jointly with the Board on Life Sciences), the Committee on Planetary and Lunar Exploration, and the Committee on Solar and Space Physics. Two other committees—the Committee on Microgravity Research and the Committee on Space Biology and Medicine—were disbanded as of August 16, 2006; their work had been largely discontinued due to changing priorities at NASA. The Board and its standing committees provide strategic direction and oversee activities of ad hoc study committees (see Chapter 3), interact with sponsors, and serve as a communications conduit between the government and the scientific community. They do not provide formal advice and recommendations, and therefore are not subject to the Federal Advisory Committee Act (FACA), Sec. 15.

SPACE STUDIES BOARD

HIGHLIGHTS OF SPACE STUDIES BOARD ACTIVITIES

First Quarter

The Space Studies Board held its 148th meeting at the National Academies' Keck Center in Washington, D.C., on March 6-8, 2006, in conjunction with the meeting of the ad hoc Committee on an Assessment of Balance in NASA's Science Programs (see Chapter 3). The meeting time of the Board was devoted to reviewing the status of selected ongoing SSB studies, planning near-term consultations with government officials regarding potential future studies, and planning the next SSB meeting.

Second Quarter

The Space Studies Board's 149th meeting on May 2, 2006, at the National Academy of Sciences' building in Washington, D.C., was devoted entirely to meeting with NASA Administrator Michael Griffin. Dr. Griffin and the Board had a dialogue about NASA's priorities and related issues.

The Space Studies Board held its 150th meeting on June 13-15, 2006, at NASA's Johnson Space Center (JSC) in Houston, Texas. Mike Coats, Director of JSC, opened the meeting by welcoming the Board and providing an overview of the center. Highlights of the first day included briefings by Wayne Hale, Space Shuttle Program Manager, JSC; Mike Sufferdini, International Space Station (ISS) Program Manager, JSC; Paul Marshall, JSC, on the Crew Exploration Vehicle; and John Mather, Goddard Space Flight Center (GSFC), Phil Sabelhaus, GSFC, and Eric Smith, NASA Headquarters, on the James Webb Space Telescope. Mary Cleave, Associate Administrator for the Science Mission Directorate (SMD), joined the Board by teleconference and provided an overview of SMD activities. On the second day, Carl Walz, NASA Headquarters, briefed the Board by teleconference on NASA's plans for spending the 15 percent of ISS research funds set aside by Congress for non-exploration research. Don Thomas, JSC, followed with an update on other ongoing and planned ISS research. Later in the day, Board members enjoyed tours of JSC's planetary science curatorial facilities. On the third day of the meeting, briefings were given by Steve Mackwell, director of the Lunar and Planetary Institute; Benjamin Neumann, NASA Headquarters on NASA's lunar robotic exploration program, via teleconference; and Jeff Hanley, JSC, on Project Constellation.

Farewells were said to several members whose terms ended on June 30, 2006, including George A. Paulikas (vice chair, Space Studies Board); Reta F. Beebe (chair, Committee on Planetary and Lunar Exploration); Roger D. Blandford (co-chair, Committee on Astronomy and Astrophysics); Radford Byerly, Jr.; Donald E. Ingber (chair, Committee on Space Biology and Medicine); Ralph H. Jacobson, Calvin W. Lowe; Dennis W. Readey (chair, Committee on Microgravity Research); and J. Craig Wheeler.

Third Quarter

The Board did not meet during the third quarter; however, the SSB executive committee (XCOM) did meet on August 22-24, 2006, for its annual strategic planning session at the J. Erik Jonsson Woods Hole Center in Woods Hole, Massachusetts. The XCOM received a visit from Senator Barbara A. Mikulski. Senator Mikulski shared her thoughts on NASA's space science program, and gave her insights and perceptions about the range of issues facing NASA and the country. She discussed her work on securing support for the Mikulski-Hutchison amendment to add $1 billion in funding for NASA in FY2007, and the best possible future for our nation in space. In addition to the discussion with Senator Mikulski, the XCOM spoke with several staff from the Senate and House Appropriations committees, the House Science Committee, and the Senate Commerce Committee. NASA SMD representatives also attended the meeting for a discussion on the outlook for future SSB–SMD interactions. The XCOM continued general discussion on the roles and operations of the Board and its standing committees, ad-hoc committees, the NRC Report Review process, potential new study projects, and planning for the November SSB meeting which would coincide with a workshop to discuss how to ensure the resilience of SSB's decadal surveys.

Fourth Quarter

The Space Studies Board held a half-day meeting at the Arnold and Mabel Beckman Center in Irvine, California, on November 14, 2006. The Board meeting was followed by a two-day Board-sponsored workshop on decadal surveys (see Chapter 4). The Board welcomed seven new members whose terms began on July 1: Steven Battel, Charles Bennett, Jack Fellows, Kenneth Nealson, James Pawelczyk, Joseph Veverka, and Warren Washington. The annual balance and composition discussion was held. The Board chair and vice-chair reported on discussions held at the Board's Executive Committee meeting in August. Board members were presented with the executive summaries of four recently released SSB reports. In addition, the statements of task for three new or potential SSB activities were reviewed: "Earth Science and Applications from Space: Ensuring the Climate Measurements from NPOESS," "NASA's Beyond Einstein Program: An Architecture for Implementation," and a potential seminar series "Celebrating the First 50 Years of Space Science: In Commemoration of the 50th Anniversary of the International Geophysical Year." The Board ended the meeting with a brief discussion of the objectives for the SSB workshop on decadal surveys, which was about to commence.

SPACE STUDIES BOARD MEMBERSHIP

July 1, 2005–June 30, 2006

Lennard A. Fisk (chair), University of Michigan
George A. Paulikas (vice chair), The Aerospace Corporation (retired)
Spiro K. Antiochos, Naval Research Laboratory
Daniel N. Baker, University of Colorado, Boulder
Reta F. Beebe, New Mexico State University
Roger D. Blandford, Stanford University
Radford Byerly, Jr., University of Colorado, Boulder
Judith A. Curry, Georgia Institute of Technology
Jack D. Farmer, Arizona State University
Jacqueline N. Hewitt, Massachusetts Institute of Technology
Donald E. Ingber, Harvard Medical School
Ralph H. Jacobson, Charles Stark Draper Laboratory (retired)
Tamara E. Jernigan, Lawrence Livermore National Laboratory
Klaus Keil, University of Hawaii, Manoa
Debra S. Knopman,[†] The RAND Corporation
Calvin W. Lowe, Bowie State University
Berrien Moore III, University of New Hampshire
Norman P. Neureiter, American Association for the Advancement of Science
Suzanne Oparil, University of Alabama, Birmingham
Ronald F. Probstein, Massachusetts Institute of Technology
Dennis W. Readey, Colorado School of Mines
Harvey D. Tananbaum, Smithsonian Astrophysical Observatory
Richard H. Truly, National Renewable Energy Laboratory
J. Craig Wheeler, University of Texas, Austin
Gary P. Zank, University of California, Riverside

[†]Resigned during 2006.

July 1, 2006–June 30, 2007

Lennard A. Fisk (chair), University of Michigan
A. Thomas Young (vice chair), Lockheed Martin Corporation (retired)
Spiro K. Antiochos, Naval Research Laboratory
Daniel N. Baker, University of Colorado, Boulder
Steven J. Battel, Battel Engineering
Charles L. Bennett, Johns Hopkins University
Judith A. Curry, Georgia Institute of Technology
Jack D. Farmer, Arizona State University
Jack D. Fellows, University Corporation for Atmospheric Research
Jacqueline N. Hewitt, Massachusetts Institute of Technology
Tamara E. Jernigan, Lawrence Livermore National Laboratory
Klaus Keil, University of Hawaii, Manoa
Berrien Moore III, University of New Hampshire
Kenneth H. Nealson, University of Southern California
Norman P. Neureiter, American Association for the Advancement of Science
Suzanne Oparil, University of Alabama, Birmingham
James A. Pawelczyk, Pennsylvania State University
Ronald F. Probstein, Massachusetts Institute of Technology
Harvey D. Tananbaum, Smithsonian Astrophysical Observatory
Richard H. Truly, National Renewable Energy Laboratory
Joseph F. Veverka, Cornell University
Warren M. Washington, National Center for Atmospheric Research
Gary P. Zank, University of California, Riverside

Ex Officio and Liaison Members

Raymond S. Colladay, Lockheed Martin Astronautics (retired) (ex-officio, Chair, NRC Aeronautics and Space Engineering Board)
Gerhard Haerendel, Max-Planck-Institut für extraterrestrische Physik (liaison, Chair of the European Space Science Committee)
Frank E. Muller-Karger, University of South Florida (ex-officio, member of the NRC Ocean Studies Board)
Edward C. Stone, California Institute of Technology (liaison, U.S. representative to COSPAR)

Membership of the 2006 SSB Executive Committee

July 1, 2005–June 30, 2006

Lennard A. Fisk (chair), University of Michigan
George A. Paulikas (vice chair), The Aerospace Corporation (retired)
Reta F. Beebe, New Mexico State University
Radford Byerly, Jr., University of Colorado, Boulder
Ralph H. Jacobson, Charles Stark Draper Laboratory (retired)
Berrien Moore III, University of New Hampshire
Suzanne Oparil, University of Alabama, Birmingham
J. Craig Wheeler, University of Texas, Austin

July 1, 2006–June 30, 2007

Lennard A. Fisk (chair), University of Michigan
A. Thomas Young (vice chair), Lockheed Martin Corporation (retired)
Daniel N. Baker, University of Colorado, Boulder
Charles L. Bennett, Johns Hopkins University
Berrien Moore III, University of New Hampshire
Kenneth H. Nealson, University of Southern California
Suzanne Oparil, University of Alabama, Birmingham
Joseph F. Veverka, Cornell University

Staff

Marcia S. Smith, Director (from March 2006)
Tamara L. Dickinson, Interim Director (through February 2006)
Joseph K. Alexander, Senior Program Officer
Arthur A. Charo, Senior Program Officer
Sandra J. Graham, Senior Program Officer
Robert L. Riemer,[‡] Senior Program Officer
David H. Smith, Senior Program Officer
Pamela L. Whitney, Senior Program Officer
Brian D. Dewhurst,[‡] Senior Program Associate
Dwayne A. Day, Senior Program Associate
Victoria Swisher, Research Associate (from December 2006)
Betty C. Guyot, Consultant
Barbara S. Akinwole, Information Management Associate
Tanja Pilzak, Administrative Coordinator
Christina O. Shipman, Financial Associate
Catherine A. Gruber, Assistant Editor
Carmela J. Chamberlain, Program Associate
Claudette K. Baylor-Fleming, Administrative Assistant
Theresa M. Fisher, Senior Program Assistant
Rodney N. Howard, Senior Program Assistant
Celeste A. Naylor, Senior Program Assistant

[‡]Staff of the Board on Physics and Astronomy who are shared with the SSB.

Space Policy Interns

Stephanie Bednarek, Summer
Brendan McFarland, Summer
Emily McNeil, Winter

U.S. NATIONAL COMMITTEE FOR COSPAR

The Committee on Space Research (COSPAR) Publications Committee, Program Committee, and Bureau meetings were held March 20-23, 2006, in Paris, France. In addition, COSPAR's new Scientific Advisory Committee, chaired by Lennard A. Fisk of the University of Michigan (and chair, SSB), held its first meeting. The advisory committee emerged from COSPAR's strategic visioning exercises held during 2004-2005. Other changes from that exercise include efforts to further involve students and young scientists in COSPAR activities, and increased attention to education.

The 36th COSPAR Scientific Assembly and affiliated Space Science Exhibition took place in Beijing, China, on July 16-23. The assembly was headquartered in the Friendship Palace of the Beijing Friendship Hotel and the scientific sessions took place on the adjacent campus of the Beijing Institute of Technology. In addition to a wide-range of presentations based on the latest findings from a variety of spacecraft missions, including Cassini, Mars Express and Deep Impact, the scientific program featured solicited contributions based on two recent SSB studies: an oral presentation of "The 2005 National Research Council Report on *Preventing the Forward Contamination of Mars*" by C. Chyba, S. Clifford, A. Delamere, M. Favero, J. Niehoff, D. Paige, J. Priscu and M. Race (presented by D. Paige); and a poster paper "Reassessment of Planetary Protection Requirements for Venus Missions" by J.W. Szostak, R.L. Riemer, D.H. Smith, and J.D. Rummel (presented by D.H. Smith).

The COSPAR Council met on July 16 and 23 and the COSPAR Bureau met on July 22. The highlight of the first council meeting was the selection of Bremen, Germany, as the host of COSPAR's 2010 scientific assembly. Runner-up, Mysore, India, will host the scientific assembly in 2012. The 2008 assembly has already been awarded to Montreal, Canada. Other highlights included elections for the next four year term for COSPAR offices. Prof. R.-M. Bonnet was reelected as President of COSPAR and Prof. Ed Stone and Dr. Wim Hermsen were reelected as Vice Presidents. The Bureau members elected were M.-H. Jiang (China); T. Kosugi (Japan); M.E. Machado (Argentina); G.G. Shepherd (Canada); R. Sridharan (India); L. Zelenyi (Russia). COSPAR also presented the 2006 awards and medals in Beijing.

COSPAR did not meet during the last quarter of 2006. COSPAR Headquarters has relocated to the French space agency, CNES (Centre National d'Études Spatiales), following the French government's decision to sell the International Council for Science building where COSPAR was previously located.

Edward C. Stone, California Institute of Technology (U.S. Representative to COSPAR)
Pamela L. Whitney, Senior Program Officer, Space Studies Board (Executive Secretary for COSPAR)
Carmela J. Chamberlain, Program Associate, Space Studies Board

STANDING COMMITTEES

COMMITTEE ON ASTRONOMY AND ASTROPHYSICS

The Committee on Astronomy and Astrophysics (CAA), which operates under the joint auspices of the SSB and the Board on Physics and Astronomy, did not meet during the first quarter.

CAA met May 19-20, 2006, in Washington, D.C. The committee traditionally uses the spring meeting to converse with agency officials and policymakers. This year the committee considered the state of the NASA Astrophysics Program. In light of the numerous changes at that agency, the committee also conducted an in-depth discussion of the James Webb Space Telescope (JWST) mission with project leadership. In addition, CAA continued its discussion about various options for conducting the next astronomy and astrophysics decadal survey.

CAA did not meet during the third quarter while planning continued for a January 2007 Town Hall meeting at the American Astronomical Society to gather community input on the upcoming decadal survey for astronomy and astrophysics.

In the fourth quarter, at its meeting at the Arnold and Mabel Beckman Center in Irvine, California, on November 28-29, 2006, the committee heard from Robin Staffin, Department of Energy; Wayne Van Citters, NSF; Rick Howard, NASA; and Todd Boroson, National Optical Astronomy Observatories; and others. CAA participated in a joint SSB-BPA-sponsored Decadal Survey Town Hall meeting on January 9, 2007, at the American Astronomical Society meeting in Seattle, Washington, in order to begin a dialogue with the community about the next survey.

A historical summary of reports from CAA and related committees is presented in Figure 2.1.

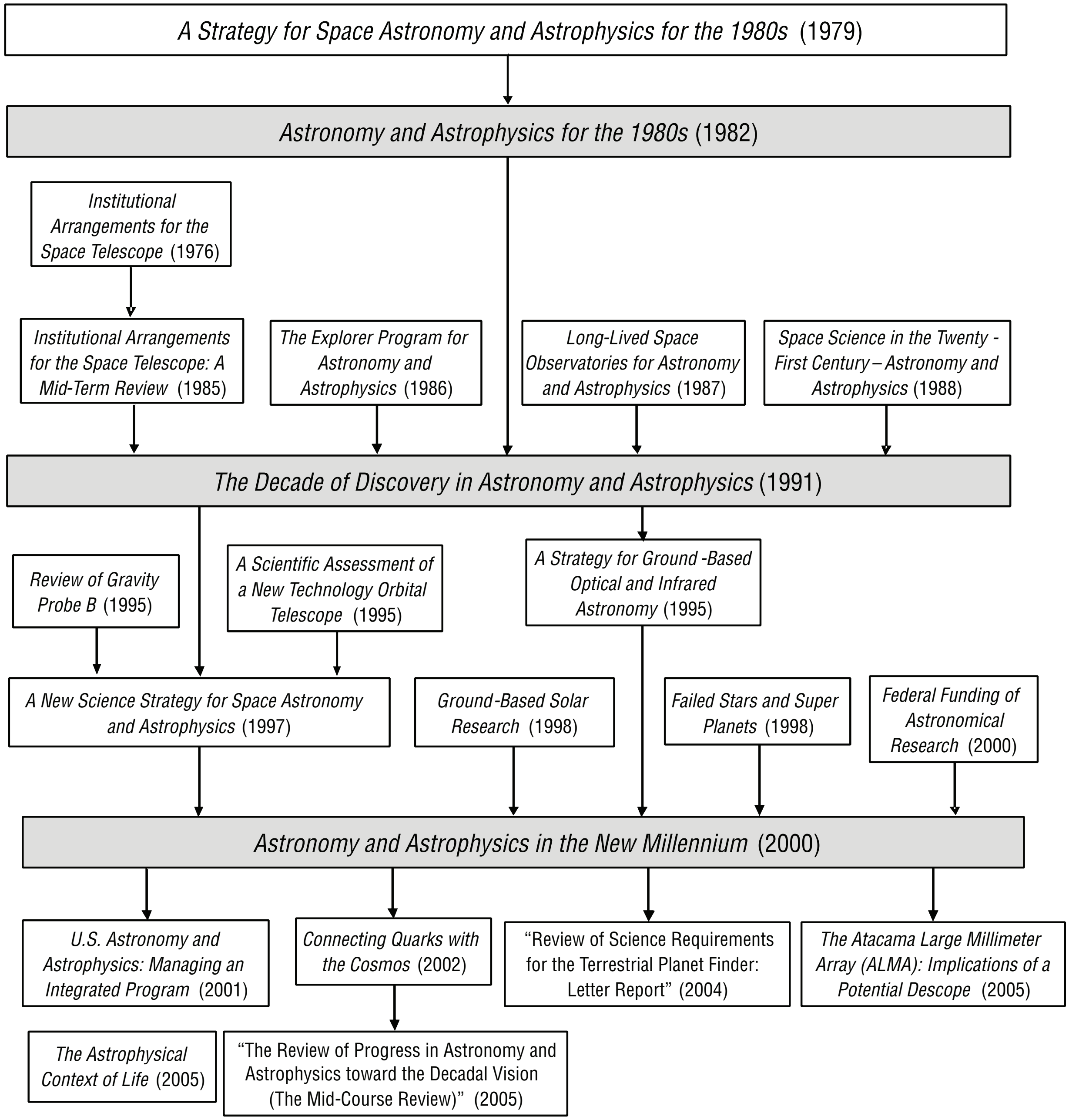

FIGURE 2.1 SSB-NRC advice on astronomy and astrophysics (1979–2006).

CAA Membership

July 1, 2005–June 30, 2006

Roger D. Blandford (co-chair), Stanford University
C. Megan Urry (co-chair), Yale University
Donald Backer, University of California, Berkeley
Michell C. Begelman, University of Colorado, Boulder
Charles L. Bennett, Johns Hopkins University
Thomas J. Bogdan, University Corporation for Atmospheric Research
Adam S. Burrows, University of Arizona
Alexei Filippenko, University of California, Berkeley
Timothy M. Heckman, Johns Hopkins University
Lynne Hillenbrand, California Institute of Technology
Charles McGruder III, Western Kentucky University
Stephan S. Meyer, University of Chicago
Eve Ostriker, University of Maryland, College Park
Mark J. Reid, Harvard-Smithsonian Center for Astrophysics
Scott D. Tremaine, Princeton University
Jean L. Turner, University of California, Los Angeles

July 1, 2006–June 30, 2007

Charles L. Bennett (co-chair), Johns Hopkins University
C. Megan Urry (co-chair), Yale University
Donald Backer, University of California, Berkeley
Michell C. Begelman, University of Colorado, Boulder
Thomas J. Bogdan, University Corporation for Atmospheric Research
Adam S. Burrows, University of Arizona
Alexei Filippenko, University of California, Berkeley
Timothy M. Heckman, Johns Hopkins University
Lynne Hillenbrand, California Institute of Technology
Charles McGruder III, Western Kentucky University
Stephan S. Meyer, University of Chicago
Scott D. Tremaine, Princeton University
Jean L. Turner, University of California, Los Angeles

Staff

Brian D. Dewhurst, Senior Program Associate, Board on Physics and Astronomy
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

COMMITTEE ON EARTH STUDIES

The Committee on Earth Studies (CES) continued to stand down as work continued on the decadal survey "Earth Science and Applications from Space: A Community Assessment and Strategy for the Future."

CES Membership*

Antonio J. Busalacchi, Jr., University of Maryland, College Park
Carol Anne Clayson, Florida State University
Ross N. Hoffman, Atmospheric and Environmental Research, Inc.
Steven W. Running, University of Montana, Missoula
Robert A. Shuchman, Altarum, Inc.
Roy W. Spencer, University of Alabama, Huntsville
Jan Svejkovsky, Ocean Imaging, Inc.

Arthur A. Charo, Senior Program Officer, Space Studies Board
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

*All terms ended during 2006.

COMMITTEE ON MICROGRAVITY RESEARCH

The Committee on Microgravity Research (CMGR) was not active during 2006, except for various tracking and dissemination activities such as providing requested materials and information on prior reports or assistance to related studies by other committees. The committee chair represented the past work and recommendations of CMGR in the recent SSB study on science balance at NASA. NASA withdrew its support for CMGR and the committee was officially disbanded as of August 16, 2006, the end of the SSB's 5-year contract with NASA. Future studies relevant to this committee's past work are expected, however, and will be carried out by ad hoc committees as needed.

A historical summary of reports from CMGR and related committees is presented in Figure 2.2.

CMGR Membership*

Dennis W. Readey, Colorado School of Mines (chair)

Sandra J. Graham, Senior Program Officer, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

*Term ended during 2006.

COMMITTEE ON THE ORIGINS AND EVOLUTION OF LIFE

The Committee on the Origins and Evolution of Life (COEL), which operates under the joint auspices of the SSB and the Board on Life Sciences, held its first meeting of 2006 in a joint session with the ad hoc Committee on the Astrobiology Strategy for the Exploration of Mars on January 23-25, 2006, in Irvine, California. The committee also conducted a conference call with Carl Pilcher, the official then in charge of astrobiology programs at NASA headquarters, on February 16, 2006. The principal topic of discussion during the call was the status of NASA's Astrobiology Program in light of the president's budget proposals for FY 2007. Following the conference call, the committee drafted comments which were forwarded to the Space Studies Board.

COEL met at the National Academies' Keck Center in Washington, D.C., on May 10, 2006. At the meeting the committee welcomed its new co-chair, Kenneth Nealson, and thanked six members for their service to the committee over the last three years. In addition, the committee was briefed on the status of NASA's astrobiology programs and, in particular, the current and future activities of the NASA Astrobiology Institute.

At its September 13, 2006, meeting at the University of Colorado's Laboratory for Atmospheric and Space Physics, the committee continued deliberations on the status of NASA's astrobiology programs and, in particular, the current and future activities of the NASA Astrobiology Institute. In addition, the committee heard a presentation on the status of the exploration of Enceladus by the Cassini spacecraft. The committee did not meet during the last quarter of 2006.

A historical summary of reports from COEL and related committees is presented in Figure 2.3.

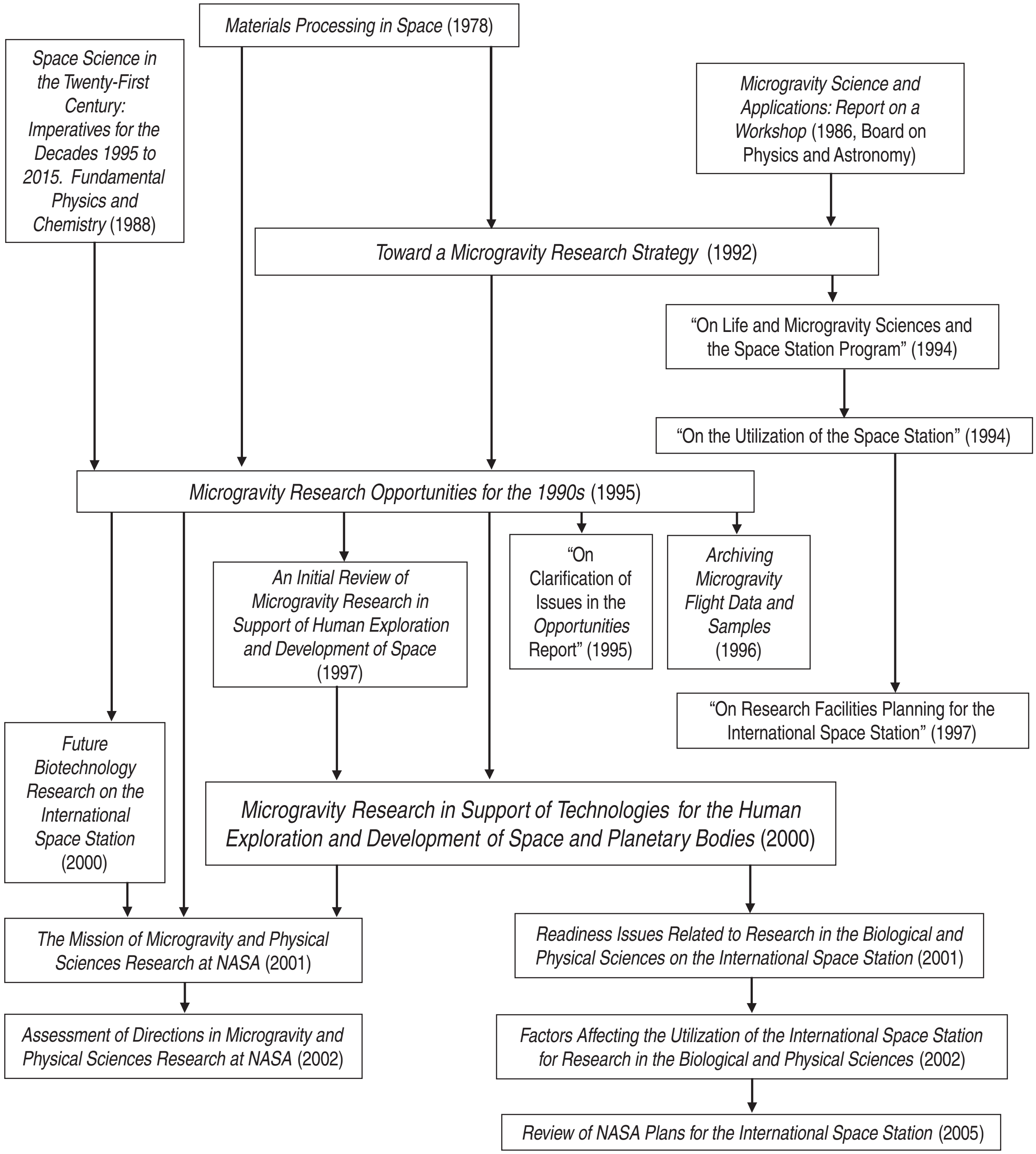

FIGURE 2.2 SSB-NRC advice on microgravity research (1978–2006).

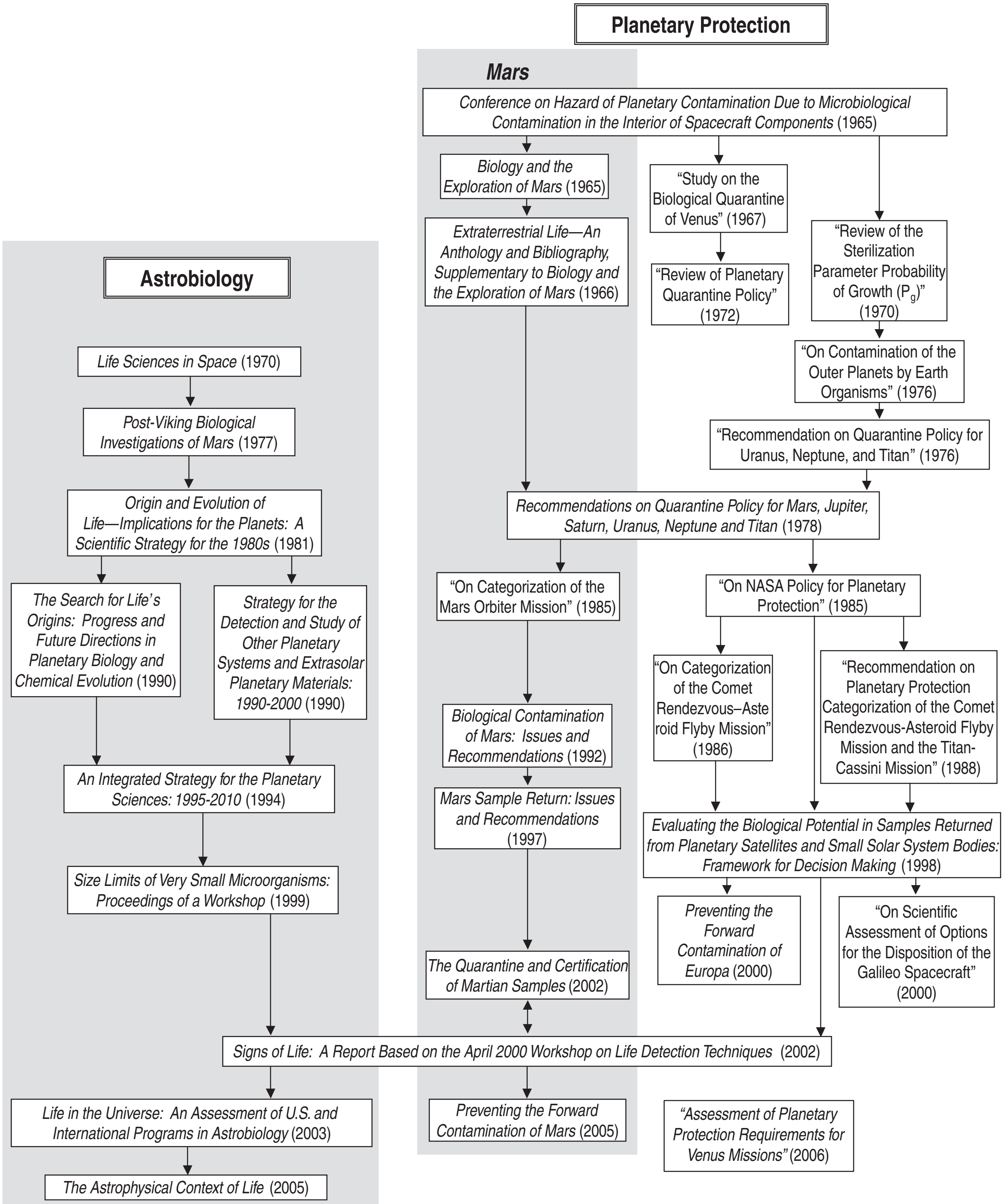

FIGURE 2.3 SSB-NRC advice on astrobiology and planetary protection (1965–2006).

COEL Membership

July 1, 2005–June 30, 2006

Kenneth H. Nealson (co-chair), University of Southern California
Bruce M. Jakosky (co-chair), University of Colorado, Boulder
Jan P. Amend, Washington University
Ruth Blake, Yale University
Michael H. Carr, U.S. Geological Survey (retired)
Michael Daly, Uniformed Services University of the Health Sciences
Anthony Keefe, Archemix Corporation
Martin Keller, Diversa Corporation
Harry Y. McSween, Jr., University of Tennessee, Knoxville
Barbara Sherwood Lollar, University of Toronto
Janet L. Siefert, Rice University
Andrew Steele, Carnegie Institution of Washington
Roger Summons, Massachusetts Institute of Technology
Meenakshi Wadhwa, The Field Museum of Natural History
Neville J. Woolf, University of Arizona

July 1, 2006–June 30, 2007

Kenneth H. Nealson (co-chair), University of Southern California
Bruce M. Jakosky (co-chair), University of Colorado, Boulder
Jan P. Amend, Washington University
Michael H. Carr, U.S. Geological Survey (retired)
Harry Y. McSween, Jr., University of Tennessee, Knoxville
Barbara Sherwood Lollar, University of Toronto
Andrew Steele, Carnegie Institution of Washington
Meenakshi Wadhwa, Arizona State University

Staff

David H. Smith, Senior Program Officer, Space Studies Board
Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy
Rodney N. Howard, Senior Program Assistant, Space Studies Board

COMMITTEE ON PLANETARY AND LUNAR EXPLORATION

The Committee on Planetary and Lunar Exploration (COMPLEX) did not meet during the first quarter in order to allow the ad hoc Committee on the Review of the Next Decade Mars Architecture to convene. COMPLEX did, however, conduct a conference call with Andrew Dantzler, the director of NASA's Planetary Science Division, on February 21, 2006. The principal topic of discussion of the call was the status of NASA's solar system exploration missions in light of the president's budget proposals for fiscal year (FY) 2007. Following the conference call, the committee drafted comments which were forwarded to the Space Studies Board.

COMPLEX held its first meeting of the year on June 5-7, 2006, at the National Academy of Sciences' building in Washington, D.C. The meeting was devoted to NASA solar system programs and the activities of the Lunar Exploration Analysis Group, the Outer Planets Analysis Group, and the Venus Exploration Analysis Group. In addition, the committee discussed future activities related to the planning of a congressionally-mandated review of NASA's Solar System Exploration Program and the next solar system exploration decadal survey.

COMPLEX's new chair, Joseph F. Veverka, presided over the committee's final meeting of 2006 at the Arnold and Mabel Beckman Center in Irvine, California, on December 4-6, 2006. Eight new committee members were present at the meeting. Two other new members were, unfortunately, unable to attend. The principal item on the committee's agenda was the identification of potential new study projects. One item explored in detail at the meeting was the possibility of a study to assess the candidates for future flagship and New Frontiers missions to explore objects in the outer solar system.

A historical summary of reports from COMPLEX and related committees is presented in Figure 2.4.

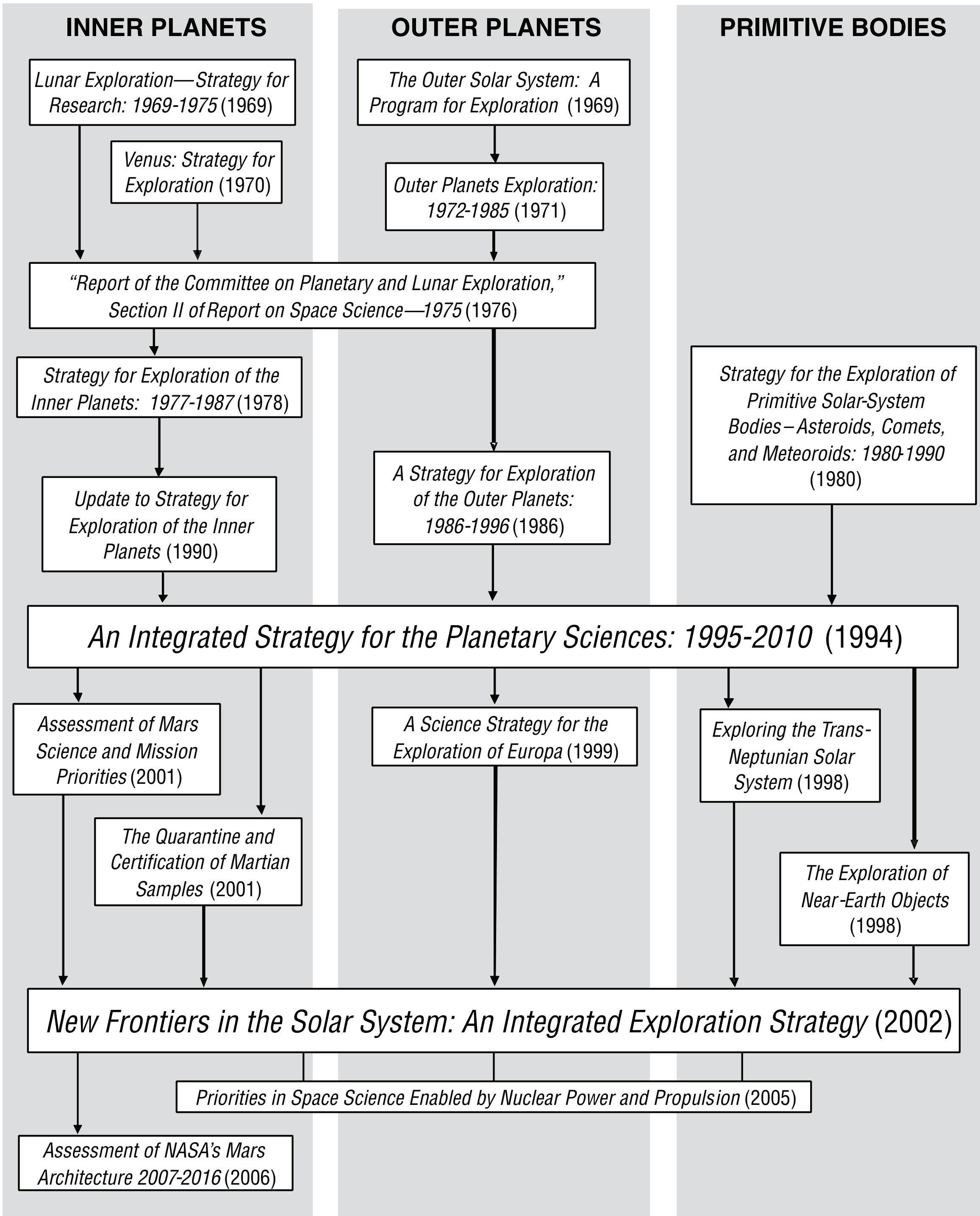

FIGURE 2.4 SSB-NRC advice on solar system exploration (1969–2006). Origins of life topics are covered in Figure 2.3.

COMPLEX Membership

July 1, 2005–June 30, 2006

Reta F. Beebe (chair), New Mexico State University
W. Bruce Banerdt, Jet Propulsion Laboratory
Stephen W. Bougher, University of Michigan
William D. Cochran, University of Texas, Austin
Martha S. Gilmore, Wesleyan University
William B. Hubbard, University of Arizona
Krishan Khurana, University of California, Los Angeles
Louise M. Prockter, Johns Hopkins University, Applied Physics Laboratory
Thomas R. Spilker, Jet Propulsion Laboratory

July 1, 2006–June 30, 2007

Joseph F. Veverka (chair), Cornell University
W. Bruce Banerdt, Jet Propulsion Laboratory
Penelope J. Boston, New Mexico Institute of Mining and Technology
Donald E. Brownlee, University of Washington
Bonnie Buratti, Jet Propulsion Laboratory
Roger N. Clark, U.S. Geological Survey
Michael R. Combi, University of Michigan
John Grant, Smithsonian Institution, National Air and Space Museum
Timothy J. McCoy, Smithsonian Institution, National Museum of Natural History
Alfred S. McEwen, University of Arizona
Francis Nimmo, University of California, Santa Cruz
Louise M. Prockter, Johns Hopkins University, Applied Physics Laboratory
Darrell F. Strobel, Johns Hopkins University

Staff

David H. Smith, Senior Program Officer, Space Studies Board
Rodney N. Howard, Senior Program Assistant, Space Studies Board

COMMITTEE ON SOLAR AND SPACE PHYSICS

The Committee on Solar and Space Physics (CSSP) met on February 24-25, 2006, in Washington, D.C. Principal agenda items included a briefing by Richard Fisher from NASA Headquarters on NASA's FY 2007 budget for heliophysics, discussions of potential new studies, preparation of briefing materials for presentation to the SSB study "An Assessment of Balance in NASA's Science Programs" and discussions with Fran Bagenal regarding her March 2, 2006, testimony to the House Science Committee on implications of the FY 2007 budget for heliophysics research and the workforce for heliophysics. The committee also developed detailed plans for its next ad hoc study which is anticipated to be a study of the impacts (especially economic) and potential for mitigation of severe space weather events.

CSSP did not meet during the second or third quarters. The committee continued developing detailed plans for its next ad hoc study to examine the impacts (especially economic) and potential for mitigation of severe space weather events. In addition, approximately half of the CSSP's members were members of the ad hoc committee that wrote and revised the report summarizing the proceedings from a October 16-20, 2005, "Solar and Space Physics and the Vision for Space Exploration" workshop that examined the solar and space physics-related issues—especially those related to the radiation environment beyond Earth—that are associated with fulfillment of NASA's Vision for Space Exploration.

The October 11-13, 2006, CSSP meeting at the National Academies' Keck Center in Washington, D.C., focused on NASA, NSF, and NOAA programs and plans. From discussions with NASA officials, the committee learned of several new missions in development with launch dates extending up to about 2013; thereafter, the program plan is less clear. NASA's Science Mission Directorate—and Heliophysics, in particular—is working aggressively to identify Lunar Science opportunities in the Vision for Space Exploration. The committee also learned that NOAA has particular current concerns about space weather monitoring programs. Steve Mango of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) described the recent changes to the NPOESS climate and space weather payload elements, which committee members characterized as "devastating." The committee also discussed plans for a workshop on the social and economic effects of severe space weather events instead of a study, as had previously been planned.

A historical summary of reports from CSSP and related committees is presented in Figure 2.5.

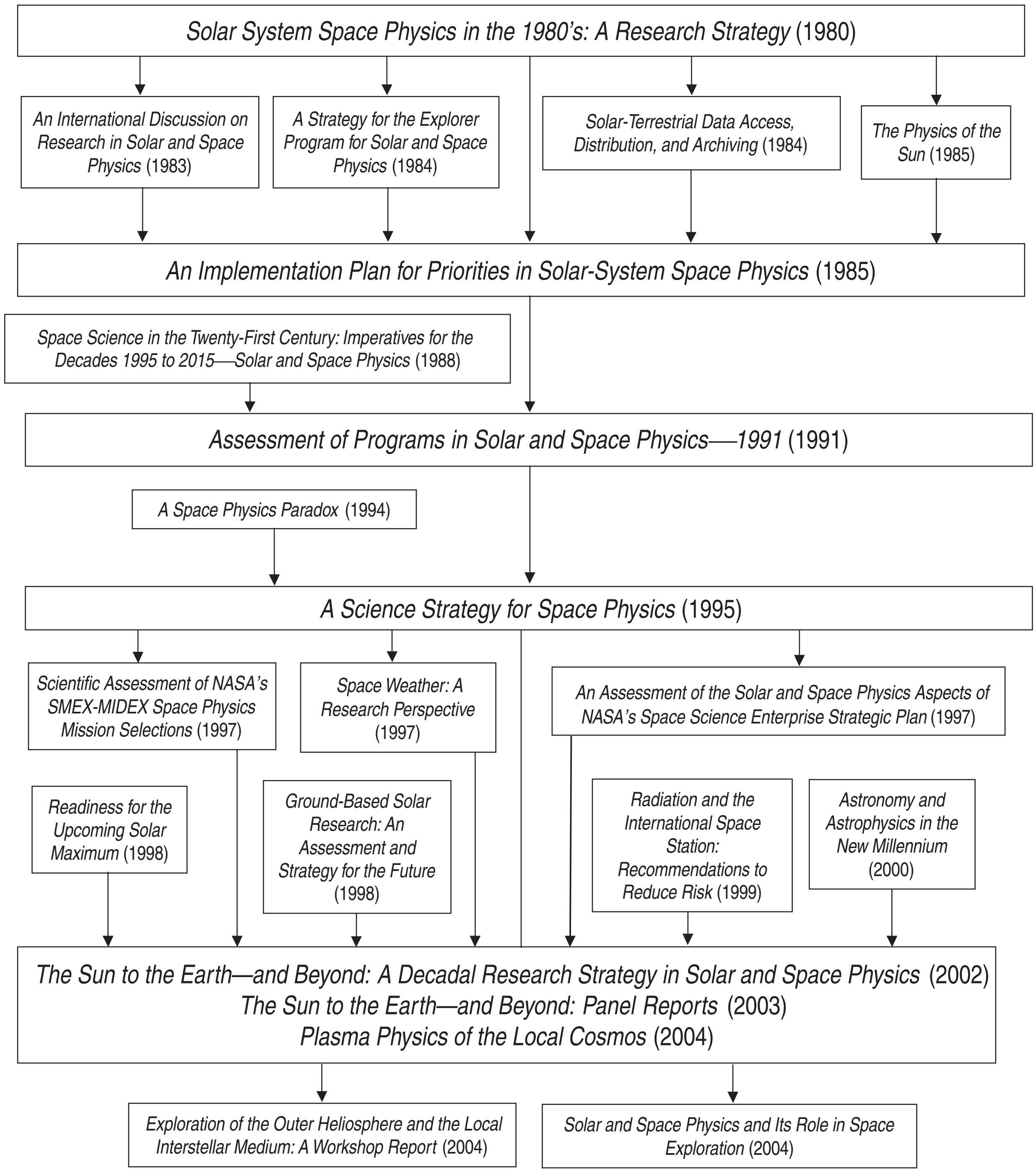

FIGURE 2.5 SSB-NRC advice on solar and space physics (1980–2006).

CSSP Membership

July 1, 2005–June 30, 2006

Daniel N. Baker (chair), University of Colorado, Boulder
Claudia J. Alexander, Jet Propulsion Laboratory
Anthony Chan, Rice University
Andrew F. Cheng, Johns Hopkins University
John C. Foster, Massachusetts Institute of Technology
Jack R. Jokipii, University of Arizona
Paul M. Kintner, Cornell University
William S. Lewis, Southwest Research Institute
Dana W. Longcope, Montana State University
Gang Lu, National Center for Atmospheric Research
Barry H. Mauk, John Hopkins University
Howard J. Singer, National Oceanic and Atmospheric Administration
Leonard Strachan, Jr., Harvard-Smithsonian Center for Astrophysics
Niescja Turner, Florida Institute of Technology
Thomas H. Zurbuchen, University of Michigan

July 1, 2006–June 30, 2007

Daniel N. Baker (chair), University of Colorado, Boulder
Joseph F. Fennell, The Aerospace Corporation
Jack R. Jokipii, University of Arizona
Krishan Khurana, University of California, Los Angeles
Paul M. Kintner, Cornell University
William S. Lewis, Southwest Research Institute
Dana W. Longcope, Montana State University
Kristina A. Lynch, Dartmouth College
Richard A. Mewaldt, California Institute of Technology
Howard J. Singer, National Oceanic and Atmospheric Administration
Leonard Strachan, Jr., Harvard-Smithsonian Center for Astrophysics
Niescja Turner, Florida Institute of Technology
Ronald E. Turner, ANSER Corporation
Thomas H. Zurbuchen, University of Michigan

Staff

Arthur A. Charo, Senior Program Officer, Space Studies Board
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

COMMITTEE ON SPACE BIOLOGY AND MEDICINE

The Committee on Space Biology and Medicine (CSBM) was not active during 2006, except for various tracking and dissemination activities such as providing requested materials and information (often to NASA and congressional staff) on prior studies, or assistance to related studies by other committees. The committee chair represented the past work and recommendations of CSBM in the recent SSB study on science balance at NASA. NASA withdrew its support for CSBM and the committee was officially disbanded as of August 16, 2006, the end of the SSB's 5-year contract with NASA. Future studies relevant to this committee's past work are expected, however, and will be carried out by ad hoc committees as needed.

A historical summary of reports from CSBM and related committees is presented in Figure 2.6.

CSBM Membership*

Donald E. Ingber, Harvard Medical School (chair)

Sandra J. Graham, Senior Program Officer, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

*Term ended during 2006.

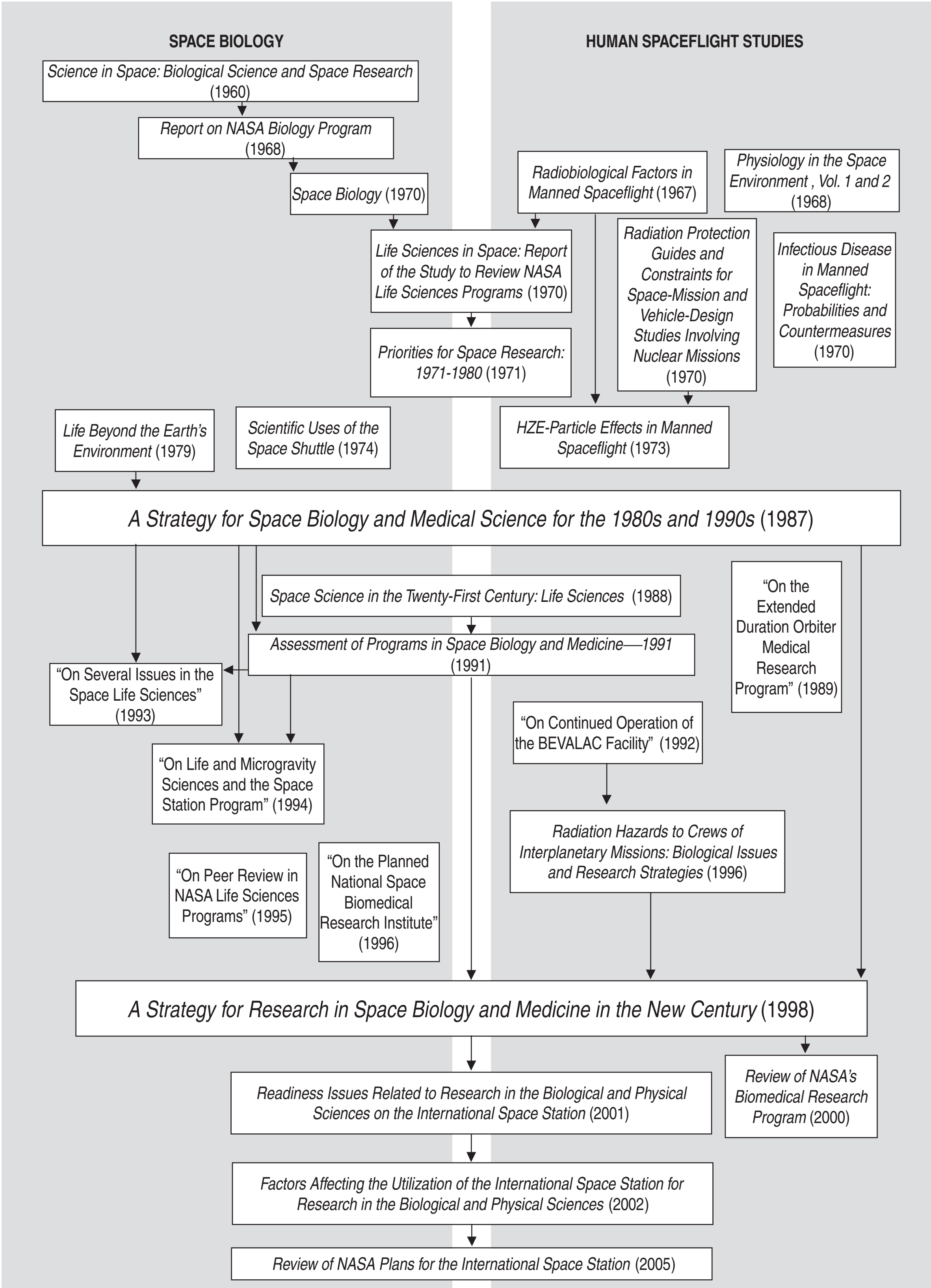

FIGURE 2.6 SSB-NRC advice on space biology and medicine (1960–2006).

3
Ad Hoc Study Committees: Activities and Membership

When a sponsor requests that the Space Studies Board conduct a study, an ad hoc committee is established for that purpose. The committee terminates when the study is completed. These study committees are subject to the Federal Advisory Committee Act (FACA), Section 15, because they provide advice and recommendations to the federal government. The SSB and/or one of its standing committees provide oversight for ad hoc study committee activities. Thirteen ad hoc committees were organized, met, or released studies during 2006. (Activities and membership are summarized below.)

In addition, four ad hoc committees that produced reports in 2005 were formally disbanded in 2006: the Committee on Planetary Protection Requirements for Venus Missions, the Committee on Preventing the Forward Contamination of Mars, the Committee on Principal Investigator-Led Missions in the Space Sciences, and the Committee on Priorities for Space Science Enabled by Nuclear Power and Propulsion. Their reports are summarized in the 2005 annual report.

ASSESSMENT OF BALANCE IN NASA'S SCIENCE PROGRAMS

The ad hoc Committee on an Assessment of Balance in NASA's Science Programs met on March 6-8, 2006, and delivered its report, *An Assessment of Balance in NASA's Science Programs*, to NASA and Congress on May 4, 2006. The report was the third and final component of the NRC's advisory response to a request, as a part of fiscal year 2005 appropriations legislation for NASA, that called for "a thorough review of the science that NASA is proposing to undertake under the space exploration initiative and to develop a strategy by which all of NASA's science disciplines . . . can make adequate progress towards their established goals, as well as providing balanced scientific research in addition to support of the new initiative." The report presents an assessment of NASA's integrated strategy and proposed science program, as set forth in materials that accompany the NASA FY 2007 budget request. The Summary is reprinted in Chapter 5.

*Membership**

Lennard A. Fisk, University of Michigan (chair)
George A. Paulikas, The Aerospace Corporation (retired) (vice chair)
Spiro K. Antiochos, Naval Research Laboratory
Daniel N. Baker, University of Colorado
Reta F. Beebe, New Mexico State University
Roger D. Blandford, Stanford University
Radford Byerly, Jr., University of Colorado

Judith A. Curry, Georgia Institute of Technology
Jack D. Farmer, Arizona State University
Jacqueline N. Hewitt, Massachusetts Institute of Technology
Donald E. Ingber, Harvard Medical School
Bruce M. Jakosky, University of Colorado
Klaus Keil, University of Hawaii
Debra S. Knopman, RAND Corporation
Calvin W. Lowe, Bowie State University
Berrien Moore III, University of New Hampshire
Frank E. Muller-Karger, University of South Florida
Suzanne Oparil, University of Alabama, Birmingham
Ronald F. Probstein, Massachusetts Institute of Technology
Dennis W. Readey, Colorado School of Mines
Harvey D. Tananbaum, Smithsonian Astrophysical Observatory
J. Craig Wheeler, University of Texas, Austin
A. Thomas Young, Lockheed Martin Corporation (retired)

Joseph K. Alexander, Senior Program Officer, Space Studies Board (study director)
Dwayne A. Day, Senior Program Associate, Space Studies Board
Claudette K. Baylor-Fleming, Administrative Assistant, Space Studies Board

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*All terms ended during 2006.

ASTROBIOLOGY STRATEGY FOR THE EXPLORATION OF MARS

The ad hoc Committee on the Astrobiology Strategy for the Exploration of Mars (Mars Astrobiology) held its first meeting on January 23-25, 2006, in Irvine, California, along with the Committee on the Origins and Evolution of Life. At its May 10-12, 2006, meeting at the National Academies' Keck Center in Washington, D.C., the committee received a briefing on the status of NASA's Mars exploration plans and the heard presentations relating to the committee's statement of task, including the geological history of Mars, recent results from Mars Express, isotopic biomarkers, the characteristics of sites of possible biological interest on Mars, and the status of astrobiology instrument development. The committee also drafted an outline of its final report and discussed presentations required for its next meeting.

The committee met at the University of Colorado's Laboratory for Atmospheric and Space Physics on September 13-15, 2006, in Boulder, Colorado. In addition to a briefing on the status of NASA's Mars exploration plans, the committee heard presentations on morphological biomarkers and on the scientific goals and status of the Mars Science Laboratory and, in particular, its astrobiologically relevant payload. In addition, the committee spent a considerable amount of time refining the outline of its report, assigning responsibility for the drafting of different sections to committee members, and drafting a schedule for the completion of its task.

The committee's November 8-10, 2006, meeting at the J. Erik Jonsson Center in Woods Hole, Massachusetts, was devoted to completing the committee's report, *An Astrobiology Strategy for the Exploration of Mars*. Following a committee conference call on December 7, 2006, a complete draft of the report was assembled and distributed to members on December 15, 2006. After review by committee members, the draft report was sent to external reviewers on December 19, 2006. (The final report was released in June 2007.)

Membership

Bruce M. Jakosky, University of Colorado, Boulder (chair)
Jan P. Amend, Washington University
William M. Berelson, University of Southern California
Ruth Blake, Yale University
Susan L. Brantley, Pennsylvania State University
Michael H. Carr, U.S. Geological Survey (retired)

James K. Fredrickson, Pacific Northwest National Laboratory
Anthony Keefe, Archemix Corporation
Martin Keller, Oak Ridge National Laboratory
Harry Y. McSween, Jr., University of Tennessee, Knoxville
Kenneth H. Nealson, University of Southern California
Barbara Sherwood Lollar, University of Toronto
Andrew Steele, Carnegie Institution of Washington
Roger Summons, Massachusetts Institute of Technology
Meenakshi Wadhwa, Arizona State University

David H. Smith, Senior Program Officer, Space Studies Board (study director)
Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy
Rodney N. Howard, Senior Program Assistant, Space Studies Board

ASTRONOMY SCIENCE CENTERS: AN ASSESSMENT OF BEST PRACTICES AND GUIDING PRINCIPLES FOR THE FUTURE

The ad hoc Committee on Astronomy Science Centers was formed to review lessons learned from experience with NASA's ensemble of space astronomy science centers in order to recommend a set of guiding principles and best practices for consideration in making decisions about approaches to meeting the needs of the astronomy community with future science centers. On February 9-11, 2006, the committee met to discuss the Education and Public Outreach (E/PO) efforts at the science centers and to continue drafting its report. The committee heard from Kathleen Lestition, Chandra X-Ray Center; James Manning, Space Telescope Science Institute; and Michelle Thaller, Spitzer Science Center; about their E/PO efforts. The committee also heard from Nick Cabot, Science Department Chair at Nathan Hale High School in Seattle; Carl Pennypacker, Principal Investigator of Hands-on Universe; and Roberta Tanner, Loveland High School, Loveland, Colorado. These educators provided their views of and advice on the center's E/PO programs. The committee chair visited the Spitzer Science Center and Michelson Science Center on April 18, 2006, and the Chandra X-Ray Center on May 3, 2006.

The committee held its final meeting May 10-12, 2006, in Irvine, California. Work on the report continued during the third and fourth quarters. (A final published report was released in June 2007.)

Membership

Steven R. Bohlen, Joint Oceanographic Institutions (chair)
Roger G. Barry, University of Colorado, Boulder
Stephen S. Holt, Babson College; Olin College
Richard A. McCray, University of Colorado, Boulder
Alexander Sandor Szalay, Johns Hopkins University
Paula Szkody, University of Washington
Paul Adrian Vanden Bout, National Radio Astronomy Observatory

Pamela L. Whitney, Senior Program Officer, Space Studies Board (co-study director)
Brian D. Dewhurst, Senior Program Associate, Board on Physics and Astronomy (co-study director)
Carmela J. Chamberlain, Program Associate, Space Studies Board

BEYOND EINSTEIN PROGRAM ASSESSMENT

The ad hoc Beyond Einstein Program Assessment Committee was formed to assess the five proposed Beyond Einstein missions (Constellation X-ray Observatory, Laser Interferometer Space Antenna, Joint Dark Energy Mission, Inflation Probe, and Black Hole Finder probe) based on their potential scientific impact and preliminary technology, management plans and cost estimates, and to recommend one mission for first development and launch. The committee held its first meeting in Washington, D.C., on November 6-8, 2006. Representatives of the 11 Beyond

Einstein mission concepts presented their projects and responded to committee questions. (The report was released in September 2007.)

Membership

Charles F. Kennel, University of California, San Diego (co-chair)
Joseph H. Rothenberg, Universal Space Network (co-chair)
Eric G. Adelberger, University of Washington
Bill Adkins, Adkins Strategies, LLC
Thomas Appelquist, Yale University
James S. Barrowman, Independent Consultant
David A. Bearden, Aerospace Corporation
Mark Devlin, University of Pennsylvania
Joseph Fuller, Jr., Futron Corporation
Karl Gebhardt, University of Texas, Austin
William C. Gibson, Southwest Research Institute
Fiona A. Harrison, California Institute of Technology
Andrew J. Lankford, University of California, Irvine
Dennis McCarthy, Independent Consultant
Stephan S. Meyer, University of Chicago
Joel R. Primack, University of California, Santa Cruz
Lisa J. Randall, Harvard University
Craig L. Sarazin, University of Virginia
James S. Ulvestad, National Radio Astronomy Observatory
Clifford M. Will, Washington University
Michael S. Witherell, University of California, Santa Barbara
Edward L. Wright, University of California, Los Angeles

Sandra J. Graham, Senior Program Officer, Space Studies Board (co-study director after January 2007)
Pamela L. Whitney, Senior Program Officer, Space Studies Board (co-study director through January 2007)
Brian D. Dewhurst, Senior Program Associate, Board on Physics and Astronomy (co-study director)
Carmela J. Chamberlain, Program Associate, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

EARTH SCIENCE AND APPLICATIONS FROM SPACE: A COMMUNITY ASSESSMENT AND STRATEGY FOR THE FUTURE

The Earth Science and Applications from Space: A Community Assessment and Strategy for the Future (ESAS) decadal survey, led by an 18-member steering (executive) committee, utilized seven thematically organized study panels:

1. Earth Science Applications and Societal Benefits
2. Land-use Change, Ecosystem Dynamics and Biodiversity
3. Weather (incl. space weather and chemical weather)
4. Climate Variability and Change
5. Water Resources and the Global Hydrologic Cycle
6. Human Health and Security
7. Solid-Earth Hazards, Resources, and Dynamics

The study was initiated in 2004 and many meetings were held in 2005. An interim report, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, was released in April 2005. During the first quarter of 2006, the following meetings took place:

- ESAS Steering Committee (January 10-12, Washington, D.C.)
- Panel on Earth Science Applications and Societal Benefits (January 26-27, Washington, D.C.)
- Panel on Climate Variability and Change (February 6-7, Irvine, California)
- Panel on Human Health and Security (March 23-24, Washington, D.C.)

Representatives from the steering committee and the panels were present on January 30, 2006, in Atlanta, Georgia, for a "town hall" community forum that was held in conjunction with the annual meeting of the American Meteorological Association. Representatives were also present on February 21, 2006, for a town hall which was held in conjunction with the American Geophysical Union's Ocean Sciences meeting in Hawaii. By the end of the first quarter, 20 of 21 planned panel meetings had been completed. Panels completed second drafts of their report chapters and identified, prioritized, and provided rough cost estimates for their recommended suite of activities.

During the second and third quarters, the following meetings took place: ESAS Steering Committee: May 2-4, 2006 (Irvine, California); Panel on Land-use Change, Ecosystem Dynamics and Biodiversity: April 24-25, 2006 (Washington, D.C.) and August 22-24, 2006 (Woods Hole, Massachusetts).

As the third quarter ended, the committee was preparing a draft of its final report for external review. A prepublication version of the final report was released on January 15, 2007. (The final report was published in October 2007.)

Also during the third quarter, the committee received a request from NASA to perform additional tasks in a subsequent report—to undertake a fast-track study that will examine strategies to recover lost capabilities stemming from the June 2006 changes to the NPOESS program. This study will also examine several issues related to recent changes in the GOES-R program.

ESAS Executive Committee Membership

Richard A. Anthes, University Corporation for Atmospheric Research (co-chair)
Berrien Moore III, University of New Hampshire (co-chair)
James G. Anderson, Harvard University
Susan K. Avery, University of Colorado, Boulder
Eric J. Barron, University of Texas, Austin
Otis B. Brown, Jr.,* University of Miami
Susan L. Cutter, University of South Carolina
Ruth DeFries, University of Maryland
William B. Gail, Microsoft Virtual Earth
Bradford H. Hager, Massachusetts Institute of Technology
Anthony Hollingsworth,** European Centre for Medium-Range Weather Forecasts (retired)
Anthony C. Janetos, Joint Global Change Research Institute, Pacific Northwest National Laboratory/University of Maryland
Kathryn A. Kelly, University of Washington
Neal F. Lane, Rice University
Dennis P. Lettenmaier, University of Washington
Bruce D. Marcus, TRW Inc. (retired)
Warren M. Washington, National Center for Atmospheric Research
Mark L. Wilson, University of Michigan
Mary Lou Zoback, Risk Management Solutions

Stacey W. Boland, Jet Propulsion Laboratory (consultant)

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

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*Through January 2006.
**The committee notes with deep regret Anthony Hollingsworth's death on July 29, 2007.

ESAS Panel on Earth Science Applications and Societal Benefits Membership

Anthony C. Janetos, Joint Global Change Research Institute, Pacific Northwest National Laboratory/University of Maryland (chair)
Roberta Balstad, Columbia University (vice chair)
Jay Apt, Carnegie Mellon University
Philip E. Ardanuy, Raytheon Information Solutions
Randall Friedl, Jet Propulsion Laboratory
Michael F. Goodchild, University of California, Santa Barbara
Molly K. Macauley, Resources for the Future, Inc.
Gordon McBean, University of Western Ontario
David L. Skole, Michigan State University
Leigh Welling, Crown of the Continent Learning Center
Thomas J. Wilbanks, Oak Ridge National Laboratory
Gary W. Yohe, Wesleyan University

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

ESAS Panel on Land-use Change, Ecosystem Dynamics, and Biodiversity Membership

Ruth S. Defries, University of Maryland (chair)
Otis B. Brown, Jr., University of Miami (vice chair)
Mark R. Abbott, Oregon State University
Christopher B. Field, Carnegie Institution of Washington
Inez Y. Fung, University of California, Berkeley
Marc Levy, Center for International Earth Sciences Information Network
James J. McCarthy, Harvard University
Jerry M. Melillo, Marine Biological Laboratory
Walter V. Reid,* Stanford University
David S. Schimel, University Corporation for Atmospheric Research

Arthur Charo, Senior Program Officer, Space Studies Board (study director)
Dan Walker, Scholar, Ocean Studies Board
Sandra J. Graham, Senior Program Officer, Space Studies Board (from August 2006)
Carmela J. Chamberlain, Program Associate, Space Studies Board

*Resigned from panel February 2006.

ESAS Panel on Weather Membership

Susan K. Avery, University of Colorado, Boulder (chair)
Thomas H. Vonder Haar, Colorado State University (vice chair)
Edward V. Browell, NASA Langley Research Center
Lt. Col. William B. Cade III, Air Force Weather Agency
Bradley R. Colman, National Weather Service
Jenni-Louise Evans, Pennsylvania State University
Eugenia Kalnay, University of Maryland, College Park
Roger A. Pielke, Jr.,* University of Colorado, Boulder
Christopher Ruf, University of Michigan
Carl F. Schueler, Raytheon Company
Jeremy Usher, Weathernews Americas, Inc.
Christopher S. Velden, University of Wisconsin-Madison
Robert A. Weller, Woods Hole Oceanographic Institution

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Curtis Marshall, Program Officer, Board on Atmospheric Sciences and Climate (from August 2006)
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

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*Resigned from panel August 2006.

ESAS Panel on Climate Variability and Change Membership

Eric J. Barron, University of Texas, Austin (chair)
Joyce E. Penner, University of Michigan (vice chair)
Gregory Carbone, University of South Carolina
James A. Coakley, Jr., Oregon State University
Sarah T. Gille, Scripps Institution of Oceanography
Kenneth C. Jezek, Ohio State University
Judith L. Lean, Naval Research Laboratory
Gudrun Magnusdottir, University of California, Irvine
Paola Malanotte-Rizzoli, Massachusetts Institute of Technology
Michael Oppenheimer, Princeton University
Claire L. Parkinson, NASA Goddard Space Flight Center
Michael J. Prather, University of California, Irvine
Mark R. Schoeberl, NASA Goddard Space Flight Center
Byron D. Tapley, University of Texas, Austin

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

ESAS Panel on Water Resources and the Global Hydrologic Cycle Membership

Dennis P. Lettenmaier, University of Washington (chair)
Anne W. Nolin, Oregon State University (vice chair)
Wilfried H. Brutsaert, Cornell University
Anny Cazenave, Centre National d'Etudes Spatiales
Carol Anne Clayson, Florida State University
Jeff Dozier, University of California, Santa Barbara
Dara Entekhabi, Massachusetts Institute of Technology
Richard Forster, University of Utah
Charles D.D. Howard, Independent Consultant
Christian D. Kummerow, Colorado State University
Steven W. Running, University of Montana
Charles J. Vorosmarty, University of New Hampshire

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
William Logan, Senior Program Officer, Water Science and Technology Board
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

ESAS Panel on Human Health and Security Membership

Mark L. Wilson, University of Michigan (chair)
Rita R. Colwell, University of Maryland, College Park (vice chair)
Daniel G. Brown, University of Michigan
Walter F. Dabberdt, Vaisala, Inc.
William F. Davenhall, ESRI
John R. Delaney, University of Washington

Gregory Glass, Johns Hopkins Bloomberg School of Public Health
Daniel J. Jacob, Harvard University
James H. Maguire, University of Maryland at Baltimore School of Medicine
Paul M. Maughan, MyoSite Diagnostics, Inc.
Joan B. Rose, Michigan State University
Ronald B. Smith, Yale University
Patricia Ann Tester, National Oceanic and Atmospheric Administration

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Raymond Wassel, Senior Program Officer, Board on Environmental Studies and Toxicology
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

ESAS Panel on Solid-Earth Hazards, Resources, and Dynamics Membership

Bradford H. Hager, Massachusetts Institute of Technology (chair)
Susan L. Brantley, Pennsylvania State University (vice chair)
Jeremy Bloxham, Harvard University
Richard K. Eisner, State of California, Governor's Office of Emergency Services
Alexander F.H. Goetz, University of Colorado, Boulder
Christian J. Johannsen, Purdue University
James W. Kirchner, University of California, Berkeley
William I. Rose, Michigan Technological University
Haresh C. Shah, Stanford University
Dirk Smit, Shell Exploration and Production Technology Company
Howard A. Zebker, Stanford University
Maria T. Zuber, Massachusetts Institute of Technology

Arthur A. Charo, Senior Program Officer, Space Studies Board (study director)
Dan Walker, Scholar, Ocean Studies Board
Sandra J. Graham, Senior Program Officer, Space Studies Board
Carmela J. Chamberlain, Program Associate, Space Studies Board

EXPLORING ORGANIC ENVIRONMENTS IN THE SOLAR SYSTEM

The Task Group on Organic Environments in the Solar System (TGOESS), an ad hoc committee under the auspices of COMPLEX, COEL, and the Board on Chemical Sciences and Technology, did not meet during 2006. The task group's activities concerned the revision and review of its report, *Exploring Organic Environments in the Solar System*, which looks at the sources, location, and history of organic carbon in the solar system. (The report was released in February 2007.)

Membership*

James P. Ferris, Rensselaer Polytechnic Institute (chair)
Luann Becker, University of California, Santa Barbara
Kristie A. Boering, University of California, Berkeley
George D. Cody, Carnegie Institution of Washington
G. Barney Ellison, University of Colorado
John M. Hayes, Woods Hole Oceanographic Institution
Robert E. Johnson, University of Virginia
William Klemperer, Harvard University
Karen J. Meech, University of Hawaii, Honolulu
Keith S. Noll, Space Telescope Science Institute
Martin Saunders, Yale University

David H. Smith, Senior Program Officer, Space Studies Board (study director)
Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy
Sandra J. Graham, Senior Program Officer, Space Studies Board
Christopher K. Murphy, Senior Program Officer, Board on Chemical Sciences and Technology
Rodney N. Howard, Senior Program Assistant, Space Studies Board

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*All terms ended during 2006.

LARGE OPTICAL SYSTEMS IN SPACE

During the first quarter, staff of the SSB and the Division on Engineering and Physical Sciences worked with NASA and the National Reconnaissance Office (NRO) to move forward on the study on large optical systems in space (LOIS)—a survey and analysis of technology opportunities and issues relevant to the development and operation of medium-size and large optical systems in space. Before committee formation was completed, however, NRO and NASA terminated the study. NASA deobligated its funds, but NRO provided a no cost extension in order to allow the use of the funds for a future study to be determined.

Marcia S. Smith, Director, Space Studies Board
Richard E. Rowberg, Associate Executive Director, Division on Engineering and Physical Sciences
Pamela L. Whitney, Senior Program Officer, Space Studies Board (study director)
Carmela J. Chamberlain, Program Associate, Space Studies Board

LIMITS OF ORGANIC LIFE IN PLANETARY SYSTEMS

The Committee on the Limits of Organic Life in Planetary Systems, an ad hoc committee of the Space Studies Board and the Board on Life Sciences, did not meet during 2006. The committee's report was sent to external review in August 2006. For the third and fourth quarters, the committee continued to revise the report in response to the comments provided by the reviewers. (The report was released in July 2007.)

Membership

John A. Baross, University of Washington (chair)
Steven A. Benner, Foundation for Applied Molecular Evolution
George D. Cody, Carnegie Institution of Washington
Shelley D. Copley, University of Colorado, Boulder
Norman R. Pace, University of Colorado, Boulder
James H. Scott, Dartmouth College
Robert Shapiro, New York University
Mitchell L. Sogin, Marine Biological Laboratory
Jeffrey L. Stein, Sofinnova Ventures
Roger Summons, Massachusetts Institute of Technology
Jack W. Szostak, Massachusetts General Hospital

David H. Smith, Senior Program Officer, Space Studies Board (study director through December 2006)
Joseph K. Alexander, Senior Program Officer, Space Studies Board (study director from December 2006)
Rodney N. Howard, Senior Program Assistant, Space Studies Board

MEETING THE WORKFORCE NEEDS FOR THE NATIONAL VISION FOR SPACE EXPLORATION

The Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, under the auspices of SSB and the Aeronautics and Space Engineering Board, was organized to assess the current and future supply of personnel for a qualified U.S. aerospace workforce to meet the needs of NASA and the larger aerospace science and engineering community in the context of the nation's long-term space exploration vision.

The committee held a two-day information-gathering workshop as a part of its first meeting at the National Academies' Keck Center in Washington, D.C., on January 23-25, 2006. The workshop was organized to examine relevant workforce demographics and factors that may impact them, future workforce skill needs, and issues that may require further study. The approximately 35 participants included study committee members and representatives from NASA, DOD, NSF, aerospace industry, academia, and several non-governmental organizations.

The committee held its second meeting at the National Academies' Keck Center on February 22-23, 2006, to gather additional information and to plan its interim report. NASA representatives presented results of workforce analyses and modeling carried out by NASA's Systems Engineering and Institutional Transition Team. The committee also heard presentations from Bureau of Labor Statistics representatives on projections of future labor force supply and demand in aerospace science and engineering, and heard additional aerospace industry perspectives on workforce issues. The committee delivered its interim report, *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce*, on April 26, 2006, and released it to the public on April 27, 2006. The Summary is reprinted in Chapter 5.

The committee held its third meeting May 8-9, 2006, at the National Academies' Keck Center in Washington, D.C., to gather additional information and to begin work on its final report. At the meeting the committee heard from representatives from university engineering departments and science departments, held discussions with NASA officials regarding the agency's education strategy and interactions with U.S. universities and regarding the final report of NASA's Systems Engineering and Institutional Transition Team, and received a briefing on university engineering enrollment data from a representative of the American Society for Engineering Education. On May 9, 2006, the committee co-chairs, David Black and Daniel Hastings, met with Scott Pace, the NASA Associate Administrator for Program Assessment and Evaluation, and other NASA officials to discuss future plans for the study. Committee co-chair David Black testified on the conclusions of the interim report at a hearing of the House Science Committee's Subcommittee on Space and Aeronautics on June 13, 2006.

The committee's fourth meeting, at the Arnold and Mabel Beckman Center in Irvine, California, on September 27-29, 2006, was devoted to discussions of the committee's response to the study charge, NASA's response to its interim report, and to writing the committee's draft final report. The draft of the committee's final report, *Building a Better NASA Workforce: Meeting the Workforce Needs for the National Vision for Space Exploration*, was completed in the fourth quarter and sent to review in January 2007. (The report was released in April 2007.)

Membership

David C. Black, Universities Space Research Association (co-chair)
Daniel E. Hastings, Massachusetts Institute of Technology (co-chair)
Burt S. Barnow, Johns Hopkins University
John W. Douglass, Aerospace Industries Association of America, Inc.
Ray M. Haynes, Northrop Grumman Space Technology
Margaret G. Kivelson, University of California, Los Angeles
William Pomerantz, X PRIZE Foundation
Joseph H. Rothenberg, Universal Space Network
Kathryn C. Thornton, University of Virginia

Dwayne A. Day, Senior Program Associate, Space Studies Board (study director from October 2006)
Joseph K. Alexander, Senior Program Officer, Space Studies Board (study director through September 2006)
Victoria Swisher, Research Associate, Space Studies Board
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

NASA ASTROPHYSICS PERFORMANCE ASSESSMENT

The ad hoc Committee on NASA Astrophysics Performance Assessment was tasked with assessing NASA's performance in achieving the goals laid out by the 2000 NRC astronomy and astrophysics decadal survey, *Astronomy and Astrophysics in the New Millennium*, as well as in the 2003 NRC report *Connecting Quarks with the Cosmos*.

At its first meeting on June 19-21, 2006, in Washington, D.C., the committee heard from a panel of congressional staff about the reasons the study was requested, as well as from Eric Smith who presented NASA's perspective on the study. The committee then discussed the current state of the NASA Astrophysics Program with the chairs of various advisory committees (including the NRC Committee on Astronomy and Astrophysics, the Astronomy and Astrophysics Advisory Committee, and the NASA Astrophysics Subcommittee). Rick Howard and Eric Smith of NASA also presented their assessments of how the current NASA Astrophysics Program measures up to the program laid out in previous NRC reports.

On August 14-16, 2006, the committee met at the Science Museum of Minnesota in St. Paul, Minnesota, to hear about a number of projects which were recommended by the NRC reports *Astronomy and Astrophysics in the New Millennium* and *Connecting Quarks with the Cosmos*.

The committee devoted its last meeting on October 20-22, 2006, at the National Academies' Keck Center in Washington, D.C., to drafting its final report. The report went to external review at the end of 2006. (The report was released in January 2007.)

Membership

Kenneth H. Keller, Johns Hopkins School of Advanced International Studies (chair)
Martha P. Haynes, Cornell University (vice chair)
Steven J. Battel, Battel Engineering
Charles L. Bennett, Johns Hopkins University
Catherine Cesarsky, European Southern Observatory
Megan Donahue, Michigan State University
Rolf-Peter Kudritzki, University of Hawaii at Manoa
Stephen S. Murray, Harvard-Smithsonian Center for Astrophysics
Robert Palmer, Independent Consultant
Joseph H. Taylor, Jr., Princeton University
Michael S. Turner, University of Chicago
Rainer Weiss, Massachusetts Institute of Technology
Charles E. Woodward, University of Minnesota, Minneapolis

Brian D. Dewhurst, Senior Program Associate, Board on Physics and Astronomy (study director)
Celeste A. Naylor, Senior Program Assistant, Space Studies Board

PLANETARY PROTECTION REQUIREMENTS FOR VENUS MISSIONS

The ad hoc Committee on Planetary Protection Requirements for Venus Missions, established under the auspices of COEL, was tasked with assessing the existing planetary protection requirements for spacecraft missions to Venus. The committee's short report "Assessment of Planetary Protection Requirements for Venus Missions" was released on February 14, 2006, and is reprinted in Chapter 6.

At the suggestion of NASA's Planetary Protection Officer, the poster paper "Reassessment of Planetary Protection Requirements for Venus Missions," by J.W. Szostak, R.L. Riemer, D.H. Smith, and J.D. Rummel was displayed at the General Assembly of COSPAR in Beijing in July 2006.

Membership*

Jack W. Szostak, Massachusetts General Hospital (chair)
Ruth Blake, Yale University
Michael J. Daly, Uniformed Services University of the Health Sciences
David H. Grinspoon, Southwest Research Institute
Anthony Keefe, Archemix Corporation
Gary J. Olsen, University of Illinois at Urbana-Champaign

Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy (study director)
David H. Smith, Senior Program Officer, Space Studies Board
Rodney N. Howard, Senior Program Assistant, Space Studies Board

*All terms ended during 2006.

REVIEW OF THE NEXT DECADE MARS ARCHITECTURE

The ad hoc Committee for the Review of the Next Decade Mars Architecture, formed to assess NASA's Mars exploration plans for the period 2007 to 2016, met in Washington, D.C., on March 29-31, 2006, and held a subsequent conference call on April 4, 2006. Edited copies of the report, formatted as a letter, were sent to NASA on June 30, 2006. A final version of the report, *Assessment of NASA's Mars Architecture 2007-2016*, was published in August 2006. The original short report is reprinted in Chapter 6; the Executive Summary of the final report is reprinted in Chapter 5.

Membership*

Reta F. Beebe, New Mexico State University (chair)
Jeffrey Barnes, Oregon State University
Penelope Boston, New Mexico Institute of Mining and Technology
Stephen Bougher, University of Michigan
Sherry L. Cady, Portland State University
Robert Clayton, University of Chicago
Jeffrey Forbes, University of Colorado
John Grant, Smithsonian Institution, National Air and Space Museum
Ronald Greeley, Arizona State University
Victoria Hamilton, University of Hawaii
Catherine Johnson, University of California, San Diego
Timothy McCoy, Smithsonian Institution, National Museum of Natural History
Ralph McNutt, Johns Hopkins University, Applied Physics Laboratory
Angus McRonald, Global Aerospace Corporation
Francis Nimmo, University of California, Santa Cruz

David H. Smith, Senior Program Officer, Space Studies Board (study director)
Rodney N. Howard, Senior Project Assistant, Space Studies Board

*All terms ended during 2006.

REVIEW OF THE NASA SCIENCE MISSION DIRECTORATE SCIENCE PLAN

The ad hoc Committee on the Review of the NASA Science Mission Directorate Science Plan, formed to conduct an assessment of NASA's draft science plan, held its only meeting on July 11-13, 2006, at the National Academies' Keck Center in Washington, D.C. The committee reviewed NASA's draft science plan and was briefed by NASA representatives and congressional staff. The committee held several teleconferences following the meeting to discuss its report. The short report was submitted to NASA on September 15 and released to the public on September 25. The chair, Tom Young, briefed NASA representatives and congressional staffers on October 5. The short report is reprinted in Chapter 6.

Membership*

A. Thomas Young, Lockheed Martin (retired) (chair)
Spiro K. Antiochos, Naval Research Laboratory
Ana P. Barros, Duke University
James Burch, Southwest Research Institute
Antonio J. Busalacchi, Jr., University of Maryland, College Park
Jack Farmer, Arizona State University
Margaret Finarelli, George Mason University
John Huchra, Harvard-Smithsonian Center for Astrophysics
Ralph Lorenz, Lunar and Planetary Laboratory, University of Arizona
Dan McCammon, University of Wisconsin

Anneila Sargent, California Institute of Technology
Jessica Sunshine, University of Maryland
Carl Wunsch, Massachusetts Institute of Technology

Dwayne A. Day, Senior Program Associate, Space Studies Board (study director)
Joseph K. Alexander, Senior Program Officer, Space Studies Board
Carmela J. Chamberlain, Program Associate, Space Studies Board

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*All terms ended during 2006.

SCIENTIFIC CONTEXT FOR THE EXPLORATION OF THE MOON

The ad hoc Committee on the Scientific Context for the Exploration of the Moon held its first meeting at the National Academies' Keck Center in Washington, D.C., June 20-22, 2006. The committee was briefed on a variety of current issues in lunar science. In addition to discussing presentations required at future meetings and drafting an outline for its interim report, the committee also discussed outreach activities designed to engage the international lunar science community in its activities. Outreach activities began at the meeting of the International Lunar Exploration Working Group in Beijing, China, in July 2006. Additional outreach activities took place at a variety of meetings including the American Astronomical Society Division for Planetary Sciences meeting in October 2006 and the American Geophysical Union meeting in December 2006.

At its August 2-4, 2006, meeting at the Arnold and Mabel Beckman Center in Irvine, California, the committee was briefed on a wide variety of lunar science and related issues which assisted in the formulation of the report draft. Also during this quarter, the committee held a teleconference to make final revisions to its draft report for submission to NRC review. The committee's interim report, *The Scientific Context for Exploration of the Moon: Interim Report*, was delivered to NASA on September 15, 2006. The Executive Summary is reprinted in Chapter 5.

The committee held its third meeting on October 25-27, 2006, in Santa Fe, New Mexico, to assess the response of the lunar science community and NASA to the interim report and to continue work on the final report. The committee heard presentations from NASA staff, other experts, and members of the committee. The committee held teleconferences on December 7, 13, and 19, 2006, to discuss progress on the final report, and, on December 13, to hear details on NASA's lunar architecture from NASA staff. (The final report was released in May 2007.)

Membership

George A. Paulikas, The Aerospace Corporation (retired) (chair)
Carlé M. Pieters, Brown University (vice chair)
William B. Banerdt, Jet Propulsion Laboratory
James L. Burch, Southwest Research Institute
Andrew Chaikin, Science Journalist, Arlington, Vermont
Barbara A. Cohen, University of New Mexico
Michael Duke,* Colorado School of Mines
Anthony W. England,** University of Michigan
Harald Hiesinger, University of Münster, Germany
Noel W. Hinners, Lockheed Martin Astronautics (retired)
Ayanna M. Howard, Georgia Institute of Technology
David J. Lawrence, Los Alamos National Laboratory
Daniel F. Lester, McDonald Observatory
Paul G. Lucey, University of Hawaii
S. Alan Stern,† Southwest Research Institute
Stefanie Tompkins, Science Applications International Corporation
Francisco P. Valero, Scripps Institution of Oceanography
John W. Valley, University of Wisconsin-Madison
Charles Walker, Independent Consultant, Annandale, Virginia
Neville J. Woolf, University of Arizona

Robert L. Riemer, Senior Program Officer, Board on Physics and Astronomy (study director)
David H. Smith, Senior Program Officer, Space Studies Board
Rodney N. Howard, Senior Project Assistant, Space Studies Board
Stephanie Bednarek, Research Assistant, Space Studies Board

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*During committee deliberations, Dr. Duke recused himself from discussion of the finding and recommendation related to the South Pole-Aitken Basin.

**Dr. England resigned from the committee on August 11, 2006, because of other commitments.

†Dr. Stern resigned from the committee on September 24, 2006, to join the NASA Advisory Committee Science Subcommittee (and on April 2, 2007, became Associate Administrator for NASA's Science Mission Directorate).

4
Workshops, Symposia, Meetings of Experts, and Other Special Projects

In 2006, one workshop and one meeting of experts were convened, and two workshop reports were published. (Projects are summarized below.) The planning committees for these projects do not provide advice and, therefore, are not governed by FACA Section 15.

Also in 2006, planning began for an ad hoc committee to organize a workshop to gather community input on the key scientific and technological questions that can be addressed on or from the Moon, focusing on science related to exploration systems and technologies. The workshop was held in 2007 and will be summarized in the 2007 annual report.

DISTRIBUTED ARRAYS OF SMALL INSTRUMENTS FOR RESEARCH AND MONITORING IN SOLAR-TERRESTRIAL PHYSICS: A WORKSHOP

In response to a request from the National Science Foundation, the ad hoc Committee on Distributed Arrays of Small Instruments for Research and Monitoring in Solar-Terrestrial Physics: A Workshop was formed under the auspices of the Space Studies Board's Committee on Solar and Space Physics to explore—via a community-based workshop—the scientific rationale, infrastructure needs, and issues related to implementation of what has become known as DASI—distributed arrays of small instruments. Participants of the June 2004 workshop, held at the J. Erik Jonsson Center in Woods Hole, Massachusetts, addressed the relevance of distributed instruments in their future program plans. *Distributed Arrays of Small Instruments for Solar-Terrestrial Research: Report of a Workshop*, released in February 2006, summarizes the discussions at the workshop; it does not present findings or recommendations. The Executive Summary is reprinted in Chapter 5.

Membership*

James L. Burch, Southwest Research Institute (chair)
Claudia J. Alexander, Jet Propulsion Laboratory
Vassilis Angelopoulos, University of California, Berkeley
Anthony Chan, Rice University
James F. Drake, Jr., University of Maryland, College Park
John C. Foster, Massachusetts Institute of Technology
Stephen A. Fuselier, Lockheed Martin Advanced Technology Center
Sarah Gibson, National Center for Atmospheric Research
Craig Kletzing, University of Iowa
Gang Lu, National Center for Atmospheric Research

Barry H. Mauk, Johns Hopkins University, Applied Physics Laboratory
Eugene N. Parker, University of Chicago (emeritus professor)
Robert W. Schunk, Utah State University
Gary P. Zank, University of California, Riverside

Arthur Charo, Senior Program Officer, Space Studies Board (study director)
Theresa M. Fisher, Senior Program Assistant, Space Studies Board

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*All terms ended during 2005.

MEETING OF EXPERTS

A meeting of experts in microgravity physical and life sciences was held on July 28, 2006, at the National Academies' Keck Center in Washington, D.C. The meeting was organized and convened by the SSB at the request of NASA's Exploration Systems Mission Directorate (ESMD) to examine NASA's current non-exploration portfolio balance and selection criteria in the areas of basic biological and physical research. The 12 invited experts, most of whom had served on previous advisory committees to NASA's life and microgravity programs, met with ESMD officials to discuss the agency's strategic and tactical approach to implementing the non-exploration based basic and applied research as stated in NASA Authorization Act of 2005. Participants discussed their own views directly with NASA during the meeting. As required for meetings of this type, no report or meeting minutes were produced by the NRC.

Sandra Graham, Senior Program Officer, Space Studies Board
Carmela Chamberlain, Program Associate, Space Studies Board

SOLAR SYSTEM RADIATION ENVIRONMENT AND NASA'S VISION FOR SPACE EXPLORATION: A WORKSHOP

The ad hoc Committee on the Solar System Radiation Environment and NASA's Vision for Space Exploration: A Workshop reported on an October 2005 workshop on Solar and Space Physics and the Vision for Space Exploration, a cross-disciplinary workshop which examined the radiation environments in the inner solar system and their effects on astronauts and operational systems in space. In 2006, the committee held several teleconferences to prepare their report for publication. *Space Radiation Hazards and the Vision for Space Exploration: Report of a Workshop* was released on October 23, 2006. The Executive Summary is reprinted in Chapter 5.

A follow-on to this workshop is the Aeronautics and Space Engineering Board's Committee on Evaluation of Radiation Shielding for Lunar Exploration, formed in September 2006 to evaluate the radiation shielding requirements for lunar missions and recommend a strategic plan for developing the necessary radiation mitigation capabilities to enable the planned lunar architecture.

*Membership**

Daniel N. Baker, University of Colorado, Boulder (chair)
Leslie A. Braby, Texas A&M University
Stanley Curtis, University of Washington (retired)
Jack R. Jokipii, University of Arizona
William S. Lewis, Southwest Research Institute
Jack Miller, Lawrence Berkeley National Laboratory
Walter Schimmerling, National Aeronautics and Space Administration (retired)
Howard J. Singer, National Oceanic and Atmospheric Administration
Leonard Strachan, Jr., Harvard-Smithsonian Center for Astrophysics
Lawrence W. Townsend, University of Tennessee, Knoxville
Ronald E. Turner, ANSER Corporation
Thomas H. Zurbuchen, University of Michigan

Dwayne A. Day, Senior Program Associate, Space Studies Board (study director)
Arthur Charo, Senior Program Officer, Space Studies Board
Celeste Naylor, Senior Program Assistant, Space Studies Board

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*All terms ended during 2006.

WORKSHOP ON DECADAL SCIENCE STRATEGY SURVEYS

The ad hoc Planning Committee for the Decadal Science Strategy Surveys Workshop organized a workshop that was held on November 14-16, 2006, at the Arnold and Mabel Beckman Center in Irvine, California. The purpose of the workshop was to promote discussion of the use of NRC decadal surveys for developing and implementing scientific priorities, to review lessons learned from the most recent surveys, and to seek to identify potential approaches for future surveys that can enhance their realism, utility, and endurance. The workshop involved approximately 60 participants from academia, industry, government, and the NRC. (A summary report of the workshop presentations, panel discussions, and general discussions, *Decadal Science Strategy Surveys: Report of a Workshop*, was released in April 2007.)

Planning Committee Membership

Lennard A. Fisk, University of Michigan (chair)
Charles L. Bennett, Johns Hopkins University
Berrien Moore III, University of New Hampshire
Suzanne Oparil, University of Alabama, Birmingham
Joseph F. Veverka, Cornell University
Warren M. Washington, National Center for Atmospheric Research
A. Thomas Young, Lockheed Martin Corporation (retired)

Jack D. Fellows, Rapporteur

Joseph K. Alexander, Senior Program Officer, Space Studies Board (study director)
Claudette K. Baylor-Fleming, Administrative Assistant, Space Studies Board

5
Summaries of Major Reports

This chapter reprints the summaries of reports that were released in 2006 (note that the official publication date may be 2007).

5.1 An Assessment of Balance in NASA's Science Programs

A Report of the Ad Hoc Committee on an Assessment of Balance in NASA's Science Programs

Summary

Congress, in the report accompanying the FY 2005 appropriation bill for NASA, directed "the National Academies' Space Studies Board (SSB) to conduct a thorough review of the science that NASA is proposing to undertake under the space exploration initiative and to develop a strategy by which all of NASA's science disciplines, including Earth science, space science, and life and microgravity science, as well as the science conducted aboard the International Space Station, can make adequate progress towards their established goals, as well as providing balanced scientific research in addition to support of the new initiative."[1] This report provides the third and final component of the National Research Council's (NRC's) advisory response to that mandate. It presents the NRC's assessment of NASA's integrated strategy and proposed science program, as indicated in materials that accompany the NASA FY 2007 budget request.

More than four decades of extraordinary achievements of NASA science have captured the imaginations of people throughout the world, and those achievements continue to astonish us and expand our appreciation for the Earth, our solar system, and the universe beyond. The technology that must be created to accomplish such ambitious scientific endeavors finds its way into other terrestrial applications and stimulates other technological accomplishments. Consequently, NASA's science programs have succeeded on many levels, thereby winning valuable prestige and support for the agency from both the public and the government. NASA's science programs have served the nation broadly in ways that expand our intellect, enhance our culture, improve our economic security, and generally enrich the nation and the world.

Plans for programs in space and Earth science in NASA's Science Mission Directorate (SMD) differ markedly from planning assumptions of only 2 years ago. The impact on the SMD program is most dramatically illustrated when one compares the rate of growth that had guided science program planning in 2004 compared to the present. The total funding available for SMD programs in 2007-2011 is to be reduced by $3.1 billion below program projections that accompanied the FY 2006 budget (corresponding to a reduction of about 10 percent for the period FY 2006-2010). At the time that the Vision for Space Exploration ("the Vision") was announced in 2004, the programs that are now in SMD were projected to grow robustly from about $5.5 billion in 2004 to about $7 billion in 2008 to accommodate the development of new scientific missions. As recently as the time of the FY 2006 budget request, the SMD budget for FY 2007 was projected at $5.96 billion. The actual request for SMD in FY 2007 is $5.33 billion, which is about $200 million less than was appropriated in 2004 even before taking inflation into account. Subsequent years have a projected growth of 1 percent, which is again less than the projected rate of inflation. Changes in plans for microgravity life and physical sciences in the Exploration Systems Mission Directorate are more pronounced. That program was supported at about $950 million in 2002 and was expected to grow to over $1.1 billion in 2008, but the new plan calls for a reduction to under $300 million in 2007 with little growth thereafter.[2]

The committee reviewed NASA's plans for research programs over the next 5 years in each of six areas—astrophysics, heliophysics, planetary science, astrobiology, Earth science, and microgravity life and physical sciences—and reached the following conclusions in response to the study charge.

Finding 1. NASA is being asked to accomplish too much with too little. The agency does not have the necessary resources to carry out the tasks of completing the International Space Station, returning humans to the Moon, maintaining vigorous space and Earth science and microgravity life and physical sciences programs, and sustaining capabilities in aeronautical research.

NOTE: "Summary" reprinted from *An Assessment of Balance in NASA's Science Programs*, The National Academies Press, Washington, D.C., 2006, pp. 1-4.

[1]Conference Report on H.R. 4818 Consolidated Appropriations Act, 2005, H. Rept. 108-792, p. 1599. The Vision for Space Exploration initiative was announced by President George W. Bush on January 14, 2004, and is outlined in *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

[2]NASA budget numbers used in this report are from NASA's annual budget books or other information supplied to the committee by NASA.

Recommendation 1. Both the executive and the legislative branches of the federal government need to seriously examine the mismatch between the tasks assigned to NASA and the resources that the agency has been provided to accomplish them and should identify actions that will make the agency's portfolio of responsibilities sustainable.

Finding 2. The program proposed for space and Earth science is not robust; it is not properly balanced to support a healthy mix of small, medium, and large missions and an underlying foundation of scientific research and advanced technology projects; and it is neither sustainable nor capable of making adequate progress toward the goals that were recommended in the National Research Council's decadal surveys.

The committee used four criteria to assess NASA's science programs in response to the committee's charge (see Chapter 1), and the committee's conclusions with respect to those criteria are as follows:

- *Capacity to make steady progress*. The proposed SMD mission portfolio will fall far short of what was recommended by the NRC's decadal surveys. The space and Earth science programs will be forced to terminate or delay numerous flight missions, curtail advanced technology preparations for other future missions, and significantly reduce support for the research projects of thousands of scientists across the country. The net result of these actions will be that NASA will not be able to make reasonable progress—in any of the major space research disciplines—toward the scientific goals that were set out for the decade, and our nation's leadership in Earth and space research and exploration will erode relative to efforts of other nations.
- *Stability*. The science program has become fundamentally unstable. As Figures 1.1 and 1.2 illustrate (see Chapter 1), there have been dramatic changes in the projected resource trajectories for all science programs over the past 3 years. Consequently, it has not been possible to follow an orderly plan for sequencing missions and projects, developing advanced technology, sizing and nurturing a research and technical community, or meeting commitments to other U.S. or international partners.
- *Balance*. The SMD program will become seriously unbalanced because the reductions in funding have fallen disproportionately on the small missions and the research and analysis (R&A) programs. The small missions such as the Explorers and the Earth System Science Pathfinders had already been reduced with the initiation of the Vision in FY 2005, to the point that their projected flight rate is now a fraction of what it had been throughout the history of the space program. The reductions in FY 2007 and the out-years compound the problem and also add a new target for reduction, the R&A program, which is the lifeblood of the space and Earth science community. Plans are to reduce R&A funding by 15 percent retroactively starting with the FY 2006 budget, with larger cuts in such programs as Astrobiology.
- *Robustness*. The proposed program is not robust because it undermines the training and development of the next generation of scientists and engineers—the generation that will be critical to the accomplishment of the agency's federal responsibilities, including the Vision. Space missions, regardless of whether they are for robotic or human exploration, generate an appropriate return on investment only if there is a high-quality, vibrant, experienced, and committed community of scientists and engineers to turn each mission's data stream into new understanding that creates intellectual, cultural, and technological benefits. Because space exploration is a long-term endeavor that spans decades and generations, NASA will need a sustained long-term investment in human capital, facilities, technology development, and progressive scientific discoveries.

The committee identified four critical areas that are especially significant contributors to its second finding:

1. Research and analysis (R&A) budgets have been reduced.
2. Astrobiology research has been severely reduced.
3. Explorers and other small missions have been delayed or canceled.
4. Initial technology work on future missions and emphasis on technical innovation have been reduced.

Recommendation 2. NASA should move immediately to correct the problems caused by reductions in the base of research and analysis programs, small missions, and initial technology work on future missions before the essential pipeline of human capital and technology is irrevocably disrupted.

If at all possible, the restoration of the small missions, R&A programs, and the technology investment in future missions should be accomplished with additional funding for science. The scale of the short-term resource allocation problem is modest, probably slightly more than 1 percent of the total NASA budget, but addressing that problem will help correct the immediate threats to the health of the research program and also permit NASA and its stakeholders to conduct a vigorous, open assessment of longer-term priorities and plans. Given the funding shortages associated with elements of the human spaceflight program, the committee further urges that funding for science (both the amounts requested and any modest additions that might be made) be isolated from other NASA accounts to ensure that the money is actually spent on science.

Finding 3. The microgravity life and physical sciences programs of NASA have suffered severe cutbacks that will lead to major reductions in the ability of scientists in these areas to contribute to NASA's goals of long-duration human spaceflight.

Recommendation 3. Every effort should be made to preserve the essential ground-based and flight research that will be required to enable long-duration human spaceflight and to continue to foster a viable community that ultimately will be responsible for producing the essential knowledge required to execute the human spaceflight goals of the Vision for Space Exploration.

The scale of the short-term resource allocation required to revive this effort is also modest (less than 1 percent of the total NASA budget), yet addressing that problem will provide a continuing source of knowledge and community commitment that is absolutely critical for the success of this endeavor.

Finding 4. The major missions in space and Earth science are being executed at costs well in excess of the costs estimated at the time when the missions were recommended in the National Research Council's decadal surveys for their disciplines. Consequently, the orderly planning process that has served the space and Earth science communities well has been disrupted, and balance among large, medium, and small missions has been difficult to maintain.

Recommendation 4. NASA should undertake independent, systematic, and comprehensive evaluations of the cost-to-complete of each of its space and Earth science missions that are under development, for the purpose of determining the adequacy of budget and schedule.

As part of this recommended NASA review, a careful examination of the approaches to cost, schedule, and risk management should be made, and a comprehensive examination should be done of options to reduce cost while maintaining a mission's capability to achieve the science priorities for which it was recommended. The committee urges that steps be taken to allow all missions currently under development to make reasonable progress while the competitive assessment of projects across the SMD is underway. Major missions are an essential part of a balanced program—it is important to have large missions as well as medium and small missions—and finding ways to keep them on track and affordable is thus crucial.

Finding 5. A past strength of the NASA science programs, in both their planning and their execution, has been the intimate involvement of the scientific community. Some of the current mismatch between the NASA plans for the next 5 years and a balanced and robust program stems from the lack of an effective internal advisory structure at the level of NASA's mission directorates.

Recommendation 5. NASA should engage with its reconstituted advisory committees as soon as possible for the purpose of determining how to create in the space and Earth science program a proper balance among large, medium, and small missions, and research and analysis programs, and for evaluating the advice in and the consequences of the results from the comprehensive reviews of the major missions called for in Recommendation 4. Reconstitution and engagement of advisory committees for the microgravity life and physical sciences are equally important and should be given attention.

5.2 Assessment of NASA's Mars Architecture 2007–2016

A Report of the Ad Hoc Committee to Review the Next Decade Mars Architecture

Executive Summary

This assessment by the ad hoc Committee to Review the Next Decade Mars Architecture was conducted at the request of Dr. Mary Cleave, NASA's Associate Administrator for the Science Mission Directorate, who asked the National Research Council (NRC) to address the following three questions:

1. Is the Mars architecture reflective of the strategies, priorities, and guidelines put forward by the National Research Council's solar system exploration decadal survey and related science strategies and NASA plans?
2. Does the revised Mars architecture address the goals of NASA's Mars Exploration Program and optimize the science return, given the current fiscal posture of the program?
3. Does the Mars architecture represent a reasonably balanced mission portfolio?

It is important to note that the original order of the questions posed by Dr. Cleave was 2, 3, and 1. That is, the one that now appears first was originally listed as last. The committee has taken the liberty of reordering the questions because it is strongly of the opinion that logic dictates that it start its assessment of the Mars architecture by first addressing the architecture's scientific foundations.

Following presentations, discussions, and deliberations, the committee developed the following findings and offers specific recommendations relating to each:

1. *Is the Mars architecture reflective of the strategies, priorities, and guidelines put forward by the NRC's solar system exploration decadal survey and related science strategies and NASA plans?* **The committee finds that the proposed Mars architecture addresses some of the strategies, priorities, and guidelines promoted by the solar system exploration (SSE) decadal survey and the Mars Exploration Program Analysis Group (MEPAG) and is basically consistent with NASA's plans as exemplified by the agency's 2006 strategic plan[1] and the Vision for Space Exploration.[2] However, the absence of a sample return mission and a geophysical/meteorological network mission runs counter to the recommendations of the SSE decadal survey and significantly reduces the architecture's scientific impact. Other topics of concern include the lack of well-defined mission parameters and scientific objectives for the Mars Science and Telecommunications Orbiter, Astrobiology Field Laboratory, and Mid Rover missions; issues relating to the phasing and responsiveness of these missions to the results obtained from past missions; and the incompletely articulated links between these missions and the priorities enunciated by the SSE decadal survey and MEPAG.**

The committee offers the following recommendations to NASA:

- ***Recommendation:*** **Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.**
- ***Recommendation:*** **Consider delaying the launch of the Astrobiology Field Laboratory until 2018 to permit an informed decision of its merits and the selection of an appropriate instrument complement in the context of a mature consideration of the results from the Mars Science Laboratory and other prior missions.**
- ***Recommendation:*** **Establish science and technology definition teams for the Astrobiology Field Laboratory, the Mars Science and Telecommunications Orbiter, the Mid Rovers, and the Mars Long-Lived Lander**

NOTE: "Executive Summary" reprinted from *Assessment of NASA's Mars Architecture 2007-2016*, The National Academies Press, Washington, D.C., 2006, pp. 1-3.

[1]National Aeronautics and Space Administration (NASA), *2006 Strategic Plan*, NP-2006-02-423-HQ, NASA, Washington, D.C., 2004. Available at <www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.pdf>.

[2]National Aeronautics and Space Administration (NASA), *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004. Available at <www.nasa.gov/pdf/55583main_vision_space_exploration.pdf>.

Network as soon as possible to optimize science and mission design in concert with each other. (This model has been employed successfully by the heliospheric community.)

- ***Recommendation:*** **Devise a strategy to implement the Mars Sample Return mission, and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission.**

2. *Does the revised Mars architecture address the goals of NASA's Mars Exploration Program and optimize the science return, given the current fiscal posture of the program?* **The committee finds that it cannot definitively say whether or not the revised Mars architecture addresses the goals of NASA's Mars Exploration Program because the architecture lacks sufficient detail with respect to the science and the cost to allow a complete evaluation. The various mission options are, as stated above, incompletely defined, and the strategic approach to, and the selection criteria to distinguish among, various mission options are lacking. The presence of Mars Scout missions in the architecture is welcomed because they help to optimize the science return and provide balance. Nevertheless, the Mars architecture as a whole is not optimized, because the importance of foundational strategic elements—for example, research and analysis programs and technology development—is not articulated.**

In response to this finding, the committee offers the following recommendations to NASA:

- ***Recommendation:*** **Develop and articulate criteria for distinguishing between the three options for missions to launch in 2016. Similarly, define a strategy that addresses the short lead time between science results obtained from the Mars Science Laboratory and selection of the mission to fly in 2016.**
- ***Recommendation:*** **Clarify how trade-offs involving mission costs versus science were made for the various launch opportunities to justify the rationale behind the proposed sequence of specific missions and the exclusion of others.**
- ***Recommendation:*** **Maintain the Mars Scouts as entities distinct from the core missions of the Mars Exploration Program. Scout missions should not be restricted by the planning for core missions, and the core missions should not depend on selecting particular types of Scout missions.**
- ***Recommendation:*** **Immediately initiate appropriate technology development activities to support all of the missions considered for the period 2013-2016 and to support the Mars Sample Return mission as soon as possible thereafter.**
- ***Recommendation:*** **Ensure a vigorous research and analysis (R&A) program to maintain the scientific and technical infrastructure and expertise necessary to implement the Mars architecture, and encourage collaboration on international missions.**

3. *Does the Mars architecture represent a reasonably balanced mission portfolio?* **The committee finds that in the context of the basic types of missions, the Mars architecture is a reasonably well balanced one: both landed and orbital missions are included in an appropriate mix, given the current state of Mars exploration. To the extent that the specific science objectives of the proposed missions are defined, one of the three cross-cutting themes for the exploration of Mars identified in the SSE decadal survey is largely neglected, as are very high priority topics related to understanding near-surface and boundary-layer atmospheric sciences, and so, in this respect, balance is sorely lacking.**

To optimize efforts to implement a balanced portfolio of missions, the committee offers the following recommendations to NASA:

- ***Recommendation:*** **Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.**
- ***Recommendation:*** **If the Mars Long-Lived Lander Network cannot be implemented in the period under consideration, provide for an effort to make some of the highest-priority measurements on the landed missions that are included in the proposed Mars architecture.**
- ***Recommendation:*** **Ensure that the primary role of the Mars Science and Telecommunications Orbiter is to address science questions, and not simply to serve as a telecommunications relay. This distinction is particularly important with respect to the required orbital parameters that are adopted.**

5.3 Distributed Arrays of Small Instruments for Solar-Terrestrial Research: Report of a Workshop

A Report of the Ad Hoc Committee on Distributed Arrays of Small Instruments for Research and Monitoring in Solar-Terrestrial Physics: A Workshop

Executive Summary

To explore the scientific rationale for arrays of small instruments recommended in the 2002 NRC decadal survey for solar and space physics,[1] the infrastructure needed to support and utilize such arrays, and proposals for an implementation plan for their deployment, an ad hoc committee established under the Space Studies Board's Committee on Solar and Space Physics organized the 1.5-day Workshop on Distributed Arrays of Small Instruments held in June 2004 at the National Academies' Jonnson Center in Woods Hole, Massachusetts. This report summarizes the discussions at the workshop; it does not present findings or recommendations.

Solar-terrestrial science addresses a coupled system extending from the Sun and heliosphere to Earth's outer magnetosphere and ionosphere to the lower layers of the atmosphere, which are connected via the thermosphere and lower ionosphere. Processes in each region can affect those in the other regions through coupling and feedback mechanisms. As the 2002 decadal survey and other related NRC reports have noted,[2] understanding and monitoring the fundamental processes responsible for solar-terrestrial coupling are vital to being able to fully explain the influence of the Sun on the near-Earth environment. These studies emphasize that monitoring the spatial and temporal development of global current systems and flows; the energization and loss of energetic particles; and the transport of mass, energy, and momentum throughout the magnetosphere and coupled layers of Earth's upper atmosphere is essential to achieving this scientific goal.

At the workshop, speakers asserted that deployment of distributed arrays of small instruments (DASI) would culminate decades of discipline-related local instrument development for the pursuit of aspects of solar-terrestrial science at the subsystem level. With the advent of the Internet and affordable high-speed computing, these local deployments can now become elements of a global instrument system. When different instrument techniques are then combined to observe all aspects of the physical system, the DASI concept will be realized.

Proponents of the DASI concept emphasized that DASI's strength is that it offers a cost-effective means of performing original and critically important science, with a development strategy that allows resulting new knowledge to enable and flow into future initiatives. DASI will complement and extend the capabilities of the next generation of space-based research and space weather instruments by providing a global context within which to understand in situ and remote sensing observations.

During the course of the workshop, three recurrent themes became evident: (1) the need to address geospace[3] as a system, (2) the need for real-time observations, and (3) the insufficiency of current observations.

1. Geospace as a system—Understanding the Sun's influence on Earth's global space environment requires detailed knowledge of the atmosphere-ionosphere-magnetosphere system. This extremely complex natural system involves many different interacting elements, and Earth is the only planetary system that scientists can expect to study in detail. Today, the science of space plasma physics has matured to the level of being able to both describe and model many of these interactions. A major goal in solar-terrestrial science now is to unify scientific understanding so as to achieve a more comprehensive computational framework that will enable prediction of the properties of this system—leading to conditions known as space weather that affect Earth and its technological systems. To do this accurately, however, requires an understanding of Earth's global behavior as it exists, rather than as it occurs

NOTE: "Executive Summary" reprinted from *Distributed Arrays of Small Instruments for Solar-Terrestrial Research: Report of a Workshop*, The National Academies Press, Washington, D.C., 2006, pp. 1-3.

[1]National Research Council (NRC), 2003, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, The National Academies Press, Washington, D.C., p. 73; NRC, 2003, The Sun to the Earth—and Beyond: Panel Reports, The National Academies Press, Washington, D.C., p. 174.

[2]For example, see NRC, 2004, *Plasma Physics of the Local Cosmos*, The National Academies Press, Washington, D.C.

[3]"Geospace" is the term used to refer to the ensemble of regions including Earth's magnetosphere, ionosphere, and thermosphere.

in an idealized representation. Realizing such goals requires the assimilation and integration of data from disparate sources.

2. The need for real-time observations—The magnetosphere-ionosphere-thermosphere (M-I-T) system is a highly dynamic, nonlinear system that can vary significantly from hour to hour at any location. The coupling is particularly strong during geomagnetic storms and substorms, but there are appreciable time delays associated with the transfer of mass, momentum, and energy between the different domains. Also, it is now becoming clear that a significant fraction of the flow of mass, momentum, and energy in the M-I-T system occurs on relatively small spatial scales and over a wide range of temporal scales. Consequently, elucidation of the fundamental coupling processes requires continuous, coordinated, real-time measurements from a distributed array of diverse instruments, as well as physics-based data assimilation models.

3. Insufficiency of current observations—Observational space physics is data-starved, leading to large gaps in the ability to both characterize and understand important phenomena. This is particularly true for space weather events, which often are fast-developing and dynamic and which extend well beyond the normal spatial coverage of current (ground-based or space) sensor arrays.

Issues addressed in presentations and discussion sessions at the workshop can be summarized in a number of fundamental science questions reflecting what participants saw as opportunities for the DASI concept to contribute to progress in understanding the Sun's influence on the near-Earth environment. They included the following:

- What is the configuration of the magnetosphere-ionosphere-thermosphere system that is most vulnerable to space weather?
- What are the processes and effects associated with plasma redistribution during disturbed conditions?
- What is the role of the ionosphere-thermosphere system in the processes associated with particle energization?
- What are the effects of preconditioning in the ionosphere and magnetosphere on the evolution of disturbances?
- What processes affect ion-neutral coupling in the presence of particle precipitation?
- What are the causes of thermosphere-ionosphere variability during geomagnetically quiescent periods?
- What are the structure and dynamics of the Sun's interior?
- What are the causes of solar activity?
- How does the structure of the heliosphere modify the solar wind?
- Can low-frequency interplanetary scintillations be used to make global determinations of solar wind velocity?

Among the major ground-based remote sensing instruments described by workshop participants were the following:

- Very-low-frequency and high-frequency receivers and radio telescopes;
- High- and medium-power active radars and low-power passive radars;
- Ionosondes;
- Magnetometers;
- Passive and active optical instruments (interferometers, spectrometers, lidars); and
- Solar imagers, spectrographs, polimeters, magnetographs, and radio telescopes.

Speakers also noted the importance of computer models that are capable of assimilating the observations made with such instruments.

Attention at the workshop sessions was also devoted to issues regarding the infrastructure needs for future distributed arrays of ground-based instruments. Information technology was especially emphasized. Speakers cited the Virtual Observatory model that is being used in the solar and astronomy communities as an excellent starting point and template for DASI. Other information technology capabilities of note included the use of Internet and computer grid technology and high-data-rate, near-real-time communications systems. Finally, the workshop illuminated logistics considerations for the DASI concept, including key instrument spacing and size requirements for some classes of instruments as well as opportunities for and constraints on instrument placement in key locations for realizing DASI science objectives.

Throughout the workshop participants discussed a number of areas in which the space research community can begin an organized effort to develop a coordinated space-research instrumentation system. Although no consensus on priorities was sought or attempted, participants identified the following near-term actions as means to further evaluate the potential of the DASI concept and to prepare for its future development and implementation:

- Hold community workshops to address in greater detail the instrumentation, science, and deployment issues associated with DASI.
- Identify areas in which existing and planned instrument arrays and clusters can share technology, data distribution architectures, and logistics experience.
- Consolidate currently planned systems to form a regional implementation of next-generation coordinated instrument arrays.
- Establish closer connections with other research communities that are developing similar distributed instrumentation systems.
- Coordinate efforts in the U.S. community with similar international efforts.
- Move toward developing rugged, miniaturized instruments that use a common data format.
- Support efforts to establish standards for data communication technologies and protocols.
- Work with agency sponsors to begin a phased implementation of the DASI program.

Achieving the science objectives for DASI will require a global deployment of instruments and a large commitment of resources. Although the workshop did not go into detail on the areas of collaboration or opportunities to be pursued, participants felt strongly that international collaboration should be a fundamental part of the DASI plan.

5.4 Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report

A Report of the Ad Hoc Committee on Meeting the Workforce Needs for the National Vision for Space Exploration

Summary

This report of the Committee on Meeting the Workforce Needs for the National Vision for Space Exploration responds to NASA's request for an interim report on a study to explore long-range space science and engineering workforce needs to achieve the nation's space exploration vision, identify obstacles to filling those needs, and recommend solutions for consideration by government, academia, and industry. The report presents a summary of highlights of a January 2006 workshop and a February 2006 committee meeting on the future of the U.S. aerospace space science and engineering workforce, and it provides some preliminary findings with respect to (1) current and projected characteristics of the workforce, (2) factors that impact the demographics of the affected workforces, and (3) NASA's list of the workforce skills that will be needed to implement the nation's vision for space exploration, both within the government and in industry. The report also presents initial recommendations that stem from these findings and initial conclusions.

There have been numerous recent studies and assessments of aspects of the future viability of the U.S. science and engineering workforce, including both broad macro-level examinations of the technical workforce across all disciplines and sectors and more focused assessments of the outlook in specific fields, such as aerospace science and engineering. These studies have considered such factors as the increasing fraction of the current workforce that soon will become retirement-eligible and the impact of science and mathematics education in the United States in the face of increasing globalization of industry. Studies that have looked in detail at the workforce for the U.S. space program have expressed concerns about the impact of shrinkage of the workforce during the aerospace industry's consolidation in the 1990s, competition for students from other technical fields that may be perceived as more exciting or having more growth potential, and a possible shortage of graduates who are eligible to receive clearances to work in areas covered by the International Traffic in Arms Regulations (ITAR).

NASA's interests in the workforce question were heightened by President George W. Bush's January 2004 announcement of a new civil space policy that would refocus NASA's broad range of research and engineering projects toward the human and robotic exploration of the Moon, Mars, and eventually other solar system bodies. This new vision for space exploration specified a phase-out of the space shuttle by 2010 and development of a new human launch vehicle to support human space missions as early as 2014, and a human return to the Moon between 2015 and 2020. NASA is using those new goals to reshape the agency's workforce in order to better align the mix of skills with the needs for future missions, and to ensure that NASA will have the necessary skills to achieve the new vision. Consequently, NASA sees a need to identify those skills that will no longer be needed, take steps to retrain and reshape the workforce, and be able to provide specific skills that will be needed in the future.

NASA's workforce issues can be thought of in terms of three timescales:[1]

1. *Immediate near-term*—the workforce problems that NASA is facing at the present moment, particularly the agency's concerns about its internal skill mix and (approximately 900) underutilized civil service staff at selected centers. This time frame is too short to be within the scope of the committee's charge, and the committee did not issue findings and recommendations concerning it. However, the committee notes that it will shape perceptions among current and potential employees about stability and opportunities in the civilian space program.

NOTE: "Summary" reprinted from *Issues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Report*, The National Academies Press, Washington, D.C., 2006, pp. 1-5.

[1]These dates are from NASA's internal SEITT study and were provided to NASA's mission directorates in a survey of future workforce needs. See: "SEITT's Identification of Workforce Competencies to Support the Vision for Space Exploration," presentation to the Space Studies Board / Aeronautics and Space Engineering Board Committee on Meeting the Workforce Needs for the National Vision for Space Exploration, Jerry W. Simpson, February 22, 2006.

2. *Mid-term, present to 2012*—corresponds with the retirement of the space shuttle in 2010, completion of International Space Station construction, the period for development of a crew exploration vehicle and crew launch vehicle, and the early development of the lunar exploration hardware.
3. *Long-term, post-2012*—the period during which NASA will be conducting full-scale development of the human lunar exploration systems.

The committee understands that NASA has concentrated heavily to date on the immediate near-term problems. However, except for the results of some modeling of age and retirement eligibility demographics, the committee received little information about NASA analyses or planning for the mid- or long-term workforce *skill mix* demand or supply. The one exception with respect to skill mix was NASA's observation about an agency-wide need for systems engineers and project managers. This concern is widely shared by senior managers in the Department of Defense (DOD) and industry, as well. During the workshop NASA did not discuss plans or options for training activities to address the agency's mid- and long-term needs in any detail. The committee did not see any information about whether or how the agency might be coordinating with other agencies (e.g., DOD) that are facing similar workforce concerns. DOD has created several programs to develop systems engineers, but there was no indication that NASA is working with DOD on these programs.[2]

The committee's initial examination of relevant demographic data about aerospace workforce supply and demand led to the following conclusions. First, although there are currently some problems in meeting demand, particularly for specific skills, the situation for employers such as the DOD and the large aerospace companies is not now a major problem. Data on employment demand are difficult to obtain, particularly broken down by relevant skill areas, and those data and projections that exist are often ambiguous as one looks beyond the near-term future. Second, many longer-term projections do forecast a gap between supply and demand that is larger than exists today. However, the size and scope of the gap are not clear. Third, the problems with meeting future demand in the DOD are influenced by the need to employ U.S. citizens and permanent residents who can obtain security clearances. NASA's workforce pool will be constrained in a similar fashion as the DOD's because NASA must hire people who can work in areas controlled by ITAR. Fourth, people with strong technical backgrounds can often acquire the specialized knowledge to go into different (but related) fields. Consequently, recruitment need not be too tightly targeted to the momentarily required specializations. Finally, NASA's mono-generational employee age distribution (i.e., having a peak at only a single age; see Chapter 2) is different from the distribution seen for the DOD and industry, both of which were described at the workshop as being either bimodal or more nearly like the distribution of the U.S. workforce as a whole. However, so far NASA has only begun to examine skill distribution and is becoming aware that it has an age distribution problem, but the committee saw no indication that the agency has begun to act on this concern.

NASA is not currently experiencing a supply problem in terms of overall available personnel. But the agency is experiencing a more complex and subtle problem that will grow over time. Like other government agencies and aerospace contractors, NASA is experiencing difficulty in finding experienced personnel in certain areas, such as systems engineers and project managers. NASA's workforce also has a skewed age distribution arising from hiring policies first implemented in the 1990s. The agency did not experience a hiring freeze during that time, but it adopted policies whereby it filled specific positions but did not hire younger people and "grow" them into positions. As a result, the agency's mean age has continued to rise over time, and it lacks younger employees with necessary skills. As the agency embarks on new human and robotic exploration programs, problems in fulfilling demand will likely increase because the agency has not been developing the necessary employees from within.

The January workshop illuminated the following factors that will influence the demographics of the future aerospace science and engineering (S&E) workforce.

[2] In January 2004 President Bush signed the NASA Flexibility Act of 2004 (P.L. 108-201). The act authorized NASA to increase recruitment, relocation, and retention bonuses, and it streamlined the hiring process for recent graduates. It also expanded pay flexibility and authorized science and technology scholarships that can pay for a student's undergraduate or graduate school education in return for a commitment by the student to work for NASA for a prescribed period of time following graduation.

- *Perception*—Potential employees need to be convinced that the vision for space exploration is an exciting effort, that it is sustainable, that they can play an important role, that they can receive training or experiences that will help in future jobs, and that their potential co-workers and managers are committed.
- *Stability*—Will the overall effort be sufficiently large to maintain constant staffing, incorporate reachable and significant milestones that can serve as starting points for both employees and employers, and be based on a vision viewed as having a sustained duration long enough on which to build a career?
- *Availability*—Will key vacancies be open for competition, thereby creating an environment that encourages and facilitates the movement of NASA employees into industry for developmental work experience assignments, the movement of industry employees into NASA where they can mentor NASA employees, and the subsequent return of these employees to their original institutions?
- *Recruitment*—Can NASA and industry properly identify required skills in advance, whether the workforce has reliable and effective feeder programs, and how much attention is paid to expanding the diversity of the workforce and recruiting from underrepresented populations?
- *Retention and engagement*—The ability to pay competitive salaries, maintain employees' sense of usefulness, prepare employees for future contributions in addition to current contributions, listen to inputs from employees, provide mentors and training, and facilitate the transfer of know-how from senior to younger employees.
- *International involvement*—Although ITAR constraints may lead to a higher demand for U.S. citizens and permanent residents than might be the case in other employment sectors, international participation in space exploration will still have a significant impact on supplying members of the workforce.

During the January workshop participants raised a number of other notable points:

- NASA's attention to workforce issues seems primarily internally focused, but a more outward looking approach is desirable that accepts that industry and academia are integral parts of the workforce.
- A solution to NASA's near-term problems will not come via training students, because that is too long a process. Instead, exchanges with industry and academia are more promising for the near term.
- There will be a need for more organizational transparency to promote the flow of workers between NASA, industry, and academia.
- Workforce pull will be more important than push; jobs will have to be made attractive to meet workforce demand.

Based on the workshop discussions and additional information that the committee gathered at its second meeting, the committee has the following preliminary findings:

1. NASA has made a reasonable start on assessing its near- and long-term skill needs, and the committee shares the view expressed by NASA representatives that there is still much more work to be done. However, NASA's work has focused on initial assessment of current workforce demographics and estimates of future needs. NASA has not yet translated that analysis into a strategy and action plan. NASA's lack of work to date limited the committee's ability to assess exactly what needs to be done.
2. NASA needs a strategic workforce plan that deals with the next 5 years and that lays the foundation for a longer-term process. This will be a new and difficult process for NASA, but it will nevertheless be vital for the agency's success in implementing the space exploration vision.
3. The committee has not seen compelling evidence for a looming, broadly based shortage in the supply of aerospace S&E workforce employees to meet NASA's needs.
4. To address those skill areas where there are concerns (both for the near term and the longer term), NASA needs to pay particular attention to identifying and expanding ways to promote exchanges of personnel between NASA and the private sector (industry, academia, and non-government organizations).
5. The degree to which the agency chooses to perform work in-house versus by a contractor will play a major role in the number of personnel that the agency will require.
6. The committee concludes that the ability to recruit and strategically retain the needed workforce will depend fundamentally on the long-term stability of the vision for space exploration and a sustainable national consensus on NASA's mission.

The committee makes the following recommendations:

1. **NASA should develop a workforce strategy for ensuring that it is able to target, attract, train, and retain the skilled personnel necessary to implement the space exploration vision and conduct its other missions in the next 5 to 15 years.** The agency's priority to date has been to focus on short-term issues such as addressing the problem of uncovered capacity (i.e., workers for whom the agency has no current work).[3] However, NASA soon might be facing problems of expanding needs or uncovered capacity in other areas and at other centers. Therefore, it is important to develop policies and procedures to anticipate these problems before they occur.
2. **NASA should adopt innovative methods of attracting and retaining its required personnel and should obtain the necessary flexibility in hiring and reduction-in-force procedures, as well as transfers and training, to enable it to acquire the people it needs. NASA should work closely with the DOD to initiate training programs similar to those that the DOD has initiated, or otherwise participate actively in the DOD programs.**
3. **NASA should expand and enhance agency-wide training and mentorship programs, including opportunities for developing hands-on experience, for its most vital required skill sets, such as systems engineering.** This effort should include coordination with DOD training programs and more use of exchange programs with industry and academia.

Finally, the committee wishes to stress that this is an interim report. The committee still has to complete its examination of the role that universities play in supplying, training, and supplementing NASA's workforce. Part of this assessment will be to consider the role that universities can play in providing hands-on space mission training of the workforce, including the value of carrying out small space missions at universities. The committee also plans to review the final version of NASA's Systems Engineering and Institutional Transition Team (SEITT) report. The committee will evaluate the skills that the study identifies as necessary to implement the vision for space exploration, assess the current workforce against projected needs, and identify gaps and obstacles to responding to NASA's projected needs. In its final report, the committee expects to develop recommendations for specific actions by the federal government, industry, and academia, including organizational changes, recruiting and hiring practices, student programs, and workforce training and improvement to enable NASA to accomplish the goals of the vision.

[3]"Uncovered capacity" is NASA's term for a serious problem with workers for whom the agency has no current work. When NASA cuts programs or reduces budgets, it is left with civil service personnel who may no longer have work to perform. Unlike industry, NASA cannot simply lay off these unneeded workers, but must conform to a complex set of civil service rules. Normally the agency will have some uncovered capacity in its workforce, but in 2005 and into 2006 this number was identified as constituting a significant percentage of its total workforce. During that time NASA was also forbidden by law from conducting a reduction in force, or RIF, to reduce its workforce. As a result, the agency exercised alternative methods to reduce this excess workforce and cut the excess capacity in half by January 2006. The cumulative effects of paying for unnecessary employees can damage the agency in a number of ways, including diversion of tight program funding and the use of poorly qualified employees for work that might otherwise be performed by contractors.

5.5 The Scientific Context for Exploration of the Moon: Interim Report

A Report of the Ad Hoc Committee on the Scientific Context for Exploration of the Moon

Executive Summary

We know more about many aspects of the Moon than any world beyond our own, and yet we have barely begun to solve its countless mysteries. The Moon is, above all, a witness to 4.5 billion years of solar system history, and it has recorded that history more completely and more clearly than any other planetary body. Nowhere else can we see back with such clarity to the time when Earth and the other terrestrial planets were formed.

Planetary scientists have long understood the Moon's unique place in the evolution of rocky worlds. Many of the processes that have modified the terrestrial planets have been absent on the Moon. The lunar interior retains a record of the initial stages of planetary evolution. Its crust has never been altered by plate tectonics, which continually recycle Earth's crust, or planetwide volcanism, which resurfaced Venus only half a billion years ago, or by the action of wind and water, which have transformed the surfaces of both Earth and Mars. The Moon today presents a record of geologic processes of early planetary evolution in the purest form.

For these reasons, the Moon is priceless to planetary scientists: It remains a cornerstone for deciphering the histories of those more complex worlds. But because of the limitations of current data, researchers cannot be sure that they have translated the message correctly. Now, thanks to the legacy of the Apollo program, and looking forward to the Vision for Space Exploration, it is possible to pose sophisticated questions that are more relevant and focused than those that could be asked over three decades ago. Only by returning to the Moon to carry out new scientific explorations can we hope to close the gaps in understanding and learn the secrets that the Moon alone has kept for eons.

NASA asked the National Research Council (NRC) to provide guidance on the scientific challenges and opportunities enabled by a sustained program of robotic and human exploration of the Moon during the period 2008-2023+ as the Vision for Space Exploration evolves. This interim report was prepared by the Committee on the Scientific Context for Exploration of the Moon. The committee will present additional material and more details in its full report, to be released in mid-2007.

PRIORITIES, FINDINGS, AND RECOMMENDATIONS

Within a balanced science program the committee provides the following prioritization of lunar science goals that can be accomplished by lunar measurements and analyses during the early phases of the Vision for Space Exploration. It has used the prioritization criteria adopted by the decadal survey *New Frontiers in the Solar System: An Integrated Exploration Strategy* (NRC, 2003) as a guideline: scientific merit, opportunity, and technological readiness. Each of these priorities has related orbital, in situ, returned sample, and human-tended measurement goals.

1. Fundamental Solar System Science
   - Characterize and date the impact flux (early and recent) of the inner solar system.
   - Determine the internal structure and composition of a differentiated planetary body.
   - Determine the compositional diversity (lateral and vertical) of the ancient crust formed by a differentiated planetary body.
   - Characterize the volatile compounds of polar regions on an airless body and determine their importance for the history of volatiles in the solar system.

2. Planetary Processes
   - Determine the time scales and compositional and physical diversity of volcanic processes.
   - Characterize the cratering process on a scale relevant to planets.

NOTE: "Executive Summary" reprinted from *The Scientific Context for Exploration of the Moon: Interim Report*, The National Academies Press, Washington, D.C., 2006, pp. 1-5.

- Constrain processes involved in regolith evolution and decipher ancient environments from regolith samples.
- Understand processes involved with the atmosphere (exosphere) of airless bodies in the inner solar system.

3. Other Opportunities (additional information is required for these)
   - Utilize data from the Moon to characterize Earth's early history.
   - Determine the utility of the Moon for astrophysics observations.
   - Determine the utility of the Moon as a platform for observations of Earth.
   - Determine the utility of the Moon as a platform for observations of solar-terrestrial processes.

FINDINGS AND RECOMMENDATIONS

Lunar science has much broader implications than simply studying the Moon. There are strong linkages between the science goals recommended for the lunar exploration program and diverse scientific and applied concerns.

Principal Finding: Lunar activities apply to broad scientific and exploration concerns.

Finding 1: Enabling activities are critical in the near term.[1]

In order to take advantage of the information expected to be returned from missions flown before 2010 by the United States and other nations, the committee finds that enabling, preparatory activities will be critical in the near term.

> **Recommendation 1:** The committee urges NASA to make a strategic commitment to stimulate lunar research and engage the broad scientific community[2] by establishing two enabling programs, one for fundamental lunar research and one for lunar data analysis. Information from these two efforts, the Lunar Fundamental Research Program and the Lunar Data Analysis Program, will speed and revolutionize understanding of the Moon as the Vision for Space Exploration proceeds.

Finding 2: Explore the South Pole-Aitken basin.

As the oldest and largest basin in the solar system, the South Pole-Aitken Basin on the Moon is a unique location.

> **Recommendation 2:** NASA should develop plans and options to accomplish the scientific goals set out in the *New Frontiers in the Solar System: An Integrated Exploration Strategy*'s[3] high-priority recommendation, through single or multiple missions that increase understanding of the South Pole-Aitken basin and by extension all of the terrestrial planets in our solar system (including the timing and character of the early heavy bombardment).

Finding 3: Determine the composition and structure of the lunar interior.

Determination of the interior structure and composition of the Moon are high-priority scientific goals.

> **Recommendation 3:** Because a globally distributed network of many geophysical stations is critical for these investigations, an international effort should be pursued to coordinate the development of a standard, small set of key instruments (e.g., seismometer, thermal profiler, retro-reflector, etc.) and to cooperate in providing for its wide deployment across the Moon.

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[1]The findings presented here are summarized from the more detailed findings given in Chapters 4 and 5.

[2]See National Research Council, I*ssues Affecting the Future of the U.S. Space Science and Engineering Workforce: Interim Repo*rt, The National Academies Press, Washington, D.C., 2006.

[3]See National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003.

Finding 4: Maximize the diversity of lunar samples.

The Moon is a complex, heterogeneous body. Samples of the Moon from diverse sites are necessary to reach science goals.

> **Recommendation 4:** Landing sites should be selected that can fill in the gaps in diversity of lunar samples. To improve the probability of finding new, ejecta-derived diversity, every landed mission that will return to Earth should retrieve at a minimum two special samples: (a) a bulk undisturbed soil sample (200 g minimum) and (b) at least 1 kg of rock fragments 2 to 6 mm in diameter sieved from bulk soil. These samples would be in addition to those collected at specific high-priority sampling targets within the landing site.

Finding 5: Proceed with lunar surface mission development and the site selection process.

Plans to return to the Moon will involve the selection of surface exploration sites. Many of the science goals the committee set out depend critically on site selection.

> **Recommendation 5:** Development of a comprehensive process for lunar landing site selection that addresses the science goals of Table 1[4] should be started by a science definition team. The choice of specific sites should be permitted to evolve as understanding of lunar science progresses through the refinement of science goals and the analysis of existing and newly acquired data. Final selection should be done with full input of the science community in order to optimize science return while meeting engineering and safety constraints.

Finding 6: Understand the lunar polar deposits and environment.

Almost nothing is known about the sources of volatiles at the lunar poles and the processes operating on these volatiles. Lunar polar deposits and the lunar polar environment are probably fragile.

> **Recommendation 6:** NASA should carry out activities to understand the inventory, lateral distribution, composition (chemical, isotopic, mineralogic), physical state, and stratigraphy of the lunar polar deposits. This understanding will be gained through analyses of orbital data and in situ data from landed missions in the permanently shaded regions. In situ studies should occur early enough in the lunar program to prevent substantial change in the polar environment due to robotic and human activities.

Finding 7: Understand and characterize the lunar atmosphere.

The lunar atmosphere is tenuous and therefore fragile. Its pristine state is vulnerable to alteration from robotic and human activities.

> **Recommendation 7:** To document the lunar atmosphere in its pristine state, early observational studies of the lunar atmosphere should be made, along with studies of the sources of the atmosphere and the processes responsible for its loss. These include a full compositional survey of all major and trace components of the lunar atmosphere down to a 1 percent mixing ratio, determination of the volatile transport to the poles, documentation of sunrise/sunset dynamics, determination of the variability of indigenous and exogenous sources, and determination of atmospheric loss rates by various processes.

Finding 8: Evaluate the Moon's potential as an observation platform.

The Moon may be a suitable site for various scientific observations of Earth, Sun-Earth connections, astronomy, and astrophysics.

> **Recommendation 8:** The committee recommends that a thorough study be done by NASA to evaluate the suitability of the Moon as an observational site for studies of Earth, Sun-Earth connections, astronomy, and astrophysics.

[4]See pages 23 and 24 of [the] interim report.

Finding 9: Establish strong ties with international programs.

The participation of other nations in lunar exploration is a fact. Coordinated and cooperative international activities would benefit all participants.

> **Recommendation 9:** NASA is encouraged to explicitly plan and carry out activities with the international community for scientific exploration of the Moon in a coordinated and cooperative manner. The committee endorses the concept of international activities as exemplified by the recent "Beijing Declaration" of the 8th International Conference on Exploration and Utilization of the Moon.

The committee also presents several related findings and recommendations intended to facilitate a balanced program to reach the scientific goals:

Finding 1R: Optimize the partnership between NASA's Exploration Systems Mission and Science Mission Directorates.

> **Recommendation 1R:** Prior Space Studies Board reports examined management approaches to the integration of human exploration and space science. They found that an optimum approach consisted of establishing a science management office within (today) the Exploration Systems Mission Directorate, reporting jointly to the Science Mission and Exploration Systems Mission Directorates. Such an office should be established as soon as possible to ensure the productive involvement of science planning and implementation ab initio.

Finding 2R: Identify and develop lunar-specific advanced technology and instrumentation.

> **Recommendation 2R:** NASA should create an advanced technology program to develop lunar-specific capabilities that are critical to successful implementation of the lunar science strategy outlined in Table 1. This program should tap the creativity of the engineering and science communities to address development of robotic and instrumentation capability to meet needs that at present are unmet.

Finding 3R: Plan curatorial and principal investigator facilities for new lunar samples.

> **Recommendation 3R:** NASA should evaluate the future needs of curatorial facilities for the collection of new lunar samples. The state and availability of instrumentation for both curation and analyses should be assessed. Such a study should include representatives of the science community in detailed planning of an appropriate strategy.

Finding 4R: Optimize astronaut lunar field investigations—an integrated human/robotic approach.

> **Recommendation 4R:** NASA should provide astronauts with the best possible technical systems for conducting science traverses and emplacing instruments. An integrated human/robotic program should be developed using robotic assistants and independent autonomous/teleoperated robotic systems. The capabilities of these systems should be designed in cooperation with the science community and operations planning teams that will design lunar surface operations. Extensive training and simulation should be initiated early to help devise optimum exploration strategies.

5.6 Space Radiation Hazards and the Vision for Space Exploration: Report of a Workshop

A Report of the Ad Hoc Committee on the Solar System Radiation Environment and NASA's Vision for Space Exploration: A Workshop

Executive Summary

The President's Vision for Space Exploration (VSE) specifies that the United States should carry out a human lunar mission no later than 2020 and eventually conduct human expeditions to Mars. NASA has already been restructured to achieve these ambitious goals. This new policy creates many challenges, but not all of them are immediately obvious. Among these, the hazards of space radiation to crews traveling to the Moon and Mars will pose unique questions and challenges, not only to the spacecraft engineering community but to the space science community as well. Between the Apollo 16 and 17 missions in August 1972, for example, a powerful solar event occurred that would have seriously endangered astronauts on the lunar surface. Now that the United States has adopted a civilian space policy that refocuses many NASA research and engineering missions toward the human and robotic exploration of the Moon, Mars, and eventually other solar system bodies, events such as the powerful solar storms between Apollo missions over three decades ago must be interpreted in a new context.

Astronauts and spacecraft participating in the VSE will be exposed to a hazardous radiation environment, made up of galactic cosmic radiation and driven by solar energetic particle events and "space weather" changes. Accurate and timely information about this environment is required in order to plan, design, and execute human exploration missions. The information required consists of estimates or measurements of the time of occurrence, duration, and spatial distribution of the radiation, as well as the type, maximum intensity, and maximum energy of the constituent particles. Unfortunately, the prediction and forecasting of solar activity and space weather are severely hampered by a lack of understanding of how the Sun affects the heliosphere and planetary environments of Earth, the Moon, and Mars. Scientific progress in this field, leading to accurate long-term and short-term predictions of the space radiation environment, is required if solar and space physics scientists are to make the significant contribution required of them by human exploration missions.

A workshop held on October 16-20, 2005, in Wintergreen, Virginia, and cosponsored by NASA, the National Science Foundation, and the National Research Council brought together members of the space science, planetary science, radiation physics, operations, and exploration engineering communities. (The list of workshop participants and the agenda are presented in Appendix C.) The objectives of the workshop were to increase awareness and understanding of the complex array of solar and space physics issues pertinent to the environments of Earth, the Moon, and Mars; to identify compelling research goals necessary to ensure the success of the Vision for Space Exploration in these environments; and to discuss the directions that research in these fields should take over the coming decades in order to achieve these goals. The workshop effectively recognized that a multidisciplinary approach to defining the challenges of human exploration is required because no single National Academy of Sciences decadal survey or combination of surveys provides the type of advice needed for the new programs that are anticipated under the Vision for Space Exploration. Also, no single scientific or engineering discipline can provide the expertise and knowledge necessary to solve these problems optimally.

The workshop placed particular emphasis on the following topics:

- The heliospheric radiation environment as understood to date, including required data sources and possible new measurements;
- Physical mechanisms of energetic particle acceleration and transport in the heliosphere as understood to date;
- Radiation health hazards to astronauts;

NOTE: "Executive Summary" reprinted from *Space Radiation Hazards and the Vision for Space Exploration: Report of a Workshop*, The National Academies Press, Washington, D.C., 2006, pp. 1-6.

- Radiation effects on materials and spacecraft systems; and
- Mitigation techniques and strategies, including forecasting and operational schemes.

A central theme that emerged during the workshop, both in the formal presentations in the plenary sessions and in focused discussions in thematically organized working groups, is the importance of the timely prediction of the radiation environment for mission design and mission operations. **There was general agreement among the participants that it is in this area that the solar and space physics community can, through improved characterization and understanding of the sources of space radiation, contribute substantively to NASA's radiation management effort and to the Vision for Space Exploration.** This statement may seem self-evident, but many workshop participants noted that it represented a change in attitude from previous community meetings. During the workshop, many of the participants focused for the first time in decades on ways that their research corresponds with NASA's needs to support humans traveling beyond low Earth orbit. Among the points that the workshop participants agreed on were the following:

- Developing timely predictions of the radiation environment is a complex task whose components vary depending on the timescale considered and on the mission characteristics;
- Delivering timely predictions requires advances in basic space and solar physics, development of observational assets, improved modeling capabilities, and careful design of communications;
- The space operations community—that is, those who plan and manage human spaceflight missions—must be informed about these advances in understanding and expanding capabilities so that operators can take advantage of advances; and
- In some cases operational tools (i.e., tools for space operations) must be developed or adapted from scientific analytical tools and converted to real-time reporting tools; the transition from research to operations is a very challenging task.

The workshop effectively assessed the following topics: the current level of understanding of solar and space physics; the issues faced by the NASA space radiation program as it deals with radiation effects on humans; the challenges of ensuring the reliable functioning of instruments and machines in space; and how progress can be made in understanding, defining, and, ultimately, making timely predictions of the space radiation environment.

Workshop participants made clear that current or planned research tools could be adapted to support the implementation of the Vision for Space Exploration. There was great enthusiasm about the ability to contribute to this endeavor. Rather than developing entirely new hardware or products, the space operations community can exploit many existing assets. However, many of the workshop participants also expressed the concern that a primary challenge will be knowledge transfer—that is, arranging existing data sets, models, research tools, and other assets in ways that make them useful to the space operations community. The solar and space physics community and the human spaceflight operations community do not have extensive existing ties, and this lack presents a barrier to effective collaboration. Better communication between these communities must be established; it will provide substantial benefits. Many workshop participants stated that NASA should conduct future interdisciplinary meetings similar to the Wintergreen Workshop to help coordinate the work of scientists and operators.

The nature of the workshop as an interdisciplinary forum demonstrated how it was possible that the space operations community might benefit from completely unexpected sources of data that it might never have realized existed except for such a collaboration. For example, recent studies of historical data from polar ice core samples suggest that solar events much larger than the August 1972 event have occurred during the past several hundred years. The largest of these events appears to have been the Carrington event of 1859. Estimates of possible organ doses from an event of this magnitude (~4 times larger than occurred in August 1972) indicate that substantial shielding would be needed to protect human crews in space. Astronauts performing extravehicular activities in space or surface exploration activities on the Moon during an event of this magnitude could receive potentially lethal exposures. Because NASA is contemplating stays on the lunar surface that may eventually last up to 6 months, there is a much higher probability of crews being exposed to a significant solar event than during the much shorter Apollo missions (which lasted no longer than 2 weeks from launch to landing).

Knowledge of the space radiation environment of the past provides the historical context for understanding the space radiation environment of the present. However, it also requires caution in extrapolating from present conditions to those that might exist in the future. With respect both to galactic cosmic radiation (GCR) intensity and to the frequency with which large solar energetic particle (SEP) events occur, the radiation environment at 1 AU appears at present to be relatively "mild." The historical record suggests that this is unusual and that if this mild interregnum ends, there might be significant consequences for human exploration.

Given the significant contribution of GCR to total radiation exposure of astronauts, it is important to understand long-timescale (decades or more) variations in the GCR. It is well established that at short timescales (months to years) the GCR flux varies with solar activity, peaking at solar minimum. But over longer timescales, the solar cycle amplitudes also vary. Some solar maxima are more intense than others. During a period known as the Maunder minimum, the number of sunspots, a measure of solar activity, essentially dropped to zero; hence the GCR flux would have been greater. What happens to the GCR intensity at such times? Recent solar cycles have had relatively large amplitudes, suggesting that the present may be a period of relatively low peak GCR intensities.

The workshop showed that a multidisciplinary approach could potentially reduce the costs of separate research efforts through the sharing of information. The information needed to meet solar and space physics objectives and to meet the requirements of the radiological health program often overlap. However, the priorities of the two areas generally differ. For example, a solar and space physics objective may require detailed particle energy resolution over a limited range of particle energies, while radiological health measurements require data for a broader range of energies but do not require the high resolution. Consequently, the data analysis phase of many solar and space physics experiments, constrained by budget limitations, did not recover all of the available information relevant to radiation protection. As a result, significant information relevant to radiological health may be available for a modest investment in the further analysis of existing data sets. Similarly, minor modifications to proposed solar and space physics instruments may result in data that will meet radiological health protection requirements, thereby eliminating the need for additional instruments intended solely for health protection measurements.

The Vision for Space Exploration raises important questions about how to determine that the knowledge base and predictive capabilities are adequate to commit crews to even longer missions to Mars. Currently, NASA's regulations governing acceptable radiation doses for human crews in low Earth orbit are for intervals significantly less than the 1,000 days it would take to send a crew to Mars. This limit is established by taking into account many poorly understood biological factors, and NASA is making progress toward reducing the size of the uncertainties. As several workshop participants noted, merely reducing the amount of uncertainty in the understanding of radiation health effects can significantly increase the number of days allowable for human crews to spend in space. But NASA will have to make a concerted research effort to reduce that uncertainty; it will not happen without planning.

Space radiation not only affects humans but can affect spacecraft, instruments, and communications as well. Some of these effects are well known, such as electrostatic charging and degradation of solar cells. Solar particles, cosmic rays, and trapped particle radiation are all of concern in this regard. Certainly a reduction in uncertainty about such radiation will improve spacecraft design and operations.

Global radiation models are beginning to become available, but they are difficult to tailor to specific events. One clear statement from the workshop is that there is a need for a better understanding of how to relate solar and space physics observations to the models. The observations have a dual role: (1) they provide the inputs to drive models, and (2) they are required to validate the models (post facto). For the near-term need, it should be possible to improve predictions of "all clear" periods when there is a very low probability that an SEP event will occur. This is possible with a better understanding of the signatures indicating that a flare or coronal mass ejection is about to erupt. New observations of solar magnetic structures with Solar-B, the Solar Dynamics Observatory, and the ground-based Advanced Technology Solar Telescope and the Frequency Agile Solar Radio Telescope will help in this regard.

Farther in the future, it is desirable to make predictions of solar events days to weeks before they occur. Initially, this will be possible only with models that use a statistical approach along with a suitable set of in situ and remote sensing measurements from multiple vantage points in the heliosphere. It will be most useful for the Vision for Space Exploration if models can predict the following: (1) the onset time for an SEP event, (2) its time-intensity profile, (3) the "spectral indices" of the energy spectrum, (4) the shock arrival time, and (5) the anisotropy in the particle velocity distribution (a lower priority). An effective warning system for SEP events will require an operational distributed network of observations from the Sun throughout the heliosphere (similar to the distributed network of weather stations on Earth). Near-Sun missions such as Inner Heliosphere Sentinels, Solar Orbiter, and Solar Probe will provide unique measurements to test more sophisticated models. Recent physics-based (dynamo) models of the Sun give hope of making accurate predictions of the size of solar activity cycles years or decades in advance.

Because of the threat posed by SEP events, taking radiation safety into account will be critical in order to ensure adequate shielding or timely access to a safe haven. Fortunately, awareness of the risk of radiation exposure is widespread, and it is hoped that systems will be designed to manage radiation risk. It is critical to decide at the outset what the radiation risk mitigation strategy will be and then to integrate this strategy into the mission concept early in the design phase. The generic elements of a radiation risk mitigation strategy include space environment situational awareness, radiation exposure forecasting, and exposure impact and risk analysis. These elements combine to generate recommendations to the mission commander, who has the responsibility for keeping the radiation exposure as low as reasonably achievable.

The large uncertainties in space radiation and biological effects that exist at present increase the cost of missions owing to the large safety margins required as a consequence. These uncertainties also limit the ability to judge the effectiveness of risk mitigation methods, such as improvements in shielding or biological countermeasures. Operational measures and radiation shielding are currently the main means of reducing radiation risk; improved biological markers have the potential to enable improved early diagnostics; discovery of means of biological prevention and intervention may lead to significantly more powerful methods, including better radioprotectants, to overcome the biological consequences of exposure to radiation. Continued basic research has the potential to address all of these key issues effectively.[1]

The challenges described here can be overcome, and NASA is making progress on many of them. But the hazards of space radiation to future space explorers can only be reduced with the assistance of the solar and space physics science community and effective collaboration between the scientists and the space operations community.

REFERENCES

Cucinotta, F.A., M-H.Y. Kim, and L. Ren. 2005. *Managing Lunar and Mars Mission. Radiation Risks Part I: Cancer Risks, Uncertainties, and Shielding Effectiveness.* 2005. NASA/TP-2005-213164. NASA, Washington, D.C.

Townsend, L.W., F.A. Cucinotta, and J.W. Wilson. 1992. Interplanetary crew exposure estimates for galactic cosmic rays. *Radiat. Res.* 129:48-52.

[1]Extraordinary shielding (~300 to 500 g/cm2) would be necessary to protect astronauts if their radiation limits were set at levels comparable to those of occupationally exposed individuals on Earth (e.g., workers at nuclear power plants) or at the even lower exposure limits established for the general public. However, astronaut limits for operations in low Earth orbit (LEO) are approximately an order of magnitude higher than limits for earthbound radiation workers (at present 50 centi-Sievert (cSv) per year for astronauts, with a lifetime limit that depends on age and sex; however, no limits have been established as yet for Mars missions). This difference is due to the shorter career exposure times for astronauts (generally assumed to be no more than 10 years) versus possible 40+ year career exposure times for radiation workers on Earth. The LEO limits for astronauts, although higher than limits for earthbound radiation workers, are based on a 3 percent excess cancer mortality risk. Shielding needed to attain this elevated level of permitted exposure is much less than the heroic value of 300 to 500 g/cm2, generally being somewhere in the range of 20 g/cm2 or somewhat above. For example, for 20 g/cm2 aluminum shielding, Townsend et al. (1992) calculate 50 cSv per year at solar minimum, but Cucinotta et al. (2005) now estimate closer to 75 cSv/year using the newer transport codes and environmental models. The effect of these levels on astronaut risk is not sufficiently well known at this time and is a subject of active research. Future human spaceflight depends on the outcome of this research. Note that the most relevant radiation protection quantity is the radiation risk, as represented by the dose equivalent, which represents risk of developing a fatal cancer. Most of the dose equivalent is contributed by the heavy ion component of the GCR spectrum and not the protons. Dose is important, but only for possible acute radiation syndrome effects (radiation sickness) resulting from very large SEP radiation exposures. Dose is relatively small from GCR particles, being only around 20 centi-Gray (20 rads) annually during solar minimum, of which only about 7 rads come from protons of all energies (Townsend et al., 1992). “Gray (Gy)” is the name for the unit joule per kilogram when that unit is applied to the absorbed dose. “Absorbed dose” is defined as the energy imparted by ionizing radiation per unit of mass.

6
Short Reports

During 2006, the Space Studies Board and its committees issued three short reports:

- Assessment of Planetary Protection Requirements for Venus Missions
- A Review of NASA's 2006 Draft Science Plan
- Review of the Next Decade Mars Architecture (later released as a full report, see Chapter 5)

Each short report was accompanied by a letter addressed to the sponsor. The text of the letters, followed by the respective short report, are reprinted in this section.

6.1 Assessment of Planetary Protection Requirements for Venus Missions

On February 8, 2006, Jack W. Szostak, chair of the Ad Hoc Committee on Planetary Protection Requirements for Venus Missions, sent the following letter report to John D. Rummel, Planetary Protection Officer, NASA Headquarters.

As originally written in your letter of February 7, 2005, to Space Studies Board (SSB) Chair Lennard Fisk and reiterated at the February 9-11, 2005, meeting of the SSB's Committee on the Origin and Evolution of Life (COEL), you asked for advice on planetary protection concerns related to missions to and from Venus. In particular, you asked that the National Research Council (NRC) address three issues in terms of their implications for planetary protection:

1. Assess the surface and atmospheric environments of Venus with respect to their ability to support Earth-origin microbial contamination, and recommend measures, if any, that should be taken to prevent the forward contamination of Venus by future spacecraft missions;
2. Provide recommendations related to planetary protection issues associated with the return to Earth of samples from Venus; and
3. Identify scientific investigations that may be required to reduce uncertainty in the above assessments.

In response to your request, the Task Group on Planetary Protection Requirements for Venus Missions was formed (the membership of the task group is listed in Attachment 1) and met at the Southwest Research Institute in Boulder, Colorado, on October 3-5, 2005. The task group's deliberations and discussions relating to the conclusions and recommendations contained in this letter report were confined to the Boulder meeting. To set the context for and define the scope of this study, presentations were given and discussions were held at two meetings of COEL earlier in 2005—the February 9-11 and May 31-June 2 meetings at the National Academies' Keck Center in Washington, D.C., and its Jonsson Center in Woods Hole, Massachusetts, respectively. These preliminary presentations and discussions were conducted under the aegis of COEL's standing oversight of NASA's Astrobiology program and in its role as the organizing committee for the SSB's astrobiological activities. And, since all but two members of the task group are also members of COEL, the majority of the authoring group of this letter report participated in all three meetings and heard the following presentations relevant to this study:

- *At the meeting in Washington, D.C.,* you briefed the committee on the topic "Planetary Protection Classification of Venus," and Dirk Schulze-Makuch (Washington State University) spoke on the question "A Case for Life on Venus?"
- *At the meeting in Woods Hole, Massachusetts,* you presented an updated version of "Planetary Protection Classification of Venus," and Linda Amaral Zettler (Marine Biological Laboratory) addressed the topic "Acidophiles in the Rio Tinto." In addition, Martha Gilmore (Wesleyan University) and James W. Head III (Brown University) gave presentations respectively entitled "NASA Planning for Venus Sample-Return Missions" and "Origin and Evolution of Venus's Environment."
- *At the meeting in Boulder, Colorado,* D. Kirk Nordstrom (U.S. Geological Survey) gave a talk titled "Negative pH, Efflorescent Mineralogy and Consequences for Environmental Restoration at Iron Mountain." Mark Bullock (Southwest Research Institute) gave the presentation "Origin and Evolution of Venus's Environment," and task group member David Grinspoon gave the summary presentation entitled "The Astrobiology of Venus." In addition, individual task group members held extensive discussions in open and closed sessions.

The task group consulted related reports issued by the SSB and other NRC committees (e.g., *Recommendations on Quarantine Policy for Mars, Jupiter, Saturn, Uranus, Neptune, and Titan [1978], An Integrated Strategy for the Planetary Sciences: 1995-2010* [1994], *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies* [1998], *A Science Strategy for the Exploration of Europa* [1999], and *Preventing the Forward Contamination of Europa* [2000][1]).

NOTE: Attachments are not reprinted in this annual report.

[1]These reports were published by the National Academy Press, Washington, D.C.

In its deliberations, the task group examined planetary protection considerations affecting Venus missions. The known aspects of the present-day environment of Venus offer compelling arguments against there being significant dangers of forward or reverse biological contamination, regardless of the unknowns. Full details are contained in the attached "Assessment of Planetary Protection Requirements for Venus Missions."

Because of the extreme temperature at the Venus surface, the fact that concentrated H_2SO_4 is sterilizing for all known Earth organisms, the consideration that the Venus cloud environment is extremely dehydrating and oxidizing, and the realization that any life forms adapted to the Venus clouds would not survive in Earth conditions, **with respect to planetary protection issues, the task group concluded as follows:**

- **No significant risk of forward contamination exists in landing on the surface of Venus;**
- **No significant forward-contamination risk exists regarding the exposure of spacecraft to the clouds in the atmosphere of Venus;**
- **No significant back-contamination risk exists concerning the return of atmospheric samples from the clouds in the atmosphere of Venus; and**
- **No significant risk exists concerning back contamination from Venus surface sample returns.**

Currently, NASA classifies Venus missions under planetary protection Category II, which "includes all types of missions to target those bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could jeopardize future exploration,"[2] rather than under the less restrictive Category I assigned by the Committee on Space Research (COSPAR) of the International Council for Science. **The task group recommends that the Category II planetary protection classification of Venus be retained.** Although there are many important scientific investigations to be carried out to improve understanding and knowledge of Venus, **the task group does not recommend any scientific investigations for the specific purpose of reducing uncertainty with respect to planetary protection issues.** The considerations that led to the above conclusions are presented in the attached assessment.

Signed by

Jack W. Szostak
Chair of the Ad Hoc Committee on Planetary Protection
Requirements for Venus Missions

[2]This explanation of Category II and of the other categories is given at the web site <planetaryprotection.nasa.gov/pp/about/categories.htm>. Last accessed February 7, 2006. The explanation of these categories is also reprinted in this letter report in Attachment 2, "COSPAR Categories for Planetary Protection."

Assessment of Planetary Protection Requirements for Venus Missions

This assessment by the Task Group on Planetary Protection Requirements for Venus Missions (the members of the task group are listed in Attachment 1) was carried out at a meeting held at the Southwest Research Institute in Boulder, Colorado, on October 3-5, 2005. The assessment was conducted at the specific written request of Dr. John D. Rummel, NASA's Planetary Protection Officer, who asked the National Research Council (NRC) to address three issues in terms of their implications for planetary protection:

1. Assess the surface and atmospheric environments of Venus with respect to their ability to support Earth-origin microbial contamination, and recommend measures, if any, that should be taken to prevent the forward contamination of Venus by future spacecraft missions;
2. Provide recommendations related to planetary protection issues associated with the return to Earth of samples from Venus; and
3. Identify scientific investigations that may be required to reduce uncertainty in the above assessments.

VENUS MISSIONS

The United States and the former Soviet Union (with France) have been sending spacecraft to Venus since the beginning of the space age.[1] Missions to land on Venus began with the Soviet Venera 3 atmospheric probe, which lost communications before atmospheric entry in March 1966. Atmospheric probes Venera 4, 5, and 6 also crashed on Venus. On December 15, 1970, Venera 7 made the first successful landing of a spacecraft on another planet and survived for 23 minutes before succumbing to heat and pressure. Venera 8 landed July 22, 1972, and survived for 50 minutes. Between 1975 and 1982, Venera probes 9 through 14 made successful landings.

In 1978, NASA sent two Pioneer spacecraft to Venus. The Pioneer Venus Multiprobe carried one large and three small atmospheric probes. The large probe was released on November 16, 1978, and the three small probes on November 20, 1978. All four probes entered the Venus atmosphere on December 9, 1978, followed by the delivery vehicle. Although not expected to survive the descent through the atmosphere, one probe continued to operate for 45 minutes after reaching the surface. The Pioneer Venus Orbiter was inserted into an elliptical orbit around Venus on December 4, 1978. It carried 17 experiments and operated until the fuel used to maintain its orbit was exhausted and atmospheric entry destroyed the spacecraft in August 1992.

The Soviet Union's Vega 1 and Vega 2 probes encountered Venus on June 11 and June 15, 1985. Landing vehicles carried experiments focusing on cloud aerosol composition and structure. The Vega 1 and 2 spacecraft each deployed a balloon-borne aerostat that floated at about 53 km altitude for 46 and 60 hours, respectively, traveling about one-third of the way around the planet. These probes measured wind speed, temperature, pressure, and cloud density.

Although the most recent spacecraft sent to Venus ceased operating over a decade ago (the last mission was NASA's Magellan radar mapper, which operated until 1994), scientific interest in Venus has not waned. The 2003 NRC report *New Frontiers in the Solar System: An Integrated Exploration Strategy*[2] recommended the Venus In Situ Explorer as one of eight high-priority planetary exploration projects for the period 2003 to 2013. As a result, NASA is considering possible space missions to Venus, including orbiters, landers, and atmospheric probes. Moreover, several other nations and space agencies are planning to launch missions to Venus in the near future. The European Space Agency's Venus Express spacecraft was successfully launched on November 9, 2005, and the Japan Aerospace Exploration Agency plans to launch a Venus orbiter, Planet-C, in 2008.

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[1]For more details of missions to Venus, see, for example, A.A. Siddiqi, *Deep Space Chronicle: A Chronology of Deep Space and Planetary Probes 1958-2000,* Monographs in Aerospace History 24, National Aeronautics and Space Administration, Washington, D.C., 2002. The brief summary that follows here was adapted from Wikipedia contributors, "Observations and Explorations of Venus," Wikipedia, The Free Encyclopedia, available online at <en.wikipedia.org/w/index.php?title=Observations_and_explorations_of_Venus&oldid=28480484>. Last accessed February 7, 2006.

[2]National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy,* The National Academies Press, Washington, D.C., 2003.

SCIENTIFIC CONSIDERATIONS AND PAST NATIONAL RESEARCH COUNCIL REPORTS

Despite Venus's being Earth's near twin in terms of its mass, radius, and other bulk properties, the surface of Venus represents perhaps the most hostile planetary environment ever explored by robotic spacecraft. The average surface temperature of Venus is more than 737 K, hot enough to melt lead. The surface pressure is 92 bar, about equivalent to 1 km deep in Earth's ocean. The surface is desolate, water is absent, and sulfur is abundant. More than 85 percent of the surface is covered by volcanic rock. Venus's atmosphere is more than 96 percent carbon dioxide, with 3 percent nitrogen and traces of other gases. Three distinct cloud layers shroud the entire planet, at altitudes from 45 to 60 km. The clouds occupy the "Earth-like" part of Venus's atmosphere, with pressures ranging from 2 bar to 10 mbar and temperatures ranging from ~240 to 390 K. Water vapor ranges from a few parts per million at the top of the cloud deck to a few tens of parts per million at the base. However, the cloud droplets are formed of extremely concentrated sulfuric acid. A high flux of solar ultraviolet radiation exists throughout the cloud deck.[3]

Although the surface environment of Venus is clearly inimical to terrestrial life, some researchers have argued that conditions in Venus's clouds may be potentially conducive to life.[4] Indeed, some authors have suggested that chemical disequilibrium among trace constituents of Venus's atmosphere is evidence for microbial life in the planet's lower cloud layers.[5,6] In particular, supporters of this conjecture point to the coexistence of chemical species—such as H_2 and O_2 and H_2S and SO_2—not normally found in association and the existence of relatively benign regions in the atmosphere where the temperature is 300 to 350 K, and where pressures of 1 bar and water vapor concentrations as high as several hundred parts per million may exist.[7] Such organisms, presumably, would have evolved when Venus's climate was more like that of Earth and then migrated to the clouds as Venus lost its surface water.

Irrespective of such speculations, the evolution and present states of Venus's atmosphere have a direct bearing on the history and evolution of both biotic and abiotic organic compounds in the solar system. For example, given the similar location in the solar nebula of Mars, Earth, and Venus, these planets are likely to have had roughly similar bulk chemical compositions 4.5 billion years ago and would have been exposed to similar early radiation processes. The extent to which the atmospheres have evolved and diverged since that time yields information on the evolution of Earth's atmosphere and the couplings of atmospheric composition with biology and life. Venus may also provide clues to the composition of past atmospheres on Earth that ultimately would have influenced the distribution of terrestrial organic compounds in the form of, for example, carbon reservoirs in the atmosphere compared with those at the surface, in the interior, and in the oceans.

The Space Studies Board (SSB) has a long track record of assessing the biological potential of Venus and making recommendations concerning appropriate planetary protection guidelines for Venus missions. In 1970, for example, the SSB's predecessor, the Space Science Board, commented as follows:[8]

> A slight possibility exists that terrestrial organisms could grow on airborne particles near to the cloud tops of Venus. The problem was discussed at the 1970 COSPAR [Committee on Space Research of the International Council for Science] meeting, and some interest was expressed in investigations of airborne life. Life on Venus is no more than a remote contingency, but the possibility of contamination by terrestrial organisms must be considered.
>
> The saving feature of all Venus missions is that there is no longer any doubt that a temperature of about 700 K prevails over the entire surface of the planet. There is no possibility that terrestrial organisms can grow at such temperatures, and we are therefore at worst concerned with a short period of transit through the cooler regions of the atmosphere.
>
> According to the COSPAR agreements, the cumulative probability up to 1988 of contaminating the planet must be less than 10^{-3}. With 20 missions, the probability per mission must then be less than 5×10^{-5}. We are satisfied that this constraint is readily met, even if the bus or orbiter should enter the atmosphere. These unshielded vehicles will mostly vaporize in the upper atmosphere, and at most a few charred members may fall rapidly through the temperate

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[3]See, for example, <nssdc.gsfc.nasa.gov/planetary/planets/venuspage.html>. Last accessed February 7, 2006.

[4]D. Schulze-Makuch and L.N. Irwin, *Life in the Universe: Expectations and Constraints*, Springer-Verlag GmbH, Berlin, 2004, pp. 128-132.

[5]D.H. Grinspoon, *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet*, Perseus Publishing, Cambridge, Mass., 1997.

[6]D. Schulze-Makuch and L.N. Irwin, "Reassessing the Possibility of Life on Venus: Proposal for an Astrobiology Mission," *Astrobiology* 2: 197-202, 2002.

[7]D. Schulze-Makuch, O. Abbas, L.N. Irwin, and D.H. Grinspoon, "Microbial Adaptation Strategies for Life in the Venusian Atmosphere," Abstract 12747, NASA Astrobiology Institute General Meeting, Tempe, Arizona, 2003.

[8]National Research Council, *Venus: Strategy for Exploration, Report of a Study by the Space Science Board*, National Academy of Sciences, Washington, D.C., June 1970, pp. 12-13.

region of the cloud tops. For numerical estimates we may start with the figures given in the Planetary Explorer, Phase A Report (Goddard Space Flight Center, October 1969, Section 6 and Appendix C). The number of spores is taken as 10^4. The probability of release in the atmosphere under the above circumstances is estimated to be less than 10^{-3}; we regard the Goddard figure of 0.3 as far too high for atmospheric release, because it was based on a hard-surface impact. The probability of growth was given as 10^{-4}, but this assumes the presence of a stable particle or droplet to grow on. However, droplets are subject to evaporation, while solid particles must be subject to rapid mixing to support them against fallout; they will therefore reach a hot region in a short time. We believe that the probability of growth in the atmosphere should be amended to less than 10^{-6} for a total probability of contamination per impact of less than 10^{-5}.

We therefore see no reason why the bus or orbiter should not be permitted to impact the planet whenever a scientific benefit is to be gained thereby. Low-periapses orbiters should also be open to consideration. Surface-sterilized entry probes, hermetically sealed and with a fully sterilized heat shield, present a far lower probability of contamination than do the bus or orbiter, and risk of contamination from them may be neglected.

We therefore recommend that, with some precautions, spacecraft be allowed to impact the planet when scientific benefit is to be gained thereby.

The most recent NRC study of the planetary protection requirements for Venus missions was issued in 1972.[9] It commented as follows:

Two values of probability of growth are used for Venus, one for the planet surface, the other for its atmosphere. Prior to the proposed new quarantine policy these values stood at P_g(surface) $\leq 10^{-6}$ and P_g(atmosphere) $\leq 10^{-4}$. The proposed new values use P_g(surface) = 0; P_g(atmosphere) $\leq 10^{-9}$.

There is now general agreement that the surface temperatures of Venus are much too high for any known terrestrial microorganism to survive. Consequently, the proposed value $P_g = 0$ is acceptable.

Regarding the atmosphere, there are some uncertainties on the likely presence of sufficient nutrients, a high water activity and the convective rate by which water droplets containing microorganisms are transported downwards and pyrolyzed at the higher temperatures. The probability of contaminating the Venus atmosphere was treated in the SSB 1970 summer study;[*] in that study, a probability of growth for the atmosphere $\leq 10^{-6}$ was recommended and approved by the Space Science Board (a recommendation which superseded the previous value of $P_g \leq 10^{-4}$).

The committee recommends that NASA evaluate their sterilization standards for the Pioneer Venus mission (surface probe) in the light of the P_g(atmosphere) number recommended in the Venus 1970 study report. If further elucidation or interpretation on the application of these numbers is needed, the SSB would be willing to review the matter again.

For the Venus/Mercury 1973 flyby mission, the committee recommends a P_g(atmosphere) $\leq 10^{-9}$ (Venus atmosphere).

[*]National Research Council, *Venus: Strategy for Exploration, Report of a Study by the Space Science Board*, National Academy of Sciences, Washington, D.C., June 1970, pp. 12-13.

Since these reports were issued, the approach to planetary protection adopted by the Committee on Space Research (COSPAR) of the International Council for Science—the de facto guardian of the planetary protection provisions mandated by the United Nations' 1967 Outer Space Treaty[10]—has been significantly revised. The quantitative, statistical approach—based in part on the probability of growth (P_g) of terrestrial organisms transferred to an extraterrestrial environment—has been abandoned.[11] In its place is a simpler, more straightforward methodology

[9]National Research Council, Space Science Board Ad Hoc Committee for Review of Planetary Quarantine Policy, *Report (Final),* February 14, 1972, pp. 3-4.

[10]United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies,* U.N. Document No. 6347, United Nations, New York, N.Y., January 1967.

[11]The quantitative planetary protection methodology was based on the concept of a probability that a particular mission will contaminate a particular planet. The probability of contamination (P_c) was determined by a formula linking such factors as the measured bioburden on the spacecraft at launch, the likelihood that terrestrial organisms on the spacecraft will survive transit to their planetary destination, the probability that organisms will be released into the planet's environment, and the probability that these organisms will grow and reproduce (P_g). For a recent discussion of this approach, see, for example, Space Studies Board, National Research Council, *Preventing the Forward Contamination of Mars* (Prepublication Text), The National Academies Press, Washington, D.C., 2005, pp. 25-27. For a detailed, quantitative discussion, see, for example, S. Schalkowsky and R.C. Klein, Jr., "Analytical Basis for Planetary Quarantine," pp. 9-26 in L.B. Hall, ed., *Planetary Quarantine: Principles, Methods, and Problems*, Gordon and Breach, New York, N.Y., 1971.

based on the type of mission (e.g., flyby, orbiter, lander, or sample return) and the degree to which the mission's destination is of interest to the process of chemical or biological evolution (see Attachment 2).

The planetary protection characterization resulting from the two NRC studies conducted in the 1970s was that although Venus was of some interest with respect to issues of chemical and biological evolution—for example, to studies relating to the divergent evolutions of Earth, Mars, and Venus—the chances of contaminating Venus with terrestrial organisms are so slight that no special requirements need be levied on spacecraft missions to that planet. As such, missions to Venus are currently assigned to planetary protection Category II (see Attachment 2 for details).

Much new information about the origin and evolution of Venus's surface and atmospheric environment has, however, been revealed in the past three decades. In the same period, there has been an explosion of new findings concerning the ability of terrestrial microorganisms to survive in extreme conditions. These two strands of new information have been woven together by various authors, who have proposed plausible theories suggesting how life may have arisen on the early Venus, when environmental conditions were much more like those of Earth.[12] Then, as Venus gradually lost its initial inventory of water and its climate became increasingly dominated by a runaway greenhouse effect, microbial life might have been able to adapt to changing conditions and survive to this day in the more clement temperature and pressures found in Venus's clouds. Thus, a reexamination of the planetary protection requirements for Venus missions is appropriate at this time.

TOPICS CONSIDERED BY THE TASK GROUP

The task group considered the following topics:

- *Origins of life*—What does our current understanding of the origins and early evolution of life on Earth tell us about the possible origins of life on Venus?
- *Survival of life on Venus*—What can the study of terrestrial extremophiles tell us about the survival of life on Venus, whether it is indigenous or inadvertently transported from Earth?
- *Planetary protection issues*—What can planetary protection studies for other solar system objects tell us about likely issues concerning Venus?
- *Venus's environment*—What can our current understanding of the origin and evolution of Venus tell us about the likely environmental conditions and potential habitable niches on the planet through time?
- *Life in Venus's atmosphere*—What is the environment in Venus's clouds, could life exist there, and what is the likelihood that life exists there?

Origins of Life

It is generally agreed that surface conditions on early Venus were much more Earth-like and far more conducive to life than they are on Venus today. A liquid-water ocean and significant atmosphere are thought to have existed, and many of the processes that have been considered to be relevant to the origin of life on Earth could equally well have occurred on Venus. These include the formation of aqueous solutions of organic compounds that may have originated from meteoritic infall, atmospheric spark-synthesis, the mineral-catalyzed reduction of carbon dioxide or oxidation of methane, and hydrothermal synthesis in submarine vents.

Even if life did independently arise on the surface of Venus, it is very clear that it must have eventually become extinct or migrated to the cloud environment as the runaway greenhouse effect heated up the surface of the planet and evaporated most of the volatiles, except for those that recondensed in the global cloud deck. Any life remaining in the cloud deck would have had to adapt to conditions that do not overlap the range of conditions inhabited by life on Earth. Consequently, considerations of a possible origin of life on Venus are not relevant to considerations of the possibility that life currently exists on the surface of Venus or that living organisms of Earth origin could survive there.

The origin of life within the Venus cloud deck must be considered to be highly improbable. While in principle a living cell could maintain an intracellular environment of neutral pH, higher free-water concentration, and higher ionic strength than that persisting in the sulfuric acid droplet within which it exists, little in the way of protection from these harsh conditions will be available to molecules constituting a newly emerged, minimal self-replicating

[12] C.S. Cockell, "Life on Venus," *Planetary and Space Science* 47: 1487-1501, 1999.

system. It seems therefore inevitable that cells would be quickly destroyed (or not exist in the first place) rather than continue to replicate.

In principle, life in the Venus ocean could have been transported to the clouds and then persisted there after the point at which life on the surface became impossible and even until the present day. While this hypothesis overcomes the problems inherent in an origin of life within the clouds, it does not overcome the formidable problems that would face an organism living in this hostile environment, which include the following:

- The extremely acidic, dehydrating, and oxidizing environment of the cloud droplet environment, which will lead to the destruction of organic matter;
- The very high energetic cost of recruiting water from concentrated sulfuric acid;
- The high temperatures of the droplets at the cloud base, through which all droplets inevitably cycle;
- The lack of persistence of individual droplets, which have a probable life span of months to, at most, a few years;
- The loss of nonvolatile elements that fall to the surface of Venus; and
- The absence of biogenic elements that do not have volatile forms (e.g., Na, Mg, K, Ca, Mn, Fe, and most other metals). Although these elements could be introduced into the atmosphere by volcanic eruptions and by meteoritic infall, there is no obvious mechanism by which they could become widely distributed among all cloud droplets.

Survival of Earth-Life on Venus

The identification of extremophiles on Earth has expanded knowledge of the physicochemical limits at which life as we know it can exist. Organisms have been shown to grow at temperatures as high as 121°C,[13] in chronic radiation fluxes of 60 gray/hour,[14] in extreme pressures at the bottom of oceans, and in acidities as extreme as pH 0.[15] However, none of these extreme but life-supporting environments approaches the severity of surface and atmospheric conditions present on Venus. In particular, the ambient surface and atmospheric conditions on Venus render all currently known extremophilic phenotypes on Earth irrelevant. Concentrated sulfuric acid is sterilizing for all known organisms. Thus, genetic and other physiologic determinants necessary for life on Earth could not function on Venus, nor would biological determinants that evolved on Venus be expected to function on Earth.

Planetary Protection Issues

Past planetary protection studies have repeatedly addressed the importance of a scientifically sound assessment of what is known and a conservative approach to the unknowns. In the case of Venus, there are many unknown details, particularly about the past, but also about present conditions. In its deliberations, the task group found that the known aspects of the present-day environment offer compelling arguments against there being significant dangers of forward or reverse biological contamination, regardless of the unknowns. Individual points, discussed in more detail elsewhere, merit emphasis. In particular, it is not necessary to know whether life is present in the atmosphere of Venus to conclude that no terrestrial life would be capable of persisting, much less replicating, in any of Venus's extant atmospheric regimes. The dominant factor in this assessment is the concentration of sulfuric acid (and corresponding lack of free water) in cloud droplets in Venus's atmosphere. No region of present atmospheric models is even close to habitable by life carried from Earth.

In terms of chemical contamination of Venus biosignatures by terrestrial material, organic material delivered to the surface of Venus will be rapidly destroyed. Biogenic material deposited in the planet's atmosphere will be either destroyed in situ or eventually (on the timescale of years) carried to lower atmosphere levels, where it will be destroyed. Thus, without biological replication, forward contamination with biomarkers is not a significant issue.

The reverse cannot be demonstrated, but is also hard to escape; life consistent with the environmental conditions in the atmosphere of Venus is not going to find a corresponding niche on Earth. The closest equivalent might be acid

[13]K. Kashefi and D.R. Lovley, "Extending the Upper Temperature Limit for Life," *Science* 301: 934, 2003.

[14]A. Venkateswaran, S.C. McFarlan, D. Ghosal, K.W. Minton, A. Vasilenko, K. Makarova, L.P. Wackett, and M.J. Daly, "Physiologic Determinants of Radiation Resistance in *Deinococcus radiodurans*," *Applied Environmental Microbiology* 66: 2620-2626, 2000.

[15]K. Edwards, P. Bond, T. Gihring, and J. Banfield, "An Archaeal Iron-Oxidizing Extreme Acidophile Important in Acid Mine Drainage," *Science* 287: 1796-1799, 2000.

mine drainage sites, which can be extremely acidic. However, even these sites are much less acidic than any portion of the Venus atmosphere. In addition, the acid mine drainage sites are generally characterized by extremely high metal-ion concentrations. Venus's clouds, while apparently containing some metallic contaminants, remain poorly characterized in terms of composition and certainly do not possess these high metal-ion concentrations. In terms of metal content, some terrestrial acidic fumaroles or solfataras might be a better match, but none comes close to the acidity of the Venus environment.

Venus's Environment

Our best current understanding of the origin and evolution of Venus suggests that Venus formed with much more water than it has at present, although the water abundance is not well constrained. Venus probably possessed liquid-water oceans during its early evolution, before the main-sequence evolution of the Sun led to warming and the loss of the oceans owing to a moist greenhouse atmosphere, photodissociation of water, and the subsequent thermal and nonthermal escape of hydrogen. The lifetime of Venus's oceans is not known or well constrained but may have been as short as a few hundred million years or as long as several billion years. When the oceans were lost and the surface temperature rose, the potential for life as we know it was completely destroyed on the surface of Venus. The only remaining habitable niche would then have been the clouds. Current understanding of the chemistry and formation of the clouds indicates that the persistence of the global cloud deck depends on continuing surface volcanic activity, as SO_2 is outgassed and oxidized to SO_3, which reacts with water vapor to form sulfuric acid. If volcanic activity ceases, the clouds will be destroyed in roughly 30 million years, as atmospheric SO_2 is destroyed by reaction with surface minerals. It is not clear whether or not the surface has been continuously volcanically active, and therefore it is not clear whether or not the clouds have persisted throughout the history of the planet. There may well have been periods when Venus was entirely cloud free. If this has occurred, any cloud-based microbial ecology would have been permanently extinguished.

Life in Venus's Atmosphere

The clouds occupy the "Earth-like" part of Venus's atmosphere, with pressures ranging from 2 bar to 10 mbar and temperatures ranging from ~240 to 390 K. Water vapor ranges from a few parts per million at the top of the cloud deck to a few tens of parts per million at the base. However, the cloud droplets are formed of extremely concentrated sulfuric acid, with weight percents ranging from 85 percent at the top of the cloud deck (with a slight dip to 82 percent within the upper cloud layer) to 98 percent at the bottom of the lower cloud layer. At these concentrations, the molar ratio of H_2SO_4 to H_2O is ≥ 1, so that all water is protonated (H_3O^+) and tightly bound to the sulfuric acid. Such concentrations dehydrate and oxidize organic compounds.

There is also a high flux of ultraviolet radiation throughout the cloud deck of Venus. The likelihood that life exists in the cloud deck is impossible to assess, given the complete lack of knowledge of the prospects of life in nonterrestrial environments. It has been suggested that some form of life may have evolved that takes advantage of the ultraviolet energy or the chemical disequilibria in the cloud-level gases, which include the coexistence of H_2 and O_2, as well as sulfur in varying oxidation states, including H_2S and SO_2. Such a cloud-based microbial biosphere, if it exists, would need to have evolved mechanisms for surviving in extremely acidic conditions that are unknown in any natural environment on Earth. Given the requirement for adaptation to this extreme environment, such organisms would not have the capacity to survive in the very different conditions found on Earth, as they would have experienced no selective pressure to evolve (or retain) such capacity.

PLANETARY PROTECTION CONSIDERATIONS

In accordance with international treaty obligations, NASA maintains a planetary protection policy to avoid the cross-contamination of Earth and extraterrestrial bodies by spaceflight missions (see Attachment 2). NASA develops implementation regulations based on recommendations from both internal and external advisory groups, but most notably these regulations have been developed on the basis of recommendations provided by the National Research Council.

Historically, constraints on missions—where deemed necessary—have ranged from the cleaning of a spacecraft to reduce its surface bioburden to the heat sterilization of an entire spacecraft prior to launch. In addition, there may be constraints on spacecraft orbits and operating procedures, requirements for the inventory and archiving of samples of the organic constituents of the spacecraft, and the need to document the locations of landing sites and impact points.

NASA has a clear need to obtain external guidance on the planetary protection requirements for Venus missions that is based on a careful assessment of the most recent planetological and biological information. Without such guidance, NASA cannot provide the appropriate guidelines to mission designers, nor can it establish operational procedures for future Venus missions.

NASA states that its planetary protection policy serves the following goals:

- To preserve planetary conditions for future biological- and organic-constituent exploration; and
- To protect Earth and its biosphere from potential extraterrestrial sources of contamination.

Obligations imposed by the United Nations' Outer Space Treaty[16] mandate that spacecraft missions be conducted in such a way as to minimize the inadvertent transfer of living organisms from one planetary body to another.

CONCLUSIONS AND RECOMMENDATIONS

The cloud layers in the atmosphere of Venus provide an environment in which the temperature and pressure are similar to surface conditions on Earth. However, the chemical environment in the clouds, and specifically in the cloud droplets, is extremely hostile. The droplets are composed of concentrated (82 to 98 percent) sulfuric acid formed by condensation from the vapor phase. As a result, free water is not available, and organic compounds would rapidly be destroyed by dehydration and oxidation. Therefore, any terrestrial organisms having survived the trip to Venus on a spacecraft would be quickly destroyed. It is not possible to demonstrate conclusively that a spacecraft returning to Earth after collecting samples of Venus's surface and atmosphere will not come into contact with hypothetical aerial life forms and inadvertently carry them back to Earth; however, this has to be considered an extremely unlikely scenario. At any rate, any life forms that had adapted to living in the extremely acidic environment of Venus's cloud layer would not be able to survive in the environmental conditions found on Earth. No special procedures are warranted beyond those required to maintain the sample integrity necessary for scientific studies of the returned samples.

Conclusions

The task group's assessment of the likely planetary protection implications of Venus missions is as follows:

- *Landers*—The prospects for indigenous biological activity on or below Venus's surface are negligible owing to the high temperature of the surface, the absence of water, and the toxic chemical environment.[17] Similarly, the prospects for the survival of terrestrial organisms deposited by probes on Venus's surface are nonexistent. **Therefore, the task group concluded that no significant risk of forward contamination exists in landing on the surface of Venus.**
- *Atmospheric probes, including balloons*—Venus's cloud layers are an environment of moderate temperature and pressure. However, because the cloud droplets consist of concentrated sulfuric acid, any terrestrial organisms would be rapidly destroyed by chemical degradation. **Therefore, the task group concluded that no significant forward-contamination risk exists regarding the exposure of spacecraft to the clouds in the atmosphere of Venus.**
- *Surface or atmospheric sample returns from Venus to Earth*—The task group discussed in detail the recent arguments for the potential for life in the Venus cloud decks. Although it is impossible to completely rule out the possibility that life might exist in such an environment, the task group considers this possibility to be extremely low because of the hostile chemical nature of the cloud environment. Specifically, concentrated sulfuric acid is a strong dehydrating and oxidizing agent that causes the rapid destruction of complex organic molecules. And, conversely,

[16]United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, U.N. Document No. 6347, United Nations, New York, N.Y., January 1967.

[17]National Research Council, *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making*, National Academy Press, Washington, D.C., 1998, pp. 31 and 77.

any organisms that had managed to adapt to such a chemical environment would not find a comparable environment on Earth and would not be expected to survive. Therefore the risk to Earth posed by organisms indigenous to Venus is considered to be negligible. **Therefore, the task group concluded that no significant back-contamination risk exists concerning the return of atmospheric samples from the clouds in the atmosphere of Venus. Similarly, no significant risk exists concerning back contamination from Venus surface sample returns.**

Recommendations

In light of the above conclusions, **the task group recommends that the Category II planetary protection classification of Venus be retained.** Although there are many important scientific investigations to be carried out to improve understanding and knowledge of Venus, **the task group does not recommend any scientific investigations for the specific purpose of reducing uncertainty with respect to planetary protection issues.**

6.2 A Review of NASA's 2006 Draft Science Plan

On September 15, 2006, A. Thomas Young, Chair of the Ad Hoc Committee on Review of NASA Science Mission Directorate Science Plan sent the following letter to Mary Cleave, NASA's Associate Administrator for the Science Mission Directorate.

In your letter of April 12, 2006, to Space Studies Board (SSB) Chair Lennard Fisk, you requested that the Space Studies Board conduct a review of the Science Mission Directorate's (SMD's) draft Science Plan[1] and provide its assessment and recommendations for how the draft might be improved. You asked for comments in the following areas:

- Responsiveness to National Research Council (NRC) recommendations in recent reports;
- Attention to interdisciplinary aspects and overall scientific balance;
- Utility to stakeholders in the scientific community; and
- General readability and clarity of presentation.

In response to your request, the ad hoc Committee on Review of NASA Science Mission Directorate Science Plan was established and met July 11-13, 2006, in Washington, D.C., to review the draft Science Plan. This report discusses the committee's findings and offers related recommendations.

The committee found the draft Science Plan to be an informative document demonstrating that a major NASA objective is to conduct scientific research to advance the fundamental understanding of Earth, the solar system, and the universe beyond. Some portions of the plan, such as that concerning astrophysics, do a truly excellent job of outlining why NASA carries out its science missions.

The committee also found that the draft plan outlines a defensible set of rules for prioritizing missions within each of SMD's discipline divisions, and it believes that SMD has made a serious effort to base its plans on the mission priorities established by the scientific communities that undertake and benefit from the missions that NASA conducts. Many of these priorities were established in NRC reports such as the decadal surveys, NASA's responsiveness to which the committee evaluates in the attached report. Historically, NASA has benefited from the advice provided by its several scientific advisory structures, and their health is vital to the agency's success in implementing its mission.

Although NASA was asked by Congress to develop a single prioritized list for missions across all four science disciplines (astrophysics, Earth science, heliophysics, and planetary science), for various reasons outlined in the report the committee does not believe that NASA should or could produce a prioritized list across disciplines at this time.

However, the committee does have some concerns about the draft plan. The committee found that the lack of a comparison of the current plan to plans produced in 2003 obscured the fact that NASA's space science plans have been significantly scaled back due to budget changes, and it recommends that NASA include a comparison between the current plan and those produced in 2003 for the Earth and space sciences.

The committee further notes that the NRC's recent report *An Assessment of Balance in NASA's Science Program*[2] is largely neglected in the draft Science Plan. Although the NRC report was released shortly before the completion of the draft Science Plan, NASA representatives informed the committee that they had sufficient time to consider it. The committee acknowledges that the draft plan is based on the assumptions contained in the FY 2007 budget request and that the *Balance* report was critical of the adequacy of the budget to accomplish the total NASA plan. Nevertheless, the committee believes that the *Balance* report's recommendations are worthy of consideration and, where appropriate, incorporation in the NASA Science Plan.

The committee found that the current plan overemphasizes mission-specific work at the expense of strategies and steps for achieving goals in mission-enabling areas such as research and analysis, maintaining the Deep Space

[1]NASA Science Plan, Draft 3.0, June 23, 2006.

[2]National Research Council, *An Assessment of Balance in NASA's Science Programs*, The National Academies Press, Washington, D.C., 2006.

Network, and technology development. In addition, the committee noted that the draft plan often declares an intention to implement a program or identifies a goal or mission as a top priority, but then does not indicate what steps NASA will take to achieve the goals or what strategies it will pursue to accomplish its priorities.

The committee is concerned about the problem of mission cost growth and believes that if it is not successfully addressed, NASA will face the possibility of having to abandon either flagship missions or the ability to execute a balanced program. Mission cost growth and other factors identified in the attached report threaten the execution of the NASA Science Plan. The committee believes that addressing the issue of executability is a prerequisite for confidently defining a robust Science Plan, and it offers several recommendations on this subject.

The committee recognizes that NASA is awaiting the forthcoming NRC decadal survey on Earth sciences. However, the committee wishes to express its concerns about recent developments in Earth science, particularly recent decisions concerning the National Polar Orbiting Environmental Satellite System (NPOESS) program, whereby climate science instruments were deleted from the satellites. Many of these instruments are crucial to understanding the changing Earth system, and a strategy is needed to deal with their deletion from NPOESS.

By design, the draft plan addresses only those science programs that are conducted by SMD. The committee notes that an appreciation of the full extent of NASA's science activity requires a look at a number of programs outside SMD, in particular, the lunar precursor and robotic program, and the life and microgravity science activities within the Exploration Systems Mission Directorate (ESMD). The committee understands that Congress directed NASA to produce a Science Plan only for SMD. The committee concludes that the document would be improved if the introduction made clear the boundaries of the Science Plan's scope and also acknowledged that science is performed elsewhere within NASA as well, and the extent to which these other science programs are sensibly complementary to those within SMD.

Some of the committee's recommendations are broad and apply to all four of SMD's science disciplines, but the difficulties underlying the committee's concerns are more acute in some disciplines than in others. For example, the problems associated with controlling mission cost growth and preserving proper balance between large and small missions are now particularly pressing in astrophysics and, prospectively, in planetary science. The need to develop strategies for meeting future computing and modeling capabilities is particularly noticeable for Earth science and heliophysics. In addition, although the committee makes discipline-specific recommendations for the planetary and Earth sciences, it stresses that the astrophysics and heliophysics sections of the draft plan are also addressed in the more general recommendations and require equal attention.

The committee's recommendations on the implementation and viability of the draft NASA Science Plan follow:

1. The NASA Science Plan should compare the key aspects of its 2003 Earth and space science plans with the 2006 plan in a list or table that shows how the current plan differs from the previous ones. This comparison would also provide some indication of the starting point for the new Science Plan, and the changes that have occurred since 2003.

2. NASA/SMD should provide some indication of the strategy it will use to determine how critically needed technologies will be developed for future missions and their proposed timescales. The committee recommends that NASA outline a strategic technology plan, providing an indication of the resources needed and the schedule that must be met to enable the ambitious goals of the plan. But NASA should also seek to protect general R&A funding from encroachment by technology R&A.

3. The NASA Science Plan should explicitly address realistic strategies for achieving the objectives of the mission-enabling elements of the overall program. The committee recommends that NASA:

   a. Undertake appropriate studies through its advisory structure in order to develop a strategic approach to all of its R&A programs (this strategy should include metrics for evaluating the proper level of R&A funding relative to the total program, the value of stability of funding levels in the various areas, and metrics for evaluating the success of these programs); and

   b. Develop a strategic plan to address computing and modeling needs, including data stewardship and information systems, which anticipates emergent developments in computational sciences and technology, and displays inherent agility.

4. NASA should improve mechanisms for managing and controlling mission cost growth so that if and when it occurs it does not threaten the remainder of the program, and should consider cost-capping flagship missions.

Although NASA already does seek to manage and control mission cost growth, these efforts have been inadequate and the agency needs to evaluate them, determine their failings, and improve their performance. NASA should undertake independent, systematic, and comprehensive evaluations of the cost-to-complete of each of its space and Earth science missions that are under development, for the purpose of determining the adequacy of budget and schedule.

5. NASA/SMD should move immediately to correct the problems caused by reductions in the base of research and analysis programs, small missions, and initial technology work on future missions before the essential pipeline of human capital and technology is irrevocably disrupted.

6. For planetary science, the committee recommends as follows:

a. NASA/SMD should incorporate into its Science Plan relevant recommendations from the NRC interim report on lunar science,[3] when they are available, in such a way as to maintain the overall science priorities advocated by previous NRC studies, while recognizing that science advice will change as scientific understanding and technology improve.

b. Although Mars should remain the prime target for sustained science exploration, the NASA Science Plan should acknowledge that missions to other targets in the solar system should not be neglected.

c. Where the question of habitability (i.e., the ability of a planet to support life) is determined to be the main focus for exploration, a proper hierarchy of scientific goals and objectives should be developed, stronger pathways between the concept of habitability and proposed missions should be articulated and maintained, and basic discovery science should not be ignored.

d. Life detection techniques should be clearly identified as an astrobiology strategic technology development area.

7. For Earth science, the committee recommends as follows:

a. NASA/SMD should incorporate into its Science Plan the recommendations of the NRC Earth science decadal survey interim report,[4] and should incorporate the recommendations of the Earth science decadal survey final report when it is completed.

b. NASA/SMD should develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction.

c. NASA/SMD should present an explicit strategy, based on objective science criteria for Earth science observations, for balancing the complementary objectives of (i) new sensors for technological innovation, (ii) new observations for emerging science needs, and (iii) long-term sustainable science-grade environmental observations.

The committee elaborates on its findings and recommendations in the attached report.

Signed by

A. Thomas Young, Chair of the Ad Hoc Committee on Review of NASA Science Mission Directorate Science Plan

[3]National Research Council, *The Scientific Context for the Exploration of the Moon—Interim Report*, The National Academies Press, Washington, D.C., 2006.

[4]National Research Council, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, Washington, D.C., 2005.

A Review of NASA'S 2006 Draft Science Plan

In a letter dated April 12, 2006 (Appendix A), the NASA Associate Administrator for Science requested that the National Research Council's (NRC's) Space Studies Board review the agency's Science Mission Directorate (SMD) draft Science Plan.[1] NASA provided the draft plan on June 23 to the NRC's Ad Hoc Committee on Assessment of NASA's Science Mission Directorate Draft 2006 Science Plan (Appendix B). NASA requested that the committee assess the draft according to the following criteria:

- Responsiveness to NRC recommendations in recent reports;
- Attention to interdisciplinary aspects and overall scientific balance;
- Utility to stakeholders in the scientific community; and
- General readability and clarity of presentation.

The Science Plan responds both to a congressional reporting requirement that was specified in the 2005 NASA Authorization Act and to SMD's need for a strategy document that implements the 2006 NASA Strategic Plan in the areas of Earth and space sciences. The NRC has reviewed previous NASA science plans that have been produced at 3-year intervals (coincident with the preparation of NASA's strategic plans).[2]

INPUT USED IN PREPARING THE ASSESSMENT

Detailed recommendations from the NRC decadal surveys and other recent NRC reports provided important input to the committee.[3] In addition, five of the discipline-oriented standing committees[4] of the Space Studies Board were asked to provide comments to the committee. Finally, NASA representatives, congressional staff members, and NRC staff briefed the committee during its meeting on July 11-13, 2006.[5]

This report is divided into six sections in keeping with the committee's charge: (1) general observations, (2) responsiveness to recent NRC recommendations, (3) attention to interdisciplinary aspects and overall scientific balance, (4) utility to stakeholders in the scientific community, (5) general readability and clarity of presentation, and (6) summary findings and recommendations.

1
GENERAL OBSERVATIONS

The committee finds that the draft NASA Science Plan provides an informative overview of SMD's objectives, goals, and associated missions. One of the plan's overarching strengths is its demonstration that a major NASA objective is to conduct scientific research to advance the fundamental understanding of Earth, the solar system, and the universe beyond. Portions of the plan do an excellent job of outlining why NASA carries out its science missions. The draft also outlines a defensible set of rules for prioritizing missions within each of SMD's discipline divisions.

NOTE: The appendixes are not reprinted in this annual report.

[1]NASA Science Plan, Draft 3.0, June 23, 2006.

[2]For the most recent NRC reviews see "Assessment of NASA's Draft 2003 Space Science Enterprise Strategy," letter report, 2003, and "Assessment of NASA's Draft 2003 Earth Science Enterprise Strategy," letter report, 2003.

[3]The NRC decadal surveys have been widely used by the scientific community and by program decision makers because they (a) present explicit, consensus priorities for the most important, potentially revolutionary science that should be undertaken within the span of a decade; (b) develop priorities for future investments in research facilities, space missions, and/or supporting programs; (c) rank competing opportunities and ideas and clearly indicate which ones are of higher or lower priority in terms of the timing, risk, and cost of their implementation; and (d) make the difficult decisions about which meritorious ideas cannot be accommodated within realistically available resources. The most recent relevant decadal surveys are *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001; *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003; and *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, The National Academies Press, Washington, D.C., 2003.

[4]The standing committees are the Committee on Astronomy and Astrophysics, the Committee on Planetary and Lunar Exploration, the Committee on Solar and Space Physics, the Committee on the Origins and Evolution of Life, and the Committee on Earth Studies.

[5]The meeting agenda is in Appendix C.

The committee notes that as NASA continues to pursue a broad-based and impressive science program, SMD has made a serious effort to base its plans on the mission priorities established by the scientific communities that undertake and benefit from the missions that NASA conducts. The committee commends NASA for this effort.

The committee does note, however, that the draft Science Plan makes no reference to the constrained budget situation that NASA is currently facing. Any analysis of the fate of past NASA science plans would demonstrate that these can undergo significant transformation during actual implementation, usually as a result of financial exigencies. Thus, the committee found it difficult to assess how realistic the current draft plan is. The draft Science Plan is almost surely optimistic. **The committee recommends that the NASA Science Plan compare the key aspects of its 2003 Earth and space science plans with the 2006 plan in a list or table that shows how the current plan differs from the previous ones.** This comparison would also provide some indication of the starting point for the new Science Plan, and the changes that have occurred since 2003.

By design, the draft plan addresses only those science programs that are conducted by SMD. The committee notes that an appreciation of the full extent of NASA's science activity requires a look at a number of programs outside SMD, in particular, the lunar precursor and robotic program, and the life and microgravity science activities within the Exploration Systems Mission Directorate (ESMD). The committee understands that Congress directed NASA to produce a Science Plan only for SMD. The committee concludes that the document would be improved if the introduction made clear the boundaries of the Science Plan's scope and also acknowledged that science is performed elsewhere within NASA as well, and the extent to which these other science programs are sensibly complementary to those within SMD.

Establishing Priorities

NASA's science planning is typically guided by priority lists established in the NRC decadal surveys. Although the NRC has produced decadal surveys in astronomy and astrophysics for four decades, equivalent surveys in the other disciplines have been instituted more recently. The first Earth science decadal survey is currently underway, with the final report due in December 2006, and will not be complete in time for consideration in the final version of the current NASA Science Plan. NASA officials informed the committee that they plan to incorporate the recommendations of the forthcoming Earth science decadal survey into a revised version of the Science Plan scheduled for release in spring 2007. While the committee supports the concept of this planned revision it notes with concern that, other than reinstating the Glory mission, there is little evidence in the SMD Science Plan of a response to the interim report of the Earth science decadal survey, which was released in April 2005.[6]

The decadal surveys involve a lengthy and complex process whereby the community of scientists within a particular discipline establishes research goals and identifies and prioritizes important investments in research capability, including, but not limited exclusively to, future NASA missions. The value of this process is that the community itself selects and ranks the priorities in a relatively open way, thereby bestowing community ownership and legitimacy on these choices.

The committee emphasizes that decadal surveys are not merely lists of missions but describe an overall research agenda. It is relatively easy to think and plan only in terms of missions. But an overall Science Plan must include consideration of *all* of the elements needed to ensure success, including the supporting research and data analysis (R&A), advanced technology development, theory and modeling, and data archiving. *In the committee's opinion, the current draft plan overemphasizes mission-specific work at the expense of strategies and steps for achieving goals in such mission-enabling areas as research and analysis and technology development.*

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[6]National Research Council, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, Washington, D.C., 2005. The interim report put forward six recommendations under the overarching title "Critical Needs for Today": (1) Proceed with the Global Precipitation Measurement (GPM) and Atmospheric Soundings from Geostationary Orbit (GIFTS) missions; (2) evaluate plans for transferring needed capabilities to NPOESS (Ocean Vector Winds, Landsat Data Continuity (LDCM), aerosols and total irradiance (GLORY); (3) develop a technology base for future Earth observation; (4) reinvigorate the NASA Earth Explorer Missions Program; (5) strengthen research and analysis programs; and (6) strengthen baseline climate observations and climate data records. Of these six, the draft Science Plan addresses recommendation 2, and LDCM and GLORY were brought back from canceled status to launch dates of 2011 and 2008, respectively.

Recommendation 1 regarding GPM and GIFTS has not been followed. GPM remains delayed by 4 years after the end of TRMM, thus threatening continuity of precipitation and latent heating data, and both the GIFTS and Ocean Vector Winds missions remain canceled. Recommendations 3, 4, and 6 are mentioned in the Science Plan but without providing objectives, as well as strategic or tactical vision. Recommendation 5 is not addressed at all.

The committee is aware that Congress specifically asked NASA to develop a single prioritized list of missions across the scientific disciplines, and it notes that NASA has not produced such a list in the current draft Science Plan. Congressional staff members who appeared before the committee reiterated this point and explained their interest in having an integrated prioritized list as guidance for budgetary situations that may be even more difficult in the future than the present.

The committee believes that, although not impossible, prioritization on a purely scientific basis across disciplines, with the intention of cutting programs, is a daunting challenge for several reasons:

- *Fundamental difficulty.* To be credible, those establishing the scientific priorities must have mastered the intellectual foundations of the proposed programs across the disciplines, the implications for success or failure, and the implications for allied fields. This requires that the purely scientific priorities of such diverse and necessary fields as astronomy, heliophysics, planetary science, and all the subdisciplines of Earth science (e.g., meteorology versus earthquake prediction) must be weighed against one another in a convincing manner.
- *Current state of NASA's advisory structure.* In practice, such integrated prioritization is based on community input provided primarily by the NRC decadal surveys and is accomplished with the ongoing, collective judgment of managers with the support of advisory committees who ideally weigh the scientific merits, the financial and human resources, technical issues, balance, and the political implications of these decisions. NASA has recently put in place a new advisory structure that may in the longer term address cross-disciplinary prioritization in a meaningful way. It is the opinion of the committee that the current advisory structure has not existed for sufficient time to constructively address SMD-wide prioritization.
- *Incompatible strategies.* The committee noted that the requested integrated prioritized list, even if attainable, would not have the desired operational utility in guiding cuts in a possibly difficult future budget climate. The strategy for developing a prioritized list of ongoing programs is quite different from the strategy for developing a prioritized list of programs to be cut. In the former case, the purpose is to indicate the order in which problems with ongoing programs get fixed, and mission-enabling activities unfortunately usually end up at the bottom. It is likely that an integrated prioritized list would take this form and therefore provide little guidance in a program-cutting scenario driven by budget reductions. The net result could be a significant loss of scientific balance.

For all of these reasons, the committee does not believe that NASA should or could produce a prioritized list across disciplines at this time.

NASA has, however, clearly addressed the subject of establishing priorities within the SMD divisions. Chapter 2 of the draft Science Plan presents an overall strategy for setting priorities in specific discipline areas. The strategy includes the following actions:

- Base the program in each discipline on key scientific questions and research objectives that have been defined by the scientific community and/or national policy directives.
- Prioritize spaceflight missions in a single list for each major discipline area. (Currently operating missions are treated separately via the senior review process.)
- Constrain launch schedules to fit within the FY 2007 budget request.
- Begin prioritization by using recommended priorities from decadal surveys as an input to preparing community-led implementation roadmaps.
- Seek a balanced portfolio of mission sizes.
- Give missions closest to being ready for launch priority over less mature missions.
- Consider technology readiness, mission science interrelationships, opportunities for partnerships, government mandates, and programmatic factors.
- Acknowledge that cost can override decadal survey recommendations for cadence.

The committee's review of this strategy and of the discussions of priorities in each of the four major SMD discipline areas led it to reach the following conclusions:

1. Recent NRC reviews of earlier NASA science strategic plans noted failures to explicitly identify priorities and the resources that would be required to implement the plans. The 2006 draft NASA Science Plan does make an effort to address priorities and is consistent with available resources as defined by the budget submittal for FY 2007, and the committee finds that this is a clear improvement that will make the plan more useful and informative. The committee commends NASA for adopting this approach.

2. The overall strategy, as summarized in Chapter 2 of the draft plan, is reasonable, and it entails an appropriate approach to setting priorities for spaceflight missions.

3. The sets of priorities for the three science discipline areas for which there are completed NRC decadal surveys—i.e., astrophysics, heliophysics, and planetary science—are all largely responsive to the flight mission priorities presented in the decadal surveys. Notable exceptions or gaps are as follows:

- *Astrophysics.* It is becoming progressively more problematic in astronomy and astrophysics to respond effectively to decadal surveys as mission costs increase across the board. This is already evident in the draft Science Plan, which includes recent major cuts or delays to the extrasolar planet initiative, despite its high ranking in the decadal survey, weakening of the R&A and MO&DA resources for fundamental scientific research, severely reduced opportunities for Explorer-class missions, and the loss of short-wavelength capabilities after 2011.
- *Heliophysics.* The heliophysics section is largely responsive to the NRC decadal survey. However, the committee believes that there may be a problem with implementation of two closely spaced Living With a Star missions starting in the next decade. This is discussed in the section below titled "Threats to Science Plan Execution."
- *Planetary science.* The planetary decadal survey called for significant technology development and "an increase over the decade in the funding for fundamental research and analysis programs at a rate above inflation that parallels the increase in the number of missions, amount of data, and diversity of objects studied."[7] The draft Science Plan does not respond to these recommendations.
- *Earth science.* The decadal survey on Earth science is expected to be complete by the end of 2006. An interim report, however, was published in 2005. The present draft of the SMD plan does not address critical needs raised by the interim report such as providing a rationale for why missions have been delayed or how NASA will meet long-term needs for science observations of the Earth system.

4. Although the overall approach described in the draft Science Plan for setting priorities is sound, the committee notes that this approach does not appear to have been used in practice in every discipline area. The actual approach appears to vary from discipline to discipline. For example, priorities in astrophysics (for missions after the infrared James Webb Space Telescope [JWST]) depend largely on planned launch date, whereas priorities in heliophysics are influenced by mission costs, scientific value, and strategic value.

5. The draft Science Plan's discussion and presentation of priorities address only spaceflight missions. There is no discussion of how critical non-flight elements of the program—e.g., R&A, suborbital flights (including balloon missions), and data analysis—are to be folded into an integrated set of strategic priorities for SMD or its four discipline programs. (See below the discussion titled "Balance" in this report.)

6. The draft Science Plan does not address the need to protect core activities, research capacity retention, and the importance of sponsoring creativity and innovation within the disciplines. Cuts to the budget threaten specific technical expertise inside and outside the agency that can make it difficult to reinstate certain types of missions in the future.

Threats to Science Plan Execution

An important characteristic of a plan that aims to direct a successful national program is clear evidence of sufficient resources to ensure that the plan is robust and appropriately resilient. Finding 2 of the NRC report *An Assessment of Balance in NASA's Science Program*[8] (published in May 2006 and hereafter referred to as the *Balance* report) cites significant budget deficiencies in R&A, astrobiology research, the Explorer program and other small

[7]National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003, p. 9.

[8]National Research Council, *An Assessment of Balance in NASA's Science Programs*, The National Academies Press, Washington, D.C., 2006.

missions, and initial technology work on future missions. Finding 1 of that report states that NASA is being asked to accomplish too much with too little.

Based on recent NASA experience, numerous science missions have experienced significant cost growth that will destabilize a science plan as tightly integrated as the current draft plan. If this trend continues the plan will not be executable. The committee believes that this issue must be addressed before a credible science plan can be established. The committee notes that some disciplines are in better shape than others, but that in each division aspects of this plan cannot be executed in the manner that NASA intends.

- *Astrophysics.* The committee notes that cost growth with the JWST has forced delays or modifications to many other programs, significantly unbalancing the program. The committee also finds that although the Space Interferometry Mission (SIM) is currently in the plan, it cannot be conducted on the timescales specified if, as expected, NASA reinstates the Stratospheric Observatory for Infrared Astronomy (SOFIA) by taking money from SIM. These examples illustrate the way in which cost, risk, and schedule delays can make it impossible to implement plans described.
- *Heliophysics.* The committee believes that the heliophysics plans are generally satisfactory, with the exception of the plan to launch two missions only a year apart in the next decade. The Ionosphere/Thermosphere Storm Probes and the Inner Heliospheric Sentinels are planned to launch only 1 year apart, and the committee believes that this approach is unrealistic from both a budgetary and an operational standpoint.
- *Planetary science.* The committee believes that the planetary science plans are generally satisfactory, but shares the broader concern expressed in the *Balance* report about the importance of managing and controlling cost growth for missions. The committee is also concerned about the delay of the next flagship mission to the outer planets.
- *Earth science.* The draft Science Plan does not address the problems of the post-Earth-Observing-System era or the implications of problems with NPOESS, nor does it provide a strategy for sustaining the discipline until the recommendations of the decadal survey can be implemented. While the committee recognizes that strategies for Earth science will be developed in the upcoming decadal survey, their absence in the current draft Science Plan means that including them in NASA's plans will require significant programmatic changes.

The committee notes that implementation of full-cost accounting at NASA has had a deleterious and unanticipated effect on science execution and balance. In effect, in many cases the applicable cost of in-house NASA personnel is now being charged to research and analysis budgets that have not been increased to compensate for this charge.

NASA's Science Mission Directorate is currently operating in a particularly dynamic budgetary climate, posing a significant challenge in balancing flagship missions, moderate-scale missions, and other critical program elements. As the *Balance* report indicates, the underlying foundation of research, technology, and small missions has been disproportionately cut. Furthermore, as the discipline-specific examples above illustrate, problems with key missions that are assumed to be integral to the scientific program outlined in the draft plan in fact threaten its scientific feasibility.

The committee notes that NASA's policy has been to expect funding problems to be solved within the individual divisions. Thus, if an astrophysics program experiences a cost overrun, that division cannot take money from the heliophysics division, and vice versa. The committee approves of this approach, because it encourages the divisions to solve their own problems. However, none of the divisions will be immune to overall budget pressures, in the form of both cuts to the top-line budget and cost growth within the programs, and this combination may make it difficult to execute current plans.

The committee believes that the issue of executability must be addressed before a robust Science Plan can be defined. Again, the findings and recommendations in the NRC *Balance* report provide an approach to establishing a robust Science Plan.

2
RESPONSIVENESS TO NRC RECOMMENDATIONS IN RECENT REPORTS

Part of the committee charge is to assess the draft Science Plan's responsiveness to recent NRC reports. A list of some of the most recent reports is included in Appendix D.

The committee finds that the Science Plan *is* responsive to the NRC decadal surveys, with the notable exception that the mission-enabling elements, which are critical to an integrated science plan, are much less integrated and emphasized than the missions themselves. The NASA FY 2007 budget request, upon which the draft Science Plan is based, illustrates the pitfalls of addressing budgetary shortfalls without also considering the relative benefits of mission-specific and mission-enabling programs. Although NASA is primarily a mission-based agency, supporting activities that involve building and maintaining the technology, workforce, and scientific infrastructure necessary to ensure the success of these missions are essential, as pointed out in the NRC *Balance* report. The committee recommends that the mission-enabling elements important to the integrated plan receive greater emphasis in the NASA Science Plan. The agency should review the decadal surveys, and particularly the *Balance* report, for further guidance on the importance of mission-enabling elements. The committee acknowledges the difficulty that the agency faces in determining the proper levels of R&A funding and addresses them in the section titled "Balance" in this report, including offering a recommendation about the need to determine proper levels of R&A.[9]

The committee does note, however, that although Mars Sample Return was rated as a top priority in the planetary decadal survey, it is mentioned only once in the draft Science Plan, and only in reference to planetary protection, not as an actual planned mission.

Although the Science Plan is generally responsive to the decadal surveys, there is one notable exception. The NRC released an interim report for its Earth sciences decadal survey over a year ago. As already noted, with the exception of the reinstatement of the Glory mission, the draft Science Plan does not reflect the recommendations made in this interim report.

The draft plan responds well to other recent NRC reports, and the committee commends NASA for this. Examples include the instigation of the decadal survey for Earth sciences and applications from space, recommended by the NRC in 2003.[10] The agency also adopted 2005 NRC advice to conduct senior reviews of extended Earth observing missions to determine if such missions were worth continuing or had outlived their usefulness.[11]

The committee commends NASA for responses by the agency to issues raised in previous recent NRC reviews of NASA science plans. Two prior reviews of Space Science Enterprise plans[12] and the 2003 review of the Earth Science Enterprise plan all cited the lack of explicit discussion of priorities and resources in those plans as weakening their utility for decision making.[13] The 2006 NASA Science Plan does address explicit priorities for spaceflight missions, and it does indicate that the plan is based on budget projections outlined in NASA's FY 2007 budget request. While the committee remains concerned about aspects of these elements of the Science Plan, it nonetheless applauds the fact that NASA has included priorities and relationship to the budget as key features of the plan.

In 2003, the NRC assessment of NASA's Space Science Enterprise strategy's balance of astrobiology across the enterprise's scientific themes expressed concern that the search for life had been referred to in many places in the strategy but lacked any real scientific substance. The current draft Science Plan does a better job of integrating the subject into the two most relevant discipline areas—astrophysics and planetary exploration. Notably, the draft does not overstate the role of astrobiology as a scientific driver in these two discipline areas. However, the committee believes that further refinements are possible. These are discussed in greater detail in the next section of this report.

The 2005 NRC report *Science in NASA's Vision for Space Exploration* emphasized the need for better integration of NASA's science program and the objectives of the Vision for Space Exploration. The committee notes that this is a challenging objective and that the agency has made good progress by evaluating science programs in terms of how they support the agency's broad science mission. The committee applauds this approach. However, the committee finds that in some areas the integration of science objectives into the exploration program remains ambiguous and could be improved.

The committee further notes that the NRC's *Balance* report is largely neglected in the draft Science Plan. The committee acknowledges that the plan is based on the assumptions contained in the FY 2007 budget request and that

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[9]The decadal surveys refer to the importance of mission-enabling programs. For example, see: "The committee emphasizes that telescopes alone do not lead to a greater understanding of the universe. . . . The committee recommends a vigorous and balanced program of astrophysical theory, data archiving and mining, and laboratory astrophysics." *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001, p. 96.

[10]National Research Council, "Assessment of NASA's Draft 2003 Earth Science Enterprise Strategy," letter report, 2003.

[11]National Research Council, *Extending the Effective Lifetimes of Earth Observing Research Missions*, The National Academies Press, Washington, D.C., 2005.

[12]National Research Council, "On the Space Science Enterprise Draft Strategy Plan," letter report, 2000; National Research Council, "Assessment of NASA's Draft 2003 Space Science Enterprise Strategy," letter report, 2003.

[13]National Research Council, "Assessment of NASA's Draft 2003 Earth Science Enterprise Strategy," letter report, 2003.

the *Balance* report was critical of the adequacy of the budget to accomplish the total NASA plan. The committee believes that the *Balance* report's recommendations are worthy of consideration and, where appropriate, incorporation in the Science Plan. This aspect is discussed in greater detail in the next section of this report.

The committee found no rationale for the agency's allocation of R&A funding, or the fraction devoted to technology development, computational capabilities, modeling, and data analysis. Both in the summary chapters and in the various discipline chapters, the Science Plan emphasizes the need for R&A, suborbital, and facilities programs. There is a clear description of the intrinsic role of these programs as mission enablers and as cost-effective methods for achieving science and technology advances. This aspect of the draft Science Plan is completely consistent with the recommendations of numerous NRC documents such as the recent *Balance* report, and with the recommendations of every NASA-commissioned community roadmap. What the draft plan does not do is outline how NASA will prioritize the programs in terms of budgets, or how it will achieve its goals in these areas. **The committee recommends that the NASA Science Plan explicitly address realistic strategies for achieving the objectives of the mission-enabling elements of the program.**

3
ATTENTION TO INTERDISCIPLINARY ASPECTS AND OVERALL SCIENTIFIC BALANCE

Some of NASA's scientific projects are, such as Mars exploration, are significantly more interdisciplinary than others, or cross administrative boundaries. Often it is difficult to conceptualize, prioritize, communicate, and budget for these projects because of the problems of crossing divisions within NASA, government organizations, and scientific disciplines. Although many of NASA's scientific undertakings are interdisciplinary, the committee identified three areas of NASA's science planning that are particularly challenging because of their interdisciplinary nature and/or the fact that they also cross administrative (i.e., bureaucratic) boundaries: lunar exploration, astrobiology, and Earth sciences. The committee believes that all three need additional attention within the draft Science Plan.

Lunar Science

Chapter 8 of the draft Science Plan, "Science Enabling & Enabled by Human Exploration," states that SMD and ESMD are "working closely." However, based on statements made by NASA officials at the committee's July meeting, it appears to the committee that enhanced consultation and communication between the two directorates are needed to optimize the broader science benefits that could be derived from these ESMD exploration-related, and potentially science-related, activities. The committee notes that Chapter 8 of the Science Plan is especially general and lacks specifics on how NASA intends to incorporate science into the agency's lunar exploration plans.

Robotic lunar missions currently planned by NASA are the responsibility of ESMD because such investigation has as its primary purpose the characterization of the lunar environment in preparation for eventual human activity on the surface of the Moon. However, given that one of the goals of the Vision for Space Exploration is "to advance U.S. scientific . . . interests," the science community should have the same opportunity to influence the planning and prioritization of ESMD's exploration science activity as it has to influence other space science activity conducted by NASA. The committee is pleased to see that NASA has requested that the NRC identify science opportunities and establish priorities for exploration-enabled science activities on the Moon.[14] That committee will produce an interim report by fall 2006 and a final report in 2007. The committee supports this planning activity as a means to improve the science benefits of NASA's exploration activity. **The committee recommends that NASA incorporate relevant recommendations from the NRC interim report on lunar science into its Science Plan in such a way as to maintain the overall science priorities advocated by previous NRC studies, while recognizing that science advice will change as scientific understanding and technology improve.**

Astrobiology

Astrobiology crosses multiple disciplines, creating unique challenges for science management, especially in terms of mission prioritization. Thus, the planetary section of the draft Science Plan emphasizes assessing "habit-

[14] National Research Council, *The Scientific Context for the Exploration of the Moon—Interim Report*, The National Academies Press, Washington, D.C., 2006.

ability" in the solar system. Habitability is loosely defined by the astrobiology community as the ability of a planet to support life, based on the presence of the key requirements: water, nutrients, and energy. NASA's exploration of Mars is focused on the search for evidence of life, and this issue is important for future missions to Europa and eventually to Titan and Enceladus. In the astrophysics chapter of the plan, astrobiology is presented in a narrower context—exploring the habitable zones around other stars, primarily through missions like the Terrestrial Planet Finder (TPF) and the Space Interferometry Mission (SIM).

The draft plan discusses the astrobiology field largely in the context of solar system exploration, although it acknowledges the importance of astrobiology as a driver in other disciplines. In the draft Science Plan, astrobiology is highlighted in a text box at the end of the planetary science chapter. The committee believes this presentation underemphasizes the interdisciplinary nature of astrobiology and sets limiting boundaries that are inconsistent with the actual subject matter. The committee notes, for instance, that even subjects that appear to have no direct connection to astrobiology can be relevant to the field. For instance, lunar studies can provide information on the impact flux of asteroids in the early solar system and therefore the hazards they present to the formation of life. The committee suggests that the draft plan would be improved by the addition of an overarching section that includes a balanced discussion of the connections between astrobiology, planetary science, and astrophysics. In the present draft, this discussion would benefit from a deeper treatment of astrobiology as a science, its value as a unifying theme, and a few of the many scientific advances in this field since its inception over a decade ago.

The draft plan does not mention or take account of NASA's Astrobiology Roadmap, which is the primary source of information on the field and its scientific objectives, as defined by the community. The committee suggests that this roadmap be included in the Science Plan as a list or table.[15]

The text box in Chapter 6 of the draft plan asserts that while the Planetary Science Division provides the institutional home for the core astrobiology R&A program, integrating its efforts, answers are pursued in the research programs and flight missions of "all four SMD Divisions." The committee could find no explicit mention of astrobiology programs or missions in the Earth science or heliophysics sections. In this context, it is worth noting that the NRC's 2003 assessment of NASA's science plan found no indication of how the Sun-Earth Connection program could advance the agency's strategic goal to "understand the origin and evolution of life and search for evidence of life elsewhere."[16] Potentially strong links could be made through studies of the origin and evolution of terrestrial life, both of which are active research areas in astrobiology. For example, access to the historical record of climate change (a major focus of the Earth science enterprise), through studies of the fossil record and the impact of long- and short-term environmental changes on biosphere diversity and evolution, are logical connections. Such research is certainly consistent with current R&A efforts in evolutionary biology under the astrobiology program.

Also worrisome is the omission of any discussion of the needs of astrobiology in the context of overall technology development goals, despite the implicit requirement to develop reliable approaches for life detection within the next 6 to 8 years in order to support proposed investigations of the Astrobiology Field Laboratory (launch of which is anticipated in 2016). Efforts to develop life detection technologies and protocols are in fact being funded under two key astrobiology technology development programs—Astrobiology Science and Technology for Exploring Planets (ASTEP) and Astrobiology Science and Technology Instrument Development (ASTID). Neither program is mentioned in the draft. Indeed, there seems to be a general unawareness of the immaturity of the field of life detection and of the time required to develop and adequately test the technologies needed to actually explore for life elsewhere.[17] **The committee recommends that life detection techniques be clearly identified as an astrobiology strategic technology development area.**

Finally, although the draft plan raises the important topic of planetary protection, the area of backward contamination is insufficiently discussed, even though it could prove to be a serious consideration for future sample returns from Mars. The committee notes that the NRC recently published a report on planetary protection and Mars and encourages NASA to incorporate the recommendations of that report into the Science Plan.[18]

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[15]Office of Space Science, National Aeronautics and Space Administration, "Astrobiology Roadmap," Ames Research Center, Moffett Field, Calif., 1999.

[16]National Research Council, "Assessment of NASA's Draft 2003 Space Science Enterprise Strategy," letter report, 2003.

[17]National Research Council, *Assessment of NASA's Mars Architecture 2007-2016*, The National Academies Press, Washington, D.C., 2006.

[18]National Research Council, *Preventing the Forward Contamination of Mars*, The National Academies Press, Washington, D.C., 2006.

Earth Science

Another example of interdisciplinary science within SMD is the field of Earth system science, which was initiated by NASA. Conceived in the 1980s and implemented in the 1990s with the Earth Observing System Interdisciplinary Science Program, Earth system science is uniquely suited to the global perspective of the interconnected nature of the atmosphere, oceans, land, cryosphere, and biosphere of our planet that Earth observing satellites provide. NASA is unique in this field. No other U.S. government agency has the discipline breadth, or requisite technological, observational, and modeling capabilities, to nurture and develop such an important field of science.

Although still in its infancy, over the past 15 to 20 years Earth system science has produced new and significant insights of atmosphere-ocean, land-atmosphere, and physical-biogeochemical coupling and cycles. The committee believes that the draft Science Plan does not adequately explain or illustrate the impressive developments in this field. For instance, global altimeter, scatterometer, ocean color, and rain radar observations of phenomena such as El Niño were not possible until relatively recently. The Science Plan could incorporate this and other examples to illustrate the evolution from inconsistent and spot observations to the development of highly integrated, global views of the Earth system (e.g., 30 years of observations of sea ice concentration and extent or space-based observations of the ozone hole). NASA has been at the forefront of these developments, and the draft Science Plan should adequately reflect the agency's impressive achievements. In short, the Earth science section does not provide the historical context for Earth remote sensing and does not appropriately capture the significance of NASA's accomplishments to date in Earth remote sensing. The committee notes that the Earth science section of the draft plan appears to reflect less community input than other sections, and trusts that this will be rectified following publication of the Earth science decadal survey.

The extraordinary progress in Earth system science has altered dramatically the capabilities and requirements to conduct leading-edge science and has unlocked a wealth of applications of immediate social relevance. Today scientists and Earth science stakeholders expect and depend on data for climate science and broader climate R&D applications. This has created a frequently unrecognized change in the types of data about Earth that satellites collect. In addition to requirements for data such as weather observations and "science" data, there is now a requirement for long time series of scientific observations. Traditionally NOAA has performed weather-related data collection and NASA has conducted scientific data collection. Today, however, the scientific community expects NASA to conduct long-term collection of scientific data that has no immediate use for decision making but is needed to study and understand natural climate fluctuations on interannual to decadal time scales, and is necessary for the development of integrated climate models, and thus requires long-term programmatic and funding commitments.[19]

Recent developments in the NPOESS program reflect the wide gap between community expectations for data collection and current plans. When NPOESS experienced severe development problems and cost overruns, the climate research and monitoring instruments were deleted from the NPOESS satellites whereas the weather instruments were preserved. Many of the instruments removed from NPOESS are crucial to understanding the changing Earth system, and some strategy is badly needed to deal with their elimination from NPOESS. Unless this is done, when the current fleet of Earth Observing System (EOS) satellites expires, there will be nothing to replace them.

The Earth science portion of the draft Science Plan is relatively vague with respect to the strategy for pursuing Earth system science beyond the EOS era. It states that the program will "exploit the vast wealth of new data from EOS," "promote interdisciplinary research . . . identified as emerging sciences areas in the Strategic Plan of the U.S. CCSP [Climate Change Science Plan]," and "pursue innovative interdisciplinary research in new topical areas." These statements begin to convey what the agency will do and why. But they do not indicate how these goals will be achieved, or when they will be achieved.

The draft NASA Science Plan lacks a strategy for an integrated synthesis of the variety and volume of Earth observations generated by NASA. The plan mentions but does not describe the unique modeling, prediction, and computational capabilities and requirements for Earth science. In addition, the plan lacks a science strategy for the development of Earth system models and a discussion of a strategy for developing understanding to enable a predictive capability for the Earth system. Finally, the committee found no indication of NASA's strategy for linking and crosscutting the six interdisciplinary science focus areas: atmospheric composition, carbon cycle and ecosystems, climate variability and change, Earth surface and interior, water and energy cycle, and weather. **The committee**

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[19]National Research Council, *Climate Data Records from Environmental Satellites: Interim Report*, The National Academies Press, Washington, D.C., 2004, p. 95; National Research Council, *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Part I. Science and Design*, National Academy Press, Washington, D.C., 2000, pp. 8-9.

recommends that NASA begin immediately to develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction.

The committee recognizes that the Earth science decadal survey to guide NASA's research priorities in this area will not be completed until the end of 2006 and that, at that time, the agency expects to incorporate decadal survey report recommendations into a revised Science Plan. However, other than the reinstatement of the Glory mission, the committee is troubled to see no reference in the current plan to the findings and recommendations in the Earth sciences decadal survey interim report that was issued more than one year ago. By addressing in the current Science Plan the recommendations from the interim report, NASA could establish the framework for accommodating the recommendations to come from the decadal survey.

The committee is concerned that the draft Science Plan suggests that NASA is waiting for the expected decadal survey, when the agency needs a more coordinated effort to develop its Earth systems science strategy now. The Earth science fiscal situation has deteriorated since the interim report was released, specifically due to cuts to R&A programs, degradation of existing missions, and the current turmoil in the NPOESS program. NASA needs to have an observing strategy in Earth sciences that balances technological innovation (new sensors), emerging science needs (new observations), and the foundational requirements of long-term sustainable science-grade environmental observations.

Balance

The NRC report *An Assessment of Balance in NASA's Science Programs* defined several different dimensions of "balance." One key aspect is scientific balance, meaning that at least the minimum health of major scientific disciplines is maintained so that each discipline can make progress toward its major scientific goals. A second dimension involves balance between the support of ongoing programs and missions, on the one hand, and opportunities for new initiatives, capacity building, and longer-term scientific development, on the other. A third, particularly important, aspect of balance is the ability to sustain a mix of large, medium, and small programs and missions and a core program of research, data analysis, technology development, theoretical studies, and modeling.

Scientific Balance

With respect to scientific balance, the committee has not found any serious imbalance across the four major discipline areas. There are specific concerns within each discipline, which are addressed here, but no particular discipline area appears to be placed at a disadvantage with respect to the others; for instance, the disciplines receive generally similar levels of funding. Furthermore, the draft Science Plan correctly notes that each discipline area can look forward to making notable scientific progress over the period covered by the plan.

Nevertheless, the committee has several concerns about scientific balance within the disciplines. Because fiscal realities do not allow NASA to maintain continuity in flagship missions, the small missions are increasingly important. However, the mix of small missions in astrophysics and planetary science has been drastically curtailed, as has the opportunity to participate in foreign missions. Under the current plan the astrophysical community faces an extended period with no access to short wavelengths on NASA's major instruments. Such gaps are probably unavoidable, but when they have occurred in the past a strong program of international participation, supporting research, and technology development sustained a healthy community, ready to support the next major NASA mission when it finally took place. This makes the current loss of such balance particularly troubling at this time.

In the past decade, planetary exploration has increasingly been divided into two parts, Mars exploration and exploration of the rest of the solar system. This has presented unique challenges for balancing efforts between these two areas. The committee notes that the NRC recently produced a report on the future of robotic Mars exploration and suggests that the Science Plan incorporate the recommendations of this report.[20] **The committee recommends that Mars should remain the prime target for sustained science exploration; the NASA Science Plan should acknowledge that missions to other targets in the solar system should not be neglected.**

Furthermore, the committee wishes to repeat the recommendations of the 2006 NRC report *Review of Goals for*

[20]National Research Council, *Assessment of NASA's Mars Architecture 2007-2016*, The National Academies Press, Washington, D.C., 2006.

NASA's Space and Earth Sciences, which reviewed NASA's science roadmaps, concerning the role that habitability should serve as an objective for exploration. **The committee recommends that where habitability is determined to be the main focus for exploration, a proper hierarchy of scientific goals and objectives should be developed and stronger pathways between the concept of habitability and proposed missions be articulated and maintained. The committee notes that basic discovery science should not be ignored in the Science Plan.**

As noted above in the discussion of interdisciplinary aspects of the plan, the Earth science section of the plan does not provide a strategy for ensuring that there will be continuity of measurements that will provide the long-term data sets needed for scientific studies of the Earth system, including climate. No strategy is provided for how such observations will enable prediction of the Earth system. Lastly, the funding situation and programmatic priorities permit only the next new start for an Earth System Science Pathfinder (ESSP), which is the small-mission component of the Earth science program, to be launched in 2014. Although two ESSP missions are currently in development, the nearly decade-long gap between the selection of new ESSP missions undercuts the entire purpose of the program, which was to produce missions rapidly, taking advantage of new scientific discovery.

Balance Between Mission and Mission-Enabling Elements

A second aspect of balance about which the committee has serious concerns relates to the balance between spaceflight missions and non-flight elements of the program, especially R&A. This problem was discussed at length in the *Balance* report, which found that under NASA's FY 2007 budget request the proposed "cuts to the R&A grants program cause disproportionately large damage to the viability of the space sciences disciplines as well as to future programs." Because the Science Plan is based on funding levels proposed in the administration's budget for FY 2007-2011, including the proposed reductions in R&A and other small programs, the draft plan also suffers from the problems that are cited in the *Balance* report. These small programs are vital for the training and development of the scientific and engineering workforce. Furthermore, new technology development both enables future missions and makes them more cost-effective. Consequently, **the committee fully concurs with the findings in the *Balance* report and reiterates that report's recommendation that "NASA should move immediately to correct the problems caused by reductions in the base of research and analysis programs, small missions, and initial technology work on future missions before the essential pipeline of human capital and technology is irrevocably disrupted"** (p. 3). While the draft Science Plan presents good arguments for the importance of these programs, it does not present a strategy for how they will be integrated into the overall program or how NASA will respond to concerns raised in the *Balance* report.

Balance of Mission Sizes

A third important balance issue in the plan relates to the mix of mission sizes and to problems that confront NASA over the feasibility of sustaining a properly mixed portfolio of mission sizes. In the plan, the Heliophysics and Planetary Sciences divisions have managed to maintain a degree of balance with respect to mission sizes—i.e., there are small and medium missions in the plan. However, the number of Explorer missions, which constitute the small mission component in astrophysics and heliophysics, and which are vital for training the scientists and engineers of the future, have been reduced substantially, creating problems that call into question the long-term health of the disciplines. As noted above, there is a similar problem with respect to opportunities for new ESSP missions in Earth science. The committee notes that the draft Science Plan makes almost no mention of suborbital and balloon programs.

Perhaps the greatest current threat to the feasibility of a mixed portfolio of flight mission sizes is the cost of execution of currently approved missions. Cost growth for NASA's large flagship missions has drawn considerable attention, but the problem has occurred across all mission sizes. SMD now faces a situation in which the overall balance of the program has been distorted by escalating costs for flight missions. The *Balance* report concluded that "the major missions in space and Earth science are being executed at costs well in excess of those estimated at the time when the missions were recommended in the National Research Council's decadal surveys for their disciplines. Consequently, the orderly planning process that has served the space and Earth science communities well has been disrupted, and balance among large, medium, and small missions has been difficult to maintain" (p. 3). This problem is especially acute in astrophysics, where the costs for the division's two highest-priority missions—HST and JWST—and funding requirements for near-term missions such as SOFIA, GLAST, and Kepler are threatening the overall program balance.

The longer-term implications of the mission cost growth problem are particularly alarming. *If the problem is not successfully addressed, the committee believes there are very real prospects that SMD will be faced with having to abandon either flagship missions or the ability to execute a balanced program. Therefore* ***the committee fully concurs with and reiterates the recommendation of the*** **Balance** ***report that "NASA should undertake independent, systematic, and comprehensive evaluations of the cost-to-complete of each of its space and Earth science missions that are under development, for the purpose of determining the adequacy of budget and schedule"*** (p. 3). This assessment should be the first step in a strategy for resolving the current mission cost growth problem and ensuring that future missions can be executed within manageable costs, schedules, and content.[21] **The committee further recommends that NASA improve mechanisms for managing and controlling mission cost growth so that if and when it occurs it does not threaten the remainder of the program, and also that NASA consider cost-capping flagship missions.** Although NASA already does seek to manage and control mission cost growth, these efforts have been inadequate and the agency needs to evaluate them, determine their failings, and improve their performance. The committee notes that a number of past missions have been successfully descoped. Examples include the Grand Tour (Voyager), the original Voyager (Viking), the Venus Orbiter Imaging Radar (Magellan), AXAF (Chandra) and SIRTF (Spitzer), where descoping and scientific reassessment were successfully used to control mission cost while preserving the most important science capabilities.

As eloquently stated in the draft plan, SMD cannot achieve its stated objectives with missions alone. Additional programs are needed in order to provide necessary infrastructure for performing the missions and in order to realize the science advances that lead to and are derived from the missions. These mission-enabling components of the strategy include R&A programs, including supporting research and technology and suborbital investigations, that consist of regularly competed principal-investigator-led projects covering the whole range of SMD disciplines and science techniques (theory, data analysis, and instrumentation). The mission-enabling components include essential facilities, such as the Deep Space Network and other space communications systems. Essential facilities include information technology infrastructure, such as the virtual observatories for accessing and storing data, and computational resources for analyzing the vast amounts of data gathered by the missions and for developing and running the models that are the expected products from the flight missions.

Although the draft Science Plan contains impressive language about the importance of mission-enabling programs, the committee found that a number of crucial elements are missing from the draft Science Plan in the following areas:

1. The plan does not present a strategy for determining the size and adjustments to the R&A programs. The lack of such a strategy can lead to arbitrary and potentially damaging decisions such as the 15 percent cut to R&A in NASA's FY 2007 budget submission. The committee notes that even small increases in data analysis budgets are frequently difficult to obtain, whereas the actual missions themselves are expensive and prone to cost increases that dwarf data analysis budgets. The committee recognizes that developing a strategy will require more time than is available for this particular Science Plan. The committee further recognizes that while past reports have called explicitly for such a strategy, this will be a difficult task for which there has been no specific guidance from previous NRC or community reports concerning the optimum size for the mission-enabling programs.[22] **The committee recommends that NASA immediately undertake appropriate studies through its advisory structure in order to develop a strategic approach to all of its R&A programs. This strategy should include metrics for determining the success of the programs.**

2. The plan identifies a number of critically needed technologies for future missions (e.g., in the planetary, Earth sciences, and heliophysics sections), but it does not present a mechanism or schedule for achieving these technologies. It is not clear, for example, if the technologies are to be developed in the R&A program or via some

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[21]A number of previous NRC reports have commented on the need for descoping and/or reprioritization of major missions (see National Research Council, "Review of Progress in Astronomy and Astrophysics Toward the Decadal Vision," letter report, 2005; "Review of the Redesigned Space Interferometry Mission," letter report, 2002; and "Scientific Assessment of the Descoped Mission Concept for the Next Generation Space Telescope," letter report, 2001).

[22]"The more the R&DA activities are integrated into the strategy and managed the implementation and evolution of the strategy, the stronger is the overall program." National Research Council, *Supporting Research and Data Analysis in NASA's Science Programs: Engines for Innovation and Synthesis*, National Academy Press, Washington, D.C., 1998, p. 42.

other dedicated technology program. The committee notes that placing technology development under R&A may lead to an erosion of the scientific R&A programs. The plan is unclear if technologies are being sought in an integrated SMD-wide manner, or are only being developed in each separate division. **The committee recommends that NASA provide some indication of the strategy it will use to determine how critically needed technologies will be developed for future missions and their proposed timescales. The committee recommends that NASA outline a strategic technology plan, providing an indication of the resources needed and the schedule that must be met to enable the ambitious goals of the plan.** NASA should also seek to protect general R&A funding from encroachment by technology R&A. In addition, the committee notes that NASA support of technology development within the science program needs to be tightly coupled to evolving science needs.

3. The plan clearly identifies the need for extensive computational technologies and facilities in order to achieve the science and application goals. This is especially true for Earth science and heliophysics, which are working toward developing operational models, but the draft plan does not present a plan and a schedule for achieving them. **The committee recommends that NASA develop a strategic plan to address computing and modeling needs, including data stewardship and information systems.**

4. The plan identifies needed enhancements to communications infrastructure such as the Deep Space Network, but again no strategy is presented as to how these enhancements will be obtained.

Finally, the committee notes that the launch rate for new missions continues to decrease, an indication of unhealthy trends for the overall program and a situation that the agency experienced before, in the 1980s. NASA faces the problem of rising launch costs, which is a situation that is largely beyond the agency's control. These increases pose a serious threat to the overall science program. The committee endorses NASA's efforts to address this problem.

4
UTILITY TO STAKEHOLDERS IN THE SCIENTIFIC COMMUNITY

The committee believes that the NASA Science Plan will be useful to scientists and graduate students as a broad overview of the agency's space science portfolio. However, scientists and graduate students are primary recipients of R&A funds, and it is therefore important that they understand the agency's strategy for allocating R&A funds, something that is lacking in the current draft. Furthermore, the committee notes that if the Science Plan clearly indicates how cost overruns will be addressed in the future, this will provide clarity that will be useful to industry when developing spacecraft and developing cost estimates for projects.

The committee believes that the draft Science Plan does not explain how NASA's Science Mission Directorate can partner with other government agencies to achieve its goals. For instance, the Department of Energy has some interests that overlap with NASA's Beyond Einstein program. The Department of Defense and the National Reconnaissance Office have technology that has been adapted to scientific uses. The plan should acknowledge these resources in other government agencies and explain how SMD can make use of them.

The committee commends the draft plan's positive assessment of the benefits of international cooperation and the plan's endorsement of playing both senior partner and junior partner NASA roles in international Earth and space science programs. International cooperation is not to be undertaken for its own sake, but rather where value is added to the NASA program and the benefits to be gained warrant the risks in taking on an external partner.

The draft plan's recognition of the importance of carefully selecting, structuring, and managing cooperative programs represents a balanced statement about the legal and policy issues that NASA faces. Joint planning can ideally lead to the coordination of national programs via the identification of synergies and the development of interdependencies among programs. The goal would be to minimize gaps and overlaps in discipline areas, while maximizing the leveraging among one another's programs. All partners should be seeking to complement one another's scientific work rather than duplicating it or competing with it.

Historically, the launching of Explorer and Discovery missions has been frequent enough to accommodate missions of opportunity, which have often included international participation. If the interval between such opportunities becomes too long, their utility as a mechanism for international involvement degrades, and an alternative strategy needs to be identified in the plan. The committee encourages NASA to seek an alternative strategy to accomplish such cooperation.[23]

5
GENERAL READABILITY AND CLARITY OF PRESENTATION

The draft NASA Science Plan is a lengthy document, and it could benefit from an executive summary that concisely outlines the contents of the report. The committee suggests that the Science Plan include graphics such as roadmap timelines and checklists, in each of its four disciplines—astrophysics, Earth science, heliophysics, and planetary exploration. The committee suggests that the report include the NASA astrobiology roadmap as well.

When discussing such a broad subject as NASA's science goals and plans, it is necessary to provide the reader with information to make comparisons. The committee suggests that NASA include a chart comparing and defining the different size missions across disciplines. This chart could compare the cost ranges of missions such as Explorers (MIDEX and SMEX), ESSPs, Discovery, Scout, New Frontiers, and flagship missions. Furthermore, it would be useful to provide the reader with an indication of the average development times for these missions.

The committee finds that the overall length of the Science Plan is appropriate, considering the amount of information that must be discussed. However, the committee recommends that the report strive to achieve a more uniform tone and quality of presentation. The astrophysics section does an especially good job at explaining the wonder of scientific discovery and the breadth of the program, and serves as an excellent model for the other chapters to emulate.

During its July 2006 meeting, the SMD Heliophysics division representative presented a table indicating the decadal survey priorities for heliophysics. The committee recommends that each of the section chapters include such a table to give the reader easy access to the decadal priorities within the document. It would be helpful for the table to indicate the status of each decadal priority in the current Science Plan.

6
FINDINGS AND RECOMMENDATIONS

Findings

1. The committee finds that the draft NASA Science Plan successfully demonstrates that a major NASA objective is conducting scientific research to advance the fundamental understanding of the Earth, the solar system, and the universe beyond. Portions of the plan do an excellent job of outlining the reasons that NASA carries out science missions. The draft outlines a defensible set of rules for prioritizing missions within each of SMD's discipline divisions.

2. The committee supports the plan's treatment of priorities on a discipline-by-discipline basis and concludes that NASA should not or could not produce a prioritized mission list across disciplines.

3. In the committee's view, the current draft plan overemphasizes mission-specific work at the expense of strategies and steps for achieving goals in mission-enabling areas. The value of space missions to the nation is not determined merely by successful launches, but by the scientific return from those missions. The research and analysis portion of the program is where the public receives its return on investment in the missions.

The committee reiterates the findings in the *Balance* report and that report's recommendation that "NASA/SMD should move immediately to correct the problems caused by reductions in the base of research and analysis programs, small missions, and initial technology work on future missions before the essential pipeline of human capital and technology is irrevocably disrupted" (p. 3).

4. The draft Science Plan often declares an intention to implement a program or identifies a goal or mission as a top priority, but it does not indicate what steps it would take to achieve the goals or strategies it would pursue to accomplish its priorities. Based on recent NASA experience, the committee believes that unless the agency takes a stronger approach to managing program cost, risk, and schedule, the current Science Plan is not executable. Clear strategies are required to ensure that the plan can be executed, and in some cases these are missing. While some

[23] See also, National Research Council, *Review of Goals and Plans for NASA's Space and Earth Sciences*, The National Academies Press, Washington, D.C., 2006.

disciplines are in better shape in the plan than others, each division has some parts of its plan that cannot be executed in the manner that the draft Science Plan presents.

If the problem of mission cost growth is not successfully addressed, the committee believes there are very real prospects that SMD will be faced with having to abandon either flagship missions or the ability to execute a balanced program. Therefore the committee fully concurs with and reiterates the recommendation of the *Balance* report that "NASA should undertake independent, systematic, and comprehensive evaluations of the cost-to-complete of each of its space and Earth science missions that are under development, for the purpose of determining the adequacy of budget and schedule" (p. 3).

5. The Science Plan lacks a strategy for an integrated synthesis of the variety and volume of Earth observations generated by NASA. The plan mentions but does not describe the unique modeling, prediction, and computational capabilities and requirements for Earth science. In addition, the plan lacks a science strategy for the development of Earth system models and a discussion of a strategy to develop understanding for enabling a predictive capability for the Earth system. Finally, the committee found no indication of NASA's strategy for linking and crosscutting the six interdisciplinary science focus areas: atmospheric composition, carbon cycle and ecosystems, climate variability and change, Earth surface and interior, water and energy cycle, and weather.

Recommendations

Some of the committee's recommendations are broad and apply to all four of SMD's science disciplines, but the difficulties underlying the concerns reflected in the recommendations are more acute in some disciplines than others. For example, the problems associated with controlling mission cost growth and preserving proper balance between large and small missions are now particularly pressing in astrophysics. The need to develop strategies for meeting future computing and modeling capabilities is particularly noticeable for Earth science and heliophysics. In addition, although the committee makes discipline-specific recommendations for the planetary and Earth sciences, it stresses that the astrophysics and heliophysics sections of the draft plan are also addressed in the more general recommendations and require equal attention.

The committee's recommendations on the implementation and viability of the draft NASA Science Plan are as follows:

1. The NASA Science Plan should compare the key aspects of its 2003 Earth and space science plans with the 2006 plan in a list or table that shows how the current plan differs from the previous ones. This comparison would also provide some indication of the starting point for the new Science Plan, and the changes that have occurred since 2003.

2. NASA/SMD should provide some indication of the strategy it will use to determine how critically needed technologies will be developed for future missions and their proposed timescales. The committee recommends that NASA outline a strategic technology plan, providing an indication of the resources needed and the schedule that must be met to enable the ambitious goals of the plan. But NASA should also seek to protect general R&A funding from encroachment by technology R&A.

3. The NASA Science Plan should explicitly address realistic strategies for achieving the objectives of the mission-enabling elements of the overall program. The committee recommends that NASA:

a. Undertake appropriate studies through its advisory structure in order to develop a strategic approach to all of its R&A programs (this strategy should include metrics for evaluating the proper level of R&A funding relative to the total program, the value of stability of funding levels in the various areas, and metrics for evaluating the success of these programs); and

b. Develop a strategic plan to address computing and modeling needs, including data stewardship and information systems, which anticipates emergent developments in computational sciences and technology, and displays inherent agility.

4. NASA should improve mechanisms for managing and controlling mission cost growth so that if and when it occurs it does not threaten the remainder of the program, and should consider cost-capping flagship missions. Although NASA already does seek to manage and control mission cost growth, these efforts have been inadequate and the agency needs to evaluate them, determine their failings, and improve their performance. NASA should undertake

independent, systematic, and comprehensive evaluations of the cost-to-complete of each of its space and Earth science missions that are under development, for the purpose of determining the adequacy of budget and schedule.

5. NASA/SMD should move immediately to correct the problems caused by reductions in the base of research and analysis programs, small missions, and initial technology work on future missions before the essential pipeline of human capital and technology is irrevocably disrupted.

6. For planetary science, the committee recommends as follows:

a. NASA/SMD should incorporate into its Science Plan relevant recommendations from the NRC interim report on lunar science,[24] when they are available, in such a way as to maintain the overall science priorities advocated by previous NRC studies, while recognizing that science advice will change as scientific understanding and technology improve.

b. Although Mars should remain the prime target for sustained science exploration, the NASA Science Plan should acknowledge that missions to other targets in the solar system should not be neglected.

c. Where the question of habitability (i.e., the ability of a planet to support life) is determined to be the main focus for exploration, a proper hierarchy of scientific goals and objectives should be developed, stronger pathways between the concept of habitability and proposed missions should be articulated and maintained, and basic discovery science should not be ignored.

d. Life detection techniques should be clearly identified as an astrobiology strategic technology development area.

7. For Earth science, the committee recommends as follows:

a. NASA/SMD should incorporate into its Science Plan the recommendations of the NRC Earth science decadal survey interim report,[25] and should incorporate the recommendations of the Earth science decadal survey final report when it is completed.

b. NASA/SMD should develop a science strategy for obtaining long-term, continuous, stable observations of the Earth system that are distinct from observations to meet requirements by NOAA in support of numerical weather prediction.

c. NASA/SMD should present an explicit strategy, based on objective science criteria for Earth science observations, for balancing the complementary objectives of (i) new sensors for technological innovation, (ii) new observations for emerging science needs, and (iii) long-term sustainable science-grade environmental observations.

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[24]National Research Council, *The Scientific Context for the Exploration of the Moon—Interim Report*, The National Academies Press, Washington, D.C., 2006.

[25]National Research Council, *Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, Washington, D.C., 2005.

6.3 Review of the Next Decade Mars Architecture

On June 30, 2007, Reta F. Beebe, Chair of the Ad Hoc Committee to Review the Next Decade Mars Architecture, sent the following letter to Mary Cleave, associate administrator, Science Mission Directorate, NASA Headquarters. Subsequently, the committee released a final version of the report as a book, Assessment of NASA's Mars Architecture 2007-2016*. The Executive Summary can be found in Chapter 5 of this Annual Report.*

In your letter of December 29, 2005, to Space Studies Board (SSB) Chair Lennard Fisk, you explained that new scientific results from ongoing Mars missions, together with changes in funding levels for the Mars Exploration Program, have compelled the Science Mission Directorate to revisit the program's architecture and the sequence of missions planned for launch to Mars after 2010. As a result you requested that the SSB review and evaluate the new architecture in a time frame to support NASA approval of the Mars Exploration Program's revised architecture in mid-summer of 2006. In particular, you requested that the SSB address the following questions:[1]

- Is the Mars architecture reflective of the strategies, priorities, and guidelines put forward by the National Research Council's (NRC's) solar system exploration decadal survey and related science strategies and NASA plans?
- Does the revised Mars architecture address the goals of NASA's Mars Exploration Program and optimize the science return, given the current fiscal posture of the program?
- Does the Mars architecture represent a reasonably balanced mission portfolio?

In response to your request, the ad hoc Committee to Review the Next Decade Mars Architecture was established (the membership of the committee is listed in Appendix 1) and met at the National Academies' Keck Center in Washington, D.C., on March 29-31, 2006. The committee's deliberations and discussions relating to the conclusions and recommendations contained in this letter report were initiated at the Washington meeting and continued in a conference call held on April 6.

During the course of the Washington meeting the members of the committee consulted related reports issued by the SSB and other NRC committees[2] and heard the following presentations:

- J. Douglas McCuistion—Director, Mars Exploration Program at NASA Headquarters—gave the committee a programmatic overview of NASA's Mars Exploration Program.
- Michael A. Meyer—Mars Exploration Program Lead Scientist at NASA Headquarters—gave the committee a scientific overview of NASA's Mars Exploration Program.
- Daniel J. McCleese—Chief Scientist, Mars Exploration Program, at the Jet Propulsion Laboratory and chair of NASA's Mars Advanced Planning Group—gave the presentation "Mars Program Plan: The Coming Decade" and distributed advance copies of the report *Mars Exploration Strategy 2007-2016*.[3]
- W. Bruce Banerdt—Principal Research Scientist at the Jet Propulsion Laboratory and member of NASA's Mars Advanced Planning Group—gave the presentation "Is the Architecture Reflective of the Strategies, Priorities and Guidelines Put Forward by the NRC Solar System Exploration Decadal Survey?"
- Raymond Arvidson—James S. McDonnell Distinguished University Professor at Washington University in St. Louis and chair of the Mars Exploration Program Analysis Group—gave the presentation "Mars Science Perspectives."

NOTE: Appendixes 1 is not reprinted in this annual report.

[1]NOTE: As explained in the attached assessment, the committee reordered the questions posed by Dr. Cleave.

[2]National Research Council reports consulted included *Preventing the Forward Contamination of Mars* (2005), *Science in NASA's Vision for Space Exploration* (2005), *Assessment of Mars Science and Mission Priorities* (2003), *New Frontiers in the Solar System* (2003), *Signs of Life* (2002), *The Quarantine and Certification of Martian Samples* (2002), "Assessment of NASA's Mars Exploration Architecture" (1998), *Mars Sample Return: Issues and Recommendations* (1997), *Review of NASA's Planned Mars Program* (1996), "On NASA Mars Sample-Return Mission Options" (1996), and *An Integrated Strategy for the Planetary Sciences: 1995-2010* (1994). These reports were published by the National Academy Press [as of mid-2002, The National Academies Press], Washington, D.C.

[3]D.J. McCleese et al., *Mars Exploration Strategy 2007-2016*, NASA, Jet Propulsion Laboratory, Pasadena, Calif., 2006.

- Noel W. Hinners, Vice President of Flight Systems (retired), Lockheed Martin Astronautics, addressed the committee on the topic “The Exploration of Mars: History, Hopes and Hallucinations and Mars Sample Return.”

In response to the question, Is the Mars architecture reflective of the strategies, priorities, and guidelines put forward by the NRC’s solar system exploration decadal survey and related science strategies and NASA plans?, **the committee finds that the proposed Mars architecture addresses some of the strategies, priorities, and guidelines promoted by the solar system exploration (SSE) decadal survey and the Mars Exploration Program Analysis Group (MEPAG) and is basically consistent with NASA’s plans as exemplified by the agency’s 2006 strategic plan[4] and the Vision for Space Exploration.[5] However, the absence of a sample return mission and a geophysical/meteorological network mission runs counter to the recommendations of the SSE decadal survey and significantly reduces the architecture’s scientific impact. Other topics of concern include the lack of well-defined mission parameters and scientific objectives for the Mars Science and Telecommunications Orbiter, Astrobiology Field Laboratory, and Mid Rover missions; issues relating to the phasing and responsiveness of these missions to the results obtained from past missions; and the incompletely articulated links between these missions and the priorities enunciated by the SSE decadal survey and MEPAG.**

The committee offers the following recommendations to NASA:

- ***Recommendation:*** **Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.**
- ***Recommendation:*** **Consider delaying the launch of the Astrobiology Field Laboratory until 2018 to permit an informed decision of its merits and the selection of an appropriate instrument complement in the context of a mature consideration of the results from the Mars Science Laboratory and other prior missions.**
- ***Recommendation:*** **Establish science and technology definition teams for the Astrobiology Field Laboratory, the Mars Science and Telecommunications Orbiter, the Mid Rovers, and the Mars Long-Lived Lander Network as soon as possible to optimize science and mission design in concert with each other. (This model has been employed successfully by the heliospheric community.)**
- ***Recommendation:*** **Devise a strategy to implement the Mars Sample Return mission, and ensure that a program is started at the earliest possible opportunity to develop the technology necessary to enable this mission.**

In response to the question, Does the revised Mars architecture address the goals of NASA’s Mars Exploration Program and optimize the science return, given the current fiscal posture of the program?, **the committee finds that it cannot definitively say whether or not the revised Mars architecture addresses the goals of NASA’s Mars Exploration Program because the architecture lacks sufficient detail with respect to the science and the cost to allow a complete evaluation. The various mission options are, as stated above, incompletely defined, and the strategic approach to, and the selection criteria to distinguish among, various mission options are lacking. The presence of Mars Scout missions in the architecture is welcomed because they help to optimize the science return and provide balance. Nevertheless, the Mars architecture as a whole is not optimized, because the importance of foundational strategic elements—for example, research and analysis programs and technology development—is not articulated.**

In response to this finding, the committee offers the following recommendations to NASA:

- ***Recommendation:*** **Develop and articulate criteria for distinguishing between the three options for missions to launch in 2016. Similarly, define a strategy that addresses the short lead time between science results obtained from the Mars Science Laboratory and selection of the mission to fly in 2016.**
- ***Recommendation:*** **Clarify how trade-offs involving mission costs versus science were made for the**

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[4]National Aeronautics and Space Administration (NASA), *2006 Strategic Plan*, NP-2006-02-423-HQ, NASA, Washington, D.C., 2004. Available at <www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.pdf>.

[5]National Aeronautics and Space Administration (NASA), *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004. Available at <www.nasa.gov/pdf/55583main_vision_space_exploration.pdf>.

various launch opportunities to justify the rationale behind the proposed sequence of specific missions and the exclusion of others.

- ***Recommendation:*** **Maintain the Mars Scouts as entities distinct from the core missions of the Mars Exploration Program. Scout missions should not be restricted by the planning for core missions, and the core missions should not depend on selecting particular types of Scout missions.**
- ***Recommendation:*** **Immediately initiate appropriate technology development activities to support all of the missions considered for the period 2013-2016 and to support the Mars Sample Return mission as soon as possible thereafter.**
- ***Recommendation:*** **Ensure a vigorous research and analysis (R&A) program to maintain the scientific and technical infrastructure and expertise necessary to implement the Mars architecture, and encourage collaboration on international missions.**

In response to the question, Does the Mars architecture represent a reasonably balanced mission portfolio?, **the committee finds that in the context of the basic types of missions, the Mars architecture is a reasonably well balanced one: both landed and orbital missions are included in an appropriate mix, given the current state of Mars exploration. To the extent that the specific science objectives of the proposed missions are defined, one of the three crosscutting themes for the exploration of Mars identified in the SSE decadal survey is largely neglected, as are very high priority topics related to understanding near-surface and boundary-layer atmospheric sciences, and so, in this respect, balance is sorely lacking.**

To optimize efforts to implement a balanced portfolio of missions, the committee offers the following recommendations to NASA:

- ***Recommendation:*** **Include the Mars Long-Lived Lander Network in the mix of options for the 2016 launch opportunity.**
- ***Recommendation:*** **If the Mars Long-Lived Lander Network cannot be implemented in the period under consideration, provide for an effort to make some of the highest-priority measurements on the landed missions that are included in the proposed Mars architecture.**
- ***Recommendation:*** **Ensure that the primary role of the Mars Science and Telecommunications Orbiter is to address science questions, and not simply to serve as a telecommunications relay. This distinction is particularly important with respect to the required orbital parameters that are adopted.**

Full details of the committee's findings and the recommendations flowing from them, together with supporting arguments, can be found in the attached "Assessment of NASA's Mars Architecture 2007-2016."

Signed by

Reta F. Beebe, Chair of the Ad Hoc Committee to Review the Next Decade Mars Architecture

7
Congressional Testimony

Members of SSB committees may be invited to testify before committees of the U.S. House of Representatives or the U.S. Senate about the findings and recommendations of their reports.

On March 2, 2006, the House Science Committee held a hearing on NASA's FY2007 request for the Science Mission Directorate. Each of the four SSB decadal surveys was represented by someone who participated in the study, although all were testifying in their individual capacities, not as representatives of the SSB or the Academies. The four witnesses were: Joseph Taylor for astronomy and astrophysics, Fran Bagenal for solar and space physics, Wes Huntress for planetary exploration, and Berrien Moore for Earth sciences. The texts of their prepared statements follow. They also are available, along with an archived webcast of the hearing, on the Science Committee's website [http://www.house.gov/science]. Click on "hearings" on the left menu, then "full committee," then the hearing listed for March 2, 2006.

During the second quarter, two hearings were held where members of the SSB family testified to Congress. Their prepared statements are reprinted here. First was the June 7 hearing before the Senate Commerce Committee's Science and Space Subcommittee where incoming Board member James Pawelczyk, and former Board member Peter Voorhees, testified on outside perspectives regarding NASA's FY2007 budget request. The prepared statements of other witnesses are available at http://commerce.senate.gov. Second was a June 13 hearing where David Black, co-chair of the NRC's ad hoc Committee on Issues Affecting the Future of the U.S. Space Science and Engineering Workforce, testified to the House Science Committee's Space and Aeronautics Subcommittee on behalf of the NRC concerning the findings and recommendations of his committee's interim report. The prepared statements of other witnesses are available at http://www.house.gov/science.

7.1 NASA's Science Mission Directorate Impacts of the Fiscal Year 2007 Budget Proposal

Statements Before the Committee on Science, U.S. House of Representatives
March 2, 2006

Statement of Joseph H. Taylor, Jr., Ph.D. NL.
James S. McDonnell Distinguished University
Professor of Physics, Princeton University

Mr. Chairman, Ranking Minority Member, and members of the committee: thank you for inviting me to testify. My name is Joseph Taylor and I am the James S. McDonnell Distinguished University Professor of Physics and former Dean of the Faculty at Princeton University. I served in 1998–2000 as co-chair of the National Academies Astronomy and Astrophysics Survey Committee, but my comments today represent my own opinions, informed by discussions with many colleagues in the U.S. astronomy community.

As you know, the astronomy community has a long history of creating, through the National Research Council (NRC), broad surveys of the field at ten-year intervals. These surveys lay out the community's research goals for the next decade; they identify key scientific questions that are ripe for answering, and they propose new initiatives that will make those goals achievable. The most recent decadal survey, entitled *Astronomy and Astrophysics in the New Millennium*, was released in the year 2000.[1] I have been asked to answer the following questions from my perspective as the co-chair of the committee that produced that report:

1. What do you see as the most serious impacts on your field of the proposed slowed growth in the Science Mission Directorate? Clearly, it would be better to conduct more science than less, but what is the real harm in delaying specific missions? At what point do delays or cutbacks become severe enough to make it difficult to retain or attract scientists or engineers to your field?
2. Do you believe the decisions NASA has made concerning which missions to defer or cancel are consistent with the most recent National Academies Decadal Survey that you released? Have there been any developments since the Decadal Survey that need to be taken into account, and has NASA considered those? Given the FY 07 budget request, do you see any need to update the most recent survey or to change the process for the next Decadal Survey?
3. How should NASA balance priorities among the various disciplines supported by its Science Mission Directorate? Do you believe the proposed FY 07 budget, given the overall level of spending allotted to science, does a good job of setting priorities across fields?

In the balance of my testimony I shall address all three questions.

In previous decades the NRC decadal survey was an activity unique to the astrophysical sciences. The most recent survey involved the direct participation of 124 astronomers as committee and panel members; moreover, these people received input from many hundreds more of their colleagues. Altogether, a substantial fraction of the nation's astronomers were in some way involved in the creation of the report. By gathering such broad community input, the survey process creates a document that reflects the consensus opinion of the active researchers in the field. The value of this advice to NASA and the National Science Foundation has been demonstrated in many ways. It clearly helped to motivate NASA's requests for the NRC to conduct similar surveys for planetary science,[2] solar and space physics,[3] and earth science.[4]

The feature of a decadal survey that distinguishes it from summaries of other fields of science is the prioritized list of recommended initiatives. This list is a valuable tool for strategic planning, and it receives considerable attention. As with the use of any tool, some judgment is required in its application. Science priorities drive the assigned priorities of the projects. The science priorities are based on the output of the research community throughout the country, including its probable extrapolation into the future. The most serious impact of the President's FY2007 budget proposal is that it threatens to significantly decrease this output by cutting the research and analysis grants lines by 15%. At a time when the administration has proposed an American Competitiveness Initiative and many members of Congress have expressed strong support for increasing research in the physical sciences, this reduction seems counter-productive at best. For the past decade NASA has provided a majority of the nation's research support in astronomy and astrophysics. The proposed reductions are therefore of considerable concern to the astronomy community.

The damage caused by these budget cuts is compounded by the fact that their impact will be disproportionately felt by the younger members of the community—the assistant professors, post-doctoral trainees, and graduate students. Without research support to pay for their time, this group will be forced to turn to other fields. Many will leave the sciences altogether, and other bright young people will decide not to enter. In a similar vein, severe reductions in the flight rate of NASA's Explorer line of smaller, lower cost missions will be damaging to the field and particularly its ability to attract and retain younger talent. The Explorer satellites have been extremely cost effective and have often been an entry point for younger researchers into mission development and project management. The scientists and engineers who will build and use tomorrow's Great Observatories are building today's Explorers. It would be a tragedy to drive these people away from space science.

It is easy to identify specific impacts of these cuts and others in the budget proposal, but I wish to call attention to a broader impact that addresses your question about the field's ability to retain scientists and engineers. The administration is proposing to reduce near term opportunities in order to fully fund large, long-term missions. At the same time it is terminating a long-planned, nearly completed facility called SOFIA and indefinitely deferring an entire program called "Beyond Einstein." I believe that the field of astronomy can sustain itself through lean budgetary times if there is opportunity on the horizon, but this budget proposal sends the message that even nearly completed missions may never be flown. It does not provide the positive view of the future that will keep members of the community engaged and attract bright young people to the field.

The primary goal of the year 2000 Decadal Survey was to provide a vision for a sustainable national effort in astronomy and astrophysics—one that would build on the enviable position of leadership in astronomy that America has developed over the past half century and more. I do not believe that the FY2007 budget submission is consistent with this vision. I believe that NASA is trying to follow the survey recommendations, and I appreciate that it has protected the highest priority mission, the James Webb Space Telescope, and the crown jewel of the space astronomy missions, the Hubble Space Telescope, in the face of significant cost increases. However, as I mentioned when I appeared before you last year to discuss the Hubble Space Telescope, I do not believe that the highest priority missions should be implemented without regard to cost or impact on the overall program. The Decadal Survey recommended that NASA have a mission portfolio with a mix of large, moderate, and small missions. The FY2007 budget proposal is weighted to an unhealthy extent towards the large missions. The Decadal Survey recommended that NASA maintain adequate funding in research and analysis grants to "ensure the future vitality of the field." I believe that the proposed reduction in the grants line is not consistent with this recommendation.

One very significant scientific development has taken place since the Decadal Survey was released. Confirmation of the universe's accelerating rate of expansion and the existence of some form of "dark energy" have stimulated new research efforts across astronomy, astrophysics, and fundamental particle physics. The NRC's 2003 report *Connecting Quarks with the Cosmos* puts these discoveries into the broader context of understanding the universe and the physical laws that govern it. NASA worked with the community to develop its Beyond Einstein plan, synthesizing the recommendations of the Decadal Survey and the 2003 report into a widely praised strategy for investment in high energy astrophysics. NASA also participated in an interagency process headed by the Office of Science and Technology Policy which produced a detailed plan for NASA, the NSF, and the Department of Energy to move forward in this area. The NSF and DOE are implementing many of these recommendations by increasing research support and planning investments in new instruments and missions, but NASA continues to push the Beyond Einstein program into the indefinite future.

National priorities outlined in the FY2007 budget submission present NASA and the astronomy and astrophysics community with significant challenges. I do not believe, however, that a new decadal survey is needed immediately. The study we completed a little over five years ago produced a positive and forward looking document that tried to capture the scientific opportunities ahead of us. Of course science has progressed in the intervening five years, but the priorities we set still look about right. Conducting a new survey at this time would set an unfortunate precedent and encourage undesirable second-guessing at any time in the future. With these things said, it is also clear that some sort of advice from the community is needed now. In the 2005 NASA Authorization Act, Congress requested that the NRC provide NASA with a mid-decade performance assessment for each of its scientific programs. The NRC and NASA have agreed to begin this process with the astronomy and astrophysics program, and the NRC is working now to assemble a review panel. One of the goals of this study will be to provide a feasible implementation plan for the rest of this decade. Such a plan should form a solid foundation on which to conduct the next decadal survey at its normal time, near the end of this decade.

One of the keys to crafting a feasible program is to acquire accurate information on the resources necessary to complete each mission. We attempted to gather such information in carrying out the 2000 Decadal Survey, but in retrospect it is clear that our efforts were inadequate. I believe that the correct procedure is for NASA to set up a task force to work with centers and contractors to improve the reliability of the cost, schedule and technology risk estimates, including proper contingencies, for each of the selected missions. Serious departures from these projections in the future should be grounds for consideration of mission cancellation, even for large missions of high priority.

In addition to these specific proposals, I believe it is essential that NASA work harder to communicate with its scientific community—the community that has contributed so much to the agency's successes over the years. Part of the difficulty in this particular budget cycle is that NASA's advisory bodies have been in disarray, leading to a perceived lack of community input into the agency's decision-making process. I do not believe there is a foolproof formula for setting priorities across different scientific disciplines, but it is clear that each of NASA's science disciplines must remain independently healthy. Rapid budgetary fluctuations can threaten that condition. I am confident that if the priority-setting process is done well it must include dialogue and consultation with representatives of the appropriate scientific communities. Without such discussion, budget proposals such as this one run the risk of touching off efforts outside the normal, proven planning channels to save troubled programs. This situation would eliminate one of the primary strengths of the decadal survey process: priorities based on the informed consensus of a highly competitive but ultimately cooperative scientific community.

To summarize, I believe that the FY2007 NASA budget proposal does not present a program that can provide the nation with a healthy and productive astronomy and astrophysics program. The budget proposal reduces astronomy and astrophysics at NASA by 20% over the five-year runout, before inflation is taken into consideration. The proposal damages programs that are necessary for the sustainability of a healthy research community, and it is skewed too heavily towards large missions. It may be that in the current budget climate, NASA is unable to provide the necessary resources to keep the program healthy. If so, NASA must do a better job of working with the community in order to find the best solutions to the challenges that lie ahead.

Thank you for your attention, and I will be pleased to answer questions.

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[1] *Astronomy and Astrophysics in the New Millennium*, NRC, 2001.
[2] *New Frontiers in the Solar System*, NRC, 2003.
[3] *The Sun to the Earth—and Beyond*, NRC, 2003.
[4] Study under way—http://qp.nas.edu/decadalsurvey

Statement of Fran Bagenal
Professor of Astrophysical and Planetary Sciences
Laboratory for Atmospheric and Space Physics, University of Colorado

Good morning, Mr. Chairman and members of the Committee. My name is Fran Bagenal and I am a professor at the University of Colorado. I served on the committee for the NRC decadal survey for solar and space physics and chaired a committee that assessed the role of solar and space physics in space exploration.

I am here today to provide an evaluation of the impact of the NASA's FY07 budget on solar and space physics—a field of research that corresponds to what is labeled, as of last week, the Heliophysics Division of NASA's Science Mission Directorate. Heliophysics has previously been called Sun-Earth Connections (SEC) and, until last week, sat with Earth Science within Earth-Sun Systems. This evaluation yields six conclusions that are summarized as follows:

1. NASA's investment in science has had a high payoff; it has spurred advances in leading edge technologies and has been instrumental in educating the next generation of scientists.
2. The claimed increase in science's share of the NASA budget is not reflected in science activity and in part arises from a change in accounting rules.

3. There will be a precipitous drop in launches of science missions beginning in 2010 and continuing forward.
4. The Explorer program is experiencing dramatic cuts and set-backs.
5. The Sounding Rocket Program, which serves our nation as a space academy, is withering after more than a decade of flat funding.
6. The FY07 budget makes major cuts in the Research and Analysis Program, which will affect disproportionately the youngest space scientists, and place the health of the space science "workforce" at risk.

To understand these conclusions I would like to begin by giving some context for this area of science.

Heliophysics

The Sun is the source of energy for life on Earth and is the strongest modulator of the human physical environment. In fact, the Sun's influence extends throughout the solar system, both through photons, which provide heat, light, and ionization, and through the continuous outflow of a magnetized, supersonic ionized gas known as the solar wind. The realm of the solar wind, which includes the entire solar system, is called the heliosphere. In the broadest sense, the heliosphere is a vast interconnected system of fast-moving structures, streams, and shock waves that encounter a great variety of planetary and small-body surfaces, atmospheres, and magnetic fields. Somewhere far beyond the orbit of Pluto, the solar wind is finally stopped by its interaction with the interstellar medium.

Thus, interplanetary space is far from empty—an often gusty solar wind flows from the Sun through interplanetary space. Bursts of energetic particles arise from acceleration processes at or near the Sun and race through this wind, traveling through interplanetary space, impacting planetary environments. It is these fast solar particles, together with galactic cosmic rays, that pose a threat to exploring astronauts. The magnetic fields of planets provide some protection from these high energy particles, but the protection is limited and variable, and outside of the planetary magnetospheres there is no protection at all. Thus, all objects in space—spacecraft, instrumentation and humans—are exposed to potentially hazardous penetrating radiation, both photons (e.g., x-rays) and particles (e.g., protons, heavy ions and electrons). Just as changing atmospheric conditions on Earth lead to weather that affects human activities on the ground, the changing conditions in the solar atmosphere lead to variations in the space environment—space weather—that affects activities in space.

Decadal Survey & Vision for Space Exploration

In 2002, the National Research Council published the first decadal strategy for solar and space physics: *The Sun to the Earth—and Beyond: A Decadal Strategy for Solar and Space Physics.*[1] The report included a recommended suite of NASA missions that were ordered by priority, presented in an appropriate sequence, and selected to fit within the expected resource profile for the next decade, which was anticipated to increase substantially through ~FY08.

In early 2004,[2] NASA proposed to adopt major new goals for human and robotic exploration of the solar system, consistent with the Bush Administration's Vision for Space Exploration. Any exploration will depend, in part, on developing the capability to predict the space environment experienced by exploring spacecraft and humans. Also in 2004, the Space Studies Board of the National Research Council tasked a committee to assess the role of solar and space physics in NASA's Exploration Vision.[3] This committee stated that:

> NASA's Sun-Earth Connection program depends upon a balanced portfolio of spaceflight missions and of supporting programs and infrastructure, which is very much like the proverbial three legged stool. There are two strategic mission lines-Living With a Star (LWS) and Solar Terrestrial Probes (STP)-and a coordinated set of supporting programs. LWS missions focus on observing the solar activity, from short-term dynamics to long-term evolution, that can affect the Earth, as well as astronauts working and living in near-Earth space environment. Solar Terrestrial Probes are focused on exploring the fundamental physical processes of plasma interactions in the solar system. A key assumption upon which the LWS program was designed was that the STP program would be in place to provide the basic research foundation from which the LWS program could draw to meet its more operationally oriented objectives. Neither set of missions can properly support the objectives of the Exploration Initiative alone. Furthermore, neither set of spaceflight missions can succeed without the third leg of the stool. That leg provides the means to (a) conduct regular small Explorer missions that can react quickly to new scientific issues, foster innovation, and accept higher technical risk; (b) operate active

spacecraft and analyze the LWS and STP mission data; and (c) conduct ground-based and sub-orbital research and technology development in direct support of ongoing and future spaceflight missions.

I will return to this issue of balance between these 3 legs of basic, applied and supporting research later in my testimony.

This re-evaluation of the Decadal Survey endorsed the original scientific and mission priorities—emphasizing a balance in the fundamental and applied aspects of space physics—but recognized that the schedule of missions would have to be considerably stretched out to fit a leaner budget.

Science Mission Directorate FY07 Budget

With this background, let me proceed to NASA's FY07 budget. First, may I commend Administrator Dr. Griffin's bold leadership of NASA and his clear command of the technical issues involved. we all recognize the enormous challenge of enacting the Vision for Space Exploration while fulfilling international obligations associated with Space Station. NASA is being asked to do Apollo with a post-Apollo budget. Yet we must also remember that science is a vital part of the Vision for Space Exploration. I repeat the refrain "Exploration without science is just tourism."

In his February 16th statement to this committee, Dr. Griffin quoted that fraction of the NASA budget allocated to science had grown from 24% to 32% between 1992 and 2007. These figures were emphasized in his oral presentation with the explicit implication that this fraction should be reduced by having the science budget slow down to a 1% growth rate while NASA as a whole grows three times faster. First of all, I do not claim to know what fraction of the NASA budget is the "correct" value to be spent on science. But I submit that the dramatic close-up views of our Sun from SOHO and Trace as well as the exciting new worlds revealed by Voyager, Hubble, Mars rovers, and Cassini have permanently changed the American people's view of space science. ***Investment in science has paid off for NASA—not only in terms of cultural and intellectual benefits but also in enabling technology and inspiring young scientists and engineers.***

Secondly, I accept that the science budget has seen net growth—and a third of the NASA's $17 billion budget is a substantial amount to spend on science. The reason for this growth is partly because of demonstrated successes. But I point out that over the past 15 years there have been significant changes in the way NASA has been bookkeeping different components of the budget (e.g. project management & operations, salaries of civil servants, and particularly launch costs which have doubled in the past ~5 years). I suggest that the quoted 8% increase in the share of the NASA budget being labeled as science does not necessarily reflect a corresponding increase in scientific activity. It might be useful for your committee to task one its support agencies; for example, the Government Accountability Office, to evaluate of how these budget figures are tracked. At the very least, I caution against taking this simple statistic at face value and using it to rationalize the diminishment of what has been one of NASA's great successes—science.

Heliophysics Budget

I have been asked to address the following specific questions:

1. What do you see as the most serious impacts on your field of the proposed slowed growth in the Science Mission Directorate? Clearly, it would be better to conduct more science than less, but what is the real harm in delaying specific missions? At what point do delays or cutbacks become severe enough to make it difficult to retain or attract scientists or engineers to your field?

Science Mission Launches

The impact of elimination of growth in SMD is most dramatically illustrated by the following chart of science mission launches for the next seven years. An impressive list of missions to be launched in the next couple of years is followed by a precipitous drop to only one launch in 2010 (ST-9, a small technology demonstration mission) and few launches per year thereafter.

Since each mission takes several years of development and construction before launch (~3 years for small mis-

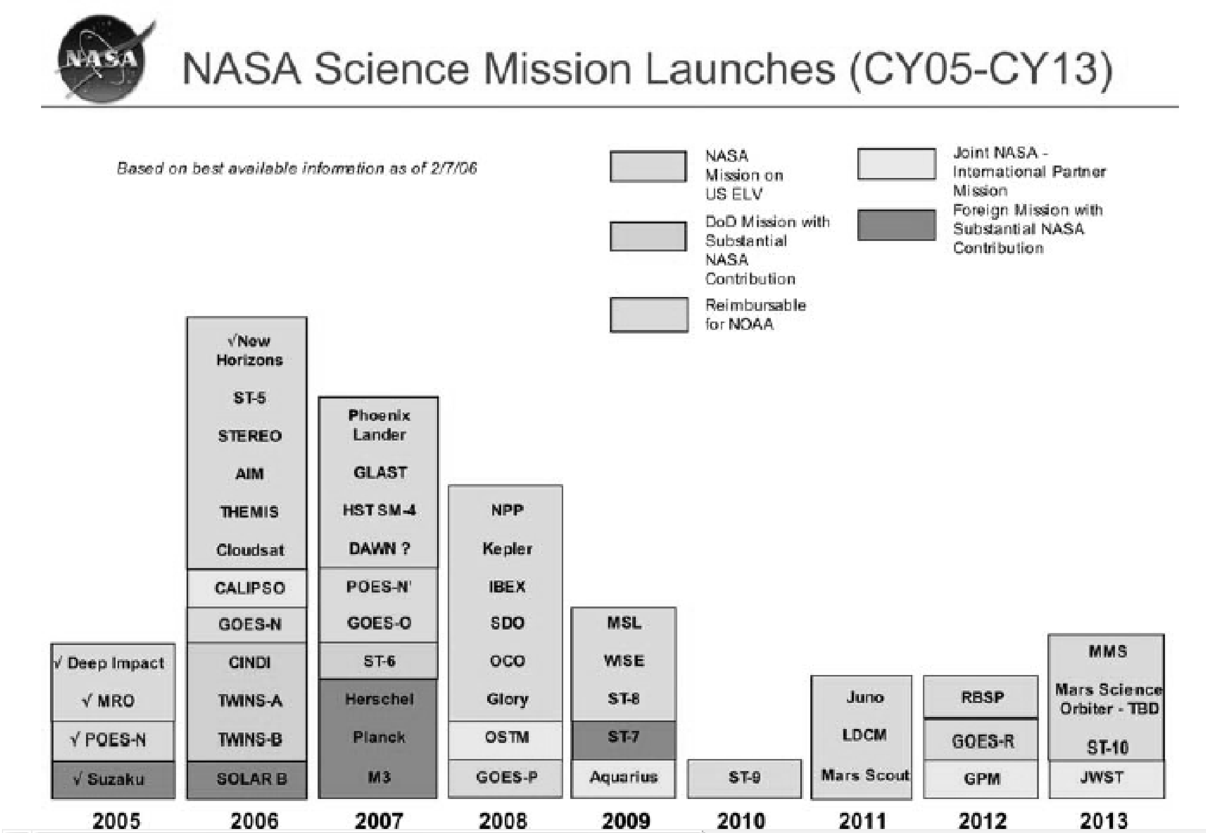

FIGURE 7.1 [no caption] SOURCE: NASA.

sions, over a decade for the largest missions) this paucity of missions beyond 2010 reflects a slowdown in mission opportunities over the past ~5 years and a lack of launch opportunities for several more years. Factors contributing to this dearth of launches are the escalation in launch costs, the impact of full-cost accounting, the under-costing of larger missions, and—most significantly—the elimination of any funding wedge for new missions from here onwards. ***The net result is that there is a significant gap during which it is inevitable that expertise will be lost and it will be hard to attract and train junior scientists and engineers—***the very people who will be needed to implement the Vision for Space Exploration. ***While the lack of any large missions on the horizon is a concern, the priority for Heliophysics must be a steady cadence of smaller missions.***

The Explorer Program

In the past, the Explorer program has offered frequent opportunities to carry out small and medium sized missions that can be developed and launched in a short (approximately four-year) time frame. The Explorer Program straddles both the Heliophysics and Astrophysics Divisions with roughly equal numbers of launches in each division.

These focused missions address science of crucial importance to these two division roadmaps and NRC Decadal Surveys: The 2004 NRC report "Solar and Space Physics and Its Role in Space Exploration" states that; Explorers "*are the lifeblood of SEC research because they provide core research, flexibility, innovative technologies, and invaluable training for the next generation of workers for our nation's space enterprise. The Explorer program provides innovative, fast-response missions to fill critical gaps.*" The report recommends "*these programs should continue at a pace and a level that will ensure that they can fill their vital roles in SEC research*". The 2001 NRC report "Astronomy and Astrophysics in the New Millennium" finds that "*the Explorer program is very suc-*

cessful and has elicited many highly innovative, cost effective proposals for small missions from the community." Specifically they recommend "*the continuation of a vigorous Explorer program,*" and that "*NASA should continue to encourage the development of a diverse range of mission sizes, including small, moderate, and major, to ensure the most effective returns from the U.S. space program*."

In the last decade, 10 Explorers were launched; 6 small explorers (SMEX) and 4 medium explorers (MIDEX). These have allowed NASA to respond quickly to new scientific and technical developments, and have produced transformational science, including:

- The best determination of the age of the universe: 13.7 billion years.
- Images of solar flares that show that ions and electrons are accelerated in different locations.
- The discovery of "baby" galaxies still in the process of forming, long after the vast majority of galaxies formed during the early universe.
- Measurements of record-speed solar winds (at ~5 million mph) from the large "Halloween" 2003 solar eruptions.
- The discovery that the plasmasphere rotates with the Earth at only 85-90% of the Earth's rotation rate as opposed to the 100% assumed by all models of magnetospheric convection.
- Direct evidence that galactic cosmic rays originate in associations of massive stars (where most supernovae occur).
- Proof that short-duration gamma-ray bursts (lasting less than 2 seconds) have a different origin than long bursts, likely resulting from the fiery mergers of binary neutron stars.
- These are a small fraction of highlights selected to illustrate the astounding breadth and productivity of the program.

The Explorer program has taken dramatic cuts in the last few budget cycles, resulting in:

- The cancellation—for purely budgetary reasons—of a peer-reviewed, selected mission, the *Nuclear Spectroscopic Telescope Array (NuSTAR)* SMEX, chosen (along with the *Interstellar Boundary Explorer (IBEX)*), from the 2002 announcement that solicited two flight missions.
- Delay in the next Announcement of Opportunity until mid 2008 at the soonest (associated mission launch beyond 2014).

The result is a minimum gap from 2008–2014 without any Explorer launch, in a program that is vital to both Heliophysics and Astrophysics, and which in the past has seen an average of one launch per year.

As noted in numerous NRC reports, in addition to its scientific importance, there are compelling programmatic, technical and educational reasons to maintain a line of small and moderate-sized competed missions. Explorers have strong involvement of the university community (eight of the ten most recent Explorers have been led by university scientists), and they provide an excellent training ground for young experimental researchers, scientists, engineers and managers, many of whom go on to play lead roles in large missions. The time from development to launch is consistent with PhD degree programs, as well as timescales for the career development of young professional scientists.

This decimation of the Explorer program will have a lasting and significant impact on the Nation's academic research base. Universities and research laboratories make significant internal investments in infrastructure to support experimental space science. Decisions on faculty and staff hires, on accepting graduate students, and the institutional investment in specialized laboratory facilities all depend on existence of a vital research and analysis (R&A) program, and opportunities to develop instrumentation for space flight. Both of these are threatened in the current NASA budget. In particular, the cancellation of missions after they have completed the arduous competitive process and been selected, as happened in the most recent budget process, is a particularly dangerous precedent. Universities, research laboratories, and their international collaborators necessarily rely on the well-established Explorer selection process in their decision to undertake such long term commitments. ***The precedent will be detrimental to the strong partnership between NASA and university researchers, a partnership that has been key to much of NASA's scientific productivity and has provided critical opportunities for developing scientists and engineers in experimental space science.***

Suborbital Sounding Rocket Program

Suborbital sounding rocket flights and high-altitude scientific balloons can provide a wide range of basic science that is important to meeting Heliophysics program objectives. For example, sounding rocket missions targeted at understanding specific solar phenomena and of the response of the upper atmosphere and ionosphere to those phenomena have potentially strong relevance. This science is cutting-edge, providing some of the highest-resolution measurements ever made and, in many cases, providing measurements that have never been made before.

The Suborbital program serves several important roles, including:

- Conducting important scientific measurements in support of orbital spaceflight missions,
- Providing a mechanism to develop and test new techniques and new spaceflight instruments, and
- Providing effective training to develop future experimental scientists and engineers.

Development of new scientific techniques, scientific instrumen-tation, and spacecraft technology is a key component of the Suborbital program. Many of the instruments flying today on satellites were first developed on sounding rockets or balloons. The low cost of sounding rocket access to space fosters innovation: instruments and technologies warrant further development before moving to satellite programs. Development of new instruments using the Suborbital program provides a cost-effective way of achieving high technical readiness levels with actual spaceflight heritage.

The fact that any long-term commitment to space exploration will place a concomitant demand on the availability of a highly trained technical work force makes the training role of the Suborbital program especially important. For example, a 3-year sounding rocket mission at a university provides an excellent research opportunity for a student to carry a project through all of its stages—from conception to hardware design to flight to data analysis and, finally, to the publication of the results. This "hands on" approach provides the student with invaluable experience in understanding the spaceflight mission as a whole. Indeed, over 350 Ph.D.s have been awarded as part of NASA's sounding rocket program. Not only have some of these scientists have gone on to successfully define, propose, and manage bigger missions such as Explorer, many more have brought valuable technical expertise to private industry and the government workforce.

NASA budgets for the Suborbital Sounding Rocket Program have remained flat. When one allows for inflation and the dramatically escalating launch costs, the net effect is a significant reduction in the capabilities of the program. ***Given the valuable educational, training and technology development roles of sounding rockets, any small saving derived from limiting this minor program has a major impact on future technical capabilities.***

Research and Analysis Programs

Research and Analysis (R&A, sometimes called Supporting Research and Technology SR&T) programs are crucial for understanding basic physical processes that occur throughout the Sun-heliosphere-planet system, and for providing valuable support to exploration missions. The objectives of R&A programs include:

- Synthesis and understanding of data gathered with spacecraft,
- Development of new instruments,
- Development of theoretical models and simulations, and
- Training of students at both graduate and undergraduate levels.

R&A programs support a wide range of research activities, including basic theory, numerical simulation and modeling, scientific analysis of spacecraft data, development of new instrument concepts and techniques, and laboratory measurements of relevant atomic and plasma parameters, all either as individual projects or, in the case of the SEC Theory program, via "critical mass" groups. Theory and modeling, combined with data analysis, are vital for relating observations to basic physics. Numerical modeling can also be a valuable tool for mission planning. Insights obtained from theory and modeling studies provide a conceptual framework for organizing and understanding measurements and observations, particularly when measurements are sparse and when spatial-temporal ambiguities exist. Theory and modeling will be especially important in the context of the space exploration initiative as exploration missions become more complex and the need for quantitative predictions becomes greater. ***These programs also are especially valuable for training students, at both the undergraduate and the graduate level, who will likely play a vital role in the NASA space exploration initiative or join the larger workforce as capable scientists/engineers/managers who cut their teeth on rigorous problems.***

NASA administration has suggested that the 2010 mission gap justifies an immediate 15% cut in R&A across the Science Mission Directorate. The high launch rate in 2006, the extensive list of on-going productive missions and the Nation's need for a technically-trained workforce all argue that R&A should be increased rather than cut.

When it comes to shear science productivity, R&A grants deliver the most "bang for the buck." These usually 3-year grants of ~$100k/year are highly competitive with only the very best 10-20% being selected via rigorous peer review. Even the most established scientists have to compete with everyone else. R&A programs provide the main basis of support for junior scientists – graduate students and post-doctoral researchers. ***Any cutbacks to R&A acutely impacts the most vulnerable and productive sector of space science.***

2. Do you believe the decisions NASA has made concerning which missions to defer or cancel are consistent with the most recent National Academies Decadal Survey that you released? Have there been any developments since the Decadal Survey that need to be taken into account, and has NASA considered those? Given the FY07 budget request, do you see any need to update the most recent survey or to change the process for the next Decadal Survey?

The 2004 NRC report, *Solar and Space Physics and Its Role in Exploration,* examined the 2002 Decadal Survey made the following three recommendations:

1. *To achieve the goals of the exploration vision there must be a robust SEC program, including both the LWS and the STP mission lines, that studies the heliospheric system as a whole and that incorporates a balance of applied and basic science.*
2. *The programs that underpin the LWS and STP mission lines—MO&DA, Explorers, the suborbital program, and SR&T—should continue at a pace and level that will ensure that they can fill their vital roles in SEC research.*
3. *The near-term priority and sequence of solar, heliospheric, and geospace missions should be maintained as recommended in the decadal survey report both for scientific reasons and for the purposes of the exploration vision.*

These recommendations remain valid today. The mission priorities within the basic science (STP) and applied science (LWS) mission lines as listed in the original Decadal Survey are generally reflected in the Heliophysics budgets for these two mission lines. Where NASA has deviated from the Decadal Survey is in putting greater weight on Living With a Star missions and losing the balance between applied and basic science. Such a priority of emphasizing short-term capability of predicting space weather over the long term goal of understanding the underlying physical principles may have some practical expedience. A more critical issue, however, is the fact that small missions and supporting research have not kept pace. If these programs—the components that comprise the third leg of the stool and the training grounds for new scientists and engineers—are allowed to wither, Heliophysics will quite quickly topple over.

The 2002 Decadal Survey, *The Sun to the Earth—and Beyond,* was the first conducted by the solar and space physics community (though smaller NRC committees have generated many shorter planning documents). The Decadal Survey involved hundreds of scientists in discussions that spanned nearly two years. The scientific priorities set out the survey remain valid today and I see no community movement to change them. But Decadal Surveys are not just a list of science priorities. To design a coherent program across a decade, it is essential to have a realistic budget profile as well reasonably accurate estimates of both technical readiness and costs of each mission. he Decadal Survey committee worked hard with engineers and NASA management to develop realistic mission costs and a program architecture that fit within budget profiles anticipated in FY03 budget. But changes to the budget profile in FY04 necessitated a substantial stretching of the mission schedule in the 2004 re-assessment of the Decadal Survey in light of the Vision for Space Exploration.[4] Furthermore, under-costing of just a few missions—Big Digs in space—wreck havoc with even the best-laid plans. The scientific community needs to work with NASA to find ways to accurately cost missions, particularly large missions (e.g., by applying lessons learned from management of smaller, PI-led missions as appropriate and greater accountability).

3. How should NASA balance priorities among the various disciplines supported by its Science Mission Directorate? Do you believe the proposed FY07 budget, given the overall level of spending allotted to science, does a good job of setting priorities across fields?

Each of NASA's scientific themes makes breakthrough discoveries that hit the press headlines. Rather than distinguish between them, I would argue that budget priorities be made within each division and, should a project exceeds its budget, any accommodation be made within the division. This would enforce accountability.

NASA conducts an outstanding program of scientific research within its Science Mission Directorate. The market place for scientific ideas—whether for a $100,000/yr research grant or a $1 billion mission—is a highly competitive world where only the very best ideas survive. NASA's science missions excite the public's interest in the universe around them, inspire young students to study math and science, and provide opportunities to generate a technically-trained workforce who contribute to the Nation's economy. Heliophysics not only has cultural and intellectual value but also adds practical and economic value as the Nation embarks on its next wave of space exploration.

[1] National Research Council, *The Sun to the Earth—and Beyond: A Decadal Strategy for Solar and Space Physics*, The National Academies Press, 2002.
[2] National Aeronautics and Space Administration, *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, DC., 2004.
[3] National Research Council, *Solar and Space Physics and Its Role in Space Exploration*, The National Academies Press, 2004.
[4] See charts on page 26 of Solar and Space Physics and Its Role in Space Exploration, The National Academies Press, 2004.

Statement of Wesley T. Huntress, Jr.

Geophysical Laboratory, Carnegie Institution of Washington

Mr. Chairman and Members of the Committee:

I am grateful for the opportunity to testify before you today. I have appeared before this Committee many times in my former job as the NASA Associate Administrator for Space Science, and few times since. I now appear before you to address concerns about the future of America's earth and space science in NASA's proposed FY07 budget.

The top line for NASA

I am an advocate for the scientific exploration of space—using both robotic and human elements—with the emphasis on *scientific* exploration. I also believe in the President's new Space Policy and that the CEV is the right way to start. But this FY07 budget proposes to implement the 2-year old Vision for Space Exploration without sufficient funding, and as a consequence does considerable damage to NASA's robotic, scientific exploration program. NASA's plans have been called Apollo on steroids, but the budget provided is Apollo on food stamps.

Two years ago when the President released his Vision, he provided an FY05 budget proposal with new funds in the five-year run out that would support it. In the intervening years, the Administration has reduced this budget to the point where the plan is insupportable. Last year, the Administration cut that budget, forcing the agency to take the money from aeronautics and technology funding. This year, the Administration has reduced the budget yet again, forcing the agency to take an even larger chunk of money from the only enterprise left undamaged in the agency—science.

The White House wants U.S. obligations to the international space station partners to be honored, the space shuttle flown as many times as necessary to complete the station's construction, and a replacement for the Shuttle (the Crew Exploration Vehicle, or CEV) flying by 2014. The only problem is that these requirements were handed to NASA without the $3 billion to $5 billion necessary for flying the required number of Shuttle flights to complete space station construction. This forced the NASA administrator to cannibalize the agency's science program even though he promised last year not to transfer "one thin dime" from scientific exploration into human spaceflight.

The President's Space Policy is not just about human space flight. The very first goal stated in the vision is to "implement a sustained and affordable human and robotic program to explore the solar system and beyond." The vision further advocates that we "conduct robotic exploration across the solar system for scientific purposes and to support human exploration." This eye of the vision seems to have lost its sight.

The top line for NASA Science

The Administration's 2007 budget proposal removes $3.07 billion from the previously planned 5-year run out of the Earth and space science budget. Of this, $2.99 billion is to come from solar system exploration alone. Of the several disciplines in earth and space science, solar system exploration alone is to pay 97% of the bill for the Shuttle even though robotic exploration of the solar system is one of the most relevant of science enterprises to human exploration.

This simply cannot be done without serious damage to an enterprise and community that should, and needs to be, a partner with human exploration.

NASA officials attempt to put positive spin on this damage by citing the growth of space science in NASA from about 21 percent of the budget in 1992 to 32 percent today. But, during that same time period space science has been carrying the agency exploration flag, and the agency has been rightly proud of the productivity of the Earth and space sciences. Missions such as Hubble, Mars Exploration Rovers and Cassini/Huygens are, as Administrator Griffin himself said, the "crown jewels" of NASA. Yet he has set NASA science on a declining course, not even keeping up with the projected growth in the rest of the agency over the next five years.

Does it make good business sense to damage the most productive enterprise in your portfolio to promote a poorly performing one that you firmly expect to terminate in five years?

The President wants to grow Federal investment in science

The President's arguments on the need to increase Federal support of the physical sciences are particularly true of NASA science. Space exploration is an enormous draw to young people. This Nation never saw such an increase in new science graduates than after the start of the Space Age in 1957. Now, at the start of the President's new Vision for Space Exploration, we are doing everything we can to turn off brilliant young earth and space scientists by pulling the rug out from their prospects for the future.

The FY07 budget proposal and the NRC's Solar System Decadal Report

The FY07 budget proposal does serious damage to the course set for the Nation's solar system exploration enterprise in the NRC's Solar System Decadal Report through its recommendations for research, technology and flight missions. This National Academy report establishes the scientific goals for robotic solar system exploration for the decade 2003-2012, the measurements at solar system destinations required to meet those science goals, and the flight missions necessary to travel to these destinations. The report also makes recommendations on the basic research and technology developments required to support those flight missions and to prepare for future missions beyond the next decade.

Depleting the Science Pool

NASA's earth and space science enterprise is not just about flight missions. It is foremost about science. Flight missions are the tools for conducting that science—for implementing scientific exploration of our solar system and beyond. Science flight missions are not furnished by the government to the science community; they are created by the science community. Scientists constantly generate new science questions from their research and from previous mission results. They then devise the measurements that need to be made in order to answer those questions. And finally they work with the engineers to create flight mission concepts to make those measurements at solar system destinations. These scientists are spread throughout the country, conducting their basic research in universities, research centers and NASA Centers. They are supported primarily by NASA research grants in what's known as Research and Analysis programs, or R&A, and by grants for mission data analysis also now covered in the R&A portion of the SMD budget.

While the 2003 Solar System Decadal Report recommends that R&A be increased over this decade at a rate above inflation, the FY07 budget would reduce funding for R&A by 15% across the board. For reasons hard to fathom, one particular program, Astrobiology, is targeted for a 50-percent reduction. Astrobiology was specifically named by the Decadal report as an important new component in the R&A program and is recognized even outside NASA as the agency's newest and most innovative research program bringing biologists, geologists and space scientists together to understand the earliest life on Earth and how we might search for life elsewhere beyond our own planet. The consequences of these unprecedented reductions would be to cripple the ability of NASA's science enterprise to create the next generation flight missions and worse of all it will short-circuit the careers of many young scientists. Precisely the opposite of what this country needs to remain competitive.

And all these cuts are immediate—today, in the 2006 budget year. Grants are to be reduced immediately, dimming the prospects of many young, motivated students now. What kind of message is that to the best and brightest of American's hopes for a rich technological future? And if there is to be any science at all in human space flight to the Moon and beyond, it needs to come from these young people.

Reducing Flight Missions

The Decadal Report also prioritizes the flight missions proposed for the next decade within separate cost categories—small, medium and large. For small missions, the report assumes a Discovery program of low cost, competed missions at a rate of about one launch per 18 months or about 6 per decade, and for the Discovery-like Mars Scouts about 3 launches per decade. Both of these assumptions are based on their historical annual budget levels.

For medium class missions, the report assumes a New Frontiers program of competed missions at a rate of about 3 per decade. This is the rate established for the New Frontiers line when it was opened with the Pluto/Kuiper Belt mission. For large, flagship missions, the report assumes 1 per decade based on historical data for new starts in this category (Viking in the 1970s, Galileo in the 1980s, and Cassini- Huygens in the 1990s).

For the Mars Exploration flight program, the Decadal report assumed approximately two launches every 26 months, either two medium class launches or one medium and one small Mars Scout mission depending on timing and cost for the specific missions. This was based on the annual funding level for Mars Exploration in 2003.

The major damage in the FY07 budget to solar system flight missions is to the Mars and the Outer Planets flight programs. Mars flight missions are reduced from a nominal 2 launches per opportunity to only 1, and the number of medium missions is reduced by alternating launch opportunities between medium and small. Two Mars Scouts are eliminated, technology developments for missions beyond 2009 are reduced, and developments for a potential Mars Sample Return mission in the next decade practically eliminated. All of this will hobble our search for signs of past water and perhaps early life on our next-door neighbor.

For the Outer Planets flight program, the Europa Orbiter mission, only flagship mission and the highest science priority, is deferred to the next decade. For the first time in 4 decades there will be no solar system flagship mission at all. For science, we will remain ignorant that much longer of Europa's deep ocean and the potential for life within it. The Discovery program of small missions is already in prolonged delay and there will be no launch until the end of the decade, for a hiatus of more than four years since the last. And the third New Frontiers mission selection is delayed by about a year. The inevitable result of these delays and deletions is the potential loss of technological expertise to conduct these missions. Young scientists and engineers will be forced to look elsewhere for a more reliable, sustainable career path. It is not possible to retain the best of people if there is a lack of stability and a no clear sense of a strong future. You can't have world-class flight missions without world-class people.

Tossing Technology

For this reason, more than the flight mission delays themselves, a failure to continue to develop the technologies required for accomplishing future missions short circuits the future. Sustaining funding for technology development is the key to surviving hard times in flight mission development and guaranteeing a future. This budget does just the opposite.

Concern for the future

The bottom line is that the future of our Nation's solar system exploration enterprise has been mortgaged. The momentum of current mission development will carry it for about two years, and then the bottom begins to fall. We must sustain the science and technology that will afford us a new future when we get there two years from now.

Consistent with the NRC Decadal study, the most important elements to sustain the enterprise are the fundamental research programs that form the basis for solar system exploration and the lowest cost, highest flight rate, widely competed flight programs in the small to medium flight mission lines. And if we are ever to recover, we must also invest in our technological readiness for flagship missions in the future.

Is this the best Vision?

The Vision is about robots and humans exploring to find our destiny in the solar system together. Instead of drawing on the strengths of both, this budget pits one vs. the other and undermines the Vision rather than promoting it. It pawns a planetary exploration program that is the envy of the world to pay for a program beset with problems and slated for termination.

The Administrator's budget message said about the Vision, "we will go as we can afford to pay." But the only way he can pay is by taking resources from the future of science and robotic exploration. If these annual reductions in NASA's budget continue, and if NASA continues to drain resources from science and technology, then America can retire as the leading nation in the scientific exploration of space, whether by robots or by humans.

Statement of Berrien Moore III, Ph.D.
University Distinguished Professor
Director of the Institute for the Study of Earth, Oceans, and Space, University of New Hampshire
and Co-Chair, Committee on Earth Science and Applications from Space,
National Research Council, The National Academies

Mr. Chairman, Ranking Minority Member, and members of the committee: thank you for inviting me here to testify today. My name is Berrien Moore, and I am a professor of systems research at the University of New Hampshire and Director of the Institute for the Study of Earth, Oceans, and Space. I appear today largely in my capacity as co-chair of the National Research Council (NRC)'s Committee on Earth Science and Applications from Space.[1] The views expressed in today's testimony are my own, but I believe they reflect community concerns. They are also fully supported by my co-chair for the NRC study, Dr. Richard Anthes, President of the University Corporation for Atmospheric Research (UCAR) and President-elect of the American Meteorological Society.

As you know, the NRC is the unit of the National Academies that is responsible for organizing independent advisory studies for the federal government on science and technology. In response to requests from NASA, NOAA, and the USGS, the National Research Council has begun a "decadal survey" of Earth science and applications from space which is due to be completed in late 2006. The guiding principle for the study, which was developed in consultation with members of the Earth science community, is to set an agenda for Earth science and applications from space, including everything from short-term needs for information, such as environmental warnings for protection of life and property, to longer-term scientific understanding that is essential for understanding our planet and is the lifeblood of future societal applications.

The NRC has been conducting decadal strategy surveys in astronomy for four decades, but it has only started to do them in other areas fairly recently. This is the first decadal survey in Earth science and applications from space.

Among the key tasks in the charge to the decadal survey committee is the request to:

- Develop a consensus of the top-level scientific questions that should provide the focus for Earth and environmental observations in the period 2005-2020; and
- Develop a prioritized list of recommended space programs, missions, and supporting activities to address these questions.

Recognizing the near-term challenges likely for FY2006 and FY2007, the sponsors of the decadal study requested an examination of urgent issues that required attention prior to publication of the survey committee's final report, which was scheduled for publication in the fall of 2006. The committee's "Interim Report," "Earth Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation," was delivered to the sponsors and briefed to this Committee on 28 April 2005.[2]

In the Interim Report, we stated that the nation's "system of environmental satellites is at risk of collapse." That statement, which may have seemed somewhat extreme at the time, was made before Hydros and Deep Space Climate Observatory missions were cancelled; before the Global Precipitation Mission was delayed for two and a half years; before the NPOESS Preparatory Program mission was delayed for a year and a half; before the NPOESS program breached the Nunn-McCurdy budget cap and was delayed for at least several years, and before significant cuts were made to NASA's Research and Analysis account. In less than a year since our Interim Report was issued, matters have gotten progressively worse.

It is against this backdrop that I turn to the Committee's questions.

What do you see as the most serious impacts on your field of the proposed slowed growth in the Science Mission Directorate? Clearly, it would be better to conduct more science than less, but what is the real harm in delaying specific missions? At what point do delays or cutbacks become severe enough to make it difficult to retain or attract scientists or engineers to your field?

The most serious impacts on Earth Sciences of the proposed slowed growth in the Science Mission Directorate are the severe cuts in the Research and Analysis program. These cuts would be very damaging to the science and technology programs in the United States, particularly those at universities. We all know that our country is struggling to attract students to physics and mathematics. In the State of the Union address, President Bush proposed, "to double the federal commitment to the most critical basic research programs in the physical sciences over the next 10 years." The President's proposal was part of a larger effort to "encourage children to take more math and science, and to make sure those courses are rigorous enough to compete with other nations." In my view, the cuts to NASA's Research and Analysis program in Earth Science are at odds with these objectives.

The numerous mission cancellations, deferrals, and de-scoping that have occurred in the previous 2 budget cycles have already had a severe detrimental effect on NASA Earth science. The table below, which is taken from the Interim Report, shows just the effects of the FY2006 budget.[3] I am concerned that the new cuts in the FY2007 budget, especially the significant reductions in funding for Research and Analysis, could have a devastating effect on a program already pared to the bone.

For example, it is my understanding that approximately half of the NASA Goddard Spaceflight Center's workforce is made up of contractors. The proposed cuts across NASA for Research and Analysis funding are approximately 15%. In the Earth sciences, I am told that the cuts for FY2007 appear to be closer to 20% in key elements. Since Goddard cannot reduce its civil service workforce, this cut will be magnified by a factor of 2 on the contractor workforce. The current contractor workforce is about 300 people and thus up to 120 people could be let go. A similar impact is likely at universities, especially as NASA will have to pay its civil servants first. Research and analysis grants will be cut; members of the community are concerned that grants already awarded might be withdrawn.

Because of the nature of the competitive process, universities, industry, and NASA centers must invest significant internal funds to prepare proposals that are compelling scientifically. Prematurely cutting missions or research awards for non-technical or cost reasons or eliminating grants after they have been awarded will have permanent, damaging consequences. The scientific community is beginning to question the reliability of NASA as a partner, and the wisdom of investing internal resources in the proposal development process.

Another impact is to reduce scientific research on missions that have already been launched and are providing novel observations of the Earth with unprecedented opportunities to learn about our planet. Cutting the research after all of the expense of building and launching the missions means that much of the up-front, and most expensive part of the mission will be wasted.

While I understand that NASA is facing difficult budgetary decisions, and priorities must be set, it would be a severe blow to NASA science to allow the R&A awards to be cut—especially given the already large investment in missions and the relatively low-cost, productive, and unique scientific understandings that result from these awards.

I shall return to this topic in answering your second question, but first let me address the other two components of the Committee's first question: the impact of mission delays and retaining or attracting scientists and engineers.

The impact of added delays are two-fold: (1) There will be increased costs downstream that will further undermine the possibilities for a revitalized future Earth science program, and (2) There will be continued nega-

TABLE 7.1 Canceled, Descoped, or Delayed Earth Observation Missions (from the April 2005 Interim Report of the Decadal Survey)

Mission	Measurement	Societal Benefit	Status
Global Precipitation Measurement (GPM)	Precipitation	Reduced vulnerability to floods and droughts; improved capability to manage water resources in arid regions; improved forecasts of hurricanes	Delayed
Atmospheric Soundings from Geostationary Orbit (GIFTS—Geostationary Imaging Fourier Transform Spectrometer)	Temperature and water vapor	Protection of life and property through improved weather forecasts and severe storm warnings	Canceled
Ocean Vector Winds (active scatterometer follow-on to QuikSCAT)	Wind speed and direction near the ocean surface	Improved severe weather warnings to ships at sea; improved crop planning and yields through better predictions of El Niño	Canceled
Landsat Data Continuity—bridge mission (to fill gap between Landsat-7 and NPOESS)	Land cover	Monitoring of deforestation; identification of mineral resources; tracking of the conversion of agricultural land to other uses	Canceled
Glory	Optical properties of aerosols; solar irradiance	Improved scientific understanding of factors that force climate change	Canceled
Wide Swath Ocean Altimeter (on the Ocean Surface Topography Mission; OSTM) Mission; OSTM)	Sea level in two dimensions	Monitoring of coastal currents, eddies, and tides, all of which affect fisheries, navigation, and ocean climate	Instrument canceled—descope of an enhanced OSTM

tive impact on the morale of scientists within and outside of NASA. The importance of this impact should not be underestimated.

As this committee knows, procurement stretch-outs always increase overall program costs. Moreover, moving costs forward in time for current missions in development means that there is less "out-year" money for the future. Once again, we are mortgaging our future. In addition, delays often mean the penalties of missed synergies and gaps in observations associated with delay in execution.

For example, the 2-year delay in the Global Precipitation Mission (GPM) will create a gap between its operation and that of the Tropical Rainfall Measurement Mission (TRMM), whose science operations were extended last year in part because of their valuable role in meteorological forecasts of severe weather events. The delay of GPM also endangers a carefully planned partnership with the Japanese space agency, JAXA.[4] Goddard will also be challenged to maintain a viable mission given a flat funding profile for GPM from FY2006 through FY08. Project scientists are rightfully concerned that the 2-year delay in GPM threatens the viability of the mission.

However, I am equally concerned about the impact of program delays on the morale of scientists within and outside of NASA and the health of the specialized workforce that is necessary to maintain core competencies. From personal conversations and anecdotal reports, the sense of gloom and discouragement is widespread, and this is obviously connected to your important question, "At what point do delays or cutbacks become severe enough to make it difficult to retain or attract scientists or engineers to your field?" In my view, we are well past that point—the prior deterioration of the NASA Earth Science program, which was discussed in the Interim Report, has already had an adverse impact on our ability to attract scientists or engineers. This situation will only grow worse unless there are significant improvements to the FY2007 budget proposal.

Do you believe the decisions NASA has made concerning which missions to defer or cancel are consistent with the interim report of the National Academies Decadal Survey that you released? Given the FY2007 budget request, do you see any need to change the process for the next Decadal Survey?

The budget is inconsistent with the Interim Report. This is the real issue.

The Interim Report endorsed the Hydros Mission; subsequently but before the FY2007 budget was released, Hydros was cancelled. So was the Deep Space Climate Observatory, which was not addressed by the Interim Report, but had been supported by an earlier panel of the Academy.[5] The Interim Report stated that the Global Precipitation Mission should "proceed immediately and without further delay." The NASA FY2007 action delays the mission by two and a half years.

The Interim Report not only recommended that NASA and NOAA complete the fabrication, testing, and space qualification of the atmospheric soundings from geostationary orbit instrument (GIFTS--Geostationary Imaging Fourier Transform Spectrometer), but it also recommended that they support the international effort to launch this instrument by 2008. While NOAA has completed some of the space qualification of GIFTS, the FY2007 budget does not provide the additional funding that would be necessary to complete GIFTS.

The Interim Report also asked for studies regarding linking of NASA missions and plans and the NPOESS program in several key measurement areas: ocean vector winds, atmospheric aerosols, solar irradiance. We also requested an analysis of the capabilities of the then planned NPOESS Operational Land Imager (OLI) to execute the LandSat Data Continuity Mission. We have not received these studies, though we recognize that events subsequent to the publication of our report have altered the circumstances for some of the requests. However, I believe that the need for such studies has increased given the budget challenges for NASA and NOAA, the delay, cost growth, and likely changes to NPOESS, and the delay and changing ideas for the development of an operational land imaging capability and implementation of the LDCM.

The Interim Report called for the release of the next Announcement of Opportunity (AO) for the Earth System Science Pathfinder (ESSP) program in FY 2005; we understand that the earliest AO for the next ESSP will be FY 2008.

Finally, in closing my April 2005 testimony before this Committee**,** I stated that the Decadal Survey Committee was "concerned about diminished resources for the research and analysis (R&A) programs that sustain the interpretation of Earth science data. Because the R&A programs are carried out largely through the Nation's research universities, there will be an immediate and deleterious impact on graduate student, postdoctoral, and faculty research support. The long-term consequence will be a diminished ability to attract and retain students interested in using and developing Earth observations. Taken together, these developments jeopardize U.S. leadership in both Earth science and Earth observations, and they undermine the vitality of the government-university-private sector partnership that has made so many contributions to society." Unfortunately, the FY2007 budget for Earth Science reflects cuts of 15% or more in the overall R&A program for Earth Science. We are headed in the wrong direction.

How should NASA balance priorities among the various disciplines supported by its Science Mission Directorate? Do you believe the proposed FY2007 budget, given the overall level of spending allotted to science, does a good job of setting priorities across fields?

As noted above, NASA's science programs have already sustained deep cuts in the last two budget cycles. Exacerbating the cuts is the recent and not widely reported downward modifications to the Operating Plan for FY2006. These cuts, which were submittedafter the release of the FY2007 budget, make the proposed FY2007 budget cuts retroactive to the beginning of FY2006. The timing of the cuts makes their effect more severe; it also masks the magnitude of what is an enormous cut to the FY2007 budget (because the comparison of FY07 to FY06 is now made with new, reduced FY2006). Budget analyses that do not account for these recent changes leave the impression that the NASA Earth Science research budget is flat when in fact it has been decimated.

In response to the committee's question above: Budget priorities at NASA must be balanced to reflect the highest priorities of the four decadal surveys. The scientific community recognizes that much will not be accomplished in our current budget environment, but we must seek to realize the highest priority elements. I strongly support the FY2006 Authorizing language charging the NASA Administrator "to develop a plan to guide the science programs of NASA through 2016."

Let me conclude my testimony by stating my strong support, which I did publicly at the December 2005 meeting of the AGU, for the new leadership at NASA. I believe that the science community as a whole is also strongly supportive of the new leadership. However, NASA is now being directed to do more than is possible with the resources it has been given. I believe the health of science programs at NASA, which less than 3 months ago were said to be protected by a "firewall" from obligations to complete the ISS, develop the CEV, and return the Shuttle to flight, is in peril. Simply stated, given the NASA “bottom line” budget number and the “demands” of Station, Shuttle, and Exploration, there is far less room ($3.1 billion less in the next 5 years) for science.

Further, one can be reasonably sure that the pressure on science to fund under-budgeted parts of NASA flight programs will only increase—few, if any, large and complex technology development projects come in under budget. While not the subject of this hearing, this situation begs for an honest appraisal of NASA’s portfolio, its priorities, and whether the Nation can afford to allow NASA science programs to languish.

I look forward to answering any questions you may have. Thank you.

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[1]<http://qp.nas.edu/decadalsurvey>.

[2]National Research Council, *Science and Applications from Space: Urgent Needs and Opportunities to Serve the Nation*, The National Academies Press, 2005. < http://www.nap.edu/catalog/11281.html>.

[3]Ibid, page 17. Note that the Glory mission was subsequently restored. The latest plan for LDCM is to implement the mission as a free-flyer with a launch in 2011.

[4]Among other items, JAXA is developing the dual-frequency precipitation radar that is at the heart of the GPM mission.

[5]National Research Council, *Review of Scientific Aspects of the NASA Triana Mission: Letter Report*, National Academies Press, 2000. <http://www.nap.edu/catalog/9789.html>.

7.2 NASA Budget and Programs: Outside Perspectives

Senate Commerce Committee
June 7, 2006

Statement by James A. Pawelczyk, Ph.D.
Associate Professor of Physiology, Kinesiology and Medicine, Pennsylvania State University

Abstract

At the midpoint between the Apollo program and a human trip to Mars, NASA's recent reductions to scientific funding are unprecedented. In particular, the thoughtfully conceived architecture to explore the Moon, Mars and beyond has produced large reallocations of research funding that jeopardizes the stability and future of space life sciences. Given current budgets, NASA does not appear to have sufficient resources to fully engage the help of the external science community to complete the President's Vision for Space Exploration.

Madame Chairperson and Members of the Committee:

Good afternoon. I thank you for the opportunity to discuss the changes NASA has made to its research funding. I have been a life sciences researcher for 20 years, competing successfully for the past 13 years for grants from NASA. From 1996-1998 I took leave from my academic position at The Pennsylvania State University to serve as a payload specialist astronaut, or guest researcher, on the STS-90 Neurolab Spacelab mission, which flew on the space shuttle Columbia in 1998. Since Neurolab I have had the privilege to serve as a member of NASA's Research Maximization and Prioritization (ReMAP) Taskforce. More recently I helped evaluate NASA's Bioastronautics Research Program for the Institute of Medicine, NASA's International Space Station Research Plan for the National Research Council, and the progress of the National Space Biomedical Research Institute (NSBRI).

During a January 19, 2006 interview with the Orlando Sentinel, Mr. Griffin shared his thoughts about his first 9 months in the position of NASA Administrator. When asked about the lessons learned from the Challenger and Columbia accidents, he stated the following:

> If you spend much time on this stuff and aviation accidents, a common theme is that of not listening to the signals the hardware is sending—the test results, the flight results, *the dissenting opinions of the people involved*. So a common theme is not listening. And I don't mean actively shutting out. I mean being so focused on what we're trying to do that *we're not aware of what nature is telling us* [emphasis added].

Those insights are remarkably prophetic, and today I find myself before you as one of those dissenters. I share Mr. Griffin's passion for the human exploration of space, but I must conclude with equal conviction that biological adaptation is a serious risk to an extended human presence in space, and that the scientific research necessary to ensure the health and safety of future astronaut crews beyond low-earth orbit is far from complete.

ReMAP—antecedent to the Vision for Space Exploration

For several years, NASA has recognized and responded to its need to complete necessary research in a fiscally responsible manner. In the spring and summer of 2002 NASA launched the Research Maximization and Prioritization Task Force, commonly known as ReMAP. Chaired by Rae Silver of Columbia University, the Task Force included two National Medal of Science awardees, one Nobel Prize winner, and more than a dozen members of the National Academy of Sciences, representing the breadth of translational research in the biological and physical sciences.

ReMAP was asked to prioritize 41 areas of research in the former Office of Biological and Physical Research.

What was unique to ReMAP was our challenge to consider both the physical sciences and biological sciences simultaneously. This resulted in spirited debate and intellectual foment of the highest caliber. When we completed our task, highest priority was assigned to 13 areas that informed two broad, often overlapping, goals: One is the category of intrinsic scientific importance or impact; research that illuminates our place in the universe, but cannot be accomplished in a terrestrial environment. The other goal values research that enables long-term human exploration of space beyond low-earth orbit, and develops effective countermeasures to mitigate the potentially damaging effects of long-term exposure to the space environment. It should be no surprise to you that over the past 17 years other review panels, both internal and external to NASA, have named similar goals.

The Task Force wrestled with the question whether one goal could be prioritized over the other. In the history of the United States space program both goals have been important, though their relative importance has changed over time. The limited amount of biological and physical research that occurred during early space exploration, particularly the Apollo era, focused on the health and safety of astronaut crews in a microgravity environment. Significant research questions that did not contribute directly to a successful Moon landing received lower priority. In contrast, more regular access to space provided by the space shuttle afforded an opportunity for "basic" research to take higher priority; the proliferation of space based research in the physical and biological sciences over the past twenty years is a testament to this fact.

Thus, the relative priority of these two goals of research—enabling long-term human exploration of space and answering questions of intrinsic scientific merit—has shifted during NASA's history. This conclusion is critical, as it suggests that one goal can receive higher priority over the other, though this ranking may change depending on NASA's definition of programmatic needs at a particular point in time.

When the President announced the Vision for Space Exploration in January of 2004, the relative balance between these two categories of research changed again. Items in NASA's research portfolio that most contributed to exploration goals would take precedence over experiments with intrinsic scientific importance and impact, and substantial realignment has occurred as a result. At the same time, the Office of Biological and Physical Research, the entity responsible for funding biological and physical research at NASA, was absorbed into the Exploration Systems Mission Directorate.

I share Mr. Griffin's view that aligning research with exploration goals is a good thing. However, naïve or wholesale elimination of scientific themes is not, and biological and physical research has certainly suffered from this effect. To the alarm of the scientific community, the process that began with ReMAP has taken a dangerous turn. Areas that we rated as highest priority, including those that contribute to exploration goals, have been de-scoped or eliminated completely.

Where is "science" at NASA today?

In many ways, the reorganization of "science" at NASA orphaned biology, and I encourage caution when you and your colleagues use the term in your discussions. Logically, "science" would seem an appropriate, generic label for research activities that occur throughout the agency. However, within NASA it appears to have a more specific meaning, often referring exclusively to the activities funded by the Science Mission Directorate, which includes the following disciplines only:

- Astrophysics—the study of matter and energy in outer space.
- Earth Science—the study of the origins and structure of our planet.
- Heliophysics—the study of planets, interplanetary space, and the sun.
- Planetary Science—the study of the origins, structure, and features of planets beyond our own.

Please note that the term, "biology," or the study of life, does not appear at all. To my more skeptical colleagues, the science of biology is disappearing at NASA.

The available evidence provides some support for this conclusion. While the Science Mission Directorate has suffered modest cuts, over the past two years, funding for biological and physical research (i.e., science not managed by the Science Mission Directorate) has decreased almost 75%, from $1,049M in FY05 to $274M in the FY07 Budget Summit. This includes the cancellation of virtually all research equipment for the International Space Station that supports animals and plants, the elimination of 20% of the funding for external research grants, and the premature termination of 84% of these grants. Approximately 500 life science graduate students in 25 states will be affected.

The next generations of space life scientists perceive a bitter lesson that is difficult to assuage: as the result of a shell game of agency-wide reorganization, life science is no longer recognized or valued within NASA.

Biological research is essential and obligatory to the Vision for Space Exploration

I wholeheartedly endorse the President's goal to return humans to the Moon and Mars, but the current reductions in biological research funding appear sorely at odds with this goal. Simply put, the biological risks associated with exploration-class spaceflight are far from being mitigated.

This conclusion is based on analysis of 30 years of NASA-sponsored research. Since the days of Skylab NASA-funded investigators conducted an aggressive and successful biological research program that was robust, comprehensive, and internationally recognized. Beginning with those early efforts, and continuing with our international partners on the *Mir* and the International Space Station, we have built a knowledge base that defines the rate at which humans adapt during spaceflight up to six-months duration, with four data points exceeding one-year duration.

Musculoskeletal deconditioning remains a paramount concern. In the past two years our ability to differentiate the trabecular bone network in the hip has helped us to appreciate that the risk to bone during spaceflight may be even greater than we previously anticipated. The rate of osteoporosis in astronauts equal patients with spinal cord injury, and exceeds that seen in post-menopausal women by a factor of 10 or more. Extrapolating from published studies of astronauts and cosmonauts spending up to six months in low-earth orbit, we can offer preliminary estimates of the changes that would occur if humans made a 30-month trip to Mars today:

- 100% of crew members would lose more than 15% of their bone mineral in the femur and hip
- Approximately 80% would lose more than 25% of their bone mineral
- More than 40% would lose greater than 50% of their bone mineral
- Approximately 20% would lose more than 25% of their exercise capacity
- Approximately 40% would lose experience a decline in leg muscle strength of 30% or more

Each of these predictions takes into the account the fact that astronauts would be using the best countermeasures available currently! To my knowledge, no engineer would accept a spaceflight system where such degradation is expected. Nor should it be so for astronauts.

What is the status of NASA's human biological risk mitigation plan?

In 2005 NASA's Chief Medical Officer asked the Institute of Medicine to evaluate NASA's Bioastronautics Roadmap, the comprehensive plan to document and reduce the biological risks to human spaceflight. Despite the alarming data I just described to you, we found that concern for these risks varied widely among astronauts, flight surgeons, and mid-level management. None of the 183 proposed risk mitigation strategies had been implemented for spaceflight, and approximately 2/3 of these strategies were considered to be so incompletely developed that they would not be addressed further.

In his 2001 book, Enlightened Experimentation: The New Imperative for Innovation, Harvard Business professor Stefan Thomke offered the following four rules for enlightened experimentation: organize for rapid experimentation; fail early and often, but avoid mistakes; anticipate and exploit early information; and combine new and old technologies. While these principles are recognizable in NASA's Constellation System architecture, they are wholly absent in the implementation of NASA's Bioastronautics Roadmap.

We desperately need to increase human capabilities in space by translating findings from cell culture to reference organisms and mammalian models such as mice and rats to future flight crews. Translational research is the "gold standard" of the NIH, and it is what the research community, and the American people, should expect from the International Space Station. We need the capability to house and test model organisms on the ISS. But equally important, we need adequate time for crew to prepare and conduct these experiments, and that time can be found only when the ISS moves beyond the core complete configuration. The potential return is immense; the application of this research to our aging public could become one of the most important justifications for an extended human presence in space.

Challenges for the future

Earlier this year, Congress received The National Research Council's review of NASA's plans for the International Space Station, which identified several serious concerns about NASA's prioritization process for current and planned life and physical sciences research.

First, allocations to research did not appear to be based on risk, but convenience. Second, little emphasis was given to future lunar or Martian outposts, opting instead for short stays on the Moon. Third, the current ISS payload and the processes used to prioritize research areas appeared to be neither aligned with exploration mission needs nor sufficiently refined to evaluate individual experiments. Finally, no process was in place to plan or integrate future research needs that may not be recognized currently.

To restore scientific credibility at NASA, a coordinated strategy is necessary. I offer several recommendations for your consideration:

- First, add sufficient funding to NASA's budget, both to answer the questions essential to the Vision for Space Exploration and to replace the Space Shuttle in a timely fashion. An addition of $150M would restore biological funding to the level of the President's FY06 budget request, but a minimal biological research program, directed primarily to external investigators, could be conducted with the addition of approximately $50M/year.
- Second, articulate a timeframe for delivering and completing a risk mitigation plan for humans exploring the Moon and Mars, and vet both the plan and the timeframe with the external scientific community.
- Third, develop a comprehensive plan for conducting research on board the International Space Station without the space shuttle, including addition of essential equipment for animal research, deployment of a crew of at least six people, and logistics that are sufficient to keep these crews safe and supplied.
- Finally, establish sufficient oversight to hold NASA accountable to these goals.

Madame Chairperson, members of the committee, make no mistake about this: in the long-term, we are retaining and accumulating human risk to spaceflight in order to progress with an under-funded Vision for Space Exploration. We have an ethical obligation to our current and future space explorers, and to the American public, to do better. Given sufficient resources, I remain optimistic that NASA can deliver the rigorous translational research program that the scientific community expects, and the American people deserve. I sincerely thank you for your vigilant support of the nation's space program, and the opportunity to appear before you today.

Written Testimony of Peter W. Voorhees

Department of Materials Science and Engineering, Northwestern University

Introduction

Chairwoman Hutchison, Ranking Member Nelson, and members of the committee, thank you for inviting me to testify today. My name is Peter Voorhees. I am the Frank C. Engelhart Professor and Chair of the Department of Materials Science and Engineering at Northwestern University. I was a member of the National Research Council Space Studies Board and Chair of the Committee for Microgravity Research. Through my tenure as Chair I have become familiar with the microgravity program and many of the areas within the physical sciences that are at the core of NASA's human exploration effort.

I believe that a strong physical sciences research program is crucial to both capitalizing on NASA's significant past investment in this area and to enabling the human spaceflight program. In 2004 President Bush provided a clear vision for NASA's human spaceflight effort and NASA has fully embraced the goal of returning humans to the Moon and eventually sending humans to Mars. However, to accomplish these goals research in the physical sciences is necessary to gain a more complete understanding of effects of microgravity on a wide range of processes as well as develop a variety of technologies to ensure the safety and success of these missions. Only by supporting an ongoing physical sciences research program will NASA be able to avoid failures that could have been anticipated by an ongoing physical sciences research program and to implement the President's vision in the most cost-effective and rapid fashion.

The Development of the Physical Sciences Research Program

The evolution of NASA's physical sciences research program provides important lessons for how to formulate a successful research program to enable human space exploration. NASA's physical sciences research program began as the materials processing in space effort during the Skylab era. The program was singularly focused on performing experiments in space. As a result, many of the experiments were ill-conceived and few yielded new insights into the physical phenomena that were operative in space or impacted their respective scientific communities. In the early 1990s a new paradigm for research was initiated in the fluids, materials, combustion and fundamental physics research areas. In order to attract the best researchers, a concentrated out-reach effort was undertaken and a rigorous peer review system was instituted. In addition, a large ground-based research program was created that ensured that ideas were refined and scientific questions identified that could be answered only through space flight experiments. As a result the "shoot and look" approach to performing experiments during the Skylab era was replaced by carefully conceived hypothesis driven experiments. At its peak there were approximately 500 investigators in the program and it supported 1700 research students.

The 2003 National Research Council (NRC) study "Assessment of the Directions in Microgravity and Physical Sciences Research" found the quality of the investigators in the program to be excellent. On the basis of an analysis of the citations of the papers published, prominence of journals in which the papers appeared, the influence of the research on the content of textbooks, documented influence on industry and the quality of the investigators in the program, we found that the microgravity program has had a significant impact on the fields of which it was a part. For example, 37 members of the fluids program were fellows of the American Physical Society, the materials science program produced some of the most highly cited papers in the area of solidification and crystal growth, and the fundamental physics program was funding six Nobel laureates. Many billions of dollars were invested in creating this successful and influential program.

NASA should take great pride in the creation of this high quality physical sciences research program in the fluids, combustion, materials and fundamental physics areas. It evolved into one of the jewels in NASA's crown. With the growth in the quality of the program NASA became the primary source of funding for research in areas such as crystal growth, low temperature physics, and low Reynolds number and interfacial fluid flow making NASA stewards of these important and broad scientific areas.

In early 2001 it became apparent that the International Space Station (ISS) program was facing major cost overruns. These financial constraints led to a major reduction in the microgravity research that had been planned for the ISS. Many of the experimental facilities that were planned were either reduced in size or delayed and the number of crew aboard the ISS was cut, making it difficult to perform experiments during the construction phase of the project. As a result, flight experiments were delayed or effectively cancelled. The catastrophic loss of the Columbia orbiter in 2003 placed even more serve restrictions on the ability to transport samples and experimental equipment to and from the ISS.

The challenges posed by these recent events, the need to retire the Shuttle by 2010, as well as develop the Crew Exploration Vehicle have placed great pressures on NASA's budget. These financial constraints have resulted in a major reduction in the size and scope of the physical sciences research program. For example, with breathtaking speed and no external input NASA eliminated the Office of Biological and Physical Research, and the Physical Sciences division within the office. The number of principal investigators has been reduced to less than 100 with still more reductions proposed. NASA's physical sciences research effort is on the verge of elimination. FY07 is the last chance to keep physical sciences research at NASA alive.

Rationales for Physical Sciences Research at NASA

The raison d'être for physical sciences research at NASA lies in both the past and future. Since 1990 NASA has been investing significant resources, measured in the billions of dollars, in developing and maintaining a community of high quality researchers in the microgravity sciences arena. The focus of this research is to use the microgravity environment to study a broad range of physical phenomena. The research spans from the basic to the applied, and will continue to impact both the scientific communities of which the research is a part as well as industry. As a result of the rigorous peer review of this research, important discoveries have been made in fields ranging from the wetting and spreading dynamics of fluids on surfaces to relativity and precision clock experiments. Moreover, many of the space flight experiments that flow from this program require the unique microgravity environment that is provided by the ISS and thus make use of a national asset that has been very costly to create. Ending the physical sciences research will squander the investment made in building the physical sciences research program and negatively impact the ability to perform high quality research on the ISS.

Just as important as this past investment is the likely impact of the physical sciences program on the future of NASA's human exploration effort. A vibrant physical sciences research program is the key to successfully accomplishing the President's Vision for Space Exploration, since important technology required for space exploration is controlled by gravitationally related phenomena that are poorly understood. This lack of understanding hampers the design of a vast array of devices such as those for heat transfer, the prevention and detection of fires, fluid handling, controlling the transport and movement of Lunar and Martian soils, and materials repair such as brazing and welding, among many others. The need for research in these areas is discussed in detail in the NRC report "Microgravity Research in Support of Technologies for the Human Exploration and Development of Space and Planetary Bodies." Given the central importance of these areas in fostering the human exploration of space effort, the impact of a physical sciences research program on one of NASA's central missions could thus be profound. As illustrations, I shall focus on two such examples: heat transfer systems and fire prevention and detection.

Thermal control is critical for spacecraft; excess heat must be rejected into space and moved from one section of the craft to another. In the past NASA relied on single-phase heat transfer systems, for example systems that involve only a liquid to transfer heat. However, there are clear advantages of employing systems that involve both a liquid and vapor (two phases), such as those used on the earth. This allows one to employ the significant amount of heat required to transform a liquid to a vapor or a vapor to a liquid in the heat transfer process. This significant heat of vaporization or condensation allows the heat to be transferred in a far more efficient manner than with a single-phase system. The successful operation of such systems on the earth frequently requires that the less dense vapor sit above the more dense liquid which, due to the presence of gravity, occurs naturally in a terrestrial environment. However this density driven stratification would not be present in space. This is but one of the many challenges of using such systems in space. Nevertheless, the advantages of using such a system in a spacecraft are significant. Given the enhanced efficiency, a multiphase heat transfer system would save considerable space and mass. Heat pipes have also been proposed as possible heat transfer devices. These have the advantage of being completely passive where the motion of the fluid is driven by the surface tension of the liquid, but they also involve evaporation and condensation to transfer heat.

The central reason why heat transfer systems that involve multiphase flow are not more commonly used in spacecraft is that the dynamics of flow in systems with more than one phase, such as a vapor and liquid, in a microgravity or partial earth's gravity environment are not well understood. A ground-based and flight program focused on the dynamics of flow in these multiphase systems could provide the insights to allow these higher efficiency devices to be used in the human spaceflight effort. While there are constraints on the mass and space available in the limited-duration environment of the Shuttle or ISS, the constraints placed on long-duration flights to Mars or even the Moon are even more stringent. Thus, the availability of high efficiency heat transfer devices, that occupy less space and have a smaller mass than existing devices, would open up much needed space for food and water. It is only through research in this area that these devices will be embraced by the spacecraft engineering community.

A second example of the importance of physical sciences research is in preventing and detecting fires in a reduced gravity environment. We have had thousands years of experience detecting and fighting fires on Earth. In contrast our experience with combustion phenomena in microgravity or partial Earth's gravity is limited to at most fifty years. As a result, our understanding of the flame propagation issues that impact spacecraft safety is very limited, and research in this area continues to uncover new and unexpected results. For example, flames can spread along surfaces in the opposite direction to that on earth, flames extend over electrical insulation 30 to 50 percent faster in microgravity than under normal conditions, and smoldering under microgravity conditions is less bright and more difficult to detect than on the ground. All of these results were determined from basic research conducted in only the past 10 years and have had a documented effect on the fire fighting procedures on spacecraft. Given the limited number of experiments performed in microgravity and the surprising results thus produced, there is much still to be learned.

Although fires on a space craft are an unlikely event, if one should occur it could be catastrophic not only for the mission but for the entire human exploration of space effort. The absence of any safe refuge on a spacecraft and, possibly, lunar base makes detecting and preventing small fires essential. Moreover, the design of lunar habitats that mitigate the effects of possible fires requires knowledge of how fires propagate in structures in partial Earth's gravity. Physics based simulation codes exist for fires in Earth-based structures, but none exist for micro or partial gravity environments. Given our lack of understanding of how fires behave in microgravity environments and the critical importance of this to the human exploration effort, I can think of few stronger rationales for a vigorous combustion research program. Such a program must involve an active ground-based program and, due to the long duration of many combustion experiments, ready access to the ISS may be required.

Going Forward

In order to leverage the past investment in physical sciences research and to ensure a successful future for the human exploration effort it is crucial that a broad spectrum of physical sciences research in NASA be retained. The importance of continuity in a research program cannot be overemphasized. Continued support of this community is essential in engaging the best researchers, producing the students interested in working with NASA upon graduation, and performing the ground-breaking research that is essential to accomplishing NASA's human spaceflight goals. The level of support needed for this continuity is quite modest given that a cadre of 250 investigators each of whom requires $130K would lead to a $32.5M per year program, a very small investment compared to the $1B of the former Office of Biological and Physical Research. This represents the minimum support needed to keep a physical sciences research program alive at NASA. Many researchers have recently had their programs terminated. If this support is not made available in the very near future these scientists will be reluctant to return to microgravity research and the remaining researchers will also likely leave the program. As a result NASA will find itself in the same position as it was in the late 1980s: without an organized and influential microgravity research program. Unfortunately, NASA will never have the time or the resources to recreate a physical sciences research community. Therefore it is absolutely imperative that NASA fund physical sciences research at no less than $32.5M for FY07.

To avoid many of the pitfalls of the past, it is essential that the program involves both ground-based research and spaceflight experiments. One of the crucial lessons of the early microgravity program is that only through the testing and refinement that is possible with ground-based theoretical and experimental research can experiments be performed in space that will yield reliable results. It is essential that both the ground-based and spaceflight research be rigorously-peer reviewed.

The future of research at NASA is being threatened as never before. It is important to realize that funding physical sciences research will not diminish in any way NASA's future plans for human exploration. Rather it will be an essential enabler in this effort. Finally, continuation of the funding will allow NASA to reap the benefits of many past years of funding of high impact research that is focused on gravitationally related phenomena.

Thank you very much for the opportunity to testify today. I look forward to responding to your questions.

7.3 The NASA Workforce: Does NASA Have the Right Strategy and Policies to Retain and Build the Workforce It Will Need?

House Science Committee
June 13, 2006

Statement of David C. Black, Ph.D.
President and CEO, Universities Space Research Association
and Adjunct Professor, Physics and Astronomy Department, Rice University

Mr. Chairman, Ranking Minority Member, and committee members: I appreciate the opportunity to testify before you today. My name is David Black. I am the President and CEO of the Universities Space Research Association. The Universities Space Research Association was incorporated in 1969 in the District of Columbia as a private, nonprofit corporation under the auspices of the National Academy of Sciences (NAS). Institutional membership in the Association has grown from 49 colleges and universities when it was founded, to the current 100 institutions. All member institutions have graduate programs in space sciences or technology. Besides the 92 member institutions in the United States, there are two member institutions in Canada, three in Europe, two in Israel, and one in Australia. USRA provides a mechanism through which universities can cooperate effectively with one another, with the government, and with other organizations to further space science and technology, and to promote education in these areas. I am also an Adjunct Professor in the Physics and Astronomy Department at Rice University.

I appear today largely in my capacity as co-chair of the National Research Council (NRC)'s Committee on Issues Affecting the Future of the U.S. Space Science and Engineering Workforce. The NRC is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine of the National Academies, chartered by Congress in 1863 to advise the government on matters of science and technology. The views expressed in my testimony today are in part those expressed by the NRC Committee in its Interim Report, as well as my own. I shall do my best to make clear which views are mine and which are those of the Committee. The latter views are fully supported by my co-chair of the NRC study, Dr. Daniel Hastings, who is Dean for Undergraduate Education and Professor of Aeronautics and Astronautics at MIT.

Prior to addressing the specific issues on which you have asked me to comment, allow me to provide some context for the NRC Committee's activity. I should note that the Committee has completed most of our fact-finding and will be preparing our final report near the end of the calendar year. As such we are not yet prepared to provide a complete set of recommendations but expect to do so in our final report.

The NRC Committee's charge from NASA is to explore long-range science and technology workforce needs to achieve the nation's long-term space exploration vision, identify obstacles to filling those needs, and explore solutions for consideration by government, academia, and industry. The specific tasks that we have been requested to undertake are the following:

1. Assess current and projected demographics of the U.S. aerospace engineering and space science workforce needed to accomplish the exploration vision;
2. Identify factors that impact the demographics of the affected workforces;
3. Assess NASA's list of the workforce skills that will be needed to implement the Vision for Space Exploration, both within the government and in industry;
4. Identify the skills needed to implement NASA's Vision for Space Exploration within the academic community;
5. Assess the current workforce against projected needs;
6. Identify workforce gaps and analyze obstacles to responding to the workforce needs, and in particular, analyze the proper role of academia and the obstacles to achieving this proper role; and
7. Develop recommendations for specific actions by the federal government, industry, and academia to address those needs, including considerations such as organizational changes, recruiting and hiring practices, student programs, and existing workforce training and improvement.

The NRC Committee has drawn upon input from two workshops and documents provided by NASA to arrive at the following preliminary findings:

1. NASA has made a reasonable start on assessing its near-and long-term skill needs, and the Committee shares the view expressed by NASA representatives that there is still much more work to be done. However, NASA's work has focused on initial assessment of current workforce demographics and estimates of future needs, and at the time of the NRC's interim report NASA had not yet translated that analysis into a strategy and action plan.
2. NASA needs a strategic workforce plan that deals with the next five years and that lays the foundation for a longer-term process. This will be a new and difficult process for NASA, but it will nevertheless be vital for the agency's success in implementing the space exploration vision.
3. The Committee has not seen compelling evidence for a looming, broadly based shortage in the supply of aerospace science and engineering workforce employees to meet NASA's needs. (This is not to say, however, that the committee disagrees with the broader issues about the adequacy of the U.S. science and engineering workforce.) However, the committee believes that in order to continue to have an adequate supply of these employees, it is important that NASA provide adequate funding for university based research programs and flight opportunities. This will help ensure that universities continue to sustain curriculum, faculty, and student interest in the aerospace sciences and technologies.
4. To address those skill areas where there are concerns (both for the near term and the longer term), NASA needs to pay particular attention to identifying and expanding ways to promote exchanges of personnel between NASA and the private sector (industry, academia, and non-government organizations).
5. The degree to which the agency chooses to perform work in-house versus by a contractor will play a major role in the number of personnel that the agency will require.
6. The Committee concludes that the ability to recruit and strategically retain the needed workforce will depend fundamentally on the perception of long-term stability of the Vision for Space Exploration and a sustainable national consensus on NASA's mission.

As a result of these findings the NRC Committee made the following recommendations:

1. NASA should develop and publicize a workforce strategy for ensuring that it is able to target, attract, and retain the skilled personnel necessary to implement the space exploration vision and conduct its other missions in the next five to 15 years.
2. NASA should adopt innovative methods of attracting and retaining its required personnel and should obtain the necessary flexibility in hiring and reduction-in-force procedures, as well as transfers and training, to enable it to acquire the people it needs. Transfers within the agency could fill many needs if coupled with appropriate training. NASA should work closely with the DoD to initiate training programs similar to those that the DoD initiated, or otherwise participate actively in the DoD programs.
3. NASA should expand and enhance agency-wide training and mentorship programs, in order to develop or improve needed skills within the existing workforce. For example, NASA could provide some of its employees opportunities for gaining on-the-job experience for its most vital required skill sets such as systems engineering.

As you can see, the NRC Committee has made reasonable progress, but much work remains to address fully the charge that we have been given. That said, let me turn to the questions your committee has posed to me.

What are the critical skills that will enable NASA to complete its goals in space and earth science, aeronautics, and exploration?

Although the Committee has not reviewed NASA's critical skill needs on an item-by-item basis, it is likely that the agency will need to maintain at least a small core of employees having skills in the majority of the same areas that the agency has depended upon throughout its history. Individuals with skills and experience in project management and systems engineering will be particularly critical to successful realization of NASA's goals. The NRC Committee intends to examine this issue in more detail in our final report after we have had a chance to evaluate the material that NASA has provided to our Committee. We recognize that this is a daunting task for NASA as it starts with essentially a blank piece of paper. The NRC Committee's initial reaction to NASA's work done so far is that it is incomplete and reflects a top-down view of what skill mixes are needed and as such is more theoretical than empirical.

An essential aspect of any answer to this question is the "make/buy ratio" that NASA decides to implement, i.e. the division of responsibilities for work to be done by the agency's field center employees vs. work to be done by outside contractors. I will comment more specifically on the role of this ratio below, but let me just say here that clearly the demands on NASA's in-house workforce will be lessened if this ratio is low, as some of the requisite skill base can then reside external to the agency.

What decisions must NASA make now to prepare for its future workforce needs?

The NRC Committee has identified several key decisions that NASA faces, and there are sure to be others that will become clear as we complete our study. In the view of our Committee, the most critical decision is the one just discussed, the amount of work done by NASA employees relative to that done in academia and industry. The extent to which NASA decides to develop and operate space systems in-house at its field centers or to contract such work out will have a substantial influence on the skills needed in-house. Moreover, such make/buy decisions also have a strong influence on recruitment of future NASA employees.

Furthermore, NASA needs to determine what means it will use to ensure that prospective employees, entering jobs either inside the government or in the private sector, gain the requisite training and experience in those critical areas that are needed to fulfill the agency's goals and objectives. NASA does have training and mentorship programs, and I should say parenthetically here that my organization has been working with NASA to expand these over the past years, but in general these programs are modest in scope and impact.

NASA also will need to make decisions regarding how it can provide assurance, or perhaps more on point, a sense of "hope and promise" to potential future members of the agency's workforce. Twenty years ago, the mere mention of NASA was an attractor. It had vocational pizzazz. That is no longer the case. Considerable publicity is given to NASA projects that are delayed or cancelled, and there are fewer opportunities for NASA staff to be engaged in meaningful science and engineering. I am concerned that many of the best and brightest young people are attracted to the science part of what NASA does, but the inability of the Administration and Congress to properly fund NASA's implementation of the Vision for Space Exploration will mean that support for science will erode. The research advisors in the academic disciplines associated with these science areas won't have the funding to support the best and brightest graduate students, who may go elsewhere. The ability of NASA to develop ways to reinvent itself in the sense of attracting the best and brightest in its science and engineering competencies is very important.

Finally, NASA will need to decide how much critical mass of expertise should be sustained in key areas such as microgravity life and physical sciences. It is easy to turn off communities with budget decisions, but it is not as easy to turn them on in a timely manner at some point in the future. The employment ecosystem extends from NASA and other similar technical employers through universities and arguably down to high schools. The life scientists needed to do cutting edge research in 2015 are in high school today. How likely are they to choose career paths that would take them to NASA in light of recent decisions to minimize that field of work? A related aspect is that the university community that is the source of NASA's future workforce is already showing signs of steering their best students to other career paths because NASA commitments appear to be uncertain or unstable.

Does NASA's workforce strategy fulfill the needs identified by the NRC interim report?

Our Committee has not had a chance to review NASA's new workforce strategy, but will do so as the NRC study moves ahead during this year. The Committee's interim report does suggest a number of important elements that should be included in such a strategy. They include an analysis of future skill needs, both in terms of types of skills and numbers of employees, that is then linked to plans for recruitment and training to meet those needs, as well as plans for partnerships with industry, other government agencies, and academia to meet future training needs.

What are the trade-offs associated with completing work in-house at NASA or contracting them out?

Our Committee has not yet addressed this question thoroughly, so I will have to give you what is largely my personal view at this point. As remarked earlier, the Committee does feel that this trade-off is one of the more critical, if not the most critical, decision that NASA must make. Whether or not there is strong reliance on external organizations, NASA must retain a cadre of expert engineers and scientists on its own staff. Administrator Griffin has made the point that NASA needs to be a smart buyer, and that requires skilled and knowledgeable employees who are involved with buying decisions and in program management. Recent experience in the DoD indicates that when the government expertise in national security space was allowed to wane, the government made major mistakes in what and how it contracted with industry.

If the decision is to buy rather than build, NASA will not need a large number of people with the requisite skills, but those on whom they rely must be exceptionally skilled and experienced. Choosing a path that emphasizes buying what is needed allows NASA to tap into a skilled workforce that is already largely in place, and which is unencumbered by civil service hiring and firing rules. This latter aspect makes it easier to adjust the workforce as budgets, and program schedules, wax and wane. Selection of the buy path also expands the support base for NASA's programs in a political sense, as employees of companies and universities beyond the NASA field centers have a vested interest in the success of those programs. However, it is important to realize that NASA can never give up the core of talented people necessary to be "smart" buyers. NASA needs to retain enough in-house projects to develop and retain these smart buyers or facilitate exchange with industry to get smart buyers with current experience.

Conversely, should NASA opt to place more emphasis on building what is needed using an in-house workforce, they will need to recognize that in next five years or so, they will have gaps in necessary expertise that cannot be rapidly filled by training current in-house people or by inexperienced new hires. The NRC Committee has examined this issue, and the Committee concludes that ways must be found for NASA to supplement its present workforce with members of industry, the retiree community, and academia who do currently possess the skills required.

The situation for the longer term will depend upon NASA's ability to train in-house staff and to establish an environment that encourages the brightest young students to seek employment with NASA. A key element of this will be to provide opportunities within universities for meaningful hands-on training and experience for students. Data on the trend of NASA-sponsored opportunities of this type show a clear decrease over the past three decades or more (see Figure [7.2]), and a projection into the future given the proposed budgets suggests that this decrease is likely to continue. The knowledge needed to become a skilled project manager is not found in a textbook or class-

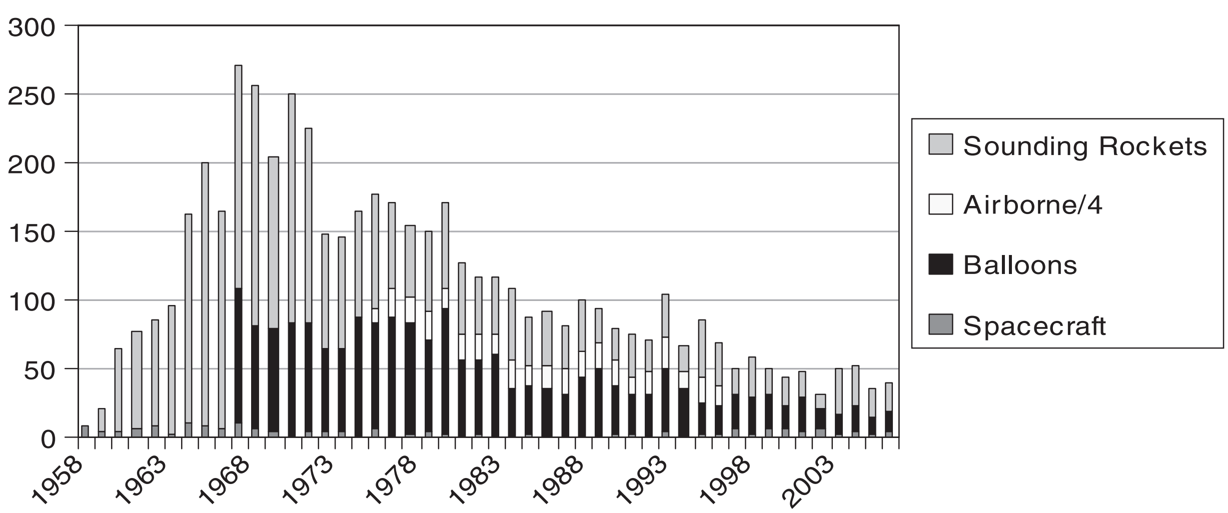

FIGURE 7.2 History of opportunities for student hands-on participation in sub-orbital flight experiments and small space missions in Earth and space science.

room; it comes from doing the work and experiencing failures as well as successes. A "build" as contrasted to "buy" approach will allow NASA to offer its employees compelling challenges, which is an important ingredient in making employment with the agency attractive to young people. However the most effective, and perhaps even essential, approach to meeting the needs of both the federal government and industry for people with hands-on experience will be to nurture and expand ways to begin to provide that experience while science and engineering students are still in universities. As a companion NRC study committee recently recommended, that will require reversing the trend of declining opportunities for programs that do provide the hands-on experiences.

In closing my prepared remarks Mr. Chairman, I would note that the NRC Committee feels strongly that NASA needs to look outside of itself in assessing the nature, scope, and possible solutions for its skill mix. NASA has historically been a "can-do" agency, but also one afflicted to some extent with the "not invented here" syndrome. The issues NASA faces in terms of workforce are national in character; they reverberate through other government agencies involved in space-related work, as well as the private sector including universities. NASA should not, in our Committee's view, try to structure a solution in isolation from consultation with the broader set of communities noted above. While we have not formulated a recommendation in this area, I believe I can speak for many people in saying that the nation's space programs would benefit if the issue of workforce is addressed by involving the representatives of the workforce ecosystem in both the assessment of the problem and the range of possible solutions.

I would be happy to expand on my remarks or address additional questions should you wish.

Thank you again for the opportunity to share with your committee the perspectives on this important issue that the NRC Committee has developed in this early stage of our work.

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