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MANAGING THE SPACE SCIENCES

Committee on the Future of Space Science
Space Studies Board
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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National Research Council
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Executive Summary

In April 1994 the National Research Council received a request from NASA Administrator Daniel S. Goldin that the NRC's Space Studies Board provide guidance on several questions relating to the management of NASA's programs in the space sciences.¹ The issues raised in the Administrator's request closely reflect questions posed in the agency's fiscal year 1994 Senate appropriations report. These questions included the following:

- Should all the NASA space science programs be gathered into a "National Institute for Space Science"?
- What other organizational changes might be made to improve the coordination and oversight of NASA space science programs?
- What processes should be used for establishing interdisciplinary science priorities based on scientific merit and other criteria, while ensuring opportunities for newer fields and disciplines to emerge?
- What steps could be taken to improve utilization of advanced technologies in future science missions?

Since the creation of NASA in 1958, space science has been a key element of its mission. Indeed, the Augustine Committee report,² submitted at the end of 1990, asserted that science was NASA's most important mission. The committee responsible for the present report has proceeded on the same premise. A balanced and healthy program of space science is crucial to the future of NASA, regardless of the overall level of support available to the agency.

The most important recommendations of this report are listed below. They are further elaborated following the list.

¹ In this report, "space sciences" refers to all of NASA's science programs conducted in or from space, including space astronomy, space physics, planetary exploration, microgravity research, space life sciences, and Earth science.

² Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990.

- NASA should not establish a “National Institute for Space Science” that would pull together the three present science program offices.
- NASA should augment the responsibilities and authorities of the NASA Chief Scientist.
- NASA should establish a set of fair, open, and understandable processes to be used in the prioritization of space science research. These processes will ensure that major project proposals considered at progressively higher levels within the agency have the heritage of scientific merit that comes from a successful confrontation with competing proposals at lower levels.
- NASA should create a comprehensive strategy and plan for the technologies that support the space sciences, with the responsibility for near-term technology development residing in the science programs to be served and the responsibility for longer-term technology strategy and development residing in the Office of Space Access and Technology.
- NASA should change the funding of its field centers to full-cost accounting (“industrial funding”). Cost accounting should be based on full program costs, including civil service salaries. The committee endorses NASA’s intentions to move in this direction.
- NASA should exercise caution in downsizing its Headquarters staff and transferring functions to the centers; this process could be carried too far and have unintended consequences. The committee identified a number of areas where it believes control should be retained at Headquarters.
- NASA science budgets should include a limited amount of dedicated funding for innovative ideas in high-risk, high-return areas lying outside the current framework of inquiry or design.
- NASA should take a cautious approach to the recently proposed establishment of focused science institutes. There should be a well-defined process for their selection and creation, and a clear plan for the phased transfer of base funds to programmatic funding.

The following expands key recommendations of the report:

Institute for Space Science—In response to direction in the FY 1994 Senate appropriations report, the committee considered a space sciences umbrella organization within NASA to coordinate and oversee all space science activities, functioning like the National Institutes of Health (NIH) within the Department of Health and Human Services. The committee reviewed the advantages and disadvantages of such a model and concluded that the NIH model, while effective in the arena of health research, is not appropriate for the space sciences. NASA space science benefits from close coordination with other elements of NASA, such as hardware development, launch services, and tracking and data operations, which have no counterparts in the NIH model. The committee believes the required coordination would be hampered by the creation of a quasi-autonomous space science institute. The committee therefore does not recommend establishment of such an umbrella institute.

The Role of the Chief Scientist—The role of the Chief Scientist was found to be a critical one from many perspectives, leading the committee to recommend expanding the authorities and responsibilities of this position. Despite the central role of the science associate administrators in the management of their respective science areas, the committee finds a need for greater integration and coordination of these programs. To achieve this, the position of Chief Scientist should be strengthened, particularly by the addition of concurrence authority in key matters affecting space science. The Chief Scientist should be a person of eminent standing in the scientific community with a significant record of accomplishment. A proposed “functional statement” for the Chief Scientist is given in Chapter 4. A major component of this official’s integration responsibility is coordination and oversight of the recommended science prioritization process. Another component is coordination of the technology development programs that support space science.

The Prioritization Process—The committee believes that peer review is the most effective form of merit review for the selection of scientific research. A clear set of criteria, known and understood by all parties, is crucial to the prioritization of scientific goals. The relative ranking of science and mission

plans will be most strongly affected by scientific factors at the entry level, where proposals from the same discipline or subdiscipline compete against one another. As the arena of competition broadens to the interdisciplinary and then to the agency-wide level, other programmatic and political influences become increasingly important. It is essential, however, that all proposals being considered at progressively higher levels retain the heritage of scientific merit that comes from successful confrontation with their peers at lower levels. The office of the Chief Scientist should oversee these prioritization processes, especially as they cross disciplinary boundaries. NASA management should cancel those programs or projects that are failing or whose priority has dropped substantially in this prioritization process. The committee found that peer review and the above corollary principles apply generally to technology research as well.

Technology Planning—New technologies are important as agents of change, enhancing the quality of scientific output and the ability to accomplish more with less. Technology development is undertaken both by NASA's science program offices and by its Office of Space Access and Technology (OSAT). The committee recommends that NASA establish an agency-wide strategy and plan for the technologies that support the space sciences. These technologies may be characterized as near-term or far-term technologies (the latter defined as requiring more than five years to be ready for flight demonstration). The space science offices should have primary responsibility for identifying and reviewing near-term technologies, giving them greatest control of the technologies that most immediately affect the success of their programs. Each science office should allocate a significant fraction of its resources to Advanced Technology Development activities and should be willing to pool resources to achieve shared objectives. Most importantly, the implementation of all categories of technology development should be undertaken by the best-qualified individuals or teams within NASA, other government laboratories, industry, or academia, as determined by peer review.

Promising far-term technologies should be identified, funded, and managed by OSAT. Projects in these areas should be reviewed jointly by the science offices and by OSAT. Like near-term technology development, far-term projects should be carried out by the best-qualified individual or teams, as determined by peer review. These projects should stimulate exploratory development of possibly unconventional technologies having the potential of producing breakthroughs in capability. Finally, a rigorous review process should be put in place to identify those projects that ought to be terminated in the present constrained budgetary environment.

Industrial Funding—The committee examined the advantages and disadvantages of an explicit full-cost accounting system in which all charges, including salaries and facilities, are charged against projects (so-called "industrial funding"). This approach permits ready assessment of comparative costs that might otherwise be hidden in an institutional funding environment. The committee endorses NASA's decision (stated in the "Zero Base Review" briefing to the Congress) to identify, budget, and manage by total program costs, including civil service labor costs. The committee recommends that NASA change the funding of its field centers to an industrial funding arrangement. The committee believes that decisions on program priorities and budgets would be more rational if based on full-cost accounting, and program accountability and discipline in personnel management would thereby be enhanced. A similar recommendation was made in the *NASA Federal Laboratory Review* report.³

The Downsizing of Headquarters—NASA is currently "re-engineering" its organization. This re-engineering entails a very large downsizing of its Headquarters staff and a concurrent transfer of functions to the centers. The result is expected to be the analog of a lean "corporate management" model. While the committee endorses the intent, it notes that an unintended consequence could be a center-dominated model as opposed to the desired enterprise-focused one. Several recommendations are offered to avert this outcome. Not all program management functions should be transferred to centers.

³Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

Those complex programs that cut across centers should be retained at Headquarters and integrated with enterprise management. Support of scientific disciplines, management of peer review, and oversight and integration across center boundaries should remain Headquarters functions. Likewise, creation of a strategy and plan for the technologies that support space science should be a Headquarters responsibility. The adoption of industrial funding will further emphasize the importance of a suitably strong Headquarters organization.

Research in New Fields—The committee recognizes the competitive obstacles faced by smaller, newer, or less well established fields of science. The committee recommends that NASA science budgets include dedicated funding for innovative, high-risk, high-return ideas falling outside current frameworks of inquiry or design. This research is highly important and deserves special management attention, including that of the Chief Scientist. This recommendation is not intended to allow circumventing of peer review for the major parts of any science program.

Science Institutes—Creation of contractor-operated institutes may be advantageous in specific instances. However, the committee recommends that, as NASA proceeds with arrangements for the first focused science institutes, it give due attention to the processes by which these institutes are selected and created and by which, over a few years, their guaranteed base funding will be transformed into competed programmatic funding. Further, there should be consideration of a review process that will ensure either (1) that they compete successfully to maintain or increase their size, or (2) if less successful, that they are phased down in an orderly fashion. The committee recommends that additional initiatives along these lines be deferred until the above processes have been defined and the success of the two proposed institute pilots can be evaluated.

The committee's recommendations are gathered together by main theme in Chapter 7.

The NASA space science programs, from the dawn of the space age to the present, have produced an unprecedented flow of discoveries. The fiscal, political, and technological environment of the agency is now in a state of rapid change. It is vital that NASA respond to its challenges and opportunities in the most constructive manner to ensure the success of its future space science endeavors. The committee believes that the recommendations made in this report, if accepted by NASA, will aid in this objective.

Introduction

GENERAL BACKGROUND

The National Aeronautics and Space Administration (NASA) was established in 1958 to conduct the civil space program of the United States in response to the challenge of the Soviet Sputnik, the first artificial Earth satellite. In founding NASA, the National Aeronautics and Space Act of 1958 directed the new agency to undertake the

- “expansion of human knowledge of the Earth and of phenomena in the atmosphere and in space” and the
- “preservation of the role of the United States as a leader in aeronautical and space science and technology.”

NASA was formed from the existing National Advisory Committee for Aeronautics (NACA) and absorbed the bulk of the Vanguard Project and its staff from the Naval Research Laboratory (NRL). The U.S. Army’s Jet Propulsion Laboratory and Redstone Arsenal were added shortly thereafter. Two NASA program offices were established, Aeronautical and Space Research (oriented toward engineering research) and Space Flight Development.¹ One of four elements in the latter office, space science, assumed responsibility for the agency’s earliest endeavors in Earth orbital, lunar and planetary, and suborbital research. A reorganization in late 1961 elevated space science to the level of a full program office. It has retained this status since that time, with some variation in the disciplines incorporated in it. In late 1963 the Office of Space Science and the Office of Applications were merged to create the Office of Space Science and Applications, joining the Earth sciences with other sciences. Because of increased emphasis on applications of space science and technology to terrestrial problems in the post-Apollo period, the offices were separated again in 1972. In 1982, they were re-merged.

Life science elements (bioscience, space medicine, and exobiology), which had previously been scattered across the agency, were consolidated in the Office of Space Science in 1975. Microgravity science became part of the program of the Office of Space and Terrestrial Applications in the 1970s. Thus, when science and applications were recombined in 1982, the reconstituted Office of Space Science

¹NASA, *The Evolution of the NASA Organization*, March 1985.

and Applications (OSSA) included all the science elements of the agency's program: the traditional space sciences (astrophysics, space physics, and solar system exploration), the life sciences (bioscience, space medicine, and exobiology), Earth science, and microgravity science.

On October 15, 1992, NASA Administrator Daniel S. Goldin announced a number of changes in the NASA organization to "better focus NASA's programs, to streamline how we do business so we can meet the challenges ahead." Among these changes was division of OSSA into two parts: the Office of Mission to Planet Earth (OMTPE), including Earth science and applications programs, and the Office of Planetary Science and Astrophysics (later renamed the Office of Space Science—OSS), consisting of the three traditional space science programs, astrophysics, space physics, and solar system exploration. At that time, no mention was made of the life sciences or microgravity science. Concurrently, the Associate Administrator for Space Science and Applications was appointed to the position of Chief Scientist for NASA, a position occupied during the 1970s and 1980s, but vacant since the late 1980s. Acting associate administrators were announced for OSS and OMTPE.

These changes were formally implemented on March 11, 1993, and an Office of Life and Microgravity Sciences and Applications (OLMSA) was established (effective March 8, 1993). OLMSA incorporated life and biomedical sciences, microgravity science and applications, flight support systems, and aerospace medicine and occupational health. With these changes, the NASA space sciences, which had been collected within OSSA for the 10 preceding years, were now distributed among three program offices—traditional space science in OSS, Earth science in OMTPE, and life and microgravity sciences in OLMSA.

During the summer of 1993, the Senate Subcommittee on VA, HUD, and Independent Agencies (NASA's appropriations subcommittee), which had been a strong supporter of the unified OSSA science office and its management prior to this reorganization, requested in the report accompanying its FY 1994 appropriations bill that the National Academy of Sciences "undertake a comprehensive review of the role and position of space science within NASA." The subcommittee, citing as especially effective the strategic planning, cross-disciplinary priority setting, and management controls of OSSA, directed that the study consider the possibility of creating an "Institute for Space Science" within NASA roughly analogous to the National Institutes of Health (NIH) in the Department of Health and Human Services. (The following year, the subcommittee restated its concerns about a lack of new science missions in NASA planning in the report accompanying the FY 1995 appropriations bill, and suggested that the Academy consider this also in its study.) Appendix A provides the subcommittee report language.

On April 7, 1994, NASA Administrator Daniel S. Goldin wrote to the National Research Council (NRC), the operating arm of the National Academies of Sciences and Engineering, to request initiation of the study (Appendix A). Study responsibility was given to the Space Studies Board, which established a "Future of Space Science" project. The committee structure proposed by the Board and approved by the NRC was a steering group and three task groups charged with tackling specific aspects of the study. The project statement of task and charges to individual task groups are provided in Appendix B.

The steering group of the committee met four times to review and guide progress on the study (August 2-3, 1994; and January 4-5, June 9-10, and August 7-8, 1995) and to hear from a number of key NASA managers on issues under study (Appendix H). The already-existing Joint Committee on Technology for Space Science and Applications (operated jointly with the NRC Aeronautics and Space Engineering Board) was charged as a first task group with examining how to improve technology development and utilization in the agency's science programs. A new Task Group on Research Prioritization was established to analyze the general problem of research prioritization and to address the problem of sheltering NASA's ability to promote and support highly innovative and unproven research in a highly competitive funding environment. A Task Group on Alternative Organizations was also formed to consider alternative organizations for the management of NASA space science.

TASK GROUP ON ALTERNATIVE ORGANIZATIONS

The charge to the Task Group on Alternative Organizations (Appendix B) encompasses a broader set of issues and alternatives than those set out in the Senate subcommittee report. Specifically, the task group felt that a number of alternative organizational arrangements employed in institutions other than the NIH were also potentially relevant to NASA space science. In addition to details of science program management in NASA Headquarters, the task group also identified as important to this study both the overall NASA organization (Headquarters institutional and staff office management and field centers) and the relationships of NASA with the external communities, including research performers, users of NASA research results, educational institutions, and international organizations.

At its first meeting (December 8-9, 1994), the task group reviewed its charge, discussed with senior NASA officials the current NASA science organization, reviewed the environmental drivers for change, and established a plan for the conduct of its study. In four subsequent meetings (February 2-3, March 10-11, March 27-28, and April 18-19, 1995), the task group conducted interviews with science managers and performers from both NASA and other institutions that use different management approaches. Those interviewed are listed in Appendix H. These interviews were arranged to address three separate but related aspects of scientific research: (1) how others manage research, that is, the approach to funding and management of science of other research organizations, both in and out of government; (2) how the performers of NASA-sponsored scientific research (both in and out of NASA) view NASA's management of that research; and (3) how users of NASA's scientific research (e.g., the Department of Defense, the National Oceanic and Atmospheric Administration) interact with NASA. A final meeting devoted entirely to writing took place on May 24-25.

Based on these interviews and the experience of its members, the task group identified key issues in science management (both generic and specific to NASA), established a set of principles that embodied the best and most successful elements of science management, and applied those principles to alternative organizational arrangements for NASA. The result led to a recommended approach for NASA that embodies the principles, applies them to the NASA context, and maintains a degree of continuity for NASA, research performers, and users of scientific research.

While the present study was in progress, the NASA Federal Laboratory Review Task Force of the NASA Advisory Council completed its report² and submitted it to NASA. Responding to a Presidential directive to the National Science and Technology Council to conduct an interagency review of research and development at federal laboratories, this report addressed some of the same subjects as the present study. There was substantial agreement in areas of overlap.

TASK GROUP ON RESEARCH PRIORITIZATION

The study history of priority setting in science is a lengthy one. In addressing its charge (Appendix B), the Task Group on Research Prioritization examined the processes, past and present, by which NASA priorities have been established and studied reports of other groups that have addressed the issue of priorities in science. The task group met on November 28-30, 1994, and February 21-22 and June 5-6, 1995, to interview managers from NASA and other agencies about their approaches to prioritization (Appendix H). Several task group teleconferences were also held to discuss findings.

TASK GROUP ON TECHNOLOGY

Unlike the other two task groups that were established specifically for this study, the Task Group on Technology built directly on previous work of the Joint Committee on Technology (JCT) for Space

² Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

Sciences and Applications operated by the NRC Space Studies Board and the Aeronautics and Space Engineering Board. Of particular relevance was the 1993 report³ of the JCT-convened Committee on Space Science Technology Planning (CSSTP, described further in Chapter 6). The Task Group on Technology was composed of the eight members of the JCT, assisted by an advisor recently retired from NASA.

At the beginning of its work, the task group found that its charge (Appendix B) had much in common with the charge of the CSSTP and approached its task as an augmentation and update of the earlier work. Unlike the CSSTP study, which was the product of a large workshop, the task group's current assessment was based on meetings with NASA Headquarters personnel and on three fact-finding visits to the field centers. To carry out its part of the study, the task group invited NASA Headquarters staff to discuss how its review might be most effective (August 23-24, 1994) and then requested Headquarters management briefings (November 14-15, 1994). The task group proceeded with site visits to the Jet Propulsion Laboratory (February 23-24, 1995), the Lewis Research Center (March 30-31, 1995), and the Goddard Space Flight Center (April 25, 1995). After these visits the task group met with the associate administrators of the three NASA science offices (OSS, OMTPE, and OLMSA) and of the technology office (Office of Space Access and Technology) to discuss some of its preliminary findings and to receive an update of the information presented by those offices at its earlier meetings (April 26, 1995). A list of individuals interviewed by the task groups is provided in Appendix H. The task group also sent a letter (Appendix G) inviting written comments from the discipline committees of the Space Studies Board and from the representatives of the 79 member institutions of the University Space Research Association.

An acronym list is provided in Appendix I.

³NRC, Committee on Space Science Technology Planning, *Improving NASA's Technology for Space Science*, National Academy Press, Washington, D.C., 1993.

Science at NASA

RATIONALE FOR NASA SCIENCE

Space Science Programs

The National Aeronautics and Space Act of 1958 directed NASA to expand human knowledge of the Earth and space and to preserve U.S. leadership in space science and technology. Thus, although the motivation for the space program was a forceful political reaction to the successful Soviet launch of Sputnik, space science was from the very beginning a major element of the program. Indeed, the first U.S. satellite, Explorer I, launched by the U.S. Army even before the establishment of NASA, was a scientific satellite carrying micrometeoroid detectors and a Geiger counter as its payload. This first space science mission discovered the Van Allen radiation belts and began an uninterrupted period of extraordinary discovery and scientific advance that continues today.

Through its commitment to the Space Act goals, NASA ushered in an age of discovery in space science and astronomy. Not since the pioneering voyages from Western Europe in the fifteenth and sixteenth centuries has our understanding of the world we inhabit changed so profoundly. The space around the Earth has been found to be an amazingly complex collection of fields and particles whose behavior has significant impact on the Earth and its atmosphere. Humans have walked on a world other than our home planet, and NASA robotic spacecraft have voyaged to all of the planets except Pluto. High-resolution images have been obtained of Mars, Jupiter, Saturn and its rings, Neptune, and Uranus, and the surface of Venus has been mapped by radar. The surfaces of Mercury and of many of the moons that orbit the planets have been imaged, revealing each as a distinct and separate world with its own geologic history. Understanding of the processes that have determined the evolution of the atmospheres and surfaces of these planets can help us develop models of the formation and evolution of the Earth and of the impact of changing conditions on the evolution of its atmosphere.

NASA has also reached far beyond the solar system in its exploration of the universe. From satellites above the Earth's atmosphere, NASA has made it possible for the first time to explore the entire electromagnetic spectrum, from high-energy gamma rays to long-wavelength infrared. The Hubble Space Telescope has provided images of stars and galaxies unblurred by the Earth's atmosphere. The Cosmic Background Explorer has provided hints of early density enhancements in the universe that were the seeds of the structure that we see today. Observations with NASA satellites have given strong

evidence for the existence of such exotic objects as black holes and have revealed disks of dust and gas around very young stars that may evolve into planetary systems much like our own.

Equally impressive, space technologies have made possible our current scientific concept of the Earth as a complex system. From Apollo photographs of the Earth as a blue marble to the recent Shuttle-based radar images of rain tracks in the Midwest or ancient drainage structures under Middle Eastern deserts, the space perspective has revolutionized our understanding of atmospheric, oceanic, and land processes. We have measured centimeter-scale distortions of the Earth's crust associated with plate tectonics; detected and understood the polar ozone holes; begun to understand the dynamics and chemistry of the stratosphere and upper atmosphere; correlated climate variations with the Pacific El Niño and with major volcanic eruptions; learned to use satellite radiometry to estimate global atmospheric temperature and moisture profiles; bounded solar variability; measured the components of the Earth's radiation budget; and used satellite observations to validate greatly improved atmospheric models for prediction of weather and climate.

The life sciences, too, were an early element of the NASA program, both for supporting human spaceflight and for studying fundamental biological processes that occur in the space environment. When longer-duration operations at zero gravity became possible (Skylab, Shuttle, Spacelab), micro-gravity science took its place among the space sciences of NASA.

But many challenges and new opportunities remain. It is because of these opportunities for continued discovery and analysis that the place of space science in the program of NASA has been repeatedly reaffirmed, both in agency planning and in external reviews. In 1983 the NASA Advisory Council's *Study of the Mission of NASA*¹ placed space science and exploration at the forefront of the space mission of NASA (Appendix C). In its 1990 report,² the Advisory Committee on the Future of the U.S. Space Program (the Augustine Committee) recommended that, in a balanced space program, highest priority be given to the space science program in the competition for NASA resources. The committee ranked science ". . . above space stations, aerospace planes, manned missions to the planets, and many other major pursuits which often receive greater visibility" (Appendix C). As the basis for its recommendation, the committee cited the central role of NASA in enabling basic discovery and understanding; gaining fundamental knowledge of our own planet to support improvements in the quality of life for people on Earth; stimulating education of future scientists; and giving vision, imagination, and direction to the space program. Subsequently, the NASA Advisory Council, in its 1994 *Report on the Recommendations of the Advisory Committee on the Future of the U.S. Space Program*,³ reaffirmed the validity of most of those findings—and, in particular, those associated with the priority of space science.

Technology for Space Science

Technology for space science includes not only the technologies related to sensors, experimental apparatuses, and data analysis, but also those necessary for spacecraft and systems technologies such as spacecraft power, control and structural systems, and information handling. The space sciences have traditionally used new technologies to enable more ambitious missions for increasingly sophisticated observations. NASA developed the technologies for large, capable spacecraft and for complex flight operations for flagship missions like the Hubble Space Telescope and the Magellan Venus Radar Mapper.

¹NASA Advisory Council, *Study of the Mission of NASA*, October 12, 1983.

²Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990.

³NASA Advisory Council, *Report on the Recommendations of the Advisory Committee on the Future of the U.S. Space Program*, October 1994.

In general, performance has been favored over economy during most of NASA's history. But in the 1980s, the high cost of programs caused NASA to become increasingly risk-averse. New technologies were perceived as risky and were avoided unless absolutely necessary to a mission. Recent recognition that NASA budgets were not only unlikely to grow, but could be expected to decrease, has spawned an emphasis on "smaller, faster, cheaper" missions. While the focus of technical development has shifted from ever-increasing capability to cost control, new space science missions and experiments remain critically dependent on the rapid deployment of new technology. Thus, the balance has shifted to place more emphasis on technologies for enhanced economy.

NASA has viewed itself as both primary developer and customer for its space technologies. Unlike its aeronautics programs, where industry and national security are the customers, NASA's spaceflight programs develop technologies primarily for their own use. Many programs during the Apollo era invested heavily in technology, and many of those technologies were developed in-house or by contractors who were closely associated with NASA field centers. At that time, NASA could be considered the primary national provider of space technology. During the years since Apollo, NASA's emphasis on operations has increased while its pursuit of new technology has narrowed to focus on specific mission needs. Meanwhile, the Department of Defense (DoD) has aggressively funded industry, academia, and government laboratories to develop a broad range of space technologies. As a consequence, DoD became the primary agent of technological advancement, and industry and academia have become the primary U.S. developers of new spacecraft technologies and some sensor technologies. Many sensors used for space science today are the result of industry/university/national laboratory collaborative efforts and are based on DoD technologies.

MANAGEMENT AND ORGANIZATION OF SCIENCE AND TECHNOLOGY AT NASA

Space Science

The organization and management of aerospace activities at NASA, including scientific activities, involve both program/project responsibilities and institutional responsibilities. Programs and projects are the activities that are conducted to reach the goals and objectives of the agency, while the institution comprises the academic laboratories, the Jet Propulsion Laboratory (JPL), and the aerospace industries expected to build the hardware, as well as the NASA staff, facilities and equipment, and plant. Projects are discrete activities with specific objectives, schedules, and costs. Programs are the broader, more encompassing scientific endeavors, often including one or more projects, and often defined by scientific disciplines (e.g., space physics) or narrower fields of science (e.g., Global Geospace Science). NASA definitions of program and project⁴ are given in Appendix D.

Program management usually resides at NASA Headquarters within a program office. The program manager is responsible to the program associate administrator for developing goals and objectives, planning and defending programs and missions (to NASA and the Administration), managing and disbursing resources, and administering Headquarters guidelines and controls under which the projects constituting the program are implemented. Project management usually resides at a field center, and a project manager is responsible for execution of the project plan by participants, both in and out of government, and for reporting on status and performance.

Institutional responsibilities of the center director include providing the technical and support staff for the project and the facilities and equipment needed for success. Field centers report to institutional associate administrators, who may or may not be the same as the program associate administrator for the

⁴NASA, *Management of Major System Programs and Projects Handbook*, NASA Handbook 7120.5, November 22, 1993.

program in question. Thus, a project manager at a field center reports to a program manager at Headquarters for program/project matters such as R&D costs and schedules, but to his or her center director and a (possibly) different institutional associate administrator at Headquarters for the staff, equipment, and facility support needed to accomplish the project.

The roles and responsibilities of each of the NASA Headquarters offices and field centers are detailed in NASA Handbook (NHB) 1101.3.⁵ The current version includes changes through November 22, 1994. Appendix E gives a summary of the contents particularly relevant to the science programs of NASA.

Table 2.1 shows, for each of the four main science programs, the responsible program office, the field centers responsible for major elements of that program, and the institutional offices for the centers involved. There is considerable "cross-involvement," that is, major science activity in a center reporting institutionally to a Headquarters office other than that responsible for the program. Note that JPL is shown reporting "institutionally" to OSS. JPL is a Federally Funded Research and Development Center (FFRDC) operated by the California Institute of Technology for NASA under contract. At JPL, unlike at the civil service NASA centers, each responsible science program office funds not only its own programmatic costs, but also staff, facilities, and equipment (institutional) costs.

These arrangements have changed over time. Table 2.2 shows the evolution of NASA's science organization since NASA's birth in 1958.⁶ Highlights of organizational changes among the science programs through NASA's history have been noted previously. These are shown here, along with changes in the institutional reporting relationships of the centers. For the most part, but not always, the centers have reported institutionally to the program offices with which they were principally involved programmatically. But twice in the agency's history the centers reported to a central agency authority for institutional purposes (personnel, facilities, general support) while maintaining their programmatic reporting to the responsible program offices. For a brief period early in the Apollo era (1961 through

TABLE 2.1 Space Science Program and Institutional Management

Science Program	Program Office	Major Field Centers	Institutional Office
Traditional Space Science	Office of Space Science (OSS)	Goddard Space Flight Center Jet Propulsion Laboratory Marshall Space Flight Center Johnson Space Center Ames Research Center	OMTPE OSS Office of Space Flight (OSF) OSF Office of Aeronautics (OA)
Earth Science	Office of Mission to Planet Earth (OMTPE)	Goddard Space Flight Center Jet Propulsion Laboratory Stennis Space Center Langley Research Center Ames Research Center	OMTPE OSS OSF OA OA
Life Science	Office of Life and Microgravity Sciences and Applications (OLMSA)	Johnson Space Center Ames Research Center	OSF OA
Microgravity Science	OLMSA	Marshall Space Flight Center Lewis Research Center	OSF OA

⁵NASA, *The NASA Organization*, NASA Handbook 1101.3, September 13, 1994, with changes through November 22, 1994.

⁶NASA, *The Evolution of the NASA Organization*, March 1985.

TABLE 2.2 NASA Science Organization—The Big Picture

Period	Space/Earth Science and Applications	Microgravity Science	Life Science	Field Centers
1958 to 1961	Space Science (later Lunar and Planetary, Satellites and Sounding Rockets) under Space Flight Development program office (AA level)	N/A	Biology and Life Systems, Biosciences Divisions under Space Flight Development ('58-'60) Life Science program office (AA level) ('60-'61)	Reported to program offices
1961 to 1963	Office of Space Science (OSS) Office of Applications (OA)	OA	OART (Biotechnology and Human Factors) OSS (Bioscience and Exobiology) OMSF (Space Medicine)	Reported to Associate Administrator (Seamans)
1963 to 1972	Office of Space Science and Applications (OSSA)	OSSA	Same through '70 Consolidated in '71 to OMSF (except Exobiology and Aero Life Science)	Reported to program offices GSFC, JPL, WFC to OSSA MSFC and JSC to OMSF Ames, LaRC, and LeRC to OAST
1972 to 1981	Office of Space Science Office of Applications (later Office of Space and Terrestrial Applications, OSTA)	OA (OSTA)	Same to '75 Transferred in '75 to OSS	Same In '74 to AA/Center Operations In '78 to Administrator
1982 to 1992	Office of Space Science and Applications	OSSA (Shuttle and Space Station Science)	Same through '92	In '82 back to program offices as before (WFC to GSFC)
1993 to date	Office of Space Science Office of Mission to Planet Earth	Office of Life and Microgravity Sciences and Applications	OLMSA	Same, but GSFC to OMTPE

1963), all the centers reported to an associate administrator and secured institutional resources from that office. Institutional reporting to appropriate program offices was reinstated after 1963, and remained in effect until 1974. From 1963 through 1974 the OSSA associate administrator controlled all the elements essential to the management of space sciences, that is, the science program content, the budget, the transportation system, and the institutions involved. Even tracking and data acquisition, though the

province of another associate administrator, were managed by the OSSA centers, GSFC and JPL, giving OSSA effective control of all the infrastructure required to conduct the science program.

This situation changed in 1974, when the Administrator placed the NASA field centers under an Associate Administrator for Center Operations and transferred expendable (unmanned) launch vehicles to another program office. The Office of Space Science (having relinquished Applications in 1972) now had to secure institutional and other infrastructure resources from others. For the next eight years, the centers reported centrally (from 1974 to 1978 to the Associate Administrator for Center Operations and from 1978 to 1982 to the Administrator himself).

The reorganization of 1982 returned institutional responsibility to the program offices, with OSSA regaining responsibility for GSFC and JPL. When the science programs were split in late 1992, institutional responsibility for GSFC went to the Office of Mission to Planet Earth and responsibility for JPL went to the Office of Space Science.

Appendix J provides a current organization chart for NASA.

In May 1994, NASA published a new strategic plan. This plan was refined and re-released in February 1995. A major feature of these new plans was the introduction of the "strategic enterprises." These enterprises form the framework in which strategic planning for the agency is being conducted. The division of NASA's programs into these separate categories explicitly reflects the new orientation toward serving external "customers"—agency analysis concluded that different elements of NASA's overall program served distinct external customer communities, and the enterprises are structured to focus on the specific needs and interests of these communities. Thus, the enterprises were devised as a planning aid for agency strategic planning. In the words of the 1995 plan:

The NASA Strategic Plan establishes a framework for making management decisions by separating key Agency activities into the distinctly different categories of externally focused Strategic Enterprises and internally focused Strategic Functions—ends and means. . . . Each of our Strategic Enterprises are analogous to strategic business units, employed by private sector companies to focus on and respond to its customers' needs. Each Strategic Enterprise has a unique set of strategic goals, objectives, and concerns with a unique set of primary external customers.⁷

NASA's analysis of its "customer base" led to the definition of five strategic enterprises: Mission to Planet Earth, Aeronautics, Human Exploration and Development of Space, Space Science, and Space Technology. Three major supporting "strategic functions" were identified: Space Communications, Human Resources, and Physical Resources. The strategic function and enterprise framework is illustrated in Figure 2.1, which also shows top-level results of the agency's customer analysis and its relationship to the strategic enterprises.

The mapping of NASA's three major science offices and their flight projects and research programs into the strategic enterprises is straightforward: the Office of Space Science into the Space Science Enterprise; the Office of Mission to Planet Earth into the Mission to Planet Earth Enterprise; and the Office of Life and Microgravity Sciences and Applications into the Human Exploration and Development of Space Enterprise, which it shares with the Office of Space Flight. These two program offices share Human Exploration and Development Enterprise leadership.

Initially, the enterprises were essentially a planning overlay onto the traditional program offices, but NASA is using them increasingly as its primary management entities. The development and evolution of the strategic enterprise approach are determined from, and in turn influence, NASA's relationships with outside communities, and an understanding of this approach is crucial background to many of the committee's findings and recommendations.

Establishment of the enterprises does not address split program and institutional management

⁷NASA, *NASA Strategic Plan*, February 1995, pp. 4 and 6.

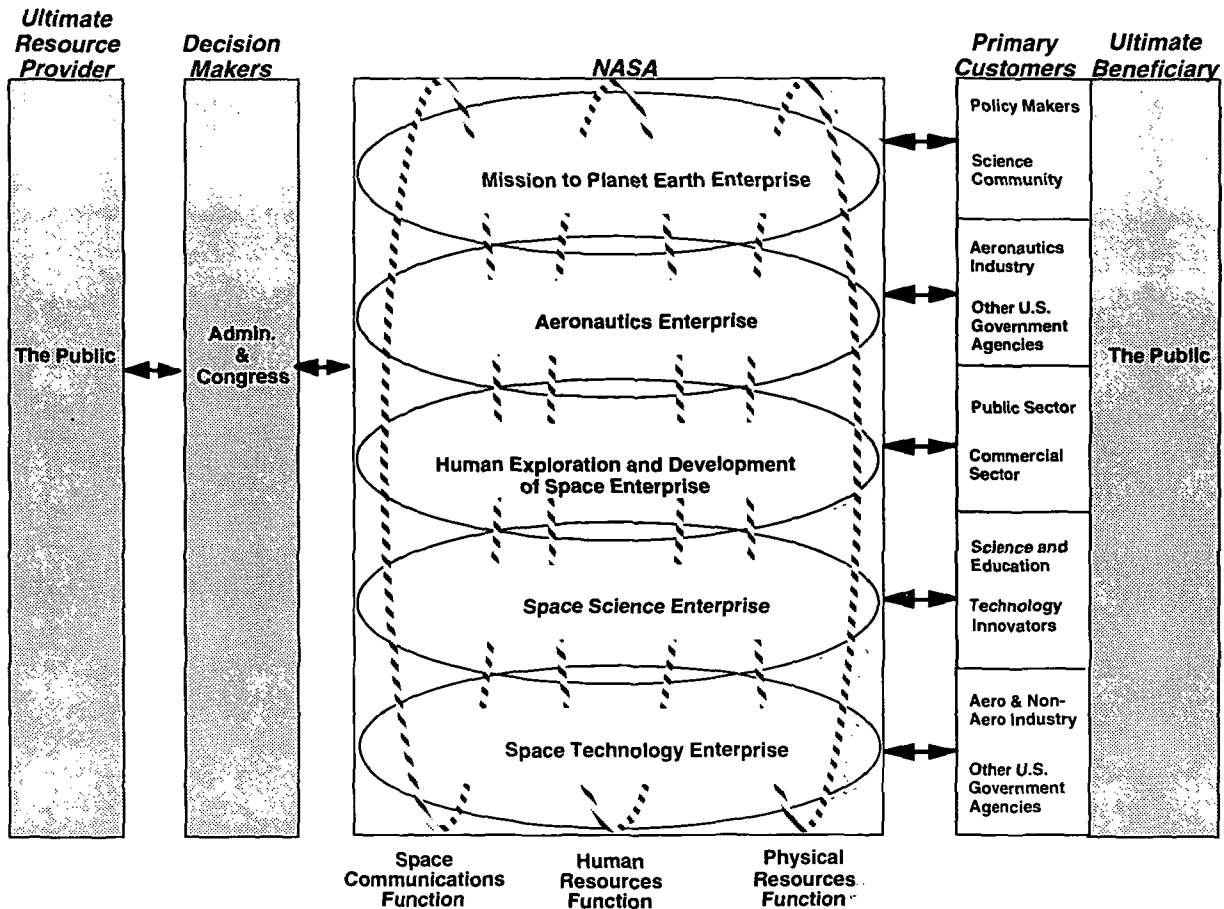


FIGURE 2.1 NASA strategic plan framework. SOURCE: 1995 NASA Strategic Plan.

responsibilities at field centers. While there is some move toward consolidation of individual science programs at fewer centers, there is little likelihood that programs will be so concentrated as to be conducted exclusively at one or more centers dedicated solely to that program. In particular, Earth science, astrophysics, and space physics are all expected to remain major elements at GSFC, a center reporting institutionally to OMTPE; at the same time, no center reports institutionally to OLMSA, in spite of its life and microgravity science programs. Thus, the question of center reporting and center program alignment must also be addressed in examination of organizational alternatives.

Technology for Space Science

Technology development for the space sciences occurs in four NASA offices: the Office of Space Access and Technology (OSAT), the Office of Space Science (OSS), the Office of Mission to Planet Earth (OMTPE), and the Office of Life and Microgravity Sciences and Applications (OLMSA). These space science technologies in turn support all four of NASA's strategic space enterprises: Space Technology, Space Science, Mission to Planet Earth, and Human Exploration and Development of Space. The identification, development, and utilization of technologies for the space sciences ultimately depend on effective management and cooperation among these four offices.

Each of the four offices manages its technology development differently. OSAT is responsible for developing generic space sensor, vehicle, and system technologies for OSS and OMTPE. OSAT was created in September 1994 by merging the Office of Advanced Concepts and Technology (OACT) with

the Office of Space Systems Development. (OACT, in turn, had been formed in 1992 from the space portion of the Office of Aeronautics and Space Technology (OAST) and the Office of Commercial Programs. Prior to this, OAST had received many of the remnants of the Office of Exploration when that office was eliminated in 1993.) OSAT is now the only office in NASA's Space Technology Enterprise. Its four goals are to "[1] reduce the cost of access to space; [2] provide innovative technologies to enable ambitious, future space missions; [3] build capability in the U.S. space industry through focused space technology efforts; and [4] share the harvest of space technology with the U.S. industrial community."⁸ The second goal is common to each of OSAT's organizational predecessors and is of primary relevance to the present study. Within OSAT, the Spacecraft Systems Development Division has the responsibility for developing space science technology.

OSAT projects may span the needs of more than one office or of multiple divisions within an office, or they may address a specific need of a single science division. Until 1994, OSAT's strategy was to dedicate 40 percent of its budget to near-term projects (less than five years to deployment) and 60 percent to far-term projects. OSAT's current strategy is to devote 80 percent of its resources to near-term projects and 20 percent to far-term projects. In spite of this, OSAT's work in technology development for space science is, with a few exceptions, not tied to missions that are currently funded and under development by a science office.

The three science offices—OSS, OMTPE, and OLMSA—and their divisions have disparate levels of effort and organizational commitments to their advanced technology programs. In general, they undertake two types of technology development—(1) that which is part of an approved flight project and (2) Advanced Technology Development (ATD), which expands future capabilities or enables future projects. Budgets and management of the former are submerged within specific flight projects, while ATD projects appear under ATD accounts in OSS and OLMSA. OMTPE does not have a separate ATD account.

The Office of Space Science produced the *Office of Space Science Integrated Technology Strategy* (April 1994) to define its technology programs and plans. This strategy has been approved and its implementation begun. Each of the three OSS divisions (astrophysics, space physics, and solar system exploration) supports ATD projects that they have identified as necessary for future missions and works with OSAT to ensure that OSAT projects are responsive to OSS needs. Each division has an individual who is responsible for managing its ATD projects. OSS also has an assistant associate administrator dedicated to ensuring that the technology that OSS will need is being developed. OSS has negotiated a significant level of effort by OSAT, and the OSS Integrated Technology Strategy was developed with help from OSAT's predecessor, OACT. Funds within OSS for ATD are limited, but the OSS ATD program is organized, well-administered, and responsive to inputs from the external community.

In 1994 the Office of Mission to Planet Earth created a staff office for "Technology Innovation and Advanced Planning." This office is responsible for determining technology readiness, identifying infusion opportunities, and coordinating and prioritizing technology "push" and mission "pull" projects. Before establishing this office, OMTPE did not have its own ATD program, but negotiated its generic technology needs with OSAT's predecessors. OMTPE is evolving a process for identifying and developing new technologies and infusing them into its flight projects. For example, where OMTPE once focused primarily on sensor technologies for instruments, it is now a team member on the OSAT Small Satellite Technology Initiative (SSTI) program, on the OSS Future Micro-Spacecraft Initiatives, and on the New Millennium program. While progress is being made, OMTPE does not yet have an agreement with OSAT concerning OMTPE technology needs. They have not yet resolved how needs are to be identified and prioritized, how the technologies will transition from OSAT to OMTPE funding, or how new technologies will be demonstrated.

⁸OSAT Associate Administrator J. Mansfield, briefing, April 26, 1995.

The Office of Life and Microgravity Science and Applications has two divisions with responsibility for carrying out scientific research in space: the Microgravity Science and Applications Division (MSAD) and the Life and Biomedical Sciences and Applications Division (LBSAD). Most of OLMSA's space-based research takes place on the Space Shuttle, and a transition to the Space Station is expected later in the decade. Thus, OLMSA technologies for space science are not "spacecraft technologies," in the sense of OSS and OMTPE technologies. The primary focus of OLMSA technologies is to enable the study of physical phenomena that are unique to the space environment or that occur differently in space than they do on the Earth's surface. Both MSAD and LBSAD have small, in-house, ATD programs dedicated to near-term technology needs, and OLSMA has recently received from OSAT the responsibility, along with some funding, for advanced technologies in support of future human missions (e.g., advanced physicochemical life support systems and extravehicular activity suits). OSAT has traditionally done little work based on OLMSA's stated needs and currently shows little interest in its needs for new technology. While OLMSA and OSAT have had several draft technology development plans and agreements, they did not have an approved plan for increasing technology development work for life and microgravity sciences at the time of the current review.

THE BUDGET FOR SPACE SCIENCE AT NASA

Space Science Budgets

For the purpose of the present study, the space sciences are defined as the science elements of the program of the Office of Space Science and Applications in the years leading up to the 1992-1993 reorganization. This includes the traditional space sciences in the present Office of Space Science (astrophysics, space physics, and solar system exploration), the Earth sciences in the Office of Mission to Planet Earth, and the life and microgravity sciences in the Office of Life and Microgravity Sciences and Applications. Omitted are aerospace engineering sciences, which are managed in other program offices and generally relate to the means for conducting spaceflight programs, rather than to their goals.

The NASA budget graphically demonstrates the importance accorded to space science. Figure 2.2 shows, in constant 1994 dollars, the actual NASA budget from 1982 to the present, and funding to the year 2000 as projected in the President's budget submitted to the Congress for FY 1996. The funding curves divide the NASA budget in three parts: Space Science R&D, Space Science Support, and Other NASA. Space Science R&D funds are the R&D (budget category) funds allocated directly for space science programs as defined for the present study, that is, traditional space science, Earth science, and life and microgravity sciences. Space Science Support includes those costs from other budget categories that may be attributed to support of space science; they include an appropriate portion of civil service personnel, expendable vehicle launch, facilities, and tracking costs, as estimated by NASA. The category Other NASA encompasses all the rest, from aeronautics to Space Station and the corresponding support costs. Because the Shuttle is built and maintained for many national purposes, its costs are excluded from Space Science Support budgets presented here and included in the category Other NASA.

In Figure 2.2, the NASA total is seen to rise essentially monotonically to just over \$15 billion in 1992, after which it begins a decline to an expected level of \$12.5 billion by 2000 (as projected in the FY 1996 budget submission). This decline reflects recent and continuing efforts to reduce the federal budget deficit. Both Space Science R&D and Space Science Support climb correspondingly, with peaks around 1995 before they begin to decline. The FY 1996 President's Budget included a proposed "middle-class tax cut," which required additional budget reductions for agencies relative to their earlier plans. The total reduction for NASA came to about \$5 billion for fiscal years 1997 through 2000, distributed over those years as shown in Figure 2.2 for the total.

Funding for the elements of NASA's Space Science R&D program, Traditional Space Science R&D, Mission to Planet Earth R&D, and Life and Microgravity Sciences and Applications R&D, is shown in

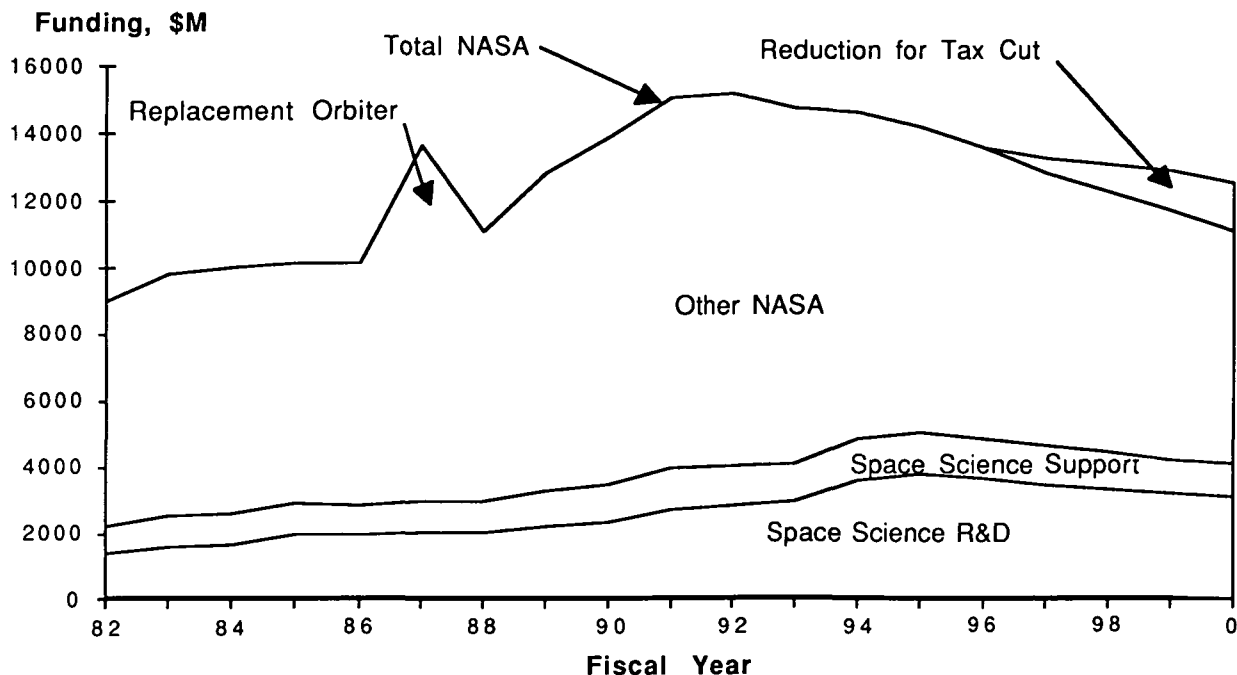


FIGURE 2.2 NASA funding for Space Science R&D, Space Science Support, and Other NASA (constant 1994 dollars; FY 1996 and beyond are projections from FY 1996 Administration budget). Shuttle costs are not included in Space Science Support.

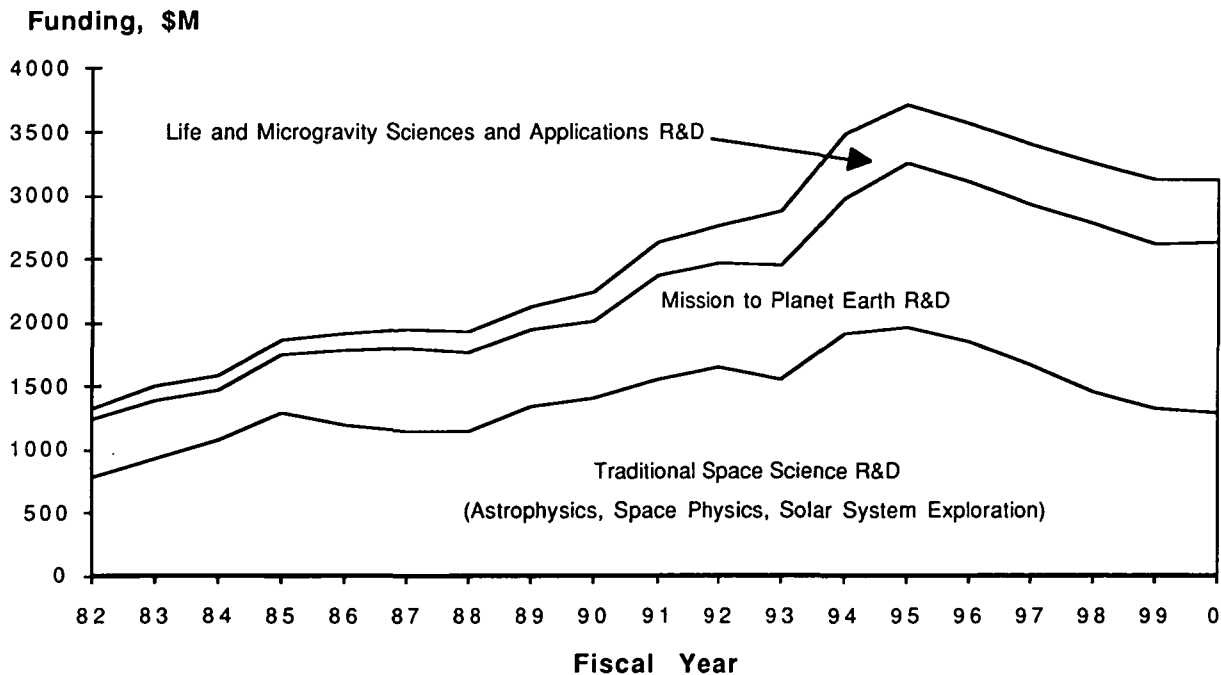


FIGURE 2.3 NASA funding for Space Science R&D components (constant 1994 dollars; FY 1996 and beyond are projections from FY 1996 Administration budget).

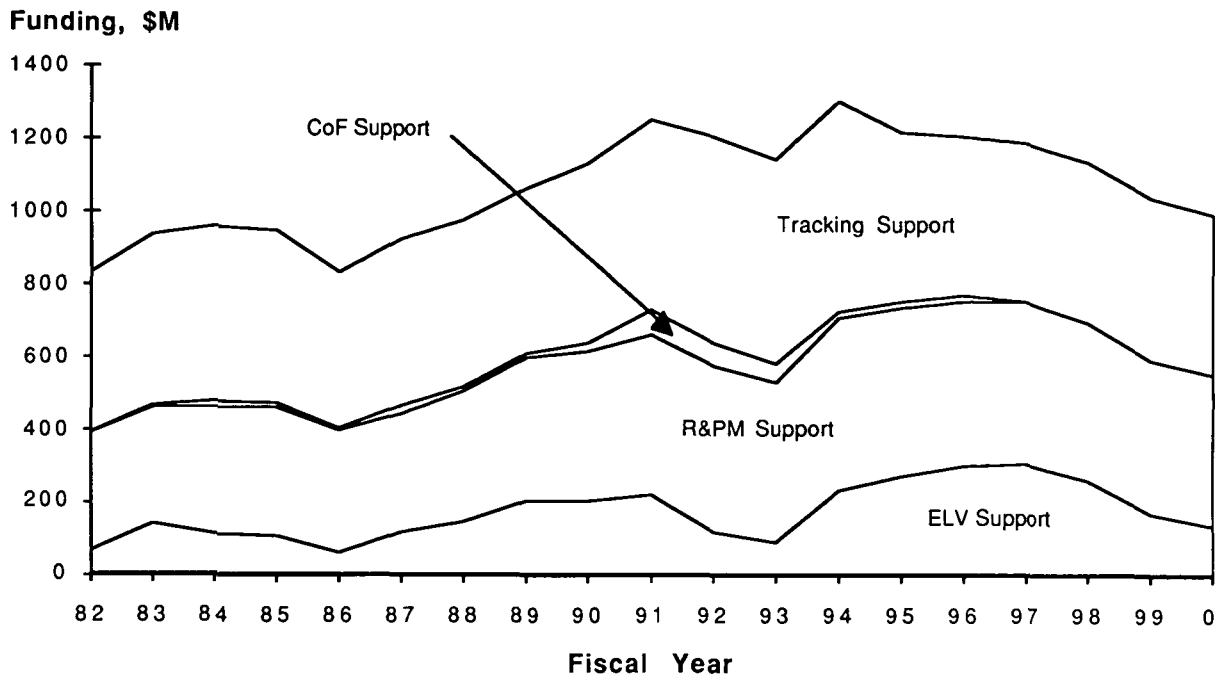


FIGURE 2.4 NASA funding for Space Science Support components (constant 1994 dollars; FY 1996 and beyond are projections from FY 1996 Administration budget). Shuttle costs are not included.

Figure 2.3. These data show the peak funding for the total reaching nearly \$4 billion in FY 1995, with a drop-off to just over \$3 billion by FY 2000. However, the individual components show that the latter two R&D elements remain roughly constant (at approximately \$1.3 billion and \$0.5 billion, respectively) for the last half of the present decade while R&D funding for the Traditional Space Science R&D program declines during the same period by about 35 percent, that is, from about \$2 billion to about \$1.3 billion. This decline results largely from completion of the Advanced X-ray Astrophysics Facility and the Cassini spacecraft and does not include initiation of any new activities of comparable scale.

The components of Space Science Support are detailed for the same years in Figure 2.4. Figure 2.5 shows Space Science R&D and Total Space Sciences (defined as the sum of Space Sciences R&D and Support) as a percentage of the total NASA budget for the same years as displayed in the other figures. During this period, Space Science R&D averages 20 percent of the total NASA budget, a figure frequently cited. In detail, it is seen here to have grown beyond that value by FY 1994, reaching a level of about 25 percent at the present. It is projected to remain there through the year 2000.

Clearly, up to the present, the space science budget has reflected the importance ascribed to science by the Space Act and subsequent reports cited above. However, the coming years will be a period of transition for NASA science, with shifting priorities among the sciences and with great pressure on the NASA budget as a whole.

Technology Budgets

The strategy of using new technologies to counter shrinking budgets will require that NASA invest more, and with greater effectiveness, in acquiring or developing relevant technologies. Figure 2.6 shows the funding levels at NASA in support of technology for the space sciences in FY 1992 and 1995. In the last three years the NASA science and technology offices have responded unevenly. OSS has increased its ATD investment, while OSAT's work on behalf of OSS has decreased. OMTPE's ATD investment

Percent of NASA Total

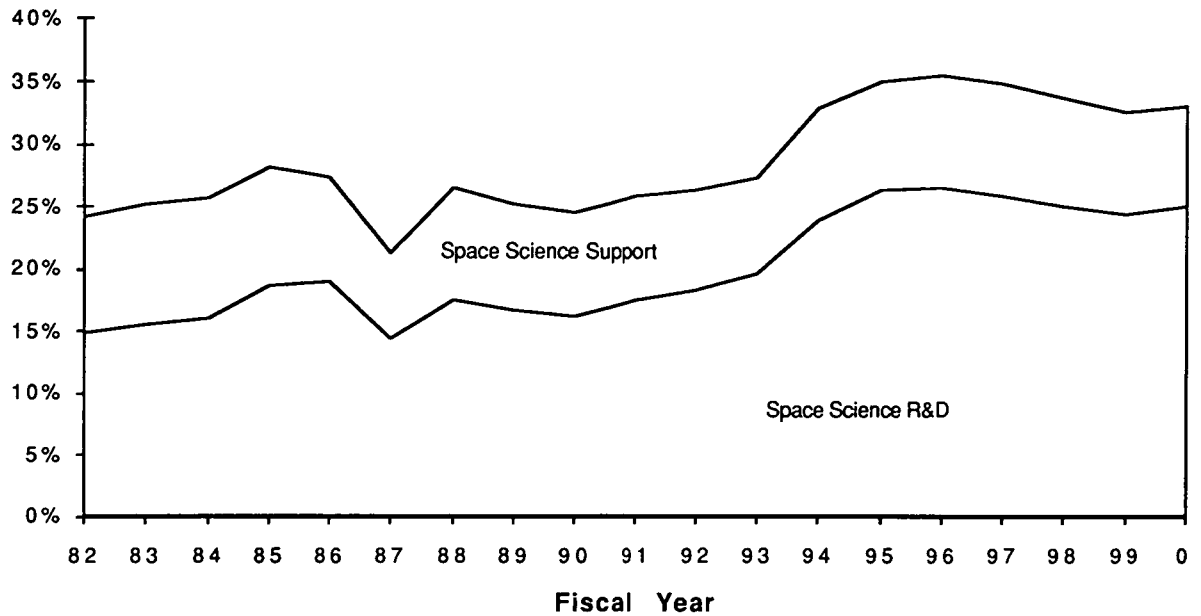


FIGURE 2.5 NASA space science funding as a percentage of total NASA funding. Shuttle costs are not included in Space Science Support.

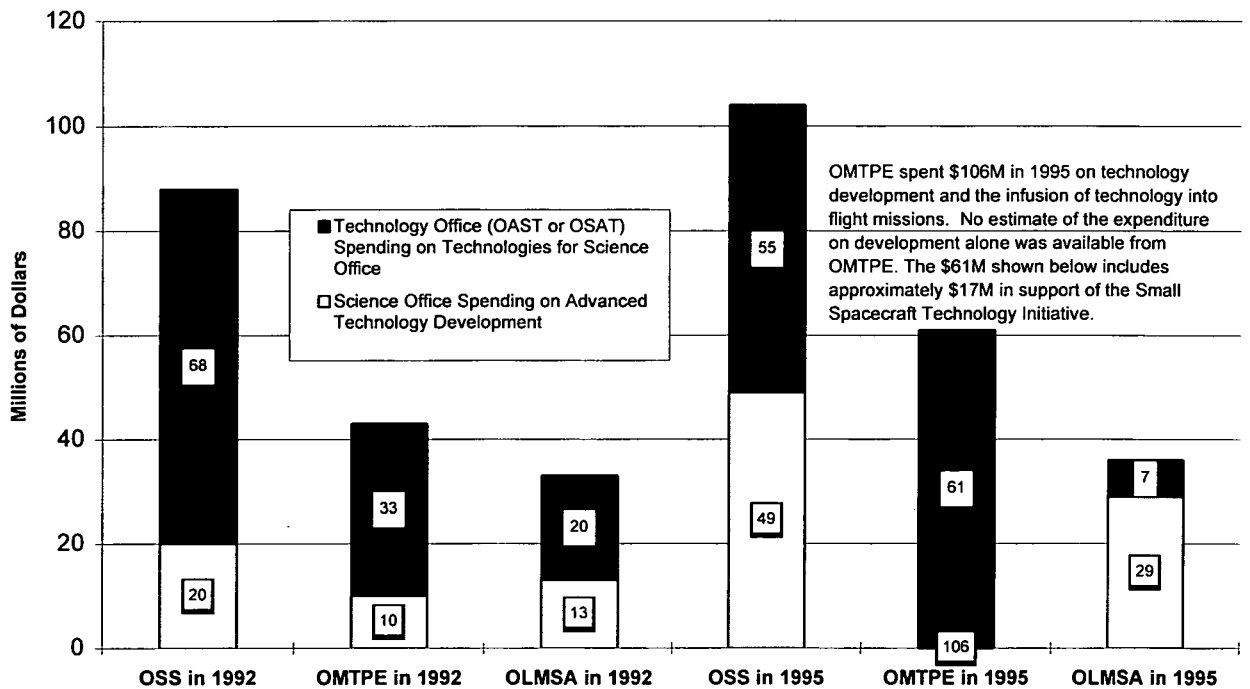


FIGURE 2.6 FY 1992 and FY 1995 NASA spending on technology for the space sciences (then-year dollars). FY 1992 budget data are based on the OSSA divisions that existed at that time, prior to the establishment of separate NASA Offices for Space Science, Mission to Planet Earth, and Life and Microgravity Sciences and Applications. Also, an additional \$7 million that OAST spent on OSSA needs in FY 1992—for high-performance computing and systems analysis—is not allocated above to the successor offices of OSS, OMTPE, and OLMSA.

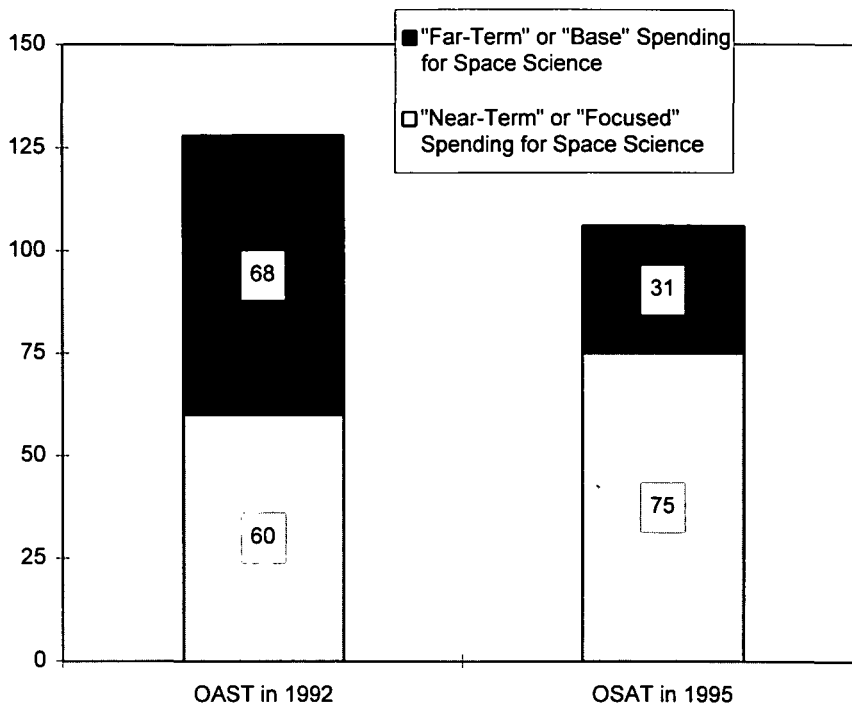


FIGURE 2.7 FY 1992 and FY 1995 Technology Office spending on the space sciences (near-term and far-term) (then-year dollars).

has remained difficult to quantify, while work on behalf of OMTPE has increased. OLMSA's ATD programs have remained small, but overall technology development spending at OLMSA has increased, due partially to the transfer of some technology responsibilities from OSAT to OLMSA. OSAT's work on OLMSA's stated science needs currently constitutes just a few selected efforts. Figure 2.7 shows that during this same period OSAT has shifted its funding to near-term needs from far-term needs. The total funding for FY 1995 devoted to advanced technology development, demonstration, and infusion related to the space sciences is clearly increased over that in 1992, but is not convincingly adequate to support NASA's current goals for rapidly developing and infusing new technologies into flight missions.

NASA SCIENCE RELATIONSHIPS

Throughout its 37 years, NASA has maintained a wide range of relationships with other parties, both in the United States and abroad, in the conduct of its programs, including those in the space sciences. The interactions between NASA and these other parties are of three general kinds: (1) cooperative partnerships with others to achieve direct scientific objectives; (2) arrangements in which NASA provides scientific information, instruments, or equipment to others, on either a reimbursable or non-reimbursable basis, for use in achieving scientific objectives; and (3) arrangements in which NASA obtains research from others on either a reimbursable or non-reimbursable basis. The first two kinds and the non-reimbursable arrangement of the third kind are generally established by international or interagency agreements and are most often established (for NASA) at the Headquarters level. The following discussion sketches their number and range. Reimbursable arrangements of the third kind consist of awards of grants or contracts for the conduct of research, and these can be executed at either Headquarters or a NASA field center.

International Agreements

The largest number of agreements for cooperative activities are international agreements, either with agencies of other nations or with one or more international agencies, such as the European Space Agency (ESA). Some international agreements are of such importance that they are established by exchanges of diplomatic notes or by government-to-government agreements, in some cases executed even by heads of state. In cooperative agreements, each party agrees to certain actions toward a mutual end. Generally, no funds or other resources change hands; that is, each party funds its own part of the cooperative activity, and all the parts are coordinated to achieve the joint goal. However, some agreements include provisions for the furnishing or loan of instruments or equipment by one party to the other.

Over the years, several thousand international agreements have been successfully concluded and implemented. Many of these agreements, such as Helios, were made to accomplish Administration or State Department goals and then jointly modified by OSSA and its foreign counterpart to maximize the scientific results of the mission. At present, more than 400 are in place with about 140 national agencies and other foreign bodies in more than 40 countries. A great many of the agreements are aimed at achieving space science objectives, ranging in scope from the mundane (e.g., bilateral technical document exchange programs) to the exotic (e.g., Solar Probe, a potential joint mission with Russia to explore the Sun's corona). All of the space sciences are represented among these agreements, with particular emphasis on cooperative endeavors in astrophysics, space physics, and solar system exploration with ESA and its member nations, as well as with Russia and Japan. Life science is prominent in the agreements with Russia, which has extensive experience in long-duration human spaceflight. Once barriers obstructing access to these life science data are overcome and differences in objectives and protocols are compensated for, these data could provide much information for research on the effects of the space environment on humans and on countermeasures. Earth science agreements are in place among many nations, including many of the smaller nations interested in environmental and resource surveys (e.g., collection of environmental data with Mongolia).

While the great majority of the international agreements are for the achievement of scientific objectives, some have been aimed at international—even global—policy issues. For example, an international meeting in 1987 leaned heavily on the results of space research to develop the “Montreal Protocol on Substances That Deplete the Ozone Layer.” That protocol and several revisions to it deal with reduction of the use of chlorofluorocarbons (CFCs) as a means to counter the reduction in stratospheric ozone.

Interagency Agreements

Interagency agreements include agreements both with other agencies of the federal government and with agencies of state and local governments. Approximately 600 such agreements are currently on the books; the partners are the 11 cabinet departments, the military services, various other federal agencies, and elements of the governments of 14 states and Puerto Rico. Science is widely represented among these agreements, although many agreements, especially with the military services, relate to aeronautics and to joint operations of space infrastructure elements. A number of agreements with the National Science Foundation are aimed at astrophysics and space physics, and life science is the subject of a number of research agreements with the Department of Health and Human Services. Earth science is a key element of agreements with the Departments of Agriculture, Commerce (NOAA), and the Interior and with the Environmental Protection Agency.

The long NASA/NOAA relationship provides an excellent example of interagency partnership. For the first 20 to 25 years of the U.S. civil space activities, NASA and NOAA worked cooperatively toward the development of satellites to serve the weather forecasting responsibilities of NOAA. NASA conducted most of the R&D related to NOAA requirements. It oversaw the construction, launch, and

check-out of operational satellites and then turned their operation over to NOAA. With termination of the Operational Satellite Improvement Program in 1982, NASA stopped its R&D for sensors and instruments meeting NOAA requirements, except where NASA requirements were also met. Today, NASA, NOAA, and DoD are cooperating in merging civil and military meteorology satellite systems. In the new partnership, DoD will lead in systems acquisition, NOAA in system operations, and NASA in new technology development. Although NASA will contribute four staff members to the integrated program office, including the Assistant Director for Technology Transition, it will contribute no program funds. Full convergence of the programs is expected by 2005, including a European component.

The Office of Mission to Planet Earth will employ the Earth Observing System (EOS)—an extensive set of sensors on several platforms in low Earth orbit—to monitor, for 15 years, elements of the atmosphere, oceans, and land for climate change research. Data from EOS will be archived and disseminated by the EOS Data and Information Service (EOSDIS). While NOAA also pursues research in climate change and has its own satellites and data and information system (the National Environmental Satellite Data and Information System—NESDIS), there have not been serious attempts to converge these programs where objectives or hardware could be shared. Although some of the EOS instruments are thought of as precursors to NOAA operational instruments and a mature EOSDIS would be operated by NESDIS, NOAA has expressed reservations about absorbing these technologies because it perceives them to be unsuited to its operational program.⁹ An operational transition might have been easier if NOAA and NASA had originally sought common ground through a technology planning process for their sensors, satellites, and data management systems.

Management Considerations

The great majority of the agreements, whether international or interagency, are negotiated at the NASA Headquarters level. On the NASA side, they involve the program office having responsibility for the program or activity involved and an appropriate staff office having responsibility for facilitating interactions with the partner. Field center staff may also be involved, but the lead in these agreements is usually with Headquarters. International agreements are the responsibility of the International Relations Division of the Office of External Relations, which also interfaces with the Department of State, the Office of Science and Technology Policy (OSTP), and other agencies as needed for interagency review and coordination purposes. Interagency agreements (both defense and civil sector) are the staff responsibility of the Defense Affairs Division of the Office of External Relations.

Because of the policy nature of international and interagency agreements and the growing mandate for international collaboration, responsibility for these agreements appears to be a necessary Headquarters function. Adequate staff must be provided to support their establishment and successful implementation.

HOW OTHERS MANAGE SCIENCE AND ASSOCIATED TECHNOLOGY

Appendix F describes research management approaches of four other government agencies—the National Science Foundation (NSF), the National Institutes of Health (NIH), the Department of Energy (DOE), and the Advanced Research Projects Agency (ARPA) of DoD. The approaches of NSF, NIH, and DOE are compared here to those of NASA's science programs, while ARPA's approach is more appropriately compared to that of NASA's advanced technology program.

⁹NRC, Committee on Earth Studies of the Space Studies Board, *Earth Observations from Space: History, Promise, and Reality*, 1995, in press.

Science—NSF, NIH, DOE, and NASA

NSF broadly supports basic research in science and engineering, focusing on three general types of research: support for individual investigators or small groups (the dominant type); support for large groups, field operations, and centers (such as the Engineering Research Centers); and support for national user facilities (such as telescopes, oceanographic research vessels, and particle accelerators). Unlike NIH or DOE, NSF neither conducts research or development nor constructs or operates any research facilities itself, that is, with NSF employees. Although NSF does own a number of major research facilities, it operates them by using contractors, which are almost exclusively universities or university consortia.

With the mission to improve the health of the people of the United States and other nations, NIH is the largest single supporter of basic and applied biomedical research in the world. The major structural units of NIH are its 17 national institutes, each with its own authorizing legislation and appropriation. Most have an “extramural program” component and an “intramural program” component, each reporting to the institute director. The extramural programs provide support to the external community through a variety of grant and contract instruments. The intramural program, included in all but one of the institutes, supports scientists working in federal laboratories and accounts for 11 percent of the NIH budget.

The DOE programs are basic and applied science and engineering in energy-related fields. DOE’s research is carried out in its national laboratories and in an extensive extramural program. Most of the basic research efforts make use of large facilities at the laboratories, such as particle accelerators, nuclear reactors, synchrotron light sources, and electron microscopes. Though located at the national laboratories, these facilities are operated for the benefit of the entire user community—scientists at universities, other laboratories, and industry, as well as the in-house staff. Applied research (energy programs, environmental cleanup, and defense programs) work is generally carried out at the DOE laboratories.

NASA and these three organizations make extensive use of peer review in the selection of proposals for funding. NIH employs a two-level “outside” review process for its extramural research program, the bulk of its program. The first level is a scientific and technical review by outside scientists who are peers of the proposers and who evaluate based solely on scientific merit. The second level is conducted by National Advisory Councils, composed of both scientists and members of the general public, and considers program relevance as well as scientific merit. Proposals surviving both rounds of review are eligible for funding, although resource limitations preclude support of all eligible proposals. Although NSF employs the peer review process for proposal ranking, NSF program managers have some flexibility in making award decisions because the reviews and reviewer rankings and comments are considered advisory. DOE has very extensive scientific research programs in both basic and applied areas. Peer review is extensively used in evaluating the basic research, but less so in applied programs. Budget decisions are made by program officers at DOE Headquarters.

NASA’s peer review system, both for proposals responding to NASA research announcements (NRAs—generally to conduct ground-based or suborbital flight research) and for those responding to announcements of opportunity (AOs—to conduct investigations on a flight project), is similar to that of the NSF. The peer review rankings are considered advisory, though given considerable weight. Funding decisions are then made by program managers, at the division director level for NRA proposals and at the associate administrator level for AO proposals. Prior to reaching the associate administrator for decision, AO proposals must also be reviewed by an internal NASA program review panel, which considers not only scientific merit but also programmatic factors.

NASA’s science program involves one feature, major flight projects, not present in the programs of the other three agencies. Although the NASA ground-based, suborbital, Explorer, and Discovery programs are largely determined by the peer review process outlined above, the larger flight projects require separate Administration and congressional approval and are subjected to separate internal review and approval processes. Individual flight investigations to be carried on these missions are selected by

peer review, but approval of the project itself involves many other factors (e.g., economic, national, and international policy) as well. These major flight projects are somewhat analogous to major NSF and DOE facility projects.

In NASA the scientists at its field centers generally compete with scientists from the outside, both for flight investigations and for ground-based research, and their proposals face the same peer review. (Recently, this principle has been expanded within the agency's life sciences programs.) NASA scientists also carry out institutional service functions, being responsible at Headquarters for the scientific aspects of Headquarters-managed programs and at the centers for an analogous role in flight projects and missions.

As noted, NSF does not itself conduct research and development. NIH does conduct in-house research (its intramural program) at federal laboratories, but the great majority of its research is extramural. Of the agencies considered, DOE comes closest to resembling the NASA model of having major in-house institutions while sponsoring extensive out-of-house research. DOE differs from NASA in that the national laboratories (its "field centers") are all government-owned, contractor-operated (GOCO) facilities like the Jet Propulsion Laboratory. There are no civil service employees at DOE laboratories. The laboratories that emphasize basic research in their missions are generally operated by universities or by university consortia. Others are operated by industrial organizations. This has been a strength of the DOE research effort and is one of the reasons for the interest shown by other agencies in the GOCO mode of operation.

Advanced Technology—ARPA and NASA

By design, the program of ARPA addresses science and technology at the high-risk, high-payoff frontier of defense research science and engineering. When it was created, ARPA did not establish a research institution to conduct its activities, choosing instead to seek out the most able investigators wherever they could be found. Because of the national importance of its projects and the frontier nature of their scientific content, ARPA has been able to attract the most capable scientists, engineers, and project managers to participate. A typical project lifetime is three or four years, after which its team may be disbanded, leaving ARPA no further obligation to fund it. Thus ARPA avoids the burden and inflexibility of maintaining a captive scientific workforce in a dynamic research environment.

ARPA policy has been to provide term appointments to its program management staff, which is composed of discipline scientists and engineers from the research environments in which ARPA works and of technically trained military officers. Typically, terms are for three years, with the option of up to two one-year extensions at the ARPA director's discretion. Motivation to serve in these positions is high because of the dynamic research setting, minimal bureaucracy, and the significant discretion given the managers in spending \$10 million to \$20 million per year on projects agreed upon with the director.

ARPA projects are selected for their relevance to DoD's mission, overall national importance, and potential for order-of-magnitude performance improvements. Program managers have considerable autonomy in selecting projects, and peer review is not employed because of the belief that it would lead to incremental, rather than revolutionary, advances. The processes employed by ARPA in supporting such research are less formal than those of other agencies. The success of the ARPA program in such areas as space surveillance, high-energy laser weaponry, and computer network communications testifies to the success of this approach and suggests that an optimal scientific research program could employ elements of both peer-reviewed research and exploratory research outside of conventional thinking.

As outlined above, advanced technology in NASA is the responsibility of both the mission program offices (OSS, OLMSA, and OMTPE for space science) and the Office of Space Access and Technology (OSAT). The mission offices typically focus on technologies for instruments and sensors and technologies for projects in development and those likely to be initiated in the near future. OSAT generally

addresses technologies that cut across the responsibilities of the mission offices (e.g., spacecraft system and subsystem technologies, launch technologies) and exploratory technologies potentially applicable to missions of the more distant future. In both areas, NASA exercises field center capabilities in carrying out technology projects, either as in-house projects or through contracts with outside sources. The exploratory technology program of OSAT most nearly resembles the ARPA program in purpose—advancement of potentially high payoff technologies for future space missions. But the way it is conducted is quite different, relying, as it does, on an essentially permanent management staff in Headquarters and a large, also permanent, research establishment at the field centers.

The Changing Environment for Science at NASA

The conditions under which NASA now operates are vastly different from those that existed when it was founded and under which many of its ground rules and traditions were established. Recognizing these differences is essential to deriving a new set of operating maxims. Addressed below are the changes in the environment that are especially relevant to the sciences.

RATIONALE FOR SPACE SCIENCE

Space science began with the use of sounding rockets immediately after World War II and rapidly evolved with the advent of satellites—indeed, the first satellite was scientific, conceived in conjunction with the International Geophysical Year. A major boost came with the creation of NASA and with the “space race,” leading to a vigorous exploration program consisting of planetary, space physics, and astronomical missions. Initially, most scientific investigations were carried out primarily for science’s sake. Later, when NASA was a major player in space applications programs and especially in those years when science and applications resided in the same program office, Earth science was conducted with an eye toward useful applications as well as for science’s sake. Nevertheless, even there science was the dominant rationale.

Today there is an increased interest in applications of scientific advancements for direct public and commercial benefit and in transfer to the larger technical communities of technological innovations stimulated by science missions. Ironically, when space applications programs were turned over to the mission agencies (e.g., NOAA), some of the more effective linkages between science and technology were lost, so that the utility of space applications programs has diminished, counter to prevailing policy.

BUDGET ISSUES

Much of the planning for space science in the late 1980s assumed continued real total budget growth and maintenance of science at the level of 20 percent of the total NASA budget. Now it has become clear that the best that can be expected is a level budget in current (“then-year”) dollars, and thus a declining budget in real terms. Indeed, in the President’s Budget for FY 1996 submitted to the Congress in February 1995, the budget for NASA is projected to fall by about 8 percent by the year 2000 in current dollars, almost 20 percent in real terms. The corresponding decrease in the real science budget is almost as large, about 16 percent for science R&D and science support, taken together (see Figure 2.2). While

the budget plan for the next five years seems to reflect a continued high priority for science, the fencing-off of the International Space Station at a fixed annual level of \$2.1 billion and the Space Station's essential need for Shuttle support potentially expose NASA's science programs to further budget reductions.

The space technology budget is equally vulnerable. New spacecraft and instrument technologies offer the potential for more productive science missions at lower cost, yet this potential may not be realized without adequate investment in the development of those technologies. Further, the space technology program includes the NASA part of advanced launch vehicle development. Though that program offers to eventually lower costs for transportation to space, it will, for the near future, compete for already limited technology funds.

THE CHANGING CHARACTER OF MISSIONS AND TECHNOLOGY

Missions

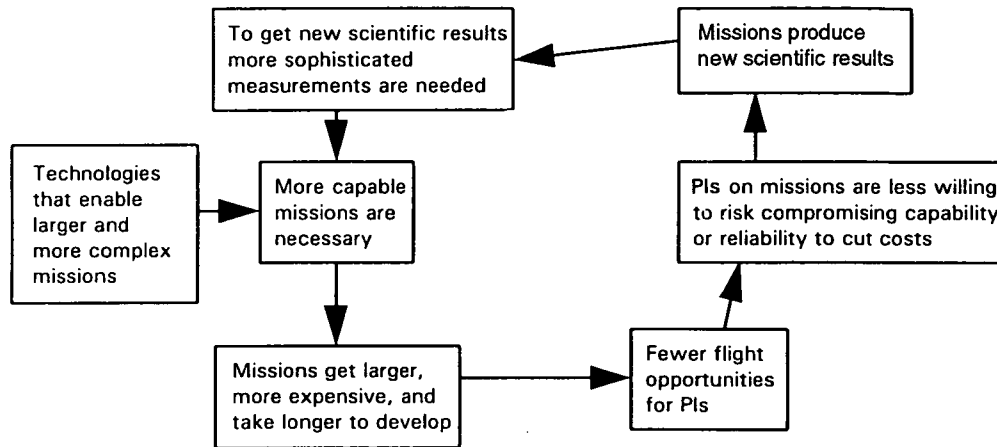
The early NASA spacecraft programs were implemented relatively rapidly and inexpensively, two- to three-year developments being the norm. As the space sciences matured during the 1970s and 1980s, the expanding knowledge base exerted pressure for more sophisticated measurements and more capable missions. These demands, along with administrative delays, led to greater expense and to longer projects. Where most cradle-to-grave project lifetimes during the Apollo era were a few years, major projects started in the late 1970s through the early 1990s often extended over a decade. By the 1980s, with "flagship" missions costing a billion dollars or more, it became evident that very few such missions could be mounted; that if they were, there would be no room for complementary missions; and that if they failed, their loss would be highly damaging. Higher costs and longer projects meant that individual investigators had fewer flight opportunities. Principal investigators of large projects became less willing to risk compromising quality, capability, or reliability to reduce mission costs. Because new technologies often appear risky, managers were wary of using them on very large space science projects, dampening the infusion of new technologies. Figure 3.1 shows schematically the large mission approach that prevailed at NASA until recently, an approach that led to sporadic, but often ground-breaking or astounding scientific results.

Ultimately, the evolution toward ever larger and longer projects became unsustainable and led to a backlash toward "smaller, faster, cheaper" missions. When combined with today's diminishing budgets, the 25-year ratcheting growth of mission cost and duration has reduced flight opportunities in many disciplines to the point where it has become difficult to maintain scientific vigor. While in some disciplines big missions may be necessary to produce seminal science, small projects are the seed corn in many others. Small projects are incubators of new ideas and of new scientific talent, and the exposure of student scientists and engineers to NASA technologies through small projects is a very effective mechanism for technology transfer.

One early response was the creation of the Planetary Observer concept for a series of somewhat smaller planetary exploration missions to be funded annually at about a constant level, analogous to the Earth-orbital Explorer family. (This concept for an annually funded series was never developed according to original precepts, and only the ill-fated Mars Observer mission was implemented.) Later, advisory groups also concluded that, while some objectives might only be achievable through large missions, a larger number of small missions could offer significant scientific advancements in reasonable time scales while encouraging technological innovation.^{1,2}

¹ Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990.

² Vice President's Space Policy Advisory Board, *The Future of the U.S. Industrial Base*, November 1992.



Total Elapsed Time: ~ 10 years

FIGURE 3.1 The past approach to space science missions.

When budget constraints became even tighter, the need for still smaller missions was recognized for FY 1992 planning in space physics, where a series of “intermediate missions,” missions costing on the order of \$200 million, was proposed. Solar system exploration joined the trend to smaller missions with the Discovery program; restructuring of the Explorer program (astrophysics and space physics) to focus on small and medium Explorer missions was also begun. Not only fiscal constraints, but also the occurrence of cost overruns, delays, and failures of the larger missions, with the attendant high cost penalty (e.g., Mars Observer, Hubble Space Telescope corrective optics), contributed to the trend toward smaller missions at a higher flight rate. Upon his arrival at NASA in spring 1992, Administrator Daniel S. Goldin accelerated the trend toward “smaller, faster, cheaper” missions employing advanced technologies, carefully focused mission objectives, lower-cost launch vehicles, simpler management techniques, and, where appropriate, reduced management oversight.

The foregoing discussion of the trend from large missions to “smaller-faster-cheaper” in space science does not answer the important question of whether the approach now being taken will yield more or less “science per dollar.” In spite of the many obvious advantages of a frequent flight rate, this is a complex issue and outside the scope of the present study. Rather, the changing mix of mission sizes was taken as a given for the purposes of analyzing management options for NASA’s space science program.

Technology for Space Science

During the heyday of the large missions, one consequence of the intense competition for costly flight projects was to encourage the Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL) to build up in-house science and engineering competence that could conceive, develop, and fly flagship missions. Unwelcome by-products of this apparent self-sufficiency were isolation of the flight centers from outside technologies and domination of flight projects by in-house perspectives on technology. Such insularity is counter to the premise that science is strengthened by open access to ideas and technology. It is also counter to the premise that NASA scientists enable science in space for the broader scientific community.

NASA has recognized these problems and is using technology to encourage industry and university participation in new programs such as Discovery, Small Explorer (SMEX), mid-size Explorer (MidEX),

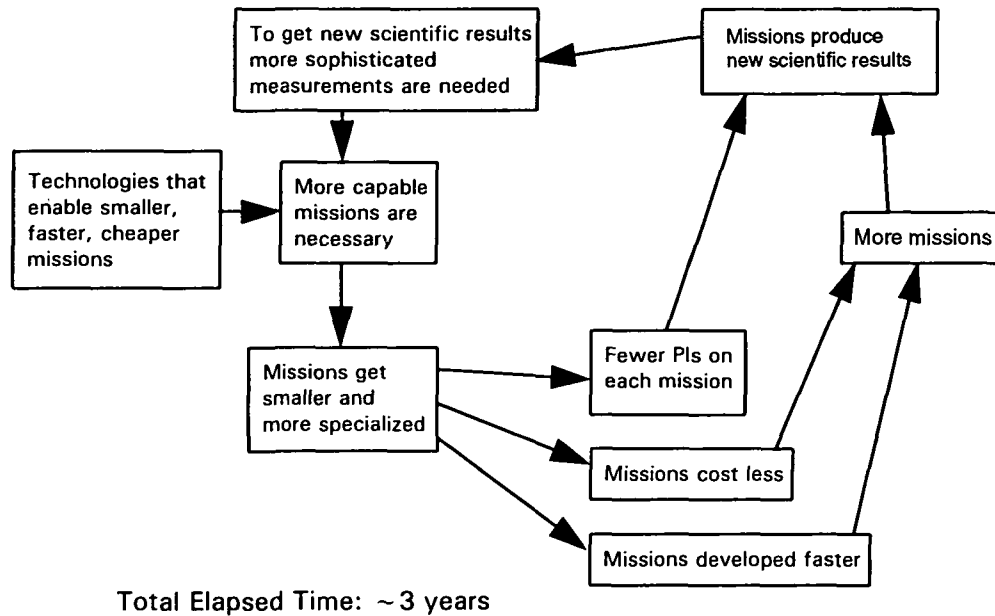


FIGURE 3.2 The current approach to space science missions.

Small Satellite Technology Initiative (SSTI—the Lewis and Clark projects), and New Millennium. To achieve higher flight rates at lower costs, NASA proposes across-the-board efforts to incorporate new technologies in flight and ground hardware and in processes for managing flight projects. NASA management has gone so far as to reject proposed flight projects that would achieve their scientific goals but did not include proposals for significant new technologies. The agency is also exploring innovative ways to accomplish significant science with smaller spacecraft. For example, it is investigating the feasibility of satisfying the need for large apertures and simultaneous observations with a constellation of small spacecraft. Not only would this avoid the cost and risk of large and complex platforms, but distributed observing systems offer the possibility of large synthetic apertures and their greater spatial resolution.

Figure 3.2 shows the new approach that NASA is now adopting to create an ongoing stream of scientific results by increasing the number of flight missions and increasing the use of new technologies.

THE GROWTH OF CAPABILITIES OUTSIDE OF NASA

NASA was formed in response to a political situation in which the United States was perceived as ominously lagging the Soviet Union in space capability. Space science became a major component of the emerging space program soon after. At that time, there was little expertise in either space science per se or in spacecraft or launch vehicle development anywhere but in government laboratories (e.g., the U.S. Army Redstone Arsenal, the Naval Research Laboratory, the National Advisory Committee for Aeronautics, and JPL). During the next several decades, capability in the space sciences was successfully fostered by NASA in the university community, resulting in a capability that in most areas of the space sciences equals or exceeds that present in government laboratories. Similarly, in spacecraft design and construction there are a number of competitive major aerospace contractors that have the capability to design, build, and operate major spacecraft. Recently, a number of smaller companies have been formed to concentrate on the small end of the spacecraft market. NASA no longer has a monopoly on technical competence; the balance of work between in-house and contracted effort must be reexamined.

A part of NASA's charter has been to transfer its technologies to U.S. industry to improve

international competitiveness and to U.S. universities to improve science and engineering education. NASA has been extremely successful in both of these areas. This transfer, when combined with the large investments in industrial space technology by DoD over the past quarter-century, has shifted leadership in many cutting-edge technologies from NASA toward industry and academia. NASA now possesses centers of excellence in particular technologies, but none of the NASA field centers is a world leader in every space technology.

NASA's culture has not evolved with these realities. The flight centers are insular, and flight projects are overly dominated by resident technologies and methodologies. The ethos of "not invented here" can go so far that technologies are not shared between GSFC and JPL and these flight centers do not seek technologies from NASA's research centers such as Lewis or Ames. When centers do not voluntarily communicate and work with each other, contractors with jobs at two or more centers often provide the only effective transfer of technologies among centers. The NASA Administrator is attempting to move this insular culture toward a recognition that NASA is now part of a larger technology community, that NASA is obligated to contribute to that community, and that it is wise to draw from it for its own programs.

Because NASA has not had an agency-wide technology planning effort since the 1991 Integrated Technology Plan, there has been no forum to involve industry or academia in global technology planning for the agency. In the past, NASA has tended to place its far-term technology investments in-house while allocating specific tasks associated with near-term development to industry and to the universities. The University Space Engineering Research Center program was an exception to placing far-term technology development in-house, but that program was mandated by Congress and ceased after only five years.

MANAGEMENT CHALLENGES

The management of science at NASA presents several challenges in today's environment. With the recent downsizing of Headquarters and the relocation of program management to the field centers, the potential exists to diminish both Headquarters' knowledge about the status of programs and its ability to defend them in the political arena. A second potential problem is conflict of interest, where centers could favor in-house capability over that existing in universities and industry. Assurances must be built into the evolving system that the entire procurement and selection process will be conducted without bias.

Another potential problem is that the crisper organizational division that now exists between NASA's strategic enterprises increases the possibility of greater fragmentation of the overall NASA program, leading to inadequate cross-enterprise cooperation and coordination. This would be especially detrimental to the relationship between the space science enterprise and the human exploration and space transportation enterprises, both of which have direct connections to the space sciences but could evolve in directions less supportive of the conduct of science.

The NASA strategic plan, which was updated in February 1995, provides important information on the agency's place in the nation's R&D environment and its planned contributions to national goals; it also explains the enterprise-based strategic planning framework that NASA has adopted. More recently, the office of the Chief Scientist has released a draft for comment of a new science policy document.³ This guide gives an overview of agency policy on a number of topics that are also discussed in the following chapters of this report, including the roles of the various participants in NASA's science programs and the agency's approach to assessing and maintaining quality.

³NASA, *Science in Air and Space: NASA's Science Policy Guide (Draft for Public Comment)*, July 1995.

Alternative Organizations: Analysis and Findings

PRINCIPLES OF SCIENCE ORGANIZATION

In addressing the issue of alternative organizations for the management of science in NASA, the committee's task group on alternative organizations focused on organizational structures that would produce the best possible quality of science given the present and likely future budget constraints. It identified a number of fundamental principles, or axioms, and goals, that characterize successful science management.

Axioms

1. **Accountability for Performance**—Science management must be accountable to higher management for achievement of programmatic or mission goals. Such a goal in the case of exploratory basic research may be a reasoned effort to understand nature. For research in support of a program or project, the timely (i.e., schedule-driven) completion of specific measurements or calculations may be required. Accountability must be accompanied by authority to make programmatic and budgetary decisions in pursuit of the goals.

2. **Separation of Program Approval from Program Execution**—The responsibility for program approval, including especially determination of whether the research is to be conducted in-house or out-of-house, should not be delegated to performing organizations, which might bias that selection toward in-house sources. If source selection must be so delegated for other reasons, controls to counter any such bias must be put in place.

3. **Involvement of Scientists in Management**—Scientific expertise is required for the effective management of scientific projects whether conducted in-house or procured under a contract arrangement (the "smart buyer" concept). Effective coordination of scientific goals with technical and engineering requirements is one of the prerequisites for the successful completion of technically complex scientific projects. Scientific expertise is needed to monitor the progress of projects, to evaluate their adherence to program goals, and to participate in trade studies necessitated by conflicts in budget, schedule, and science requirements.

4. **Maintaining Effective Relationships**—Successful science management requires effective relationships among science partners, performers, and eventual users of the scientific output.

5. Single Line of Authority—All direction, both program/project direction and ancillary functional direction, should come down to performing organizations from higher management levels through a single management chain. Decision making must be consistent with budget allocation, lest conflicts arise.

Goals

1. Quality of Science Output—A fundamental principle of successful science management must be that high-quality science be produced. Factors that contribute to high quality include informed and unbiased selection of the best performers and openness of the program to involvement by the scientific community in program planning and execution. As a corollary to achieving high-quality science, systems to evaluate that quality must be in place and must be used to constructively influence program activities. Evaluation systems include peer review for selection; visiting committees of scientific authorities to evaluate programs, projects, and institutions; performance reviews of individual performers; and such statistics as number of refereed publications.

2. Cost-effectiveness—Not only must the absolute quality of the science be high, but quality must be high in relation to program cost. High quality is achieved by the factors cited above. Low cost follows from reducing infrastructure costs (both workforce and facilities) to the minimum and eliminating excessive oversight of performers. Careful planning and management on the part of both managers and investigators are crucial to achieving high cost-effectiveness.

3. Responsibilities of a National Capability in Space Science—Science programs of an agency like NASA do not exist in isolation but must relate to the corresponding national interest in promoting national security, economic health, and societal well-being. NASA's programs must address maintenance of key national space science competences and capabilities, including those of the universities (research and education) and industry, as well as government. Planning and decision making must therefore address national—and perhaps even international—interests and capabilities along with narrower programmatic factors.

MANAGEMENT OF THE NASA SCIENCE ORGANIZATION

Chapter 2 briefly describes the way that space science is currently organized and managed in NASA. A number of changes have been or are being introduced concurrently with this study. Because of this, the recommendations that follow are stated so as to be broadly applicable and transcend the specific details of the organization.

The major imperatives for the recent and coming changes are the continuing pressure for budget reductions and the Administration initiative to reinvent government. These imperatives have led to a significant downsizing of NASA, now under way. An internal "Zero Base Review,"¹ the subject of briefings to Congress on May 19, 1995, concluded that the budget targets of the Administration can be achieved by reducing infrastructure costs (streamlining operations, reducing overlap, and so forth) without cutting programs or closing any of NASA's 10 major field centers.² Cuts beyond those in the budget submission are likely to threaten program content.

The NASA civil service workforce has already been reduced through buyouts and attrition. Actions are being taken to further reduce the NASA Headquarters infrastructure, both civil service and support

¹"Review Team Proposes Sweeping Management, Organizational Changes at NASA," NASA News Release, May 19, 1995. "NASA Zero Base Review and FY 1997 Budget Process," briefings to Congress, May 1995.

²The House Committee on Appropriations report (104-201, p. 85) subsequently questioned whether it would be possible to continue to fund all of the centers in future years, however.

contractor, including the transfer of functions and personnel to the field centers. In the view of the “new NASA,” Headquarters would be based on a “corporate management” model and concentrate on policy development and implementation, external relations and liaison, and agency-level and enterprise-level management. Program management would be shifted to the field centers, where project management already generally resides. By this shift, NASA intends to eliminate a layer of management with its attendant personnel.

Changes at the field centers are also under study. One involves consolidating similar activities at a single center and thus eliminating duplicative activities. Another is to establish certain specialized center activities as “institutes” affiliated with a nongovernment organization (e.g., a university). Many of the proposed changes are consistent with the recommendations of the *NASA Federal Laboratory Review*.³ At present, transforming entire civil service centers to contract operation (as is already the case at JPL) is not under consideration.

In assessing organizational alternatives for NASA, the committee first addressed the issue of fundamental responsibilities of the various major elements of the NASA science establishment: NASA Headquarters, the field centers, and the large and diverse outside industrial and academic research community. Management of NASA’s scientific research must, of course, remain within NASA. Management functions will be exercised at various organizational levels, depending on scope and function. The following are the committee’s findings:

1. NASA’s strategic enterprises are evolving as the basic business units of the agency at the highest strategic level,⁴ including within each enterprise one or more programs. Clearly, enterprise management must be located at Headquarters. At this level, NASA addresses goals, objectives, policy, and budget allocation and thus provides the overall direction, guidance, and constraints to individual programs.

2. Program management (see NASA’s definition of “program” in Appendix D) may be either at Headquarters or at a center. Cautions with respect to the assignment of program management are as follows:

- a. Programs with extensive and complex elements at more than one NASA center should be managed from Headquarters. While day-to-day program support might be delegated to a center, program definition, resource allocation, and project review should be Headquarters’ responsibilities. The management of space science technology is an example of a complex, multicenter program that should not be managed by a field center (see Recommendation 6-4).

- b. Programs whose elements reside primarily within a single center or that have simple interfaces between participating field centers may be managed by a field center if there is clear separation of the program function from project management. Project management is narrowly focused on project execution, while program management considers more broadly all elements of the program. The authorities, accountabilities, objectives, and motivations of the respective management groups are different, and separation is required. The New Millennium program is an example of a relatively simple, multicenter program that is currently managed by a field center (JPL).

- c. The program management center must rigorously enforce a policy that mandates fairness to program elements outside the center vis-à-vis program elements within.

- d. Any decisions on out-sourcing (make-buy decisions) that may involve the center as performer must be made at Headquarters. This principle applies both for in-house/out-of-house decisions on spacecraft development and for selection of investigations (both for flight projects and for the Research and Analysis program), including oversight of the peer review process.

³Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

⁴NASA, *NASA Strategic Plan*, February 1995.

3. Project management (see the definition in Appendix D) is properly located at a center, even if a center is operated under a contract. Again, some limitations are necessary:

- a. Major make-buy decisions should be approved at higher levels.
- b. Any delegation of project management responsibilities to contract centers must adhere to procurement law and regulations.

4. Because of the existence outside the agency of larger and more diverse industrial and academic research communities and the importance of maintaining that national capability, scientific research should, for the most part, be conducted outside the agency. The committee believes this to be true for flight projects, for the scientific experiments that fly on them, and for the supporting work conducted in ground-based laboratories. There are important exceptions to this rule, and these are discussed under “Balance Between In-House and Out-of-House Research” at the end of this chapter.

In summary, Headquarters should be responsible for enterprise management, including establishment of scientific vision, goals, and objectives; guidance on program content; cost guidelines and constraints; requesting program plans; integrating and approving submitted plans; source selection; scientific discipline support; oversight; and cross-discipline integration. Centers should be responsible for creating program plans in response to Headquarters requests; executing programs and projects; providing program and project oversight; and possibly managing the solicitation process (with selection controlled by Headquarters). Scientific research should be conducted primarily by the academic and industrial communities. The *NASA Federal Laboratory Review* report⁵ reaches similar conclusions and recommendations with respect to Headquarters and center roles and missions.

NASA HEADQUARTERS SCIENCE ORGANIZATION

The committee followed closely the charge given it and looked at three alternatives for the Headquarters science organization: an institute approach to science management, following the NIH model, distributed management among the three science offices as exists today, and centralized science management as existed prior to the 1993 reorganization. The committee assumed that a degree of program management would be retained at Headquarters in any of the models. Thus, for example, the Headquarters Office of Space Science (which is responsible for the Space Science Enterprise in its entirety) is assumed to retain a broad management function for the three science programs, Astrophysics, Space Physics, and Solar System Exploration, as well as for the Space Science Enterprise as a whole.

1. Institute for Space Science—Responding to direction in the FY 1994 Senate appropriations report, the committee considered a space science “umbrella organization within NASA to coordinate and oversee all space science activities,” functioning “just as the National Institutes of Health now does within the Department of Health and Human Services.” This was taken to mean an institute constituted with all the science programs of the pre-1993 OSSA, funded separately from the rest of NASA and operating much as does NIH and the many individual institutes coming under its umbrella. The operation of NIH is described in Chapter 2 and Appendix F. (Let it be clear that this model is not what NASA has recently proposed as “science institutes,” which are discussed below.)

The advantages of such an approach are

- relative independence of science and
- relative budgetary autonomy.

⁵Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

The disadvantages are

- possible disconnection from other elements of NASA that support science (e.g., launches, tracking, facilities operations) and
- budgetary vulnerability.

The committee concluded that the NIH model, while quite effective in its own arena of research with a heavy emphasis on fundamental or basic research leading to the understanding of disease processes, the development of new drugs and treatment protocols, and their clinical evaluation, is not appropriate for the space sciences. NASA space sciences depend on close coordination with other elements of NASA, for example, hardware development, launch services, and tracking and data operations. There are no obvious counterparts in the NIH model, which instead involves primarily self-contained research endeavors. Although NIH research projects are conducted in laboratories, hospitals, and the like, the basically stable infrastructure of these facilities is dealt with simply as “overhead” for the investigation. With a few exceptions, such as establishment of cancer, eye research, and AIDS vaccine development centers, NIH researchers do not generally have to build hospitals or new laboratories from the ground up to carry out their work.

While ground-based laboratory research supporting science conducted in space may resemble NIH research, NASA research carried out on space missions does not. Of necessity, space science proceeds incrementally, flight project by flight project, whereas most other scientific programs proceed by the steady interplay between discovery, new questions, new concepts, new technology, and the changing research interests of scientists. Only creation of a major new particle accelerator, for example, approaches the long lead times, engineering teams, costly and complex infrastructure, and need for schedule management inherent in spaceflight projects.

It also is not clear how such an institute model would deal with budgetary issues. Presumably, an institute could be funded separately from the rest of NASA, perhaps within the same appropriation, but otherwise independently. The committee was concerned about possible mismatches in science funding and related infrastructure funding. Even if science support infrastructure funding were joined to science program funding for the institute, the resulting “fences” between fund sources could constrain trade-offs and thus severely hamper management of the overall NASA endeavor.

Much of the remarkable success of the space sciences since the dawn of the space age has resulted from a tight link between science and space technology. The inspiring goals of scientific discovery and exploration spurred new capabilities in space access and technology, which in turn pushed the scientific goals still further into the unknown. While some technology came from the science programs themselves, much of it came from other parts of NASA. Separating the space sciences from critical space technologies within the agency by forming an independent institute for space science would break this symbiotic link. The committee found the downside risks of breaking this link too large to accept.

In summary, the committee does not favor establishment of an institute for space science or other entity that might be separate or “semiseparate” from NASA as a whole.

2. Distributed Management (current organization) Versus Centralized Management (pre-1993 organization)—In the current organization, three program offices manage elements of the science program—OSS (traditional space science), OMTPE (Earth science), and OLMSA (life and microgravity sciences). They are directly aligned with the respective enterprises, OSS and OMTPE uniquely, with OLMSA sharing the Human Exploration and Development of Space Enterprise with the Office of Space Flight. The pre-1993 science organization was wholly contained within the Office of Space Science and Applications (OSSA), which consisted of program divisions for Astrophysics, Space Physics, Solar

System Exploration, Earth Science, Life Science (both Space Medicine and Space Biology), and Microgravity Science.

The advantages of the distributed management model over the centralized management model are

- more focused management to achieve enterprise goals (or to implement strategic enterprises),
- simpler management interactions with centers, particularly if centers are realigned as proposed to achieve greater program focus,
 - for life science and microgravity communities, the possibility of greater funding attracted through their Human Exploration and Development of Space Enterprise connection, and
 - simpler strategic planning because of tighter focus of programs.

Conversely, the disadvantages are

- reduction of budgetary and scientific flexibility for the respective science leaders,
- greater vulnerability of science quality because of program trade-offs necessitated by budget reductions or policy changes independent of the science programs,
 - greater vulnerability of smaller programs through their increased “visibility” in the budget process,
 - greater difficulty in integrating related science programs, such as life science experiments with planetary spacecraft,
 - weaker advocacy for science within NASA (three voices, not necessarily in agreement, heard by the Chief Scientist and the Administrator), and
 - larger Headquarters staff overhead.

In conclusion, from a pure science perspective, a centralized-management-type organization appears to be preferable. But NASA is not a pure science organization. Science activities must be closely integrated into the other parts of the space program. The enterprise concept now in place provides a solid basis for that integration in the context of program rationale. In addition, the advantages offered by tighter focus for planning and simplicity of center interactions were given positive weight by the committee. It is also true that the science programs have changed dramatically since the days of the previous organization (for example, the advent of the Space Station and the great expansion of the Earth observation program). The committee therefore endorses the present approach, which distributes science among three separate enterprises.

Recommendation 4-1: The committee found no compelling reason to establish an independent institute for space science modeled on the National Institutes of Health. Rather, NASA should retain its science programs in the present three-enterprise distributed form, but also take action to provide the necessary integration among the programs (see Recommendation 4-2).

With this distributed management model, the three science associate administrators must coordinate and integrate their respective programs into a single, coherent NASA science program. The Chief Scientist can exercise the strong, central coordinating function that is required to ensure that this integration occurs, but the current authorities and responsibilities of the Chief Scientist position are not, in the view of the committee, explicitly sufficient. In addition to its advisory, coordination, and interface responsibilities, the position should include a formal concurrence on planning, programming, and budget matters of all the sciences and authority to resolve conflicts among the science offices. The NASA Science Council, currently chaired by the Chief Scientist and including as members the science associate administrators, would provide a mechanism for the Chief Scientist to use in meeting these expanded

Proposed Functional Statement for the Chief Scientist

The Chief Scientist exercises NASA-wide leadership for the space sciences and serves as the principal scientific advisor to the NASA Administrator. He or she should be a person of strong standing in the scientific community with significant accomplishment in his or her own field. The individual filling this position should have a breadth of interest and understanding transcending the space sciences to encompass technology and the interaction of science and technology with elements of society. This person should also have management experience, preferably in large organizations. Understanding of government processes is highly desirable. Specific functions of the position are as follows:

- Serves as *primary advisor to the NASA Administrator*.
- Provides formal concurrence on planning, programs, budgets, and so forth, for the NASA science programs.
 - Acts to resolve conflicts among the science programs and between science programs and other NASA programs.
 - Chairs the NASA Science Council.
 - Maintains oversight of science quality across the agency, recommending corrective action where necessary.
 - Maintains oversight of the integration of advanced technology into science programs across the agency, recommending corrective action where necessary.
 - Provides for coordination among the sciences at many levels: programs, advisory groups, other agencies, the scientific community.
 - Serves as representative of NASA science to the outside world and represents the scientific community to NASA.

Proposed Functional Statement for the NASA Science Council

The NASA Science Council, chaired by the Chief Scientist, is the internal NASA body responsible for coordination and integration of science programs and activities.

Specific functions are as follows:

- Sets principles and policies for scientific aspects of strategic planning.
- Reviews and integrates resulting strategic plans for consistency with policies and agency-level guidance.
 - Provides a forum for coordinating programs.
 - Provides a forum for conflict resolution.
 - Reviews and makes recommendations to help ensure the health of the intellectual and physical infrastructure.

Membership of the NASA Science Council consists of the Chief Scientist (chair), the Associate Administrators for the space science programs (OSS, OLMSA, OMTPE), and the Associate Administrator for Space Access and Technology.

responsibilities. The responsibility for formal concurrence on planning, conflict resolution, oversight of science quality, and representation of NASA to the outside world exceeds the capabilities of any one individual. For this reason, recommendations for strengthening the role of the Chief Scientist will require creation of a small office staff of experienced and technically astute personnel to support the Chief Scientist.

In NASA, as in other R&D organizations, the strongest control of prioritization lies with officials who control budgetary decisions, in this case the science associate administrators. If the Chief Scientist were given general budgetary authority over these offices, the effect would be tantamount to re-creation of a single science office, like OSSA. What is being recommended here instead is the establishment of a

formal planning and budgeting concurrence by the Chief Scientist; in practice, the coordinating influence of the Chief Scientist would be enforced by the location of that position within the office of the Administrator. The budget development and advocacy process would continue to reside with the line associate administrators.

Recommendation 4-2: The position of Chief Scientist should be strengthened to ensure full integration of the space sciences. A proposed functional statement that encompasses the necessary authority is provided, followed by a proposed functional statement for the NASA Science Council (see box).

With the establishment of enterprise management, NASA seems to have created another management layer to add to those already in existence. There is an overlap in the functions of enterprise management and program management. The committee recommends that program management functions be subsumed by the enterprises and appropriate elements then delegated to the centers.

Recommendation 4-3: NASA should eliminate the separate “program management” layer, assign to the enterprises the program management functions properly located at Headquarters, and delegate to the field centers those program management functions properly located there.

NASA CENTER SCIENCE ORGANIZATION

With enterprise management at Headquarters, the major functions of field centers will be management of out-of-house projects and execution of in-house program elements (i.e., projects and investigations).

The committee considered two primary alternative organizational arrangements for a science-oriented field center: (1) the current civil service arrangement for centers (except JPL) and (2) centers wholly operated by an appropriate university, consortium, or joint university/industry partnership as a government-owned, contractor-operated (GOCO) installation (the JPL model). Because only GSFC and JPL are primarily science centers, the first alternative is equivalent to making no change and the second corresponds to converting Goddard to a GOCO; the committee considered the latter option even though it was not recommended by the Zero Base Review report. No consideration was given to converting JPL to the civil service.

The committee also considered establishment of “institutes,” defined as university- (or consortium- or university/industry partnership-) staffed and operated organizations to conduct certain specific science operations now residing at a nonscience center.⁶ This approach was considered not as an alternative to the two preceding options for a whole center, but in the more limited sense considered by the Zero Base Review for collecting the scientific activities of a center that are not closely aligned to the primary mission of that center. Examples currently under consideration are a life science institute at Ames Research Center, primarily an aeronautical research center, and biomedical and planetary science institute(s) at Johnson Space Center, primarily a human spaceflight center. (Advantages and disadvantages for such focused “institutes” for discrete scientific activities in a predominantly nonscience-oriented center are discussed below.)

Table 4.1 displays the advantages and disadvantages of the two organizational concepts for entire centers.

Current Civil Service Arrangement—Perhaps the principal advantage to retaining the present civil

⁶NRC, Space Studies Board, letter to NASA Chief Scientist France A. Cordova, August 11, 1995.

TABLE 4.1 Advantages and Disadvantages of Alternative Science Center Organizations

Civil Service Center (Present Approach)	GOCO (University-, Consortium-, Partnership-Operated)
<p>Advantages:</p> <ul style="list-style-type: none"> • No action required; no transition • Civil servants fully authorized to perform government functions • Priorities of center match those of NASA • Stability of staffing during short-term budget fluctuations <p>Disadvantages:</p> <ul style="list-style-type: none"> • Possible detrimental impact on staff quality • Inflexibility of civil service regulations • Split accountability; Headquarters institutional authority possibly different from program authority 	<p>Advantages:</p> <ul style="list-style-type: none"> • Flexibility in personnel management in the private sector: hiring, firing, and enhancement of staff quality • Synergy of center science and that of parent university • Better responsiveness and accountability of center to NASA via contract <p>Disadvantages:</p> <ul style="list-style-type: none"> • Difficulty of transition • Cost of transition • Vulnerability of staff to short-term budget fluctuations • Somewhat restricted ability of contractor to perform government functions • Possible conflict of center and operating university priorities

service system for GSFC is that no action is required; there would be no change to the present system and thus no lengthy transition to undergo. The last advantage, stability of staffing, results from the present NASA budgeting system, which provides funds for civil service staff from one account (Research and Program Management—R&PM) and program funds (contract costs and in-house project costs other than staff salary) from another account (R&D). The R&PM account has been relatively stable over time, linked closely to staff size for the agency as a whole. Thus staff can be maintained during short-term gaps in program funding (such as deferral of new project starts) and a center director has the discretionary authority to assign staff to high-priority activities.

The chief disadvantage of retaining the present system at GSFC is the inflexibility associated with the civil service system, such as hiring, firing, and salary rigidity. This may negatively affect staff quality over the long term, especially in a period of downsizing, as is the case at present. The committee considered this the principal reason for favoring a change.

Government-Owned, Contractor-Operated (GOCO) Centers (the JPL model)—This alternative envisions converting GSFC into a university-operated GOCO center like JPL. If this could be accomplished, the principal advantage would be the flexibility in personnel management inherent in the private sector. Through this mechanism, staff quality in the long run could be enhanced. Further, increased flexibility in personnel management would facilitate adjustments in staff capabilities to meet changing requirements, such as infrastructure reduction.

The principal disadvantage of converting GSFC to a GOCO center would be the difficulty of the transition itself. Conceptually, conversion would be quite straightforward: disestablishing the center as an organization of federal employees and establishing the GOCO under federally funded research and development center (FFRDC) rules, establishing a competition for the operation of the center as a GOCO, and closing out the civil service complement effective the date the contractor assumes responsibility. The difficulties focus on the conversion of civil servants to private sector employees, particularly with respect to retirement programs, but also involving other facets of personnel management, such as

salary scale, seniority, union representation, and benefit programs. The committee believes it is feasible but recognizes the potential for upheaval. Indeed, the committee was briefed on a similar plan prepared for the Naval Research Laboratory (NRL) some years ago. Though the Navy has not implemented the plan, it appears feasible.

A second disadvantage of conversion is the transition cost and duration; cost was estimated for NRL to be in the range of \$137 to \$162 million, depending on the generosity of severance and other payouts, and three years was the estimated time required, provided no legislation was necessary. Corresponding cost and time for NASA conversion of GSFC would likely be of the same order of magnitude. Finally, as a contract organization, the center could not be responsible for certain inherently governmental functions (e.g., fundamental make-buy decisions), and these would therefore have to be retained in Headquarters.

The committee does not list recurring costs as either an advantage or disadvantage in comparing the present civil service system with a GOCO system. At first look, one might conclude that total costs for the GOCO might be higher because of a higher salary scale and the contract fee. But other efficiencies inherent in a contract arrangement might compensate, and which system has greater cost is not clear. Given the likelihood of little difference, the committee concluded that cost was not a decisive factor. However, it is important to recognize that any long-term cost comparisons between in-house and out-of-house alternatives must include all program costs, both R&D and R&PM. Considering only R&D costs would make the civil service in-house alternative look far lower in cost, because in-house R&PM costs are not currently charged to R&D programs.

Later in this chapter, the committee recommends the adoption by NASA of an industrial funding approach for its field centers, whereby all costs of executing a program, including the cost of civil service staff, would be charged to that program. This full-cost accounting, toward which NASA is already moving, would considerably reduce any advantage in responsiveness and accountability held by a GOCO management approach.

The flexibility in personnel management and attendant positive impact on staff quality drive the committee to the conclusion that the GOCO approach offers the greatest long-term benefit. There has been concern⁷ that the technical competence of government laboratories employing civil servants erodes over time; this possibility provided some of the motivation for the proposal to convert NRL. Despite the formidable difficulties of conversion to GOCO status, a decline of personnel quality at GSFC would favor such a move. However, even within the present civil service system, GSFC has been able to maintain a high staff quality. The committee concluded that GSFC should be left as is for the present, but that this conclusion should be reexamined periodically.

Recommendation 4-4: The Goddard Space Flight Center should remain a civil service center for the time being. However, NASA should establish periodic external reviews of GSFC to determine whether new consideration should be given to conversion to a GOCO arrangement.

As remarked above, NASA is also considering establishment of a class of university-, consortium-, or partnership-operated institutes. Not an alternative for operation of an entire center, this institute concept is being considered for a focused science activity within a center having broader, and generally nonscientific, responsibilities. Such institutes would be operated by a nongovernmental entity (e.g., a university) under contract. A number of such arrangements have been proposed in the Zero Base Review plan.

Some advantages and disadvantages of this scheme are displayed in Table 4.2. NASA's stated intent in creating such institutes is to upgrade the quality of the science programs concerned, bringing them to a

⁷Report of the White House Science Council Federal Laboratory Review Board, May 1983, David Packwood, chairman.

TABLE 4.2 Advantages and Disadvantages of Focused University-, Consortium-, and Partnership-Operated Science Institutes

Advantages:

- Essentially the same as for GOCO (Table 4.1)
- Enhanced visibility and stature of activity
- Ability to focus research
- Readily assessed quality of work and staff

Disadvantages:

- Essentially the same as for GOCO (Table 4.1)
 - Possibly self-perpetuating
 - Creation of two classes of employees at the center
 - Possibly greater infrastructure expense
 - Possibility that focus could restrict initiatives in new areas
-

level from which they can compete successfully for support, and then to reduce the “guaranteed” or “base” NASA funding level. The institutes would then have to survive (or shrink and “sunset”) on the basis of merit competition for funding.

Synergy of an institute’s science with that of its adoptive parent is an especially important feature of the concept. In most similar current arrangements, both at NASA and elsewhere (e.g., DOE and NSF), the contractor is a nonprofit entity, usually a university or a consortium of universities, and that is the arrangement assumed here. It is further assumed that the institute’s scientific staff are contractor employees, hired by the university or consortium, either after conversion from civil service or based on criteria established in the contract. There are several especially positive features to this approach:

- If the scientific and geographical match is carefully chosen, the staff of the institute and the faculty and research staff of the university or consortium will have overlapping scientific interests that should result in scientific collaboration, benefiting both parties. The university should contribute something of value (e.g., facilities, faculty participation, or student involvement) to enhance the focus on common goals and problems.
 - The institute staff will be an additional resource for, and will benefit from, the interaction with graduate students.
 - By retaining the institute, with its economic and cultural benefits to the community, it might be possible to secure some support from the state government(s).
 - As noted for a GOCO-type center, establishment of a personnel system that is outside the civil service should increase the flexibility of NASA in establishing and retaining a high-quality staff that can adapt to fit a NASA mission that evolves in size, scope, and focus.

Some negative features of such institutes exist, as well:

- Funding will be problematical; first, the institute will have to compete successfully for NASA program funds. Then, if not fully successful, the institute will need to seek outside funding to maintain itself, and, because of limited outside interest in its research areas, such outside funding might be difficult to attract.
 - The host NASA center is likely to be less motivated to provide support to the institute than to

support its own elements. Of particular concern is the danger that the institute might lose the coupling between its scientific research and NASA engineering support.

- There will be a need for a somewhat increased NASA infrastructure to see to the “care and feeding” of the institute.
- The tendency for such institutes to proliferate, sometimes in response to political pressures, must be controlled. Similar pressures will exist to maintain individual institutes indefinitely, irrespective of merit.

The committee believes that the institute model for NASA scientific staff can, in appropriate cases, help to preserve and improve the quality of some focused science activities, while providing other potential benefits in flexibility and NASA-university collaboration. However, success of these institutes will depend, in large measure, on the not-yet-developed specific agreements between NASA and the operator. In the long run, if budgets continue to decline, quality will be maintained only if the less-competitive institutes are reduced in size or terminated as a consequence of a continuing process of peer-reviewed scientific competition.

Recommendation 4-5: Creation of contractor-operated institutes (a focused science activity operated under contract within a center having broader, possibly nonscientific, responsibilities) may be advantageous for specific science functions or facilities. The selection and creation of such institutes should be limited to special circumstances, specifically,

- to be responsible for a narrow, bounded area of science,
- to operate a special facility for the scientific community, and
- to maintain a unique national facility or staff capability,

but

- NOT just to lower civil service headcount and
- NOT if the entity is an integral part of the larger organization (the host center).

The committee recommends that, if NASA proceeds to establish pilot science institutes, it give due attention to the out-years process by which these institutes will have their guaranteed base budgets ramped down, and to the competitive process under which they will be expected to compete successfully and maintain or increase their size, or to compete less successfully and shrink or terminate in an orderly fashion. The committee recommends that other institute initiatives be deferred until the success of initial pilots can be evaluated.

OTHER ISSUES

A number of management issues that bear directly on one or another of the center alternatives were identified and are discussed in the following sections.

Balance Between In-House and Out-of-House Research

NASA requires in-house scientists for its space research, exploration, and technology programs. These scientists coordinate science and operations on larger missions, guide development and utilization of unique research facilities, assist outside scientists and technologists to effectively use NASA facilities or flight opportunities, and enable NASA to act as a “smart buyer.” The number of in-house scientists

should be determined by the extent of these support functions and not by a desire to exploit perceived flight opportunities. Space science leadership and the generation and testing of new ideas should be the domain of the broader scientific community, of which the NASA scientists are only a part. As noted earlier, the committee believes that scientific research should, for the most part, be conducted outside the agency.

The in-house scientists should be of the highest quality. To maintain that quality, they should be encouraged to practice their science at the cutting edge of research and instrument development. However, their research should be thought of as being “derived” from the NASA mission and not their sole duty. For the most part, NASA scientists should be expected to devote a significant fraction of their time to support functions (e.g., as project scientist) and a commensurate fraction of their funds should come from the programs and projects that benefit from these efforts. Additional research funds should be earned through open competition among the broader scientific community. By linking the responsibilities of the scientific staff directly to programs and projects, NASA can establish and maintain a positive feedback between the size of its programs and the size of its scientific staff.

Recommendation 4-6: NASA should conduct scientific research activities in-house only to the extent required to compete successfully for high-quality staff, to maintain capability to manage and interface with corresponding activities on the outside (e.g., as a “smart buyer”), or to maintain and operate an in-house capability that is unique in the nation. Otherwise, if a valid out-of-house capability exists, the work should be done there.

Industrial Versus Institutional Funding

In discussing the two alternatives for a science field center, civil service versus GOCO, it was noted that NASA funds operation of the institution (personnel, facilities, and so forth) from the R&PM budget, determined chiefly by staff size and operations costs of the installation, while program costs (primarily procurement costs) are funded by the relevant program’s R&D budget. This is termed “institutional” funding. Conversely, “industrial” funding provides that all costs of a specific program (including personnel) be charged to the sponsor of that program. Although all the NASA civil service centers are institutionally funded, JPL, as a contract center, is essentially industrially funded, with personnel as well as program costs charged to the responsible program office.

Advantages of employing institutional funding, rather than industrial funding, are

- flexibility in assigning people,
- ability to maintain a stable workforce, and
- ability to conduct possibly high-payoff, speculative research.

Disadvantages of institutional funding, compared to industrial funding, are

- less accountability,
- tendency for workforce factors to drive program decisions,
- disincentive for detailed workforce planning,
- greater difficulty in managing staff size, quality, and skill mix, and
- distorted make-buy decisions.

An additional disadvantage of industrial funding is that research sponsors may tend to use it as a management tool, that is, “buying” research in little bits and pieces, thus creating a paper problem and stimulating researchers to spend excessive time seeking funding.

Overall, the committee strongly favors the concept of industrial funding because it reflects total program costs and permits ready assessment of comparative costs that might otherwise be hidden by an institutional funding approach. The committee recognizes as a potential problem the assignment of responsibility for maintenance of agency infrastructure but believes that higher priority must be given to applying the budget discipline of industrial funding. The committee expects that senior management will be able to resolve these infrastructure issues even under the discipline of industrial funding. The committee endorses NASA's decision (stated in the Zero Base Review briefing to the Congress) to identify, budget, and manage by total program costs, including the costs of civil servants.

Recommendation 4-7: NASA should adopt an industrial funding model for field centers. Decisions on program priorities and budget would be more rational if based on full-cost accounting, and program accountability and discipline in personnel management would be thereby enhanced. The principal objective is that cost accounting should be based on full program costs, including civil service salaries, to achieve the advantageous features cited above. A similar recommendation was made in the *NASA Federal Laboratory Review* report.⁸

Reporting Relationship of the Centers to Headquarters

Currently, each NASA field center reports institutionally to a NASA Headquarters program office that has major, but not necessarily exclusive, program responsibility at that center. Center institutional costs (salaries and other personnel costs, facility operations, and other nonprogram specific support costs) are funded from the R&PM budget. Program direction and funding, however, come to the center from Headquarters program offices. For example, although the Office of Space Science funds a large fraction of the programs located at GSFC, institutional management is provided by OMTPE, the institutional "parent" of GSFC, and institutional costs are charged to the R&PM account. Likewise, institutional management of the atmospheric research program of OMTPE at the Langley Research Center is provided by the Office of Aeronautics, Langley's "parent" institutional office, with institutional costs again charged to R&PM. Thus programs at a center "owned" by a different institutional office operate in a dual (in some cases multiple) management and funding environment. If the respective office priorities are significantly different, programs may be impaired.

An alternative institutional reporting arrangement, that is, with all centers reporting to one Headquarters institutional manager, has been employed by NASA in the past⁹ (see Table 2.2). Under this arrangement, all programs executed by field centers would face split funding, as all institutional costs would be provided by this separate office. An advantage of this system is that institutional resource priorities would be established for the agency as a whole and would presumably directly reflect overall program priorities of the Administrator, to whom the single institutional director would report. A disadvantage is that it would be difficult for a program associate administrator to redirect institutional resources within his or her program area even at a center that dominantly supports that program.

Three different kinds of requirements can be imposed on a program, that is, programmatic, institutional, and regulatory (e.g., environmental, safety, procurement). Neither of the alternatives for institutional management can completely eliminate this complexity. Therefore, whatever the system, it is important that all potentially competing requirements and directions flow down to center program/project management through a single channel. Given the trend toward concentration of center capabilities toward a primary mission for that center, coupled with more focused enterprise management, the committee concluded that center reporting arrangements should remain as they currently are, with each

⁸Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

⁹NASA, *The Evolution of the NASA Organization*, March 1985.

center reporting to an appropriate enterprise and all direction channeled through that enterprise. Some split reporting will result, but the alternative of having centers report to a central office would exacerbate that split. If some form of industrial funding is put in place (by R&PM allocation, budget structure change, or center GOCO transition), the problems resulting from split reporting will be further reduced because program budgets would then include staff and other institutional costs. In those cases where a significant split in center responsibilities exists (e.g., at GSFC, where astrophysics and space physics programs constitute a major part of the center's activities, though it reports institutionally to OMTPE), NASA must actively work to ensure that program and institutional needs are well served.

Recommendation 4-8: Center reporting arrangements should remain as they currently are, with each center reporting to an appropriate enterprise. All requirements and directions addressed to a center from any source should be directed through that enterprise.

Role of the Project Scientist

Successful execution of a project, whether in-house or through a contract, depends on meeting simultaneously the established schedule, budget, and scientific requirements. These three sets of requirements will come into conflict repeatedly during the course of any project. Therefore, it is essential that the management structure permit trade-offs throughout the life of the project. Science advocacy is usually embodied in the position of the NASA "project scientist," who specifies scientific performance, leads the science working group, and provides an ongoing assessment of whether or not the project will achieve that performance. This function is independent of whether the center is a civil service or GOCO center and applies both for projects executed in-house and those procured under contract.

The project scientist is responsible for documenting the scientific requirements and for evaluating engineering designs and other documentation in order to determine whether the requirements will be met. In order to fulfill this responsibility, he or she must normally be co-located with the project team and must be given the opportunity to concur in all significant project decisions that will affect scientific performance. The project scientist should participate in all major project reviews, including preliminary and critical design reviews. While the project scientist is responsible for scientific performance, the project manager is responsible for overall mission performance, including keeping the project on schedule and within budget. When they cannot agree on a course of action, resolution must be sought at a higher level.

Committee members involved with NASA science projects have observed instances of what appears to be a diminished role of the project scientist in science project management. Fundamental decisions bearing on the ability of the project to meet its scientific objectives have sometimes been made without adequate project scientist (or investigator) input and involvement.

Recommendation 4-9: Renewed emphasis should be given to the essential role and responsibility of the project scientist in project trade-offs and decisions through the life of the project.

Oversight

A recurring theme heard from interviewees from other organizations and from some committee members was that NASA imposes an excessive degree of oversight on its contractors. While the discussion centered on anecdotal evidence, the committee was struck by the high frequency with which the subject was raised. The issue arose regarding oversight of contractors by field centers, of investigators by Headquarters scientific staff, and of field centers by Headquarters. This heavy oversight has two important detrimental effects: performers may be required to devote unwarranted time to satisfying oversight requirements at the expense of project performance, and managers spend excessive time in

questionable oversight, including heavy attendance of monitoring staff at project meetings. Redundant oversight in a period of constrained budgets can impose especially severe penalties.

Historically, a hallmark of NASA management has been rigorous engineering oversight and penetration into all high-value space flight projects extending well beyond the safety-critical human flight programs. This management practice was established early in the Apollo Program and grew in intensity with mission complexity, becoming identified within NASA as a key component and major contributor to early agency success. High-visibility accidents such as the Apollo Command Module launchpad fire, Skylab meteoroid shield failure, and the 1986 *Challenger* accident only reinforced the belief that active independent program oversight was necessary for success. The Rogers Commission *Challenger* report¹⁰ was particularly critical of decentralized NASA management, so that attention was further focused on strong Headquarters oversight, short rein on center authority, and an independent review process to balance the decision-making process. Delegation of program execution exclusively to project managers at field centers was not viewed as compatible with the oversight requirement, and program management was centralized at NASA Headquarters with a Levels 0, 1, 2, 3, and 4 chain-of-command architecture (Administrator's Office, associate administrator, lead center, center project office, and contractor management, respectively). A strong argument can be made that this heightened oversight worked, but not without costs. The practice has penetrated most of NASA's programs, bringing with it the bureaucracy necessary for its implementation. The Space Shuttle and Space Station programs have clearly been subject to this renewed management style fashioned during the Apollo era; however, science programs within the agency have also seen tighter control and oversight from Headquarters, especially since the Hubble Space Telescope mirror problem.

For a number of reasons, management decisions being made at NASA over the past several years are reversing this trend. Reasons include declining budgets, substantial NASA staff reductions, and an emphasis on shorter development cycles and smaller-scale projects. Greater responsibility and accountability for project execution are being given to contractors. The large human space flight programs, the Space Shuttle and Space Station, have also seen decreased centralization and delegation of authority to the field sites. These delegations are consistent with the movement of Total Quality Management principles to the forefront of both government and industry, where the intent is to build in quality from the beginning, rather than try to achieve it through intensive oversight.

Recommendation 4-10: NASA should maximize delegation of project responsibility to the executing agents of its space science programs (center, laboratory, university, or industry) and minimize redundant NASA oversight. This practice can yield excellent results at an affordable cost. High-value, one-of-a-kind space science missions may justify increased independent oversight. If necessary, this increased oversight should be clearly established in the program definition stage and should not be permitted to creep or evolve with program maturity. The committee makes no recommendation regarding oversight, delegation of responsibility, or privatization in the human spaceflight program.

¹⁰Presidential Commission on the Space Shuttle Challenger Accident, *Report of the Presidential Commission on the Space Shuttle Challenger Accident*, Washington, D.C., 1986 (5 volumes).

Research Prioritization: Analysis and Findings

As a mission agency with numerous objectives and a broad range of programs, NASA presents a complex multidimensional prioritization problem with its research programs. Not only are diverse scientific disciplines represented within the agency's research portfolio, but planning and execution are strongly affected by the challenging and costly space environment in which the research is done, institutional imperatives for technology innovation, and the distributed field center network.

Several studies on the space research priority-setting problem have been carried out with varying degrees of success. The Space and Earth Sciences Advisory Committee of the NASA Advisory Council released an influential report¹ in 1986 that outlined a framework of factors to be considered in prioritizing missions. In 1992 the NRC Space Studies Board Task Group on Priorities in Space Research laid out the rationale² for a more general cross-disciplinary prioritization of scientific objectives and broad initiatives. The arguments presented therein for an active role by scientists in the priority-setting process were generally well received. A specific implementing methodology proposed in a second report³ for effecting this broadened prioritization, on the other hand, was not as well accepted as the underlying principles laid out in the predecessor report.

The present committee's task group on research prioritization therefore set out to reexamine the existing process of priority setting for science programs within NASA, with special attention to the roles of advisory groups and the agency's management organization. The central thrust was to reexamine these roles and to clarify the necessary functions on the basis of the following fundamental premises and overall goals.

PRINCIPLES OF RESEARCH PRIORITIZATION

Axioms

The committee made the following assumptions in analyzing the priority-setting problem:

¹Space and Earth Sciences Advisory Committee of the NASA Advisory Council, *The Crisis in Space and Earth Sciences*, 1986.

²NRC, Space Studies Board, *Setting Priorities for Space Research: Opportunities and Imperatives*, National Academy Press, 1992.

³NRC, Space Studies Board, *Setting Priorities for Space Research: An Experiment in Methodology*, National Academy Press, 1995.

1. In conformance to the Space Act of 1958, science will continue to have a central role among NASA activities.
2. Because of the rich return from earlier missions, there are more opportunities for new discovery than there are resources available to exploit them.
3. To fulfill its scientific mandate, NASA will continue to receive appropriated funds for scientific research, and, as an agency, will have the responsibility of distributing and administering these science funds. Because opportunities will outstrip these resources, this responsibility will entail priority setting.
4. Judgments about scientific merit will have a major role in the agency's administration of resources allocated to it for scientific research.
5. Practicing scientists are the most qualified arbiters of scientific merit.

Goals

The following goals have been identified for priority setting in NASA's space research programs:

1. Conforming to its charter in the Space Act, the scientific research sponsored and managed by NASA should vigorously advance knowledge in the areas in which it is undertaken.
2. Scientific efforts sponsored by NASA should be proposed and evaluated in the context of research sponsored and conducted elsewhere and should be competitive with this other research in interest, quality, and importance.
3. In order to optimize the return on expended resources for science while addressing other technological objectives for the agency laid out in the Space Act, NASA's scientific research program should appropriately balance innovation with risk of failure. This will help set the directions for technological development and ensure that benefits of new capabilities are realized for the science programs.
4. NASA's research portfolio should be opportunistic, not only in the technological sense (goal 3 above), but also in terms of focusing on areas most ripe for significant advances with the resources and capabilities available. Prioritization should consider all relevant factors, including opportunities to contribute to policymaking and other public needs, in optimizing scientific return for the resources invested.

PRIORITIZATION OF SCIENCE AT NASA

Defining the Problem

The space sciences, like any natural science, begin with scientific ideas and goals that are transformed into research programs⁴—the means of carrying out the necessary experimental or observational research. In space science, though, the cost and complexity of many missions are much greater than in most other areas of science. Therefore, the relative practical priority of the scientific goals, that is, the strategy and timing of attacking them, might be more strongly determined by mission considerations than is the case in other areas of science. This is especially true in light of the extraordinarily long lead times that are associated with some of the large space science missions.

Figure 5.1 presents a schematic life cycle for the priority-setting process. Figure 5.2 shows relationships between various key players in this process. As is seen below, the level of scientific and technical detail involved in the inner feedback loop in Figure 5.1 will vary depending on where it is being done in the flow diagram of Figure 5.2. In some instances, scientists on disciplinary committees can

⁴By "program" is meant the collective activities in a discipline or subdiscipline (or even across disciplines) that include both missions and ground-based research—all the activities directed toward a goal or set of goals.

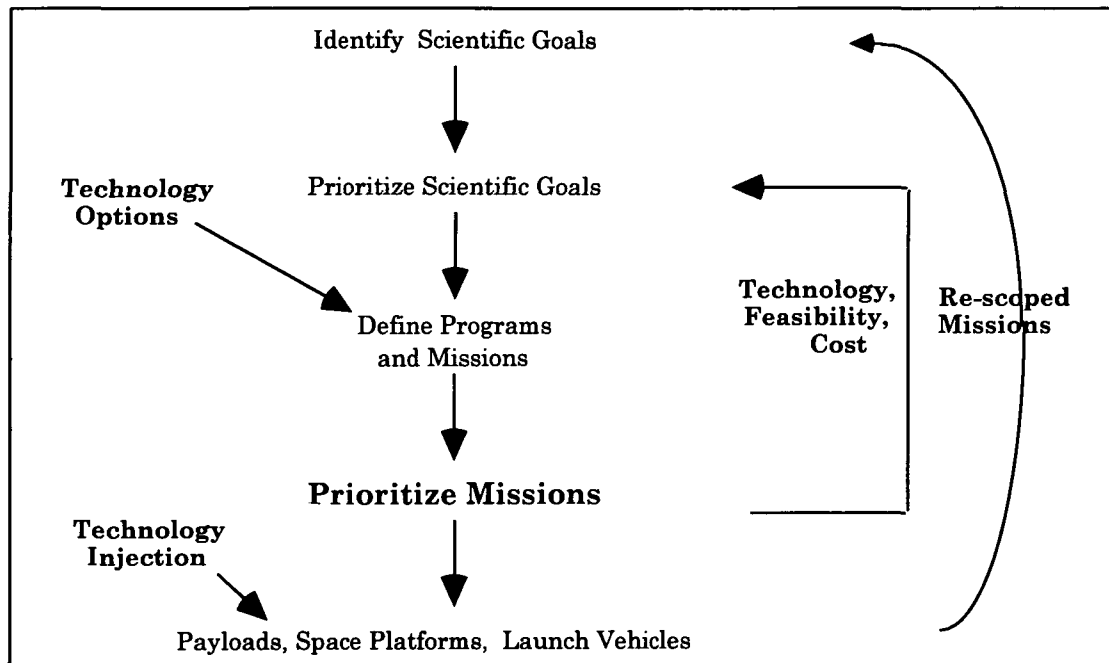


FIGURE 5.1 Prioritization life cycle.

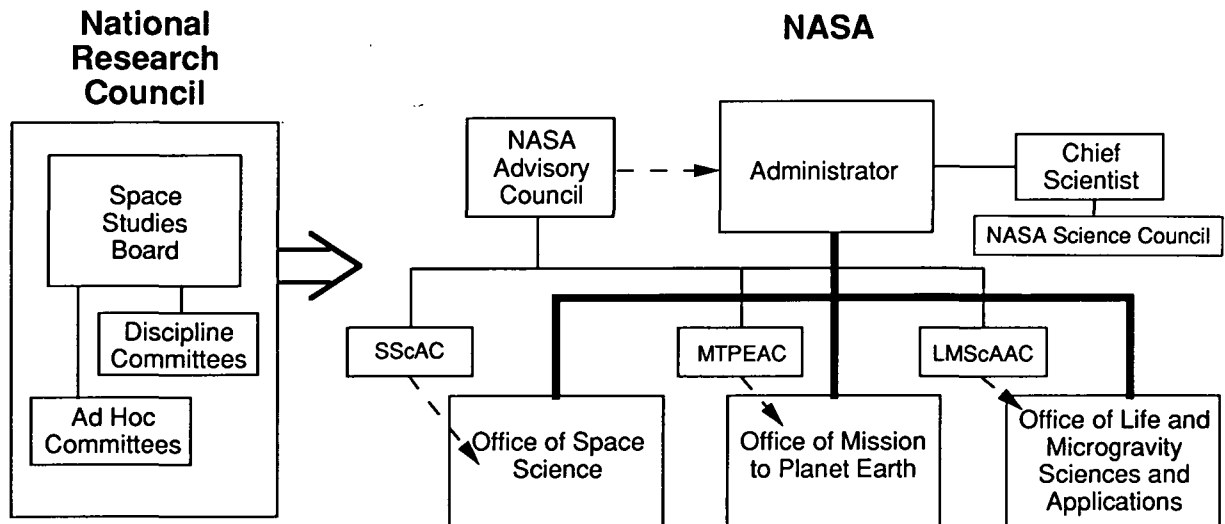


FIGURE 5.2 Key priority-setting participants.

complete the loop with a general knowledge of technology options and “ballpark” estimates of cost. But before final decisions are made within the NASA program offices, this loop has to be closed in great detail. The outer feedback loop recognizes the fact that the Administration or Congress sometimes reduces outlays to the point where missions have to be rescoped or rethought entirely.

There are many participants, tasks, criteria, and processes involved in the life cycle in these diagrams. The details vary from discipline to discipline. In microgravity, for example, the “space platforms,” principally the Shuttle and Space Station, correspond to “missions” (Figure 5.1) and are responsive to

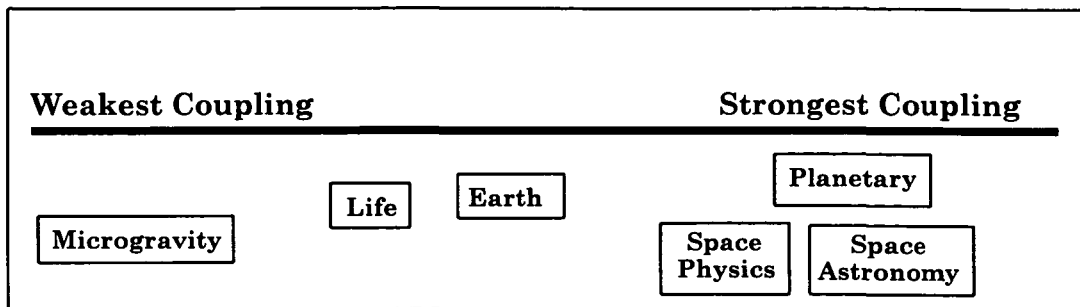


FIGURE 5.3 Coupling between science and mission platform.

national priorities outside of science; here, scientists focus almost entirely on prioritizing scientific goals within these constraints. In the classical space sciences (astronomy, planetary science, space physics), on the other hand, the scientific goals and the designs of missions are tightly bound, and the scientific community must conduct at least the initial trade-offs all the way down to “Prioritize Missions.” In the case of the “Great Observatories,” prioritization of some scientific goals takes place even after launch when user time on the instruments is allocated. In all disciplines, after in-depth studies of design, cost, and timing, the initial recommendations from the scientific community may repeat the cycle.

Thus, the disciplines present varying circumstances: a space platform built for other purposes that can accommodate scientific experiments (e.g., Shuttle, Space Station); new launch vehicles and space platforms being designed to accommodate a variety of science observations and experiments (e.g., the New Millennium spacecraft); and space platforms that must be designed explicitly for the particular scientific goal being pursued (e.g., larger observatories, planetary surface exploration systems). The strength of the coupling between scientific goal, program, and mission (illustrated schematically in Figure 5.3) must be recognized by the science prioritization process. For areas in which coupling is strong, the process loop of Figure 5.1 must be traversed early in the prioritization process at least at the level of conceptual design and ballpark cost estimates. For weak coupling, the loop is not traversed until late in the process.

The entire process of establishing space science priorities is dependent on a number of parameters:

- disciplinary level at which priorities are established,
- organizational level at which priorities are set,
- participants in the process,
- criteria to be applied,
- approach or process to be used, and
- tasks to be performed.

Disciplines

The committee used the word “discipline” to signify the six areas so designated in the current NASA program structure. These areas and the current NASA major offices having responsibility for each are as follows:

- Office of Space Science (OSS)
 - Astrophysics
 - Space physics
 - Planetary science

- Office of Life and Microgravity Sciences and Applications (OLMSA)
 - Life science
 - Microgravity science
- Office of Mission to Planet Earth (OMTPE)
 - Earth science

A discipline is an area, such as those represented in university hierarchies by academic departments, in which there is a coherent, communicating body of scientists who understand the scientific and technical aspects of one another's fields of research well enough to judge overall quality but who cannot easily trade places in performing research. The disciplines have different characteristics that affect the manner in which priorities are eventually established. Four (astrophysics, space physics, planetary science, and Earth science) are observational disciplines,⁵ while two (life science and microgravity science) are laboratory disciplines. Further, "microgravity" is, strictly speaking, a variable, not a discipline; it addresses the question of what can be learned in a variety of disciplines by experimentation in a low-gravity environment.

A few characteristics of NASA's six space science disciplines are as follows:

Astrophysics—Depends on remote-sensing techniques; NASA's program is a substantial part of the whole field of astronomy (certainly in dollar terms), which is therefore heavily dependent on NASA; may require large, expensive instruments.

Space Physics—Uses both remote-sensing and in situ techniques; field is strongly dependent on NASA, although it varies somewhat by subdiscipline (e.g., small for atmospheric science, moderate for solar physics, large for magnetospheric physics); can probably manage well with "smaller, faster, cheaper" missions.

Planetary Science—Uses both remote-sensing and in situ techniques; almost entirely dependent on NASA; requirements for interplanetary flight and planetary capture or landing lead to mission complexity.

Life Science—Laboratory science; NASA supports only a very small part of the total research field; this small part includes operational support (e.g., long-term effects of spaceflight on human biology) and operational (or strategic) research, as well as fundamental research. Operational (strategic) research in the life sciences is research that addresses problems directly related to the presence of humans in space and their short- and long-term ability to survive and function in that environment.⁶

Microgravity Science—Laboratory science; a loose collection of several disciplines (fluid mechanics and transport, biology and biotechnology, materials, combustion, and physics), some of which are phenomenological. The microgravity science portion of these disciplines is always a very small fraction of the total reach of the discipline. Individual microgravity studies are relatively small in scope and (relatively) small in incremental costs because the platform (Shuttle, Space Station) is presumed available.

Earth Science—Mainly remote sensing of Earth, ocean, and atmosphere parameters best examined from space; small part of the total field.

One of the most important effects of these differences is the degree to which the design of missions influences a determination of priorities of scientific goals. For example, scientists concerned with

⁵The committee recognizes the laboratory and theory components of these four sciences and is here referring to those areas of these sciences that are conducted in or from space by NASA. NASA will need to ensure that the ground-based research essential for understanding space observations is carried out.

⁶NRC, Space Studies Board, Committee on Space Biology and Medicine, letter to NASA's Life and Biomedical Sciences and Applications Division Director Joan Vernikos, July 27, 1995.

microgravity studies come from a variety of different traditional disciplines. Therefore, at the discipline advisory committee stage in the setting of priorities, scientists deliberating on scientific priorities within the program will be judging the relative scientific merits of projects outside the traditional boundaries of their personal disciplines. Although they cannot judge with the same precision as a corresponding panel in other space disciplines, participants are expected to obtain necessary information from one another and be able to make judgments regarding the relative importance of microgravity studies outside their own discipline. They should be able to explain this judgment to one another and through such discussions arrive at relative science priority rankings. A microgravity experiment of great significance to protein crystal growth, for example, ought to have higher priority than an experiment in fluid flow of only modest significance to that field. Competent scientists with adequate breadth of knowledge can have constructive discussions, even arguments, about such issues and arrive at a conclusion if asked to do so.

In astronomy, on the other hand, the commonly agreed-on science frontiers or goals are often expressed as new observational capabilities, that is, as a mission. This is because there is usually an array of frontier science questions that share a common need for a new observational capability.

As the process of prioritization engages the organizational entities shown in Figure 5.2, it passes through various levels of “disciplinarity”:

Subdisciplinary level—A field in which there is a communicating body of scientists who regard each other as active, working experts in the field, who believe that their own work can be adequately understood and judged by one another, and who could do one another’s research.

Disciplinary level—A field in which there is a communicating body of scientists who understand the scientific and technical aspects of one another’s fields of research, who could not necessarily easily trade places in the research they perform, but who can readily understand one another’s work and can easily cooperate in joint research. (Note: In the NASA lexicon, the “discipline” of microgravity is, strictly speaking, inconsistent with this definition, but it can be accommodated.)

Cross-disciplinary level—Fields in which there are communicating bodies of scientists with general knowledge of one another’s fields of expertise but (usually) having insufficient initial understanding to collaborate closely without reciprocal education and tutelage. At this cross-disciplinary level, two new elements arise in addressing priorities: (1) The need to “interleave” the priorities put forth by the disciplines. An important new element enters at this level: the conventional notion of “peer review” cannot be relied on exclusively, because areas with different sets of peers or expert constituencies are being intercompared. (2) Factors outside of pure scientific merit become more important. In fact, some of these, entering for the first time, may alter the order of priority established at the disciplinary level.

Agency level—Total scope of all research performed by NASA.

Structure and Participants

Figure 5.2 depicts the general context for setting science priorities for NASA. In the past, disciplinary committees of the NRC’s Space Studies Board (SSB), tapping into a broad constituency of scientists, would issue reports describing the important scientific goals to be pursued in their fields. These reports would be taken up by internal NASA groups, often working at the subdisciplinary level, and incorporated into plans for various space missions. A number of these missions were very large—at the billion dollar level or above—and required many years to be brought to fruition.

The expenditures on such a mission would include space vehicles and launch costs. Further, the projects involved considerable expenditure on continuing data collection, research, and analysis. Not too many of these large projects could be pursued concurrently, and so they would be ordered into a “mission queue” designed to meet the needs of the various scientific disciplines sequentially. Within NASA, the Associate Administrator for Space Science and Applications orchestrated the process of transforming

disciplinary scientific goals into this mission queue. The scientists in any discipline could be reasonably certain that, periodically, "their time would come."

In establishing the priority and sequence of these projects, the OSSA associate administrator not only used internal NASA resources, but also continued to tap into the broad community of scientists for advice and counsel. Occasionally, as convened by NASA in 1991 at Woods Hole, Massachusetts, scientists from internal and external committees in various fields assembled to discuss and argue about the entire set of plans and priorities. In general, this system was perceived to work well. The various disciplines felt that their arguments and suggestions had been heard even when their own programs did not head the resulting queue. However, the environment was one of budgets more or less adequate to accommodate much of what the scientific community thought important to do. While there were delays and occasional mission failures, few projects were canceled in midstream for budgetary reasons.

The future will be different. It will likely be a future of decreasing budgets, smaller missions, stronger emphasis on controlling costs, and greater competition between disciplines. Thus, the task of establishing priorities and making choices will be more difficult, and possibly more contentious, than in the past. In addition, NASA's science programs are now distributed among several organizations. Subdisciplinary and disciplinary trade-offs are made in separate units before choices are presented to each associate administrator for disciplinary and cross-disciplinary selection. Final decisions for major initiatives are then made by the Administrator with advice from the Chief Scientist.

The process in the various disciplines is not managed uniformly. While this variation may be logical from the point of view of the different national goals and purposes served by the major science offices, it is not clear that an appropriate balance of science and other objectives results. Moreover, the process has become less transparent to the scientific community at a time when its input may be more rather than less useful. The scientific community has not had to choose the highest-priority scientific goals from among many desirable goals, to participate actively in cross-disciplinary choices, or to help identify projects that should be stopped. Yet all of these things are going to be part of the future scene. In addition, innovative ways of conducting space science missions must be sought to enhance the ability to advance the space sciences. These novel methods of doing space science will be ever more important as budgets become tighter. The scientific community must find ways to help optimize these choices. Otherwise, decisions will be made primarily on administrative or political grounds.

Thus, the scientific community and NASA each face a challenge: the scientific community must address issues not addressed in the past, and NASA must establish and maintain a system of prioritization that is transparent and open in the new and more challenging climate of today. Meeting these challenges will be necessary if NASA's space science programs are to be strengthened and energized.

As NASA faces ever-increasing budgetary pressure, it is becoming increasingly important not only to prioritize among science initiatives and missions, but also to address issues of efficiency and productivity. The present NASA culture for accomplishing missions is sometimes inefficient, and many aspects of mission design, oversight, quality assurance, and management need to be remodeled and reduced. The top priority is to execute the highest-quality set of NASA science missions and initiatives possible within whatever budget is available. As a consequence, the real work of prioritizing among missions, both ongoing and new, must be done in an environment where an ever-increasing fraction of the science budget is devoted to science rather than to supporting functions. More must be done for less, rather than permitting an inefficient culture to squeeze out existing and future science initiatives.

The participants in this priority-setting process fall into three categories, as described below.

NRC Participants

Space Studies Board and its discipline committees—Mirroring NASA's historical administrative structure, the Space Studies Board (SSB) has divided space science into six disciplines: astronomy and

astrophysics, solar and space physics, planetary science, Earth science, microgravity, and life science. Each of these disciplines is overseen by a committee reporting to the Board; in two cases (astronomy and astrophysics, and solar and space physics) committee oversight is shared with another NRC board. The committees are charged with identifying research opportunities, setting and prioritizing the overall scientific goals within their discipline, and evaluating NASA's success in implementing these strategies.

NRC ad hoc committees—In the case of astronomy and astrophysics, the overall prioritization has been done once per decade by an ad hoc NRC committee. Unlike the committees that oversee the other five disciplines, the NRC astronomy and astrophysics survey committees prioritize missions and projects from major to relatively modest sizes.

NASA Advisory Participants

NASA advisory committees—NASA has established an extensive advisory committee system that, in the Office of Space Science at least, operates at both the associate administrator (cross-disciplinary) level and the division (disciplinary) level. That is, at the major office level, each associate administrator has an advisory committee (cross-disciplinary) that spans the fields in his office and reports directly to the NASA Advisory Council. Likewise, each division director within the major office has a disciplinary subcommittee that reports upward to the full committee as well as to the disciplinary division. Typically, the chair of each panel sits on the next highest level body. The primary task of these internal committees is advising NASA on science programs in their areas of competence. These programs are developed on the basis of scientific merit, technical readiness, and programmatic factors operative at their levels. Developing these programs entails prioritizing and integrating proposals submitted by their subordinate panels. The panels also serve some of the review functions of a university visiting committee, continually assessing the progress and status of their sponsoring NASA organizations.

The role of the NASA committees is primarily tactical and program planning, in contrast to the strategic focus of NRC committees. The NASA committees are also subject to the Federal Advisory Committee Act. As a result of these distinctions, meetings of the two groups of committees are quite different. The NASA committee meetings and deliberations have a much stronger programmatic flavor and typically address nearer-term and more specific planning issues. They are also always attended by a senior NASA manager and have more direct access to agency scientists, engineers, and budget information. The NASA advisory committees consist primarily of scientists drawn from the external community, but may include NASA scientists with particularly relevant expertise. While individual external community scientists may serve on the SSB (or its committees) and NASA committees (or their subcommittees) serially, simultaneous participation in both SSB and NASA committee structures is precluded by custom. This is to avoid the perception that any individual has excess influence or is serving as an advisor to both strategic planning and program execution at the same time.

NASA ad hoc committees—In order to provide regular access to space, NASA has established the Explorer program in astrophysics and space physics and the Discovery program in planetary science. In these programs, missions are prioritized by ad hoc program peer review panels during investigator and team selection. The degree to which SSB strategies are used in setting the priorities depends on details of the proposals under review and the extent to which SSB science priorities are accepted by the members of the ad hoc panel.

NASA Management Participants

Associate administrators—The associate administrators have the responsibility for managing the entire scientific program within their purview. In the Office of Space Science and the Office of Life and Microgravity Sciences and Applications, this involves setting priorities across disciplines. The associate

administrators are also responsible for coordinating with other federal agencies working in related areas. Finally, they serve as advocates for their programs to the Administrator in structuring funding priorities for the agency.

Science Council—This group comprises the science associate administrators and the Chief Scientist, is chaired by the latter, and acts as an advisory body to the Administrator.

Chief Scientist—The Chief Scientist provides advice to the Administrator on all issues relating to science within the agency. This official chairs the Science Council. The Chief Scientist tracks the choices made within the science programs of NASA and, with the Science Council, provides a forum for their coordination and balance.

Administrator—The Administrator of NASA makes final decisions that not only incorporate the best scientific and technical advice that has come up through the previous channels, but also reflect NASA strategy, national goals, and policy direction provided by the Administration and Congress.

THE PRIORITIZATION PROCESS

Key Elements

The scientific community strongly supports the practice of peer review for selection of research support and refereeing of results for publication. The scientific community regularly uses peer review to render judgment about the relative scientific value of research projects. Peer review implies judgment by others who are as expert in the field of inquiry as the one proposing work or reporting results. Scientists are comfortable with judgments rendered by peers, and were this process fully adequate for establishing priorities, the issue would be simple. But it is not.

The scientific community is uncomfortable with priority setting in which factors beyond pure scientific merit come into play, partly because it implies judgment by people who are not experts. Moreover, the degree of discomfort grows as the degree of scientific expertise of the decision makers goes down. Nevertheless, in the real world, priorities are virtually synonymous with budgets, so they cannot be escaped. Thus, if scientists are to play an expanded role in establishing priorities, they must engage in deliberations outside their areas of primary scientific expertise. They must also become accustomed to the intrusion of nonscientific factors.

Beginning with decision making within the narrowest boundaries, priority-setting mechanisms in use include the following:

Peer review—Scientific peers (i.e., experts in a common subdiscipline) determine a project's scientific merits, novelty, originality, importance, timeliness, methodologies, uncertainties, and conceptual reservations and reach agreement about a project's importance in relation to other projects.

Peer judgment—After peer review, projects must often be evaluated by a broader-based group, still in the same general discipline, who understand one another's work. This evaluation involves interleaving the recommendations of subdiscipline groups. The group's decisions are based primarily on scientific merit, but technical feasibility and cost, if known in some degree, can enter this review.

Science advocacy and challenge—Any proposed scientific effort has advocates who can argue its merits to the groups or authorities making priority decisions. Such advocacy provides informed support in the face of critical evaluation so that the scientific community will consider the proposal to have had fair representation.

Technical evaluation—At some level a decision has to be made not only on scientific merit, but also on technical feasibility. This decision will involve cost, whether needed technology exists or can be reasonably developed, and its effect on other projects. This decision process is not totally separable from scientific merit, and there will be elements of technical evaluation at all decision levels.

Management review—At the program and agency levels, if not at lower levels, there should be a comprehensive and vigorous confrontation of competing proposals. It is here that all of the factors going into priority setting must come together and the factors outside of science, technology, and cost (e.g., foreign policy, national needs, NASA strategies) must be considered by line management. Final review must ensure that all prior evaluations were made competently and in accordance with the agency's policies and procedures and that all significant criteria have been taken into account.

Analytic/algorithmic methods—The Space Studies Board has explored this type of process in the past.⁷ The process involves specifying a set of criteria and a set of entities to be evaluated. Each entity is evaluated or ranked by each criterion and the results combined by an agreed-upon method to obtain an overall rank or priority. Obviously, there can be many alternative ways of doing this, ranging from hard numbers assigned at every step to much "softer" rankings and combinations.

The main virtue of an algorithmic approach is that it forces an analysis of the substance and importance of the criteria to be used in prioritization. The danger is that the process can degenerate into an exercise in numerology. Anyone who wishes to use such a process should be careful to verify that the final outcome is consistent with his or her overall judgment.

The committee developed the following specific recommendations for the prioritization process:

Recommendation 5-1: A clear set of criteria for prioritizing scientific goals and missions should be established by NASA and adopted by all participants. Even though different subsets of the criteria may be applied by the various parties in the system, all of these participants should know what the complete set is, and, ideally, agree with it.

Recommendation 5-2: Goals and priorities within subdisciplines, and to some extent within disciplines, have been set in the past by panels of scientists; feasibility is demonstrated by a number of NRC committee reports. It is highly important that scientific criteria be applied by scientists.

Recommendation 5-3: Scientific goals need to be kept foremost in view at all times, even as NASA establishes priorities across the disciplines. As the scientific goals and priorities get modified by considerations of missions and/or broader national interests, including the priorities of other federal agencies, the scientific community needs to be continually involved in formulating these compromises and modifications.

Recommendation 5-4: Processes should be fair and sufficiently open and transparent to ensure credibility among nonparticipants. Broad participation is desirable—a significant and respected part of the scientific community should be involved in major priority-setting exercises. These characteristics will also ensure credibility among the participants themselves. Some of the participants at lower levels of priority setting should also participate at higher levels.

Recommendation 5-5: Processes and criteria at each priority-setting step must be able to identify new initiatives and rank ongoing efforts. The task of identifying new initiatives will occur automatically provided the formal exercise of priority setting is done periodically. Ongoing efforts must be rigorously included in the processes to ensure their continued priority. Management must face the task of canceling programs or projects that are failing or whose priority has dropped.

⁷NRC, Space Studies Board, *Setting Priorities in Space Research: An Experiment in Methodology*, National Academy Press, 1995.

Recommendation 5-6: Participation by scientists should continue up the hierarchy as far as scientific goals and criteria continue to play a role in priority setting. At each level, parties must have confidence that they are dealing only with propositions that have “passed scientific muster” below. There are separate and complementary roles for in-house NASA committees and for external advisors.

Recommendation 5-7: At each level in the hierarchy, priority-setting processes should incorporate (1) appropriate criteria, (2) competent and forceful advocacy, (3) strong challenge by dispassionate adversaries, and (4) involved discussion, all leading to consensus and/or concurrence. The processes should be public and widely understood and should include knowledgeable but disinterested individuals. NASA must buy in to the process, be a significant part of it, and accept the results. Interaction between NASA and the groups engaged in the process is necessary.

A key element of the process is review of proposals for scientific investigation by peers of the proposers. There are, however, two issues that must be dealt with in the proper management of peer review. The first is that the process must be free of any taint of conflict of interest. The use of experts in the same or related fields carries with it the risk that the reviewers may influence the outcome in ways that are favorable either to their own programs or to their close collaborators. The second issue relates specifically to NASA programs where NASA center scientists may compete for support with outside scientists. It is essential that the review process, whether for flight missions or laboratory research, not create real or perceived advantages for center scientists. If program management functions are moved from Headquarters to field centers, it is particularly important that Headquarters retain responsibility for the selection process in order to ensure that no bias is introduced into the evaluation.

Recommendation 5-8: Peer review for scientific investigations should be continued. Control of the peer review process should remain with Headquarters, and adequate Headquarters staff should be retained for this purpose. The process should be structured such that proposals from either outside or inside the agency are not placed at a real or apparent disadvantage.

One of the charges to this committee is to ensure the preservation of funding opportunity for highly innovative or high-risk research in an environment of budget constraints and well-entrenched existing constituencies. An innovative proposal typically suggests a pilot project designed to explore a scientific or technological idea that falls outside contemporary frameworks of inquiry or design. In principle, applying a criterion for scientific merit such as “Potential for New Discoveries and Understanding, and Uniqueness” in a rigorous, systematic way would ensure high rankings for highly innovative research. However, innovative and high-risk research does not always enter the system by conventional means, and even when it does, it may not be easy to rank against more conventional proposals during the peer review process. The most effective way to ensure that innovative, high-risk proposals get due attention is to build some flexibility and discretion into the system. Such a proposal, which might well be considered “high risk” by peer-review panels, would be considered for funding if it meets two criteria:

- the possible payoff of a successful outcome would more than compensate for the perceived level of risk; and
- the proposed experiments are well-designed and in the hands of competent investigators. Program managers would announce the opportunity to submit such proposals to the scientific and technological communities. Review panels would also be encouraged to forward to the relevant program manager proposals that they perceive to fall into this category.

The funding of innovative research should be adequate to test and explore an idea but should not

become a permanent source of funding for it. At some point, after appropriate seeding, the research either should be terminated or should enter the normal channels of program definition and prioritization.

Because proposals for innovative research may arise from many different sources and because, by definition, their precise nature is not easily anticipated, they need to be supported by an explicit budgetary item. Thus NASA budgets should include a line devoted to small grants for innovative ideas in space science, and the funds should not be used for any other purpose (e.g., for funding or “topping off” marginal projects in established budgets). The difficulty of maintaining room for innovative research will be much greater in the future than in the past because of intensified budgetary pressures.

Recommendation 5-9: Innovative research that may lead to new and important scientific findings should be fostered through allocation of limited discretionary funding for innovative, high-risk, high-return ideas falling outside current frameworks of inquiry or design. This research is highly important and deserves special management attention, including that of the Chief Scientist. This recommendation is not intended to allow circumventing of peer review for the major parts of any science program.

As an aside, small initiatives play an extremely important role in providing the opportunity for innovative ideas or unproved concepts to be included in the science enterprise. They should be judged principally on scientific merit and potential payoff.

Tasks

The tasks that must be performed to arrive at a final set of prioritized scientific goals and missions are suggested in Figure 5.1 and elaborated on below:

Identify scientific goals—In any advancing field of science, research participants are knowledgeable about the most compelling unanswered questions. These questions lead to the definition of common scientific goals that would be most likely to advance scientific understanding. Peer review is the proper means of screening scientific goals to identify those items that are legitimate and important scientific goals.

Prioritize scientific goals—Prioritization can take many forms. It may be a rigorous numerical ranking of items under consideration, or it may be no more than the identification, without ranking, of those items that exceed a defined threshold of importance. It is, basically, devising and using an explainable method—of whatever nature—to discriminate between things that are more important and those that are less important, and doing this to the extent necessary to make the decisions that must be made. Part of the entire process is deciding what issues (criteria) need to be addressed in determining importance.

Define programs—Given scientific goals and priorities, it is possible to structure the content of a program, including both flight missions and ground-based research, appropriate to the prioritized scientific goals. It is important that the science program not be warped excessively to conform to the current high-priority flight missions, which, after all, address only certain of the priorities.

Identify technology options—In order to define the missions necessary to pursue scientific goals, alternative technical approaches must be identified and judged. Space science projects must always be alert to new technology that might make missions more effective scientifically and less expensive.

Define missions—With an understanding of science priorities, overall program structure, and technology options, it should be possible to devise an optimal set of missions to carry them out. In astronomy the missions are essentially defined by the scientific goals as noted. In the microgravity sciences the mission is set by nonscientific national priorities, and the science rides “piggyback” on them. In other disciplines the coupling varies in depth and strength.

Prioritize missions—The primary consideration in prioritizing missions should be the quantity of high-quality science that can be achieved per dollar of expenditure.

Evaluate technology, feasibility, and cost—This task is represented by the inner feedback loop in Figure 5.1. It is the means by which scientific goals and missions become integrated and, as noted earlier, varies in intensity and depth from discipline to discipline.

Design payloads, platforms, vehicles—Conceptual versions of this task have to be performed as missions are defined to deduce feasibility and cost; these are iterated with prioritization of scientific goals. After the feedback loop in Figure 5.1 has been traversed enough to converge on science and mission priorities, the final, detailed design of payloads, platforms, and vehicles is the last step in planning the observational or experimental science. After collecting the data and observations, the investigators must be able to carry out their analysis and evaluation.

SUMMARY OF PRIORITIZATION TASKS, TOOLS, AND PARTICIPANTS

Summary Matrix

Table 5.1 collects and summarizes the elements of prioritization. This matrix illustrates the approximate distribution and relationship of the factors involved in priority setting and is not meant as a hard prescription. The degree of scientific involvement from the subdiscipline to the agency level will vary depending on discipline, and tasks duplicated from one level to the next will vary in style and depth.

During its analysis, the committee also considered the advisory functions traditionally carried out by the boards and committees of the National Research Council (see box).

TABLE 5.1 Matrix of Factors Involved in Prioritization and Science Program Level

Level	Tasks	Participants	Criteria	Approach
Subdiscipline and discipline	<ul style="list-style-type: none"> • Identify and prioritize scientific goals • Identify technology options 	<ul style="list-style-type: none"> • SSB disciplinary committees • NRC ad hoc committees • NAC committees • NASA program associate administrators 	<ul style="list-style-type: none"> • Scientific merit • Programmatic merit (initial) 	<ul style="list-style-type: none"> • Peer review • Peer judgment • Science advocacy • Initial technical evaluation
Cross-discipline	<ul style="list-style-type: none"> • Prioritize scientific goals (interleave disciplines) • Define programs and prioritize missions • Evaluate technology feasibility, costs 	<ul style="list-style-type: none"> • NAC advisory committees • NASA program associate administrators • NASA Chief Scientist • NASA Science Council 	<ul style="list-style-type: none"> • Scientific merit • Programmatic merit 	<ul style="list-style-type: none"> • Science advocacy and challenge • Management review
Agency	<ul style="list-style-type: none"> • Prioritize and select missions 	<ul style="list-style-type: none"> • NASA Administrator • NASA Chief Scientist • NASA Science Council 	<ul style="list-style-type: none"> • Scientific merit • Programmatic merit • Political and social merit 	<ul style="list-style-type: none"> • Science advocacy and challenge • Program advocacy and challenge • Management review

NOTE: At each level the process deals only with propositions that have the heritage of scientific merit from earlier reviews.

Role of the National Research Council

- National Research Council committees, including the Space Studies Board, should continue to be the channel and surrogate for participation by the broader scientific community and should be used by NASA to solicit and draw on the best ideas and judgment of this community. These committees should be made up of scientists not supported by NASA, as well as those who are. The establishment of space science priorities should begin, as it has in the past, with the efforts of the scientific community through the NRC and the Space Studies Board. This prioritization will address broad research thrusts, not individual proposals or technical approaches. The disciplinary committees of the Board have been effective in the past in suggesting important scientific goals for NASA to pursue. This process should be continued.

- Clear statements of priorities among suggested scientific goals should be made by all NRC committees that address priorities.

- The disciplinary committees should give some weight, in the beginning, to costs and timing. Scientists can often help in finding low- or lower-cost ways of addressing scientific goals. There is no reason to leave this factor totally out of consideration, even at the early stages of formulating scientific goals.

- Information about mission constraints, to the extent known, should be obtained by NRC disciplinary committees.

- An important output of the disciplinary committees should be a relatively small number of important scientific goals, major or moderate-sized programs, and the scientific justification for them. Arguments in support of their importance should be founded on defined criteria.

Recommendations for NASA Management

The committee offers the following additional prioritization-related management recommendations for NASA.

Recommendation 5-10: The NASA Advisory Council and its committees should continue to play a major advisory role in determining program priorities. The Council and committees should be composed primarily of external members, with internal NASA scientists included as appropriate.

Recommendation 5-11: The Chief Scientist should attend all key internal NASA meetings concerned with priorities and ensure that adequate scientific representation is maintained throughout the prioritization process and that a properly balanced set of recommendations reaches the Administrator. The Chief Scientist needs to be able to argue issues directly to the Administrator of NASA, independent of decisions by committees or managers at lower levels.

Recommendation 5-12: Within NASA Headquarters, there must be a capable scientific staff to support management priority setting in order to help ensure compatibility of program content and science priorities. These scientists must also interface with field center managers and external investigators to ensure science program integrity.

Technology: Analysis and Findings

The committee's task group on technology was charged to perform a broad analysis of the role of technology in the space sciences. As noted in Chapters 2 and 3, NASA is beginning to emphasize the benefits of new technologies for ameliorating the effects of diminished budgets. NASA refers to these new technologies as enabling both "faster, better, cheaper" missions and "smaller, faster, cheaper" missions. The "smaller" and "faster" adjectives draw upon Freeman Dyson's observations about the compelling scientific advantages of simple and rapid experimentation.¹ The "cheaper" adjective is a reflection of the current budget environment and was introduced to NASA by Administrator Goldin in 1992.

The slogan "faster, better, cheaper" is often misunderstood to mean that the new approach can be expected to yield "better" science. In fact, NASA's prior emphasis on scientific performance over cost often produced excellent science that may not be equaled by cost-limited missions. The "smaller, faster, cheaper" technologies may, on the other hand, be "better" primarily in the sense that they enable vigorous space science programs at an acceptable cost.

THE NEW RELATIONSHIP BETWEEN TECHNOLOGY AND THE SPACE SCIENCES

The development and utilization of "smaller, faster, cheaper" technologies offer many opportunities to energize the space sciences. The vision of frequent launches of small probes is an appealing one for rapid discovery, testing of hypotheses, and extension of understanding. While the laws of physics dictate that large, capable spacecraft will be needed for some missions, the new technologies should restore the balance between "large" and "small" science and lessen the cost of the remaining large missions.

Some new technologies will require adjustments in the practice of science. In addition to more frequent launches, "smaller, faster, cheaper" flight projects will often employ new technologies in sensors and for the interpretation of data. These new instruments may not measure everything that is possible, but only what is necessary, and, in some cases, data from new instruments and systems will not have the heritage of data from earlier instruments. Scientists will have to learn to use these new data, to relate them to older data where appropriate, and to replace through insights enabled by improved analyses what the new data may lack in desired breadth. In the process, accepted practices in the space sciences will change and science will evolve.

¹Dyson, F., *Infinite in All Directions*, Harper and Row, 1988.

On the other hand, development of technologies for the space sciences should be driven by significant science objectives. For new technologies to have the desired effect on the space sciences, NASA must be sensitive to boundaries that cannot be crossed without exchanging valid science for mere technology demonstrations. The identification, development, and utilization of new technologies must be subject to the discipline of meeting high-priority science objectives. The criterion for judging new technologies should be their potential for enabling more high-quality science within the constraints of realistic budgets. This judgment should be made through reviews by scientists and engineers who represent the best scientists and technologists in NASA and other agencies, in industry, and in academia.

The Integration of Science and Technology

If “smaller, faster, cheaper” missions are to yield high-quality science, scientists and engineers must work more closely during design, development, integration, flight operations, and data archiving than has been the general practice with large missions. The synergism of talents that is possible in team environments has proven effective in industry and should prove equally effective with flight projects. The necessary compromises and the mutual learning among scientists and engineers can best be realized in these team settings where everyone understands the enabling value of new technologies and recognizes that science and technology are mutually supportive in ensuring the future vitality of the space sciences.

A key to the success of integrated projects is balance between immediate scientific results and the validation of technologies that not only enable these immediate results, but also improve scientific capability for future missions. While that balance might lie anywhere between the extremes of “science is supreme” to a “validation of technology,” a moderation should be sought. The former does not help achieve better or more affordable science later; the latter may ultimately prove of little or no value unless the technologies selected for flight validation are based on real space science needs.

The development of new technologies for the space sciences should be coupled to current science objectives. NASA will not have the resources to develop every technology in the anticipation that a few will prove of eventual value to science. Nor will it have the resources to develop a broad range of technologies in the belief that the process will significantly enhance the competitiveness of U.S. industry. While many new technologies will have some commercial value, it would be unwise to distort space science priorities in anticipation of large, but unspecified, benefits to industry or science.

Previous Studies

A wide-ranging study of the civil space program was delivered in December 1990 by the Advisory Committee on the Future of the U.S. Space Program² (chaired by Norman Augustine). One recommendation of this report that is relevant to the current study was “that an agency-wide technology plan be developed [for NASA] with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds.” The study also recommended “a two- to three-fold enhancement of the current modest budget [for advanced technology development].”

NASA’s Office of Aeronautics and Space Technology (OAST) responded to the call for a technology plan by developing the 1991 *Integrated Technology Plan for the Civil Space Program* (ITP)³ and by having its Space Systems and Technology Advisory Committee (SSTAC) review that ITP.⁴

²Advisory Committee on the Future of the U.S. Space Program, *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990.

³NASA, *Integrated Technology Plan for the Civil Space Program*, 1991.

⁴NASA, *Advanced Technology for America’s Future in Space*, 1991.

In December 1991, NASA's OSSA and OAST suggested that the existing NRC Space Studies Board/Aeronautics and Space Engineering Board Joint Committee on Technology for Space Science and Applications review NASA's plans for developing new technologies in support of future space science and applications programs as described in the ITP. The NRC assembled a broadly representative group, named the Committee on Space Science Technology Planning (CSSTP) and composed of 26 engineers and scientists (including 7 members of the SSB/ASEB Joint Committee), to conduct the review. The CSSTP convened a workshop in June 1992 and delivered its report, *Improving NASA's Technology for Space Science*,⁵ in February 1993. This study and report formed the background and starting point for the work of the present committee. Summary recommendations of the report are provided in Appendix C. The Aeronautics and Space Engineering Board Committee on Advanced Space Technology published a relevant report on small spacecraft technology in 1994.⁶

TECHNOLOGY PLANNING

The present committee found that NASA lacks an agency-wide process for identifying, developing, and using new technologies in its space science missions. While each of the science offices has developed, or is in the process of developing, independent plans of varying quality, the lack of an overarching strategy or process makes it difficult for the science offices to combine limited resources to acquire relevant technologies that span the needs of more than one office, or for the agency to sustain development of technologies over more than a few budgeting periods. Without a unifying plan, NASA cannot be confident that it has identified critical weaknesses in space technology—particularly for those technologies that are unique to the space environment. The planning process should foster closer interaction between scientists and technology developers so that relevant scientific data can be used in technology development and so that needed directed research is identified and done.

Principal recommendations of both the report of the Augustine Committee (Appendix C) and the NRC's *Improving NASA's Technology for Space Science* (Appendix C) were that NASA develop an agency-wide Integrated Technology Plan (ITP) and that the ITP undergo periodic external review. As described above, NASA briefly had an ITP in 1991 (which was reviewed again in 1992), but because that plan was tied to the extraordinary budget growth recommended by the report of the Augustine Committee that never occurred, the ITP was never more than an extensive list of technologies that might be developed if funds became available. There has not yet been a successor to the 1991 ITP. In the interim, OSAT has funded candidate space science technologies without the benefit of explicit priorities. While ad hoc decision making is often necessary within dynamic organizations, there is no virtue in the permanent absence of a well-understood plan.

The agency planning process may encompass the needs of all NASA space technology stakeholders, but the resulting plan must, at a minimum, incorporate the interests of all the science offices and the relevant activities of OSAT. The planning process should consider the needs of the operational federal agencies that use NASA technologies in their operational systems (e.g., the National Oceanic and Atmospheric Administration and the U.S. Geological Survey). The plan should reflect realistic budgets and indicate how each new technology will be validated, that is, whether through flight or through ground demonstrations. It should include a strategy for ensuring an adequate systematic knowledge base for designing systems that must operate efficiently and reliably in the space environment. While the details of the plan will vary from year to year, the planning process should be stable.

⁵NRC, Committee on Space Science Technology Planning, *Improving NASA's Technology for Space Science*, National Academy Press, 1993.

⁶NRC, Committee on Advanced Space Technology, *Technology for Small Spacecraft*, National Academy Press, 1994.

The plan should be generated through project-level queries within the science offices to identify desired near-term and far-term technologies and through queries among the scientific and technology-developing communities to identify the far-term technologies that would enable important new science. The aspects of the plan relevant to space science should be reviewed annually by a committee chaired by the NASA Chief Scientist and made up of the NASA Science Council plus recognized scientists and engineers from inside NASA, from industry, and from academia. The first recommendation of a 1993 NRC report, *Improving NASA's Technology for Space Science*, has gone unheeded: "The NASA Administrator or OAST [now OSAT] Associate Administrator should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA—from early research through the various stages of technology development and readiness."

Recommendation 6-1: NASA should establish an agency-wide process for identifying, developing, and using technologies for the benefit of the space sciences. The aspects of the plan relevant to space science should be reviewed annually by a committee chaired by the NASA Chief Scientist and made up of the NASA Science Council plus recognized scientists and engineers from inside NASA, from industry, and from academia.

TECHNOLOGY DEVELOPMENT

Technology development suffers from the paradox that if no new missions needing new technologies are started, then no new technologies are needed; but if no new technologies are developed, then no new missions requiring new technologies can be started. The cycle can be broken only if the risks and costs of technology development are amortized over a number of missions. Therefore, the risk and cost of first flight demonstrations of new technologies must be charged to a program rather than to a single specific flight project. Unless NASA can uncouple the cost and risk of technology development from first flight applications, the most innovative new technologies are unlikely ever to fly.

Near-term Technologies

At least four categories of near-term technology development (development times of less than five years) can be identified:

1. Technologies that must be refined as part of a flight project. This category includes developments such as the first use of well-understood, composite structures to accommodate weight growth in another part of the spacecraft, or the incorporation of well-understood, autonomous operations to reduce mission operations costs.

2. Advanced Technology Development (ATD) in support of anticipated flight projects within a single space science office. This category includes projects such as the development of a new sensor array or a more effective in situ soil analyzer.

3. Focused technology development in support of anticipated flight projects in more than one space science office. This category includes projects such as the development of a smaller and more powerful flight control computer or a lighter attitude control system—items that might be used in Earth orbit or on missions to the planets.

4. Technology development in support of an approved program designed to validate technologies for future space science missions. Examples include projects under way as part of the Small Satellite Technology Initiative (SSTI) or New Millennium programs.

Recommendation 6-2: The space science offices should have primary responsibility for identifying and reviewing near-term technologies. This arrangement gives the science offices the greatest control of the technologies that most immediately affect the success of their programs. Each science office should allocate a significant fraction of its resources to ATD activities and should be willing to pool resources to achieve shared objectives. Most importantly, the implementation of all categories of technology development should be undertaken by the best-qualified individuals or teams within NASA, industry, or academia, as determined by peer review. The overall processes for near-term development would be coordinated by the Chief Scientist (or a designated representative of the Chief Scientist) through the NASA Science Council.

Category (1) technologies (above) should be identified, funded, managed, and reviewed within their associated flight projects. Category (2) technologies should be identified, funded, and reviewed by the science offices, but management would be where the expertise can be found—either within a science office or within OSAT. Category (3) technologies should be identified and reviewed jointly by the space science offices and OSAT, but they should be funded and managed by OSAT. Category (4) projects would be best funded by OSAT and the science offices and managed by OSAT, because they would provide the platform and operations to serve more than one customer.

Far-term Technologies

Far-term technologies (those requiring more than five years to be ready for a flight demonstration) should be selected for their potential to enhance performance significantly or lower the cost of undertaking science in space. These should not be projects designed to yield a 10 percent improvement, but rather they should attempt to double the cost-effectiveness or entirely change the way some aspect of science in space is undertaken. Such technologies need not involve space flight; for example, they might include high-altitude aircraft or new balloon technologies if these promise a significant improvement in quality or reduction in cost of the space sciences. Currently, OSAT states that it allocates 20 percent of its space science technology funds to primarily in-house, far-term technologies.

Recommendation 6-3: Promising far-term technologies should be identified, funded, and managed by the Office of Space Access and Technology (OSAT). Projects should be reviewed jointly by the science offices and OSAT. These far-term projects should be carried out by the best-qualified individuals or teams within NASA, industry, or academia as determined by peer review. Tight budgets make it more important than ever that a regular and rigorous review process be put in place to identify those projects that ought to be terminated.

Note that the allocation of \$31 million for FY 95 on far-term projects (as seen in Figure 2.7) at OSAT seems small, especially because of the inherent risk in far-term projects.

The Role of NASA Headquarters

As part of NASA downsizing, OSAT plans to reduce its Headquarters staff and transfer some of its functions to field centers. In one interpretation of this change, detailed management of the Spacecraft Systems Division—the OSAT organization that is responsible for space science technology—might move to the Engineering Directorate at Goddard Space Flight Center (GSFC). In this scenario, by 1997, an office within the GSFC Engineering Directorate would coordinate among all NASA centers the identification and prioritization of needed technologies for future space science missions and would manage issuance of announcements of opportunity, peer-reviewed selection, and performance reviews of

technology development projects. The technology development projects would be competed among industry, academia, and the NASA centers.

This GSFC-based function would encourage GSFC flight project managers and resident user scientists to cooperate in identifying, developing, and using new technologies. This cooperation would be particularly appropriate for near-term technologies seeking a flight opportunity. However, it is not clear how outside scientists would be heard in this arena, how a GSFC-based function could achieve the same coordination role for the Jet Propulsion Laboratory (JPL), or why GSFC is the appropriate environment for managing far-term technology development for the space sciences. The centers have an obvious conflict of interest in make-or-buy decisions; they tend to out-source on the basis of critical path decisions rather than the merit of proposed work, and they tend to use universities as low-cost alternatives to industry for deliverables rather than as places best suited for the development of the scientific underpinnings of far-term technologies.

Recommendation 6-4: NASA-wide oversight of technology for the space sciences belongs at Headquarters. While field centers might be asked to manage the day-to-day affairs of programs, it should be Headquarters' role to maintain a comprehensive, formal technology plan and to manage announcement, selection, and review of technology grants and contracts.

The Role of the Field Centers

As previously noted, NASA and the Department of Defense have been successful in building technological competence within industry and academia, so that national leadership in many aspects of space science technology development now resides outside of government laboratories. NASA field centers continue to develop needed technologies, particularly those associated with unique facilities, but they also invest in internal projects that are duplicative or below the standards of those now within industry and academia. Whatever their merit, a characteristic of many of these internal projects is that they are starved for resources to maintain and upgrade facilities.

Recommendation 6-5: NASA field centers should explicitly define those technological subdisciplines that require in-house research and development, for example, those associated with mission development, integration, testing, and operations; with a unique, national facility; or with "smart buying" of external technologies. Field centers must rely on the research and development capabilities of other NASA field centers and of laboratories of the Departments of Energy and Defense, industry, and academia wherever it is reasonable to do so. The essential, in-house capabilities should be sufficiently supported to ensure their quality as a national resource. Their effectiveness should be reviewed periodically by experts from other NASA field centers, industry, and academia. Evidence of continued excellence might include significant contributions to NASA technology development initiatives, key contributions to the technological advancement of their subdiscipline, journal publications, presentations at technical conferences, and patents.

The two science field centers—GSFC and JPL—have attempted to become largely self-sufficient by acquiring in-house talent either through federal employment or through support contracts. Both science centers take pride in the stability of their technology/engineering workforce. At the same time, they resist constructive exchanges of technology or of responsibility for technology between themselves, between themselves and NASA's research centers such as the Ames Research Center or the Lewis Research Center, or between themselves and industry or academia. The consequent isolation of these centers has led to a "not invented here" culture that distorts "make-or-buy" decisions and impedes technology infusion. This field center behavior must be modified so that centers seek common cause among

themselves and seek success through marshaling the broader science and technology communities to achieve the most effective space science projects that are possible for the available budget. While the current process of clarifying center responsibilities (essentially Earth orbit at GSFC and deep space at JPL) should help reduce competition between centers for similar projects, their insular culture is so deeply embedded that it may not be sufficient to achieve the desired cooperation.

Recommendation 6-6: NASA should develop aggressive programs for changing the insular culture of the field centers. Among these should be programs for personnel exchanges among the centers, industry, and academia. A fraction of the engineering/technology workforce should be viewed as transient.

Rotation of personnel might be achieved through increasing the participation of postdoctoral engineers in the Resident Research Associateship Program (as “NRC Fellows”) and in NASA-funded Intergovernmental Personnel Act (IPA) exchanges between the field centers and academia and by coupling promotions to extended visits to other field centers or to industry. These exchanges should be for a year or more so that the participants have opportunities to both teach and learn new technologies. While scientists accept the need to publish and to present papers, engineers and technologists are slower to do so. NASA should encourage these professional communications and the seeking of patents as mechanisms for ensuring awareness of new technologies.

Participation of Industry and Academia

Competence in space science technology has successfully diffused through industry and the universities. NASA must increasingly view its role as marshaling these skills and building on them for the benefit of the space science programs. While NASA has traditionally been willing to seek out-of-house talent to develop near-term technologies, far-term technology development has generally been the province of the field centers. This practice restricts the use of potentially useful technologies that reside in industry and academia. Talent and innovation that can be found in industry and academia, and the technology transfer and educational value of funding technology development outside NASA, should not be ignored.

Recommendation 6-7: NASA should use the nation’s best talent to develop both near-term and far-term space science technologies. Grants or contracts for space science technology development should be awarded on the basis of peer-reviewed proposals, and progress should be critically reviewed annually. Other funding from the agency should be provided on the basis of informed and conscious decisions by NASA upper management (at Headquarters or a center) and not as an automatic allocation to support the indefinite perpetuation of a laboratory or facility. Where NASA in-house capability is unable to compete on the basis of quality, NASA should decide whether to abandon the activity or to improve its quality so that it can compete.

TECHNOLOGY UTILIZATION

While most levels of NASA recognize that the future of the space science programs requires “smaller, faster, cheaper” technologies, the project managers who have to absorb these technologies are not given sufficient incentives to do so. Because projects are driven by cost, schedule, and mission success, and new technologies are perceived as a threat to all three, project managers resist incorporating technologies that have never been used on a flight. There is also a tension between the desire to use new technologies and the strong penalty provisions in new NASA contracts. There are several ways to encourage the use of new technologies: JPL assigns a technology advocate to each major project; GSFC

uses edicts from engineering management; and NASA Headquarters has created the SSTI and New Millennium programs to fund flight demonstrations of new technologies.

Recommendation 6-8: NASA should make special efforts to ensure that the emphasis it has newly placed on the incorporation of new technology in missions truly carries over to the processes for evaluation and selection of proposals. If increased use of new technology on NASA missions is valued by the agency, it should ensure that this value is explicit in the selection criteria for new projects. Furthermore, there should be stronger incentives for project managers to incorporate new technologies.

First, project managers should participate in the selection and review of technology development projects so that they are familiar with new technologies and, in some sense, have committed themselves to their use. Second, the project's objectives should include references to the use of new technologies. Third, the cost of incorporating a new technology in a flight project should be borne by the parent program so that there is an incentive for the manager of an individual project to use the new technology. While the committee concurs with the value of flight demonstration programs like New Millennium, it urges that every technology demonstration flight that is to benefit the space sciences use the new technology to accomplish valid science. Technology development that is divorced from its application is much less likely to prove fruitful.

TECHNOLOGY BUDGETS

The prospect of decreasing budgets has forced NASA to recognize that the vitality of its science programs depends on the infusion or development of new technologies and the incorporation of new practices in the development, integration, and operation of flight projects. The New Millennium program has been created to increase the demand for needed technologies and practices. However, the relevant expenditures by the science offices and OSAT have not increased sufficiently to foster a level of technology development appropriate to these new realities. While \$30 million to \$50 million per year is to be available for technology demonstration flights, the committee was not apprised of a corresponding allocation of resources to develop the technologies that could be meaningfully demonstrated.

Recommendation 6-9: While the committee endorses NASA's creation of programs like New Millennium, such programs should be coordinated across the agency to ensure that their appetite for technology is balanced by appropriate technology development budgets, that the new technologies truly serve the space sciences, that validation flights test technologies through the incorporation of real science objectives, and that there is an appropriate balance in the spectrum between flights that are dominated by the immediate needs of science and flights that devote significant resources to the incorporation of technologies that enable better or lower-cost science in the future.

Collected Recommendations

In responding to the charge by the NASA Administrator and the Senate appropriations subcommittee (Appendix A), the committee divided its task in terms of organizational, priority-setting, and technology utilization issues. The resulting broad set of recommendations reveals a number of common themes. For convenient reference, this chapter collects and reorders the major recommendations of the committee grouped according to these overarching themes.

ESTABLISHMENT OF A “NATIONAL INSTITUTE FOR SPACE SCIENCE”

Recommendation 4-1: The committee found no compelling reason to establish an independent institute for space science modeled on the National Institutes of Health. Rather, NASA should retain its science programs in the present three-enterprise distributed form, but also take action to provide the necessary integration among the programs (see Recommendation 4-2).

ROLE OF THE NASA CHIEF SCIENTIST

Recommendation 4-2: The position of Chief Scientist should be strengthened to ensure full integration of the space sciences. A proposed functional statement that encompasses the necessary authority is provided, followed by a proposed functional statement for the NASA Science Council (see box).

Recommendation 5-11: The Chief Scientist should attend all key internal NASA meetings concerned with priorities and ensure that adequate scientific representation is maintained throughout the prioritization process and that a properly balanced set of recommendations reaches the Administrator. The Chief Scientist needs to be able to argue issues directly to the Administrator of NASA, independent of decisions by committees or managers at lower levels.

Recommendation 6-1: NASA should establish an agency-wide process for identifying, developing, and using technologies for the benefit of the space sciences. The aspects of the plan relevant to space science should be reviewed annually by a committee chaired by the NASA Chief Scientist and made up of the NASA Science Council plus recognized scientists and engineers from inside NASA, from industry, and from academia.

Proposed Functional Statement for the Chief Scientist

The Chief Scientist exercises NASA-wide leadership for the space sciences and serves as the principal scientific advisor to the NASA Administrator. He or she should be a person of strong standing in the scientific community with significant accomplishment in his or her own field. The individual filling this position should have a breadth of interest and understanding transcending the space sciences to encompass technology and the interaction of science and technology with elements of society. This person should also have management experience, preferably in large organizations. Understanding of government processes is highly desirable. Specific functions of the position are as follows:

- Serves as primary advisor to the NASA Administrator.
- Provides formal concurrence on planning, programs, budgets, and so forth, for the NASA science programs.
 - Acts to resolve conflicts among the science programs and between science programs and other NASA programs.
 - Chairs the NASA Science Council.
 - Maintains oversight of science quality across the agency, recommending corrective action where necessary.
 - Maintains oversight of the integration of advanced technology into science programs across the agency, recommending corrective action where necessary.
 - Provides for coordination among the sciences at many levels: programs, advisory groups, other agencies, the scientific community.
 - Serves as representative of NASA science to the outside world and represents the scientific community to NASA.

Proposed Functional Statement for the NASA Science Council

The NASA Science Council, chaired by the Chief Scientist, is the internal NASA body responsible for coordination and integration of science programs and activities.

Specific functions are as follows:

- Sets principles and policies for scientific aspects of strategic planning.
- Reviews and integrates resulting strategic plans for consistency with policies and agency-level guidance.
 - Provides a forum for coordinating programs.
 - Provides a forum for conflict resolution.
 - Reviews and makes recommendations to help ensure the health of the intellectual and physical infrastructure.

Membership of the NASA Science Council consists of the Chief Scientist (chair), the Associate Administrators for the space science programs (OSS, OLMSA, OMTPE), and the Associate Administrator for Space Access and Technology.

Recommendation 6-2: The space science offices should have primary responsibility for identifying and reviewing near-term technologies. This arrangement gives the science offices the greatest control of the technologies that most immediately affect the success of their programs. Each science office should allocate a significant fraction of its resources to ATD activities and should be willing to pool resources to achieve shared objectives. Most importantly, the implementation of all categories of technology development should be undertaken by the best-qualified individuals or teams within NASA, industry, or academia, as determined by peer review. The overall processes for near-term development would be coordinated by the Chief Scientist (or a designated representative of the Chief Scientist) through the NASA Science Council.

THE ROLE OF HEADQUARTERS

Recommendation 4-3: NASA should eliminate the separate “program management” layer, assign to the enterprises the program management functions properly located at Headquarters, and delegate to the field centers those program management functions properly located there.

Recommendation 5-8: Peer review for scientific investigations should be continued. Control of the peer review process should remain with Headquarters, and adequate Headquarters staff should be retained for this purpose. The process should be structured such that proposals from either outside or inside the agency are not placed at a real or apparent disadvantage.

Recommendation 5-12: Within NASA Headquarters, there must be a capable scientific staff to support management priority setting in order to help ensure compatibility of program content and science priorities. These scientists must also interface with field center managers and external investigators to ensure science program integrity.

Recommendation 6-4: NASA-wide oversight of technology for the space sciences belongs at Headquarters. While field centers might be asked to manage the day-to-day affairs of programs, it should be Headquarters’ role to maintain a comprehensive, formal technology plan and to manage announcement, selection, and review of technology grants and contracts.

NASA FIELD CENTER ISSUES

Recommendation 4-4: The Goddard Space Flight Center should remain a civil service center for the time being. However, NASA should establish periodic external reviews of GSFC to determine whether new consideration should be given to conversion to a GOCO arrangement.

Recommendation 4-5: Creation of contractor-operated institutes (a focused science activity operated under contract within a center having broader, possibly nonscientific, responsibilities) may be advantageous for specific science functions or facilities. The selection and creation of such institutes should be limited to special circumstances, specifically,

- to be responsible for a narrow, bounded area of science,
- to operate a special facility for the scientific community, and
- to maintain a unique national facility or staff capability,

but

- NOT just to lower civil service headcount and
- NOT if the entity is an integral part of the larger organization (the host center).

The committee recommends that, if NASA proceeds to establish pilot science institutes, it give due attention to the out-years process by which these institutes will have their guaranteed base budgets ramped down, and to the competitive process under which they will be expected to compete successfully and maintain or increase their size, or to compete less successfully and shrink or terminate in an orderly fashion. The committee recommends that other institute initiatives be deferred until the success of initial pilots can be evaluated.

Recommendation 4-6: NASA should conduct scientific research activities in-house only to the extent required to compete successfully for high-quality staff, to maintain capability to manage and interface with corresponding activities on the outside (e.g., as a “smart buyer”), or to maintain and operate an in-house capability that is unique in the nation. Otherwise, if a valid out-of-house capability exists, the work should be done there.

Recommendation 4-7: NASA should adopt an industrial funding model for field centers. Decisions on program priorities and budget would be more rational if based on full-cost accounting, and program accountability and discipline in personnel management would be thereby enhanced. The principal objective is that cost accounting should be based on full program costs, including civil service salaries, to achieve the advantageous features cited above. A similar recommendation was made in the *NASA Federal Laboratory Review* report.¹

Recommendation 4-8: Center reporting arrangements should remain as they currently are, with each center reporting to an appropriate enterprise. All requirements and directions addressed to a center from any source should be directed through that enterprise.

Recommendation 4-9: Renewed emphasis should be given to the essential role and responsibility of the project scientist in project trade-offs and decisions through the life of the project.

Recommendation 4-10: NASA should maximize delegation of project responsibility to the executing agents of its space science programs (center, laboratory, university, or industry) and minimize redundant NASA oversight. This practice can yield excellent results at an affordable cost. High-value, one-of-a-kind space science missions may justify increased independent oversight. If necessary, this increased oversight should be clearly established in the program definition stage and should not be permitted to creep or evolve with program maturity. The committee makes no recommendation regarding oversight, delegation of responsibility, nor privatization in the human space flight program.

Recommendation 6-4: NASA-wide oversight of technology for the space sciences belongs at Headquarters. While field centers might be asked to manage the day-to-day affairs of programs, it should be Headquarters’ role to maintain a comprehensive, formal technology plan and to manage announcement, selection, and review of technology grants and contracts.

Recommendation 6-5: NASA field centers should explicitly define those technological subdisciplines that require in-house research and development, for example, those associated with mission development, integration, testing, and operations; with a unique, national facility; or with “smart buying” of external technologies. Field centers must rely on the research and development capabilities of other NASA field centers and of laboratories of the Departments of Energy and Defense, industry, and academia wherever it is reasonable to do so. The essential, in-house capabilities should be sufficiently supported to ensure their quality as a national resource. Their effectiveness should be reviewed periodically by experts from other NASA field centers, industry, and academia. Evidence of continued excellence might include significant contributions to NASA technology development initiatives, key contributions to the technological advancement of their subdiscipline, journal publications, presentations at technical conferences, and patents.

¹Federal Laboratory Review Task Force, NASA Advisory Council, *NASA Federal Laboratory Review*, February 1995.

Recommendation 6-6: NASA should develop aggressive programs for changing the insular culture of the field centers. Among these should be programs for personnel exchanges among the centers, industry, and academia. A fraction of the engineering/technology workforce should be viewed as transient.

THE SCIENCE PRIORITIZATION PROCESS

Recommendation 5-1: A clear set of criteria for prioritizing scientific goals and missions should be established by NASA and adopted by all participants. Even though different subsets of the criteria may be applied by the various parties in the system, all of these participants should know what the complete set is, and, ideally, agree with it.

Recommendation 5-2: Goals and priorities within subdisciplines, and to some extent within disciplines, have been set in the past by panels of scientists; feasibility is demonstrated by a number of NRC committee reports. It is highly important that scientific criteria be applied by scientists.

Recommendation 5-3: Scientific goals need to be kept foremost in view at all times, even as NASA establishes priorities across the disciplines. As the scientific goals and priorities get modified by considerations of missions and/or broader national interests, including the priorities of other federal agencies, the scientific community needs to be continually involved in formulating these compromises and modifications.

Recommendation 5-4: Processes should be fair and sufficiently open and transparent to ensure credibility among nonparticipants. Broad participation is desirable—a significant and respected part of the scientific community should be involved in major priority-setting exercises. These characteristics will also ensure credibility among the participants themselves. Some of the participants at lower levels of priority setting should also participate at higher levels.

Recommendation 5-5: Processes and criteria at each priority-setting step must be able to identify new initiatives and rank ongoing efforts. The task of identifying new initiatives will occur automatically provided the formal exercise of priority setting is done periodically. Ongoing efforts must be rigorously included in the processes to ensure their continued priority. Management must face the task of canceling programs or projects that are failing or whose priority has dropped.

Recommendation 5-6: Participation by scientists should continue up the hierarchy as far as scientific goals and criteria continue to play a role in priority setting. At each level, parties must have confidence that they are dealing only with propositions that have “passed scientific muster” below. There are separate and complementary roles for in-house NASA committees and for external advisors.

Recommendation 5-7: At each level in the hierarchy, priority-setting processes should incorporate (1) appropriate criteria, (2) competent and forceful advocacy, (3) strong challenge by dispassionate adversaries, and (4) involved discussion, all leading to consensus and/or concurrence. The processes should be public and widely understood and should include knowledgeable but disinterested individuals. NASA must buy in to the process, be a significant part of it, and accept the results. Interaction between NASA and the groups engaged in the process is necessary.

Recommendation 5-8: Peer review for scientific investigations should be continued. Control of the peer review process should remain with Headquarters, and adequate Headquarters staff should be retained for this purpose. The process should be structured such that proposals from either outside or inside the agency are not placed at a real or apparent disadvantage.

Recommendation 5-9: Innovative research that may lead to new and important scientific findings should be fostered through allocation of limited discretionary funding for innovative, high-risk, high-return ideas falling outside current frameworks of inquiry or design. This research is highly important and deserves special management attention, including that of the Chief Scientist. This recommendation is not intended to allow circumventing of peer review for the major parts of any science program.

Recommendation 5-10: The NASA Advisory Council and its committees should continue to play a major advisory role in determining program priorities. The Council and committees should be composed primarily of external members, with internal NASA scientists included as appropriate.

Recommendation 5-11: The Chief Scientist should attend all key internal NASA meetings concerned with priorities and ensure that adequate scientific representation is maintained throughout the prioritization process and that a properly balanced set of recommendations reaches the Administrator. The Chief Scientist needs to be able to argue issues directly to the Administrator of NASA, independent of decisions by committees or managers at lower levels.

Recommendation 5-12: Within NASA Headquarters, there must be a capable scientific staff to support management priority setting in order to help ensure compatibility of program content and science priorities. These scientists must also interface with field center managers and external investigators to ensure science program integrity.

TECHNOLOGY PLANNING AND IMPLEMENTATION

Recommendation 6-1: NASA should establish an agency-wide process for identifying, developing, and using technologies for the benefit of the space sciences. The aspects of the plan relevant to space science should be reviewed annually by a committee chaired by the NASA Chief Scientist and made up of the NASA Science Council plus recognized scientists and engineers from inside NASA, from industry, and from academia.

Recommendation 6-2: The space science offices should have primary responsibility for identifying and reviewing near-term technologies. This arrangement gives the science offices the greatest control of the technologies that most immediately affect the success of their programs. Each science office should allocate a significant fraction of its resources to ATD activities and should be willing to pool resources to achieve shared objectives. Most importantly, the implementation of all categories of technology development should be undertaken by the best-qualified individuals or teams within NASA, industry, or academia, as determined by peer review. The overall processes for near-term development would be coordinated by the Chief Scientist (or a designated representative of the Chief Scientist) through the NASA Science Council.

Recommendation 6-3: Promising far-term technologies should be identified, funded, and managed by the Office of Space Access and Technology (OSAT). Projects should be reviewed jointly by the science offices and OSAT. These far-term projects should be carried out by the best-qualified individuals or teams within NASA, industry, or academia as determined by peer review. Tight budgets make it more important than ever that a regular and rigorous review process be put in place to identify those projects that ought to be terminated.

Recommendation 6-4: NASA-wide oversight of technology for the space sciences belongs at Headquarters. While field centers might be asked to manage the day-to-day affairs of programs, it should be Headquarters' role to maintain a comprehensive, formal technology plan and to manage announcement, selection, and review of technology grants and contracts.

Recommendation 6-5: NASA field centers should explicitly define those technological subdisciplines that require in-house research and development, for example, those associated with mission development, integration, testing, and operations; with a unique, national facility; or with “smart buying” of external technologies. Field centers must rely on the research and development capabilities of other NASA field centers and of laboratories of the Departments of Energy and Defense, industry, and academia wherever it is reasonable to do so. The essential, in-house capabilities should be sufficiently supported to ensure their quality as a national resource. Their effectiveness should be reviewed periodically by experts from other NASA field centers, industry, and academia. Evidence of continued excellence might include significant contributions to NASA technology development initiatives, key contributions to the technological advancement of their subdiscipline, journal publications, presentations at technical conferences, and patents.

Recommendation 6-6: NASA should develop aggressive programs for changing the insular culture of the field centers. Among these should be programs for personnel exchanges among the centers, industry, and academia. A fraction of the engineering/technology workforce should be viewed as transient.

Recommendation 6-7: NASA should use the nation’s best talent to develop both near-term and far-term space science technologies. Grants or contracts for space science technology development should be awarded on the basis of peer-reviewed proposals, and progress should be critically reviewed annually. Other funding from the agency should be provided on the basis of informed and conscious decisions by NASA upper management (at Headquarters or a center) and not as an automatic allocation to support the indefinite perpetuation of a laboratory or facility. Where NASA in-house capability is unable to compete on the basis of quality, NASA should decide whether to abandon the activity or to improve its quality so that it can compete.

Recommendation 6-8: NASA should make special efforts to ensure that the emphasis it has newly placed on the incorporation of new technology in missions truly carries over to the processes for evaluation and selection of proposals. If increased use of new technology on NASA missions is valued by the agency, it should ensure that this value is explicit in the selection criteria for new projects. Furthermore, there should be stronger incentives for project managers to incorporate new technologies.

Recommendation 6-9: While the committee endorses NASA’s creation of programs like New Millennium, such programs should be coordinated across the agency to ensure that their appetite for technology is balanced by appropriate technology development budgets, that the new technologies truly serve the space sciences, that validation flights test technologies through the incorporation of real science objectives, and that there is an appropriate balance in the spectrum between flights that are dominated by the immediate needs of science and flights that devote significant resources to the incorporation of technologies that enable better or lower-cost science in the future.

Appendixes

APPENDIX

A

Requests for Study

U.S. SENATE
COMMITTEE ON APPROPRIATIONS
SUBCOMMITTEE ON VA, HUD, AND INDEPENDENT AGENCIES

Text of report accompanying NASA's FY 1994 appropriation:

The future of space science—The Committee has included \$1,000,000 for the National Academy of Sciences to undertake a comprehensive and independent review of the role and position of space science within NASA. It will come as no surprise that the Committee did not support or recommend the dismantling of the Office of Space Science and Applications. The contributions made by that office in strategic planning, cross disciplinary priority setting, and management controls were among the best that the Federal Government has ever undertaken in any of its many scientific components. Given the administration's desire to reinvent Government, the Committee believes the time has come to seriously consider the creation of an institute for space science that would serve as an umbrella organization within NASA to coordinate and oversee all space science activities, not just those in physics, astronomy, and planetary exploration. Such an institute could function just as the National Institutes of Health now does within the Department of Health and Human Services. The Committee recognizes that there are certain tradeoffs in the creation of any new entity. The Academy should look at mechanisms for priority setting across disciplines on the basis of scientific merit, better means to include advanced technology in science missions, and ways to permit less developed scientific disciplines to have a means of proving their value, despite skepticism about them in the more established scientific fields.

Text of report accompanying NASA's FY 1995 appropriation:

The future of space science—The Committee is concerned that no new space science missions are now planned to be launched by NASA after 1997 at this time. In addition, it is deeply troubled by reports that a so-called wedge of funding in the 1996 budget for any new science flight projects may require one-half of the funds to come from existing science budgets. Neither condition is acceptable, and the Committee will expect whatever pool of funds to be used for future new starts to come from outside of the existing base of space science funds. The Committee expects the National Academy of Sciences to factor this funding and mission vacuum into its assessment for the need for a national institute for space science.

LETTER FROM NASA ADMINISTRATOR DANIEL S. GOLDIN

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001



Dr. Bruce Alberts
President
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

APR 7 1994

Dear Dr. Alberts:

The Conference Report accompanying H.R. 2491, the FY 1994 VA-HUD-Independent Agencies appropriations bill, provides \$1.0 million "for an assessment of whether a National Institute of Space Science should be established within NASA." I request that the NAS's Space Studies Board (SSB) initiate this study in accordance with Congressional guidelines.

Specific directions are provided in the Senate Appropriations Subcommittee Report 103-127. In compliance with these directions, a task group should be formed to examine alternative organizational approaches to coordinating and overseeing NASA's science programs. In addition, the SSB should utilize existing task groups and/or subpanels to evaluate possible mechanisms for establishing interdisciplinary science priorities based on scientific merit and/or other pertinent criteria; improving utilization of advanced technologies in future science missions; and ensuring opportunities for smaller, newer science disciplines to successfully compete for limited resources against larger, more established ones. A statement of work outlining the specific study tasks has been mutually agreed upon by NASA's Chief Scientist and the SSB Chair.

The NAS should incorporate its findings into a report that addresses all issues specified above. It is essential that recommendations clearly define the pros and cons for any proposed changes to the existing organization. Since this type of assessment is within the scope of our current contract, funding for this activity will be provided through this channel. I am grateful to NAS for its assistance in this endeavor, and I look forward to hearing from you in the near future.

Sincerely,

A handwritten signature in cursive script that reads "Daniel S. Goldin".

Daniel S. Goldin
Administrator

cc:
S/Dr. Huntress

APPENDIX B

Statements of Task

COMMITTEE ON THE FUTURE OF SPACE SCIENCE

The Project on the Future of Space Science (FOSS) will advise the Space Studies Board on assessing the role and conduct of space science within NASA. This assessment will analyze specific areas identified by FY95 Senate Appropriations report language and requested by the NASA Administrator: (1) organization of civil space research programs within the agency; (2) merit-based cross-disciplinary prioritization, including preservation of innovative initiatives; and (3) improvements in technology insertion into science missions. The Board will charge two ad hoc task groups and its existing joint committee on technology to perform the needed analyses. An ad hoc steering group will integrate the findings of the task groups and joint committee into a single report, which will be approved by the Board and published in a NRC-reviewed report.

TASK GROUP ON ALTERNATIVE ORGANIZATIONS

On behalf of the Space Studies Board, and working under the oversight of the Future of Space Science (FOSS) Steering Group (FOSS-SG), the Task Group on Alternative Organizations (AO) will study issues and options relating to the organization of NASA's science programs, as directed in FY1994 report language of the Senate Subcommittee on VA-HUD-IA. Additional guidance is provided in the FY1995 Senate report language. The work of the FOSS-AO will be combined with that of two other subpanels, the FOSS Task Group on Research Prioritization (FOSS-RP) and the Board's standing Joint Committee on Technology (JCT) to compose an integrated recommendation on the "role and position" of science within NASA and the nation's research agenda.

This task group will consider alternative approaches to coordinating planning and management of NASA's space science programs. One possible model recognized in the Senate Report is the National Institutes of Health (NIH) within the Department of Health and Human Services. The task group will also examine other relevant federal (e.g., NIST, DOD, and DOE) and quasi-government (FFRDC) research and development institutions; private sector institutions and non-U.S. management models may be considered. The study will be structured to facilitate input by space research communities.

Specific tasks of the FOSS-AO are:

- (1) Interact with the FOSS-SG to finalize the FOSS-AO Statement of Task
- (2) Schedule and conduct meetings as needed and budgeted

(3) Examine alternative management and organizational structures and approaches that could be used to conduct NASA's science programs, including:

- organization of research within federal agencies other than NASA, e.g., NOAA, NIST, DOE, DOD, NSF; special consideration should be given to NIH as requested in the Senate language
- organizations external to the federal government, e.g., FFRDCs, industry, academic institutions, and public, not-for-profit entities

(4) Consideration should be given to:

- intra-NASA interfaces
- roles and capabilities of government, universities, and industry in performing research (consideration should be given to both applied and basic research, large- and small-scale programs, and long- and short-term efforts)
- impact on graduate education and research community renewal
- role of international collaboration and impact on it
- transition issues

(5) Document its findings and recommendations in a report to the FOSS-SG

(6) As needed, support preparation by the Steering Group of an integrated report composed of FOSS-AO, FOSS-RP, and JCT reports; also, support NRC review and publication of the integrated report

TASK GROUP ON RESEARCH PRIORITIZATION

On behalf of the Space Studies Board, and working under the oversight of the Future of Space Science (FOSS) Steering Group (FOSS-SG), the Task Group on Research Prioritization (RP) will study issues and options relating to the prioritization of space research as directed in FY1994 report language of the Senate Subcommittee on VA-HUD-IA. Additional guidance is provided in the FY1995 Senate report language. The work of the FOSS-RP will be combined with that of two other subpanels, the FOSS Task Group on Alternative Organizations (FOSS-AO) and the Board's standing Joint Committee on Technology (JCT) to compose an integrated recommendation on the "role and position" of space science within NASA and the nation's research agenda.

Specific tasks of the FOSS-RP are:

- (1) Interact with the FOSS-SG to finalize the FOSS-RP Statement of Task
- (2) Schedule and conduct meetings as needed and budgeted
- (3) Survey and evaluate candidate mechanisms for priority setting across disciplines on the basis of scientific merit; the study should include consideration of the following issues:
 - alternative interpretations and presentations of "priority setting"
 - approaches to priority setting within the NIH, NSF, NOAA, and DoD (also former OSSA approaches)
 - role of criteria other than scientific merit in research priority setting
 - relative roles of diverse participants in priority setting
 - processes for culling and termination prioritization
 - preservation of funding opportunity for highly innovative or high risk research in an environment of budget constraints and well-entrenched existing constituencies
 - appropriate role for international agreements
 - transition issues

- (4) Document its findings and recommendations in a report to the FOSS-SG
- (5) As needed, support preparation by the Steering Group of an integrated report composed of FOSS-AO, FOSS-RP, and JCT reports; also, support NRC review and publication of the integrated report.

The task group should consider the draft final report of the Board's former Task Group on Priorities in Space Research, as well as the same task group's published interim report, *Setting Priorities in Space Research—Opportunities and Imperatives* (NAP, 1992).

TASK GROUP ON TECHNOLOGY

On behalf of the Space Studies Board of the National Research Council (NRC), and working under the oversight of the Future of Space Science Steering Group (FOSS-SG), the Task Group on Technology (FOSS-T) will study issues relating to better means to include advanced technology in science missions. The FOSS study is being sponsored by NASA and conducted by the NRC in response to the FY 1994 report language of the U.S. Senate Subcommittee on VA-HUD-IA, and the FY 1995 report language of the U.S. Senate Appropriations Committee which reaffirmed the request for a formal NAS [NRC] assessment of the need for a national institute of space science.

In carrying out its duties in accordance with a written request from the NASA Administrator and authority from the FOSS-SG, the FOSS-T will analyze opportunities and obstacles in the incorporation of advanced technology into NASA's space sciences programs. The Task Group will specifically investigate the:

- (1) Status of NASA's development, infusion, utilization, and transfer of advanced technology for space sciences; and the processes used by NASA in planning, selecting, and evaluating and terminating relevant technology development projects
- (2) Effect of NASA's current organization and modes of internal communication (and potential alternatives) on technology development, infusion, utilization, and transfer
- (3) Current relationships among NASA, private industry, and universities in the development of technology for space sciences

Consideration will also be given to the:

- interplay between innovation, risk management, and cost
- technology exchange with other government agencies (e.g., DOD and NOAA)
- effect of "smaller, faster, cheaper" on innovation
- effect of NASA's goal to foster technology transfer to U.S. industry on its technology development for space sciences
- assurance of flexibility to explore unconventional ideas
- use of the Space Station in the development of technology for space sciences
- effect of extremely prolonged space program and mission development times on the development, selection, and use of advanced technologies.

The FOSS-T will use as its starting point the NRC report prepared under its direction by the Committee on Space Science Technology Planning, SSB/ASEB, *Improving NASA's Technology for Space Science* (NAP, 1993). While advanced technology for spacecraft and other flight hardware should be the focus of the Task Group, it should not rule out consideration of other relevant technologies, such as that for improved ground-based user data access and distribution systems.

APPENDIX
C

Relevant Recommendations of Previous Studies

STUDY OF THE MISSION OF NASA
NASA ADVISORY COUNCIL
OCTOBER 12, 1983

Recommendation

The Task Force recommends this "Mission of NASA" that rests on current statute and policy and provides a framework for NASA's activities for the next 20 to 40 years.

Mankind has acquired the ability to move within and beyond the confines of the surface and the atmosphere of Earth, creating apparently limitless opportunities for beneficial human activity. In this regard, NASA has a dual mission—in space and the atmosphere—portions of which are overlapping.

NASA's space mission is to conduct activities on behalf of the people of the United States in collaboration with other nations, to:

- explore the solar system and study its planetary processes, including, as appropriate, those governing the Earth, for the benefit of humankind
- pursue a program of fundamental scientific research in space to expand human knowledge
- plan and implement space technology programs and research into the use of the environment of space in order to provide for the continued advance of the national space capability and its exploitation for public and commercial purposes
- and, to achieve these ends, create the capability for an expanded human presence in space and develop and assure the operation of launch and space vehicles.

The Task Force believes that it is inevitable that human habitation will eventually extend beyond the confines of the Earth in many ways and on a scale far larger than is currently envisioned. Although it may not now be productive to debate the specific nature or the timing of this most dramatic of all human ventures, it is appropriate to use such a venture as a distant goal to guide our search for an understanding of the solar system and to stimulate the further advance of humankind.

**REPORT OF THE ADVISORY COMMITTEE
ON THE FUTURE OF THE U.S. SPACE PROGRAM
WASHINGTON, D.C., DECEMBER 1990**

From the Executive Summary:

A Balanced Space Program. It is our belief that the space science program warrants highest priority for funding. It, in our judgement, ranks above space stations, aerospace planes, manned missions to the planets, and many other major pursuits which often receive greater visibility. It is this endeavor in science that enables basic discovery and understanding, that uncovers the fundamental knowledge of our own planet to improve the quality of life for all people on Earth, and that stimulates the education of the scientists needed for the future. Science gives vision, imagination, and direction to the space program, and as such should be vigorously protected and permitted to grow, holding at or somewhat above its present fraction of NASA's budget even as the overall space budget grows.

From the Principal Recommendations:

Principal Recommendations Concerning Space Goals

It is recommended that the United States' future civil space program consist of a balanced set of five principal elements:

- a science program, which enjoys highest priority within the civil space program, and is maintained at or above the current fraction of the NASA budget (Recommendations 1 and 2);
- a Mission to Planet Earth (MTPE) focusing on environmental measurements (Recommendation 3);
- a Mission from Planet Earth (MFPE), with the long-term goal of human exploration of Mars, preceded by a modified Space Station which emphasizes life sciences, an exploration base on the Moon, and robotic precursors to Mars (Recommendations 4, 5, 6 and 7);
- a significantly expanded technology development activity, closely coupled to space mission objectives, with particular attention devoted to engines (Recommendation 8);
- a robust space transportation system (Recommendation 9).

Principal Recommendations Concerning Programs

With regard to program content, it is recommended that:

- the strategic plan for science currently under consideration be implemented (Recommendation 2);
- a revitalized technology plan be prepared with strong input from the mission offices, and that it be funded (Recommendation 8);
- Space Station Freedom be revamped to emphasize life sciences and human space operations, and include microgravity research, as appropriate. It should be reconfigured to reduce cost and complexity; and the current 90-day time limit on redesign should be extended if a thorough reassessment is not possible in that period (Recommendation 6).

Principal Recommendations Concerning Affordability

It is recommended that the NASA program be structured in scope so as not to exceed a funding profile containing approximately 10 percent real growth per year throughout the remainder of the decade and then remaining at that level, including but not limited to the following actions:

- place the Mission from Planet Earth on a go-as-you-pay basis, i.e., tailoring the schedule to match the availability of funds (Recommendation 5).

Principal Recommendations Concerning Management

With regard to management of the civil space program, it is recommended that:

- major reforms be made in the civil service regulations as they apply to specialty skills; or, if that is not possible, exemptions be granted to NASA for at least 10 percent of its employees to operate under a tailored personnel system; or, as a final alternative, that NASA begin selectively converting at least some of its centers into university affiliated Federally Funded Research and Development Centers (Recommendations 14 and 15);
- NASA management review the mission of each center to consolidate and refocus centers of excellence in currently relevant fields with minimum overlap among centers (Recommendation 13).

It is considered by the Committee that the *internal* organization of any institution should be the province of, or at the discretion of, those bearing ultimate responsibility for the performance of that institution.

IMPROVING NASA'S TECHNOLOGY FOR SPACE SCIENCE **REPORT OF THE COMMITTEE ON SPACE SCIENCE TECHNOLOGY PLANNING** **NATIONAL RESEARCH COUNCIL, 1993**

Summary and Recommendations

1. The NASA Administrator [. . .] should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA—from early research through the various stages of technology development and readiness.
2. As NASA acts to improve its programs through the use of new or improved technologies, an emphasis should be placed on technologies with the potential to reduce end-to-end mission costs.
3. [NASA's technology development division—the Office of Space Access and Technology (OSAT)] should bring increased rigor (including external review) to determining not only which projects should be initiated or continued, but which should be canceled.
4. Each [science office] should endeavor to work closely with [OSAT] in order to be involved in, or cognizant of, [OSAT's] projects relevant to their technology needs.
5. Since industry is heavily involved in the development of spacecraft and systems, and university scientists are heavily involved in the development of space instruments and sensors, [OSAT] should increase the inclusion of representatives who are external to NASA in the early evaluation of users' technology needs and goals.
6. The [OSAT] base program projects in support of space science should be subjected to more visible external review on a regular basis.
7. NASA should act to broaden the foundation of its research base by increasing the direct involvement of university research laboratories in the development of technology for space science.
8. [The science offices] should consider earmarking a modest level of funding for use at OSAT on mutually agreed-upon projects.
9. Each [science office] that has not yet done so should act to formalize technology planning responsibilities to identify, coordinate, and report relevant work within the [office].

APPENDIX
D

NASA Definitions of Program and Project

Policies and detailed implementation procedures for program and project management in NASA are given in NASA Handbook 7120.5, *Management of Major System Programs and Projects Handbook*, dated November 1993. Included in the Handbook are definitions of program and project relevant to the Future of Space Science Study. They are quoted in the following:

Project. A defined, time-limited activity with clearly established objectives and boundary conditions executed to gain knowledge, create a capability, or provide a service as part of an overall development program. A project typically encompasses design, development, fabrication, test, and as applicable, operation of advanced hardware and software, including data collection, distribution, and analysis and reporting of results.

Program. A related series of undertakings that continue over a period of time (normally years), which are designed to pursue or are in support of a focused scientific or technical goal, and which are characterized by: design, development and operations of systems; relatively high funding levels; firm schedules; and firm technical and/or scientific objectives. Programs are typically planned and executed as a series of individual projects or as a group of projects to provide a major system capability.

Major Program/Project. A program/project for system(s) development that:

- (1) Is directed at and critical to fulfilling an agency mission;
- (2) Entails the allocation of relatively large resources; or
- (3) Warrants special management attention.

The above include but are not limited to:

- (4) All programs/projects for which external agency reporting on a regular basis is required;
- (5) All multiple field installation programs; and
- (6) All projects whose DCC's (Development Cost Commitments) exceed \$200 million.

APPENDIX
E

NASA Roles and Responsibilities in the Science Programs

Extracted from NASA Handbook 1101.3, *The NASA Organization* (September 1994), the following is not intended to be a detailed accounting of NASA's planning, budgeting, and managing of its programs, but it does describe some elements of that system as a context for identifying the roles and responsibilities of the key officials associated with the science program. In the following, excerpts from the formal responsibilities statements are employed, and in some cases, paraphrased.

The content of each science program is established by the Program Associate Administrator, who:

1. Develops strategic plans consistent with the NASA strategic plan to define program goals and objectives and establish program priorities.
2. Plans the programmatic activities, including financial and technical plans, consistent with the program strategic plan.
3. Manages the program, delegating authority as appropriate, to include establishing program budgets and allocating resources, identifying and funding program facility requirements, overseeing and controlling program performance schedules, and expending resources to meet program objectives.
4. Provides for full coordination with other NASA offices and program managers and with persons, groups, and organizations external to NASA who have responsibilities related to the program.
5. Participates with other senior NASA officials to provide advice and counsel to the Administrator in the development and administration of the overall NASA program and in the continual development of NASA program policies and direction and the review of NASA programs.

The out-of-house science research program is carried out by universities, industry, other government groups, and others, either managed directly from Headquarters by the staff of the Program Associate Administrator or managed by field center staff. The in-house science research program is carried out by personnel at the centers. Program funds are provided to the center, for either in-house or out-of-house research, through center management by the Program Associate Administrator. However, other resources (in-house research personnel, facilities, and other support) are provided by the Center Director. Specifically, each Center Director:

1. Develops strategic plans consistent with the NASA strategic plan to define center goals and objectives and establish center priorities.

2. Allocates and reprograms resources as required to meet approved objectives in accordance with delegated authority.
3. Manages the day-to-day operations of the Center in support of program roles and missions.
4. Assures the safety, reliability, maintainability, and quality assurance for facilities, operations, functions, and products of the Center.
5. Participates with Headquarters in the continual development of NASA policies and the review of NASA programs.

Each NASA Center Director acquires his/her institutional resources (personnel, facilities, etc.) from and reports to an Institutional Associate Administrator, who, because each center may work on many different programs, may or may not be the same as the Program Associate Administrator. Each Institutional Associate Administrator, in addition to any program responsibilities he or she might have:

1. Develops strategic plans consistent with the NASA strategic plan to define institutional goals and objectives and establish institutional priorities.
2. Allocates and reprograms resources as required to meet approved objectives in accordance with delegated authority.
3. Provides direction, leadership, and support to reporting Centers in order to maintain the infrastructure, as well as the technical and management capabilities commensurate with their roles and missions within the Agency.
4. Provides leadership and policy guidance to reporting Centers regarding the assignment of projects from all Program Offices, including the assurance of program-level documentation committing sufficient institutional resources to adequately support the assigned projects.

The program, institutional, and center relationships most relevant to the science programs are:

1. The AA for MTPE is the Institutional AA for GSFC. GSFC has a major role in the Space Science Program, as well as the MTPE Program.
2. The AA for SS is the Institutional AA for JPL (a contract "center"). JPL has a significant role in the MTPE Program, as well as the Space Science Program.
3. Other centers having significant involvement with the indicated NASA science programs, and their respective institutional AA's, are:

<i>Center (science program)</i>	<i>Institutional AA</i>
MSFC (microgravity, space science)	AA for Space Flight
JSC (life, space science)	AA for Space Flight
ARC (life, Earth, space science)	AA for Aeronautics
LaRC (Earth science)	AA for Aeronautics
LeRC (microgravity science)	AA for Aeronautics

The Program and Institutional Associate Administrators report to the NASA Administrator, who:

1. Serves as the Agency head in carrying out the mission of the Agency and conducting all of its activities.
2. Represents NASA before the President, Congress, and the heads of Federal or other appropriate governmental agencies, external organizations, and communities.
3. Serves as the final Agency decisionmaker concerning all NASA activities, except as may be specified by law, regulation, Presidential directive, or delegated authority.

4. Organizes the NASA workforce, delegating authority, and determining Agency priorities in accomplishing its mission, activities, or goals.

The Administrator is supported, not only by the Program and Institutional Associate Administrators and their staffs, but by a number of senior officials in the Office of the Administrator and by Officials-in-Charge of staff offices. In the Office of the Administrator, the Chief Scientist is responsible for providing the principal interface between NASA and the national and international science community to ensure that NASA programs are universally regarded as scientifically and technologically well-founded and are appropriate for their intended applications.

Two Officials-in-Charge of staff offices particularly closely involved with the science program are the Chief Financial Officer/Comptroller and the Associate Administrator for Policy and Plans. The former is the Administrator's principal advisor on financial and budgetary matters and plays a major role in the budget decision process. Specifically, the Chief Financial Officer/Comptroller:

1. Provides for the overview and financial management of Agency resources relating to programs and operations, including all resources aspects of the planning, programming, and budgeting process.
2. Reviews, assesses, and validates Agency resources requirements, including recommendations to the Administrator for fiscal resources approvals and authorizations.
3. Performs economic and cost analyses for Agency assessments of program alternatives.
4. Develops and maintains an integrated Agency budgeting, accounting, and financial management system, including financial reporting and financial management internal controls.
5. Monitors the financial execution of the Agency budget in relation to actual expenditures, and prepares and submits to the Administrator timely performance reports.

Finally, the Associate Administrator for Policy and Plans is the Administrator's senior advisor on policy and strategic planning and is responsible for providing executive leadership for Agency-level policy and strategic-planning activities. Specifically, that official:

1. Directs, conducts, and coordinates analyses and activities to identify Agency policy needs; investigates alternative policy strategies; and develops compelling rationales for Agency-level programs and plans. Ensures coherence and consistency in the formulation, integration, and dissemination of Agency-level policy and plans.
2. Evaluates, facilitates, and assures implementation and compliance of cross-cutting Administration, congressional, and Agency-level policies and directives.
3. Organizes and leads the strategic-management process, including the annual update of the Agency's Strategic Plan.
4. Serves as the focal point for NASA interactions with Executive branch interagency forums, advisory committees, commissions, and other external and internal committees and groups. Facilitates and supports the activities of the NASA Advisory Council.
5. Facilitates NASA participation in interagency forums and communicates guidance and direction from the Administrator for such participation.

APPENDIX F

Science Management in Other Institutions

NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) has three general types of research programs: support for individual investigators or small groups (the dominant type); support for large groups, field operations, and centers (such as Engineering Research Centers); and support for national user facilities (such as telescopes, oceanographic research vessels, and particle accelerators). The process NSF uses to select awardees is fundamentally the same for all three modalities, with modifications as appropriate.

The type of proposals NSF receives varies greatly by field of research or education. In the research programs, NSF receives mostly solicited proposals in response to program announcements, similar to NASA Research Announcements (for laboratory research) and NASA Announcements of Opportunity (for flight missions). In these programs, proposals tend to differ greatly from each other. In the case of centers or user facilities and in Education and Human Resources, there are more targeted solicitations, so the proposals tend to look fairly similar. Once received by NSF, proposals are assigned to the appropriate program for review. Each program is headed by a program officer. Depending on their proposal volume and complexity, programs may have one, two, or even three program officers. At least one of these individuals is usually a “rotator,” a scientist or engineer from the relevant disciplinary community (usually from a university) who is serving a 1- to 3-year term at NSF. At any one time, about 40 percent of NSF program officers and division (collections of related programs) directors are rotators. One of the most important responsibilities of the program officer is to select knowledgeable reviewers for each proposal. Reviewers are also scientists and engineers outside of NSF and who have expertise in the area of the proposal or in a related area (in the case of multidisciplinary proposals). Anywhere from 6 to 10 reviewers are selected, with a minimum of 3 reviews needed to process a proposal further. Proposals average 5.5 reviews. This “peer review” is the cornerstone of NSF’s proposal review process.

Reviews are done in writing, and a numerical (1 to 5) or verbal (“excellent,” “very good,” “good,” “fair,” etc.) rating is assigned by each reviewer. In some programs, program officers use only reviews by mail (or e-mail). In other programs, mail reviews are solicited, and then a standing panel of different experts is convened on a regular basis to consider and rate the proposals yet again. The reviewers consider scientific merit and the capacity of the investigator (track record and/or potential) as the primary, but not exclusive, criteria for evaluation. In the case of centers or large user facilities, program officers may stage a site visit by a team of external reviewers to each candidate on a “short list” of competitors. The site visit is generally used to validate and assess more fully the plans and capabilities of the proposers. Site visits are usually reserved for the largest, most complex proposals.

The program officers do not formally review proposals, nor are they voting members of review panels. However, reviews and reviewers' comments are viewed as advisory to the program officer, not controlling. The reviews are given great weight, but, by design, the program officer is charged with arriving at an independent recommendation based on his or her own analysis of the merits of the proposal and taking into account broader NSF objectives. NSF program officers have considerable flexibility in making award decisions, but that flexibility is used most often "at the margin," that is, among proposals ranked in the middle of the averaged ratings. Program officers also work hard to "stretch" their available resources by negotiating award levels for individual proposals.

The written mail reviews and summaries of the panel meetings are provided to investigators after the award decision. This information is used by investigators to respond to criticisms or weak points in rewriting and resubmitting proposals. Even successful awardees find the comments useful. Program officers spend countless hours talking and visiting with applicants at every stage of the process, particularly counseling unsuccessful applicants. There is also a well-established process whereby unsuccessful investigators may ask in writing for reconsideration of their proposal by a higher NSF official if the investigator believes he or she did not receive a fair evaluation.

Oversight of this process is accomplished in several ways. On a day-to-day level, no award action may be taken without concurrence by at least one supervisor at least one level higher. Perhaps more importantly, scientific approval is separate from "business" approval. The program officer cannot actually commit money. This can be done only by a grant or contract officer (a nonscientist with expertise in business and financial matters) in a separate part of NSF. Thus, scientific approval is necessary but not sufficient for the actual award to occur. In the end, however, the most effective controls are the program officer's own integrity and the openness of the entire process to external scrutiny.

In this rather loose management milieu, NSF program officers are much more independent than their counterparts at the National Institutes of Health, for example, but do not have as strong a role in decision making as program officers in U.S. military agencies.

In recent years, especially in the education programs and others where large numbers of proposals are anticipated, NSF has instituted a two-tiered proposal process. The first tier consists of a relatively short "preproposal," which is evaluated by a small number of reviewers selected by the program officer as to whether it is in the competitive range. Investigators with successful preproposals are permitted to continue to the second tier, a full proposal, which is then evaluated as above. Another strategy NSF uses is the "planning grant." Planning grants are stand-alone competitions for modest sums (usually a total of \$50,000 or less for 1 to 2 years) to allow investigators to conduct preliminary studies or build a proposal team in advance of submitting a full proposal for a much greater level of funding. The value of these approaches is evident—proposals not in the competitive range can be weeded out without expending the time and resources (on both the investigator's and NSF's part) that the preparation and review of a full proposal entails. In addition, for the last 3 years, investigators have had the option of applying specifically for a Small Grant for Exploratory Research (SGER). These are non-renewable, 1- to 2-year awards of \$50,000 or less for small-scale, high-risk research. The criteria cited most often for approval were "untested or novel idea" or "severe time urgency with respect to collection of data." The proposals are very short, and the program officers do not seek external reviews. This program was instituted to counter criticisms of the traditional process as being too "picky," risk-averse, and conservative. On average, program officers employ 1 to 3 percent of their budgets for SGER proposals (the upper limit is 5 percent).

NSF has two basic types of awards: standard grants and continuing grants. Standard grants are generally used for individuals and small groups. They may be made for multiple years (usually 2), but the total funding is essentially approved and committed at the beginning of the award. Continuing grants are also made for multiple years (3 years or longer), but the funding is approved and committed annually and is subject to satisfactory progress toward the stated goals of the project. For example, in the case of

Engineering Research Centers, initial awards are made for 5 years with annual reviews and a major review after 3 years that determines whether the award will be renewed noncompetitively for an additional 3-year period.

Unlike virtually any other agency, NSF conducts no research or development and neither constructs nor operates any research facilities itself, that is, with NSF employees. NSF does own a number of major research facilities, but it operates them by using contractors, which are almost exclusively universities or university consortia. NSF monitors and often manages the processes used by these contractors to provide access to these facilities to the broader scientific and engineering communities. The performance of these contractors is periodically reassessed, and the operations contracts are periodically subject to recompetition. NSF's approach to these contracts is performance-based. That is, goals, objectives, and performance are specified in the proposal solicitation—the detailed methodology is up to the proposers. The “science effectiveness,” or scientific benefits for the dollar, of the proposer's approach is an important criterion for evaluation.

As noted above, NSF relies heavily on the participation of external scientists and engineers in the proposal review process. It is worth spending a moment to note the involvement of the external scientific community in NSF priority setting and program planning. Program officers, especially rotators, play a significant role in identifying areas of scientific opportunity (and, therefore, ripe for additional funding) in their respective disciplines. The rotator system was specifically designed to accomplish this. All Directorates, which are groups of programs covering broad areas of science, engineering, and education, have advisory committees of external scientists and engineers. These advisory committees assist the Directorate leadership in setting overall programmatic priorities and in reviewing the balance between the three modalities of support. The advisory committees are also playing an increased role in the evaluation of NSF programs—a key area of emphasis in recent years. At the highest level, the National Science Board (NSB), a Presidentially-appointed group, meets several times a year to approve NSF budget requests to the President, all major policies and new programs, and major (multimillion dollar) awards. The NSB also works with the NSF Director to set the overall strategic direction of the agency. NSF is the only federal agency governed by a board in the manner of a private grant-making organization.

NATIONAL INSTITUTES OF HEALTH

The National Institutes of Health (NIH) is the largest single supporter of biomedical research in the world. Its mission is to improve the health of the people of the United States and other nations through the pursuit of fundamental knowledge about the behavior and nature of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. The major avenue through which NIH pursues this mission is through the support of more than 50,000 scientists working at 1700 institutions in this country and abroad.

The major structural units of NIH are its 17 national institutes, each with its own authorizing legislation and appropriation. They are referred to as “categorical institutes” because most are responsible for specific categories of disease. While there are some internal variations in the categorical institutes, there is a typical organizational pattern. Most have an “extramural program” component and an “intramural program” component, each reporting to the Institute Director. The extramural programs provide support to the external community through awards for research project grants, training grants and fellowships, specialized centers and program projects, construction and resources grants, special programs for the development and support of minority scientists, research and development contracts, and cooperative agreements. The latter two instruments permit the agency to establish the plans, parameters, and detailed requirements for the projects it wishes to support. In all programs, permanent extramural staff are responsible for the oversight and management of scientific programs in each institute.

The NIH relies heavily on the national pool of scientists actively engaged in research to provide

advice on research directions and opportunities, to evaluate the scientific and technical merit of proposed research projects, and to select those meritorious projects that are likely to advance the goals of the institutes. This evaluation and selection process is achieved through the "peer review system." Since extramural awards constitute about 84 percent of the NIH budget, which in turn accounts for about one-third of the nation's investment in biomedical and behavioral research, the impact of the peer review system is fairly large in shaping scientific programs and progress for NIH and the nation.

The NIH Peer Review System is based on two sequential levels of review. The first level involves the evaluation of the scientific and technical merit of applications by knowledgeable experts who are, for the most part, nonfederal scientists. They are aggregated into legislatively mandated initial review groups (IRGs) established according to scientific discipline or current research area. Most IRGs or study sections are managed by the Division of Research Grants (DRG), reflecting a long-standing policy to have organizational separation between the awarding institute and the initial review process. Each study section is managed by a scientific review administrator (SRA) and meets three times each year to discuss and evaluate the applications assigned to it. All members of a study section are sent applications by the SRA well in advance of each meeting and are expected to read and become familiar with each application. Two or more members are assigned to each application and prepare independent, detailed reviews based on well-established criteria. Based on these evaluations, the study section may either not recommend the application for further consideration, defer for additional information, or approve the application for the time and amount requested or with appropriate reductions in these areas. Approved applications are assigned a scientific merit rating ranging from 1.0 (outstanding) to 5.0 (acceptable). Following the meeting of an IRG, the SRA prepares a summary statement for each application. These summaries describe the proposed research, the reasons for the recommendations, and priority scores for applications that are scored. These statements are forwarded to the appropriate institute or center for the next level of review. The summary statement is automatically sent to the principal investigator of each application.

The second level of review is conducted by National Advisory Councils composed of both scientists and the general public. They not only assess the scientific merit of the applications but consider the relevance of the proposal to the programs of the Institute or Center. Extramural program staff attend study section meetings as program resource persons and present the applications for which they are responsible to their institute's Advisory Council. SRAs attend Council meetings to provide information needed in support of the recommendations of the IRG. Council members review the summary statements received in advance of the three meetings held each year, and, in consideration of both the recommendation of the IRG and the programmatic priorities of the institute, may accept or modify the recommendation of the IRG. When there is disagreement with the IRG recommendation, the Council may recommend that the application be returned for additional review by the same or another IRG. If upon re-review the IRG recommendation remains the same, the action of the IRG stands. The NIH Councils are unique in that, by legislative mandate, an award of a grant can be made only if approved by a Council. This feature greatly reduces the likelihood that an award will be made on the basis of political or other considerations.

Among the various instruments of support, research project grants representing investigator-initiated research continue to receive NIH's highest priority. While they are not solicited, researchers are informed about the program areas of special interest to an awarding institute through program announcements or a request for applications in specific areas at a specified funding level. For the research grant mechanism, NIH is essentially a patron providing assistance and encouragement. As an indication of the magnitude of support for research project grants, \$7.5 billion was expended for this mechanism in FY 1994, with most in the research project grant category. These grants support individual projects, each with a senior principal investigator. A total of 24,964 awards were made in this category in FY 1994.

Initial Review Groups may be established by an institute to review certain types of grant applications, such as those for large multifaceted program projects and centers, institutional fellowships, academic

awards, conference grants, minority programs, and resource grants, among others. Contract proposals are generally solicited to produce a specific service or product. Institutes also draw from the national pool of scientists in constituting Program Advisory Committees to advise on specific programs and future research needs and opportunities and to identify and evaluate future extramural initiatives.

All of the NIH institutes, except one, have "intramural research programs." These, collectively called the NIH Intramural Research Program (IRP), constitute a federal laboratory and represent the largest biomedical research enterprise in the world. They represent, however, only a small fraction of the NIH budget, a little over 11 percent. A unique feature of the IRP is that its scientists do not have to compete for grants in the same manner as extramural scientists. However, there is a parallel, retrospective review of accomplishments conducted by Boards of Scientific Counselors. Each laboratory and its permanent investigators, including junior staff who are not "tenured," is reviewed at least every 4 years. The results of this review are submitted to the Institute Scientific Director, the Institute Director, and the NIH Deputy Director for Intramural Research for appropriate action. These recommendations are discussed by a Board composed of all Scientific Directors at NIH. In addition to the possibility for long-term and stable research support, intramural scientists have the availability of the NIH Clinical Center's facilities for patient investigations. The passage of the Federal Technology Transfer Act has resulted in the development of more than 200 Cooperative Research and Development Agreements (CRADAs) between intramural scientists and industry.

Organizationally, the Director of NIH presides over a large and complex organization in which major authority resides in the Institute, Center, and Division (ICD) Directors. They manage their programs on a day-to-day basis with significant autonomy, but within the framework of legislative mandates, regulatory requirements, corporate policies and procedures developed by NIH, and a very strong and effective advisory system. The NIH Director has his or her own Advisory Committee, which advises him or her, and ultimately the Secretary, DHHS, on policy matters pertinent to the NIH mission. The coordination and management of the extramural and intramural programs of NIH are accomplished both at the level of the Director, NIH, and at the individual institutes by means of an elaborate but highly effective matrix-type organizational system.

DEPARTMENT OF ENERGY

The Department of Energy has very extensive scientific research programs in both basic and applied areas. This research is carried out in the DOE's national laboratories as well as in the university community. The assignment of these programs differs from area to area. Most of the basic research efforts make use of large facilities at the national laboratories, such as particle accelerators, nuclear reactors, synchrotron light sources, and electron microscopes. These facilities and a portion of the research that utilizes them are located at the national laboratories. The facilities are, however, operated for the benefit of the user community—scientists at universities, other laboratories, and industry. In general, the laboratories carry out only a minimal research effort in "small science," which is the provenance of the university scientists.

In applied research (energy programs, environmental cleanup, and defense programs), the work is generally carried out at the laboratories, with a fraction increasing in the order of the above list. Peer review is extensively used in evaluating the research in the basic areas, but less so in applied programs. The budget decisions are made by the program officers in DOE headquarters.

DOE differs from NASA in that the national laboratories (the DOE equivalents of the NASA Centers) are all government-owned, contractor-operated (GOCO) facilities like the Jet Propulsion Laboratory. There are no civil service employees at the laboratories. The laboratories that emphasize basic research in their missions are generally operated by universities or by university consortia. Others

are operated by industrial organizations. This has been a strength of the DOE research effort and is one of the reasons for the interest shown by other agencies in the GOCO mode of operation.

ADVANCED RESEARCH PROJECTS AGENCY

The Advanced Research Projects Agency in the Department of Defense was chartered in February 1958 largely as a response to the orbiting of Sputnik by the former Soviet Union. This occurred early in the same year NASA was chartered by the Space Act of 1958. However, from the beginning ARPA adopted a set of management principles, an organizational structure, and an approach to formulating and carrying out its research projects and programs quite different from those of NASA. The principal difference in approach was that ARPA chose not to create a large civil service and government facilities infrastructure. Rather, it chose to operate with a small staff of entrepreneurial program managers and through existing government and private scientific and engineering resources to execute its programs.

ARPA has maintained these initial approaches largely unchanged to this date and has had substantial success in promoting significant research advances in many scientific and engineering disciplines. These factors motivated the committee to examine the ARPA research management approach and to assess the applicability of its principles to NASA space science management.

Explicitly, what are some of the principles and approaches that have apparently served ARPA so well in research management for the past 37 years? How has it stayed in the forefront of U.S. research accomplishments? How has it been able to renew its own internal intellectual capital? How has it been able to accomplish so much with such modest financial resources by comparison, say, with those of the military departments? How has it been able to capture the approbation of the research community, the Congress, industry, U.S. allies and enemies, and even, grudgingly, the military departments it was created to serve?

- **Important Mission**—The mission of DoD to provide for national security is the foremost responsibility of the federal government. Within that context and by charter, ARPA has the DoD mandate to work at the high-risk, high-payoff frontier of defense research science and engineering. Since risk taking is accepted as part of the culture at ARPA to achieve high payoff, some failure of individual projects to achieve their goals is expected and accepted. In contrast to the military departments, which have traditionally structured their laboratory research programs to make steady, incremental improvements to existing technologies and mission capabilities, ARPA seeks advanced concepts and technologies with potential to achieve order-of-magnitude performance improvements and increased military capability. Some of its early programs involved missile technology development, space surveillance, ballistic missile defense, high-energy laser weaponry, nuclear weapon detonation detection, advanced digital computation, computer network communications, and many other emerging technologies.

- **Quality Science and Engineering**—ARPA has been able to select projects of national importance with crucial relevance to the DoD's mission and with extremely high military impact. Because of their national importance and the frontier science they employ, these projects have attracted the most capable scientists, engineers, and project managers in the nation to participate in their execution. Since ARPA chose not to create and support institutions to pursue its objectives, its policy has been to seek out the most competent investigators to carry out its programs wherever they could be found. Dedication to this principle is probably the single most important factor in the record of success achieved in ARPA programs and in the cost-effectiveness of those achievements. A typical ARPA project may span a three- to four-year period, after which the project team may be disbanded and ARPA's obligation to support it ceases. Through this mechanism it has avoided the burden and inflexibility of a captive scientific workforce in a dynamic and changing research environment. ARPA has investigators located at universities, defense laboratories, Federally Funded Research and Development Centers, industrial

research and development organizations, national laboratories, foreign research establishments, and private research centers, and it even relies on private individuals for some projects.

- **Quality Research Management Staff**—Historically, ARPA policy has been to provide term appointments for its staff members in order to ensure a rapid turnover of people and ideas. The staff is composed of discipline scientists and engineers from the research environments in which ARPA executes its programs as well as technically trained military officers. A typical term for an ARPA program manager has been 3 years, with 1-year extensions at the director's discretion. Recently, ethics in government legislation has made it increasingly difficult to recruit and retire ARPA program managers according to this policy. Motivation for ARPA program managers to serve a term managing programs there is threefold. First, there is little bureaucracy in this small organization, and dynamic technical entrepreneurs operate best in such a setting. Second, each program manager has an average of \$10 million to \$20 million per year during his or her term to pursue the programs agreed upon with the director. Most have not had such large discretionary research funds available to them to achieve their goals in the past. Third, there is a great deal of discretion given to the individual program manager as to how he or she will pursue his or her program. Oversight is minimal, but accountability for achieving results is substantial.

- **Program Selection Process**—Military problems are selected in areas laid out by guidance from the director. Counsel is sought with military combatant commands to determine and study the most pressing military problems that may yield to technical advances. Concept studies are commissioned, and discipline scientific and engineering advice is sought from highly qualified scientists and engineers both through informal contacts and through workshops and public solicitations for ideas. From these raw materials, research programs and projects are devised by the program manager for execution. Approval is requested from the director with an abbreviated formal program description and an oral report. Proposals are solicited using a variety of formal and informal mechanisms. Except on very large programs, where the director takes a direct role in the procurement, the program manager is most often the selecting authority. Selections can be competitive or often sole source. Although this process is often much more informal than typical government procurements, it contains the essential ingredient of substantial consultation with the technical community before a program is formulated. This results in a high probability that the best ideas have been exposed to the program manager before he or she structures the programs.

- **Ingredients of Success**—ARPA has been widely accepted as one of the nation's most successful research and development organizations. It has a reputation both here and abroad as an instigator of some of the country's most important achievements in advancing both military and commercial technologies. Two features stand out as the ones most responsible for that measure of success. One is the importance of its mission within the national security community and the willingness of Congress to fund its mission so generously down through the years. The other is the high quality of the technical staff, which has been engendered by ARPA personnel policies and the opportunity and excitement of the research environment there.

APPENDIX
G
Request for Comments from the University Space
Research Association Member Institutions

NATIONAL RESEARCH COUNCIL
JOINT COMMITTEE ON TECHNOLOGY FOR SPACE SCIENCE AND APPLICATIONS
2101 Constitution Avenue Washington, D.C. 20418

SPACE STUDIES BOARD
(202) 334-3477
FAX: (202) 334-3701
MSALLEN@NAS.EDU

AERONAUTICS AND SPACE ENGINEERING BOARD
(202) 334-3275
FAX: (202) 334-2482
NELDRIDG@NAS.EDU

May 10, 1995

Dear :

Congress, through NASA, has requested that the National Research Council undertake an advisory study on the Future of Space Science. "Space Science", in this context, includes not only the traditional space sciences of astronomy, cosmology, planetology, and solar-terrestrial processes, but also includes Mission to Planet Earth and NASA's life and microgravity sciences.

There are three elements of the study: Organization of the Space Science enterprise, prioritization in a highly constrained budget environment, and the infusion of technology. This letter concerns the infusion of technology.

It is widely believed that the innovative vitality of NASA's science enterprise will require the combined creative engineering talents of NASA, industry, and the universities. We are seeking your thoughts about the process of university involvement. There are several options. Among them are independent investigators participating through competitively awarded grants, development of university centers of excellence, contracts to universities for deliverables, and development of NASA centers of excellence populated by competitively selected teams of government, industry, and university research engineers. Recognizing that most of NASA's technology needs are highly focused and that part of the process of technology infusion occurs in sharing the development experience:

- (a) Can you cite examples where the universities have successfully teamed with government and industry to develop new technologies? Why were they successful?
- (b) Can you cite examples where a government-university technology development process did not work well? Why were they less than successful?
- (c) How do these NASA technology programs affect your institution?
- (d) Have you had difficulty supporting foreign students on NASA technology grants and what are your thoughts about such limitations?

We respectfully request your comments by the end of May. Enclosed for your information are a short description of the technology element of the Future of Space Science study and a list of panel members. We apologize for the short lead time, but we are trying to be responsive to NASA's need to plan for downsizing in the wake of budget reductions.

Sincerely,

APPENDIX
H

Meetings and Guest Presenters

STEERING GROUP

August 1-3, 1994, Woods Hole, Massachusetts. The Steering Group met with the Space Studies Board's Executive Committee; no guest presenters.

January 4-5, 1995, Washington, D.C. Daniel Goldin, NASA Administrator; France Cordova, NASA Chief Scientist.

June 9-10, 1995, Washington, D.C. Daniel Goldin, NASA Administrator.

August 7-8, 1995, Woods Hole, Massachusetts. The Steering Group met with the Space Studies Board's Executive Committee; no guest presenters.

TASK GROUP ON ALTERNATIVE ORGANIZATIONS

December 8-9, 1994, Washington, D.C. France Cordova, NASA Chief Scientist; Kevin Kelly, outgoing Clerk for Senate Appropriations Subcommittee on VA, HUD, and Independent Agencies; Harry Holloway, Associate Administrator for NASA Life and Microgravity Sciences and Applications; Charles Kennel, Associate Administrator for NASA Mission to Planet Earth; and Wesley Huntress, Jr., Associate Administrator for NASA Space Science.

February 2-3, 1995, Washington, D.C. Anita Jones, Director for DoD Defense Research and Engineering; Robert Winokur, Director for NOAA National Environmental Satellite, Data, and Information Service; Ruth Kirschstein, NIH Deputy Director; Stamatios (Tom) Krimigis, Applied Physics Laboratory Space Science Director; Robert LaFande, Naval Research Laboratory; Ian Pryke, Head of European Space Agency Washington Office; Harry Holloway, Associate Administrator for NASA Life and Microgravity Sciences and Applications; John Klineberg, Director of NASA Goddard Space Flight Center; and Alan Ladwig, Associate Administrator for NASA Policy and Plans.

March 10-11, 1995, Irvine, California. Ray Colladay, Lockheed Martin.

March 27-28, 1995, Washington, D.C. Edward Stone, Director of Jet Propulsion Laboratory; John

Mansfield, Associate Administrator for NASA Space Access and Technology; Walter Morrow, Director of MIT Lincoln Laboratory; William Miller, West Virginia University and formerly Director of the Office of Naval Research; Lew Allen, Director of Draper Laboratory and formerly Director of Jet Propulsion Laboratory; Lennard Fisk, University of Michigan and formerly Associate Administrator for NASA Space Science and Applications; and John Dailey, NASA Deputy Administrator.

April 18-19, 1995, Washington, D.C. John Naugle, former NASA Chief Scientist; Timothy Coffey, Director of Naval Research Laboratory.

May 24-25, 1995, Washington, D.C. France Cordova, NASA Chief Scientist; Harry Holloway, Associate Administrator for NASA Life and Microgravity Sciences and Applications; and Charles Kennel, Associate Administrator for NASA Mission to Planet Earth.

TASK GROUP ON RESEARCH PRIORITIZATION

November 28-30, 1994, Washington, D.C. Kevin Kelly, outgoing Clerk for Senate Subcommittee on VA, HUD, and Independent Agencies; Diana Josephson, Deputy Undersecretary of Commerce for Oceans and Atmospheres; Judy Sunley, Assistant to the Director for NSF Science and Policy Planning; France Cordova, NASA Chief Scientist; and Joseph Alexander, Deputy Assistant Administrator for EPA Research and Development and formerly Assistant Associate Administrator for NASA Space Science and Applications.

February 21-22, 1995, Washington, D.C. Alan Ladwig, Associate Administrator for NASA Policy and Plans.

June 5-6, 1995, Washington, D.C. No guest presenters.

TASK GROUP ON TECHNOLOGY

August 23-24, 1994, Washington, D.C. Mary Kicza, Giulio Varsi, and Michael Kaplan, NASA Office of Space Science; Bert Hansen and Gary Martin, NASA Office of Life and Microgravity Sciences and Applications; Robert Norwood and Wayne Hudson, NASA Office of Advanced Concepts and Technology; Granville Paules, NASA Office of Mission to Planet Earth; and Wayne Littles, NASA Acting Chief Engineer.

November 14-16, 1994, Washington, D.C. France Cordova, NASA Chief Scientist; Mary Kicza, NASA Office of Space Science; Michael Kaplan, NASA Astrophysics Division; Miriam Forman, NASA Space Physics Division; Giulio Varsi, NASA Solar System Exploration Division; Granville Paules and Mike Luther, NASA Office of Mission to Planet Earth; Samuel Venneri, NASA Office of Space Access and Technology; Bert Hansen, NASA Office of Life and Microgravity Sciences and Applications; Gary Martin, NASA Microgravity Science and Applications Division; and Guy Fogleman, NASA Life and Biomedical Sciences and Applications Division.

February 23-24, 1995, NASA Jet Propulsion Laboratory, Pasadena, California. Edward Stone (Director), Garry Burdick, Richard Capps, E.K. Casani, Moustafa Chahine, Terry Cole, Esker Davis, Charles Elachi, James Evans, David Linick, Robert Mackin, Arthur Murphy, Donna Shirley, William Spuck, Barbara Wilson, Thomas Yunck.

March 30-31, 1995, NASA Lewis Research Center. Donald Campbell (Director), Henry Brandhorst,

Marvin Goldstein, Donald Palac, Ronald Schertler, Raymond Burns, William Bifano, Jack Salzman, Joe Sovie.

April 24, 1995, Washington, D.C. Samuel Venneri, Director of NASA Spacecraft Systems Division.

April 25, 1995, NASA Goddard Space Flight Center. John Klineberg (Director), Joseph Rothenberg, James Abshire, Mitch Brown, Michael Fitzmaurice, Dolly Perkins, Allan Sherman.

*April 26, 1995, Washington, D.C.** Harry Holloway, Associate Administrator for NASA Life and Microgravity Sciences and Applications; Wesley Huntress, Associate Administrator for NASA Space Science; Charles Kennel, Associate Administrator for NASA Office of Mission to Planet Earth; John Mansfield, Associate Administrator for NASA Office of Space Access and Technology.

*June 5-6, 1995, Washington, D.C.** No guest presenters.

*Dr. F. Andrew Gaffney, a member of the Space Studies Board's Committee on Space Biology and Medicine, participated.

APPENDIX
I

Acronyms

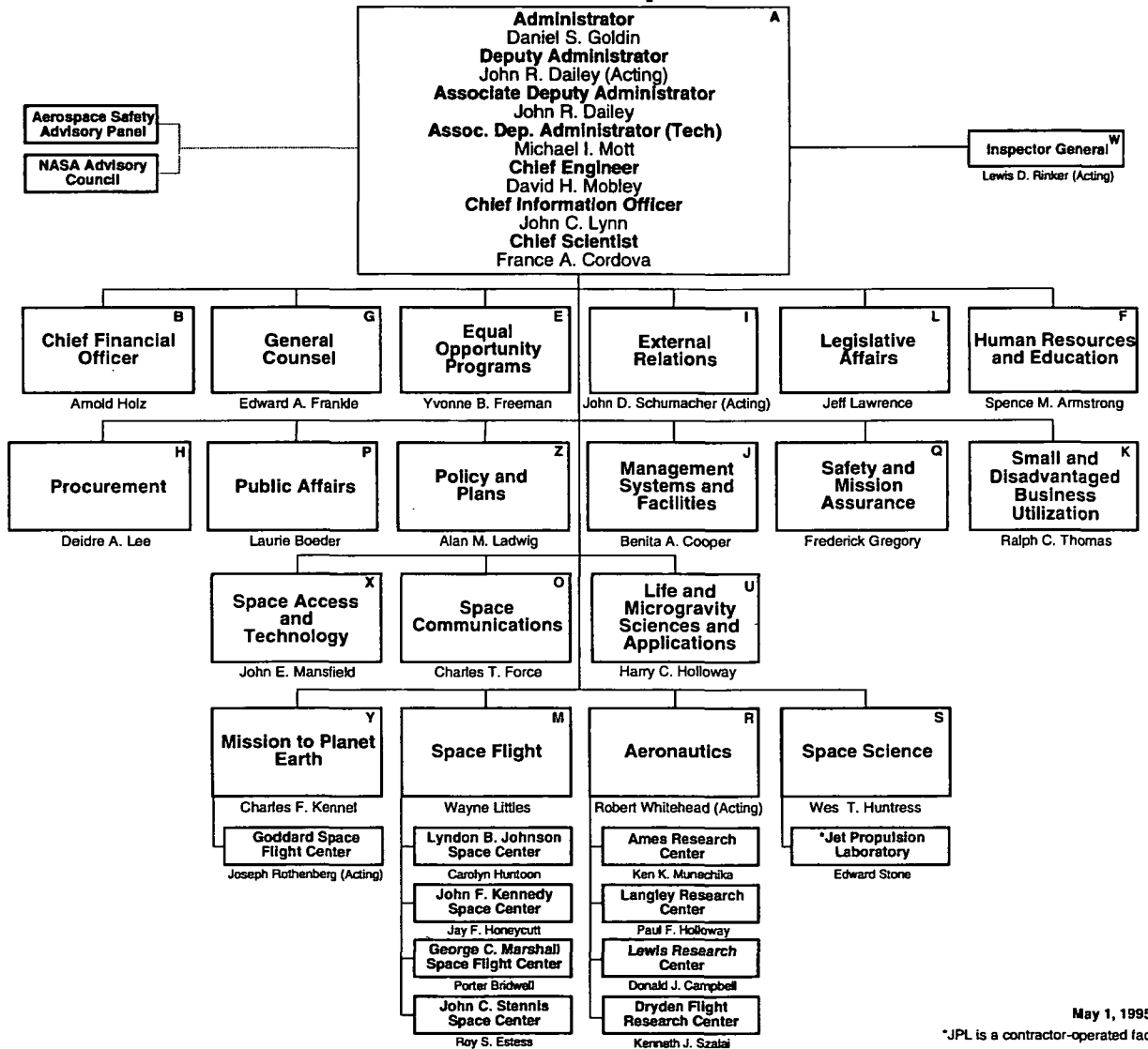
AA	Associate Administrator
AO	Announcement of Opportunity
ARPA	Advanced Research Projects Agency
ASEB	Aeronautics and Space Engineering Board
ATD	Advanced Technology Development
CSSTP	Committee on Space Science Technology Planning
CFC	Chlorofluorocarbon
CoF	Construction of Facilities
CRADA	Cooperative Research and Development Agreement
CSSTP	Committee on Space Science Technology Planning
DHHS	Department of Health and Human Services
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DRG	Division of Research Grants (NIH)
ELV	Expendable Launch Vehicle
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
ESA	European Space Agency
FFRDC	Federally Funded Research and Development Center
FOSS	Future of Space Science
FOSS-AO	FOSS Task Group on Alternative Organizations
FOSS-RP	FOSS Task Group on Research Prioritization
FOSS-SG	FOSS Steering Group
FOSS-T	FSS Task Group on Technology
FY	Fiscal Year (federal government)
GOCO	Government-owned, contractor-operated
GSFC	Goddard Space Flight Center
ICD	Institute, Center, and Division
IPA	Intergovernmental Personnel Act
IRG	Initial review group
IRP	Intramural research program
ITP	Integrated Technology Plan (for the civil space program)

JCT	Joint Committee on Technology
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center
LaRC	Langley Research Center
LBSAD	Life and Biomedical Sciences and Applications Division
LeRC	Lewis Research Center
LMScaAC	Life and Microgravity Sciences and Applications Advisory Committee
MFPE	Mission from Planet Earth
MidEX	Mid-size Explorer
MSAD	Microgravity Science and Applications Division
MSFC	Marshall Space Flight Center
MTPEAC	Mission to Planet Earth Advisory Committee
NAC	NASA Advisory Council
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite Data and Information System
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRA	NASA research announcements
NRC	National Research Council
NRL	Naval Research Laboratory
NSB	National Science Board
NSF	National Science Foundation
OA	Office of Aeronautics
OACT	Office of Advanced Concepts and Technology
OART	Office of Advanced Research and Technology
OAST	Office of Aeronautics and Space Technology
OLMSA	Office of Life and Microgravity Sciences and Applications
OMSF	Office of Manned Space Flight
OMTPE	Office of Mission to Planet Earth
OSAT	Office of Space Access and Technology
OSF	Office of Space Flight
OSS	Office of Space Science
OSSA	Office of Space Science and Applications
OSTP	Office of Science and Technology Policy
R&D	Research & Development
R&PM	Research & Program Management
SGER	Small grant for exploratory research
SMEX	Small Explorer
SRA	Scientific review administrator (NIH)
SScAC	Space Science Advisory Committee
SSB	Space Studies Board
SSTAC	Space Systems and Technology Advisory Committee
SSTI	Small Satellite Technology Initiative
VA	Veterans Administration
VA-HUD-IA	Veterans Administration/Housing and Urban Development/Independent Agencies
WFC	Wallops Flight Center

APPENDIX
J

NASA Organization (May 1, 1995)

National Aeronautics And Space Administration



May 1, 1995

*JPL is a contractor-operated facility.

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