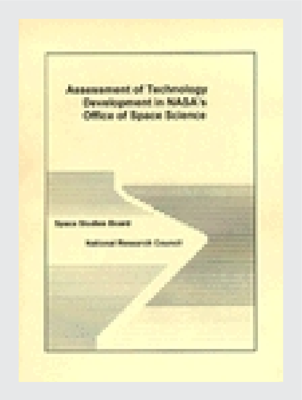

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Space Studies Board
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND APPLICATIONS

Foreword

A steady stream of new technology is absolutely essential for progress in space research. Science advances by asking more and more difficult questions and demanding increasingly capable instruments to provide the answers. It is technology, far more than sheer money, that fuels this advance. Technology has the added role of enhancing capability at reduced cost, which is especially important in times of limited budgets.

NASA recently reorganized the management of technology development, assigning most of the responsibility to its Office of Space Science. This report responds to the agency's request for an assessment of that effort in the context of current needs, concerns expressed by Congress, and previous recommendations of the Space Studies Board (particularly in the 1995 report, *Managing the Space Sciences*). The task group comprised experienced developers of technology from universities, industry, and government.

Key issues addressed here include near- and long-term planning, selection of the players in developing new technology, and maintaining core competency within NASA's own field centers. A major theme is the role of independent external review throughout the technology program. This, in fact, is the focus of the recent congressional attention. Peer review can mean different things in different communities, and some believe it to be incompatible with some of the objectives of a technology development program. The Board has been consistent in holding that the appropriate application of independent, external merit review can be made to function in nearly all situations and is the best way to ensure excellence.

NASA and the scientific community have ambitious plans for the coming decade in space research. These plans can be achieved within the expected funding levels if, and only if, the enabling technology is ready when needed. This readiness depends, in turn, on NASA continuing the organizational progress it has made in recent years.

Claude R. Canizares, *Chair*
Space Studies Board

Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

Lew Allen, Jr., Jet Propulsion Laboratory (retired),
John A. Armstrong, IBM (retired),
James Arnold, University of California at San Diego,
Alexander H. Flax, Institute for Defense Analysis (retired),
Frank B. McDonald, University of Maryland at College Park,
Norman F. Ness, University of Delaware, and
Marcia J. Rieke, University of Arizona.

Although the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring task group and the NRC.

Contents

APPENDIXES

Executive Summary

The 1995 Space Studies Board report *Managing the Space Sciences* (NRC, 1995) examined the changing environment in which science is conducted at NASA, alternative organizational structures for managing science, prioritization of science at NASA, and development of technology in support of science. The management of technology development was emphasized because NASA's new approach to smaller, more frequent, lower-cost missions requires ongoing new technical developments in order to ensure the continuing flow of achievements in space science that our nation has enjoyed. In addition to actions taken in response to the 1995 report, NASA has made a number of organizational changes that affect the technology development programs. Most pertinent was the assignment of responsibility (and budget) for cross-program technology development to the Office of Space Science (OSS). The increasing enabling power of new, flight-ready technology (recognized also by an interested Congress), coupled with important organizational changes within NASA, prompted OSS to request this NRC follow-on study to assess NASA's current approach to technology development. The Space Studies Board established the Task Group on Technology Development in NASA's Office of Space Science to conduct this study.

The importance of planning as the first step in the technology development process was emphasized in *Managing the Space Sciences.* In that regard, the task group recognizes the transfer of the technology function to OSS as a positive action. Programs under the space science enterprise (one of four mission program areas in NASA's strategic plan) are the largest consumers of space technology. Furthermore, OSS has a well-developed strategic planning process. OSS enlists a large segment of the external scientific community, through a broad advisory committee structure, in the development of its science roadmaps. This process is being extended to include development of time-phased technology roadmaps in support of OSS's science missions. Maturation of this process should be continued and subjected to external review[1] within 1 year.

Much advanced technology development (ATD) has application to more than one NASA enterprise. Advances in the use of lightweight structures, autonomous navigation, precision pointing, electronic component miniaturization, detector development, and data compression, for example, have application not only to space science missions but also to those pertaining to other NASA enterprises. It would be fiscally irresponsible to allow separate, overlapping technology development programs in such fields. Accordingly, NASA has grouped such technologies under the label “Cross-Cutting Technologies,” which also have been assigned to OSS. Unfortunately, in this case the planning has not matured to a satisfactory level. The establishment of the position of Chief Technologist in the Office of the Administrator is a useful step, but the position of Chief Scientist, which has stood vacant for 2 years, also should be filled. Management of such a cross-enterprise program is more difficult than management of enterprise-specific programs.

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[1] The term “external review” as used in this report signifies evaluation by independent, objective experts whose outside perspective and expertise in the subjects at hand can broaden and strengthen the feedback they provide. “Peer review” is the term commonly used throughout the scientific community. The task group has elected to use “external review” to emphasize that it does not mean simply the review of technology by scientists, but merit review by appropriate, independent, relevant experts.

Effective management of cross-cutting technologies by OSS requires improved collaboration and communication among enterprises and individuals, even if many of the latter are already stretched. The task group recommends a planning process that mirrors the one used by OSS for the space science technologies.

The 1995 report made a number of recommendations regarding the selection and management of technology programs using the best-qualified individuals or teams within NASA, industry, and academia as determined by peer review. The report went on to note that 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. The task group believes that true, world-class competency is required to compete on such a basis and does not believe that NASA's current definition of “core competency” would meet this test of competition in many of its technologies. For one thing, some NASA Centers[2] claim that their core competencies cover an extensive and broad range of technologies. No organization that has realistic fiscal constraints can hope to be competitive or world class across such a sweep. Modern industrial organizations are confining their core competency technologies to those that are key to their competitive survival and that are not available to be purchased at a lower cost on the outside. NASA should develop equivalent constructs for defining the core competencies of the Centers. NASA should recognize that when a technology important to its missions is available on the outside from either academic or industrial organizations, this fact represents a NASA success. In many cases NASA provided the vision and funding for that technology sometime in the past. NASA should now leverage that success and confine its core technologies to those needs that can not be met better by outside developers. External review can assist NASA in defining its core competencies, but competitive results in terms of degree of innovation, advances in the state of the art, and impact on cost and performance will be the ultimate test of those competencies.

Some of NASA's core competency groups are already world class and should be able to compete successfully with external groups for technology programs. Other areas may require some nurturing before achieving true core competency status. In such cases it may be necessary to target some limited ATD funds for this purpose, but a deadline should be set for accomplishing the objective, not to exceed 3 years. ATD funds should not be used more broadly to bolster in-house capability.

A narrowing of core competencies to those that meet stringent criteria will mean that NASA personnel will not be the performers in all technologies that support the principal mission responsibilities of a particular Center. In the past, NASA has relied on the “smart-buyer” argument for maintaining many of these technology development activities even when they may have been available externally. Neither the concept of core technology nor NASA's budget constraints should be invoked simply to support the continuation of past practice. Further, there is ample evidence that there are alternatives to maintaining in-house, hands-on R&D programs that can be used to achieve smart buying. The variation in approaches used by agencies of the Department of Defense such as the Defense Advanced Research Projects Agency (DARPA), the National Reconnaissance Office (NRO), and the three military services demonstrates that there is no single avenue for procuring technology. Each agency, including NASA, can point to stunning

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[2] To distinguish between NASA Centers (e.g., Ames Research Center or Goddard Space Flight Center) and NASA's centers of excellence, the former is capitalized (“Centers”), and the latter is referred to in lower case (“centers”).

successes (as well as unfortunate failures). The most appropriate strategy for maintaining the expertise needed to be a smart buyer can vary depending on the nature of the organization and its missions. Thus, NASA would do well to examine alternatives and develop an explicit strategy for remaining a smart buyer.

Increasingly, successful approaches to acquiring the skills needed to be a smart buyer involve enhancements to workforce mobility. Increasing workforce mobility can improve organizational effectiveness in many ways, by facilitating the transfer of information, obtaining fresh points of view, and maintaining workforce expertise. Use of the Intergovernmental Personnel Act and cooperative agreements with outside organizations are options that NASA can use to support exchanges of technical staff.

To be most successful, an ATD program should have its planning and execution involve a careful mix of centralized and decentralized activities, which, in NASA, means appropriate roles for headquarters and the Centers. Planning should be a headquarters-led effort with execution residing at the Centers. The 1995 NRC report made it clear that management of the technology selection process, including make-vs.-buy decisions, should be retained at headquarters. The selection process for near-term technologies for particular missions can be delegated to the Centers when they are not competing for the technology development activities. This division of responsibility is necessary to eliminate both perceived and real conflicts of interest. As NASA exits from non-core-competency technology execution, it should be possible to delegate more of the management and selection process to the Centers.

Collecting cost data within NASA for analysis purposes is very difficult. Part of the difficulty is associated with NASA not operating on a full-cost basis. More important than analysis, however, is the problem that this lack presents to rational management decision making. NASA wholeheartedly agreed with the *Managing the Space Sciences* recommendation to move to full-cost accounting. Unfortunately, 3 years later NASA still states that it is a year or two away from the goal. The task group cannot emphasize too strongly the necessity, for NASA's own management purposes, to accomplish this task expeditiously. The task group was surprised, when conducting this review, that useful historical data were not readily available on such items as the breakdown of long- versus short-term research support, in-house versus academic versus industrial technology performance, and the amounts competitively awarded. The task group hopes that when it shifts to a new accounting system, NASA will access, track, and use such information in the related planning process.

Many of the recommendations of the above mentioned 1995 NRC report, as well as the present report, call for external review and advice. External review is recommended for the planning function, review of programs, evaluation of competing proposals, core competency selection, and Center quality review. Providing adequate headquarters staff to handle the reviews, utilizing clear investment and performance metrics, and making Centers accountable to headquarters are essential elements of the review process. Effectively implementing the review and advisory process depends on a synergistic relationship between NASA, academia, industry, and other government organizations that has, in large part, already been achieved and needs to be increased and maintained. It carries on a tradition that goes back to NASA's predecessor organization, the National Advisory Committee for Aeronautics. Nevertheless, the final decision making is always a government responsibility, putting a premium on the quality of NASA's personnel. The task group hopes that the recommendations of this and the previous NRC report will assist in promoting excellence in all aspects of the nation's space endeavors. To that end, NASA should make regular formal reports to appropriate external bodies on its response to the recommendations.

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1

Introduction

Development and utilization of new technologies have always been pivotal elements of the space program. Advances in spaceflight and space science and the beneficial applications of new knowledge from space research over the past 40 years have been driven, or constrained, by the pace of growth in technological capabilities and their innovative exploitation to open new fields and pursue new scientific questions. Space research today is striving to tackle increasingly complex scientific problems and to do so by accomplishing more with less, in terms of both constrained budgets and an emphasis on smaller but more frequent spaceflight missions. These factors make the effective development, adaptation, and adoption of new technologies every bit as important as in the past, and probably more so.

The issue of technology development in NASA in recent years has been addressed by the National Research Council in several reports—e.g., *Improving NASA's Technology for Space Science* (1993), *Managing the Space Sciences* (1995a), *The Role of Small Missions in Planetary and Lunar Exploration* (1995b), *Assessment of Recent Changes in the Explorer Program* (1996), *Lessons Learned from the Clementine Mission* (1997a), *Reducing the Cost of Space Science Research Missions* (1997b), *Scientific Assessment of NASA's SMEX-MIDEX Space Physics Mission Selections* (1997c), *Report of the Workshop on Biology-based Technology to Enhance Human Well-being in Extended Space Exploration* (1998a), and *Space Technology for the New Century* (1998b). Notable among these is the 1995 report *Managing the Space Sciences,* which devoted a major section to technology planning and implementation. The report made nine recommendations pertaining to technology planning (pp. 65-69; see Box 1.1); the relative roles and relationships of NASA headquarters, the NASA field Centers, industry, and academia; technology utilization; and budgets.

BOX 1.1 TECHNOLOGY RECOMMENDATIONS FROM *MANAGING THE SPACE SCIENCES*

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.

Since the NRC's release of *Managing the Space Sciences,* NASA has made several significant internal changes. The Office of Space Access and Technology has been disbanded, responsibilities and budgets for technologies with mission-specific applications have been transferred to the appropriate NASA offices, and the responsibilities and budgets for cross cutting technologies have been transferred to the Office of Space Science (OSS). The position of Chief Technologist has been established and filled in the Office of the Administrator. However, the position of NASA Chief Scientist, which was expected to be a key link in implementing several of the recommendations in the 1995 report, has been vacant for 2 years.

During the fiscal year 1998 appropriations process, Congress expressed concerns about one aspect of NASA's technology development process that had also been addressed in *Managing the Space Sciences,* namely the extent to which opportunities to receive support for technology research and development are made available through open competition, and NASA was given specific guidance. For example, the report of the House of Representatives Committee on Appropriations stated:

> The Committee is concerned about the absence of competition in the selection of funding recipients for the new millennium, advanced space technology, and portions of the supporting research and technology program elements. The Committee believes that these funds, whether awarded intramurally or extramurally, must be fully competed through broad announcements of opportunity with selection by external peer review panels, rather than at the discretion of agency managers. (See Appendix A for the complete congressional text.)

The subsequent report from the House-Senate Conference Committee went on to direct NASA to “consolidate all space science ATD [advanced technology development] activities into an easily accessible consolidated budget line item and award not less than 75 percent of these funds through broadly distributed announcements of opportunity that solicit proposals from all categories of organizations . . . and that allow partnerships among any combination of these entities, with evaluation, prioritization, and recommendations made by external peer review panels, consistent with the recommendations contained in the 1995 National Academy of Sciences report on managing the space sciences.”

On March 24, 1998, OSS Associate Administrator Wesley Huntress requested that the NRC conduct an updated assessment of OSS technology development processes in the context of the recommendations in the 1995 *Managing the Space Sciences* report and the recent organizational changes at NASA. (A copy of the Huntress letter appears in Appendix B.) The Task Group on Technology Development in NASA's Office of Space Science was established by the NRC in May 1998, and this report presents its conclusions and recommendations. The statement of task for the study is presented in Appendix C.

The task group held meetings on June 29-July 1, 1998, and July 13-14, 1998. The task group had discussions with personnel from the Office of Management and Budget, NASA headquarters, NASA field Centers, industry, and academia to understand the perspectives of policy makers, users, and providers of advanced technologies developed for NASA. Agendas for both meetings are presented in Appendix D.

The remainder of this report presents the results of the work of the task group. Chapter 2 divides ATD into four areas—planning, implementation, infrastructure, and measurement and follow-up—and describes the study's findings and recommendations that are relevant to each area. Chapter 3 summarizes the task group's conclusions and recommendations, especially as they pertain to the recommendations of *Managing the Space Sciences.*

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2

Advanced Technology Development

This chapter addresses NASA's Office of Space Science (OSS) advanced technology development (ATD) process by examining it from four perspectives—planning, implementation, infrastructure, and performance measurement.

PLANNING

The 1998 NASA strategic plan establishes four “enterprises” through which the agency implements its missions and executes its programs. The enterprises are space science, Earth science, human exploration and development of space, and aeronautics and space transportation technology (NASA, 1998a). The intellectual framework for the space science enterprise rests on four science themes—the astronomical search for origins, the structure and evolution of the universe, solar system exploration, and Sun-Earth connections. Each theme has a science roadmap, developed in consultation with representatives of the outside scientific community, that outlines scientific goals, objectives, and mission plans covering a 20-year period. The requirements for technology development for each theme, and plans for meeting those needs, are outlined either in companion technology roadmaps or as part of the theme science roadmaps. The four theme roadmaps provide building blocks used to develop the OSS strategic plan, which outlines a top-level set of goals, objectives, missions, and program strategies for the space science enterprise. The OSS strategic plan also was prepared through broad consultation with the research community, and a draft was reviewed independently by the Space Studies Board (NRC, 1997c). OSS representatives indicated to the task group that new mission concepts being considered for incorporation in the strategic plan will include intermediate technology milestones that must be met before a “new start” decision is made to move a mission into development for flight. This policy will become a forcing function for developing technology and, therefore, it makes the effective management and implementation of the technology program all the more important.

OSS is responsible for all technology development activities directed toward enabling and enhancing missions in the space science enterprise. In addition, when the Office of Space Access and Transportation was disbanded in 1996, the responsibility for “all cross-cutting, common spacecraft-related technology supporting multiple missions across enterprises” (NASA, 1996a) also was assigned to OSS. (The only exception is technology for cross-cutting space transportation-related technology, which was assigned to the Office of Aeronautics and Space Transportation Technology.)

The OSS technology program is subdivided into three main elements—core programs, focused programs, and flight validation programs (see Table 2.1). The core programs include both the cross-enterprise technology development efforts transferred from the Office of Space Access and Transportation and a space science core program of advanced technology and broadly based research and development, such as work on OSS information systems, integrated space microsystems, science instrument technologies, and advanced radioisotope thermo-electric generators. The focused programs include support of mission definition studies and ATD for specific missions under each of the four science themes in OSS. The flight validation element covers the New Millennium Program (NMP) of flight demonstrations of new technologies for both space science and Earth science. Figure 2.1 illustrates how NASA views the emphasis in the different elements of the program in terms of the relative maturity of the technology topics being addressed.

TABLE 2.1 Office of Space Science Technology Program Budget Organization and Technology Investment (in millions of dollars)

	FY 1997 (Actual)	**FY 1998 (Appropriated)**	**FY 1999 (Requested)**
Core Programs			
• **Advanced Concepts Program** conducts studies and proof-of-concept efforts for far-term (10 to 25 years) technology	1.5	1.5	3.0
• **Cross-Enterprise Technology Development Program** supports the cross-cutting technology requirements for all NASA space enterprises, focusing on developments supporting multiple enterprise customers	130.5	124.8	126.3
• **Space Science Core Program** supports mid- to far-term technologies for the Space Science Enterprise	55.5	74.5	85.5
Focused Programs			
Dedicated to OSS mission-specific technology areas in the current OSS Strategic Plan	26.7	170.7	153.2
Flight Validation Program			
Completes the technology development process by validating technologies in space	45.6	39.7	60.4
Total Technology Budget	259.8	411.2	428.4
OSS Budget	1,969.3	1,983.8	2,058.4
Percent of OSS Budget	13.2	20.7	20.8

SOURCE: NASA's Office of Space Science.

The four theme technology roadmaps, derived from the broadly inclusive science planning process in OSS, are intended to form the basis for planning advanced technology activities to support the orderly progress of the program outlined in the OSS strategic plan. Cross-cutting technology needs and priorities in support of more than one NASA enterprise are identified by the Joint Enterprise Strategy Team composed of senior technology managers from each of the enterprise program offices at headquarters and from NASA's Centers.[1] The agenda

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[1] To distinguish between NASA Centers (e.g., Ames Research Center or Goddard Space Flight Center) and NASA's centers of excellence, the former is capitalized (“Centers”), and the latter is referred to in lower case (“centers”). (See Box 2.1, which clarifies the relationship.)

TRL 1	**Basic principles observed and reported**
TRL 2	**Technology concept and/or application formulated**
TRL 3	**Analytical and experimental critical function and/or characteristic proof-of-concept**
TRL 4	**Component and/or breadboard validation in laboratory environment**
TRL 5	**Component and/or breadboard validation in relevant environment**
TRL 6	**System/subsystem model or prototype demonstration in a relevant environment (ground or space)**
TRL 7	**System prototype demonstration in a space environment**
TRL 8	**Actual system completed and “flight qualified” through test and demonstration (ground or space)**
TRL 9	**Actual system “flight proven” through successful mission operations**

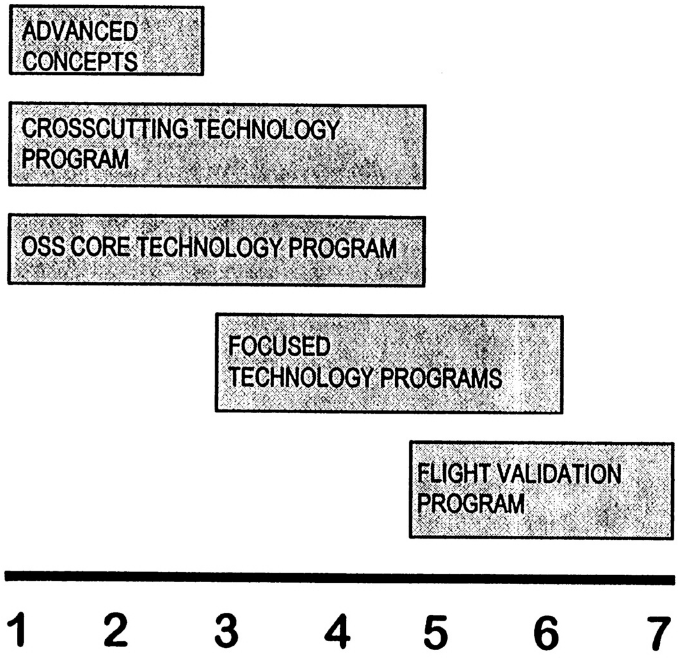

FIGURE 2.1 Techonology readiness level (TRL). SOURCE: NASA OSS.

for the team, which is chaired by the director of the OSS Advanced Technology and Mission Studies (AT&MS) Division, includes cross-enterprise policy, coordination, oversight, and conflict resolution. The team is expected to integrate the technology requirements defined by the individual enterprises and implementation approaches proposed by the Centers and to provide cross-enterprise priorities and recommendations to OSS. NASA representatives have emphasized that the process described above is still “a work in progress.” Because the transition to the new organization is only in its second year and the new AT&MS Division is still in a formative stage, NASA officials acknowledged that more work is needed to make the process effective.

Assessment of the Current Process

NASA recognizes the importance of establishing an agency-wide process for identifying, developing, and using space science technologies. The task group was pleased with many of the efforts that NASA has made since *Managing the Space Sciences* (NRC, 1995) was published. Of particular note are the ongoing efforts to develop a NASA-wide integrated technology plan and parallel efforts within the AT&MS Division to improve planning for technology related to the space science enterprise as well as cross-enterprise technology. However, as noted above, there have been major changes in ATD organizational structure and management processes at NASA headquarters, and some of these changes are not yet complete. Also, NASA has appointed a Chief Technologist to provide staff oversight in the Administrator's office on matters relating to technology and to coordinate technology activities across the agency. The relative authorities of the Chief Technologist and the director of the OSS Advanced Technology and Mission Studies Division need to be clarified. Furthermore, coordination between NASA's technology and science communities will remain impeded as long as the position of Chief Scientist remains vacant.

A “technology roundtable” comprising an ad hoc group of senior people from industry, academia, and NASA met in June 1998 at the request of OSS to discuss technology development by NASA. Based on those discussions, the AT&MS Division then drafted an ATD policy document, “NASA Space Technology Program Policies/Decision Rules.” The draft policy document, which appears in full in Appendix E, describes seven specific policies that highlight the importance of achieving excellence; describes the roles of NASA headquarters, Centers, and outside organizations; and discusses the importance of external reviews, technology transfer, and protection for proprietary information.

The task group concurs with several of the proposed policies. Excellence should serve as the primary metric, and expert reviews are essential for accurately assessing excellence. Defining “excellence” in a meaningful way will require careful attention to establishing an objective framework with definitive criteria. Such criteria might include relevance, cost-effectiveness, risk, timeliness, and so on. Personnel involved in these reviews must be carefully selected to avoid actual or perceived conflicts of interest. Similarly, the planning process should be open to individuals not involved in the current program to help ensure that ATD budgets address NASA needs, not the desire to preserve historic spending patterns.

Linking ATD to requirements established by the enterprises will increase the likelihood that ATD results will be relevant to agency missions. Requirements must address both near- and far-term agency missions to allow the ATD program to include an appropriate balance. Also, the task group believes it is essential for Centers to maintain appropriate core competencies. On the other hand, the task group disagrees strongly with the portion of policy 3 that says “in-house efforts justified as the minimal core to discharge management and leadership responsibilities will not be subject to competition with outside organizations.” Such a blanket delegation to the Centers goes far beyond what was recommended in *Managing the Space Sciences.* Preserving a broad range of in-house activities has too often been justified on the basis of a Center's need to be a “smart buyer” in all the areas for which the Center has management responsibility. As many private corporations have learned, an organization does not need to maintain hands-on efforts to make sound decisions about acquiring goods and services from outside sources. Other high-technology agencies have demonstrated that there are ample alternative ways to be smart buyers. For example, the Defense Advanced Research Projects Agency (DARPA) has capitalized on a process of recruiting very good people from within the military and outside the government for temporary assignments of only a few years, thus ensuring regular turnover. The National Science Foundation and the National Institutes of Health, taking an alternative approach, rely heavily on panels of outside experts to guide their decisions on which research programs to support. The most appropriate strategy for maintaining the expertise needed to be a smart buyer can vary depending on the nature of the organization and its mission. The task group believes that NASA would do well to examine alternatives for meeting these needs and develop an explicit strategy for remaining a smart buyer. The task group also believes that it is unwise to sustain core competencies through non-competitive allocations of ATD funding on a routine basis.

It remains to be seen what policies will be formally adopted, what methods OSS will use to implement approved policies, or how effective those methods will be. Thus, it is too soon to assess the long-term effectiveness of the ATD management process that is currently being established. Even so, some preliminary judgments are possible. It is essential for offices responsible for ATD and those responsible for future missions to communicate with each other effectively about technology planning and future mission needs. The ATD planning process should also draw on other planning efforts. For example, NRC reports such as *A New Science Strategy for Space Astronomy and Astrophysics* (1997b), *A Science Strategy for Space Physics* (1996a), *An Integrated Strategy for the Planetary Sciences: 1995-2010* (1994a), and the most recent report on decadal consensus strategies in astronomy and astrophysics (NRC, 1991) provide an important body of integrated science priorities for the OSS program. The ATD planning effort should take these external assessments into account, perhaps through the use of an advisory committee.

The task group saw little evidence that technology development is planned in a consistent and coordinated manner among different enterprises and Centers. Although the task group did not have an opportunity to conduct a comprehensive examination of this area, some Centers seemed to conduct ATD much more effectively than others. While not the only Center with exemplary approaches, the Jet Propulsion Laboratory (JPL) has described efforts to explicitly align and integrate new missions and technology that the task group can cite as being promising. As presented to the task group, the process included the use of management fora (a cross-Center Technology Planning Integration Working Group), designation of staff experts as “Technology Community Leaders” charged with promoting technology planning and transfer, and attention to supporting an end-to-end development process that can carry needed technologies from concept to infusion into prototypes of new products. It would be worthwhile for NASA to formally recognize Centers with effective ATD and transfer their best practices to other Centers.

The task group also believes that many of the recent and ongoing changes have the potential to improve the utility of NASA's ATD. For example, shifting responsibility for enterprise-specific technologies to the appropriate enterprise and shifting responsibility for cross-enterprise technology to OSS should improve the mission utility of ATD. Similarly, the emphasis that the AT&MS Division is placing on the incorporation of new technology into future missions should help address the long-standing complaint that too much new technology sits on the shelf and never—or too late—finds its way into operational missions. Finally, the concept advocated in policy 2 of the proposed OSS technology policy (Appendix E)—to use “vision pull” rather than “technology push” for enterprise-driven, long-term technologies—is also meritorious.

Recommendation 1. NASA's advanced technology development (ATD) planning process should be formally evaluated in 12 months, after changes that are just now being completed have had time to mature. Factors to be considered in the evaluations should include (1) responsiveness to input from the outside research community and (2) the extent to which program balance is addressed regarding such dimensions as technology push versus program pull, near-term versus far-term applications, and science instruments versus spacecraft systems. The evaluation should be conducted by an independent, external body such as the NASA Advisory Council.

Cross-Enterprise Technology

The cross-enterprise technology program was assigned to OSS in the reorganization that disbanded the Office of Space Access and Transportation. To the task group this part of the program appears to be operating largely as it did before, with the planning done at the Centers by the technology performers themselves and with little outside input to the process of setting priorities. Managing cross-enterprise ATD is potentially more complex than managing enterprise-specific ATD because it is necessary to decide whether a proposed effort is indeed cross-enterprise, and if so, how such an effort is to account for the differing needs of multiple enterprises. In general, there seems to be little support in NASA for cross-enterprise technology programs outside of the personnel directly involved in those efforts; personnel associated with specific enterprises often view cross-enterprise ATD as less effective than and not as desirable as having additional resources available to support their own, enterprise-specific programs. The task group does not share this view, but accepts it as evidence of the importance of providing attention to relevance, priorities, and communication in developing the entire ATD program.

Recommendation 2. The planning process for cross-cutting technology should be modified so that it mirrors the process used by the Office of Space Science for space science technologies. Key attributes are the use of technology roadmaps that are linked to enterprise science roadmaps and that are developed with the broad participation of the research community.

Long-Term Technology Development

NASA was unable to provide the task group with much historical budget data. For example, NASA could not say how much of its ATD resources have been devoted in the past to long-term technology development. Investing in long-term technology is essential for many ambitious missions NASA envisions for the future. Thus, an appropriate balance is needed in how technology development resources are split between projects with near-term and long-term objectives. Achieving this balance is a task for the overall ATD planning process, which must consider the needs of near-term objectives and the promise of long-term projects and then make informed decisions. With the aid of better data on investment allocations and trends, it would be possible to follow up on the efficacy of this implementation. Retaining data on current expenditures would build a historical record of value to future planning efforts.

Some technologies lend themselves to a continuous process of incremental improvements. In other cases, significant improvements require revolutionary changes that involve totally new approaches. Thus, the task group believes that work on revolutionary technology should be viewed as an essential element of long-term ATD, and sufficient ATD funds should be set aside for this purpose. As with short-term technology development, the AT&MS Division should use open, competitive processes to allocate resources for development of long-term and revolutionary technologies to ensure that the best-qualified people and organizations participate (see below).

IMPLEMENTATION

The Space Act, which provides NASA with its legislative charter, establishes as one of NASA's objectives the preservation of U.S. leadership in space science and technology (Code of Federal Regulations, Title 42, Section 2451). OSS shares responsibility for fostering U.S. scientific, technical, and economic leadership through development of advanced technologies.

To facilitate U.S. leadership in technology and science, NASA has an obligation to rely on the best available national resources. In the early years of the civil space program, the best (often the only) available technical resources resided within NASA. As the program progressed, however, research funded by NASA and other federal agencies fostered the emergence of a large and highly competent academic and industrial base. Further, as the commercial space industry grew and matured, industry investments in some areas greatly exceeded comparable activities by NASA. Over the same period, NASA downsized from its peak during the Apollo program, and there is reason to believe that this trend will not be reversed. NASA must increasingly view its role as marshaling the space science and technology skills of academia and industry and building on them to develop necessary technologies for the short and long term (NRC, 1995). It is especially important to include experts from academia and industry in the early evaluation of technology needs and goals related to the development of sensors, instruments, and spacecraft systems—areas in which academia and industry are heavily involved in advancing the state of the art (NRC, 1993). This inclusion will require a spirit of true cooperation between NASA and the rest of the U.S. aerospace and space science community, and the NRC has suggested that NASA aggressively seek partnerships with both private companies and universities (NRC, 1998).

The task group believes that the most effective approach to increasing the involvement of academia and industry in ATD involves open, competitive processes to identify the best-qualified people and organizations to undertake each new project. The task group recognizes that there are likely to be cultural and administrative obstacles to implementing a fair and open competitive process that includes NASA Centers, and to define a competitive process that builds—instead of tears down—NASA partnerships with industry and academia. However, open competition and teaming have worked successfully in the space sciences for years, and there is no reason to expect a more difficult implementation for technology. Key aspects of the competitive process are the use of clear and objective criteria by which to establish merit and the use of independent experts to evaluate the merits of competing proposals or approaches. An ATD program based on competition would maximize the value of NASA's technology development efforts and do the most to continue U.S. technological and scientific leadership, while also fostering collaboration between NASA Centers and outside organizations with complementary expertise as they team to bid on competitive ATD opportunities.

Core Competencies

For NASA Centers to thrive in a competitive environment keyed to excellence, they must develop and maintain core competencies in advanced technologies critical to NASA's future missions. Studies of how both successful and unsuccessful organizations have addressed the topic of core competencies can be instructive for NASA. Quinn and Hilmer (1994) present a set of key attributes of core competencies. They note the following:

- Core competencies are intellectual skills or knowledge-based activities rather than products or functions.
- Core competencies should be limited in number; most companies identify two or three and rarely more than five.
- Successful core competencies are built around areas in which an organization is uniquely qualified to perform and where investments can be highly leveraged to add value to an overall business or mission.
- Core competencies are ingrained in an organization's systems and are not dependent on one or two superstars in the organization.

For NASA, these findings translate into a need for each Center to concentrate on a few technologies, areas of expertise, or activities that are critical to its central missions and that are not being handled adequately by the external community, either in industry or academia. Although in the early decades of the space program there may have been many such areas, a strong measure of NASA's past success is the fact that now communities outside NASA are much more capable of filling many of these needs.

NASA has designated centers of excellence, which are intended to provide NASA-wide leadership in a specific area of technology or knowledge (see Box 2.1). In some cases the centers of excellence do, indeed, possess expertise that is unsurpassed elsewhere. Studies of successful organizations have shown, however, that the concept of core competencies includes the ability to integrate multiple streams of technologies, including ones from outside sources (Prahalad and Hamel, 1990). Centers of excellence need not be preeminent in every aspect of the area for which they are so designated by the agency, and therefore there need not be a one-to-one match between a Center's core competencies and the area for which the Center serves as a center of excellence.

Each Center director is responsible for planning and implementing the designated center of excellence, for annually assessing its capabilities, and for correcting shortfalls in capabilities, either by consolidating capabilities or proposing programs to maintain capabilities. Centers of excellence are not program entities, although they are fiscally supported by program and/or institutional resources with funding provided through one or more enterprises. Proposals to significantly alter center of excellence facilities, staffing levels, or skill mix are treated as investment issues and, therefore, reside with NASA's Capital Investment Council, which makes recommendations to the NASA Administrator. The Capital Investment Council also addresses proposals to designate new centers of excellence. In some cases, the capabilities to support a center of excellence involve multiple Centers (NASA, 1997, 1998a).

BOX 2.1 NASA CENTERS OF EXCELLENCE

Facility	Center of Excellence for
NASA Headquarters	Agency Management
Ames Research Center	Information Technology
Dryden Flight Research Center	Atmospheric Flight Operations
Goddard Space Flight Center	Scientific Research
Jet Propulsion Laboratory	Deep-Space Systems
Johnson Space Center	Human Operations in Space
Kennedy Space Center	Launch and Cargo Processing Systems
Langley Research Center	Structures and Materials
Lewis Research Center	Turbomachinery
Marshall Space Flight Center	Space Propulsion
Stennis Space Center	Rocket Propulsion Testing

SOURCE: NASA (1998a).

Some NASA Centers have taken the next step and formally identified specific core competencies; for example, the core competencies claimed by Langley Research Center (LaRC) and Lewis Research Center (LeRC) are listed in Box 2.2 and Box 2.3, respectively. However, if core competencies are defined as world-class capabilities, it seems highly unlikely that any organization could truly master the large number of core competencies listed in each of these boxes. Furthermore, it is doubtful either that such a wide range of core competencies would be needed for a Center to feed its principal lines of activity or that trying to fill them all internally would make good business sense. In U.S. industry today companies winnow down the list of core capabilities to those few that are really critical to their competitive position and then rely increasingly on subcontractors, vendors, and strategic partners to supply the rest.

In Box 2.2, LaRC lists four core competency topics in structures and materials, the area for which it is a center of excellence. That number seems to be appropriately small. While ambitious, the list does not suggest that LaRC is trying to cover all aspects of structures and materials. In contrast, the range of topics in Box 2.3 for LeRC under materials and structures is as broad and probably overlaps with the LaRC list. Both Centers present broad lists of competencies in other areas that appear to go far beyond their center-of-excellence foci.

Trying to establish and maintain too many core competencies within a particular Center or within NASA as a whole has several disadvantages. It disperses available resources among too many different areas. Also, if NASA incorrectly believes it possesses certain world-class capabilities, it will be less likely to rely on other organizations where world-class capabilities actually reside. Instead the NASA manager of a complex program will be expected to rely on various Centers claiming to have the requisite core competencies. If the supporting Centers do not, in fact, possess world-class capability, the resulting effort will cost more, take longer, and/or provide an inferior product compared to the alternative of going directly to a true source of world-class capability.

Establishing and maintaining a world-class core competency require focus, funding, and dedication. They will require a process that is no less rigorous than a successful industrial concern uses to first define those capabilities that are central to its competiveness. Rather than trying to do everything in-house, the Centers will need to be able to be “smart buyers” by nurturing a staff of “smart people” who remain aware of and attuned to contemporary developments and technology pacesetters outside NASA. This approach has well served other organizations such as DARPA. While there are some Centers that likely are already demonstrably at the forefront or are highly competitive, the task group recognizes that years may be needed before each Center core competency group—on a much winnowed list—is on an equal footing with academia and/or industry.

BOX 2.2 CORE COMPETENCIES FOR LANGLEY RESEARCH CENTER

Mission and Systems Analysis, Integration, and Assessment—Aeronautics

- Identify and prioritize new aeronautical concepts and systems. including the critical technologies involved, investment options, and system-level global and societal benefits resulting from proposed programs for subsonic through hypersonic speed vehicles.
- Provide continuing evaluations and technology assessments for ongoing focused and base programs.
- Develop advanced methods and data for performance, economic, and safety assessments of aeronautical systems, including vehicles and the integrated air transportation system.
- Conceive, develop, and validate multidisciplinary methods for analysis and design of aerospace systems and products.

Mission and Systems Analysis, Integration, and Assessment— Space

- Conduct mission and systems analysis of space transportation, spacecraft, planetary entry, and sensor concepts.
- Lead independent assessments of critical space missions for the agency.
- Conduct technology assessments to enhance space transportation, spacecraft, planetary entry, and sensor concepts.
- Conceive, develop, and implement computational, multidisciplinary optimization for design and development of space and trans-space transportation vehicle systems.
- Develop life-cycle analyses (including cost) to support

Airborne Systems and Crew Station Design and Integration

- Design, build, integrate, and test highly reliable, digital electronic and electromagnetic systems for aerospace applications.
- Develop and demonstrate methodologies for designing and verifying high-integrity digital and electromagnetic systems in mission- or life-critical aerospace applications.
- Develop techniques to use the microgravity environment to improve semiconductor materials.
- Develop aerospace vehicle flight dynamics design requirements, modeling methods, analysis tools, and test techniques and conduct flight dynamics evaluations of aerospace vehicle configurations.
- Develop and validate guidance and control design methods, analysis tools, and algorithms for aerospace vehicles.
- Develop requirements, concepts, and design guidelines for flight deck systems and their integration into airplane flight decks.

Structures and Materials

- Develop advanced materials and processing technologies to enable the fabrication of low-cost structural concepts for high-performance aerospace applications.
- Conduct research and technology development that accurately and efficiently predicts behavior, durability, and damage tolerance, evaluates concepts, and validates performance of advanced materials for aerospace structures.
- Conduct research and technology development for advanced

independent assessments of the early conceptual stages of projects and programs for the purpose of making informed decisions on selection as well as investment choices for the agency.
- Develop and utilize spacecraft and space transportation vehicle preliminary design and mission design and evaluation tools for application to flight mission concepts, agency space mission concepts, and independent assessment evaluations.
- Develop and implement planetary entry analysis tools for robotic and human spaceflight missions for Earth orbit and planetary systems.

Atmospheric Sciences and Remote Sensing

- Conceive, develop, and use advanced instrumentation to observe, characterize, and analyze regional and global atmospheric processes with emphasis on remote sensing from space.
- Develop advanced technologies and measurement techniques to enable new science measurements and to reduce science instrument life-cycle cost.
- Develop and utilize theoretical models and analytical techniques to interpret atmospheric observations and understand global change.
- Produce, analyze, interpret, and disseminate atmospheric data sets necessary for understanding atmospheric radiative, chemical, dynamic, and meteorological processes and interpreting trends.
- Identify critical atmospheric science issues and contribute to national and international assessments of the environment, including the impact of aircraft and other anthropogenic activities on long-term global changes.
- Conduct analysis, design, and hardware development of advanced materials and structures, detectors, electro-optic materials, and controls for advanced aircraft and spacecraft remote sensing systems.
- Develop advanced remote sensing technique instrumentation and integrated sensors for low-cost, high-performance monitoring of Earth and planetary atmospheres.
- Develop models and perform measurements and simulation for advanced electro-optic materials and atmospheric lidar systems to predict system performance in both Earth and planetary atmospheres.
- Develop advanced diode-pumped solid-state lasers and lidar systems to meet the unique atmospheric science needs of the Earth science and space science enterprises.
- Leverage space and atmospheric science remote sensing technology to develop atmospheric monitoring instruments applicable to aircraft operations performance and safety. sensors, intelligent systems, and ground operational behavior to ensure structural integrity, reliability, and safety for aerospace vehicles.
- Conduct research and technology development to quantify and control aeroelastic response, unsteady aerodynamic flow phenomena, and structural dynamics behavior for flexible aerospace vehicles.

Supporting Capabilities

- Develop, evaluate, integrate, and implement enabling state-of-the-art technologies for test articles, instruments, and facilities for airframe systems, atmospheric sciences, and related space technologies research programs.
- Develop, provide, operate, and maintain research models, instruments, facilities, and systems to meet the evolving ground-based requirements of the research community.
- Develop and provide scientific and technical information services and products for assimilating, managing, and disseminating research results.
- Develop and provide institutional services and products to maintain the research support infrastructure and facilities.

Aerodynamics, Aerothermodynamics, and Hypersonic Airbreathing Propulsion

- Develop, assess, and apply aerodynamic and component integration technologies to enable development of advanced subsonic, supersonic, and high-performance aircraft.
- Manage, operate, and provide aerodynamic, acrothermodynamic, aero- and hypersonic-propulsion, and acoustic test capabilities for agency and industry research and development of a broad class of aerospace vehicles.
- Develop, assess, and apply aerothermodynamic technologies to enable development of hypersonic aircraft, launch vehicles, and planetary and Earth entry systems.
- Develop, assess, and apply hypersonic airbreathing propulsion technologies to enable development of hypersonic airbreathing vehicles.
- Develop, assess, and apply acoustic technologies in the development of advanced aerospace systems and to meet environmental requirements.

SOURCE: NASA (1998b).

BOX 2.3 CORE COMPETENCIES FOR LEWIS RESEARCH CENTER

Combustion

- Emissions measurement and diagnostics
- Flow field measurement and diagnostics
- Combustor design technology for emissions reduction
- Fuel injection and spray technology
- Combustor materials and cooling techniques
- Combustion testing, analysis, instability, and heat transfer codes
- Propellants, including high-density monopropellants, high-cooling-capacity fuels, and high-energy-density fuels

Instrumentation and Control

- Temperature, heat flux, and chemical species measurements
- Strain sensing
- High-temperature silicon-carbide electronics and sensors
- Optical measurements
- Laser-based measurements
- Integrated control and robust control synthesis techniques
- Intelligent controls including fault diagnostics and neural networks

Fluid Physics

- Multiphase flows in reduced and variable gravity environment
- Pool boiling and phase change in reduced gravity
- Surface-tension-driven or thermocapillary flows in reduced gravity
- Disorder-order transition in colloids
- Laser light-scattering instruments
- Flow of cohesionless granular media
- Rheological properties of non-Newtonian materials
- Pattern formation during solidification
- Dynamics and growth of bubbles
- Behavior of colloids, foams, and suspensions
- Magneto-rheological fluids
- Liquid crystals: hydrodynamics, structure, and phase transition
- Microscale hydrodynamics of moving contact line (i.e., wetting of solids)
- Fundamental studies of heat pipes and capillary pumped loops
- Nonintrusive flow and temperature measurement techniques
- Biological fluid flows

Materials and Structures

- Advanced materials (polymers, metals, and ceramics) and composites
- Structural mechanics concepts
- Environmental durability
- Fatigue and fracture (life and reliability prediction)
- Turbomachinery structural dynamics
- Tribological (friction and wear) concepts
- Materials processing, fabrication, and testing
- Computational materials and structures
- Materials characterization and analysis techniques (including nondestructive evaluation)
- Materials and structures laboratory facilities
- Surface analysis, texturing, and thin-film technology
- Advanced concepts (including deicing)
- Dynamic modeling of fluid systems
- Life-extending controls

Communication and Computing

- Microwave technologies
- Advanced antennas
- Digital communication technologies (modulation, coding, onboard processing and switching, and network terminals)
- Communication networks and systems
- Advanced space communication experiment capabilities with ACTS [Advanced Communications Technology Satellite]
- Enabling computing capabilities

Power Generation and Management

- Development and testing of next-generation solar cells and concentrator arrays
- Development and testing of advanced solar concentrators, heat receivers, and thermal transport and radiator technologies
- Development of Stirling engines for space and terrestrial power applications
- Development and testing of advanced batteries and fuel cells
- Development and testing of low-, wide-, and high-temperature electrical components and devices
- Development and testing of magnetic and dielectric materials
- Modeling and analysis of space-system-generated plasma effects
- Modeling and analysis of integrated spacecraft power systems

Turbomachinery

- Mechanical design of high-speed rotating machinery
- Turbomachinery flow physics
- Materials, seals, bearings, and lubricants for both high- and low-temperature applications
- Computer-aided design and modeling
- Facilities capable of simulating actual operating environments for testing materials, components, subassemblies, and entire gas turbine engines

SOURCE: NASA (1996b).

The task group believes that NASA should first determine which areas need to be developed into true core competencies (and which should not) and then use objective, external reviews[2] to determine which of the winnowed set of core competencies exist at the Centers, at a level of excellence that can sustain success in a competitive ATD environment. All Centers report that they conduct external

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[2] The term "external review" as used in this report signifies evaluation by independent, objective experts whose outside perspective and expertise in the subjects at hand can broaden and strengthen the feedback they provide. "Peer review" is the term commonly used throughout the scientific community. The task group has elected to use "external review" to emphasize that it does not mean simply the review of technology by scientists, but merit review by appropriate, independent, relevant experts.

reviews of their programs, but the character and effectiveness of evaluations conducted by individual Centers vary widely and generally should be improved. For example, Ames Research Center and Langley Research Center reported that they conduct an external review of all programs every 3 years, whereas Johnson Space Center indicated that it relied on internal reviews rather than external reviews. Also, it is not clear in all cases that these reviews provide critical, independent assessments. The reviews should focus on excellence, and success in competitions against other organizations should be viewed as a critical element of validating excellence. Some of NASA's core competency groups are already world class and should be able to compete successfully with external groups for technology programs. Other areas may require some nurturing before achieving true core competency status. In such a case it may be necessary to target some ATD funds for this purpose, but a deadline should be set for accomplishing the objective, probably not to exceed 3 years. ATD funds should not be used more broadly to bolster in-house capability. For core competency groups that are close to achieving world class, the 3-year limit provides an opportunity for new staff and improved facilities to significantly enhance existing capabilities. The orderly completion and termination of programs that will be phased out can be accomplished over the same interval. However, the time limit rules out open-ended efforts to fabricate core competencies in areas where NASA's current capabilities are far behind those of outside groups. Each Center director has discretionary funds that can be used for seed efforts, nurturing efforts, and quick response to opportunity. Such funds would help in easing workforce concerns, and headquarters review would prevent misuse.

Finally, the AT&MS Division has suggested that it is appropriate to maintain NASA's core competencies using ATD resources, and that resources dedicated to this effort would not be made competitively available to outside organizations. The task group believes that protecting core competencies from competition is counterproductive to achieving excellence, and the excessive number of core competencies listed in Box 2.2 and Box 2.3 increases the magnitude of this problem.

Recommendation 3. NASA should establish a comprehensive Center evaluation process that includes regular, objective, external evaluations of core competencies. Those internal core competencies essential to achieving a Center's main mission should be identified and appropriate recommendations made to achieve and maintain excellence. As a result of these evaluations, NASA will have to make difficult choices about limiting internal research emphasis in some areas. External organizations with world-class capabilities should be selected competitively to complement the in-house work and ensure the maintenance of NASA's centers of excellence. ATD funds should not be set aside to provide support for in-house capability but should be earned by Centers through open competition with outside organizations.

Roles of NASA Headquarters and the Centers

As it becomes more common for Centers to compete against academia and industry, increased reliance on objective external reviews will help avoid real or perceived conflicts of interest. Proposal reviews should be carried out by knowledgeable, disinterested individuals from other government agencies, industry, and academia whose collective expertise spans the relevant scientific and technical areas in the projects or programs to be reviewed.

One of the challenges associated with the widespread use of external reviews is how to manage the review process effectively. Good management is especially important with procurement actions. The government procurement process is already long and complex, and it would be unfortunate if the advantages produced by increased competition were offset by comparable increases in the time taken to complete procurement actions. Therefore the task group believes that NASA's recent efforts to streamline the proposal review and award process for science research grants should be applied also to technology awards. Furthermore, adequately staffing the external review process is essential.

Although the Centers may be asked to manage technology development programs, NASA-wide oversight of technology for the space sciences belongs at headquarters. Currently, the Office of the Chief Technologist plays an agency-wide coordination role, and line management for space science technology resides in OSS. In make-or-buy decisions for individual elements of the technology program, the relative roles of OSS and the Centers are unclear. Open competitions, in which NASA Centers are eligible to compete with industry and academia, are important for ensuring that ATD is conducted by the best-qualified people. However, it would be difficult to structure fair competitions were they administered by Centers that also have a self-interest in funding in-house activities. That situation is handled satisfactorily for OSS competitions for space science funding by administering proposal solicitations (which are open to all organizations, including academia, industry, Centers, other federal agencies, and not-for-profit laboratories) and proposal merit reviews, and making award selection decisions at headquarters. The task group views the stated intention of the director of AT&MS D to follow this process for advanced technology as a sound approach.

Recommendation 4. With the support of external reviewers, NASA headquarters should conduct make-or-buy decisions and competitive procurements for all long-term ATD.

Recommendation 5. For near-term technology development needed to support ongoing programs already under the direction of a particular Center, that Center should conduct make-or-buy decisions. However, if the Center decides to buy, then NASA should avoid real or perceived conflicts of interest by either administering the competition and external review from headquarters or excluding from the competition all in-house organizations located at that Center. A Center decision to “make” should have headquarters concurrence.

Recommendation 6. NASA should ensure that adequate resources, especially personnel, are available for headquarters to organize, conduct, and respond to the needed number of external reviews to support competitive ATD procurements.

INFRASTRUCTURE

Workforce Development

After the Centers winnow the number of areas in which they seek to sustain core capabilities and focus on those few where they may remain preeminent, then one of the important consequences is likely to be that fewer members of a Center's technical staff will be “hands-on, bench” practitioners. Given NASA's ongoing efforts to reduce its workforce, a strategic approach that considers core competencies will become an essential tool in workforce planning. More importantly, the task group believes that the functional responsibilities of the Centers will be broader than the select set of skills that Centers will preserve as internal core competencies. Hence, to sustain a total workforce that stays on the cutting edge to meet the demands of the Centers' mission roles, NASA will have to expand its activities to nurture the skills and maintain the currency of its workforce. As Centers make the transition from being heavily oriented toward in-house technology development to taking the role of facilitating external projects and partnerships, the need to be a “smart buyer” will grow. A key to keeping the workforce sharp in such a transition is exploitation of means to promote staff mobility, both among Centers and between Centers and academia, industry, and other government laboratories. Vehicles such as Intergovernmental Personnel Act (IPA) exchanges are one such means. NASA representatives reported to the task group that most Centers had a few employees (typically one to five) detailed for temporary assignments at other Centers or laboratories, but that limited relocation funding and family considerations were impediments to broader use of exchanges. This number seems too small for organizations the size of the Centers. Centers can attract and retain highly qualified scientists and technologists on their staffs by continuing to use the “dual career ladder” that provides opportunities for researchers to be rewarded and promoted on the basis of their technical work and performance as an alternative to entering the management track. *Managing the Space Sciences* noted the importance of having competent space scientists at the Centers working closely with project managers to support the most effective flight projects. Promoting teaming of Center scientists and technologists is also important to sustain strong technology programs. Another way to enhance the intellectual vigor of the Centers is to ensure that there is a steady flow of young researchers from outside organizations (e.g., via the use of temporary postdoctoral appointments).

Organizational Interdependencies

Effectively managing interdependencies among NASA Centers and between NASA and other government agencies is important. The strong technological alliance between DOD and NASA in aeronautics has been a positive example in this regard. An increased level of interdependency will help break down the insular culture that persists at some Centers. Declining budgets in both the civil and military space programs have been increasing the pressure for greater interagency cooperation. Missions by the Department of Defense (DOD) such as Clementine also indicate that a technological alliance between NASA and DOD could produce potentially important benefits to space science in general and technology endeavors such as the New Millennium Program in particular. It will be constructive for NASA to include non-NASA government laboratories and quasi-government facilities in competitive procurements (NRC, 1994b, 1995, 1997a). NASA representatives reported on more than 70 partnership arrangements in support of OSS technology development between Centers and DOD agencies plus a handful of activities with the Department of Energy and other agencies and at least 90 inter-Center collaborative projects (see Figure 2.2). The task group finds these arrangements to signal an encouraging trend.

On the other hand, having multiple Centers or laboratories involved in a given project can complicate the management structure and lead to inefficiencies. Thus, the involvement of multiple Centers or facilities should occur only when there is technical or scientific advantage to

	AFRL	DARPA	BMDO	U.S. Navy	ARL	NRO	DOE	NOAA	NIJ
ARC	Currently no partnerships within OSS funding.								
GSFC	9			4	1	3	1		1
JPL	7	5	11	2	2	2	5	1	
JSC	Currently no partnerships within OSS funding.								
LaRC	2	1	1	1					
LeRC	6	7	5				1		
MSFC	1				1				
Totals	25	13	17	7	4	5	7	1	1

AFRL: Air Force Research Laboratory
ARC: Ames Research Center
ARL: Army Research Laboratory
BMDO: Ballistic Missile Defense Organization
DARPA: Defense Advanced Research Projects Agency
DOE: Department of Energy
GSFC: Goddard Space Flight Center
JPL: Jet Propulsion Laboratory
JSC: Johnson Space Center
LaRC: Langley Research Center
LeRC: Lewis Research Center
MSFC: Marshall Space Flight Center
NIJ: National Institute of Justice
NOAA: National Oceanic and Atmospheric Administration
NRO: National Reconnaissance Agency

FIGURE 2.2 Partnerships between NASA Centers and government agencies to support Office of Space Science technology development. SOURCE: NASA OSS.

doing so and there is a clear delineation of roles between the lead Center and the other involved parties.

Recommendation 7. NASA should foster increased workforce mobility among Centers and between NASA and industry, universities, and other government agencies to facilitate the transfer of information, obtain fresh points of view, and maintain the expertise of its workforce. Expanded use of Intergovernmental Personnel Act exchanges and cooperative agreements should be considered to facilitate these efforts.

Role of Chief Scientist

NASA needs a strong Chief Scientist for many reasons, particularly since NASA's scientific programs are managed by three separate offices. NASA has created and filled the position of Chief Technologist, but the need for an active Chief Scientist remains. The associate administrator for space science is not in a position to carry out the role of Chief Scientist. A Chief Scientist is needed to work in partnership with the Chief Technologist, the director of the AT&MS Division, and other key NASA officials to coordinate the integration of the needs of all of NASA's science offices into an ATD program that appropriately considers NASA's scientific goals and to establish a balanced agency science and technology program. In particular, the Chief Scientist should play a key role in technology planning related to all the space sciences and help ensure that external reviews are scientifically sound.

Recommendation 8. NASA should take prompt action to re-staff the Office of the Chief Scientist.

Full-Cost Accounting

The funds for civil service salaries, office expenses, and other related personnel and operating costs appear in NASA's budget separately from funds allocated for scientific and technical programs. Thus, it has been—and still is—difficult to accurately determine and compare the cost of different programs. A $10 million research program may cost NASA $10 million if all the labor is provided by contractors, who are paid with funds set aside for that program. However, that same program may appear to cost NASA less, but actually cost significantly more because the present NASA accounting procedure omits a large number of civil service employees, whose salaries are paid from a separate account provided to each Center.

Without accurate fiscal data about funds allocations and program costs, it is impossible for NASA to make informed judgments about Center roles, make-or-buy decisions, or contract awards for competitive procurements that include proposals from NASA Centers. NASA needs a new financial management system that provides a full accounting of individual program and project costs. This need has been long recognized. Although NASA is in the process of implementing a new, full-cost accounting system, little progress is evident since *Managing the Space Sciences* was issued in 1995, and implementation of a full-cost accounting system is still at least a year or two away.

Although necessary, the implementation of full-cost accounting could raise significant personnel management issues for NASA. Currently, program cancellations generally do not threaten the civil service workforce because their salaries are separately budgeted. However, under a full-cost accounting system, civil service salaries would presumably be included in the budgets of each program and project—and center of excellence. Suppose, in a full-cost, competitive environment, that a center of excellence is unable to compete for and win enough work to keep its staff funded. As discussed above, the task group recommends against continued use of ATD funds to perpetuate centers of excellence or maintain claimed core competencies when lack of competitiveness demonstrates that they are inferior to other organizations in government, industry, and/or academia. NASA will have to develop plans to deal with workforce redeployments. Given that a complete shift to a fully competitive environment will take several years to implement, there is time to address this issue and put a plan in place.

Recommendation 9. Full-cost accounting is essential to effective management of ATD programs, and NASA should provide sufficient resources to complete and implement a full-cost accounting system. NASA should also determine how it will address workforce issues that may be raised when funding allocations are guided by full-cost accounting and organizational excellence, as determined through full and open competition.

PERFORMANCE MEASUREMENT

Data Collection

Effective management is greatly hampered without accurate information on the history and current status of ongoing programs. Implementing a full-cost accounting system, as described above, is an essential first step. With regard to ATD, it is important to structure the cost accounting system to provide all necessary information. For example, NASA managers currently have little or no historical information on how ATD funding has been split between long-term and short-term programs; how funding has been divided between in-house efforts and efforts by industry, universities, and other government laboratories; and how much of the ATD funding is competitively awarded. Neither is data readily available to describe the details from collaborative efforts among NASA Centers or between NASA and outside organizations, in which both NASA and its collaborators contribute funding and personnel.

Recommendation 10. NASA should identify performance measurement approaches (including independent external reviews) and metrics (including adequate investment data) needed to effectively manage its ATD programs. The findings and recommendations of external reviews of the Centers should be reported to headquarters as well as to senior Center management. Investment data should cover the current program, and these metrics should be tracked for future use.

Technology Insertion

There is an inherent contradiction between NASA's wish to advance new technologies and its desire to avoid mission failures. Balancing the long-term payoff that a new technology may provide—if and when it has been proven in flight—with the risk of losing a near-term mission that tests the technology is difficult (NRC, 1996b). OSS representatives indicated that they intend to foster the incorporation of new technology into missions by including such use of new technology as an explicit factor in the selection criteria for new projects. One approach OSS could apply to managing the risk accompanying the use of unproven technologies would be to be more aggressive in incorporating new technologies in smaller-class missions (e.g., Small Explorers [SMEX] and University Explorers [UNEX]) than in more expensive ones. In addition, a Transition and Infusion Manager staff position dedicated to increasing the inclusion of new technology in the flight program has been established in the AT&MS Division. The individual selected to fill this position will need to address several important challenges:

- How to use new technology in flight programs without adding unacceptable risks;
- How to arrange for *timely* flight tests of new technology, so that it can be incorporated into science missions before it becomes obsolete; and
- How to broker agreements between technology developers and flight program managers to bridge the gap between ground-based validation of technology and prototype flight demonstrations of mission readiness. ATD efforts generally are not funded for flight demonstrations, and managers of flight programs are reluctant to divert program funds to flight demonstrations of technologies that may not work and could endanger the success of the one mission for which the manager is currently responsible.

NASA's New Millennium Program (NMP) is intended to help address the above problems. NMP is sponsoring a series of missions with the dual objective of demonstrating advanced technology, while still conducting scientifically useful experiments. Because of the dual objective, however, the desire to ensure a successful scientific outcome can interfere with the goal of determining if new technology is ready for use in future missions. NASA representatives indicated that early in the program the cost and time necessary to prepare new technologies for flight demonstrations had both been significantly underestimated by the NMP. The director of the AT&MS Division reported to the task group that he plans to take action to avoid these problems with future NMP missions. Although *Managing the Space Sciences* “urges that every technology development flight that is to benefit the space sciences use the new technology to accomplish valid science” (p. 69), the task group believes that exceptions to this principle may sometimes be required in order to sponsor timely and cost-effective demonstrations of important new technology. Although the use of NMP missions to accomplish interesting science remains a desirable goal, it should not be permitted to impede the primary purpose of such missions—the flight validation of new technologies.

Follow-up

Even when the need for change is accepted and a plan for making change is broadly endorsed, day-to-day crises can interfere with efforts to improve long-term effectiveness. The task group believes that the response to *Managing the Space Sciences* provides a good example of this phenomenon. That report contained few controversial recommendations, yet many recommendations remain unfulfilled as attention has been distracted by changes in organizational structures, personnel, and policies.

Recommendation 11. To ensure accountability, NASA should formally respond to the recommendations contained in this task group report. Regular status reports should be made to external bodies, such as the NASA Advisory Council.

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3

Summary

The charge to the task group had four main elements:

1. Assess the current OSS approach to and process for technology development and how well it meets agency needs.
2. Assess OSS's response to the intent of recommendations regarding technology development outlined in *Managing the Space Sciences.*
3. Assess the extent to which the new OSS approach addresses concerns expressed by Congress with regard to ATD in support of NASA's science programs.
4. Recommend changes or new approaches that NASA should consider to improve ATD efficacy.

Chapter 2 addresses the first item and provides groundwork for items 2 and 3. This chapter summarizes the task group's assessment for items 2 and 3 and, in response to item 4, includes a summary list of all of the task group's recommendations to NASA.

RESPONSE TO MANAGING THE SPACE SCIENCES

The first technology recommendation in *Managing the Space Sciences* (NRC, 1995; see Box 1.1) addresses the need for integrated planning and effective interaction between scientists and technology developers. NASA has made good progress here, especially through the work of the Chief Technologist to develop an integrated NASA technology plan and through the new OSS technology roadmaps and the planning process being established by the AT&MS Division. There is more work to be done, however, to increase and improve the involvement of the broad scientific community in establishing consensus plans and priorities for cross-cutting and long-term technology activities. There also is still a need for having the NASA Chief Scientist as a key senior participant in the planning process along with the Chief Technologist.

The second recommendation addresses roles and responsibilities for near-term technology development. NASA's assignment of responsibility for mission-specific technologies to the individual enterprises is fully consistent with this recommendation. In the case of OSS, the planning process for mission-specific, near-term technology development appears to be working well, especially for the focused-programs element. Nevertheless, the task group remains concerned that there appears to have been little response to the portion of the recommendation that states “all categories of technology development [including near-term] should be undertaken by the best-qualified individuals or teams within NASA, industry, or academia,” as determined by external review (see Box 1.1).

The third technology recommendation in *Managing the Space Sciences* addresses the potential of far-term technology development to significantly enhance future mission cost-effectiveness or even revolutionize some aspects of space science. The transfer of the cross-cutting technology program formerly under the Office of Space Access and Technology to OSS appears to be a sound approach, although, as noted above, more progress is still needed to enhance scientific participation in the planning and priority-setting process. Also as noted above, use of open competition and rigorous external review for all aspects of the program is still needed.

Technology recommendation 4 focuses on the roles of headquarters and the Centers. Establishment of the position of Chief Technologist in the Office of the Administrator to coordinate technology activities agency-wide and the creation of the OSS AT&MS Division to manage the OSS ATD program, including all competitions for cross-cutting activities and OSS-specific far-term activities, are consistent with this recommendation. It is important, however, to clarify the relative roles and responsibilities of the Chief Technologist and the director of the AT&MS Division. The task group was concerned also about inherent conflicts of interest in situations in which a Center is making make-or-buy decisions or managing competitions for technology development when that Center is also a competitor. Finally, proper implementation of the essential headquarters role of administering full and open competitions will require adequate headquarters staff and resources.

Technology recommendations 5, 6, and 7 in *Managing the Space Sciences* address the roles and character of Center, industry, and academia participation in technology development. These recommendations urge NASA Centers to identify those technologies that require in-house research and development, to rely more on outside organizations for research related to other technologies, to develop aggressive programs for changing the insular culture of Centers, and to use open competition to identify and use the nation's best talent available to conduct both near-and far-term technology development. The task group was pleased to see efforts to reduce duplication between Centers and to build partnerships both among Centers and between Centers and outside organizations. As indicated in Chapter 2, however, the basis for NASA's designation of centers of excellence and of Center core competencies is not always clear, and the need for more rigorous metrics and regular external review to evaluate competence and excellence are just as critical as when *Managing the Space Sciences* was published in 1995. There is also a need, at least at some Centers, to pare down the core competencies to an attainable number. NASA representatives noted that for the programs transferred from the former Office of Space Access and Transportation to OSS, a transition period would be needed before the program could be put entirely on an openly competed basis so as to avoid having to precipitously cancel projects in progress. The task group accepts that rationale but remains concerned that there seems to have been very little progress toward the transition from an approach that was largely earmarked for the Centers to one that engages the best available institutions through competition.

Technology recommendation 8 pertains to the need for incentives for technology utilization so that flight program and project managers would not view new technologies as threats to mission success. Here the task group saw good progress. In spite of some difficulties with the first missions in the queue, the New Millennium Program offers a promising opportunity to provide flight validation for new technologies. The task group supports the process of having flight project offices and the AT&MS Division jointly fund technologies as they are handed off from development to infusion into missions. Likewise, the OSS policy of not committing to a new start for a mission until specified technology readiness milestones are met is sound. Finally, the task group supports the plan to appoint an AT&MS Division "transition and infusion" manager to facilitate the process.

The final technology recommendation in *Managing the Space* Sciences addresses technology budgets and the need to have adequate resources to take technologies from the laboratory bench to flight readiness. As noted above, the creation of the New Millennium Program and the recent growth in OSS technology budgets (see Table 2.1) are very positive steps. If there is a notable weakness in the OSS technology budget, it is the very low funding level for science instrument technologies compared to budgets for spacecraft systems and information systems.

ADDRESSING CONGRESSIONAL CONCERNS

The Congress has provided explicit direction to NASA (see Appendix A) regarding competition in making ATD awards, saying that not less than 75 percent of all ATD funds should be allocated through broad announcements of opportunity. Methods cited for meeting this direction include greater use of external reviews, greater use of guidance from advisory bodies representing the scientific community, and application to management of ATD of the approach traditionally employed for management of space science research grants. NASA officials described a plan to gradually move the ATD program from its current position with less than 50 percent of the funds awarded through open competition, to a level of nearly 70 percent by fiscal year 2000 and ultimately to a steady-state level of 75 percent, the minimum level directed by Congress. The task group believes that achieving this goal will require a concerted effort by headquarters. Also, there are no compelling arguments for stopping at 75 percent, and the task group believes strongly that a fully competitive program will best serve the interests of NASA and the space sciences.

LIST OF RECOMMENDATIONS

In response to the fourth task in the charge to the task group, the task group offers the following recommendations.

Planning

Recommendation 1. NASA's advanced technology development (ATD) planning process should be formally evaluated in 12 months, after changes that are just now being completed have had time to mature. Factors to be considered in the evaluation should include (1) responsiveness to input from the outside research community and (2) the extent to which program balance is addressed regarding such dimensions as technology push versus program pull, near-term versus far-term applications, and science instruments versus spacecraft systems. The evaluation should be conducted by an independent, external body such as the NASA Advisory Council.

Recommendation 2. The planning process for cross-cutting technology should be modified so that it mirrors the process used by the Office of Space Science for space science technologies.

Key attributes are the use of technology roadmaps that are linked to enterprise science roadmaps and that are developed with the broad participation of the research community.

Implementation

Recommendation 3. NASA should establish a comprehensive Center evaluation process that includes regular, objective, external evaluations of core competencies. Those internal core competencies essential to achieving a Center's mission should be identified and appropriate recommendations made to achieve and maintain excellence. As a result of these evaluations, NASA will have to make difficult choices about limiting internal research emphasis in some areas. External organizations with world-class capabilities should be selected competitively to complement the in-house work and ensure maintenance of NASA's centers of excellence. ATD funds should not be set aside to provide support for in-house capability but should be earned by Centers through open competition with outside organizations.

Recommendation 4. With the support of external reviewers, NASA headquarters should conduct make-or-buy decisions and competitive procurements for all long-term ATD.

Recommendation 5. For near-term technology development needed to support ongoing programs already under the direction of a particular Center, that Center should conduct make-or-buy decisions. However, if the Center decides to buy, then NASA should avoid real or perceived conflicts of interest by either administering the competition and external review from headquarters or excluding from the competition all in-house organizations located at that Center. A Center decision to “make” should have headquarters concurrence.

Recommendation 6. NASA should ensure that adequate resources, especially personnel, are available for headquarters to organize, conduct, and respond to the needed number of external reviews to support competitive ATD procurements.

Infrastructure

Recommendation 7. NASA should foster increased workforce mobility among Centers and between NASA and industry, universities, and other government agencies to facilitate the transfer of information, obtain fresh points of view, and maintain the expertise of its workforce. Expanded use of Intergovernmental Personnel Act exchanges and cooperative agreements should be considered to facilitate these efforts.

Recommendation 8. NASA should take prompt action to re-staff the Office of the Chief Scientist.

Recommendation 9. Full-cost accounting is essential to effective management of ATD programs, and NASA should provide sufficient resources to complete and implement a full-cost accounting system. NASA should also determine how it will address workforce issues that may be raised when funding allocations are guided by full-cost accounting and organizational excellence, as determined through full and open competition.

Performance Measurement

Recommendation 10. NASA should identify performance measurement approaches (including independent external reviews) and metrics (including adequate investment data) needed to effectively manage its ATD programs. The findings and recommendations of external reviews of the Centers should be reported to headquarters as well as to senior Center management. Investment data should cover the current program, and these metrics should be tracked for future use.

Recommendation 11. To ensure accountability, NASA should formally respond to the recommendations contained in this task group report. Regular status reports should be made to external bodies, such as the NASA Advisory Council.

REFERENCE

National Research Council (NRC). 1995. Managing the Space Sciences. Space Studies Board and Aeronautics and Space Engineering Board. Committee on the Future of Space Science. National Academy Press, Washington, D.C.

APPENDIXES

A

FY 1998 Congressional Appropriations Report Language

SENATE

1st Session—105-53

REPORT

[To accompany S. 1034]

. . . . The Committee on Appropriations reports the bill (S. 1034) making appropriations for the Departments of Veterans Affairs and Housing and Urban Development, and for sundry independent agencies, boards, commissions, corporations, and offices for the fiscal year ending September 30, 1998, and for other purposes, reports favorably thereon and recommends that the bill do pass.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

. . . . The Committee is concerned about the absence of competition in the selection of funding recipients for the new millennium, advanced space technology, and portions of the supporting research and technology program elements. The Committee believes that these funds, whether awarded intramurally or extramurally, must be fully competed through broad announcements of opportunity with selection by external peer review panels, rather than at the discretion of agency program managers. For this reason, the Committee directs NASA to develop and submit to the Committee a plan, concurrent with the 1998 operating plan, that lays out a specific strategy to implement this competitive framework, including the allocation of fiscal year 1998 funds, so that approximately one-half of these funds are made available to extramural academic institutions or private industry, with selection by external peer review panels.

HOUSE OF REPRESENTATIVES

1st Session—105-297

CONFERENCE REPORT

[To accompany H.R. 2158]

MAKING APPROPRIATIONS FOR THE DEPARTMENTS OF VETERANS AFFAIRS AND HOUSING AND URBAN DEVELOPMENT, AND FOR SUNDRY INDEPENDENT AGENCIES, COMMISSIONS, CORPORATIONS, AND OFFICES FOR THE FISCAL YEAR ENDING SEPTEMBER 30, 1998, AND FOR OTHER PURPOSES.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

. . . . The conferees concur with the direction of the Senate to promote competition in the award of advanced technology development (ATD) funds. To achieve this end, commencing with fiscal year 1998 and continuing in each year thereafter, NASA should consolidate all space science ATD activities into an easily accessible consolidated budget line item and award not less than 75 percent of these funds through broadly distributed announcements of opportunity that solicit proposals from all categories of organizations, including educational institutions, industry, nonprofit institutions, NASA Centers, the Jet Propulsion Laboratory, and other Government agencies, and that allow partnerships among any combination of these entities, with evaluation, prioritization, and recommendations made by external peer review panels, consistent with the recommendations contained in the 1995 National Academy of Sciences report on managing the space sciences. In awarding ATD funds in this manner, the conferees wish to make clear that final selection of all proposals rests with NASA officials consistent with Office of Procurement Policy guidelines; and that setting technology requirements that are the foundation of the AO's rests with NASA program managers, consistent with guidance provided by advisory bodies of the at-large science community. In this fashion, NASA's technology investments will be managed in a manner parallel to that traditionally employed in implementing the agency's science program.

B

Request from NASA's Office of Space Science

National Aeronautics and Space Administration
Headquarters Washington, DC 20546-0001

NATIONAL ACADEMY OF SCIENCES
OFFICE OF THE PRESIDENT

reply to Attn of: S

Dr. Bruce Alberts
Chair
National Research Council 2101 Constitution Avenue, NW Washington, DC 20418

Dear Dr. Alberts:

In 1995, the Space Studies Board released a report, entitled *Managing the Space Sciences,* that analyzed several important issues in the management of NASA's space science programs. Since then, the structure and organization of the Office of Space Science (OSS) have been totally overhauled, and a number of the recommendations of the 1995 report have been implemented while others have been superseded by intervening events. As a result, I would like to request that the National Research Council carry out an updated assessment of OSS management processes in the context of the original recommendations and the new organizational environment.

The reassessment should focus particularly on structure and management of technology development. OSS has acquired management responsibility and budget for spacecraft and related technology development from the former Office of Space Access and Technology. During the past year, these technology tasks have been assimilated with other technology tasks formerly OSS funded into a restructured program that must support both generic agency technology needs and OSS-specific requirements in alignment with the new OSS strategic plan. Specific issues that should be addressed are:

- How well does the current management approach meet the objectives of those technology recommendations provided in *Managing the Space Sciences* (section 6) that remain relevant in the new organization?
- How well does OSS's new management approach for Advanced Technology Development tasks meet related congressional concerns articulated in the FY 1998 space science appropriations legislative report?

The study should take account of scientific, technological, and management considerations. The results will be most useful if they can be made available to us by November 1, 1998.

Sincerely,

Wesley T. Huntress, Jr.
Associate Administrator for Space Science

C

Statement of Task

Background Over the past several years NASA has moved toward a “smaller, faster, cheaper” approach to space science missions that is intended to deal with constrained budgets and the need to increase the number of flight opportunities by introducing more small, low-cost, rapidly developed missions into its flight mission portfolio. This shift has led to an increased reliance on development of improved technologies and a heightened need for the integration of space science and technology. Since these issues were addressed in the SSB's 1995 report *Managing the Space Sciences,* NASA has implemented a number of significant programmatic and organizational changes that call for a reassessment of the earlier recommendations and of NASA's overall approach to technology development. In addition, there have been recent congressional requests for attention to NASA's handling of technology development. In recent discussion with National Research Council staff, Office of Management and Budget (OMB) officials have identified this topic as an area of particular interest and concern to OMB in terms of the content and direction of the Office of Space Science (OSS) program.

In the “technology” section of the 1995 SSB report, specific recommendations were made in the areas of technology planning; roles and responsibilities for near-term and far-term technology development; relative roles of NASA headquarters, field centers, and extramural organizations; insularity and other “cultural” impediments at NASA field centers; open competition for technology projects; technology utilization; and technology budgets. NASA has subsequently taken a number of actions which are relevant to those recommendations and which are likely to impact aspects of technology development and utilization. Those actions include full implementation of the New Millennium series of technology demonstration spacecraft, transfer of the technology development responsibilities and budget of the former Office of Space Access and Technology to the OSS, and adoption of future-year budgets that make explicit assumptions about cost-savings derived from incorporation of new technologies.

Plan The SSB, with assistance of the ASEB, will establish a task group composed of six to eight members with expertise and/or specific knowledge regarding aspects of advanced technology development and the uses of advanced technologies in NASA science programs. Task group members will be drawn from membership of the SSB or its Committee on Space Science, from participants in the earlier (1995) SSB study, and additional experts.

The study will provide an independent technical assessment of:

1. the current OSS approach and process for technology development and how well it meets agency needs;
2. OSS's response to the intent of SSB recommendations regarding technology development outlined in Section 6 of *Managing the Space Sciences;* and

3. the extent to which the new OSS approach addresses concerns expressed by Congress with regard to advanced technology development in support of NASA's science programs.

In addition, the study will recommend changes or new approaches NASA should consider to improve the efficacy of advanced technology development.

Schedule The study is planned as a fast-track effort with approximately two three-day meetings during a six-month period. NASA officials will be invited to give detailed briefings on the approaches and processes utilized by OSS in its technology development programs and on the relation of those programs to space science. The SSB and the ASEB will collaborate in identifying candidates for task group membership and will jointly staff the study. The product of the study will be a short report.

D

Meeting Agendas

TASK GROUP ON TECHNOLOGY DEVELOPMENT IN NASA'S OFFICE OF SPACE SCIENCE

Meeting, June 29–July 1, 1998

National Research Council, Green Building Room 120

2001 Wisconsin Avenue, N.W., Washington, DC

MONDAY, JUNE 29, 1998

Closed Session

A. Organizational Affairs

8:25 a.m.	1.	Introduction and bias discussion
8:45 a.m.	2.	Chair's perspective and direction a. FACA issues: Dev Mani
9:00 a.m.	3.	Charge, issues, and scope: study approach
10:00 a.m.	*Break*	

Open Sessions

B. Recap of Future of Space Science (FOSS) study

10:15 a.m.	Are recommendations still valid? Have they been met?

C. NASA briefings, Part 1: Headquarters

10:25 a.m.	1.	The origin of the study: Earl Huckins
11:00 a.m.	2.	NASA Space Technology Issues: Sam Venneri
11:45 a.m.	*Lunch*	
12:30 p.m.	3.	Specific context and planning process: Peter Ulrich

D. NASA briefings, Part 2: client requirements

1:30 p.m.	1.	Office of Earth Science (Code Y): Ghassem Asrar
2:20 p.m.	2.	Office of Space Science (Code S): Alan Bunner, Harley Thronson, Jay Bergstralh
3:10 p.m.	*Break*	
3:25 p.m.	3.	Office of Life and Microgravity Sciences & Applications (Code U): Roger Crouch

Executive Office input

4:15 p.m.	1.	Brant Sponberg (OMB)

4:55 p.m.	**F. Discussion**
	Recap; prepare for Center presentations

TUESDAY, JUNE 30, 1998

Open Sessions

A. NASA briefings, Part 3: the Centers

8:30 a.m.	1.	Jet Propulsion Laboratory: M. Sander
9:30 a.m.	2.	Goddard Space Flight Center: M. Kicza

NASA briefings, Part 1: Headquarters (continued from Monday)

10:30 a.m.	Q&A: Wesley Huntress via teleconference
11:00 a.m.	*Break*

A. NASA briefings, Part 3: the Centers (continued)

11:15 a.m.	3.	Ames Research Center: S. Zornetzer
12:15 p.m.	*Lunch*	
1:15 a.m.	4.	Lewis Research Center: J. Barna
2:15 p.m.	5.	Langley Research Center: W. Smith
3:15 p.m.	*Break*	
3:30 p.m.	6.	Marshall/Johnson Space Flight Centers: J. Bilbro, R. Kahl

Closed Session

4:30 p.m.	**B. Discussion**
	Identify areas where more information is needed
5:30 p.m.	*Adjourn*

WEDNESDAY, JULY 1, 1998

Closed Sessions

8:00 a.m.	**A. Continued discussion of Center presentations**

9:00 a.m.	**B. Determine remainder of study; organize report; plan second meeting** Objectives; additional information needed (other agencies?); determine scope of findings and recommendations; plan table of contents; initial writing assignments; any follow-up procedures needed?
12:00 p.m.	*Adjourn*

TASK GROUP ON TECHNOLOGY DEVELOPMENT IN NASA'S OFFICE OF SPACE SCIENCE

Meeting, July 13-14, 1998

National Research Council, Green Building Room 120
2001 Wisconsin Avenue, N.W., Washington, DC

MONDAY, JULY 13, 1998

Closed Session

8:30 a.m.	Task group discussion

Open Session

9:00 a.m.	Discussion of NASA OSS technology development strategy and approach	Peter Ulrich
11:00 a.m.	Discussion with industry representatives	Frank Martin, Lockheed Martin Art Napolitano, Raytheon
12:30 p.m.	*Lunch*	
1:15 p.m.	Discussion with university representatives	Steven Kahn, Columbia University
2:15 p.m.	Continued discussion with non-NASA representatives	John Appleby, Johns Hopkins University Applied Physics Laboratory Mike Griffin Orbital Sciences Corporation
3:15 p.m.	*Break*	

Closed Session

3:30 p.m.	Task group work
5:30 p.m.	*Adjourn*

TUESDAY, JULY 14, 1998

Closed Session

8:30 a.m.	Task group work, continued
4:00 p.m.	*Adjourn*

E

Draft Technology Policy Statement from NASA's Office of Space Science

Policy # 1: Excellence above all else.

The NASA/OSS Space Technology Program is vital to the future of NASA and its Enterprises. Therefore, we can, and will accept nothing less than excellence in all program activities. These include the technology development activities, as well as the processes we use to manage the program, both in Headquarters and at the Centers. All program activities will be reviewed by experts and benchmarked against "best in class."

Excellence goes beyond just management and implementation. Excellence includes the leadership that makes NASA a technology-driven agency. Our leadership role includes ensuring the proper balance between near-term needs, and the long-reach technologies that will position and maintain NASA on the cutting edge into the next millennium. Thus, a first test of every decision will be "which choice supports and enhances excellence?"

Policy # 2: In service to the Enterprises, period.

All activities in our program must be in service of, and directly traceable to, one or more identified customers; that is, one or more Enterprises. The Centers will develop and maintain documentation that shows a one-to-one correspondence between resource allocations and specific Enterprise requirements. All technology funds will be traceable to a specific and documented requirement from one or more Enterprises.

The Enterprises need technologies with maturity levels that span from the near term (a few years, "Mission-Pull") to the far term (a few decades, "Vision-Pull"). Enterprise-driven "Vision-Pull" replaces the concept of "technology push" in assuring sufficient resources are applied to long-lead (low-TRL) technologies. Vision-pull ensures direct connection of the technology program to Enterprise needs. This connection will be at the foundation of our budget justification and advocacy.

Our charge is to work closely with the Enterprises to make them informed requirements developers. We need to help them identify high-leverage technologies and advise on the balance of low and high technology readiness levels (TRLs). For example, we must advise them of technologies (e.g., biological computers, kilometer sized sails) that could enable missions not now under study. We will also communicate the perspectives of upper management so they can respond to these desiderata.

The OSS technology program contains two components: technologies for Space Science Missions and technologies that serve multiple Enterprises known as "cross-Enterprise" technologies. Space Science technology requirements, for example, must lead to "missions which return the best possible science at the lowest possible cost." Ultimately, the Enterprises are our only customers—we will implement the technology programs they want.

Policy # 3: The NASA Centers manage the NASA Technology Programs

The responsibility for managing the technology program is delegated to the NASA field Centers. They provide technological leadership, system engineer the technology program, and assign appropriate roles within NASA, industry, academia and other Government laboratories. They assure that technological "gaps" are filled in the end-to-end mission systems picture.

The Centers are directed to develop and maintain an in-house "corporate knowledge" base that is: 1) in direct support of assigned Enterprise requirements and 2) necessary and sufficient to discharge their program management responsibilities. They must justify and maintain the critical masses in key core competencies that make them "smart buyers." They must hire and retain managers and technologists of the first rank.

Those in-house efforts justified as the minimal core to discharge management and leadership responsibilities will not be subject to competition with outside organizations. The Centers will, however, establish and implement the measures necessary (e.g., external peer reviews) to ensure excellence.

Policy # 4: Engagement of the broader community to promote excellence.

Having established the rationale for a non-competed critical mass of in-house activity (see policy # 3 above) the Centers will aggressively integrate industry, academia, and other Laboratories into the program. These entities offer the unique assets and perspectives that program excellence demands. Industry, for example, contains valuable technology developed by internal resources (IR&D and profit dollars) and by other (restricted / military) customers. Technology from restricted programs may be available to NASA even though the customers mission remains classified.

Similarly, the university community holds a vast and unique technological resource. University groups, receiving significant funding from other sources, lead in many technology areas (e.g., instrument and detector technologies). They offer world-class expertise at low cost. With faculty salaries underwritten by universities, faculty-led teams of students and post-docs can be highly cost-effective technology developers. Finally, many of these same scientists stake their professional careers on the initiation and success of NASA science missions—they are uniquely motivated.

Each Center will document and implement visible processes to maximize the opportunity for others to compete with in-house staff for technology program resources. Outreach activities will ensure the opportunities are broadly advertised, especially for small businesses. Fair evaluation criteria will ensure a "level playing field," especially with the way NASA civil salaries are included in cost-benefit assessments. The burden-of-poof for demonstrating fair and open competition lies with the centers. The Director, Advanced Technology & Mission Studies in Headquarters will approve these processes.

Policy # 5: Reviews processes to ensure excellence.

Each Center will design and maintain a set of processes that use external/peer review to assure excellence in both in-house and out-of-house work. The reviews will consider such factors as:

- Whether the work is "best-in-class"

- The contribution to specific and documented Enterprise requirements;
- Whether the work is significantly advancing the state of the art; and
- Whether the work creates a resource for the community that doesn't already exist.

The Director, Advanced Technology & Mission Studies in Headquarters will approve these processes.

If non-competitive in-house work fails to meet the highest standards of excellence, Center management will generate a plan for prompt remedy that will be approved by the Director, Advanced Technology & Mission Studies in Headquarters as a condition of continued funding.

Policy #6: Technology Transfer

The overarching goal of the OSS technology program is to enable Space Science, and other NASA missions to be implemented with higher returns and lower cost through the use of advanced technology. It is the responsibility of the Centers to ensure transfer of these technologies to the implementing organizations (e.g., the industrial contractors and academia). There is little value in developing technology in-house if the systems and instrument development are out-of house, unless the technologies are efficiently transferred. Each technology development effort will have a plan for transferring the technology to the user at the appropriate time.

Policy # 7: Proprietary Data Protection and Intellectual Property Protection

As we cooperate more closely with others, we must ensure that sensitive data are protected. Whenever NASA solicits information that is competition sensitive, proprietary, or classified, it is incumbent on us all to implement the protective processes defined in NASA regulations. These may include verification of training for NASA employees, conflict of interest management, facility security and so on.

Whenever others provide sensitive data to NASA, it is incumbent on the provider to be clear with NASA about the nature of the sensitivity and to ascertain which processes NASA will use to protect the data. They are responsible for ascertaining the adequacy of these approaches before providing such data to the Agency. In the case of intellectual property, although ideas cannot generally be copyrighted, information providers could request credit or attribution.

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Biographical Information

Daniel J. Fink, ***Chair***
President
D.J. Fink Associates, Inc.
Potomac, MD

Mr. Fink received his B.S. and M.S. in aeronautical engineering from the Massachusetts Institute of Technology. He was deputy director of defense research and engineering for strategic and space systems and assistant director for defensive systems at the U.S. Department of Defense (DOD) from 1963 to 1967. Mr. Fink joined General Electric in 1967 as vice president and general manager of the Space Division (1967-1977), vice president and group executive of the Aerospace Group (1977-1979), and finally as senior vice president of corporate planning and development (1979-1982). He formed his own consulting firm in 1982. Mr. Fink's honors include DOD's Distinguished Public Service Medal (1967), election to the National Academy of Engineering (1974), the National Aeronautics Association's Collier Trophy (1976), NASA's Distinguished Public Service Medal (1986), NASA's Medal for Outstanding Leadership (1988), and American Institute of Aeronautics and Astronautics von Karman Lecturer (1980).

Robert S. Cooper
President
Atlantic Aerospace Electronic Corporation
Greenbelt, MD

Dr. Cooper received his Ph.D. in electrical engineering from the Massachusetts Institute of Technology (MIT) and then joined the MIT staff as assistant professor of electrical engineering and staff member of the Research Laboratory for Electronics (1963-1968) and staff member, group leader, and division director at MIT's Lincoln Laboratory (1968-1972). He was assistant director of defense research engineering at the U.S. Department of Defense from 1972 to 1975. From 1975 to 1979, Dr. Cooper was director of NASA Goddard Space Flight Center. He was vice president for engineering at Satellite Business Systems from 1979 to 1981. Dr. Cooper was director of the Defense Advanced Research Projects Agency from 1981 to 1985 and assistant secretary of defense for research and technology from 1984 to 1985. Dr. Cooper is currently the president of Atlantic Aerospace Electronics Corporation.

Anthony W. England
Electrical Engineering and Computer Science
Associate Dean, Rackham School of Graduate Studies
University of Michigan
Ann Arbor, MI

Dr. England received his Ph.D. in geophysics from the Massachusetts Institute of Technology. He served as scientist-astronaut for NASA's Manned Spacecraft Center from 1967 to 1972 and again as a senior scientist-astronaut from 1979 to 1988. He was mission scientist for Apollo 13 and 16, and he flew as a mission specialist on space shuttle Challenger's Spacelab 2 in 1985. He served as program scientist for the space station during 1986 and 1987. Between 1972 and 1979, he was a research geophysicist and the deputy chief of the Office of Geochemistry and Geophysics with the U.S. Geological Survey. Dr. England has been at the University of Michigan since 1988, where he is professor of electrical engineering and computer science; professor of atmospheric, oceanic, and space science; and associate dean of the H.H. Rackham School of Graduate Studies. He has received several honors from NASA: the Outstanding Science Achievement Medal (1973), the Space Flight Medal (1985), and the Exceptional Achievement Medal (1988). Dr. England has also received the U.S. Antarctic Medal (1979) and the Flight Achievement Award from the American Institute of Aeronautics and Astronautics.

Donald C. Fraser
Director, Center for Photonics Research
Boston University
Boston, MA

Dr. Fraser received his B.S. and M.S. in aeronautics and astronautics and his Sc.D. in instrumentation from the Massachusetts Institute of Technology (MIT). Dr. Fraser joined MIT's Instrumentation Laboratory (which became the Charles Stark Draper Laboratory in 1973) as a member of the technical staff (1962-1969), advanced to director of the Control and Flight Dynamics Division (1969-1981) and vice president of technical operations (1981-1988), and became executive vice president of the Laboratory in 1988. From 1990 to 1991, Dr. Fraser was deputy director of Operational Test and Evaluation for Command, Control, Communications, and Intelligence at the U.S. Department of Defense (DOD). He was the appointed principal deputy under secretary of defense (acquisition) from 1991 to 1993. Since 1993, Dr. Fraser has been the director of Boston University's Center for Photonics Research and a professor of engineering and physics. Dr. Fraser's honors include DOD's Defense Distinguished Service Medal and election to the National Academy of Engineering (1990).

Aram M. Mika
Vice President
Business Development, Advanced Programs and Technology
Lockheed Martin Missiles and Space
Sunnyvale, CA

Mr. Mika received his M.S. in electrical engineering from Stanford University. His responsibilities as vice president of business development for advanced programs and technology at Lockheed Martin Missiles and Space encompass strategy formulation, business acquisition, and advanced programs for the Missiles and Space business portfolio, including remote sensing, telecommunications, defensive systems, and strategic missile programs. These responsibilities also include technology development for all of these product lines at the Lockheed Martin Advanced Technology Center. Prior to his career at Lockheed Martin, he was vice president of Hughes Aircraft Company and president of its Space Electro-Optics Business Unit, where he directed the design, development, and production of spaceborne electro-optical sensors and associated signal/data processing systems for civil space and U.S. Department of Defense applications. Mr. Mika served as vice president of Hughes's Santa Barbara Research Center and manager of its Systems Division (now Santa Barbara Remote Sensing), where he led the development of civil-space instruments for NASA, NOAA, and international customers.

Irwin I. Shapiro
Director
Harvard-Smithsonian Center for Astrophysics
Cambridge, MA

Dr. Shapiro received his Ph.D. in physics from Harvard University. His current research interests include precollege science education and applications of radio and radar techniques to astrophysics, geophysics, and tests of theories of gravitation. Dr. Shapiro was a staff member at the Massachusetts Institute of Technology's (MIT's) Lincoln Laboratory (1954-1970) and a professor of geophysics and physics at MIT (1967-1985). He has been the director of the Harvard-Smithsonian Center for Astrophysics since 1983, as well as a University professor at Harvard (1997-present) and a senior scientist of the Smithsonian Institution (1982-present). Dr. Shapiro has won various awards and prizes from professional societies in the United States and abroad. He is a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences. He is a fellow of the American Physical Society, the American Geophysical Union, and the American Association for the Advancement of Science.

Oswald Siegmund
Associate Director
Space Sciences Laboratory
University of California
Berkeley, CA

Dr. Siegmund is an adjunct professor at the University of California at Berkeley's Astronomy Department. He is also an associate director of Berkeley's Space Sciences Laboratory and the experimental astrophysics group leader. Dr. Siegmund has participated in the development and application of a number of rocket, shuttle, and satellite instruments, and technology programs, including instruments for the Solar and Heliospheric Observatory (SOHO), the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission, the International Solar-Terrestrial Physics Program (ISTP) ultraviolet imager, and others. His instrumentation systems experience encompasses scintillators, phosphors, proportional counters, image intensifiers, photocathodes, microchannel plates, electronic readout systems, charge and time encoding electronics, and supporting analysis tools. His honors include the H.S.W. Massey Research

Prize, University College London (1979-1980) and NASA group and individual awards (1994, 1995, 1996, 1997, and 1998). Dr. Siegmund received his Ph.D. in physics and astronomy from University College London.