(PB92-181692) INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM, 1991 (NASA) 137 p

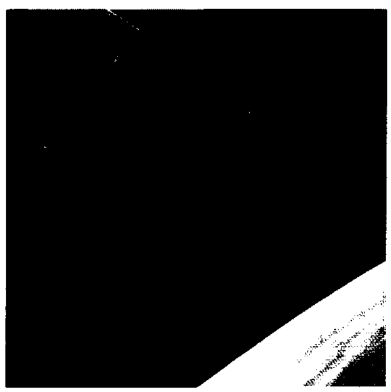
N92-31634

Unclas

NASA TM-107988

H1/12 0112250

1991
INTEGRATED TECHNOLOGY PLAN
FOR THE CIVIL SPACE PROGRAM



OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

This report has been prepared as an internal OAST document, and it will serve as the basis for OAST program planning in the future.

1991
Integrated Technology Plan
for the Civil Space Program

Office of Aeronautics and Space Technology
National Aeronautics and Space Administration
Washington, D.C. 20546

PREFACE

During 1991, the National Aeronautics and Space Administration (NASA) tasked the Office of Aeronautics and Space Technology (OAST) to prepare an Integrated Technology Plan for the Civil Space Program. This action came in response to the recommendations of the Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine. The purpose of the Integrated Technology Plan (ITP) is to serve as a strategic plan for the OAST space research and technology (R&T) program, and as a strategic planning framework for other NASA and national participants in advocating and conducting technology developments that support future U.S. civil space missions.

OAST's ITP planning effort was comprised of the following six steps:

(1) establish an overarching strategy for civil space technology development and transfer
(2) develop a program structure and a set of decision rules
(3) solicit civil space mission strategic plans, technology needs and priorities from potential users
(4) develop a strategic plan, including integrated technology investment priorities
(5) coordinate OAST space R&T with other NASA and national efforts
(6) demonstrate that the OAST Space R&T Program can be tailored to fit within annual budgets.

The product of this activity is an integrated technology development strategy that meets both NASA and national civil space mission needs, assures technological consistency in long range R&T and mission planning, and allows for timely and effective adaptation to a changing external environment.

The ITP begins with a discussion of the national policy and NASA organization which establishes the overall framework for civil space R&T planning. The second chapter provides a top-level review of the potential users of civil space R&T, their strategic mission plans, and the technologies they have identified as needed to achieve those plans. Chapter 3 sketches the overall methodology used to develop a civil space technology strategy and describes the technical details of the 1991 strategic plan, ending with a review of civil space R&T priorities. The fourth chapter describes how the strategic plan is annually translated into the OAST Space R&T Program, with a summary of the fiscal year 1992 program. The ITP concludes with a discussion of requirements for technology development coordination and strategies for facilitating the transfer of civil space technology to the private sector. Several appendices also are attached that provide further information regarding budget implications of the strategic plan, organizational roles, and other topics.

The ITP will be revised annually to reflect changes in mission planning, approval of new focused and research base efforts, and progress in ongoing technology development efforts. Moreover, both the ITP and derived OAST space technology development planning and implementation will be subjected to annual external and internal review to ensure continuing quality and relevance.

During recent years, industry, academia and government groups have examined the U.S. civil space effort from a wide variety of perspectives. From each of the examinations has come one resounding, primary message: advances in space technology are critical to ensure that our future civil space goals can be achieved, while reducing risks and costs to a minimum. In addition, timely development and transfer of selected new technologies have been identified by both government and industry leaders as a vital ingredient in the continuing economic competitiveness of the Nation.

NASA's Integrated Technology Plan will help enable the United States to achieve its civil space goals, as well as support U.S. technological competitiveness, through the establishment of a clear and coherent strategy for civil space research and technology development for the coming decades.

Richard H. Petersen
Associate Administrator for Aeronautics and Space Technology

Editorial Note

As the 1991 edition of the ITP was being finalized, a number of major changes were implemented within NASA. Two new Program Offices were created: the Office of Space Systems Development and the Office of Exploration. In addition, the details of mission planning and technology needs of the Office of Space Science and Applications (OSSA) continued to be refined. A limited number of adjustments have been made in the 1991 ITP to reflect these changes; general updates will be incorporated in the 1992 edition of the Plan.

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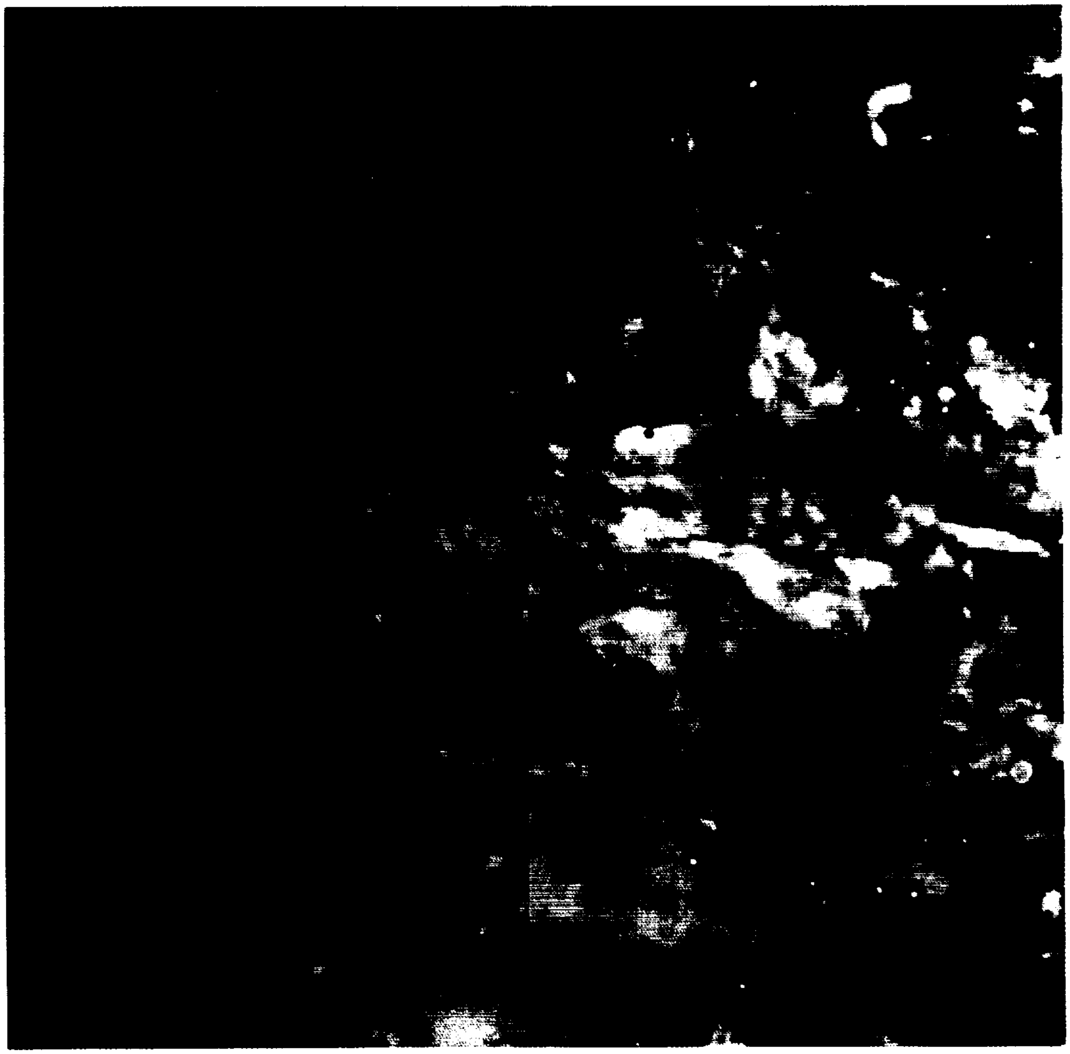

NASA's current space science mission are enabling enormous strides in our understanding of the universe. For example, this photograph depicts the "Window-Curtain" structure seen by the Hubble Space Telescope in Orion's Great Nebula. Future advances in space science will depend increasingly on new space technologies, such as sensors, telescope optical systems and long-lived coolers, and on improvements in science data management and analysis tools. In addition, the scientific value of future robotic exploration missions will be greatly enhanced by in situ science technologies. The ITP Space Science Technology Thrust provides a technical strategy for achieving these objectives.

Chapter 1
Introduction

During recent years, diverse groups have examined the U.S. civil space program and have consistently concluded that advances in space technology are critical to our future civil space goals. The space policy of the United States embodies this conclusion in a series of specific policy statements and directives regarding space technology. In addition, timely development and transfer of new technologies have been identified by both government and industry leaders as necessary to U.S. economic competitiveness. This chapter summarizes key aspects of national policy as they relate to civil space technology development,and summarizes how they have been incorporated into the ITP. It also provides a selection of national level assessments, and describes the way in which the ITP will serve as a strategic framework to respond to many of these recommendations. Finally, strategic plans for civil space technology development and transfer must be formulated and applied within NASA. The chapter concludes with a brief overview of the OAST organization, its space technology mission and principles.

National Policy

National policy provides the framework within which strategic planning for civil space research and technology (R&T) must be developed. Because of this, the ITP responds to several different aspects of national policy, including: the National Aeronautics and Space Act, and the Bush Administration's National Space Policy (and related directives); and U.S. Technology Policy (regarding technology transfer).

National Aeronautics and Space Act

Through the National Aeronautics and Space Act passed in 1958, the United States government assigned responsibility for U.S. civilian space activities to NASA. With respect to space R&T, the 1958 Space Act directs that the Nation's civil space activities be conducted to contribute materially to "the preservation of the of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere." The Space Act, as amended in 1969, further directs NASA to ensure "the preservation of the United States preeminent position in aeronautics and space through research and technology development related to associated manufacturing processes." Thus, in addition to addressing civil space missions, the Space Act also directs NASA to conduct necessary research and technology development to assure continuing U.S. civil space leadership.

National Space Policy

On November 2, 1989, President Bush issued a U.S. National Space Policy which provides a broad policy framework for U.S. space activities. This policy, and subsequent refinements through specific policy directives, includes several statements that directly pertain to planning for civil space R&T. These include guidance on: (1) specific national space technology objectives; (2) determination of appropriate governmental roles in space R&T; and (3) enhancing the benefit of space technology investments to the Nation.

Specific Space Technology Objectives

National policy has included the identification of a variety of specific technology objectives. For example, Earth remote sensing is identified in the 1989 National Space Policy as important to diverse U.S. space goals. To help meet those goals, the policy directs that the United States will "continue government research and development for future advanced remote sensing technologies or systems." In addition, because "communications advancements are critical to all United States space sectors," the 1989 Policy directed that the U.S. government will "continue research and development efforts for future advanced space communications technologies." Finally, the same policy directed the U.S. government to "continue research and development on component technologies in support of future transportation systems."

The Bush Administration released the National Space Launch Strategy, in 1991, which further elaborated the policy. The strategy identified "sustaining a vigorous space launch technology program to provide cost effective improvements in launch systems, and to support development of advanced launch capabilities, complementary to the new launch system" as a key element of the National Space Launch Strategy. The 1991 Strategy included the following two directives:

(1) In addition to conducting the focused development program for a new launch system, appropriate U.S. government agencies will continue to conduct broadly based research and focused technology programs to support long term improvements in national space launch capabilities. This technology effort shall address launch system components (e.g., engines, materials, structures, avionics); upper stages; improved launch processing concepts; advanced launch system concepts (e.g., single-stage-to-orbit concepts including the National Aerospace Plane); and experimental flight vehicle programs.

(2) The Department of Defense (DOD), the Department of Energy (DOE), and NASA will coordinate space launch technology efforts and, by December 1, 1991, jointly prepare a 10-year space launch technology plan.

On February 21, 1990, the U.S. National Space Council issued a further explication of national policy, directing that: (1) the Space Exploration Initiative (SEI) will include both Lunar and Mars program elements; (2) the early program will focus on technology development with a search for new/innovative approaches and technology; (3) the program will include investment in high leverage innovative technologies with potential to make a major impact on cost, schedule, and/or performance; (4) the program will take at least several years defining two or more significantly different human space exploration reference architectures, while developing and demonstrating technology broad enough to support all; and (5) by spurring research and development in high technology fields, the space program will help promote American economic leadership. The SEI policy directive stated that "the program will require the efforts of several agencies." However, "NASA will be the principal implementing agency." At the same time, "the Department of Defense and the Department of Energy will also have major roles in the conduct of technology development and concept definition."

Governmental Roles

As directed in the portion of the National Space Policy concerning the civil space sector, NASA has the lead role, in conjunction with other agencies, for advancing space science, exploration and appropriate applications through the conduct of activities for research, technology, development, and related operations. As noted previously, DOE and DOD will have significant roles in the implementation of SEI technology development with NASA as the principal implementing agency. Similarly, in the area of space launch systems, NASA, DOD and DOE have been directed to prepare jointly a strategy for advanced technology development.

Enhancing the Benefits: Commercial Space Policy

An investment in space technology advancement will not only benefit future U.S. government civil space missions, but also the U.S. aerospace private sector as a whole. In addition to national policies that directly address government civil space objectives, two other U.S. policy directives provide guidance to promote the transfer of advanced space technology: the U.S. Technology Policy and the U.S. Commercial Space Policy.

On February 12, 1991, the Bush Administration released a set of U.S. Commercial Space Policy Guidelines that were directed at expanding private sector investment in space. The guidelines suggest that "in an increasingly competitive international environment, the U.S. government encourages the commercial use and exploitation of space technologies and systems for national economic benefit." Toward that end, the guidelines identify five market areas: (1) satellite communications; (2) remote sensing; (3) materials processing; (4) launch and vehicle services; and (5) commercial infrastructure. To support these areas, the guidelines direct that "U.S. government agencies shall promote the transfer of U.S. government-developed technology to the private sector." The directive includes the direct transfer of technology to the U.S. commercial space sector; cooperative research and development activities (where appropriate); and, limiting U.S. rights to technology generated in the performance of government contracts.

The ITP provides an investment strategy to address each of the specific policy-driven technology objectives, including technology to support Earth observing, communications, transportation, and SEI. (For example, the 10-year space launch technology plan currently in preparation incorporates the planning for transportation technologies embodied in the ITP.) In addition, the ITP has been designed to serve a strategic framework to aid in the coordination of technology development by a wide variety of institutions, including other government agencies, national laboratories, universities, and private sector organizations. Thus, the ITP embodies the national policy to implement civil space technology as a partnership between several agencies, with NASA assuming the lead role in that partnership.

U.S. Technology Policy

The U.S. Space Policy stated that one of the goals of the U.S. space activities is "to obtain scientific, technological and economic benefits for the general population and to improve the quality of life on Earth through space-related activities." In addition, the policy promulgated the principle that the "United States shall encourage and not preclude the commercial use and exploitation of space technology and systems for national economic benefit."

The Office of Science and Technology Policy (OSTP) of the Executive Office of the President issued the first U.S. Technology Policy on September 26, 1990. It calls for integration of the various components of technology-related national issues, and represents a key framework within which the ITP was developed. The U.S. Technology Policy defines the role of the Federal government in this arena as including: "increased ... investment in support of basic research;" and, "participation with the private sector in pre-competitive research on generic, enabling technologies that have the potential to contribute to a broad range of government and commercial applications." With respect to technology transfer, the policy directs the U.S. government to "improve the transfer of federal laboratories R&T results to the private sector," including "greater consideration to potential commercial applications in the planning and the conduct of R&T." To achieve successful technology transfer, the policy directs that closer working relationships be formed among government laboratories, industry, and universities, including increased industry-government-university collaboration and personnel exchanges to facilitate the conversion of government research into U.S. industry products.

Two of the civil space objectives of national space policy are: to "develop space technology for civil space applications and, wherever appropriate, make such technology available to the commercial sector;" and "to preserve the United States preeminence in critical aspects of space science, applications, technology, and manned space flight." The ITP provides a strategic plan to accomplish these objectives. As part of the continuing development of the ITP, explicit strategies and plans will be defined to facilitate the transfer of NASA space research and technology results to government flight programs, to the aerospace industry (including the private sector), and to the broader economy.

National Technology Assessments[1]

During the past several years, a number of national level groups evaluated the status of U.S. aerospace technology development, for the space program in particular, and for the Nation in general. The groups included those of the government, government advisory groups and independent review by the private sector. Their assessments, including both general and space-specific reviews, represent a part of the national context within which the ITP has been defined and will be implemented.

General Reviews and Recommendations

Critical Technologies Report

Under the auspices of the White House OSTP, the National Critical Technologies Panel released its first biennial report on March 22, 1991.[2] Drawing upon the expertise and interests of a broad array of U.S. government agencies, including the DOD, the Department of Commerce (DOC) and NASA itself, the OSTP report identified twenty-two technologies as critical to national economic prosperity and to national security. (Appendix D contains a complete listing of the twenty-two technologies.) One of the central results of the OSTP study was the conclusion that the U.S. needs to enhance efforts to identify and implement technology development programs. As stated in the report:

> The timely development and deployment of technologies is essential to satisfy such national needs as defense, economic competitiveness, public health, and energy independence. Identification of technologies for concentration of effort becomes, therefore, a matter of considerable importance.

Although motivated by future U.S. civil space program planning, the technology advancements proposed in the ITP will represent a central part of an overall strategy to accomplish the "timely development and deployment" of many technologies that are critical to continuing U.S. competitiveness.

Federally-Funded Research: Decisions for a Decade

The Office of Technology Assessment (OTA) is a nonpartisan Congressional agency providing supporting analyses on major public policy issues related to science and technology. Responding to requests from Congressional committees, OTA's relatively small staff prepares assessments by drawing extensively on the technical expertise of industry, university, research organizations and public interest groups, as well as the various departments and agencies of the Executive Branch. OTA does not itself formulate policy. However, the Office does analyze and evaluate complex policy issues related to space science, exploration and technology. This includes identification of alternative policy options. For example, recent assessments have addressed topics such as: space stations; advanced space transportation technologies; strategies for SEI; and technology transfer.

The OTA has conducted numerous studies during recent years addressing the issues associated with funding and the impacts of new technologies on U.S. society. One recent report identified four "pressing challenges" for U.S. research in the 1990's: (1) setting priorities in funding research; (2) understanding trends in research expenditures; (3) preparing human resources for the future research workforce; and (4) supplying appropriate data for ongoing research decision makers.[3]

Two of those four challenges mirror the primary management objectives of the ITP: determination of the technologies needed for the civil space program; the relative priorities of investments in those technologies for the decade of the 1990's; and communication of those results to the U.S. research and technology community.

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[1] Detailed assessments of the technology areas needed for the civil space program, compared against the assessments of other groups, such as the OSTP, are provided in Appendix D.

[2] White House, OSTP, Report of the National Critical Technologies Panel, PB91-156869 (Washington, D.C.: U.S. Government Printing Office, March 1991).

[3] U.S. Congress, OTA, Federally Funded Research: Decisions for A Decade, OTA-SET-490 (Washington, D.C.: U.S. Government Printing Office, May 1991).

Other U.S. Government Assessments

DOD formulates an annual planning document which delineates the status of selected technologies that are critical to the successful implementation of their objectives.[4] The document provides a summary assessment of the value of a wide variety of technologies to U.S. national security. Similarly, the DOC has a particular interest in the health and progress of the U.S. private sector. In keeping with that responsibility, DOC issued in 1990 a survey of the technical and economic opportunities inherent in twelve "emerging" technologies.[5] This list provides a preliminary score-card of the potential value to U.S. commerce of various R&T investments. (Appendix D includes the complete DOD and DOC technology listings.)

In the majority of cases, the ITP provides a roadmap for development of technologies that are included on the DOC emerging technologies list. Considerable commonality also exists at a high-level with the technologies identified by the DOD as critical. A careful coordination of NASA R&T investments and DOD planning will be an essential part of the annual development of the ITP.

Technology Priorities for America's Future

The U.S. Council on Competitiveness, founded in 1986, is a nonprofit, nonpartisan organization of chief executives from business, higher education and organized labor — the goal of which is to improve the ability of American companies and workers to compete more effectively in world markets. Under the auspices of the Council, an in-depth, two year study of U.S. national technology priorities was recently conducted. The key recommendation from that study's report is that:

> In order to create quality jobs, generate strong economic growth and safeguard national security, the U.S. government and private sector should work together to develop coherent policies to ensure U.S. leadership in the development, use and commercialization of technology.[6]

As was the case with the critical technologies identified by OSTP and the "emerging" technologies identified by the DOC, the ITP addresses many of the technologies discussed by the Council on Competitiveness. Appendix D provides a complete listing of the technologies found to be most important to competitiveness by the Council, and a comparison of those technologies to those of the ITP.

Technology and Economic Performance

As a final example, a task force sponsored by the Carnegie Commission (created in 1988 by the Carnegie Corporation of New York for the purpose of advising the U.S. government regarding advances in science and technology) released a report in 1991 that assesses the linkages between technology development and economic performance, and relates those issues to potential activities within the Executive Branch.[7] As noted in the report:

> The only permanent source of improved economic performance is a sustained growth in productivity, and advances in the development and use of technology and its underlying science have been a major source of such growth. That is the fundamental connection between science, technology, and economic performance.

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[4] U.S. Department of Defense, DOD Critical Technologies Plan, (Washington, D.C., 1991).

[5] U.S. Department of Commerce, Technology Administration, Emerging Technologies —A Survey of Technical and Economic Opportunities, (Washington, D.C.: U.S. Government Printing Office, Spring 1990).

[6] Council on Competitiveness, Gaining New Ground: Technology Priorities for America's Future, (Washington, D.C., 1991).

[7] Carnegie Commission on Science, Technology, and Government,Task Force on Science, Technology, and Economic Performance, Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base, (New York, New York, September 1991).

Although the task force states that "industry has the primary responsibility" for "technology innovation, development, commercialization, and distribution," it asserts:

> Government policies and programs, however, play a crucial role in promoting that process and require a coherent decision-making structure at the highest levels of government.

One conclusion reached by the task force is that several new mechanisms are needed, including: both "a structure for formulating, reviewing, and evaluating federal programs and initiatives for technology, and for oversight and review of key programs" and also "effective execution, management and coordination of key programs by the appropriate departments or agencies."

While fulfilling its primary responsibility to meet the technology needs of the civil space program as identified by NASA, other government, and industry mission planners, the U.S. investment in advanced technology for space applications must also provide value to the broader U.S. economy. Thus, the ITP has been developed in light of the technological recommendations of various national groups, including those discussed in the preceding paragraphs.

SPACE-RELATED REVIEWS AND RECOMMENDATIONS

REPORT OF THE ADVISORY COMMITTEE ON THE FUTURE OF THE U.S. SPACE PROGRAM

In December, 1990, the Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, issued its final report.[8] With respect to advanced, generic space technology for the civil space program, the Committee requested in Recommendation 8 of their report:

> That NASA, in concert with the Office of Management and Budget and appropriate Congressional committees, establish an augmented and reasonably stable share of NASA's total budget that is allocated to advanced technology development. A two- to three- fold enhancement of the current modest budget seems not unreasonable.
>
> In addition, we recommend that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from Headquarters, to assist in the allocation of technology funds.

In addition, with regard to SEI, the Augustine Committee stated in Recommendation 7 of their report:

> That technology be pursued which will enable a permanent, possibly man-tended Outpost to be established on the Moon for the purposes of exploration and for the development of the experience base required for the eventual human exploration of Mars.
>
> That NASA should initiate studies of robotic precursor missions and Lunar outposts.

Recommendations 7 and 8 embody and crystallize similar recommendations from many previous reports on the civil space program (e.g., the 1986 National Commission on Space and the 1987 National Research Council Report on space technology to meet future needs). These reports represent some of the foundations of the ITP.

[8] Advisory Committee on the Future of the U.S. Space Program, Report of the Advisory Committee on the Future of the U.S. Space Program, (Washington, D.C.: U.S. Government Printing Office, December 1990).

America at the Threshold

As a part of President Bush's SEI, a team known as the "Synthesis Group" was formed in 1990 to review and evaluate SEI options for the Nation. The 1991 report from that group documented a series of alternative mission architectures, made several programmatic recommendations regarding SEI, and identified specific technology areas that were determined to be of high value for the successful implementation of SEI.[9] The technical details of the recommendations of the SEI Synthesis Group Report are discussed in Chapter 2.

Reports of the Aerospace Industries Association

Numerous reports have been issued during recent years from the Aerospace Industries Association (AIA), the principal focus of which is to develop national strategies to achieve continuing preeminence for the U.S. aerospace industry. As noted in a 1991 report prepared by the AIA:[10]

> A strong case is building for a strategy of nurturing generic, enabling technologies — technologies that encompass both civil and military applications and are vital to worldwide competitiveness. The case for a national technology strategy is strengthened by the increasing speed with which technology is being developed and transferred globally.

To support that view, the AIA and the AIA National Center for Advanced Technology (NCAT) have undertaken a series of industry-sponsored strategic planning efforts for advanced aerospace technology during recent years. The results of those efforts include the definition of both an overarching strategy for the development of advanced aerospace technologies, as well as detailed strategies for eleven specific "key" technology areas. (Appendix D provides a listing of these technologies.)

The assessments reviewed in the preceding paragraphs are by no means binding. However, in order to be fully successful, the ITP must constitute an overarching framework for civil space technology — and one for which there is a strong consensus within the aerospace and technology community that the ITP is in fact essentially *correct*. Thus, although the content of the ITP has been explicitly defined to meet the future needs of the civil space program, the ITP also attempts to respond to many of the recommendations of the several space-related national level studies cited above. In particular, the ITP provides for civil space R&T both a clear and coherent framework for decision-making, as well as a strategic plan for advanced technology development for the 1990's. Creating effective mechanisms for successful coordination of R&T efforts and technology transfer is equally important; this topic is discussed in Chapter 5.

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[9] Space Exploration Initiative Synthesis Group, America at the Threshold—Report of the Synthesis Group on America's Space Exploration Initiative, (Washington, D.C.: U.S. Government Printing Office, May 1991).

[10] Aerospace Industries Association, The U.S. Aerospace Industry in the 1990's — A Global Perspective, (Washington, D.C., September 1991).

The NASA Context

Just as the ITP was developed to operate within the framework of national policy and provide a response to various national-level recommendations, planning for NASA's space R&T efforts must translate this strategic plan for civil space technology development into a NASA organizational context. Technology development is a shared responsibility among many of NASA's offices. Research and development, including the development of new flight systems, constitute a major share of NASA's total annual budget.[11] For most of the offices, the development of technology is largely a means by which to achieve some mission objective, such as the launch of a scientific probe or a space station, and not an end in and of itself.[12] However, the development of new technologies is the primary purpose of OAST.

OAST's mission includes the following two goals: (1) to conduct research to provide fundamental understanding, develop advanced technology and promote technology transfer to assure U.S. preeminence in aeronautics and to enhance and/or enable future civil space missions; and (2) to provide unique facilities and technical expertise to support national aerospace needs.

OAST includes both NASA Headquarters operations as well as programmatic and institutional management of the Ames Research Center (ARC), the Langley Research Center (LaRC), and the Lewis Research Center (LeRC). In addition, a considerable portion of OAST's Space R&T Program is conducted through the flight and science program field centers of NASA. Within OAST, the Space Technology Directorate is responsible for the planning and implementation of the NASA Space Research and Technology Program.

OAST Space R&T Mission

The Space Technology Directorate's mission is "to assure that OAST shall provide technology for future civil space missions and provide a base of research and technology capabilities to serve all national space goals." Accomplishing this mission entails several objectives, including:

- Identify, develop, validate and transfer technology to:
  - Increase mission safety and reliability
  - Reduce flight program development and operations costs
  - Enhance mission performance
  - Enable new missions
- Provide the capability to:
  - Advance technology in critical disciplines
  - Respond to unanticipated mission needs.

OAST Space R&T Program Principles

In order to accomplish this mission, the OAST Space Technology Directorate has defined the following principles for the NASA Space Research and Technology (R&T) Program:

- Stress technical excellence and quality in all activities and ensure the availability of appropriate support and facilities
- Be responsive to customers and assure technology transfer and utilization
- Sustain commitment to ongoing R&T programs
- Maintain the underlying technological strengths which are the well spring of NASA's technical capability

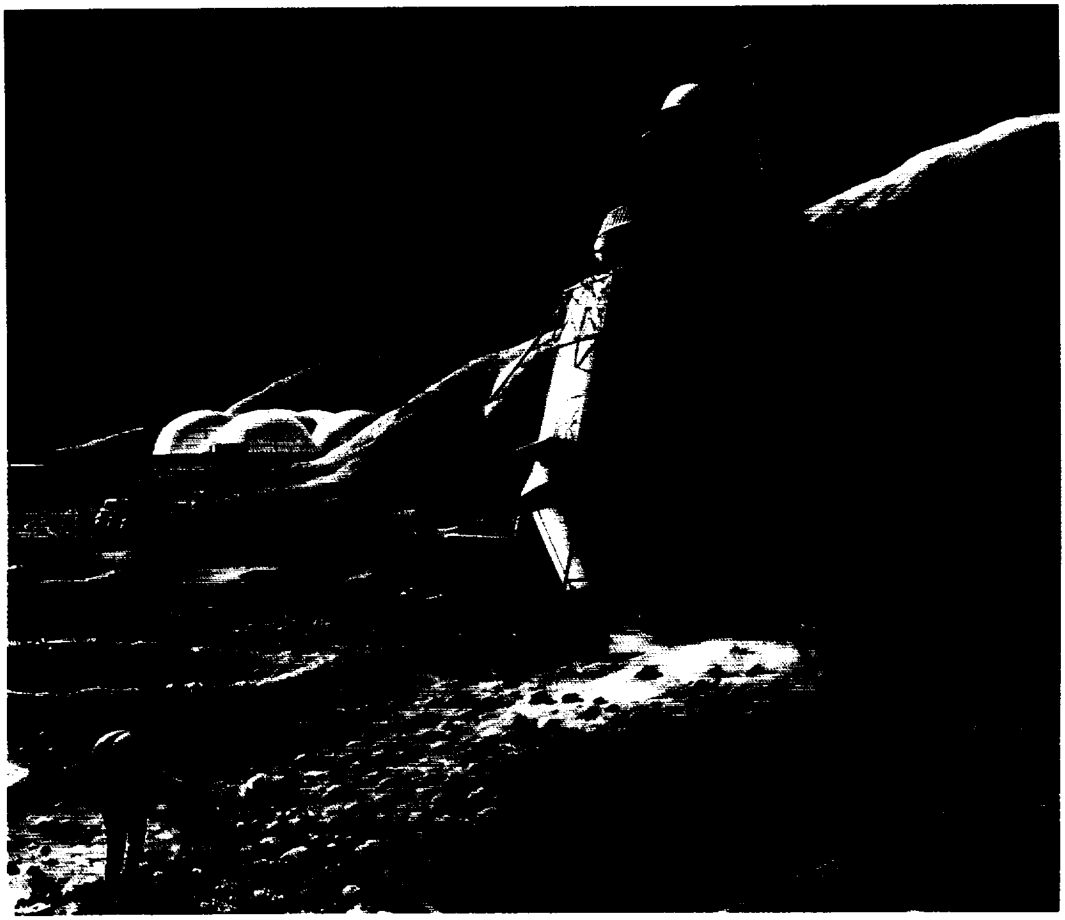
[11] Some of the detailed technology development responsibilities of other parts of NASA, including both the several Flight Program Offices and the Office of Commercial Programs, is discussed in Chapter 5.

[12] In addition, the Office of Commercial Programs (OCP) within NASA has responsibility to promote the development of the commercial space sector and to support technology transfer. The relationship between OAST and OCP is described in more detail in Chapter 5.

- Assure the introduction of new technology activities on a regular basis
- Maintain balance among NASA customers, critical disciplines, and near and far term goals
- Support science and engineering education in space R&T
- Make effective use of technologies and capabilities of other government agencies, industry, academia and international partners
- Enhance the nation's international competitiveness.

Many of these principles could be contradictory if taken to their extremes. Nevertheless, the ITP attempts to implement the goals they reflect in a balanced way. This is true for the ITP process, the ITP strategic plan and priorities, and especially for the annual definition of the OAST Space R&T Program. That implementation is largely accomplished by incorporating these principals into a series of decision rules for both base and focused R&T efforts. These rules, and the resulting strategic planning prioritization, are discussed in Chapter 3.

The next chapter reviews the potential users for civil space R&T, including NASA, other U.S. government agencies and the commercial space sector. It also provides a summary of their strategic plans for future civil mission activities and the technologies and priorities that are needed to effectively accomplish those missions.



The moon represents a potential testbed for technologies and systems that could be used for a human mission to Mars. This artist's concept depicts one potential scenario, in which a Mars mission demonstration is implemented near an established Lunar outpost. The ITP's Planetary Surface Technology Thrust provides a plan for achieving a strategic advance in surface system capabilities, such as 100-kilowatt levels of local electrical power or in situ resource utilization, and in human support technologies, such as water reclamation, radiation protection, and extravehicular activity systems.

CHAPTER 2
U.S. CIVIL SPACE TECHNOLOGY NEEDS

The U.S. National Space Council has defined a National Space Strategy[1] with five elements: provide ***Transport*** to ensure U.S. access to space; make a renewed commitment to ***Exploration*** and scientific discovery; use space to find ***Solutions*** to problems here on Earth; exploit the ***Opportunity*** of space for commercial endeavors; and ensure ***Freedom*** of access to space for ourselves and all nations. Within those broad strategic elements, the "operational mission" objectives of the United States can be grouped into four categories: (a) space science, including the Earth Observing System (EOS); (b) space exploration, including both Space Station *Freedom* (SSF) and the Space Exploration Initiative (SEI); (c) transportation, including the Space Shuttle and expendable launch vehicles (ELVs); and (d) space utilization, including support for commercial space industries.

Four program offices within NASA[2] have responsibility for planning and implementing the majority of the U.S. government's civil space missions: the Office of Space Science and Applications (OSSA); the Office of Exploration (OEXP); the Office of Space Flight (OSF); and the Office of Space Communications (OSC). Each office has both strategic program plans and specific concepts for missions during the coming decades. As part of their participation in the ITP effort, each office has identified the priority technologies needed to make those missions feasible, safe and cost-effective. In addition, other agencies within the government, (e.g., the National Oceanographic and Atmospherics Administration in DOC), have responsibilities for future space systems that can be enabled or improved through advances in technology. The U.S. commercial space sector also entails projected potential future civil space activities which would benefit substantially from an early investment in generic, advanced technology. These technology needs are of equal overall importance in a civil space technology strategic plan. The following sections provide initial projections of the future plans and concomitant technology needs for each of these types of potential users of space technology. They are merely preliminary, considerable effort will be required to fully understand these needs. That is one of the goals of the 1992 ITP planning cycle.

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[1] White House, National Space Council, 1990 Report of the President, (Washington, D.C.: U.S. Government Printing Office, January 1991).

[2] As was noted previously, when the 1991 edition of the ITP was being finalized, a number of NASA organizational changes were implemented. Two new Offices were created: the Office of Space Systems Development and the Office of Exploration. In addition, the details of mission planning and technology needs of the Office of Space Science and Applications (OSSA) continued to be refined. A limited number of adjustments have been made in the 1991 ITP to reflect these changes; general updates will be incorporated in the 1992 edition of the Plan.

Using inputs from NASA offices, other government agencies and industry planners, a strategic forecast of approximate dates for flight programs over the next twenty to thirty years was developed as an integral component of the ITP effort. The forecast addresses activities in the near term (1993 through 1997), the middle term (1998 through 2003), and the far term (2004 through 2011). Figure 2-1 provides a summary of this initial ITP flight programs forecast.[3] The flight programs forecast forms one of the foundations for the annual prioritization of proposed space R&T program investments. It is anticipated that this forecast will be the subject of continuing revisions during future planning cycles and as national space goals are further refined.

NEAR TERM FORECAST (1993-1997)	• COMPLETION OF INITIAL SPACE STATION FREEDOM (SSF) • SOME SPACE SHUTTLE IMPROVEMENTS • INITIAL EARTH OBSERVING SYSTEM (EOS) AND EOS DATA & INFORMATION SYSTEM (EOS-DIS) • SELECTED SPACE SCIENCE "NEW STARTS" • NATIONAL LAUNCH SYSTEM (NLS) DEVELOPMENT • EARLY SEI ROBOTIC MISSIONS • INITIAL SEI ARCHITECTURE SELECTION • EVOLVING GEO COMMERCIAL COMMUNICATIONS SATELLITES • MINOR UPGRADES OF COMMERCIAL ELVs
MID TERM FORECAST (1998-2003)	• EVOLUTION OF INITIAL SSF AND RELATED INFRASTRUCTURE • FINAL SPACE SHUTTLE IMPROVEMENTS • ADVANCED LEO EOS PLATFORMS AND EVOLVING EOS-DIS • MULTIPLE SPACE SCIENCE 'NEW STARTS' • NLS OPERATIONS AND EVOLUTION • EVOLVING LAUNCH AND GROUND OPERATIONS FACILITIES • INITIAL SEI/LUNAR OUTPOST SYSTEMS START • DEEP SPACE NETWORK (DSN) EVOLUTION (Ka-Band UPGRADE) • NEW GEO COMMERICIAL COMM. SATELLITES • NEW COMMERCIAL ELV's
FAR TERM FORECAST (2004-2011)	• SSF EVOLUTION TO SUPPORT MARS MISSION STAGING • BEGINNING OF ADVANCED MANNED LAUNCH SYSTEM (AMLS) OR PERSONNEL LAUNCH SYSTEM (PLS) DEVELOPMENT • DSN EVOLUTION (OPTICAL COMMUNICATION LINKS) • INITIAL MARS MISSION HEAVY LIFT LAUNCH VEHICLE DEVELOPMENT • EVOLVING LUNAR SYSTEMS • MARS SEI ARCHITECTURE CHOSEN • LARGE GEO COMMERCIAL COMMUNICATIONS SATELLITES • NEW COMMERCIAL ELV's

Figure 2-1
Civil Space Flight Programs Strategic Forecast

[3] The detailed forecast is provided in Appendix E.

Office of Space Science and Applications

OSSA has responsibility for using the unique environment of space to conduct scientific study of the universe, to understand how the Earth works as an integrated system, to solve practical problems on Earth, and to provide the scientific (and contribute to the technological) foundations for expanding human presence beyond Earth. OSSA plans to conduct a wide range of missions in the years ahead. The missions will cover the variety of scientific discipline areas, including: astrophysics, solar system exploration, Earth science, space physics, life sciences, and microgravity science. Within each of these areas, development flight projects are being planned that will be initiated in the near term (during the next five years), the mid term (the next ten years) and the far term (after the next ten years). In the paragraphs that follow, specific program objectives in each of the major OSSA areas are listed, including representative missions. (Additional specific missions are referenced in the detailed discussion of OSSA technology needs and their priorities which follows.)

Space Science Mission Plans

Astrophysics

The OSSA Astrophysics Program uses the vantage point of Earth orbit — and it may someday use the surface of the Moon — to observe the universe. Implemented in close coordination with the astronomical science community, the themes of the program are three-fold: cosmology, which is the study of the origins, structure and eventual fate of the universe; astronomy - research into the origin and evolution of galaxies, stars, planets and life; and physics - studies to understand the physics of matter under the extreme conditions found in astrophysical objectives. To address those themes, a strategy of contemporaneous observations across the electromagnetic spectrum has been developed. Four Great Observatories are planned: the *Hubble Space Telescope* (HST); the *Compton Observatory* (formerly known as the *Gamma Ray Observatory* (GRO); the *Advanced X-ray Astrophysics Facility* (AXAF); and the *Space Infrared Telescope Facility* (SIRTF). HST and GRO are currently in flight. AXAF and SIRTF are planned for implementation during the 1990's. The Great Observatories purview will include the entire universe across the full electromagnetic spectrum. In the near term, top-priority is given to the operation of the HST and its planned Space Shuttle servicing mission in 1993. A later servicing mission also is planned to install advanced ultraviolet (UV) and near infrared (IR) instruments. During the next five to ten years, a high priority will be the continuing operations of the *Compton Observatory*. Also, AXAF is scheduled for launch in the late 1990's, and SIRTF will be launched at the beginning of the first decade of the next century. As we begin to understand the implications of these data, yet another generation of observatories will be needed.

Several other astrophysics observation missions are planned, including the *Explorer* Program and *Spacelabs*, moderate-scale "intermediate-class" missions, and suborbital instruments. For example, the *Explorer* Program plans increasing annual flights during the next few years for a wide variety of science missions (including submillimeter, ultraviolet and x-ray studies). Also planned is a suborbital instrument, the *Stratospheric Observatory for Infrared Astronomy* (SOFIA). Several intermediate class mission options are being studied as well, including submillimeter, gamma-ray, and general relativity studies. Many international collaborations also are planned.

While current missions are implemented, future astrophysics mission concepts will be defined and a robust Advanced Technology Development (ATD) effort will continue the identification of critical technologies to help prepare for future missions. Long-range astrophysics mission plans envision "second generation" orbiting observatories and Lunar surface based telescopes. Also, advanced concepts are being studied for possible gravitational radiation observations. Lunar missions may evolve from the Lunar Transit Telescope (LTT) concept, an automated mission that would perform a deep sky survey in the UV, visible and IR ranges. A projected series of missions could culminate with an optical interferometer capable of detecting planets orbiting nearby stars.

Solar System Exploration

During the past three decades, the *reconnaissance phase* (initial robotic mission flybys) of solar system exploration was completed, with the exception of the Pluto-Charon system. In addition, a more capable robotic *exploration phase* has been underway for several years for the Moon (e.g., Surveyor) and Mars (e.g., Viking). Finally, an *intensive study phase* of the Moon was initiated during the Apollo era. In the coming decades, efforts will include missions to both the outer and inner planets, as well as to the small bodies (e.g., asteroids) of the solar systems. Also, in preparation for missions with humans, both the Moon and Mars will be studied extensively by robotic spacecraft, either on their surfaces or from low orbits.

At present, solar system exploration is being pursued with vigor. The ongoing *Magellan* mission's radar mapping of Venus continues to produce stunning results. In addition, the *Mars Observer* spacecraft will be launched in the early 1990's to orbit Mars for at least one Martian year to provide a detailed global assessment of the planet. In the next few years, the recently launched *Galileo* spacecraft will visit Jupiter and its moons as a follow-on to the two Voyager spacecraft. The *Cassini* spacecraft will tour Saturn and its moons for a long term, close-up study. Also the *Comet Rendezvous/Asteroid Flyby* (CRAF) mission currently under development will provide close observations of small bodies in the solar system. Other spacecraft will follow in their paths.

A variety of exciting missions are being considered for implementation over the next several decades, including: (1) completion of the *reconnaissance phase* of solar system exploration via a flyby of Pluto-Charon and beginning the search for planetary systems around neighboring stars; (2) continuing the *exploration phase* through missions to Neptune and Uranus (e.g., orbiter/probe missions similar to *Cassini* to Saturn) and to the asteroids; and (3) beginning in earnest the *intensive study phase* of solar system exploration, including robotic support for the Mission From Planet Earth (MFPE) through advanced orbiters and network missions (such as a *Mars Network*), sample return and rover missions (e.g., a *Mars Sample Return* and the *Comet Nucleus Sample Return* concept), and advanced outer planet missions (e.g., the *Jupiter Grand Tour* concept).

Earth Science

Over the past three decades, Earth remote sensing has evolved from development and demonstration of new technologies, to focused research on specific topics. For example, Landsat demonstrated the benefit of taking infrared photographs of the Earth. NASA's Seasat and Nimbus satellite series demonstrated active and passive microwave systems for characterization of the oceans and atmosphere. NASA's efforts have resulted in major advances in understanding our home planet. Additional core program missions, such as TOPEX/POSEIDON (the *Ocean Topography Experiment*) and the *Upper Atmosphere Research Satellite* (UARS) will continue to expand our understanding of the Earth. These missions will build upon the existing data base and are planned for the very near term. There are also sensors planned for short term deployment from the Space Shuttle, including: the *Shuttle Imaging Radar* (SIR); the *Shuttle Solar Backscatter Ultraviolet* (SSBUV) sensor; and, the *Atmospheric Laboratory for Applications and Science* (ATLAS). The data from these missions will be supplemented by small probes such as the *Total Ozone Mapping Spectrometer* (TOMS), which will provide interim ozone observations until the initiation of the EOS .

Understanding global change and the increasing demands of human activity on our planet require that we document and comprehend how the Earth works as a system. Led by the U.S., the international Mission to Planet Earth (MTPE) will build upon the information from earlier missions that have studied the nature and dynamics of the myriad of components of the Earth's biosphere. The EOS and a complementary set of *Earth Probes*, the major elements of the U.S. Global Change Research Program (GCRP), will provide long term, continuous observations of our planet from low Earth orbit (LEO). Multiple platforms carrying a wide diversity of instruments over decades will be required for the GCRP. In addition, the success of EOS will depend upon development of the EOS Data and Information System (EOS-DIS), which is a planned state-of-the-art information system that will provide rapid and easy access to EOS data for scientists and other users.

In the far term, advanced geostationary Earth orbit (GEO) platforms are being planned that would provide long term observations from large scale instruments at high altitudes. Combined with ground based measurements and observations, information received from these systems will advance our understanding of the Earth on a global scale.

Space Physics

Space physics is principally the study of naturally-occurring plasmas. The objectives of the NASA Space Physics Program include: solar and heliosphere physics (understanding the Sun, both as a star and as the dominant source of energy, plasma, and energetic particles in the solar system); and the physics of the magnetosphere, the upper atmosphere and solar-terrestrial coupling (understanding the interactions between the solar wind and other particles and the electromagnetic fields and atmospheres of solar system bodies). Comparative planetary studies of interactions of the solar wind with other bodies allows solar terrestrial interactions to be placed in a broader context.

Planning for the Space Physics Program has been significantly adapted following recent OSSA strategic planning efforts. In the near term, NASA will participate in the *International Solar Terrestrial Physics* Program (including NASA instruments on international spacecraft). Several other near term missions also are being planned. These include the *Thermosphere Ionosphere Mesosphere Energetics and Dynamics* (TIMED) mission and the *High Energy Solar Physics* (HESP) mission. In the mid term, the *Grand Tour Cluster* (GTC) mission is being planned, which will make simultaneous measurements at several locations in the Earth's magnetosphere using a system of multiple precisely-located spacecraft.

In the long term, a number of major space physics missions are planned. For example, the *Solar Probe* mission (planned for early in the next century) will provide *in situ* measurements of the solar atmosphere to a distance of approximately three solar radii. The planned *Orbital Solar Laboratory* (OSL) will study photospheric magnetic and velocity fields (visible), coronospheric and transition zone spectroscopy (UV) and coronal imaging and spectroscopy (extreme-UV and x-ray). OSL is now planned for launch in the early part of the next century. A *Mercury Orbiter* mission is being studied (involving dual orbiters of the planet Mercury) that will produce a three-dimensional map of its magnetospheric structure and plasma dynamics. Finally, in the long term, the *Interstellar Probe* mission will explore the structure of the outer heliosphere, study its interaction with the local interstellar medium and explore the nature of that medium and its implications for the origin and evolution of matter in the galaxy. These missions entail a wide variety of technology needs such as advanced thermal shields, near-sun telecommunications, and inter-spacecraft ranging and positioning.

Life Sciences

The effects of long duration space flight on living organisms must be better understood if our astronauts are to live and work productively in Earth orbit, deep space or on the surfaces of the Moon and Mars. The OSSA Life Sciences Program includes ground and space research into these and related issues, including efforts to study the role of gravity on living systems in space and to expand our understanding of the origin, evolution and distribution of life in the universe. In particular, the program addresses the impact of weightlessness and natural radiation on human beings, plants, and animals.

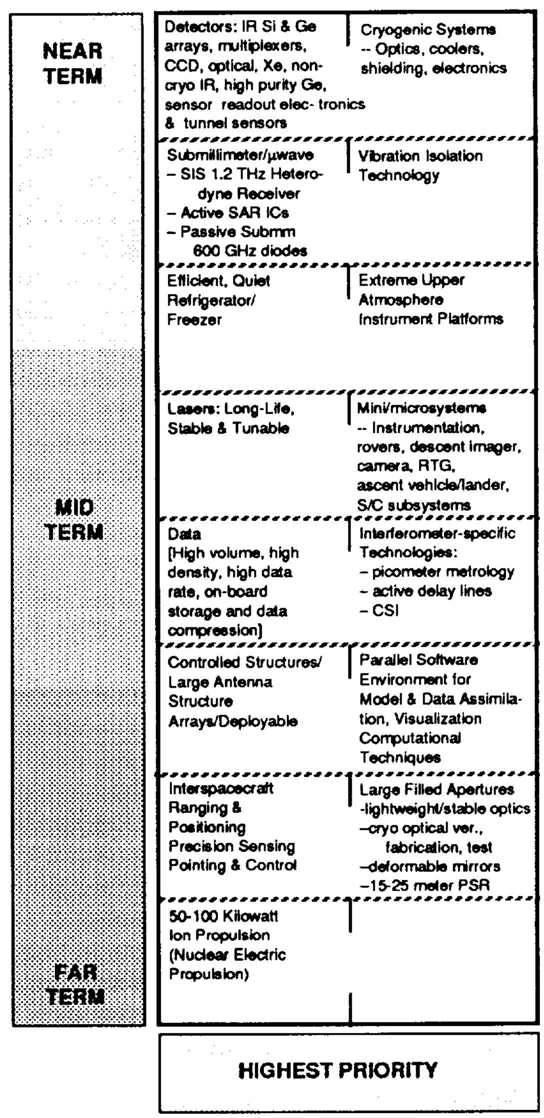
In the near term, a variety of scientifically rich life sciences missions will be flown, including those using the *Spacelab* in the payload bay of the Space Shuttle. Current programs also include the ground based *Search for Extraterrestrial Intelligence* (SETI) and research into technologies related to bioregenerative life support systems (Controlled Ecological Life Support System - CELSS). Moreover, the Life Sciences Program is currently undertaking the *Extended Duration Orbiter Medical Program* (EDOMP) to insure that crews are capable of safe landing following 13- to 16-day Space Shuttle missions. In mid term, small new missions are being planned, such as the *Lifesat* concept, that would fly on ELVs. In the long term, the Life Sciences Program is planning intensive use of Space Station *Freedom* to conduct long duration microgravity studies of human crews that will directly support future exploration missions. Finally, the Life Sciences Division has continuing NASA responsibility for defining exobiology science and planetary protection requirements.

MICROGRAVITY SCIENCES

Hand-in-hand with U.S. industry, academia, other federal agencies, and our international partners, NASA plans to exploit the microgravity environment provided by the Space Shuttle and Space Station *Freedom.* A multidisciplinary research program is being developed to advance our understanding of fluid physics, material science, combustion science, health sciences and biotechnology. It is expected that over the next several decades, a flow of practical applications will arise that have the potential to significantly impact U.S. competitiveness in materials science and processing technologies. The microgravity research programs have used a broad base of available carriers including the Space Shuttle middeck, cargo pallet, *Spacelabs* and *Get Away Special* (GAS) opportunities.

In the near term, the Microgravity Sciences Program is soon to enter a period of significantly increased experimental activity. In 1992, the first *International Microgravity Laboratory* will be launched and the *United States Microgravity Laboratory* and the *United States Microgravity Payload* are schedule to begin operation. During the latter part of the decade, the Space Shuttle will continue to represent a carrier for Microgravity Sciences Program missions. In addition, pioneering research will begin onboard Space Station *Freedom.*

Figure 2-2
Office of Space Science and Applications Technology Needs Summary



SPACE SCIENCE AND APPLICATIONS TECHNOLOGY NEEDS

The determination of space science technology needs is an important part of OSSA's annual planning. However, technology prioritization has tended to be limited to the individual OSSA divisions. As part of the 1991 ITP activity, OSSA strengthened this process to focus on an integrated set of advanced technology priorities that were reviewed OSSA-wide and endorsed by the OSSA Associate Administrator. To foster this process, an OAST liaison was assigned to the Associate Administrator of OSSA to better assist the divisions in a grassroots assembly and prioritization of their technology requirements.

In early 1991, OSSA prioritized space science and applications technology needs according to two criteria: (a) value (including criticality and commonality); and (b) urgency (assessing the timing of when technology readiness to begin flight project development would be needed). This resulted in OSSA technology needs being categorized according to highest, second highest, and third highest priority, and ranging from schedule requirements of near to far term timing. This prioritization was used as one basis for the 1991 ITP.

In late July, 1991, OSSA sponsored a major space science strategic planning workshop at Woods Hole, Massachusetts. As a result of that meeting, planning revisions were made that will be reflected in the next OSSA Strategic Plan.[4] Moreover, on this basis OSSA revised their initial 1991 technology matrix. These changes dealt principally with the projected timing of particular mission start dates rather than the details of the missions. For example, the projected start date for two Space Physics Program missions was adjusted outward: the *Solar Probe* and the *Orbiting Solar Laboratory.* The importance of some technologies also was reevaluated. For example, a stronger emphasis

[4] Due to the timing of the federal government budget cycle, the ITP civil space technology strategic plan prioritization provided in Chapter 3 was based on the preliminary OSSA technology matrix. The ITP prioritization will be updated vis-a-vis the new matrix as a normal part of the 1992 cycle. An initial assessment of the Woods Hole results suggests that only minor changes will needed at the strategic level of the ITP (e.g, concerning R&T for miniaturized systems), while additional coordination will be needed to refine specific R&T tasks.

was placed on mission operations R&T (e.g., artificial intelligence), on technology for miniaturized planetary spacecraft systems, and on direct detectors. Additional minor adjustments also were made. Figure 2-2 provides the final, integrated OSSA technology priorities matrix for FY 1991.

Several of OSSA's technology needs are summarized in the following paragraphs. These technology needs are accommodated across the full range of OAST focused R&T program thrusts, including science, transportation, space platforms, operations, and planetary surface technology.

High Frame Rate, High Resolution Video	2.4 to 4.0 meter, 100 Kelvin Lightweight, Precision Segmented Reflector (PSR)	Fluid Diagnostics	Real-Time Radiation Monitoring	Solar Arrays/Cells	Telerobotics	High Transmission UV Filters
Telescience, Telepresence, and Artificial Intelligence (AI)	Automated Biomedical Analysis	Radiation Hardened (Electronic) Parts and Detectors	Solid/Liquid Interface Characterization	Laser Light Scattering	High Temperature Materials for (space experiments) Furnaces	K-Band (RF) Transponders
Batteries – Long lifetime – High energy density	Real-time Environmental Control and Monitoring	Space Qualified Maser and Ion Atomic Clocks	Field Portable Gas Chromatographs	Advanced (space experiments) Furnace Technology	3-Dimensional Packaging for 1 MB Solid State Chips (Integrated Circuits)	Rapid Subject/ Sample Delivery and Return Capability
Low-Drift Gyroscopes, Trackers and Actuators	Combustion Diagnostics	Plasma Wave Antennas/Thermal	High Temperature Electronics	Non-contact Temperature Measurement	Ultra-high Gigabit/second Telemetry	Microbial Decontamination Methods
Microphonics Technology, FET development	AutoSpacecraft Monitoring and Fault Recovery	Improved Extravehicular Activity(EVA) Suit and Portable Life Support System (EMU)	Thermal Control System	Special Purpose Bioreactor Simulator System	Animal and Plant Reproduction Aids	
X-Ray Optics Technology: – imaging system – low cost optics – Bragg concentrators – coated apertures	SETI Technologies – Microwave and Optical/Laser Detection	Regenerative Life Support	Autonomous Rendezvous, Autonomous Sample Transfer, Autonomous Landing	Non-Destructive Monitoring Capability	Non-Destructive Cosmic Dust Collection	----
Sample Acquisition, Analysis and Preservation	32 GHz (Traveling Wave Tube) TWT, and Optical Communications	High Resolution Spectrometer	Spacecraft Thermal Protection	Partial-Gravity/Micro-Gravity Medical Care Delivery Systems	Dust Protection/ Jupiter's Rings	----
Radiation Shielding for Crews	SIS 3 THz Heterodyne Receiver	Human Artificial Gravity Systems	Controlled Ecological Life Support System (CELSS) Support Technologies	----	----	----
SECOND-HIGHEST PRIORITY			**3rd-HIGHEST PRIORITY**			

Highest Priority OSSA Technology Needs

There are several near term, high priority OSSA needs for new technology. For example, submillimeter and microwave technology are needed by both the Earth Science and Applications and the Astrophysics Divisions, for applications on the *Earth Observing System-Synthetic Aperture Radar* (EOS-SAR), TOPSAT, and *Submillimeter Moderate Mission* (SMMM) spacecraft, as well as the Microwave Limb Sounder (MLS) and MIMR instruments for the EOS spacecraft. Long life mechanical and cryogenic coolers and cryogenic shielding technologies are required by the several divisions (Earth Science and Applications, Astrophysics, and Space Physics) for a wide variety of applications over the next 10 to 15 years. These include applications on EOS spacecraft, OVLBI-NG, *Nuclear Astrophysics Explorer* (NAE), *Submillimeter Intermediate Mission* (SMIM), *Submillimeter Interferometer* (SMMI), *Large Deployable Reflector* (LDR), *Space Telescope-Next Generation* (ST-NG), and IST-NG spacecraft, the *High Energy Solar Physics Mission*, and the *High Resolution Gamma Ray Spectrometer*.

A wide range of detectors across ten orders of magnitude in the electromagnetic spectrum (including IR, visible, UV, X-ray, and gamma-ray frequencies) will be needed for future missions. Many of these detectors can benefit from customized readout electronics that increase signal-to-noise ratios. These technologies are required by the Earth Science and Applications, Solar System Exploration, Space Physics, and Astrophysics Divisions. Even more than was the case with cryogenic coolers, advanced detector technologies must be developed to support a truly diverse suite of science missions over many years. Detector applications include: EOS spacecraft; TOPS-1; NAE; *Hard X-ray Imaging Facility* (HXIF; IST-NG; *Imaging Interferometer (II)*; ST-NG spacecraft; the Geoscience Laser Ranging System (GLRS) instrument for EOS; solar investigators using *Explorer* missions and the *Solar Probe Coronal Companion*; the *Pluto Flyby*, *Neptune O/P*, *Uranus O/P*, and *Jupiter Grand Tour* missions; and micro-weather stations for *in situ* measurements.

There are several mid term needs in OSSA's highest priority technology category. Long life, stable, tunable lasers are required by the Earth Sciences and Applications, Astrophysics, Solar System Exploration, and Life Sciences Divisions for applications in the Laser Atmospheric Wind Sounder (LAWS) and GLRS instruments for EOS, the *Precision Optical Interferometer*, the *Orbiting Stellar Interferometer*, a variety of interferometers for astrophysics, Lunar and planetary exploration, and in the *Search for Extraterrestrial Intelligence* (SETI) Program. Interferometer-specific technology is needed by the Astrophysics, Solar System Exploration, and Life Sciences Divisions for use in a variety of interferometers in all of these areas. Also, for the *Mars Network* and other small probe missions, the Solar System Exploration Division has a mid term need for miniaturized spacecraft and instrument subsystems (including micro-rovers, descent imagers, cameras, mini-RTGs, ascent stage systems, and other spacecraft subsystems). Other needed technologies include advanced space data systems, large space structures and controls-structures interaction (CSI).

There are also several far term needs. Interspacecraft ranging and positioning technology and precision sensing, pointing and control technology is needed by the Space Physics, Solar System Exploration, and Astrophysics Divisions for use in a variety of missions, such as *Mercury Orbiter*, ST-NG, and OVLBI-NG spacecraft. (Note this technology may also be needed in the near term for the *Grand Tour Cluster* mission.) Technology development for a parallel software environment for model and data assimilation and visualization and related areas is required by the Earth Science and Applications Division for a wide range of uses in the MTPE and the U. S. GCRP, as well as in mission operations and data analysis applications for the Solar System Exploration Division. Also, technology developments for large filled apertures will be needed by the Astrophysics, Solar System Exploration, and Earth Science and Applications Divisions for use in the LDR, ST-NG, SMMI, IST-NG, MOI, II, TOPS-1, and *Precision Optical Interferometry in Space* (POINTS) spacecraft, in the *Orbiting Stellar Interferometer*, and in geostationary observations. Another high priority far term technology need is for nuclear electric propulsion (NEP) for high energy (e.g. outer planet) missions.

Second Highest Priority OSSA Technology Needs.

There are several near term needs in this category. High-frame-rate, high resolution video and data compression technologies are required by the Solar System Exploration and Microgravity Science and Applications Divisions for use in the full range of unmanned missions to explore the solar system, and in a variety of microgravity missions. Technology development for a 2.5 to 4 meter, 100 K lightweight PSR *(Precision Segmented Reflector)* is needed by the Astrophysics Division for use in the SMMM mission. Fluid diagnostics technology is needed by the Microgravity Science and Applications Division for a variety of important microgravity research missions. Space-qualified masers and ion clocks will be required by the Astrophysics Division for the OVLBI-NG mission. Another need is for advances in artificial intelligence (AI) and telescience R&T, in particular to support advanced mission operations (including auto-sequencing and command generation, and auto spacecraft monitoring and fault recovery), which is required by the Solar System Exploration, Life Sciences, and Microgravity Science and Applications Divisions.

Beyond the near term, a variety of mid term, second highest priority OSSA needs also were identified. These include both space qualified maser and ion atomic clocks and low-drift gyroscopes, trackers and actuators for future Astrophysics missions. Also, several Life Sciences Division technology needs fall in this category, including regenerative life support, improved EVA Suit/PLSS (EMU), and mid to far term needs for technologies for SETI (including microwave and optical/laser detection). There are several far term needs as well. Sample acquisition, analysis and preservation R&T is needed for either *Mars Rover/ Sample Return* (MRSR) or *Comet Nucleus Sample Return* (CNSR) missions for Solar System Exploration. SIS 3 THz heterodyne receivers are needed by the Astrophysics Division for use on the LDR and SMMI missions. Finally, X-ray optics technology is needed by the Astrophysics Division for the HXIF spacecraft.

Third Highest Priority OSSA Technology Needs

Several near term OSSA needs relating to the Space Science Technology Program exist. Descent imaging and mini-camera are needed by the Solar System Exploration Division for the *Mars Network* and the *Discovery* NEAR mission. Solid-liquid interface characterization and laser light scattering will be studied by the Microgravity Science and Applications Division. High temperature materials for furnaces and advanced furnace technology will be required by Microgravity Sciences for a number of important flight experiments. Telerobotics technologies will be needed by the Microgravity Science and Applications Division for containerless processing, solidification, biotechnology, and protein crystal growth experiment operations. Robotics technologies also may be applicable to Life Sciences needs for advanced in-space medical care.

There are also a variety of mid term OSSA needs in the third highest priority category, including: non-contact temperature measurement technology for Microgravity Science and Applications experiments; and, 3-D packaging for 1 MB solid-state memory chips required by the Astrophysics Division for the MOI and II spacecraft. Other third highest priority technologies include: autonomous rendezvous and docking, autonomous landing and autonomous sample transfer for Solar System Exploration Division missions; technologies to support Controlled Ecological Life Support System (CELSS) for the Life Sciences Division.

Office of Exploration

The NASA Office of Exploration (OEXP) is responsible for developing integrated strategies for the Space Exploration Initiative (SEI). In addition, an activity to develop ideas and architectures for SEI was conducted during 1990 through the early part of 1991 by the "Synthesis Group" under the direction of Lieutenant General Thomas Stafford. The four SEI architectures defined by the Synthesis Group will be the framework for studies of SEI mission options and technology needs during the next several years.

The Advisory Committee on the Future of the U.S. Space Program endorsed SEI, the so-called "Mission From Planet Earth" and requested in Recommendation 7 of their report:

> That technology be pursued which will enable a permanent, possible man-tended outpost to be established on the Moon for the purposes of exploration and for the development of the experience base required for the eventual human exploration of Mars. That NASA should initiate studies of robotic precursors and Lunar outposts.

The relevant aspects of Recommendation 7 (i.e., those pertaining to the development of space technology) were incorporated by the NASA Administrator into the OAST activity that responded to Recommendation 8 - the preparation of the ITP.

Space Exploration Initiative Mission Planning

Returning to the Moon and sending the first Americans to Mars will occur as part of a long term, evolutionary civil space program. The Synthesis Group defined four, broad-ranging architectural options for SEI.

Exploration of Mars

The major objective of this architectural option is to explore Mars and provide scientific return. The emphasis of activities performed on the Moon is primarily in support of mission to Mars preparation, and also includes significant Lunar infrastructure and scientific return from Lunar operations.

Science Emphasis for the Moon and Mars

The major objective of this architectural option is a balanced scientific return from the Moon and Mars. Emphasized throughout are exploration and scientific activities, including complementary human and robotic missions required to assure optimum mission returns.

Moon to Stay and Mars Exploration

The major objective of this option is to establish a permanent presence on the Moon and to conduct Mars exploration. Long term human habitation and exploration in space and on planetary surfaces provide terrestrial spinoffs to improve our life on Earth and increase our knowledge of the solar system, the universe, and ourselves.

Space Resource Utilization

The objective of this architecture is to make maximum use of available resources to support SEI mission operations. In this case, SEI programs would seek to develop resources in such areas as transportation, habitation, life sciences, energy production, and construction, that reduce costs and approach self-sufficiency.

Each of these architectural options entails several common strategic features. In all cases, SEI will begin with mission planning and technology development. Subsequently, SEI will include programs of experimentation (particularly in life sciences, but also including technology demonstrations) onboard Space Station *Freedom* and some robotic precursor missions to Mars and (in some options) the Moon. The capability will be developed to permanently live on the Moon and to visit Mars for increasingly longer periods.

Building on studies that began in the 1960's, significant, high level planning for future human missions to the Moon and Mars has been underway at NASA since 1986. This planning, which includes the development of alternative scenarios and space infrastructures using the framework of the Synthesis Group architectures, will continue during FY 1992 with an increasing level of detail. Over time, detailed planning will shift from the precursor missions to the initial human return to the Moon, and eventually to evolutionary Lunar scenarios, more advanced robotic missions and then to the human exploration of Mars.

In parallel with the earlier mission planning and the Synthesis Group's definition of SEI architectures, the identification of new technology needed for future human missions to the Moon and Mars has been initiated. Like the mission planning, the near term needs have tended to receive, in general, a higher level of priority than the far term needs. The following paragraphs provide top level information regarding each of the different programmatic components of SEI.

Space Station Freedom Based Research

The initial version of Space Station *Freedom* (SSF) will begin operation in the 1997 timeframe. From that point forward, SSF will contribute to our knowledge concerning the long term effects of weightlessness on human beings, plants and animals. This knowledge is needed to complete the design of the spacecraft that will take the first Americans to Mars, and to develop any necessary countermeasures to the effects of weightlessness.

Robotic Precursor Missions to the Moon and Mars

In addition to the research done onboard SSF, current planning calls for other activities to be undertaken prior to, or concurrent with, human missions to the Moon and Mars:

- The *Mars Observer* spacecraft will gather additional data about Mars in the early 1990's
- Small, Lunar orbiting spacecraft may be used to conduct selected specific studies of the Moon in the mid to late 1990's (small landers are also possible)
- In the late 1990's or early 2000's, a *Mars Network* may be implemented to provide data at several places on the surface of Mars
- Robotic Mars rovers may be used to gather data at several Martian locations beginning in the early 2000's
- Samples of the surface material at two or more of these Martian locations may be gathered by one or two sample return missions, starting at approximately the same time.

Returning to the Moon

The last two Apollo astronauts departed from the Moon in 1972, and the first American astronauts will not return until the middle of the first decade of the next century, a gap of more than three decades. Several years after we return, possibly during the latter part of the first decade of the 21st-century, an initial *Lunar Outpost* is projected to be "up and running," and Americans will begin to permanently live on the Moon. At present, the objectives of a return to the Moon and establishing a base include:

- To increase further our scientific knowledge of the Moon
- To set up and maintain large astronomical instruments on the Lunar surface
- To begin to determine the practical uses of Lunar material
- As a testbed for similar human activities on the Martian surface.

Missions to Mars

For ITP planning purposes, the assumption is that the first Americans will land on Mars during the five year period from 2014 to 2019, approximately fifty years after the first Americans landed on the Moon. (The realism of these dates is directly dependent upon the availability of specific technologies.)

Space Exploration Initiative Technology Needs

On the basis of previous studies, during early 1991, OEXP defined a set of technology needs for exploration. These needs were prioritized on the basis of two primary criteria: (1) importance/value to a particular SEI mission or objective; and (2) commonality across segments of SEI. In this initial prioritization timing was not considered as a criterion for assessment. On the basis of these criteria, technologies were categorized as: (a) *highest priority* (being both extremely valuable and common to several cases); (b) *second highest priority* (being either very valuable and common to many cases or extremely valuable and unique to one or a few cases); and (c) *third highest priority* (being very valuable and unique to one or a few cases). Figure 2-3 provides a summary of these technologies and priorities. Additional details are presented in the paragraphs that follow. These technology needs are accommodated within four of the OAST focused R&T program thrusts: planetary surface technology; transportation; operations; and space science.

SEI Office Assessment: Highest Priority Technology Needs

The highest priority SEI technology needs, as identified by NASA SEI personnel, include the following areas: (1) radiation protection, including shielding and materials; (2) EVA systems, including portable life support systems (PLSS), gloves, materials, mobility aids, dust seals; (3) nuclear thermal propulsion, including reactor design, fuel development, shielding and control systems; (4) regenerative life support, including sensors, controls, physical-chemical process based systems and bioregenerative systems; (5) cryogenic fluid management, storage and transfer for space transfer vehicles; (6) microgravity countermeasures or artificial gravity, including centrifuges and other countermeasures equipment (and protocols); and (7) aerobraking, including both low energy (less than 12 km/second) and high energy (greater than 12 km/second) entry speeds.

SEI Office Assessment: Second Highest Priority Needs

The second highest SEI technology needs identified include: (1) autonomous rendezvous and docking — unmanned docking and verification of successful mating; (2) health maintenance and care, including health monitoring, emergency surgery; (3) in-space systems assembly and processing, including mating and verification/checkout techniques; (4) surface system construction and processing, including heat transport/rejection, radiation shielding emplacement and surface stabilization; (5) cryogenic space engines for space transfer vehicles and landers, including restart capability, ability to throttle over a wide range and ease of maintainability; (6) *in situ* resource utilization, targeted primarily on the production of liquid oxygen (LOX) from Lunar surface regolith; and (7) surface power, including a variety of specific technology options (i.e., nuclear, solar, energy storage, power conversion, heat rejection, power management).

Category 1 Technologies
• Radiation Protection
• EVA Systems
• Nuclear Thermal Propulsion
• Regenerative Life Support
• Cryogenic Fluid Management, Storage and Transfer
• Micro-gravity Countermeasures/Artificial Gravity
• Aerobraking

Category 2 Technologies
• Autonomous Rendezvous and Docking
• Health Maintenance and Care
• In-Space Systems Assembly and Processing
• Surface System Construction and Processing
• Cyrogenic Space Engines
• In Situ Resource Utilization
• Surface Power (Nuclear and Solar)

Category 3 Technologies
• Autonomous Landing
• Human Factors
• Surface System Mobility and Guidance (piloted and unpiloted)
• Electric Propulsion (nuclear and solar)
• Sample Acquisition, Analysis & Preservation

Figure 2-3
Office of Exploration Pre-Synthesis Group Report Technology Needs Summary

Fundamental Technologies/Capabilities
• Heavy Lift Launch Vehicle (minimun – 150,000 metric tons to LEO, preferred – 250,0000 metric tons to LEO)
• Nuclear Thermal Propulsion

Enhancing Technologies
• Nuclear Electric Surface Power to megawatt levels
• Extravehicular Activity Suit
• Cryogenic Transfer and Long-Term Storage
• Automated Rendezvous and Docking of large masses
• Zero-gravity Countermeasures
• Radiation Effects and Shielding
• Telerobotics
• Closed Loop Life Support Systems
• Human Factors for long duraction space missions
• Lightweight Structural Materials and Fabrication
• Nuclear Electric Propulsion for follow-on cargo missions
• In Situ Resource Evaluation and Processing

Selected Other Technologies Cited
• Chemical Propulsion
• Aerobraking
• Power Beaming
• Surface Excavation and Construction

Figure 2-4
SEI Synthesis Group Report Technology Needs Summary

SEI Office Assessment: Third Highest Priority Needs

The third highest priority technologies include several high leverage technology areas, applicable to a specific SEI architecture. These are: (1) autonomous landing, including guidance, navigation and control, transition from aeroassist to propulsion and landing at a fixed spot, navigation aids and hazard avoidance; (2) human factors, such as human-machine interfaces, habitability and automated training aids; (3) surface system mobility and guidance, including technology for both manned and unmanned surface systems; (4) electric propulsion, including development of propulsion thruster development for either nuclear or solar power sources; and (5) sample acquisition, analysis and preservation, including surface and subsurface Lunar and Martian samples.

SEI Synthesis Group Assessment of Technology Needs

As part of their activities, and in addition to internal NASA efforts, the SEI Synthesis Group conducted an independent assessment of potential SEI technologies and identified those that could significantly enhance its implementation.[5] The latter list included 14 very important technologies for SEI, which were not prioritized within the list. However, nuclear propulsion and heavy lift launch vehicles technologies were identified separately by the Synthesis Group as strategically crucial to the success of SEI. Although the list of 14 was not prioritized, those technologies should be regarded as higher in priority than the others on the list. Similarly, of the remaining twelve technology areas, nuclear-electric surface power was identified as very important. The results of these SEI technology need definition activities are summarized in Figure 2-4 and are discussed.

The 14 significantly enhancing technologies or capabilities for SEI, identified by the Synthesis group include: (1) heavy lift launch vehicle systems, with a minimum capability of 150 metric tons with designed growth to 250 metric tons; (2) nuclear thermal propulsion, which was judged as a key technology area for humans to Mars missions; (3) nuclear electric surface power with power levels ranging up to megawatt levels; (4) extravehicular activity (EVA) suits, including both Lunar and Mars surface suits, as well as in transit suits; (5) cryogenic(fluids) transfer and long term storage; (6) automated rendezvous and docking of large mass; (7) microgravity countermeasures; (8) radiation effects and shielding; (9) telerobotics; (10) closed loop life support systems; (11) human factors for long duration missions; (12) light weight structural materials and fabrication; (13) nuclear electric propulsion for follow-on cargo missions; and (14) in situ resource evaluation and processing.

[5] See SEI Synthesis Group, America at the Threshold.

Office of Space Flight

The Office of Space Flight (OSF) has the responsibility for the planning, development and operations of existing and future Earth-to-Orbit (ETO), and Orbit-to-Orbit transportation systems and for Space Station *Freedom*. As a part of the 1991 ITP effort, OSF assembled an overall strategic program schedule to support technology planning. Following an extensive effort, with detailed review by top-level OSF management, an array of technology needs were identified.

OSF Program Planning

Transportation

OSF supports existing space transportation requirements with the Space Shuttle, Spacelab, unmanned expendable launch vehicles (ELVs) and deployable upper stages. The Office is also responsible for developing future space transportation capabilities through advanced development, conceptual studies, and preliminary design and development. The advanced development component of the program includes planning and evolutionary development of follow-on programs to build upon the Shuttle, define a heavy lift launch vehicle, and lead in the development of a next generation manned space launch system. It seeks to improve the reliability, reduce the operational costs and enhance the performance of current systems through advanced operations demonstrations, advanced hardware development and demonstration programs to bridge technology development and applications.

OSF planning for the near to mid term (between 1992 and approximately the end of the decade) includes continuing operation of the Space Shuttle, in particular to support Space Station *Freedom* launch and assembly, continuing launch of ELVs, and development of the *National Launch System* (NLS). There is also the option of developing an upper stage vehicle for the NLS, a *Cargo Transfer Vehicle* (CTV). The NLS, which is a joint NASA-USAF program, is discussed in greater detail in Chapter 5.

For the mid to far term, new manned launch systems are being considered. These include a *Personnel Launch System* (PLS) or an *Advanced Manned Launch System* (AMLS). The AMLS is projected to enter system development in the early to middle years of the next decade, and have an operational capability approximately ten years later.

Space Station Freedom.

Space Station *Freedom* is an international cooperative program involving NASA, the European Space Agency (ESA), and the space agencies of Japan and Canada. A permanently habitable space laboratory with a projected lifetime on-orbit of more than 30 years. SSF is planned to begin its initial assembly phase in the middle 1990's, with completion of Permanently Manned Capability (PMC) around the turn of the century. SSF will provide a valuable in-space facility for extended duration life sciences research, microgravity experiments and observational experiments. In addition, SSF may provide a continuing in-space testbed for a variety of advanced technologies, including power systems, life support systems and in-space vehicle processing capabilities. Following PMC, two phases of evolutionary changes in SSF systems while on orbit are projected. These include improvements in SSF basic capabilities, such as power and autonomy, but also may entail enhancements in user accommodations (e.g., the addition of essential in-space operations capabilities for Mars mission staging).

OSF Technology Needs Summary

Technology needs were identified within each of the major programs of OSF, including: SSF; Space Shuttle; and Flight Systems (e.g., ELVs and upper stages). OSF's major technology needs included sixteen areas which OSF judged likely to be driven by NASA investments and/or to be largely unique to NASA programs. Figure 2-5 provides a summary listing of those priorities. The identified OSF technology needs are addressed within three of OAST's focused R&T program thrusts: transportation; space platforms; and operations. The following paragraphs describe some of the details of OSF's technology needs.

Program Unique Technologies

1 Vehicle Health Management
2 Advanced Turbomachinery Components and Models
3 Combustion Devices
4 Advanced Heat Rejection Devices
5 Water Recovery and Management
6 High Efficiency Space Power Systems
7 Advanced Extravehicular Mobility Unit Technologies
8 Electromechanical Control Systems/Electrical Actuators
9 Crew Training Systems
10 Characterization of Al-Li Alloys
11 Cryogenic Supply, Storage and Handling
12 Thermal Protection Systems for High Temperature Applications
13 Robotic Technologies
14 Orbital Debris Protection
15 Guidance, Navigation and Control
16 Advanced Avionics Architectures

Industry Driven Technologies

- Signal Transmission and Reception
- Advanced Avionics Software
- Video Technologies
- Environmentally Safe Cleaning Solvents, Refrigerants and Foams
- Non-Destructive Evaluation

Figure 2-5 *Office of Space Flight Technology Needs Summary*

Several of OSF's highest priority technology needs address advances for future transportation systems. *Vehicle Health Management* is one of the highest priority technology needs identified by OSF, including advances in sensors, processors and networks, in maintenance diagnostic and algorithms, and in selected system components. Overall system integration demonstrations will be required for technology maturation. Another high priority technology need is in the area of *Advanced Turbomachinery Components & Models.* This includes R&T in the areas of large scale bearings, seals and structures for launch vehicle LOX, LH2 & LHC turbines and pumps, and demonstrations of smaller scale turbines/pumps for space transfer vehicles (STVs). In the high priority area of *Combustion Devices,* R&T should address fabrication methods for thrust chambers, nozzles and injector concepts (with wide design margins), and expander cycle engines for future STVs. Moreover, technology demonstrations will be essential to assure future design-to-cost.

The next several high priority OSF technology needs address the requirements of advanced space platforms, such as future SSF development. For example, *Advanced Heat Rejection Devices* are identified as a technology need. In particular, thermal management research and technology is needed to develop heat pumps for microgravity operations and low mass, high efficiency heat pipes. *Water Recovery and Management* also was identified as a life support R&T requirement. Life support R&T is needed for real time microbial analysis and water reclamation and waste processing technologies (such as long life membranes and filters). In the area of *High Efficiency Space Power Systems*, R&T is needed for Earth orbiting applications, as well as for future SSF systems implementation. *Advanced Extravehicular Mobility Unit* technologies are identified as an area in which R&T should specifically focus on suit components (such as high pressure, high operability gloves) and portable life support systems (including regenerable heat storage and rejection systems).

The mid level OSF technology priorities address technologies that are needed for both vehicle and platform systems. (Several are in fact common to both applications.) *Electromechanical Control Systems/ Electric Actuation* needs are principally in the area of avionics system component advances to support future transportation systems. *Crew Training Systems* technology development should address both ground and in-space training systems, particularly retraining in flight during long duration SSF missions. *Characterization of Aluminum-Lithium Alloys* is needed to support development of future large scale and/ or low cost ETO transportation systems. In addition, *Cryogenic Supply, Storage and Handling* R&T is a requirement in the areas of long duration storage, including insulation and refrigeration options, and for cryogen handling, including modeling and experimental model validation in flight experiments. *Thermal Protection Systems (TPS) for High Temperature Applications* R&T is needed for future transportation system applications.

The final four OSF technology needs are largely cross-cutting, and apply equally to transportation and platforms. For example, *Robotic Technologies* are needed, including technology for future in-space vehicle servicing and processing operations (e.g., on SSF). R&T is needed in the area of *Orbital Debris Protection*, including both protection and determination of the debris environment. Also, *Guidance, Navigation & Control* is a priority for ETO and in-space transportation systems GN&C. Lastly, *Advanced Avionics Architectures* R&T should be directed toward defining unique advanced avionics architectures for both transportation and SSF systems that could then guide government and contractor technology development.

In several other areas, OSF judged that new technology development was likely to be driven by industry research rather than government efforts. Nevertheless, in those areas, some NASA investment targeted on specific applications of new technology could be required. Five items were identified: (1) Signal Transmission and Reception; (2) Advanced Avionics Software; (3) Video Technologies; (4) Environmentally Safe Cleaning Solvents, Refrigerants and Foams; and (5) Non-Destructive Evaluation.

Office of Space Communications

The Office of Space Communications (OSC) has responsibility for the development and operation of ground and space systems for tracking, data acquisition and management, and telemetric navigation functions for NASA. As a part of the ITP planning effort, OSC identified priority technology needs in several areas, including both general needs, as well as those associated with future OSC participation in SEI.

OSC Program Planning

OSC identified the flight program "drivers" of its technology needs within the same timing framework as that used for overall ITP planning. General technology strategies in that timeframe included:

- For Near Term Needs
  - Refine and extend state-of-the-art technology to meet demands for enhanced capabilities
  - Upgrade existing equipment and techniques
  - Provide more power, higher data rates, and lower error rates
- For Longer Term Needs
  - Develop new technologies needed for future missions
  - Dependent on mission characteristics to be defined by users: SSF; EOS; others
- For Far Term Needs
  - Technology needs linked to emergence of mission characteristics defined by users, however in general, develop new technologies for Lunar and Mars exploration.

Also as a part of this effort, OSC reviewed its own internal "advanced systems program" which is analogous to advanced development or planned product improvement efforts in OSF.

OSC Technology Needs Summary

OSC's major, but not SEI-specific technology needs concentrated primarily in the near and mid term. These were: high data rate communications; advanced data systems; advanced navigation techniques; and mission operations. In addition, OSC identified longer term technology needs for SEI support that fell into three similar areas: telecommunications; information management; and navigation. Figure 2-6 provides a listing of these priorities. These OSC technology needs are accommodated for the most part in the Operations Technology Thrust (with some data related R&T addressed in the Space Science Thrust). Each of OSC's technology needs is described briefly below.

Figure 2-6
Office of Space Communications Technology Needs

- High Data Rate Communications
- Advanced Data Systems
- Advanced Navigation Techniques
- Mission Operations

High Data Rate Communications

This technology need addressed projected requirements for very high data volumes for space-to-Earth communications as well as space-to-space transmissions. As defined for non-SEI needs, this area included optical and millimeter wave radio frequencies. These two technologies (Ka-band and optical communications) also were identified as needs in the related, but potentially far term arena of technologies to support SEI.

Advanced Data Systems

This technology need addressed both space based and ground based data systems. For non-SEI support, this need addressed the development of advanced data storage, data compression, and information management systems. These technologies were also identified as needed for SEI support in the long term, with the addition of power/bandwidth efficient modulation and coding techniques, unattended network operations capabilities, overall fault tolerant systems designs, and data standards and protocols.

Advanced Navigation Techniques

For non-SEI mission support, a priority need was identified for new techniques for navigation with applications to cruise, approach and in-orbit phases of robotic and future piloted deep space missions. In this same area, SEI-supporting technology needs were identified by OSC for navigation transponders, GPS-type navigation receivers, altimeters/pressure/temperatures sensors and narrow angle and wide angle cameras, advanced inertial measurement units, and stable, long life clocks and oscillators.

Mission Operations

This OSC technology need incorporated artificial intelligence, expert systems, neural networks, and increased automation in future ground based mission operations systems. The need, as defined, also identified a requirement for testbed development to checkout advanced software, for the coordination of distributed software, and for automated performance analysis of networked computing environments.

Other Government Needs

In addition to the long range plans and technology needs of program offices within NASA, the ITP effort has addressed other civil space technology, including both the needs of other components of the federal government (e.g., NOAA) as well as the needs of the commercial space sector. These technology needs of other government agencies are discussed in this section. At the present time, this discussion addresses only NOAA. In future cycles of the ITP, it is anticipated that the technology needs of other areas also will be included. These may include support for the Federal Aviation Administration (FAA), with regard to advanced air traffic control systems; as well as for the National Science Foundation (NSF) in areas related to ground based astronomy (for example, adaptive optics, radio astronomy and interferometry).

NOAA

The National Oceanographic and Atmospheric Administration (NOAA) currently depends heavily upon NASA for its future space instruments and technology. Consequently, NOAA's input to this process is an important consideration. The following is a prioritized listing of NOAA's remote sensing technology needs, as identified by a NOAA Representative during the ITP process:

Sensor Optical Systems

Studies are needed of sensor optical systems, focused on visible calibration systems. Application: Determination of cloud and land surface properties for studies of global change.

Passive Microwave Sensing

Studies should focus on antenna systems to allow for high resolution (e.g., approximately 10 km resolution) spatial sensing at low frequencies (e.g., 5-6 GHz). Application: All-weather sea surface temperature determination.

Active Microwave Sensing

Studies should focus on more efficient and less expensive scatterometers, altimeters, and SARs. Application: For scatterometers, sea surface wind speed and direction determination; for altimeters, wave height, ocean circulation; and for SARs, sea ice thickness.

Laser Sensing

Studies should focus on efficient methods for laser wind sounding. Application: Determination of global wind profiles which are required for input to numerical weather prediction models.

Coolers & Cryogenics

Studies should focus on support for precision IR sensors such as the EOS/AIRS (Atmospheric IR Sounder) to increase vertical resolution of sounding retrievals. Application: AIRS data are needed for impact to numerical weather forecast models.

Direct Detectors

Studies should focus on detector technology extending to the 18 micrometer region in support of EOS/AIRS (see above).

Commercial Space Sector Technology Needs

A variety of technology needs were identified during the development of the ITP by industry participants. In particular, two specific areas were defined in which the ITP could and should address the development of new technologies in a manner that is analogous to the relationship of the NASA aeronautics technology efforts. Those areas include the commercial launch industry (e.g., using expendable launch vehicles with chemical upper stages) and the commercial space telecommunications satellite industry.

Launch Vehicles

A variety of advanced technologies have been identified as needed for future commercial ETO transportation systems. The primary technology development objectives in this area include: (1) increasing reliability and the probability of launch success; (2) reducing costs; and (3) improving "launch on time" performance. Needed advanced technology developments include: (1) low cost, low risk engines; (2) light-weight, low cost structures and materials; (3) avionics; and (4) operations.

Low Cost/Low Risk Engines

Life cycle cost (LCC) drives the propulsion system cost component for ELVs. R&T needed to reduce LCC includes reducing the number of engine parts, developing engine designs that reduce the tolerance on critical engine components, and lower cost engine manufacturing processes.

Light-weight/Low Cost Structures and Materials

Efforts are needed in ELV-specific advanced materials and structures for low cost cryogenic propellant tankage, including Al-Li metallic tanks and filament-wound composites, in advanced thermal protection systems, and in low cost manufacturing and processing methods.

Avionics

To increase reliability, safety and flexibility (while reducing costs), technology development needs include: wind loading predictive capability; fault-tolerant avionics; and integrated electromechanical actuators (EMAs), power and controls.

Operations

Improvements in ground and launch operations through the application of automation can reduce workforce requirements (and costs), improve safety and performance, increase reliability, and reduce turnaround times and costs.

Commercial Communications Satellites

Technology development also can have a significant impact on future commercial satellite communications systems. Given the overall goal of reducing costs while improving services, selected specific objectives include: (1) reducing communications system costs; (2) improving space system data management performance; and (3) extending satellite lifetimes. Examples of the needed technology advances include the following:

Efficient Solid State High Power Transmitters and Low Noise Receivers

Maximum performance and efficiency can depend upon discrete components (e.g., field effect transistors — FETs) for low noise receivers and transmitter power amplifiers.

Advanced Data/Signal Processing and Distribution

R&T for both the ground and space segments is needed to reduce the costs of providing very high data rate processing (e.g., for large, data base transmission) across complex networks in near real-time.

Low Cost ELVs

Because of their reliance on ELVs for access to orbit, reductions in the cost of ELV services bears a direct relationship on the costs for commercial satellite communications systems.

Further refinement of potential long term commercial space sector activities and derived technology needs will be a key goal of OAST in preparing the 1992 ITP.

Assessment of Technology Needs Commonality

The preceding sections provide an overview of the wide variety of technology needs that have been identified by the various national users of civil space research and technology and which were input to OAST as part of the development of the ITP. They include potential users both within and outside of NASA. In general, the technology needs fall into three primary categories: (1) technologies that are broadly applicable to several missions (these tend to be more generic in character); (2) technologies that are enabling for a specific mission concept or program objective (e.g., R&T pertaining to science instruments or SEI goals); and (3) technologies that are of high value to using offices planning similar systems (e.g., transportation technologies for OSSA deep space missions and for SEI).

OAST has not attempted to prioritize between various user plans because such a prioritization is well beyond the scope of this document. However, technology prioritization is required to guide investment decisions. The subject of prioritization is discussed in detail in Chapter 3, however two general criteria that can be used are *commonality* and *criticality*.

Many of the specific technologies identified as needs are common to several different users and their respective mission plans, differing in some cases only in the projected timing or performance requirements of specific technology program deliverables. The more common a technology need is, the more broadly useful an investment in that technology can be considered. Figure 2-7 provides an assessment of the needs that are common to two or more of the using offices within NASA, including identification of certain top level areas (common to three or more users) that emerge from an integrated assessment of these needs.[6]

However, several of the technologies that are unique to a user office, and perhaps to a single mission concept, are extremely important (and perhaps enabling) for specific civil space national and programmatic objectives. These include: (1) technologies for future Earth and space science observations; and (2) technologies for certain potential SEI mission objectives. Science technologies include advanced sensors and sensor processors, telescope materials and optics, precision controls-structures interactions, and science data management and visualization, plus others. SEI capabilities include high leverage areas (such as radiation protection in deep space, nuclear thermal propulsion, in situ resource utilization, and planetary surface system construction and maintenance.)

[6] Note: For non-NASA technology needs, the three clear areas of technology commonality revolve around: (1) R&T for telecommunications spacecraft, (2) expendable launch vehicle R&T; and (3) NOAA R&T requirements related to remote sensing

Figure 2-7 *NASA Technology Needs Commonality Assesssment*

Common Technology Areas	OSSA NEEDS (Selected)
ADVANCED EVA SYSTEMS	Advanced Data Systems
REGENERATIVE LIFE SUPPORT	Advanced Space Structures
ADVANCED GN&C	Robotics/Rovers (micro)
ADVANCED DATA SYSTEMS	Spacecraft Position/GN&C
AUTOMATION AND ROBOTICS	Software/Data VIsualization
AEROASSIST R&T (TPS, GN&C, Aerobraking)	Nuclear Electric Propulsion
STRUCTURES AND MATERIALS	Advanced Solar Arrays
ADVANCED SPACE POWER (Nuclear and Solar)	Radiation Shielding for Crews
THERMAL MANAGEMENT & CRYOGENIC SYSTEMS	Auto. Rendezvous & Docking
	Autonomous Landing
	Regenerative Life Support
	Advanced EMU's
	Micro-G Countermeasures
	Sample Acquisition
	Auto Sequencing
	Auto S/C Fault Recovery
	High Rate Communications (Optical, Ka-Band)
	High Energy TPS
	Micro-G Medical Care
	Thermal Control
These General Technology Areas are Common to Three or more Offices	

In planning civil space technology investments, it is particularly important to develop a strategic approach that both inspires a consensus among those reviewing the plan and is essentially correct. Therefore, it is vital to achieve a balance between investments in technologies that are unique to a particular mission (but which may be enabling for that mission) and investments in technologies that are needed by a variety of future civil space program users (but which are only enhancing when compared to the current state of the art). This issue — balancing criticality versus commonality — when combined with the question of timing, lies near the heart of the ITP. The next chapter describes the ITP planning methodology, provides the actual ITP technical strategic plan, and then presents the process used for making key prioritization decisions that establish the needed balance.

OSF NEEDS (Selected)	**OEXP NEEDS (Selected)**	**OSC NEEDS**
Vehicle Health Management Advanced Turbomachinery Components & Models Combustion Devices Adv. Heat Rejection Devices Water Recovery and Management High Efficiency Space Power Systems Advanced EMU's Crew Training Systems Characterization of Al-Li Alloys Cryogenic Supply, Storage andHandling Thermal Protection Systems Robotic Technologies Guidance Navigation/Control Advanced Avionics Arch.	<u>Common to NASA & Synthesis SEI</u> Radiation Protection EVA Systems Regenerative Life Support Cryogenic Fluid Management Micro-G Countermeasures Surface Power (nuclear) Auto. Rendezvous/Docking Human Factors (Nuclear) Electric Propulsion <u>Synthesis SEI</u> Heavy Lift Launch Vehicles Telerobotics Materials and Fabrication <u>NASA OEXP</u> Cryogenic Space Engines Aerobraking Surface Power (non-nuclear) Autonomous Landing Sample Acquisition/Analysis Surface Mobility Health Care In-Space Construction and Processing	High Data Rate Communications Advanced Data Systems (Ground/Space) Advanced Navigation Techniques Mission Operations (AI, Software)

These specific technology needs are (approximately) common across two or more of the NASA User Offices; The specific technology areas are shown, drawn from the various User Offices' inputs

Transportation to and from low Earth orbit will always be the cornerstone for success in U.S.. civil space endeavors. As this artist's concept illustrates, some of the key challenges of the future include the next manned launch system, operations and evolution of the National Launch System, and continuing operation of the Space Shuttle. Reducing the cost of future commercial space sector Earth to orbit transportation systems will be particularly important. Similarly, the scope and scale of human and robotic deep space missions will depend directly on future space transportation systems. The ITP's Transportation Technology Thrust lays out a technical strategy for developing needed technologies in this area, including propulsion systems, advanced materials and manufacturing and vehicle avionics.

CHAPTER 3
CIVIL SPACE TECHNOLOGY STRATEGIC PLAN

Timely implementation and operation of U.S. civil space missions and ground facilities is the common goal of NASA's program offices. Similarly, the aerospace industry, along with other government agencies, plan and implement their own commercial and U.S. government flight programs. For each organization, the availability of needed or anticipated technology plays a vital role in achieving success. The ITP contributes to this process in two ways: (1) as the basis for the OAST space R&T program investment in technology over the next several years; and (2) by providing an integrated technical strategy for civil space research and technology development for the coming decades. This chapter provides the 1991 ITP technical strategy for civil space R&T.

The chapter begins with a review of the ITP planning methodology. It then presents both general and specific technical strategies for civil space R&T implementation. NASA's space R&T efforts are comprised of two major parts: an R&T Base (which is organized primarily by research discipline and constitutes predominantly the "technology push" section of the program); and, a collection of focused programs, the Civil Space Technology Initiative (CSTI), which encompasses the existing elements of CSTI along with the elements of the Exploration Technology Program, (ETP, a.k.a., Project Pathfinder).[1] The space R&T technical strategy provided here follows this structure, and includes both basic research goals and objectives as well as objectives for focused technology development and demonstrations. The chapter concludes with a statement of the 1991 ITP priorities for civil space technology investment. (Appendix A provides a summary of the resource implications of the ITP strategic plan and investment priorities.)

In addition to the civil space mission-driven responsibility of the programs, NASA's space R&T efforts are also a part of the Nation's overall investment in strategically important technology areas. An assessment has been made across the several focused technology thrusts and the R&T Base to determine how well the ITP addresses these strategic areas.[2] Appendix D provides the results of this assessment.

METHODOLOGY

The ITP methodology is comprised of a series of discrete components. The initial step which forms the principal basis for the technical content of the ITP, is the development of a forecast of future civil space flight programs and their technology needs and priorities. This forecast was discussed in Chapter 2. In addition, two other key aspects of the ITP methodology include: (1) definition of an overarching strategy for technology maturation and transfer; and (2) development of a program structure and investment

[1] See Figure 3-3 for an overview of this program structure.

[2] In order to facilitate the assessment, a set of 'technology keystones' for future civil space missions was identified; these are listed in Appendix D. (A 'keystone technology" area is one which is a necessary ingredient for future civil space mission success, and which can be readily mapped against the various National technology assessments.)

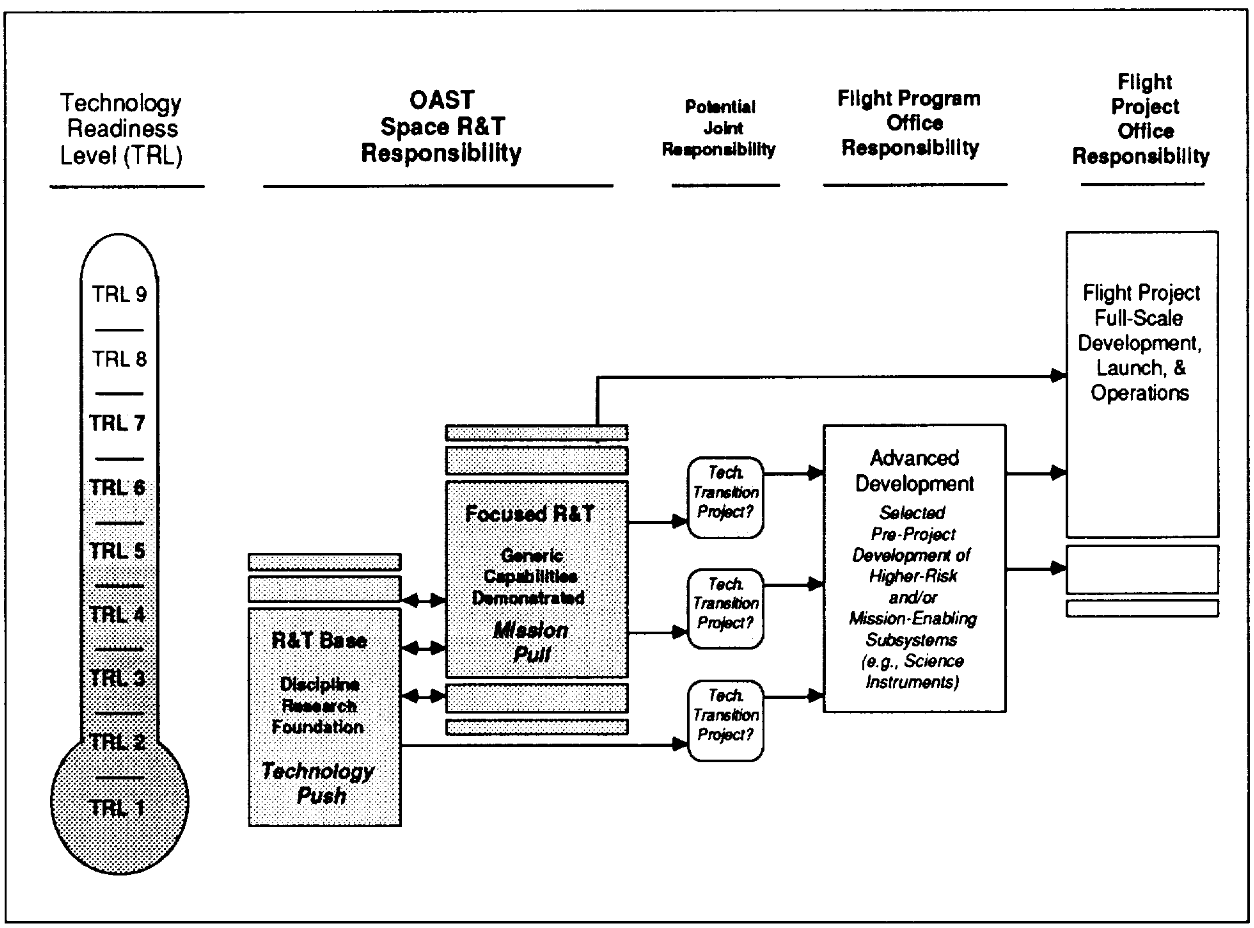
decision rules intended to support the maturation strategy. These aspects are summarized in the following section. Another important step is the definition of the actual ITP technical strategic plan. This strategic plan is reviewed in the following sections, including both the top level strategy for space R&T implementation as well as derived individual technical strategies for both base and focused R&T. A discussion of the process for strategic prioritization and of the 1991 ITP strategic investment priorities concludes this chapter.

The final step in the ITP methodology is the development of specific programs and budgets on an annual basis. Chapter 4 describes the process by which the ITP strategic plan is updated and used to develop annually OAST space R&T program. It also provides a detailed assessment of the FY 1992 OAST space R&T Program and evaluates how well this program supports the ITP's strategic objectives.

TECHNOLOGY MATURATION STRATEGY

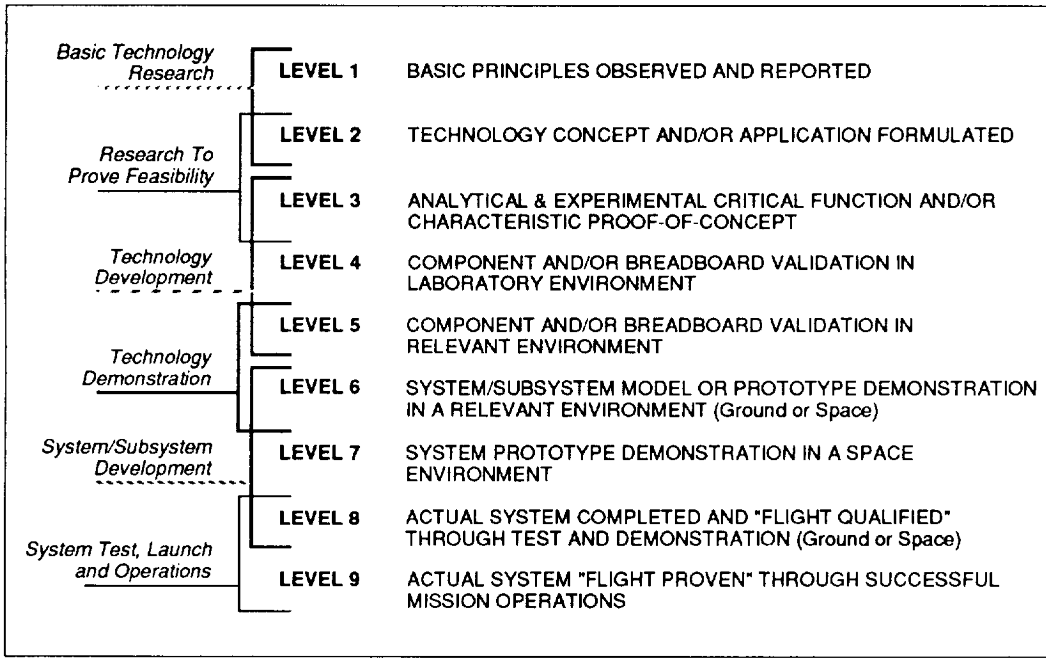
The successful transfer of technology from the researcher's laboratory to a flight project system has been one of the primary issues identified by recent external evaluations of the space R&T program. A central component of the ITP is an effort to improve this transfer process. The basic ITP approach is a reliance upon an explicit strategy for the maturation of space technology. It is critical to recognize in this strategy that advanced, generic space R&T is only part of the total space R&T maturation strategy. In addition to space R&T, the application of new technologies depends upon successful pre-project advanced development (or advanced technology development) programs. Technology maturation is really only completed during the program office full scale development (FSD) flight project and flight operations. Figure 3-1 depicts the overall technology maturation strategy used in developing the ITP.[3] It includes not only advanced, generic R&T, but also the later stages of technology maturation.

Figure 3-1
NASA Civil Space Technology Maturation Strategy



Within this strategy, nine technology readiness levels have been defined, ranging from the basic physical principles, to a "flight proven" system. Figure 3-2 provides these definitions. Typically, the goal of space R&T is to take technology to a maturity of "level 5"which is characterized as component or breadboard validation in a relevant test environment (including space). On the basis of this strategy for space technology maturation and transfer, the program structure for the ITP has been defined.

Figure 3-2
NASA Civil Space Technology Readiness Levels



PROGRAM STRUCTURE

The space R&T program structure incorporated in the ITP includes two major types of space technology research and development: the R&T Base, which addresses result-driven research or technology opportunity-driven R&T activities; and the Civil Space Technology Initiative (CSTI), which incorporates a series of focused programs directed at meeting the technology needs identified by civil space mission planners.[4] Figure 3-3 provides an overview of this structure.

Given the technology maturation strategy and the program structure, two key issues remain: (1) how to construct a viable annual space R&T investment from a seemingly infinite set of possible research efforts; and (2) how to assure concurrently that the program adequately implements established space R&T Program principles. To guide this definition, OAST first developed an overall strategy for balancing basic and focused investments. Secondly, OAST defined two sets of more detailed decision rules: one for the R&T Base and a second for the focused technology programs. In addition, the focused programs are planned to be driven by the "pull" of mission needs for technology advances. Thus, the "mission pull" component of the space R&T program investment is also driven by prioritization against a set of mission-driven criteria. The program structure and the decision rules that follow are specifically intended to embody the program principles of the OAST space R&T program, discussed in Chapter 1.

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[3] The relationship between advanced, generic space R&T programs and flight program office technology development is a vital one. This topic is discussed more fully in Chapter 5 on "Space Technology Transfer and Development Coordination."

[4] This approach represents a significant revision of the space R&T program structure from previous years. Within the ITP, the R&T Base component of the program includes both the ongoing content of the R&T Base as well as the content of the "in-space technology experiments program" (IN-STEP) line item. Similarly, in the ITP, CSTI includes both the ongoing content of CSTI, as well as the work previously accounted for under the Space Automation and Robotics line item, and the Exploration Technology Program (a.k.a., Project Pathfinder). In addition, the program structure discussed here represents several more specific adjustments to improve technology planning and transfer.

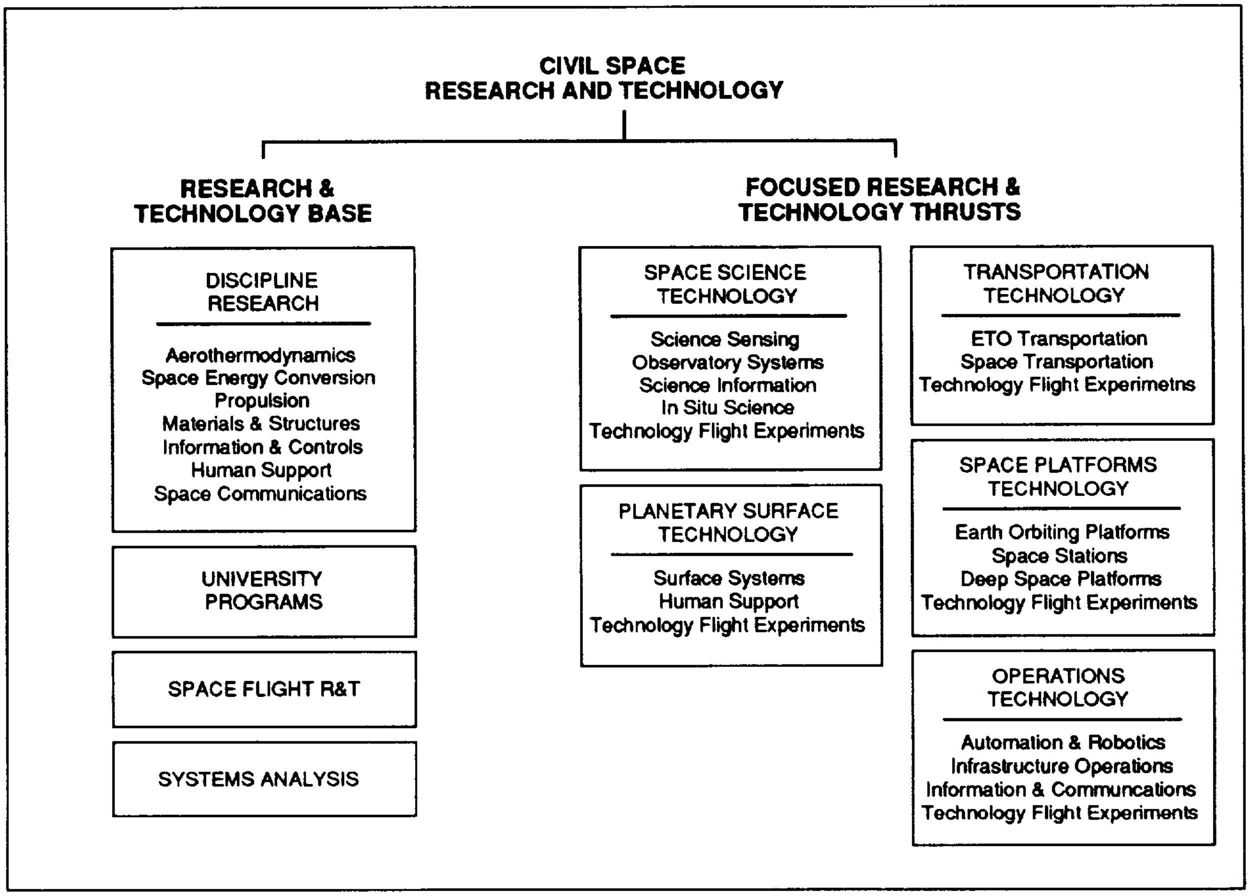

Figure 3-3
NASA Civil Space R&T Program Structure

Decision Rules

The basic space R&T budgeting strategy used in the development of the ITP deals with the issue of maintaining the right balance between R&T Base and focused technology development. In particular, the budget strategy was to assure that the R&T Base is to be maintained at least at a constant purchasing power, and targeted in future years at a funding level of approximately one-third the total budget for space R&T in planning growth.

R&T Base Decision Rules

The space research and technology (R&T) Base is that portion of the R&T program within which NASA proposes to conduct discipline oriented, "technology push" activities. In terms of budget, the proposed ITP would set the R&T Base at approximately one-third of the total space R&T investment.[5] With regard to the program content, Figure 3-4 provides a summary of the decision rules used in developing the detailed investment strategies for the R&T Base. These rules include: (1) general rules applying equally to all aspects of the Base; and (2) specific rules for discipline research and small flight validation experiments, for university programs, and for the IN-STEP program. This budgeting approach is intended to assure that an adequate foundation of critical expertise and a strong level of activities in new and innovative research areas will be maintained. Although the major focus of the NASA space R&T program in the future will be on technology development and demonstration for capabilities that directly support stated mission needs.

[5] In other words, whatever the mission derived focused programs (see below) are determined to be, the total target budget value for the R&T Base would be strategically set at approximately one half that amount.

Figure 3-4 *Space R&T Base Decision Rules*

GENERAL RULES

- USE EXTERNAL REVIEWS TO AID IN ASSURING PROGRAM TECHNICAL QUALITY
- PROVIDE STABILITY BY COMPLETING ON-GOING DISCRETE EFFORTS

DISCIPLINE RESEARCH

- ASSURE ADEQUATE SUPPORT TO MAINTAIN HIGH-QUALITY IN-HOUSE RESEARCH CAPABILITIES IN AREAS CRITICAL TO FUTURE MISSIONS
  - — PROVIDE CAPABILITIES FOR AD HOC SUPPORT R&T FOR FLIGHT PROGRAMS
- PROVIDE GROWTH IN R&T BASE AREAS NEEDED FOR FUTURE FOCUSED PROGRAMS
  - — COORDINATE WITH ANNUAL FOCUSED PROGRAM PLANNING
- CREATE ANNUAL OPPORTUNITIES FOR THE INSERTION OF NEW R&T CONCEPTS
  - — GOAL: PROVIDE APPROXIMATELY 15-20% "ROLL-OVER" PER YEAR
- SUPPORT TECHNOLOGY PUSH FLIGHT EXPERIMENTS WHERE SPACE VALIDATION IS REQUIRED

IN-STEP FLIGHT PROGRAMS

- MAINTAIN COMPETITIVELY-SELECTED STUDIES/IMPLEMENTATION OF IN-HOUSE AND INDUSTRY/UNIVERSITY SCALE FLIGHT EXPERIMENTS, ORIENTED ON NASA's TECHNOLOGY NEEDS

UNIVERSITY PROGRAMS

- EVALUATE TO FOCUS PARTICIPATION IN NASA SPACE R&T BY U.S. UNIVERSITIES AND COLLEGES — USING COMPETITIVE SELECTION

Focused Programs Decision Rules and Criteria

The focused space R&T program is that portion of the R&T program within which NASA proposes to conduct functionally oriented "mission pull" activities. In terms of budget, under the proposed ITP, OAST will develop grassroots cost estimates for focused "technology projects" to achieve certain technology development and demonstration objectives on specific schedules. Figure 3-5 provides a summary of the decision rules used in developing the detailed investment strategies for the focused technology programs of CSTI. These rules include: (1) general rules applying equally to the several elements of CSTI; and (2) specific rules for major future OAST flight experiments.

To implement the first general rule for focused programs, a set of specific "investment prioritization criteria" is used. (Figure 3-6 presents the set of prioritization criteria.) These criteria center upon: (a) mission need for the proposed technology (including the degree to which the technology is needed by several potential users, i.e., commonality); (b) programmatic and timing issues associated with the technology development (when the user needs the technology to be sufficiently mature to use at the beginning of detailed design versus the R&T program duration OAST planners project will be required to reach that level of maturity); and finally, (c) special issues or factors that bear on the investment decision (the R&T team's readiness to begin a focused technology project or possible interrelationships with other government programs).

Detailed budget levels for focused programs are driven by the content of individual element technology plans. Building on user-provided mission forecasts, technology needs and priorities and the R&T program decision rules, priorities for the elements of the focused programs are established.[6] The prioritization of the elements of the strategic plan is discussed at the end of this chapter. The application of that prioritization to the development of a particular OAST space R&T program (e.g., for fiscal year 1992) is delineated in Chapter 4.

[6] Figure 3-24 provides a summary of the prioritization of focused program elements at the "strategic plan" level. This prioritization was both a product and a tool in the development of the ITP.

GENERAL

- ANNUALLY ASSESS AND FUND PROJECTS IN ORDER OF PRIORITY AGAINST MISSION-DERIVED INVESTMENT CRITERIA
  - — EXTERNAL REVIEW WILL BE USED TO AID IN ASSURING QUALITY
  - — REVIEW WITH USER OFFICES WILL BE USED TO AID IN ASSURING RELEVANCE AND TIMELINESS
- PROVIDE STABILITY BY COMPLETING ON-GOING DISCRETE EFFORTS
- START A MIX OF TECHNOLOGY PROJECTS WITH SHORT-, MID- AND LONG-TERM OBJECTIVES EACH YEAR
- ASSURE BALANCED INVESTMENTS TO SUPPORT THE FULL RANGE OF SPACE R&T USERS
- FUND NEW TECHNOLOGY PROJECTS THAT HAVE PASSED INTERNAL REVIEWS AS REQUIRED (E.G., NON-ADVOCATE REVIEW FOR MAJOR EXPERIMENTS)

MAJOR FLIGHT EXPERIMENTS

- SUPPORT COMPETITIVELY-SELECTED IMPLEMENTATION OF IN-HOUSE AND INDUSTRY MAJOR TECHNOLOGY FLIGHT EXPTS IN ACCORDANCE WITH MISSION-DERIVED PRIORITIZATION CRITERIA
- FUND MAJOR FLIGHT EXPERIMENTS WHERE ADEQUATE GROUND-BASED R&T IS UNDERWAY OR HAS BEEN COMPLETED

Figure 3-5 *Focused Programs Decision Rules*

MISSION NEED	Engineering Leverage Performance (Including Reliability) Leverage of the Technology to A System Importance of That Technology/System Performance To A Mission And Its Objectives Cost Leverage Projected Cost Reduction For A Given System/Option Projected Cost Reduction for A Mission of That Savings Breadth Of Application Commonality Across Missions/Systems Options Commonality Across Systems in Alternative Mission Designs
PROGRAMMATICS & TIMING	Timeliness Of Planned Deliverables Timing of the Mission Need for Technology Readiness Projected Duration of R&T Needed To Bring Technology to Readiness Criticality Of Timely R&T Results To Mission Decisions Timing of Mission Planning Need for Technology Results Importance of Technology To Mission Objectives/Selection Uncertainty in Planned R&T Program Success/Schedule
SPECIAL ISSUES	Readiness to Begin A Focused Technology Project Commitment To An Ongoing R&T Program Interrelationships To Other Government Program(s) Projected "National Service" Factors

Figure 3-6 *Focused Programs Mission-Driven Prioritization Criteria*

Overarching Space R&T Strategy

A forecast of future civil space activities and technology needs, discussed in Chapter 2, provides the basis for an overall implementation strategy for civil space research and technology. To meet those needs, a space research and technology program structure was defined, including both R&T Base and focused R&T efforts. (Figure 3-3 depicts the structure.) Within this structure the overarching ITP space R&T implementation strategy is: plan and prioritize technology to achieve specific objectives in specific timeframes. First, to meet near term technology needs, second to meet mid term needs, and finally, to meet far term technology needs. In each case, the goal is to define the top level actions that need to be accomplished during the next five to ten years to achieve key future civil space R&T objectives. Figure 3-7 provides a summary of this overall programmatic strategy for civil space R&T, which is described in the following paragraphs.

For Near Term Needs

In 1993 through 1997, the approach will be to complete the ongoing program that supports near term needs, and to implement key selected new tasks. By 1993 through 1997, the program will deliver selected high leverage subsystem capabilities for projected mission new starts. The support for this block of missions/technology needs will be targeted as a relatively small share of the total space R&T investment.

For Mid Term Needs

In 1993 through 1997, the approach will be to complete the ongoing program that supports mid term needs, to begin high priority new R&T efforts and to begin emplacement of, or initiation of, critical R&T testbeds and facilities into place. By 1998 through 2003, the program will deliver major new system capabilities, conduct major ground demonstrations and flight experiments, begin the use of Space Station *Freedom* for R&T experimentation and demonstrations, and prepare to leverage NASP technology and demonstrations for space system applications. The support for this block of missions/technology needs will be targeted as the majority of the total space R&T investment.

For Far Term Needs

In 1993 through 1997, the approach will be to complete the ongoing program that supports far term needs, and to begin selected, long term R&T efforts. By 2004 through 2011, the program will deliver major new systems capabilities, achieve technology readiness for human missions to Mars applications, and begin use of the Lunar outpost for R&T experimentation and demonstrations. The support for this block of missions/technology needs will be targeted with the remaining share of the total space R&T investment.

The top level aspects of this overall strategy will be reviewed and adjusted only minimally on an annual basis. However, the details in any given technology area will be updated annually to reflect changes in the flight programs forecast or other aspects of the program planning process. The following sections provide the details of the specific strategic plans for base and focused space R&T programs.

FOR NEAR TERM NEEDS IN 1992-1997, COMPLETE THE ONGOING PROGRAM; IMPLEMENT KEY SELECTED NEW SPACE R&T FOCUSED AND BASE TASKS	• BY 1993 THROUGH 1997: — DELIVER SELECTED HIGH-LEVERAGE NEW SUBSYSTEM CAPABILITIES
FOR END-OF-DECADE NEEDS IN 1992-1997, COMPLETE THE ONGOING PROGRAM; BEGIN HIGH PRIORITY NEW FOCUSED SPACE R&T; CONDUCT EARLY R&T BASE PROGRAMS AS REQUIRED; BEGIN TO PUT CRITICAL R&T TESTBEDS & FACILITIES INTO PLACE	• BY 1998 THROUGH 2003: — DELIVER MAJOR NEW SYSTEM CAPABILITIES — CONDUCT MAJOR DEMONSRATIONS AND FLIGHT EXPERIMENTS — BEGIN SIGNIFICANT USE OF SSF FOR R&T — LEVERAGE NASP DEMONSTRATIONS AND/OR GENERIC HYPERSONICS RESEARCH — LEVERAGE HPCC DEMONSTRATIONS
FOR FAR-TERM NEEDS IN 1992-1997, COMPLETE THE ONGOING PROGRAM, BEGIN SELECTED, VERY LONG LEAD TIME & HIGH PRIORITY NEW FOCUSED R&T PROGRAMS; CONDUCT EARLY R&T BASE PROGRAMS AS REQUIRED	• BY 2004 THROUGH 2011: — DELIVER MAJOR NEW SYSTEM CAPABILITIES — CONDUCT MAJOR DEMONSRATIONS AN FLIGHT EXPERIMENTS — BEGIN USE OF LUNAR OUTPOST FOR R&T — ACHIEVE MARS MISSION TECHNOLOGY READINESS

Figure 3-7
Civil Space R&T - Overarching Technical Program Strategy

R&T BASE STRATEGY

The space R&T Base is the "technology push" component of NASA's space research and technology strategy. It provides the discipline foundation for the ITP, as well as resources for major, integrated university program activities and small scale technology flight experiment activities. The basic investment strategy for the R&T Base is two-fold: first, that the R&T Base will be maintained at least at its current budget level, with modest growth commensurate with sustaining purchasing power; and second, that as space R&T Program augmentations are achieved, the balance of R&T Base to focused R&T programs will be targeted at a one-third (Base) to two-thirds (focused) mixture.

Specific program areas in the R&T Base include:

- Discipline Research, including aerothermodynamics, space energy conversion, propulsion, materials and structures, information and controls, human support and advanced communications R&T
- University Programs, including the OAST University Space Engineering Research Center (USERC) Program
- Space Flight R&T, including the In-Space Technology Experiments Program (IN-STEP)
- Systems Analysis, which addresses technology assessments and analysis for future space R&T planning support.

Within the discipline research areas in particular, the 1991 ITP R&T Base strategic plan can be organized into three major categories: (1) base capabilities; (2) advanced technologies; and (3) breakthrough technologies. Figure 3-8 provides a summary of the space R&T Base strategic plan against these areas. The following sections provide the details of the technical strategy in each discipline research area, in university programs, space flight R&T, and systems analysis.

Discipline Research

The overall strategy for NASA OAST Discipline Research is to: (1) maintain high-quality in-house NASA technology research in base capability areas critical to future civil space missions; (2) provide early advanced technology investments in research areas targeted to become focused programs in the future; and (3) create opportunities for innovative R&T proposals to enter the program that could lead to major breakthroughs for future missions ("technology push"). This overall strategy is applied throughout the complete family of specific R&T Base Programs. In the following paragraphs, the near term investment strategy for the individual Discipline Research areas is provided.

Aerothermodynamics

The program will address computational tool development, experimental research and computation validation, research and development for new aerothermodynamics R&T facilities, and configuration assessment studies for future flight systems. As resources permit, efforts in each of these areas will be augmented, with particular emphasis on growth in facilities research and configuration assessments.

Space Communications

This program represents the integration of the ongoing OAST communications R&T efforts and the advanced communications technology development program that was previously a part of OSSA's former communications research program. The program will continue R&T in the areas of radio frequency (RF) communications links, digital data transmission, optical communications links, and mobile satellite communications.

Human Support

This program will provide continuing research in the areas of physical-chemical life support systems (including sensors for trace contaminant monitoring and habitat thermal management), extravehicular activity systems (e.g., high-pressure joints and portable life support system regenerable thermal management components), and human factors (including human performance modeling and virtual reality systems).

Information Sciences and Controls

This program will address ongoing efforts in controls, sensors, artificial intelligence, telerobotics, and computer science/software engineering. In addition, as resources permit, minimally funded activities will be augmented, including neural networks, photonics, computational controls, and high-temperature superconductivity. Finally, new areas for future program activities include micromachines, microsensors, and sensor optics.

Materials and Structures

This component of the R&T Base will continue NASA efforts in materials science, space environmental effects, aerothermal structures and materials, space structures, and the dynamics of flexible structures. As resources permit, efforts in each area will be augmented. In addition, new efforts may be started in the areas of computational materials, optics, arcjet facilities research, space mechanisms, space bonding and welding, non-destructive evaluation and non-destructive inspection (NDE/NDI), spacecraft dynamics analyses, and vibration and acoustic isolation.

Propulsion

This program will continue to invest in low-thrust propulsion (both primary and auxiliary propulsion), high-thrust chemical propulsion, cryogenic fluid management, and in advanced propulsion concepts. If resources permit, ongoing R&T will be augmented in each of these propulsion areas, including: (1) high-thrust chemical—alternate materials for engine components and high-mixture ratios; (2) low-thrust propulsion—water resistojets and solar electric propulsion system (SEPS) class electric thrusters; and (3) very innovative advanced propulsion concepts, such as antimatter applications. The emphasis in program augmentation will be on creating new, advanced concepts opportunities.

Space Energy Conversion

The R&T Base program will continue efforts in photovoltaic (PV) energy conversion, chemical energy storage and conversion, thermal energy conversion, power management and distribution, and thermal management. Resources permitting, the principal emphasis for growth will be in PV energy conversion (e.g., advanced solar cell materials and fabrication techniques). Other specific areas for maintenance of NASA capability include advanced power system diagnostics and modeling, and facilities for space environmental effects simulation. Also, other areas for investment in future focused programs include chemical/thermal energy conversion, and power/thermal management. Finally, high-leverage, high-risk technology push research areas will be addressed, including R&T challenges such as diamond film power electronics and lithium-carbon dioxide (Li/CO_2) cells.

Figure 3-8
1991 ITP Strategic Plan: R&T Base Program Categorization

	BASE CAPABILITIES			ADVANCED TECHNOLOGIES		
Aerothermo-dynamics	Hypersonic Flowfield Sim.	Hypersonic Vehicle Synth.	----	Flt. Environ. Instrument'n	Configuration Design/Optimiz.	----
	Fundamental Data Bases	----	----	Aerothermo. Design Tools	----	----
Advanced Communications	Travelling Wave Tubes (TWTs)	----	----	KaBand TWT	Digital Switching Processors	Ground Terminals
	MMICs	----	----	Solid State MMIC Systems	Direct Broadcast (Audio)	----
Space Energy Conversion	Photovoltaic Perf. Validation	Solar Dynamics Design/Analysis	----	Adv. Solar Cells (GaAs, In-P)	Adv. Batteries (Rechg/Life)	Thermoelectric Conv. Systems
	Electrochemical Diagn./Models	----	----	Concentrators and Arrays	Solar Dynamics Conv. Systems	Power Mgt. & Distribution
Human Support	-Extravehicular Activity Suit	----	----	EVA Gloves	EMU Components	Life Support Models
	Human Modeling (Cogn./Physical)	----	----	PLSS Components	Interactive EVA Displays	Life Support Sensors/Cntrls
Information and Controls	Electro-optic Mat's/Sensors	----	----	Advanced AI Research	Computational Controls	----
	----	----	----		Software Develop. Tools	----
Materials and Structures	Materials Synthesis	Space Durable Materials	Sp. Environ. Effects (Mat's)	Optics	High Precision Structures	Durable Polymers
	High Temp. TPS	Advanced Space Struct. Concepts	Tribology	Mechanisms	Lg./Deployed Struct.	High Temp. Veh. Struct.
				Extreme TPS	Debris Shielding	
Propulsion	Combustion Models/Diagn.	Internal Pump Flow CFD	----	Ion Thrusters	Water Resistojets	H-O Engines
	Engine Analysis Expert Systems	Cryo. Fluid Modeling	----	Hydrogen Arcjets	Iridium-Rhenium Engine Liners	Propulsion Health Mgt.
				MPD Thrusters		

University Programs

NASA's space R&T programs are universally conducted with a high degree of participation by the U.S. academic community. In addition, one segment of the R&T Base is dedicated to engaging academia more directly in space technology advancement. The university programs of the R&T Base are organized into three major categories:

University Space Engineering Research Centers

The University Space Engineering Research Center (USERC) Program fosters independent, creative concepts for future space systems and expands the national pool for advanced R&T. The objective of the USERC Program is the creation of major university centers, each targeted on some important, often interdisciplinary, R&T challenge facing the civil space program. Currently funded centers address areas such as planetary resource use, advanced propulsion systems, advanced electronics, and space structures.

University Investigators Research Program

The University Investigators Research Program sponsors small, individual research efforts on highly innovative concepts. Examples of areas covered by current grants include low power signal processing, advanced concepts for metallic cryogenic temperature space structures, inflatable structures for a Lunar base, and photonics components for a variety of applications.

"BREAKTHROUGH" TECHNOLOGIES		
----	----	----
----	----	----
Laser Comm. Components	----	----
Mobile Comm. Systems (Personal)	----	----
Laser Power Components	Alkali Metal T-E Conversion	Diamond Film Pwr Electronics
Adv. Fuel Cells (Li/CO2)	Liquid Sheet Radiators	----
Visualization Research	AI Computer Associates	----
Virtual Reality Environments	----	----
Micromachines	Photonics	Multiple Inter-active Robots
Neural Networks	High-Temp Superconductors	----
Intermetallics & Metal Matrix	Computational Materials	Adaptive Materials
Computational Chemistry	"Smart" Materials	----
High Energy Density Propell.	Laser Rocket Propulsion	Superconduct. Bearings
Electrodeless Thrusters (ECR)	Fission/Fusion Propulsion	----

University Advanced Design Program

The University Advanced Design Program has encompassed approximately 1,000 students in interdisciplinary university engineering design, through small grants that are administered by the University Space Research Association (USRA). In the advanced design program, the goal is to foster engineering design education, and universities are teamed with NASA field center mentors.

Preliminary options for future augmentations to the OAST university programs include solicitation and selection of additional full-scale USERCs and the potential for creation of smaller-scale "associate" USERCs at additional universities.

Space Flight R&T[7]

The OAST approach to technology flight experimentation as a part of R&T Base follows three major themes. First, the space environment can be a natural extension of a NASA laboratory in conducting technology research. (For example, to achieve technology readiness level 4 as depicted in Figure 3-1.) Thus, technology flight experiments may be needed to extend R&T Base ground laboratory efforts and obtain fundamental information on the performance of a particular component or process in the space environment. Second, access to space for smaller-scale technology flight experimentation in areas of interest is a service that OAST plans to provide to university and industry space R&T participants. Thus, the R&T Base space flight program includes the In-Space Technology Experiments Program (IN-STEP), which provides, through a competitive selection process, the opportunity for non-NASA technology researchers to conduct in-space technology experiments. (Support for experiment integration is also provided.)

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[7] Strategies and plans for in-space technology experimentation are discussed in more detail in Appendix C: Space Technology Validation.

Finally, as part of the focused programs, technology development can be taken to demonstration in the space environment to validate the technology and facilitate transfer to user applications. In the R&T Base, the strategy provides for early studies to be implemented for potential moderate-to-major technology flight experiments to determine their feasibility and provide early evaluation of costs.

Preliminary options for future activities in OAST Space Flight R&T programs include solicitation and selection of additional IN-STEP experiments, as well as continuing studies of potential focused program flight experiments.

SYSTEMS ANALYSIS STUDIES

Systems analysis studies represent a continuing analytical foundation for space R&T planning. Key areas of expertise required for OAST space R&T program systems analyses include space technology forecasting and assessment, R&T and flight project cost estimation, and operations research. Specific studies are conducted in a wide variety of potential technology program topic areas. During the next two to four years, these should include studies within each of the various technology thrusts: space science, planetary surface technology, transportation, space platforms, and operations. In addition, the development of new tools and methodologies for technology assessments and systems analysis studies will continue to be an important goal. Finally, preliminary studies of extremely innovative, "breakthrough" concepts also may be conducted.

FOCUSED TECHNOLOGY PROGRAMS STRATEGY

The focused technology programs within CSTI are the "mission pull" component of NASA's space research and technology strategy. They provide focused technology development and demonstration for the ITP. Specific CSTI program thrusts include: (1) *Space Science Technology*; (2) *Planetary Surface Technology*; (3)*Transportation Technology*; (4) *Space Platforms Technology*; and (5) *Operations Technology*. Within each thrust, a series of functional program areas has been defined, and a family of related element technology activities and/or strategies has been established.

The top-level strategies for each of the focused program thrusts, program areas, and elements are provided in the following subsections. In addition, in technology thrust discussion a series of tables is provided that include a technology assessment and a structure statement of objectives for each program area in the thrust. In particular, these tables provide preliminary information of: (1) key technical goals; (2) the current state of the art in that technology area; and (3) a projection of near, mid and far term R&T objectives.[8]

Also, the ITP, which is a strategic plan, is only one part of a larger planning system that guides the implementation of NASA's space R&T efforts. The next level of detail regarding the program is documented in a separate long range program plan for each thrust.[9] Similarly, within each thrust, a detailed technology project plan is developed for each of the elements that are funded. This planning system (the ITP, the thrust program plans, and the technology project plans for funded elements) will be updated annually. A discussion of the annual planning cycle, the process by which the strategic plan is translated into the OAST Space R&T Program, as well as a summary of the FY 1992 program, is provided in Chapter 4.

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[8] The information provided in these program area tables is preliminary, and intended only as a reference point in the 1991 ITP. As a part continuing refinement of the ITP, including additional interaction with user offices, as well as with other R&T participants, these data will be revised (and the results incorporated in the 1992 ITP).

[9] These 'thrust plans" were still under development when the 1991 ITP was finalized.

Space Science Technology

The Space Science Technology Thrust is primarily concerned with developing the advanced technologies required for acquiring and understanding observations from future space and Earth science missions. This can include missions undertaken by either NASA, including OSSA, or by other government agencies, such as NOAA. Such missions are concerned with broadening our scientific understanding of the Earth, our solar system, and the universe beyond. To do this, NASA will make observations from both the Earth's surface and Earth orbit, and send a series of increasingly sophisticated piloted and robotic spacecraft to a number of solar system bodies for *in situ* observations. Specific space science program areas include: science sensing; observatory systems; *in situ* science; and science information.

Science Sensing

The goal in this area is to develop and demonstrate science sensing components across the electromagnetic spectrum for increasing sensitivity as well as greater spatial and spectral resolution. Figure 3-9a provides a summary of the space R&T objectives for this technology program area. During the coming decade, the science sensing strategy includes development in: (1) direct detectors; (2) submillimeter sensing; (3) laser sensing; (4) active microwave sensing; (5) passive microwave sensing; (6) sensor electronics and processing; and (7) optoelectronics sensing.

Direct Detectors

The goal for direct detectors is to demonstrate the feasibility of advanced detector technologies for Earth science, solar system exploration, space physics and astrophysics missions. Objectives include increased detector sensitivity, spatial resolution, and spectral coverage in all regions of the electromagnetic spectrum. Activities include detectors (and/or arrays) for visible, IR, X-ray and gamma-ray photons.

Submillimeter Sensing

The space R&T goal for submillimeter sensing is to develop and demonstrate submillimeter wave heterodyne components to 3000 GHz for astrophysics and Earth science missions. Objectives are increased sensitivity spatial resolution and spectral resolution submillimeter components including spectrometers, arrays, mixers and local oscillators.

Laser Sensing

The goal for active laser sensing is to support Earth sciences through development of models of laser processes and characteristics, and efficient, long-lifetime doppler LIDAR measurement systems for atmospheric wind, water and gas measurements. Laser sensor technologies to be developed include laser diodes at new wavelengths and longer lifetimes and laser diode arrays.

Active Microwave Sensing

The goals in this program element are to broaden frequency bands and increase efficiency for active microwave sensing, including development of lightweight, conformal array designs utilizing monolithic microwave integrated circuits (MMICs) transmit/receive modules and operating between 0.5 and 90.0 GHz, with improved flexibility using advanced digital correlators. Potential applications include Earth science spacecraft (e.g., EOS), topographical measurement missions, meteorological radar missions, and advanced planetary radar mappers.

Passive Microwave Sensing

The space R&T focused program goal in passive microwave sensing is to develop the technology needed for future LEO Earth sciences (e.g., multifrequency imaging microwave radiometers and advanced microwave limb sounders), GEO Earth sciences (e.g., low and high frequency radiometers), as well as for potential deep space applications. Technical objectives include amplifiers, MMIC components and electronic steering, including instruments such as synthetic aperture radars (SARs) and large aperture radiometers.

Sensor Electronics and Processing

The goal in space R&T for sensor electronics and processing is to develop sensor readouts for future detectors, including packaging amplifiers, multiplexers, and backplane processing. Objectives are to develop reduced noise electronics with reduced heat loads to support cryogenic sensor operations (in the 2 to 4 K range) with high throughput and low power consumption.

Optoelectronics Sensing

The goals in this element are to develop and demonstrate photonics (optoelectronics) for science data acquisition applications. Specific technical objectives include advanced optoelectronic tunable filter (AOTF) multispectral imagers, fiber optics systems for space interferometry, special-purpose sensor lasers, and all optical mixers for submillimeter sensing.

Figure 3-9a
Space Science R&T Objectives

SCIENCE SENSING	Direct Detectors	Submillimeter Sensing	Laser Sensing	Active Microwave Sensing	Passive Microwave Sensing	Optoelectronics Sensing
KEY TECHNICAL GOALS	• Increase Detector sensitivity in all EMS regions • Increase Spectral coverage in all EMS regions • Increase size of detector arrays	• Demonstrate submillimeter wave heterodyne components to 3000 GHZ • Develop submillimeter arrays • Demonstrate spectrometers with 200k channels	• Develop analytic models of Laser Processes and Characteristics • Increase effiency to 5% • Extend shot life to $5x10^9$ cycles • Develop continuous tuning	• Extension of component frequency from10 GHz to 90 GHz • Increase peak power from 250W to 600W • Increase efficiency >35%	• Greater resolution, extended swath width • Develop calibration methods • Low-loss MMIC Components • Phased Array steering	• High power stable tunable semiconductor lasers • Optical fibers for interferometry • AOTF multispectral imager • Optical mixer for millimeter wave suitable for arraying
CURRENT STATE OF THE ART ASSESSMENT	• Discrete Gamma and X-ray detectors • UV and visible Si CCD's (2048x2048) • SWIR HgCdTe & InSb arrays (256x256) • LWIR HgCdTe <12µm • Far IR single pixel bolometers	• Local Oscillators - output power- 50 u-watts@700GHz - Bandwidth - 3% • Mixers - Sensitivity 20hv/k at 492GHz - Bandwidth 5% • Spectrometer 1000 at 20mW	• <1J/pulse • $< 10^9$ shots pulsed • Limited Tuning	• 1-10 GHz • Surface Accuracy 0.5 cm • Antenna Mass $75kg/m^2$ (Al) • Calibration Error 2-3dB	• Technology demo for 15 M at 12GHz • Operational systems at 5 M, 20GHz • No electronic scanning	• filter wheel and camera • Array of high frequency diodes • Limited wavelength .83, 1.3, 1.55 micron
RESEARCH AND TECHNOLOGY OBJECTIVES — NEAR TERM	• High sensitivity IR array with 250 micron cutoff for SIRTF • EOS IR array with >18 micron cut off at 65K	• 600GHz Astro Demo • 640GHz Planar Ga:As for Earth observing • 800GHz Intial Demo for Astronomy	• CO2 LAWS Breadboard demo 10-20J/pulse	• 1-10 GHz • Surface Accuracy 0.5 cm • Antenna Mass $20kg/m^2$ (composite) • Calibration Error 1.5dB, 10^0 rms	• Conceptual designs for filled and unfilled radiometers • Conceptual design for large aperture low frequency Geo Radiometer	
RESEARCH AND TECHNOLOGY OBJECTIVES — MID TERM	• X-ray P-N CCD Si CCD Detector Array • UV, Visible Advanced CCD large format array	• Spectrometer with 10k channel design • 1x5 Array (600GHz) • 1000GHz initial Demo	• 2 micron semiconductor diode local oscillator • Injection seeding demo	• 35 GHz • Surface Accuracy 0.1 cm • Antenna Mass $5kg/m^2$ (composite) • Calibration Error 1dB, 3^0 rms	• ESTAR receiver-correlator design • Demonstration phased array electronic steering	• optical submm mixer
RESEARCH AND TECHNOLOGY OBJECTIVES — FAR TERM	• Advanced Bolometer Arrays • Broad band IR tunneling Golay cell • Xray, Gamma-ray detector arrays with energy and spatial resolution	• Mixers and Local Oscillators at 3000 GHz • Spectrometer with 200k channels • 2x20 array at 1000GHz	• Solid state breadboard demo • Tunable mid IR demo	• 35,94 GHz • Surface Accuracy 0.03 cm • Antenna Mass 1kg/m • Calibration Error .5dB	• Radiometer Brassboard completed technology demo	• Demo baseline fiber optic space interferometer • Demo superlattice submm detector array • Demo 8-12 micron AOTF spectral imager

OBSERVATORY SYSTEMS

In addition to the technologies needed directly for science sensing, advances also are needed to develop and demonstrate space instrument support and observation technologies to maximize science return for large optical systems at reasonable cost and to provide optimum operating conditions for science instruments. Figure 3-9a provides a summary of the space R&T objectives for this area. The observatory systems strategy includes R&T that addresses: (1) coolers and cryogenic; (2) microprecision CSI; (3) telescope optical systems; (4) sensor optics; and (5) precision pointing.

	OBSERVATORY SYSTEMS				
Sensor Electronics and Processing	Coolers and Cryogenics	Microprecision Control-Structures Interaction (CSI)	Telescope Optical Systems	Sensor Optics	Precision Pointing
• 2-4K readout electronics • 3x heat load reduction • 10x sensor system throughput • Array size10,000x 10,000	• Extend cooling technology from 2K to 100K • Demonstrate long life 5 years • Assure thermal and vibrational stability	• Vibration reduction 4 orders of magnitude • Strategies- multi-layer • Develop submicron methods, instruments, and facilities	• Develop component and system level technology to enable astrometric telescopes in the submillimeter, infrared, UV/visible, and high energy.	• Metrology at nano-meter level • Modelling of straylight diffraction, polarization • Long term flight calibration	• Increase space based telescope and instrument pointing capability by two orders of magnitude beyond HST • Increase reliability, life-time and efficiency
• Noise unacceptable below 10K • Read noise 3-5 e rms in CCD • Array size 256x256 (IR)	• Lifetime ~ 1 yr • cooling power 30mW • 80K cooler on UARS • Unacceptable vibrational levels • Unacceptable parasitic thermal loads	• Local feedback low authority (10dB) • Viscoelastics- 10dB nonlinear suppression • Isolation- passive 10dB • No active members • No simultaneous structure control	• 2.8 meter monolithic glass mirror • 10^{-6} dimensionally stable structure • 4 meter segmented panels, 200kg/m^2	• Minimal modeling • AOTF demo in UV and visible	• 30M pixel •108 arcsec control • 50 arcsec knowledge • 100 arcsec/100sec • 10 arcsec/1sec • 1 arcsec/0.01sec
• Low noise 2-4K readout (IR)	• Complete 30K technology demo breadboard cooler	• MOI CSI component development for interferometer testbed • First generation tools	• 100K materials characterized • 3 micron, 3M ROC, 100k, 1M panel demo		
• Demo content addressable readout	• Complete fabrication and performance testing of 65-80K sorption cooler	• Complete performance modeling for microprecision testbed • Testbed fully operational	• Integrated figure control demo for 4 M panel • Develop 1 micron, 7.5 M ROC, 100K, 2M panel	• X-ray gratings conical, variable line space	LEO • 3 M pixel • 10 arcsec control • 5 arcsec knowledge • 10 arcsec/100sec • 1 arcsec/1sec • 0.1 arcsec/0.01sec
• Sub-electron read noise in CCDs • Demo large format mosaic • Demo low power VHSIC circuits for microwave radiometer signal processor	• Complete fabrication and testing of 2-5K cooler • Complete fabrication and performance testing of advanced 20-30K pulse tube cooler	• Complete testbed validation • Complete CSI technology develop-ment for MOI	• 1M class optical coronograph testbed demonstration • Develop submicron, 100K,2M parabolic panel; submicron figure control demonstration	• Interferometer wide-band optical fiber mixer • Phase conjugated optics for telescope distortion compensation	GEO • 30M pixel •1 arcsec control • 0. 5 arcsec knowledge • 1 arcsec/100sec • 0.1 arcsec/1sec • 0.01arcsec/0.01sec

Coolers and Cryogenics

The space R&T focused program goal is to support Earth and space science instrument cooling and cryogenic temperature requirements from 300 K down to 2 K. The technical objectives include both Stirling and sorption coolers, and extended operational life times with increased efficiency, with minimal vibration, and reduced thermal leakage.

Microprecision CSI

The goal in space R&T for microprecision controls-structures interactions (CSI) is to develop micron and sub-micron level position and stabilization for astrophysics, for the search for planetary systems around other stars, and for microgravity science applications requiring ultra low noise platforms. Objectives are to reduce vibration by factors of three to four orders of magnitude, with multiple-layer CSI designs, and to develop methods for highly accurate prediction and later identification of actual system dynamic performance. One objective of ground based testing is to simulate zero-gravity behavior.

Telescope Optical Systems

Goals in this program element are to develop component and systems level technology to enable the design and development of advanced space imaging and astrometric telescopes with either filled or unfilled apertures. Projected applications range from submillimeter and IR telescopes, UV and visible telescopes and interferometers, to high energy telescopes, and both space based and Lunar surface option telescopes. Technical objectives address low mass precision surface, advanced coatings, extremely dimensionally stable materials and support structures, and submicron figure control.

Sensor Optics

The space R&T focused program goal for sensor optics is to provide full access to the electromagnetic spectrum with orders of magnitude improvement in sensitivity, spatial and spectral resolution, and dynamic range. Technical objectives include interferometric beam combiners, stray light excluders, advanced gratings, and tunable filters. They also include analytical modeling, materials characterization, fabrication and testing techniques for these devices.

Precision Pointing

The strategic objectives of the space R&T focused program for precision instrument pointing include increasing space based telescope pointing capabilities by a factor of ten to one over the HST and by one hundred to one over current remote sensing instrument pointing capabilities. In addition, R&T efforts will address improvements of three to one in reliability, lifetime and efficiency of pointing spacecraft components. Technical objectives include advanced pointing system architectures, multi-aperture pointing, improved attitude transfer, and target referenced pointing leading to sensor and actuator breadboard demonstrations.

In Situ Science

The capability to conduct scientific investigations *in situ* using integrated systems of sensors, mechanical aids, and probes will be of increasing importance during the coming years. The objective of this program area is to develop technologies to enable advanced planetary probes, *in situ* science investigations and robotic mission sample return systems. Figure 3-9b provides a summary of the space R&T objectives for the *in situ* science technology program area. Current planning in this R&T area addresses capabilities for: (1) sample acquisition; analysis and preservation; and (2) small probes (and penetrators).

Sample Acquisition, Analysis and Preservation (SAAP)

The goal in space R&T for sample acquisition, analysis include inquiry methods to identify and classify remotely, mechanical systems for surface sample collection, drills for rock and subsurface coring, and methods to analyze samples chemically and physically. Goals for sample preservation address seals and containers, including R&T to meet forward and backward contamination planetary protection requirements. Potential applications include both Lunar and Mars exploration missions, as well as comet nucleus sample return (CNSR) mission concepts.

Figure 3-9b
Space Science R&T Objectives (con't)

	IN SITU SCIENCE		SCIENCE INFORMATION	
	Sample Acquisition, Analysis and Preservation	Probes and Penetrators	Data Archiving and Retrieval	Data Visualization and Analyisis
KEY TECHNICAL GOALS	• Develop capability to remotely locate sites and samples from spectral data • Develop ability to acquire fresh samples • Enable physical and chemical sample analysis	• Develop the component technologies required for small planetary probes	• Pattern and feature recognition techniques for classifying high rate data • Knowledge-based techniques for capturing critical information	• Visualization approaches for high rate instruments • Multidimensional visualization techniques and display paradigms
CURRENT STATE OF THE ART ASSESSMENT	• 0.4-0.8 micron AOTF based imaging spectrometer • Manual lunar coredrill • Viking instruments • DOE "hot cell" teleoperation • Manual closed containers	• Current technologies derived from Gallieo and DOD are functionally acceptable but large, heavy, and expensive	• On line and near line archiving for gigabyte to teratbytes of data • DAVID, extensive knowledge of location and structure of individual data sets	• 3-D goggles • "Mars the movie" class visualization techniques
RESEARCH AND TECHNOLOGY OBJECTIVES — NEAR TERM	• Remote sample imaging 0.4-2.4 microns • Automated rock coring		• Prototype concepts for recognition of image and spatial data features • Analysis of user requirements	• Document scope of prospective high rate instruments, data structures, metrology, goals
RESEARCH AND TECHNOLOGY OBJECTIVES — MID TERM	• Automated regolith coring • Methods for physical chemical analysis	• Full scale test atmospheric test of deployable aeroshell • Demo descent/impact attitude control	• Prototype system for capturing and organizing meta-data • Prototype system for data screening and classification	• First generation testbed for interactively visualizing and animating science data models
RESEARCH AND TECHNOLOGY OBJECTIVES — FAR TERM	• Integrated SAAP testbed for a robotic science mission in a natural environment	• Demo prototype aeromaneuvering, anchoring, absorbers, and high-g structures • Demo prototype high-g mini RTG in 5 Watt class	• Demonstration of integrated testbed	• Demonstrate an integrated family of techniques and computing environments for interactively visualizing science instrument data as well as merging and comparing with science models

Small Probes and Penetrators

The goals in this program element are to develop and demonstrate the technologies needed for small, low cost probes (and penetrators) to be used as part of an integrated program of planetary science and exploration. Specific technologies for probes/penetrators include: aeromaneuvering; implanting, anchoring, and impact absorption; and miniaturization of spacecraft subsystems for probe use (e.g. power). Planned R&T must also address forward and backward contamination planetary protection requirements.

Science Information

During the next ten years, a variety of missions will require increasingly capable systems for the management and transmission of vast science data sets. The data expected from the multi-decade Earth Observing System (EOS) is an example of this requirement. The strategy in this area is to develop and demonstrate key technologies to enable sustained, near real-time conversion of massive data sets from space science missions into scientific information, facilitating greater understanding of scientific phenomena. Figure 3-9b provides a summary of the space R&T objectives for the science information technology program area. Advances in information technologies are: (1) data archiving and retrieval; and (2) visualization and analysis.

Data Archiving and Retrieval

The space R&T focused program goals are: (1) to develop very large scale data management techniques to enable organizing and structuring of a dynamic, extremely large volume, global data set of observations and derived parameters; and (2) to develop an intelligent user interface to aid scientists in locating and accessing information from massive heterogeneous distributed data bases. Technical objectives address pattern and feature recognition techniques for screening and classifying high rate image and spatial data, advanced data structures and data definition languages, and knowledge based techniques for capturing critical information on parameter-derivation processes.

Visualization and Analysis

The goal in this area is visualization and analysis of large, high rate scientific data sets. The space R&T goal in this element is to develop and demonstrate an integrated family of techniques, procedures and computing environments for interactively visualizing science instrument data, and merging and comparing the data with scientific models. Projected applications include mission planning visualization and simulation, real-time visualization of remotely sensing data, and virtual reality as a tool for scientific investigation. (For example, developments should allow real-time parametric data "touring" through visualization.)

Space Science Technology Flight Experiments

As a part of the overall strategy for space R&T, technology flight experiments will be used to validate critical science technologies. For example, technology flight experimentation may be needed to validate large telescope optical systems, microprecision CSI, or specific sensor technologies. At the present time, however, no specific candidates have been identified in this thrust.

Planetary Surface Technology

The Planetary Surface Technology Thrust is primarily concerned with providing the technology needed for future planetary missions. Such missions have not yet been approved by the Congress, but may occur during the next several decades. The strategic space R&T objective in this area is to develop and demonstrate critical technologies needed for human and robotic exploration of planetary surfaces and the emplacement of human outposts on the Moon and Mars. Specific technology program areas include surface systems and human support.

Surface Systems

The scope and scale of potential planetary surface operations as a part of future robotic and human exploration, in particular of the Moon and Mars, will depend directly upon the technologies incorporated in the surface systems used for the mission. The goal of this R&T program area is to reduce the cost, logistics and maintenance requirements, while increasing the lifetimes and capabilities of future surface systems. Areas of strategic importance are those that increase the self-sufficiency of surface system operations. Figure 3-10 provides a summary of the space R&T objectives for this technology program area. The surface systems strategy includes R&T that address: (1) space nuclear power; (2) high capacity power; (3) planetary rovers; (4) surface power and thermal management; (5) *in situ* resource utilization; (6) surface habitats and construction; and (7) laser-electric power beaming.

Space Nuclear Power

Goals in this program element are to develop space nuclear reactor power systems for a variety of space (and planetary surface) applications with lifetimes that are greater than seven to ten years, and that range from 10 to 1000 kilowatts of electric power. The primary effort in this element is the ongoing joint NASA, DOD and DOE space nuclear reactor power system program, SP-100. Technical objectives include the development and testing of reactors and fuel pins, thermal-to-electric solid state conversion, and thermal management systems. These technologies will be demonstrated as key products in two major tests: (a) a nuclear assembly test; and (b) an integrated assembly test.

High Capacity Power

The space R&T focused program goal in this element is to develop and demonstrate the technologies needed to enhance substantially the power output performance and efficiency of space nuclear reactor power systems. (This effort addresses primarily the SP-100 program reactor power system.) Technical objectives include dynamic power conversion, advanced thermoelectric conversion, and high capacity thermal management systems. The key product from the high capacity power element will be validation (i.e., performance and life testing) of a Stirling cycle engine (1050 K).

Planetary Rovers

The goal for planetary rovers is to develop and demonstrate a wide range of technologies and concepts for application in a variety of mobile planetary surface systems. Technical objectives include vision and route planning, onboard system executives and surface mobility concepts for full size (400 to 1000 kilogram class), moderate-size (100 to 400 kilogram class) and miniature (5 to 100 kilogram class) rover systems. Potential applications include telerobotic and piloted, science and exploration rovers for both the Moon and Mars, as well as operational rovers for a Lunar outpost. Near term research goals are focused on unpiloted science and exploration rovers. Key products from this activity will be a series of planetary rover breadboard demonstrations (of varying system fidelity) in simulated field environments.

Power and Thermal Management

The strategic objectives of the space R&T focused program for surface power include long life and low maintenance regenerative fuel cells, power management and distribution (PMAD) systems, and advanced solar arrays designed for operations on a planetary surface. The space R&T focused program goal in thermal management addresses Lunar and Mars surface tailored heat pumps and radiators. A key product from this activity will be laboratory demonstration (performance and lifetime) for an advanced regenerative fuel cell (RFC) for extended Lunar surface applications. This element will be closely coordinated with the platform power and thermal activity within the Space Platforms Thrust.

In Situ Resource Utilization

The goals in space R&T for *in situ* resource utilization (ISRU) is to develop the information needed to select the optimal processes for resource extraction and to develop the technology for operations based on those processes. Technical goals include resource extraction processes to produce oxygen, metals, and construction materials, and release gasses such as hydrogen, nitrogen and helium. Other technical goals include mining and beneficiation techniques, and selected *in situ* resource processing to produce simple manufactured end-items (e.g., construction elements such as bricks and beams). An early key product for ISRU will be laboratory validation of several (i.e., four to six) potential regolith processing approaches, leading to a down-selection and the development of technology for one or two specific processes.

Figure 3-10
Planetary Surface R&T Objectives

	SURFACE SYSTEMS PROGRAM AREA					
	Space Nuclear Power	High Capacity Power	Planetary Rovers	Surface Power and Thermal Management	In Situ Resource Utilization	Laser-Electric Power
KEY TECHNICAL GOALS	• Solar-Independent power at levels ranging from 100 to 1000 kilowatts • Lifetime > 7-10 years • Little/No Servicing • Stationary & Mobile Applications • 100% availability	• High-efficiency Thermal to electric energy conversion (dynamic and solid-state options) • Low Mass/High Power Level Heat Rejection Systems	• Small, largely autonomous mobile surface systems • Piloted rover vehicles (pressurized and unpressurized) • Surface Construction Equipment Mobility • Lunar & Mars Ops	• Power levels @≥ 25-50 kW • High-efficiency PV • Local Area Lunar Power Mgt and Distribution • Long-Life Energy Storage • Utilization of in situ materials	• Largely Self-Sufficient Lunar and Mars Operations • Local Mining of Regolith • Extraction of Useful Materials • Simple Local Fabrication	• Very high local power (≥ 1000 kW) • Earth-to-space power transmission (LEO to Lunar) • Long-term goal: space-to-Earth power transmission option
CURRENT STATE OF THE ART ASSESSMENT	• Radioisotope Thermoelectric Generators (RTGs) - Power ≤ 1 kilowatt @ 5-10 W/kg - Life = 5-10 years • Thermoelectrics @ 4% efficiency	• 650 K, 20% efficiency terrestrial stirling	• Apollo LRV (5-day) • Teleoperated ground based systems • Onboard Autonomy: traverse distance per command ≤100m • Related terrestrial systems	• APSA Array @ 60 Watts/kg • Shuttle Fuel Cell @ < 2000 lifetime • Cycles - 1000 (GEO) - 40000 (LEO) • Lifetime (batteries) - 6 years (LEO) - 10 years (GEO+)	• Paper studies • Relevant terrestrial systems • Apollo and Viking surface materials databases	• 1-25 kW Power (SSF to be ≥ 75 kW+) • Onboard power supplies - Batteries - Photovoltaics - RTGs • Other technologies under development
RESEARCH AND TECHNOLOGY OBJECTIVES: NEAR TERM	• n/a	LUNAR • 1050 K, 25% efficiency stirling • Thermoelectrics @ ≥ 6% efficiency • Lunar environment	LUNAR/MARS • Early micro-rover breadboard demo - @ ≤ 1 km class LUNAR • Early piloted rover demo (mobility)	LUNAR • Early surface array breadboard	• n/a	• n/a
RESEARCH AND TECHNOLOGY OBJECTIVES: MID TERM	• NEP supporting LUNAR • SP-100 Space Nuclear Power - Thermoelectrics @ 4% efficiency - Life = 7-10 years - 10-300 kWe • Specific Mass @ ≤ 25-35 kg/kW • Lunar Environment	• Advanced Lunar thermal mgt systems	LUNAR/MARS • Moderate-scale semi-autonomous robotic "regional" rover demo - 100-1000 km class • Lifetime ≥ 1-2 yrs MARS • Sample return option (deep coring sppt)	LUNAR • Validated Regenerative Fuel Cell @ ≥ 25 kWe • Lunar PMAD and active thermal mgt @ ≤ 25 kg/kW	LUNAR • Small-Scale ISRU Experimentation • Lunar Oxygen Pilot Plant	• Earth-to-LEO/GEO power transmission demonstrated ≥ 100 kWe @ GEO (scalable to 1 MW) • Demonstration of low-cost, adaptive segmented optics
RESEARCH AND TECHNOLOGY OBJECTIVES: FAR TERM	• NEP supporting LUNAR • Space Nuclear Reactor Power Syst. - Life = 3-5 years - 100-1000 kWe • Specific Mass @ ≤ 20 kg/kW MARS • Life 2-7 years • Power = 50-100 kWe • Mars Environment	MARS • 1300 K, 30% efficiency stirling • Mars environment	MARS • Robust, semiautonomous robotic rover demonstraition -@ ≥ 1000 km • Lifetime ≥ 1-5 yrs • TBD	LUNAR • Regional power distribution systems • Utilization of in situ materials MARS • Mars array demo • Validated Mars RFC @ ≥ 25 kWe	LUNAR • Processing Technology Ready: - 10 Year Lifetime - 75+ MT/yr Oxygen • Mining Tech. Ready: - 30000 MT/yr mined - Minimal Servicing MARS • Small ISRU Expts	• Earth-to-Lunar power transmission demonstrated ≥ 1000 kWe @ Lunar (scalable to 10 Mw) • Validation of 10 m aperture using low-cost, adaptive segmented optics

Laser Power Beaming

The goals in this program element are to develop and demonstrate technologies for cost-effective optical transmission of high levels of electric power from Earth-to-space and from space-to-Earth. Technical objectives include developments such as free electron lasers (FELs), large-scale and low-mass adaptive optical systems and laser frequency-tailored high-efficiency photovoltaic arrays. Although the long term application of this work is projected to be transmission of power to (and perhaps eventually from) the surface of the Moon, potential near term applications include power transmission for Earth orbiting spacecraft (e.g., during periods when the spacecraft is in Earth's shadow) and for OTV electric propulsion. The key products from this element will consist of a series of increasingly ambitious subsystem demonstrations, leading to full demonstration of laser power beaming to space.

	HUMAN SUPPORT PROGRAM AREA						
Surface Habitats and Construction	Regenerative Life Support	Radiation Protection	EVA Systems	Exploration Human Factors	Remote Medical Care	Artificial Gravity
• Lunar and Mars Operations • Site Preparation • Dust Control • Passive Thermal Management • System Deployment or Construction • Large Volume Surface Habitation	• Safe and efficient long-duration ops • Long-life systems • Minimal logistics • High reliability • Stationary, mobile surface applications • Utilization of in situ materials	• Highly accurate shielding mass predictive codes, over extensive materials database • Vehicle/Shielding configurations and analysis • Utilization of in situ materials	• High operability/ mobility Lunar and Mars EVA systems • Long Life • Local maintenance • Low logistics systems • Low mass EVA systems • Utilization of in situ materials	• Safe and efficient human-machine long-duration operations • Human-machine system reliability ≥ 0.99 for single faults • Fault-tolerant systems	• Safe and efficient human-machine long-duration operations	• Safe and efficient human-machine long-duration operations • Artificial gravity or other mechanical countermeasures as required
• Apollo-era Lunar surface tools, LEM module • No database on current materials vs. usage • Related terrestrial systems (high mass)	• Apollo-era Lunar surface systems • Space Shuttle database • SSF systems under development	• Apollo-era Lunar surface systems • Predictive Codes accurate to +/- 100% with narrow materials database	• Apollo-era Lunar surface systems • Space Shuttle low gravity suit systems	• Apollo-era Lunar surface systems • Space Shuttle database • SSF systems under development	• Space Shuttle health care systems • Space Station health care systems under development	• Skylab experience • Soviet experience • Space Station systems under development
LUNAR • Early demonstration of Dust Control breadboard tech.	LUNAR • Early Lunar surface options demos	LUNAR/MARS • Predictive Codes accurate to +/- 20% with full materials database LUNAR • Limited Lunar shielding demos	LUNAR • Complete breadboard for early EVA system options (suit)	LUNAR • Initial 1/6-gravity human performance database (EVA/IVA)	• n/a	• n/a
LUNAR • Extended Duration Dust Control • Habitat/System Site Preperation • Deployable Habitat Systems	LUNAR • Lifetime ≥ 5-10 years • Closure ≥ 95 % - Water Loop closure > 99%	LUNAR/MARS • Predictive Codes accurate to +/- 10% with full materials database LUNAR • Full Lunar shielding demonstrations (w/ in situ materials)	LUNAR • Complete validation of Advanced Lunar EVA System (w/ PLSS) - Limited local repair	LUNAR • Up to 1 yr missions • Human-machine system reliability ≥ 0.99 for single faults • Fault-tolerant Lunar systems	LUNAR • Initial telepresence based trauma and dental support	LUNAR • Lunar validation experimentation MARS • Early vehicle concept assessments • Mechanical Lab demonstrations
LUNAR • Habitat Life ≥ 15 yrs • Pressure: 10-14 psia • Locally Repairable • Construction Equipment/Systems MARS • Dust Control • Habitat/System Site Preperation • Passive Thermal Mgt	LUNAR • Lifetime ≥ 10-15 yrs • Local Mainenance • Biological subsystems validated • Closure ≥ 99% • Utilization of in situ materials MARS • Lifetime ≥ 1-3 yrs • Common transfer/ surface technologies	MARS • Full Mars shielding demonstrations (w/ in situ materials)	LUNAR • Demonstration of Utilization of in situ materials MARS • Complete breadboard demonstration of Mars EVA Systems (PLSS) - Local repair - Common between transfer & surface	LUNAR • Up to 1-2 yr missions MARS • 1-2 yr missions • Complete integrated database of human performance for transfer/surface ops (0 and 1/3-gravity)	LUNAR • Partial telepresence based surgical, dental support MARS • Planetary quarantine requirements met • Initial AI-based trauma and dental support	LUNAR • Extended duration operations countermeasures (mech.) MARS • Detailed vehicle concepts assessed • Flight validated artificial-G (if req'd)

Surface Habitats and Construction

The space R&T focused program goal for this element is to develop and demonstrate concepts, techniques and technologies needed to enable cost-effective emplacement and construction of planetary outposts and bases. That includes surface preparation, covering habitats with regolith for radiation protection, and development of large and small habitats and enclosures for occupancy, storage and work areas. Specific technical objectives include site preparation and dust management, and development of various concepts and capabilities including, construction equipment concepts, passive habitat thermal management capabilities, and alternative habitat concepts and materials.

Human Support

The ultimate success, and in fact the feasibility, of deep space human exploration will depend in large measure on the balance between the cost-effectiveness and the safety of astronaut operations. The goal of space R&T in the program area of human support is to develop and demonstrate the technologies needed to support safe and efficient human activities during very long duration missions in deep space and on planetary surfaces. Figure 3-10 provides a summary of the space R&T objectives for the human support technology program area. The following section describes the strategy for this area of space R&T, which includes the following elements: (1) regenerative life support; (2) radiation protection; (3) surface extravehicular activity systems; (4) exploration human factors; (5) remote medical care; and (6) artificial gravity.

Regenerative Life Support

The goal in space R&T for regenerative life support systems is to reduce dramatically the logistics requirements, while increasing the degree of autonomy for piloted systems during long duration space flight. This effort will focus initially on physical-chemical process-based life support systems, including air revitalization, water reclamation, waste management, and real-time contamination monitoring, and evolve toward the integration of bioregenerative concepts. A key product of this program element will be to demonstrate advanced life support technologies for deep space applications in an integrated systems-level testbed environment (with humans in the system). Development in this element will be closely coordinated with R&T for life support systems for zero-gravity applications. (See the following discussion of the Space Platforms Thrust.)

Radiation Protection

The space R&T focused program goals in radiation protection are: (1) to develop the ability to accurately predict the radiation environment within a shielded vehicle or habitat to within ten percent uncertainty level for a variety of shielding materials and designs and (2) to develop lightweight shielding concepts. Primary applications will include planetary surface and transfer vehicle systems for SEI. Development in this element also will support radiation shielding required for future robotic missions. Key products in this element include: radiation transport codes (with less than a 10 percent uncertainty factor); shielding materials to address both Lunar and Mars missions; and accurate predictability of galactic cosmic radiation (GCR) and solar particle events (SPEs), in line with "as low as reasonably achievable" (ALARA) requirements as defined by the Life Sciences Division.

Extravehicular Activity (EVA) Systems

The strategic objective of the space R&T focused program in this program element is to develop planetary EVA systems with minimal cost and logistics requirements. Specific EVA subsystem areas are: portable life support systems; high-pressure and high-operability suits; and, highly dexterous gloves. One of the key products for surface EVA systems may include simulated low gravity testing of a breadboard advanced technology suit (e.g., in a water tank). Development in this program element will be closely coordinated with R&T for extravehicular mobility units (EMUs) for zero-gravity applications. (The Space Platforms Technology Thrust also discusses EMUs in relation to SSF.)

Exploration Human Factors

The goal in this program element is to conduct supporting technology development research in human factors issues related to long duration space flight and for surface operations. This includes human performance models and validated human-automation-robotics system design guidelines and tools. Simulated low gravity flight testing (e.g., onboard the NASA KC-135 aircraft) is a potential activity to support technology research in this element. Key products will include assessments of potential SEI habitat and vehicle concepts; virtual reality base workstations for planetary mission applications; and human performance models.

Remote Medical Care

The space R&T focused program goal for remote medical care is to define the key areas in which technology can enhance the long term operational health and safety of future deep space explorers. Advanced technology capabilities will include: telemedicine, with video, voice and medical data transmission; and advanced health maintenance systems for both primary and emergency medical care, general surgery and dental care. Planning for this element will be coordinated with life sciences researchers, operational mission planners, and developments in the areas of high rate communications and artificial intelligence.

Artificial Gravity

The current space R&T goal for artificial gravity is to support continuing life sciences research by conducting integrated technology assessments of the feasibility of alternative approaches. These will include both mechanical and controls-structures interactions (CSI) concepts and analyses that are consistent with evolving exploration mission and life sciences research-derived requirements.

Planetary Surface Technology Flight Experiments

As part of the overall strategy for space R&T, technology flight experiments will be used to validate critical planetary surface technologies. For example, current long range planning for the SP-100 Program includes the option of a flight demonstration of the space nuclear reactor power system. Similarly, early planning has suggested that Lunar surface demonstrations may be required of *in situ* resource utilization technologies (perhaps as a payload on an operational robotic precursor mission) However, at present, no specific candidates have been identified in this thrust.

Transportation Technology

The Transportation Technology Thrust is primarily concerned with providing the technology needed for major future transportation improvements that may be undertaken by OSF, OSSA, or OEXP. This could include new transportation systems such as a heavy lift launch vehicle (HLLV), a second generation Space Shuttle, and a family of space transportation vehicles for transferring humans or cargo between the Earth and the Moon or the Earth and Mars. Specific program areas include: Earth-to-orbit transportation; space transportation; and transportation technology flight experiments.

Earth-to-Orbit (ETO) Transportation

The strategic objectives of this program area are to: increase Space Shuttle safety margins and performance; provide technology options for next-generation manned launch systems; support evolutionary development of robust, low cost HLLVs; and, develop and transfer technologies for future commercial ELVs. Figure 3-11 provides a summary of the space R&T objectives for this area. The ETO transportation R&T strategy includes the following elements: (1) Earth-to-orbit propulsion; (2) low cost commercial ETO transports; (3) ETO vehicle structures and materials; and (4) ETO vehicle avionics.

[10] Note: the results of this R&T often produce products which can be used in the near term to enhance Space Shuttle main engine (SSME) safety margins through the application of advanced manufacturing processes R&T.

Earth-to-Orbit Propulsion

The two strategic objectives of the ETO propulsion element are: (1) to create design tools and conduct R&T to support future development of the propulsion systems for the next manned launch system (e.g., the advanced manned launch system - AMLS); and (2) evolution of the space transportation main engine (STME) for the NLS, and other future HLLVs. As a part of the ETO propulsion strategy, the Space Shuttle main engine (SSME) will be used as a technology testbed (TTB) for component level research for future cryogenic ETO engines.[10] Specific technologies will include turbomachinery and combustors, integrated engine system controls and health management, advanced design methodologies and tools, and low cost manufacturing processes. Key products in this program element include breadboards of integrated engine health management (IEHM) systems, and demonstration of low cost fabrication systems for vital large engine subsystems and components.

Figure 3-11
Transportation R&T Objectives

		ETO TRANSPORTATION					
		Earth-to-Orbit Propulsion	Low-Cost Commerical ETO Transports	ETO Vehicle Structures & Materials	ETO Vehicle Avionics	Advanced Cryogenic Engines	Cryogenic Fluid Systems
KEY TECHNICAL GOALS		• Low-Cost/High-Quality Mfg • Predictable Design Margins • Automated Ground Operations • Service by Need • Maximum Performance Commensurate with LCC	• Achieve a significant reduction in costs • High Performance Upper Stages • Automated ELV launch processing • Improved launch reliability	• Significant Savings in Vehicle Mass • Signficant Savings in Manufacturing and Processing Costs • Integrated Thermal-Structural Vehicle Design Capability	• Fault-Tolerance • Adaptive, Reconfigurable GN&C ("Fly on Demand") • Integrated VHM • Adaptive & compact electric actuators, Power Mgt/controls • Low-Cost Software	• Increased Efficiency • Life/Space Basing Option • Multiple Use Option • Throttling (Varying Thrust)	• Long-Term Cryogen Storage (2-5% loss/year) • Nonvented 0-g Fluid Transfer • Mass gaging and slosh control in 0-g • 0-g autonomous pressurization
CURRENT STATE OF THE ART ASSESSMENT		• \$30-40 M@Engine • Engine Mfg = 4yrs • Engine Turnaround ≥30-60 Days • T/W ≤ 60-65 • Hands-On Inspect'n • Min. Design Margins • Forgings, Milling, Welding, Electroforming, Tube Assy	• ≥\$5-10,000 /lb • 35 year-old propulsion (high manufacturing costs) • Pressure Stabilized S.Steel Structures & Al skin/stringers • Simplex Avionics (w/ manual VHM, & hydraulic actuators)	• Aluminum Structure • Limited Composites in Secondary Structures • Thick Plate Machining for Cryotank Sections • X-ray Inspection of all Welds	• Simplex Architecture (unmanned) • Redundant Subsystems (manned) • Manual VHM/Power • Std. Software Mgt (@ \$100/line appx) • Hydraulic Actuators, Valves, TVC	• Isp ≤ 444 seconds • Ground-Based Operations • 1-to-5 Firings • Minimal Throttling	• ≥ 5-10 % Cryogen Loss/Year • ≥ 5 % Cryogen Loss/Transfer • no 0-g liquid transfer data • no 0-g mass gaging
RESEARCH AND TECHNOLOGY OBJECTIVES	NEAR TERM	• 50% Reduction in Cost per Engine • 50% Reduction in Engine Mfg Time • Precision Castings & Fewer Welds • Design for Max Perform./Derated Ops • Limited Autonomy & IEHM • Safe Shutdown	• 25% Cost Reduction vs SOA • Low-Cost ELV turbomachinery • Leak-free Cryogenics • Al-Li Continuous Forming Mfg. • Adaptive GN&C • Onboard VHM • 20% more Mass to GTO than SOA (U/S)	• Al-Li Alloys Characterized (8-13% lighter than SOA) • Non-Autoclave Process for Primary Composite Struct. • Early AMLS Structural Concepts Identified for Study (Up to 40 % mass savings vs SOA)	• Computer Automated Software Design Tools • Real-time Launch Loads/Winds Prediction	• Isp ≥ 480 seconds • Reuse ≤1-5 Firings • Minimal Engine Throttling	• characterization of thick MLI for lunar applications • 1-g supply system demonstration • High flow rate system test at 1-g • 3-D slosh model validation for 0-g • 0-g pumps, valves & disconnects
	MID TERM	• 75% Reduction in Cost per Engine • 50% Reduction in Eng. Turnaround • Precision Castings, VPS/Platelet Liners • Increased Ground Ops Autonomy • Operate Nearer Max. Performance • Increased IEHM	• 40 % Cost Reduction vs SOA • Demonstrated Large Scale Hybrid Booster • Advanced LOx/H2 Upper Stage Engine • Low Pressure LOX/ Hydrocarbon Engine • Very Low Cost INS	• Automated Mfg Process for Cryotank Sections • Automated Welding for Al-Li • ≥10 % Savings in Mfg Cost over Current Processes	• Integrated VHM sensors/software (Subsystem-Level) • Onboard Adaptive GN&C • Integrated Fiber Optics/GPS INS • "Smart" EMA power systems	• Isp ≥ 480 seconds • Space-Based Systems • ≥ 10:1 Throttling	• Fluid handling technology available for liquid oxygen & liquid nitrogen • Demonstrate thick MLI for Mars app. • Health monitoring systems demo.
	FAR TERM	• 90% Reduction in Eng. Cost v. SOA • 75% Reduction in Engine Mfg Time • Reuse w/o Service ≥25-50 Flights • 80% Reduction in Eng. Turnaround • T/W ≥2:1 vs SOA (for reusable vehicles) • Known Design Margins (4 to 1) • Fault-Tolerant Ops	• n/a	• ≥20-40 % Savings in Mass vs SOA • ≥20-30 % Savings in Mfg Costs over Current Processes • Continuous Al-Li Cryotank Process'g • Continuous Weld'g • Integral Structure-Cryotank	• Rapid prototyping & Reconfiguration of Avionics System • Fully Automated S/W Design, Development,V&V (@ 10:1 Savings) • VHM System-Level Validation • Auto. Vehicle Reconfiguration	• Isp ≥ 480 seconds • Space-Based Systems • ≥ 20:1 Throttling	• Liquid hydrogen fluid handling technology validation flight experiment • Cryo systems technology ready for Mars mission (<2% loss/year demonstrated)

[10] In all cases, planning for space transportation concepts and technologies will be closely coupled to developments in ETO transportation systems and plans. For example, the capability of the baseline and evolutionary NLS strategies will be folded into assesments of space transportation basing strategies (e.g., ground vs. space based).

Low cost Commercial ETO Transports

The primary goal of this element program is to develop, demonstrate and transfer to industry those technologies that meet commercial aerospace industry requirements for advanced, low cost expendable launch vehicle (ELV) system concepts, including upper stages. The emphasis will be on developing component and subsystem capabilities that reduce initial and recurring costs and increase the reliability and performance of future commercial launch systems. The focus will be on advanced low cost methods, processes, procedures and techniques to enable and/or enhance capabilities in the technology discipline areas of propulsion, structures, materials, manufacturing processes and advanced avionic systems. Key products in this element will be ELV engine subsystem breadboards and demonstrations of low cost manufacturing processes.

SPACE TRANSPORTATION

Nuclear Thermal Propulsion	Nuclear Electric Propulsion	Aerobraking	Transfer Vehicle Structure & Tankage	Transfer Vehicle Avionics	Autonomous Rendezvous & Docking	Autonomous Landing
• High-Thrust • Highly Efficient Use of Fuel • Multiple Use Option • Long Lifetime w/ Space-Basing Option • Moderate to High Thrust-to-Weight • Safe, reliable systems	• Very High Fuel Efficiency • High thrust efficiency • Long-Life/Space-Basing • 100 to 10,000 kW power levels • Low Specific Mass • Modular/Deployable System	• Low Mass Aero-shell • Precision Entry and Landing at Mars • Multiple Use Option • High System Mass Efficiency	• Reduced Mass Vehicles (10-30%) • Low Cost Manufacturing • Long Life/Space-qualified materials for long duration missions	• Ultra reliable, open architectures @ high commonality • Advanced GN&C for rapid prototyping • AutomatedVehicle Health Management (Self diagnosing & compensating) • Adv. PMAC/EMA's	• Autonomous Operations (no real-time ground control) • Multiple Use Option • Onboard Tracking & data processing	• Autonomous Operations • Precision Landing • Descent Hazard detection & Avoidance • Algorithms for Mars terrain navigation
• Thrust = 25,000 to 200,000 lbs. • Isp ≥ 825 seconds • Successful Ground Tests; Multiple start/shutdown cycles demo'd (28 • TRL = 6 achieved w/ NRX-XE	• 10-30 kilowatt-Class Ion Thrusters • Short-term MPD Thrusters (200 kW) • Efficiency ≥ 0.6 • SP-100 Reactor under development • No Thermal Mgt. • 1 kWe SEPS (NSSK)	• Apollo Ablator Shield • Shuttle TPS Tiles & GN&C • Viking Ablator at Mars	• Standard Aluminum & Titanium Mat'ls and Tankage	• Single Use (with Long Lif for Deep Space S/C Cases) • Ground Based Systems • SSF Avionics Under Development	• Ground-Controlled R&D Operations • Crew Onboard Proximity Ops • Ground Radar Tracking	• Shuttle Landing Systems • Viking Landing Systems • No Real-time Hazard Avoidance
• Candidate Fuels Tested	• 1-25 kWe SEPS-class technology ready	• Early Mars Probe Decelerator	• n/a	• n/a	• Augment manned rendezvous/docking • Prototype hardware & software • Requirements for deep space missions defined	• sensor models and algorithms dev. • Prototype sensors selected
• Key subsystems tested	• 10-100 kilowatt-class Ion Thruster • 100-1000 kW MPD • Efficiency > 0.5 • 10-1000 kW SP-100 available • Specific Mass ≤ 25 kilograms/kilowatt • 2-10 year system life & operations	• Advanced Probe Decelerator (Deployable) • Precision Entry at Mars (small vehicle) • Lunar Aerobrake (20% Mass Fract'n)	• Composite cryotank • Advanced metallic alloys for primary structure • Space environment resistant coatings • LEO Environment Operations	• AGN&C test beds • Requirements for modular, smart Power Mgt. & Control systems • Breadboard sensors & algorithms for VHM	• Fully autonomous operations prototype for planetary rendezvous	• Mars landing test bed simulations
• Thrust = 25,000 to 75,000 lbs • Isp ≥ 875 to 925 seconds • Multiple Firings • Long-Life (multi-hour) • Space Based Systems	• 1000-5000 kilowatt-Class MPD Thrusters • 10000 hr thruster life • 5000-10000 kWe power supply • Specific Mass ≤ 20 kg/kWe (cargo) ≤ 10 kg/kWe (piloted) • 2-10 year system life and operations	• Precision Entry at Mars (piloted) • Lunar Aerobrake (15% Mass Fract'n) • Mars Transfer Vehicle Aerobrake (15% Mass Fract'n)	• Advanced Composite Materials • 30% Reduction in Vehicle Mass vs. State-of-the-Art • LEO Environment Operations • Deep Space Operations	• Open architectures optimized for Mars missions • AGN&C reqmts. satisfied for Mars transfer, capture & landing	• n/a	• n/a

ETO Vehicle Structures and Materials

The space R&T focused program goal for ETO vehicle structures and materials is to develop technology that will substantially reduce the weight and increase the durability of structures for the next generation of ETO vehicles (including NLS, AMLS and/or PLS). Examples of technical objectives include characterization of aluminum-lithium (Al-Li) alloys and processing to manufacture cryogenic tankage, metallic thermal protection systems (TPS), integral structural design, and automated welding and nondestructive evaluation (NDE). With respect to the next manned launch system, the strategy in this critical program element is to provide a basis for either a two stage to orbit (TSTO) or a single stage to orbit (SSTO) concept. The key products will include demonstrations of continuous Al-Li processing for cryogen tankage, and breadboards of selected structural concepts and Al-Li welding and inspection systems.

ETO Vehicle Avionics

The primary goal in space R&T for this element is to develop technologies that improve all phases of ETO vehicle life cycle costs. Such technologies will include: more affordable and reliable avionics hardware and software systems; increasing vehicle reliability through automated fault detection and fault management; and, improving systems availability and on time launch performance by reducing weather and other performance constraints. A second goal is to provide new capabilities for automated on orbit vehicle operations and automated vehicle recovery and/or landing. Technical objectives include: adaptive vehicle GN&C systems; automated vehicle health management including sensors and software; smart, compact EMA power management and conditioning (PMAC); real-time wind profiling; and modular/scalable avionics architectures. Several key products include prototype demonstrations for automated software development, verification and validation systems, advanced EMA breadboards, and integrated demonstration of vehicle health monitoring (VHM) sensors, processors and software.

Space Transportation

The strategic objectives of this program area are to support the development of advanced space transfer systems for the following general LEO-to-GEO transfer: robotic solar system exploration missions; future space physics missions beyond LEO; and, transportation systems to support the SEI. Planning for developments in space transportation include R&T in advanced cryogenic engines, nuclear thermal propulsion, nuclear electric propulsion, aerobraking/aeroassist, cryogenic fluid systems, autonomous landing, autonomous rendezvous and docking, transfer vehicle avionics, and transfer vehicle structures and cryogenic tankage.[11] Figure 3-11 provides a summary of the space R&T objectives for the space transportation program area. The program area R&T strategy addresses the following elements: (1) advanced cryogenic engines; (2) cryogenic fluid systems; (3) nuclear thermal propulsion; (4) nuclear electric propulsion; (5) aerobraking; (6) space transfer vehicle structures and cryogenic tankage; (7) space transfer vehicle avionics; (8) autonomous rendezvous and docking; and (9) autonomous landing.

Advanced Cryogenic Engines

The space R&T focused program goal in this element is to develop and demonstrate the technologies needed for a high performance, highly reliable, expander cycle engine in the 15,000 to 50,000 pounds (lbs.) thrust range. Potential applications include high energy upper stages, SEI Lunar transfer vehicles, and SEI Lunar and Mars lander and ascent vehicles engines, either manned or unmanned. Technical objectives include: high reliability (including human-rated); operational efficiency; deep throttling; low cost manufacturing; high performance; space storability; and, reuse and in-space maintenance. A key product of the program is the advanced expander cycle testbed (AETB). The AETB will incorporate a variety of increasingly advanced component technology options, including: engine system technology; integrated component interactions; and advanced technology verification in an engine system.

Cryogenic Fluid Systems

The goal in space R&T for cryogenic fluid systems is to develop and provide ground demonstration of the technologies needed to improve the storage, transfer and handling of cryogenic fluids (such as oxygen and hydrogen) for use as propellants, reactants, coolants and life support system fluids. Ground based R&T in this program element will require close coordination with planning and implementation of potential flight experiments. Technology development activities include: advanced thermal insulation systems for long duration, low mass and minimal boil-off cryogen storage; cryogenic fluid handling, storage, transfer and supply; and, pressure and thermal control. The objective is to provide a validated design criteria data base that can be used with confidence on NASA missions.

Nuclear Thermal Propulsion

The strategic objective of the space R&T focused program for nuclear thermal propulsion (NTP) is to provide the optimal suite of transportation system technology choices for a future human mission to Mars. NTP ground testing facilities issues will form a major topic for early evaluation. Program activities in this element are planned to be closely coordinated with the DOE and DOD. Technical objectives include: innovative reactor concepts and fuels; engine turbopumps nozzles to support a hot hydrogen system; and early studies of technology concepts in terms of operational safety issues.

Nuclear Electric Propulsion

The space R&T focused program goal for nuclear electric propulsion (NEP) addresses three major application options: (a) robotic deep space exploration missions (e.g., to the outer planets); (b) unpiloted cargo vehicles (in support of a human mission to Mars); and (c) piloted Mars transfer vehicles. Technical objectives include: low specific mass; high level power conversion and processing; and, thruster and control concepts. (Research and technology planning in this transportation thrust program element will be closely coordinated, with regard to objectives and implementation, with both the SP-100 Space Reactor Program and the high capacity power technology projects.)

Aerobraking/Aeroassist

Goals in this element are to develop and provide ground based validation of key technologies needed to use aeroassist techniques (e.g., aerobraking) in future robotic and piloted exploration missions. Technical objectives in this program element include: adaptive, onboard GN&C; thermal protection systems (TPS); aerothermodynamics (CFD) and configuration studies for a wide range of applications; atmospheric modeling; and structural concepts, CSI and structural-thermal interactions. Key products will include: integrated computer analysis of alternate aerobraking vehicles; laboratory validation of TPS breadboards; and simulation-validated GN&C prototypes. Close coordination of this ground R&T program with planning for potential technology flight experimentation is crucial. The discussion at the end of this section concerning transportation technology flight experiments provides a further elaboration related to the aerobraking concept.

Space Transfer Vehicle Structures and Cryogenic Tankage

The space R&T focused program goal in this element is to develop and ground-validate low cost, space-durable space transfer vehicle structures and tankage. The technical objectives of this element include: low mass advanced metallic and/or composite material cryogen tankage; and vehicle bus structure advanced thermal insulation. Key space transfer vehicle (STV) structures and cryogenic tankage R&T products will include breadboards of low mass tankage and selected STV structures.

Space Transfer Vehicle Avionics

The goal in space R&T for transfer vehicle avionics is to develop and validate the technologies needed for more complex mission requirements to be accommodated without increasing costs. Key objectives include: ultrareliable attitude controls; integrated vehicle health management (VHM); automated and autonomous vehicle checkout and test; and in-space application advanced electromechanical actuators (EMAs). A second key objective is development of technologies to provide for inter-vehicular avionics component, subsystem, and system compatibility is a key objective. Rapid prototyping and development of a family of testbeds is key to the strategy in this program element, including testing for advanced GN&C prototype demonstrations, VHM, power systems, and integrated avionics software verification and validation.

Autonomous Rendezvous and Docking

The strategic objectives of the space R&T focused program in this program element are to develop and provide ground demonstration of rendezvous and docking of vehicles in space without real-time terrestrial control of the vehicles. Potential applications include: increasing reliability for LEO rendezvous and docking; enhancing Lunar Orbit operations; and enabling autonomous rendezvous and docking for Mars orbit (and other deep space) vehicle operations. Key technical objectives include: range, attitude and range-rate sensors (e.g., laser ranging sensors); adaptive mechanisms and effecters for docking; and onboard GN&C software and processing. These technology products will be validated through ground based laboratory testing (i.e., two dimensional, simulated zero-gravity operations using a flat floor facility).

Autonomous Landing

The space R&T autonomous landing program goal is to develop and demonstrate the technology to enable safe, accurate, autonomous spacecraft landings for both robotic and piloted vehicles. Potential applications of autonomous landing developments focus on deep space missions. However, this technology may also be applied to AMLS, PLS, or to assured crew return vehicle (ACRV) concepts. Specific planned developments include sensors and onboard autonomous GN&C processing for precision landing at a specific point on a planetary surface, while allowing hazard avoidance during terminal descent.

Transportation Technology Flight Experiments

Planning for the Transportation Technology Thrust includes requirements for a significant program of technology flight experimentation. This planning focuses around two major areas: aerobraking and cryogenic fluid management.

Aerobraking Technology Flight Experiments

These may include the a near term validation, such as the Aeroassist Flight Experiment (AFE) concept,[12] technology flight experiments that provide a database on the GEO-to-LEO and Lunar-to-LEO aerobraking energy regime in the Earth's atmosphere; a late 1990's or early 2000's High Energy Aerobraking (HEA) Flight Experiment to demonstrate aerobraking at Earth with energies consistent with a return from a deep space mission; and possible technology research instrumentation on future planetary probes (e.g., temperature monitoring instruments on the aeroshells to be used for a Mars network mission).

Cryogenic Fluids Technology Flight Experiments

These technology flight experiments may include two efforts, the first to be conducted in the middle to late 1990's, and the second to be conducted in the late 1990's and early 2000's. The former is the Cryogenic Orbital Nitrogen Experiment (CONE) designed to conduct a variety of space based research studies using nitrogen as an analog for liquid oxygen, and includes low gravity passive and active pressure control and pressurization, zero-gravity liquid acquisition devices, no-vent fill and rapid venting and safing, and zero-gravity tank chill-down. The second experiment is the Cryogenic Orbital Hydrogen Experiment (COHE) which will study liquid hydrogen withdrawal, no-vent fill, insulation systems and components, autogenous pressurization in transfer and passive pressure control, and demonstrate flight qualified zero-gravity mass-gauging. These major cryogenic flight experiments will be supplemented by a series of smaller experiments using appropriate simulant fluids, that will be pursued through the OAST Transportation Technology Thrust in the early 1990's.

[12]The Aeroassist Flight Experiment (AFE), funded in FY 1988-1991, was terminated by Congressional action as part of the FY 1992 NASA budget appropriation. Requirements for flight experimentation in the Earth's atmosphere at energies consistent with Lunar return will be reevaluated and revised planning incorporated in the 1992 ITP.

Space Platforms Technology

The Space Platforms Technology Thrust is primarily concerned with providing the technology needed for future spacecraft systems for use by NASA (e.g., OSSA, OEXP, OSF, OSC) or other government agencies (e.g. NOAA), or by private industry (e.g., telecommunications satellites). Advances in this technology thrust will benefit both future human platforms, such as SSF, and future large science spacecraft, such as EOS. The goals of this thrust are to enable reductions in launched weight through spacecraft mass reductions, increased spacecraft lifetimes, increased maintainability, and decreased logistics resupply needs. Specific program areas include Earth orbiting platforms, space stations, deep space platforms, and space platform technology flight experiments.

Earth Orbiting Platforms

The objectives for Earth orbiting platforms program area include the following: to improve the long term dynamic environment on spacecraft (e.g., for instruments); to increase the available onboard power for solar power spacecraft, while holding even or reducing power system costs; to provide new space-durable structures and materials for LEO and GEO spacecraft; and to increase the reliability and control of these platforms. Figure 3-12 provides a summary of the space R&T objectives for this area. The Earth orbiting platforms program area strategy includes R&T addressing the following elements: (1) platform structures and dynamics; (2) platform power and thermal management; (3) materials and environmental effects; (4) non-destructive evaluation (NDE) and non-destructive inspection (NDI); and (5) platform controls.

Platform Structures and Dynamics

The goals in space R&T for structures and dynamics are to develop and apply controls-structures interactions (CSI) techniques to space platforms and to develop advanced platform structure concepts. Technical objectives include: advanced CSI demonstrations to support multiple interacting payload pointing; demonstration of concepts for precision deployable antenna and erectable reflectors for earth observation; and adaptive structures and configuration control. Another objective of the program is develop a CSI design handbook for future Earth orbiting platforms (e.g., for future LEO and GEO Earth science platforms). Ground based hardware testbeds is a key product for this element's strategy, including both in-house and non-NASA guest investigator activities. Finally, close coupling of ground R&T and testing with future flight experimentation is a vital part of the overall strategy for platform structures and dynamics R&T.

Platform Power and Thermal Management

The power and thermal management goal is to develop and demonstrate key technologies for increased power at reduced costs for future Earth-orbiting spacecraft, including SSF, LEO or GEO Earth science spacecraft, and future astrophysics missions. In addition, developments in this program element may significantly benefit solar powered deep space spacecraft (e.g., a Mercury orbiter). A variety of technical objectives are addressed in this element including: solar dynamic power systems; heat pumps (e.g., 100 watts to 1 kilowatt) and heat pipes; advanced solar array concepts including concentrators (e.g., for a 300 watt per kilogram PV array); and advanced power storage systems (e.g., a 100 watt per kilogram battery). A 2 kilowatt ground test of a solar dynamics-based power systems is one of the key products needed for this element.

Materials and Environmental Effects

The goals in this program element are to study Earth orbit environments and to develop and demonstrate advanced, long life, space durable materials to resist LEO and GEO environmental effects. Applications will include Earth sciences spacecraft, collector and reflector antenna components, and SSF evolution. Building on the results of the Long Duration Exposure Facility (LDEF), technical objectives include R&T in material systems, films, coatings, adhesives, and environmental testing. Atomic oxygen effects in LEO are of particular interest. A key product of this effort will be methodologies to test, predict, and qualify new materials for long term use in space applications. (A flight experiment to measure in space debris may be implemented in coordination with this element. The following section further elaborates this subject.)

NDE/NDI

The strategic objectives of the space R&T focused program for non-destructive evaluation and non-destructive inspection (NDE/NDI) are to dramatically improve the reliability and extend the lifetime of future space platforms. Technical objectives include "smart structures" that incorporate non intrusive NDE sensors for health monitoring and structural control, thermal NDE systems for coating and material evaluation, and built-in electronics NDE.

Figure 3-12
Space Platforms R&T Objectives

	EARTH-ORBITING PLATFORMS					
	Platform Structures & Dynamics	Platform Power & Thermal Management	Materials & Environmental Effects	NDE/NDI	Platform Controls	Zero-Gravity Advanced EMUs
KEY TECHNICAL GOALS	• On-Orbit Construction & Deployment of Large Structures • Advanced Control of Large Structures & Multi-Payload Platform	• Long-Life, Efficient PV Arrays & Solar Dynamic Systems • Lightweight, Autonomous PMAD • Efficient Heat Pipes, Radiators & Heat Pumps • Long-Life, Efficient Batteries	• Materials Systhesis & Fabrication • Env. Resistant Coatings & Films • Env. Testing & Analysis	• "Smart Structures" • Thermal Systems NDE • NDE for Tethers • Electronics NDE • On-Orbit NDE • Contamination Monitoring	• Pointing/Isolation Mechanisms • Recision Attitude & Geometry Control • On-Orbit Characterization & System ID • Pointing, Dynamics & Control Testbed	• Low Cost, On-Orbit Maintainable, High Pressure AEMU • Efficient, Regenerable PLSS
CURRENT STATE OF THE ART ASSESSMENT	• Limited Deployment Capabilities • S/C Designed as Fully Integrated, Launchable Units • Limited Control Capabilities for Large Structures	• Planar Array Power <170 W/kg • Concentrator Array Power<40 W/kg Life<10 yr • Solar Dynamics Power=5-8 W/kg • Battery Energy=50 Whr/kg Life=5000 Cycles	• AO Screening for Coatings and Films • Composites Based on Aircraft Applications • Films/Coatings/ Composites Deteriorate in Space • Single Exposure Env. Effects Testing	• No Space Application of Current NDE/NDI Systems	Sensor Accuracy (arc-sec) • IRU= 0.05 • Star Tracker>1.4 • Sun Sensor>60 • Earth Sensor>36	• Suit Operating Pressure=4.3 psi • Manual Reservicing • Refurbishment After 3 EVA's • Limited On-Orbit Resizing Capability
RESEARCH AND TECHNOLOGY OBJECTIVES — NEAR TERM	• Improved Pointing & Flight Path Control • Larger Platforms & Expanded Multi-P/L Platform Utility	• Solar Dynamic Ground System Test				
RESEARCH AND TECHNOLOGY OBJECTIVES — MID TERM	• Erectable/Deployable Trusses & Precision Surfaces • Volumetric Structures • Rigid & Inflatable Shell Structures	• Planar Array Power>300 W/kg • Concentrator Array Power>100 W/kg Life=15-30 yr • Solar Dynamics Power=15-20 W/kg • Battery Energy=100 Whr/kg Life>40000 Cycles	• Space Durable & Rigidizable Polymers • Space Tailored Composites • Combined Env. Effects Testing • Life Prediction Methodology	• In-Situ Health Monitoring & Control • Defect Detection in Thermal Systems • Weld & Bolt Tension Testing • Quantitative Contamination Monitoring • Improved Reliability for Electronics	Sensor Accuracy (arc-sec) • IRU= 0.01 • Star Tracker=0.1 • Sun Sensor=1 • Earth Sensor<10 • Figure Sensor=1 • Accelerometer=1	• Suit Operating Pressure=8.3 psi • Auto Reservicing • Yearly Refurbishment • Complete On-Orbit Resizing Capability
RESEARCH AND TECHNOLOGY OBJECTIVES — FAR TERM						

Platform Controls

The space R&T focused program goal in platform controls is to develop and ground test technologies for advanced, onboard Earth orbiting spacecraft controls. Specific R&T objectives include: (1) payload isolation mechanisms to improve pointing accuracy; (2) jitter suppression and vibration isolation; precise spacecraft attitude determination and geometry control (including multi payload spacecraft attitude information sensing); and (3) design concepts and tools for multi-user platform control systems. Precision interspacecraft ranging is one potential mission application. One of the key products needed in this effort is a pointing and controls testbed, designed to support total platform system evaluation.

SPACE STATIONS			DEEP SPACE PLATFORMS		
Zero-Gravity Regen. Life Support	Station-Keeping Propulsion	User Support	Deep Space Power & Thermal Mgt	Onboard Propulsion	Spacecraft GN&C
• Automated ECLSS Operations • High Efficiency ECLSS Components & Subsytems • Testbeds for ECLSS Development • Safe, Reliable Fire Protection Systems	• Low Contamination, Gas Operated Resistojets • Low Contamination, H/O Auxillary Propulsion	• Efficient, Quiet, Safe, Long-Life Refrigerator • Advanced User Accommodations Systems • Platforms Systems Analysis	• Efficient Solar Arrays • Efficient, Long-Life Radioisotope Power Systems • Efficient, Autonomous PMAD • Efficient Radiators & Heat Pipes	• High Performance, Low Contamination "Hot Rockets"	• Adaptive Guidance • Navigation Techniques • Precision Attitude Control • Trajectory Control
• Open Loop LSS • Manual Servicing & Control • No Sensors & Monitors for Many Processes • Fire Protection Systems Based on Aircraft Applications	• IOC for Resistojet Test Stand • Several Resistojet Concepts Tested & Evaluated	• Refrigerators are Heavy, Noisy, Energy Inefficient, and Have Low Reliability • Shuttle-Class Health Care • S/C Subsystem & Component Costs Data Base	• Planar Array Power=96 W/kg • Concentrator Array Power<40 W/kg • Radioisotope System Power=5.5 W/kg Inventory=130 KCI	• Thrust = 100 lb • NTO/MMH Propellants • High Contamination	
		• Safe & Efficient Refrigerator		• Thrust=100-200 lb • NTO/N2H2 Propellants • Isp=330@467:1 • Lifetime=10@200+ Cycles • Contamination <1000X Galileo	
• Improved Fire Protection Systems	• Resistojet That Operates on Both Waste Water & Gases • "Hot Rocket" That Operates on Waste Water	• Independent S/C Subsytems Cost Estimate Capability • Capability to Assess Advanced Platform Technology	• Planar Array Power=380 W/kg • Concentrator Array Power>100 W/kg • Radioisotope System Power=7.1 W/kg Inventory=29 KCI		
• Real-time, On-Line Contaminant Monitoring & Control • Improved ECLSS Processing					

Space Stations

The goal of the space stations program area is to provide selected improvements in key system capabilities for SSF, or other piloted future space stations (e.g., in low Lunar orbit).[13] The objectives include reduced maintenance and reduced cost zero-gravity space suits and regenerative life support systems, long life and low logistics requirement station keeping propulsion, and selected space station user accommodation systems (e.g., refrigerator systems). Figure 3-12 provides a summary of the space R&T objectives for this program area. The program area strategy includes R&T that addresses: (1) advanced, zero-gravity extravehicular mobility units (EMUs); (2) zero-gravity regenerative life support systems; (3) station-keeping propulsion; and (4) advanced refrigerator systems.

Advanced Zero-Gravity Extravehicular Mobility Units (EMUs)

The goal in this program element is to develop extravehicular mobility units (EMUs) that reduce the life cycle costs for future zero-gravity applications, including EDO Space Shuttle operations, SSF, and the transfer segments of future human deep space exploration missions. Technical objectives include: higher pressure suit operations to minimize prebreathe time requirements; on-orbit maintainability improvements; and, regenerable zero-gravity portable life support subsystems. Human testing of advanced EMU breadboards in water and vacuum represent key products of the element strategy. Development in this element will be closely coordinated with R&T for EVA systems for planetary surface applications. (See the preceeding discussion of the Planetary Surface Technology Thrust.)

Zero-Gravity Regenerative Life Support Systems

The goal in this element of space R&T is to develop and demonstrate regenerative life support capabilities to increase human productivity and safety in a pressurized, zero-gravity environment. Some of the element's technical objectives include real-time in situ chemical and microbial sensors, integrated sensor subsystems, and life support system controls. The conduct of ground and space based testing represent important parts of the strategy in this program element. Key products include space validation of required components and subsystems, as well as ground testbeds for integrated closed system testing (with humans in the test). Development in this element will be closely coordinated with R&T in life support for planetary surface applications. (See the preceeding discussion of the Planetary Surface Technology Thrust.)

Station-Keeping Propulsion

The space R&T focused program goal in this element is to develop and demonstrate capabilities for reducing the logistics requirements and the operational costs for Earth orbiting platform station-keeping propulsion. The major technical objectives include development of two concepts: resistojet thrusters (using either water, ammonia, or carbon dioxide) and small scale hydrogen-oxygen thrusters.

Advanced Refrigeration Systems

The strategic objectives of this space R&T focused program are to develop technologies for selected user accommodation systems, including advanced refrigeration systems. Currently only identified R&T effort is in advanced refrigeration systems for zero-gravity applications, including new refrigerants and more efficient refrigeration pumps for use in supporting experiments and health care systems. The key product for this element strategy is a ground based breadboard demonstration of an advanced refrigerator system.

Deep Space Platforms

This component of the program includes planning for reducing the costs and increasing the performance and lifetime for future deep space solar system exploration and space physics missions. Developments in this area will also enhance the development of future SEI mission systems. Figure 3-

[13] As planning and development proceeds for future Extended Duration Orbiter (EDO) Space Shuttle operations, and possibly still longer Shuttle mission capabilities, some of the technologies identified in this program area may also be applicable to such missions.

12 provides a summary of the space R&T objectives for the deep space platforms technology program area. The program area strategy includes R&T addressing: (1) spacecraft power and thermal management; (2) spacecraft onboard propulsion; and (3) spacecraft guidance, navigation and control (GN&C).

Spacecraft Power and Thermal Management

Goals in this program element are to increase the available power and reduce the costs for future deep space spacecraft. Technical objectives include high power density (≥ 300 watts per kilogram) solar arrays with low mass deployment mechanisms, advanced radioisotope thermoelectric generators (RTGs) with a reduction in isotope required of 4:1 versus current technology, and power integrated circuits (PICs). Key strategic products for this element include an integrated, autonomous power management and conditioning (PMAC) breadboard ground demonstration and a possible flight demonstration of an advanced solar array brassboard.

Spacecraft Onboard Propulsion

The space R&T focused program goal is to develop advanced spacecraft propulsion technologies for future deep space missions (e.g., outer planet missions). Technical objectives include demonstration of high performance, long life, low plume contamination thrusters utilizing a variety of propellants (e.g., space storable propellants such as NTO/N_2H_2 O_2/N_2H_2, or H_2/O_2). The key product in this element is the ground based evaluation of a breadboard rocket engine in a simulated environment.

Spacecraft Guidance, Navigation and Control

Space R&T program strategic goals in the element of deep space spacecraft guidance, navigation and control (GN&C) include: adaptive and autonomous onboard GN&C systems; application of onboard planetary surface feature recognition for navigation; and development of advanced inertial measurement systems, techniques and software. Potential key products for this program element include laboratory breadboards of advanced subsystems and the evaluation of advanced GN&C systems using integrated computer simulation techniques.

Platform Technology Flight Experiments

Several potential space platform related flight experiments are being examined, including planning for a future orbital debris mapping flight program. (Such a flight program would develop an improved database of the debris environment in both LEO and GEO, and provide a passive sensor testbed for future debris collision warning systems.) At the present time, however, no specific technology flight experiment candidates have been identified in the Space Platforms Thrust.

Operations Technology

The goal of the Operations Technology Thrust is to develop and demonstrate the technologies needed to reduce the cost of civil space operations, to improve the safety and reliability of those operations, and to enable new, more complex activities to be undertaken. The thrust will provide technology for most users and support major operational improvements for future robotic and human missions, both on the Earth, in space, and on another natural body in the solar system (e.g., substantial improvements in the operation of mission control at JSC, improvements in communications between mission control and its spacecraft, and improvements for in-space assembly and construction techniques). Specific program areas within the thrust include automation and robotics, infrastructure operations, information and communications, and operations technology flight experiments.

Automation and Robotics (A&R)

While a variety of the other, function-specific elements of the space R&T program incorporate the use of one or more A&R components (for example, autonomous landing), the A&R program area of the Operations Technology Thrust provides a focused investment in artificial intelligence (AI) and telerobotics (TR) applications to a broad range of civil space mission operations objectives. Figure 3-13 provides a summary of the space R&T objectives for the A&R technology program area.

ARTIFICIAL INTELLIGENCE

The goal of the space R&T focused program in AI is to develop, integrate and demonstrate new capabilities to increase the operational capability, safety, and reliability of future NASA systems, while reducing the cost of those systems. Application areas include ground and space based mission operations, scientific and engineering data analysis, and preservation of life cycle information on complex devices. Specific technical objectives include mission operations assistance, AI-based data analysis techniques, autonomous control, and knowledge-based data systems. Projected key products from the element include an automated Space Shuttle scheduler.

TELEROBOTICS.

The space R&T telerobotics (TR) program goal is to develop, integrate and demonstrate technologies for teleoperations, telepresence, robotics and supervisory control applied to problems in launch processing, on-orbit operations and processing and science operations. Selected technical objectives include: (a) varying levels of

Figure 3-13
Operations R&T Objectives

	AUTOMATION & ROBOTICS		INFRASTRUCTURE OPERATIONS			
	Artificial Intelligence	Telerobotics	In-Space Assembly and Construction	Ground Testing and Processing	Flight Control and Operations	In-Space Processing and Servicing
KEY TECHNICAL GOALS	• Improve quality of flight decision making • Reduce flight controller training needs • Migrate AI technologies to spacecraft onboard systems	• Space Servicing & Assembly • Space Cranes • Space IVA Robots • STS Ground Proc. • Satellite Inspection • Ground Operations	• Accurate position and control of major vehicle components • Join/separate vehicle components in space • larrge scale vehicle outfitting and inspection	• Automated documentation generation and design knowledge capture • Advanced test management technologies • Automated testing technologies	• Technologies for increased number & long term missions • Adaptive operations to support science targets of opportunity • Automated aids to increase productivity and reduce training needs	• Develop technology to support pre- and post flight inspection and refurbishing of large space vehicles • Minimize EVA
CURRENT STATE OF THE ART ASSESSMENT	• Embedded stand-alone rule based expert systems used in mission control • HST batch schedule • Bayesian learning applied to time-independant data	• STS RMS (Canada) • No Space Robots in current US plans	• Hand assembly from Shuttle • No welding or bonding • No experince with large scale structures or flexible structures	• Rudimentary and dis-connected documentation application • No effective life-cycle design knowledge capture • Test rigs and chambers lack robotic and automatic aids	• Commanding and up-link processing labor-intensive and error prone • Rudimentary spacecraft analysis tools • Training and cross-training is largely on-the-job and costly	• Labor intensive highly strauctured ground systems • Little automation • No space experience • RMS used in very limited role
RESEARCH AND TECHNOLOGY OBJECTIVES — NEAR TERM	• Automated planning and scheduling • Spacecraft health monitoring and analysis • AI technology testbed	• Deploy ground processing robots in support of STS, spacecraft test, etc. • Ground test space telerobots in realistic tasks • High fidelity Simulation for full-task demonstrations	• In-space construction for lunar transfer vehicle • Aerobrake assembly • Space Construction Facilities Studies	• Design automated diagnostic system for spacecraft test • Design on-line DKC information retrieval system • Implement environment measurement robot in spacecraft test chamber	• Develop prototype spacecraft simulator • Validate adaptive sequencing concept • Demonstrate integrated telemetry analysis tools	• Develop system requirements • Develop built-in-test capability concepts • Define robotic scaffold builder
MID TERM	• Embedded real-time systems for scheduling & health monitoring • Distributed diagnostic systems • Life-cycle knowledge capture	• Expand ground test robotics • Flight test and validate EVA class telerobots	• Mechanical, welded and bonded joint concepts • Complete scenarion modeling of entire construction	• Implement test management decision support system • Implement test document generation system	• Demonstrate multi-control center distributed test bed • Design and test reactive sequencing • Develop 21st century control room concept	• Develop integrated servicing testbed • Algorithms for multiple manipulator coordinatiojn • Demonstrate modular manipulator self-repair
FAR TERM	• Use of natural language interfaces • self-modifying AI programs • Reactive realtime scheduling systems • On-board autonomous health management	• Demonstrate Exoskeleton tele-presence system • Robot assembly of solar-dynamic structure	• Advanced concepts for autonomous and telerobotic operation • Focus on reusable LTV • Support for Mars class vehicle construction	• Demonstrate automated analysis of requirements system • Implement and test system for test flow methods	• Develop advanced control room test bed • Demonstrate automated planning and sequence generation for SSF/EOS class spacecrafts • Evaluate instant, automated sequencing	• Complete full dynamics software simulation • Develop integrated operator workstation

human interaction in the telerobotic operation (including, robotics, supervisory control, and telepresence); and (b) specific types of functional applications (e.g., advanced launch teleoperations, launch processing, and remote science operations). Key products in this element are demonstrations of selected TR operations, including: a Solar Max repair-class operation with a single operator.

Infrastructure Operations

Planning is included in the elements of in-space assembly and construction, ground test and processing, flight control and space operations, space processing and servicing of systems, and training and human factors (focusing on ground crew systems). Figure 3-13 provides a summary of the space R&T objectives for the infrastructure operations technology program area. The program area strategy addresses the following: (1) in-space assembly and construction; (2) ground testing and processing; (3) flight control and operations; (4) in-space processing and servicing; and (5) operator systems and training.

	INFORMATION AND COMMUNICATIONS					
Operator Systems and Training	Space Data Systems	Ground Data Systems	High-Rate Communications	Photonics Systems	Commercial Satellite Communications	Navigation and Guidance
• Adapt air-transport technologies to support space and ground operations	• Develop advanced space qualifiable technologies for space data systems • High performance architectures, processsors, storage devices and systems	• Develop technologies for the effecient production of very reliable complex software • Develop advanced software reuse, reliability and risk management tools	• Technology to support future NASA mission communications needs • Near earth and deep space RF and optical communications • Gigabit + data communication rates	• Develop hybrid opto-electronic devices & systems for sensing, information processing and communications • 10-Fold improvements over existing systems	• New and enabling satellite and ground technologies developed to remove risk to U. S. industry in introducing new communication services	• Versatile high accuracy navigation and guidance techniques • Improve existing ground based systems • Migrate navigation and guidance activity from ground based to spacecraft
• Experience based methods • Overlearning and shared task training • Minimal Manual aids	• Fixed rate, noisy tape recorders • Very limited national capability to produce flight qualified data systems components • Decade + lag between ground and space data system capability	• Current software is acceptable but very expensive • Huge annual maintenance costs • No effective tools or policies for software reuse	• 300 Mbps digital switching/modulation • Early demonstratio/ fabrication of solid-state RF components	• FDDI optical fiber ring network • Magnetic tape mass memory • Microwave phase shifters	• Bent pipe transponders • C and Ku band • Foreign industry mounting serious challenge to U. S. leadership	• Optical and radio navigation techniques do not support planned mission to outer planets and primitive bodies • Accuracy and timing demands of SEI missions beyond current SOA
• Implement crew coordination training program • Implements initial circadian distribution countermeasures	• Evaluate and select silicon based computer technology • Evaluate GaAs computer technology • Develop data systems technology test bed • Test non-volatile RAM	• Establish metrics program • develop software reuse tools • Perform NASA needs assessment	• Demonstrate 60 Ghz Travelling Wave Tube (TWT) • Demonstrate 60 watt TWT amplifier bread board • Demonstrate coherent optical transponder	• Evaluate current national and world capabilities • Develop and demonstrate optoelectronic component technologies	• High power/hihg efficiency Ka/Ku-band TWT	• Demonstrate major navigation algorithms on parallel computer • Develop improved trajectory propagation techniques • Develop new validation techniques for radiometric data
• Enhanced training for high workload situations • Combine new technologies into STS Procedures	• Develop advanced image processor • Flight demonstration of optical disk recorder drive unit • Demonstrate 3-D RAM technology	• Initiate advanced software technology transfer activities • Develop technologies for complex software reverse engineering	• Demonstrate multi-beam MMIC sub-array at 20 Ghz • Demonstrate ultra-fast diode module for optical communications	• Demonstrate low-power 1Gbit/sec network breadboard • Demonstrate volume optical memory • Demonstrate analog microwave fiber optic link	• Develop system level MMIC's • Demonstrate innovative mobile and small fixed terminal • Demonstrate active phased array attenna using digital beam forming • Demonstrate optical processor/router	• Develop improved natural bodies motion & gravitational models • Develop ground-based navigation expert system • Develop improved trajectory optiomization techniques • Optical Navigation for small irregular bodies
• Provide AI-based support for NASA Test Director	• Demonstrate two-port dual head optical disk recorder • Test advanced flight computer brassboard • Perform integrated test bed demonstration	• Demonstrate life-cycle suite of tools for software production • Demonstrate mission software reuse methodologies	• Demonstrate phase-locked two-dimensional diode array	• Demonstrate pre-processor breadboard for 100 Gbps correlation • Demonstrate integrated antenna array system • Demonstrate 2.4 Gbps, terabyte storage capacity network	• Complete advanced mobile terminal components • Complete optical beam forming proof-of-concept • Develop advanced onboard communications processing and routing system	• Demonstrate onboard autonomous maneuvering capability • Develop low-thrust nav/guidance algorithms • Develop navigation/ autonomous guidance system for planetary rover

In-Space Assembly and Construction

The strategic objectives of the space R&T focused program for in-space assembly and construction are directed toward providing cost-effective new capabilities to enable large systems to be built in space, such as future large Earth orbiting science missions (e.g., LDR) as well as potential SEI missions (e.g., Mars mission staging). Technical objectives include structural systems for accurate positioning and holding of system components, joining methods including welding, bonding and mechanical connections, and general methods for integrated, EVA, telerobotic and robotic assembly, and construction operations.

Ground Testing and Processing

The goal in space R&T for ground test and processing is to develop new capabilities to reduce the work force, the time and therefore the costs of ground testing for flight systems, without reductions in reliability. Technical objectives include automated and autonomous ground test equipment as well as increased reliance on built-in test and check-out sensors and systems. Use of telerobotic systems in ground processing is one technical option.

Flight Control and Operations

The space R&T focused program goal for flight control and operations is to reduce the work force and costs associated with mission control for very long or complex civil space missions. Technology goals include increased use of artificial intelligence in a variety of ground control activities, such as command generation, integration of science commands with engineering commands, and faster than real-time simulation of spacecraft responses to potential ground commands.

In-space Processing and Servicing

The goal in space R&T for in-space processing and servicing is to develop new capabilities to enable in-space system integration and testing without the work force or the time required for ground testing of flight systems. Technical objectives include automated and autonomous built-in test and check-out sensors and systems. Use of telerobotic systems for processing is one technical option.

Operator Systems and Training

The space R&T focused program goal in this program element is to adapt techniques, countermeasures, workload measures and support aids used for air-transport crews to enable and support space operations ground, mission control and flight crews. Technical objectives include crew coordination, circadian countermeasures, crew workload analysis and adjustment, flight deck procedure enhancements, and test director aids.

Information and Communications

This program area includes planning for space data systems, ground data systems, high rate communications, photonics systems, commercial communications satellite communications R&T, and navigation and guidance (focusing on radiotelemetry GN&C). Figure 3-13 provides a summary of the space R&T objectives for the information and communications technology program area. The program area strategy addresses: (1) space data systems; (2) ground data systems; (3) high rate communications; (4) commercial satellite communications; (5) navigation and guidance; and (6) photonics-based data systems.

Space Data Systems

The strategic objectives of the space R&T focused program in advanced space data systems are to develop and demonstrate new onboard processing and data storage capabilities for a broad range future space and Earth science, exploration and infrastructure systems. This includes general and special purpose flight processors, dynamic data storage (e.g., nonvolatile RAM) and long term data storage components, onboard data networks, and flight systems architectures. Key products include breadboard demonstration of a variety of specific system components (e.g., advanced space optical disc recorders (SODR)).

Ground Data Systems

The goal in space R&T for ground data systems is the application of state of the art ground information systems to space mission operations through the development of NASA-tailored software development environments. A key technical objective is the development advanced, highly fault tolerant software architectures. Ground based data system testbeds are an essential part of the strategy for this element. One potential key product is the demonstration of advanced software development and verification tools, using advanced architectures and support environments (applied to NASA requirements).

High Rate Communications

The space R&T focused program goal in this program element includes development and demonstration of advanced deep space and near Earth mission high data rate information transmission, for both space-to-space, space-to-planetary surface, and space-to-Earth links. Technical objectives include digital communications technology, as well as both high rate radio frequency (RF) communications links in the Ka Band and extremely high rate optical communications using laser links. Some of the key products in the high rate communications element include breadboard demonstrations of optical communications subsystems and high frequency traveling wave tubes (TWTs). Planning for this focused program element will be closely coordinated with the R&T Base Advanced Space Communications Program.

Commercial Satellite Communications

The space R&T focused program goals for this element address technologies to increase capabilities and reduce risk to the U.S. satellite industry with new onboard satellite subsystem concepts and advanced ground systems for Earth-orbiting telecommunications satellites. Preliminary technical objectives include small fixed ground terminals, active phased array satellite antennas with digital beam forming, bandwidth- and power- efficient modem, coding and onboard routing and processing systems, and advanced mobile terminals. The strategy for this element will be closely coupled to future planning for flight validation of communications subsystems and components. Planning for this focused program element will be closely coordinated with the R&T Base Advanced Space Communications Program.

Navigation and Guidance

The goal for navigation and guidance R&T complements the GN&C related R&T planned in the Transportation and the Space Platforms Thrusts through the addition of R&T to support advanced radiometric navigation and related trajectory design techniques. Specific goals include the development of new or improved accuracy of existing navigational data types, force models and trajectory propagation and optimization techniques, as well as related mission design techniques and tools. Key products in this element will include operational demonstrations of advanced radiometric navigation techniques.

Photonics Systems

The goals in this element are to develop and demonstrate selected photonics (optoelectronics) technology based-information systems for space applications. The strategy for this element is four-fold: optoelectronic integrated circuit design (OEIC); real-time onboard photonics-based processing; real-time onboard image processing; and photonics-based extremely high rate and fault tolerant data networks. Key products will include demonstration of breadboard optical memories, signal processor modulator/ demodulators, and networks.

Operations Technology Flight Experiments

Several potential operations thrust technology flight experiments are being evaluated. These include possible robotics experiments, future optical communications flight experiments, and commercial communication satellite communications R&T flight experimentation.

Strategic Plan Priorities

Given the planning methodology sketched at the beginning of Chapter 3 and the individual technical strategic plans discussed in the preceding sections, the following issue remains: how to construct a viable space R&T program from a very large set of potential efforts. Clear and effective prioritization of the various potential program elements is essential. To achieve this objective, OAST first developed an *a priori* space R&T budgeting strategy that resolves the issue of how to maintain the proper balance between R&T Base and focused technology development resources. The initial budgeting strategy is: (a) to assure that the R&T Base is maintained at no less than its current purchasing power, while (b) targeting future R&T Base funding growth at a level of approximately one third the total budget for space R&T. This budgeting strategy is deliberately holistic in character, but it is consistent with practices elsewhere in the government and in industry.

At the same time, however, the Space R&T Program that is defined must implement OAST's program principles as identified in Chapter 1. Therefore, OAST defined two sets of detailed decision rules — for the R&T Base and for the focused technology programs. Although not used to determine the overall

Figure 3-14
1991 ITP Strategic Plan: Focused Programs

Space Science Technology	Submillimeter Sensing	Direct Detectors	Active µwave Sensing	Sample Acq., Analysis & Preservation	Passive Microwave Sensing	----
	Cooler and Cryogenics	Sensor Electronics Microprecision CSI	Laser Sensing Telescope Optical Systems	Data Archiving and Retrieval	Data Visualization	----
Planetary Surface Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	Planetary Rovers	Surface Habitats and Construction
	----	----	Extravehicular Activity Systems	Surface Solar Power and Thermal Mgt.	In Situ Resource Utilization	Laser-Electri Power Beaming
Transportation Technology	ETO Propulsion	Nuclear Thermal Prop.	Aeroassist/ Aerobraking	Transfer Vehicle Avionics	ETO Vehicle Avionics	ETO Vehicle Structures & Materials
	Cryogenic Fluid Systems	Aeroassist Flight Expt Advanced Cryo. Engines	Low-Cost Commercial ETO Transport	Nuclear Electric Propulsion	CONE	----
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.	Zero-G Life Support	Platform Materials & Environ. Effects	Station-Keeping Propulsion	----
	----	----	Zero-G Advanced EMU	Platform NDE-NDI	Deep-Space Power and Thermal	----
Operations Technology	Space Data Systems	High-Rate Comm.	Artificial Intelligence	Ground Data Systems	Optical Comm Flight Expt Flt. Telerobotic Servicer/DTF-1	Flight Control and Operations
	----	CommSat Communications	TeleRobotics	Operator Syst./Training	Navigation & Guidance	CommSat Communicat'ns Flight Expts
		HIGHEST PRIORITY			2nd-HIGHEST PRIORITY	

budget level, the R&T Base decision rules are used to categorize and prioritize the content of that component of the Space R&T Program within a given budget level. Figure 3-8 provides the summary R&T Base discipline research categorization for the FY 1991 ITP.

The focused program decision rules were applied to the detailed program thrust, area and element technical strategic plans by teams of NASA personnel comprised of mission and flight programs personnel, mission operations personnel and NASA technologists. Using the focused program decision rules and evaluation criteria, and the strategic forecast of user mission plans and technology needs (and priorities) a prioritization of the focused programs has been developed. The elements within each thrust have been identified as *highest priority, second highest priority* and *third highest priority.* Based on this prioritization, annual resource allocation decisions will be made. Figure 3-23 provides the 1991 ITP strategic plan prioritization of potential focused element technology projects within the full space R&T technical strategy.

To assure the quality of the planning methodology, the technical content and the priorities of the Integrated Technology Plan, the 1991 ITP was submitted to an extensive external review process led by the Space Systems and Technology Advisory Committee (SSTAC). This external review involved participants from other government agencies, the Space Science and Applications Advisory Committee (SSAAC) and the Aerospace Medicine Advisory Committee (AMAC) of the NASA Advisory Council (NAC), the Aeronautics and Space Engineering Board (ASEB) and Space Studies Board (SSB) of the National Research Council (NRC), as well as other groups such as the Aerospace Industries Association (AIA). The result of this external review was a strong endorsement for the initial ITP, along with a series of specific recommendations — several of which have been incorporated in the 1991 ITP.[14] The remaining recommendations will be addressed in the 1992 ITP.

One of OAST's objectives for space R&T in FY 1992 will be to repeat the process for defining ITP technology priorities in light of refinements in civil mission planning and of greater familiarity with the process. Those updates will be provided in the 1992 edition of the ITP.

The next chapter describes the cycle through which the ITP strategic plan is updated and used to develop an OAST Space R&T Program on an annual basis. It also provides a summary of the content of the FY 1992 program.

Optoelectrncs Sensing & Processing	Probes and Penetrators	----
Precision Instrument Pointing	Sensor Optical Systems	----
Exploration Human Factors	----	Artifical Gravity
Medical Support Systems	----	----
Autonomous Rendezvous & Docking	COHE	Auxiliary Propulsion
Autonomous Landing	TV Structures and Cryogenic Tankage	HEAb
Spacecraft On-Board Propulsion	Earth-Orbiting Platform Controls	Advanced Refrigerator Systems
Spacecraft GN&C	Debris Mapping Experiment	----
Space Assembly & Construction	Space Processing & Servicing	Photonics Data Systems
----	Ground Test and Processing	----
	3rd-HIGHEST PRIORITY	

[14]NASA Advisory Council, Space Systems and Technology Advisory Committee, Advanced Technology for America's Future in Space, (Washington, D.C., December 1991).

This illustration depicts the concept of multiple space platforms operating cooperatively to achieve some future space science mission objectives in Earth orbit. This is just one of the potential challenges facing future space platforms. In addition, timely evolution of Space Station Freedom, and longer-lived, more capable deep space spacecraft are important requirements for the civil space program. The Space Platforms Technology Thrust establishes a framework for technology advances in a variety of areas, including space environmental effects, platform dynamics, spacecraft power, and platform management.

Chapter 4
Space R&T Fiscal Year 1992 Program

The ITP strategic plan is the framework within which the OAST Space R&T Program will be developed on an annual basis. During the same cycle, the ITP will be updated each year to ensure continuing relevancy to user needs and concurrency with technological developments. This chapter provides an overview of the annual planning cycle, the process of program development, and a summary of the FY 1992 OAST Space R&T Program.[1]

Program Development Process

Annual Planning Cycle

NASA Space R&T Program planning is of necessity linked directly to the annual preparation of the U.S. Federal budget. Therefore, every year at the beginning of the federal fiscal year in the fall, the process of reviewing progress and revising the ITP is initiated by OAST. (See Figure 4-1 for a summary of this annual cycle.)

The annual cycle begins in the late summer or early fall with a request from OAST for formal updates of strategic planning and resulting technology needs from the several Associate Administrators responsible for NASA's flight programs, as well as from the external community. Concurrently, progress on the past year's R&T programs is reviewed, and new technology opportunities are identified. Late in the fall, preliminary planning adjustments and R&T progress are reviewed by the external community (through the Space Systems and Technology Advisory Committee-SSTAC, and the SSTAC's Advanced Research and Technology Subcommittee-ARTS). Also, an external review is conducted through the National Research Council's Aeronautics and Space Engineering Board (ASEB). In addition, progress and possible planning adjustments are reviewed with the user program offices within NASA.

The user-identified technology needs and center identification for technology opportunities are synthesized with the results of the previous year's technology development efforts to formulate very preliminary revisions to the past year's ITP and detailed R&T plans. Initial revisions to ITP program technical strategies are considered at this time. These data are used to develop a call to the NASA field centers for proposed ITP strategic planning adjustments and specific space R&T program proposals.

[1]In FY 1992, the Space R&T budget consists of three focused technology programs: the Civil Space Technology Initiative, the Exploration Technology Program and the Space Automation and Robotics Program. This structure would be dramatically revised as a part of ITP implementation. The new structure, although used in the ITP, will not be official until it has been reviewed and approved by both the Office of Management and Budget in the White House and by the appropriate Congressional Committees. The following discussion of the FY 1992 focused programs is provided in the revised ITP structure.

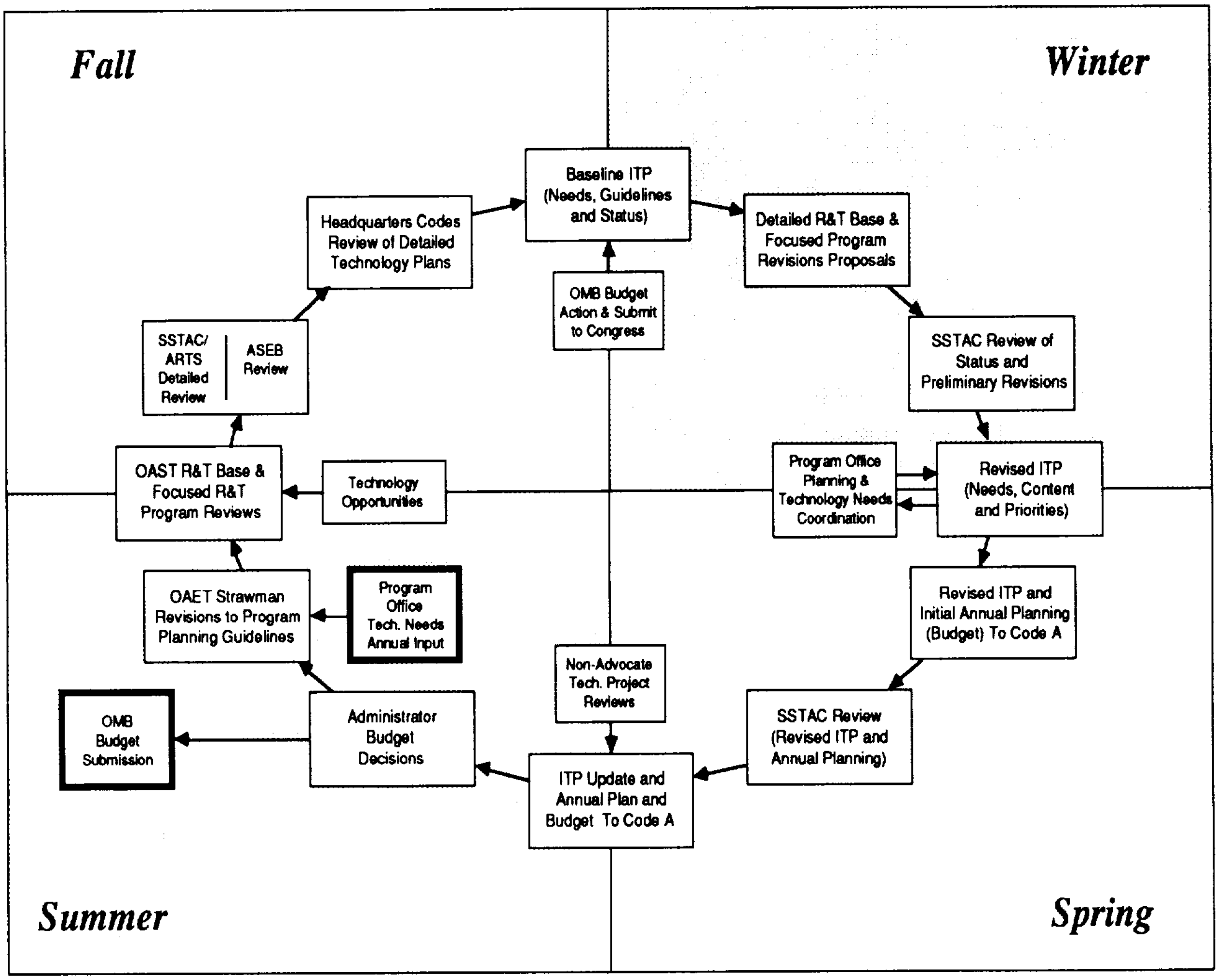

Figure 4-1
Annual Space R&T Planning and Budgeting Cycle

In the early winter, the OMB completes and issues the Administration's Congressional budget request for the next fiscal year. On this basis, plus the center responses to the program call, a revised baseline ITP is developed, incorporating new technology needs, proposed content, and preliminary revised priorities. The revised ITP and detailed plans are reviewed and critiqued once more by the external community (SSTAC). In the late winter or early spring, any necessary adjustments are made to user-identified technology needs initially provided during the preceding fall, and the ITP focused program element prioritization for the upcoming fiscal year is essentially finalized. The resulting version of the ITP is used to prepare OAST's input to the NASA spring planning exercise (including a preview budget to the NASA Administrator).

In the late spring or early summer, the NASA Administrator provides program guidance as a result of the spring budget review. Also, the results of any required non-advocate reviews (NARs) of proposed major technology projects (e.g., major flight experiments), are incorporated into the process. Following a final review with the external community, the ITP is set for the cycle and a space R&T budget is developed and submitted for approval by the NASA Administrator and submission to the OMB. Beginning in the late summer or early fall, the cycle is repeated.

PROGRAM DEVELOPMENT

The ITP is structured in a modular fashion to allow: (a) the clear delineation of strategic planning priorities and budgets by individual program elements within each of the five major focused program thrusts; and (b) the use of those priorities to fit the resultant Space R&T Program within resource constraints that arise as part of the federal budget process. Program priorities are determined at each level of planning within the ITP by a tiered system of coordinating teams comprised of both flight program office and R&T personnel. These teams then determine priorities according to the most recent user needs and the ITP decision rules.

During the first year of the ITP, the degree of prioritization was consistently implemented at the level of a thrust or program area (e.g., down to the level of the Space Science Thrust). A synthesized ITP-level strategic prioritization was then based on those prioritizations. A space R&T planning team, developed (and approved by a space R&T planning team, made up of personnel from all of the NASA field centers, revised and concurred in that prioritization. During the first year — as it will be in coming years — once the strategic plan prioritization was established, working through the team process, it was used to develop strawman programs for alternate budget levels, as they were required.

The general content of the FY 1992 Space R&T Program predates the development of the ITP; hence there are some inconsistencies between the strategic plan prioritization and the program budget. (Perhaps the most significant example of this inconsistency is lack of a focused technology project in the area of Cryogenic Fluid Systems in FY 1992.) Nevertheless, as discussed, the FY 1992 results are similar to those that would be expected with a more thorough application of the ITP process. That is, a great majority of the elements and of their investments have been assessed as the highest priority category.

FY 1992 PROGRAM OVERVIEW

The overall goal of the space research and technology program for FY 1992 is to provide advanced and enabling technologies that are validated at a level suitable for user-readiness, for future space missions, thus ensuring continued U.S. leadership in space. To reach this goal several objectives must be achieved, including: (1) development of a broad base of advanced technology for vehicle and subsystems concepts, components, devices, and software; (2) development of technical strengths in the engineering disciplines within NASA, industry, and academia; and (3) performing critical technology validations that facilitate the transfer of new technology, with a high level of confidence, to future space missions.

The Space R&T Program (including both the R&T Base and the focused programs) was evaluated in 1990 in terms of five user office-focused thrusts, including: space platforms (i.e., SSF), space transportation (i.e., OSF), space science (i.e., OSSA), exploration (i.e., SEI and OSSA/SL) and breakthrough technologies that offer the potential for innovative, high payoff but high risk technology advances. As a part of the ITP planning effort, the 1990 user office-oriented thrust structure was substantially revised. This new structure, which is discussed in detail in Chapter 3, provides for a "technology push" portion of the program, the R&T Base, and a "mission pull" portion of the program, the focused technology programs (a.k.a., the Civil Space Technology Initiative). The following sections provide summaries of the fiscal year 1992 R&T Base and focused program components of the OAST Space R&T Program.

FY 1992 R&T BASE SUMMARY

The objective of the R&T Base program is to gain an increased understanding of the fundamental aspects of phenomena in critical engineering disciplines. The R&T Base program consists of eight program elements: aerothermodynamics; space energy conversion; propulsion; materials and structures;

space flight; systems analysis; information and controls; and human support. In addition, the university space research program, supported by the R&T Base, includes research in critical areas to enhance and broaden the capabilities of the nation's academic community to participate more effectively in the U.S. civil space program.

In FY 1992, the R&T Base program will continue to serve as the seedbed for new technologies and capability enhancement. Also in FY 1992, additional emphasis will be placed on high leverage technologies, including aerothermodynamics, materials and structures, and on systems analysis studies of emerging technologies. The In-Space Technology Experiments Program (IN-STEP) will develop key flight experiments to provide valuable information for solving critical technology problems. The next section describes the objectives and status of the R&T Base elements.

Discipline Research

There are six programs that comprise the discipline research components of the R&T Base program. These include: aerothermodynamics; space energy conversion; propulsion; materials and structures; information and controls; and human support. In addition, in FY 1992, an advanced space communications R&T program was transferred to OAST from OSSA as a part of a general NASA realignment of work formerly in the OSSA Communications and Information Systems Division. Additional information on this program will be provided in the 1992 ITP. The following sections describe the FY 1991 goals of the six ongoing OAST R&T Base programs and presents the research emphasis for FY 1992 for each.

Aerothermodynamics

The Aerothermodynamics Program focuses on the fundamental understanding and prediction of the detailed aerodynamic and thermodynamic loads experienced by high speed vehicles during ascent, entry and maneuver in both Earth and other planetary atmospheres. This activity enables advanced aerospace vehicles to be designed and developed successfully. The program includes the following objectives: (1) development and application of advanced computational methods and numerical techniques covering the entire spectrum of continuum, transitional, and rarefied flows; (2) development of accurate and detailed real-gas chemistry and high speed turbulent flow models and the efficient integration of these models with standard computational flow codes; (3) establishment of a high quality ground and flight experimental data base for code validation and verification; (4) direct correlation and comparison of computations with available ground and flight data; (5) establishment of a detailed aerothermal loads data base and development of fully integrated analysis techniques; and (6) enhancement of engineering design codes and advanced configuration analysis capability to support rapid evaluation of future vehicle/mission concepts. Progress continues in developing advanced CFD codes that incorporate thermochemical nonequilibrium effects and coupled radiation, developing flight test capability sufficient to validate computational predictions and provide correlation for ground test data bases, and increasing the sophistication and efficiency of engineering design codes for configuration assessment.

The focus of the Aerothermodynamics Program in FY 1992 will be to advance the understanding of chemical and radiative nonequilibrium flow phenomena necessary to reduce aerospace vehicle design risk and uncertainties. This will be accomplished by expanding the capability of computational techniques to predict accurately these flow phenomena, in addition to, conducting appropriate experimental testing to verify and validate the codes.

Space Energy Conversion

The objective of the Space Energy Conversion Program focuses on technology alternatives that improve performance, reliability, and cost effectiveness of space power for both manned and unmanned space operations, including autonomous spacecraft and vehicles in near-Earth, interplanetary transfer, and surface activities. To meet this challenge, improvements of a factor of two to five in energy density, power density and power per unit area, as well as increased lifetimes, are being sought in various systems, including: solar power generation components; chemical energy conversion systems; energy storage systems; electrical power management and distribution systems; and thermal management systems. For spacecraft photovoltaic and energy storage technologies, the goal is to improve the total system performance enough to permit a 50 percent increase in payload mass, while not increasing the spacecraft overall mass. Progress continues to be made in the successful testing of a solar array that is five to ten times lighter than existing arrays and in extending the lifetime of nickel-hydrogen batteries while reducing their mass by a factor of two.

In FY 1992, improvements in the conversion of thermal power into electrical power are being pursued. Approaches include higher efficiency thermoelectric materials, the advanced alkali metal thermoelectric conversion system (i.e., threefold improvement), and improved solar dynamic power systems (i.e., three- to five- fold reduction in weight). The solar dynamic program includes development of: (1) high temperature thermal energy storage; (2) lightweight, high concentration-ratio solar concentrators; and (3) lightweight, high efficiency thermal receivers. Research continues on higher efficiency (50 percent increase) radiation tolerant solar cells and the development of a lighter (two to four times lighter) lithium rechargeable battery for space science missions.

Propulsion

The Propulsion Program focuses on a number of critical technologies that will greatly improve our ability to gain access to and operate in space in a significantly more efficient manner. One focus is on extending our knowledge and understanding of fundamental rocket engine chemical and physical processes to enhance future component designs and to predict accurately the life and performance of individual components. Research efforts in this area emphasize rocket engine combustion stability and turbomachinery internal fluid and dynamic processes, including predictive modeling. In addition, extremely high performance low thrust electric propulsion systems research addresses technology issues and advanced concepts for electrothermal, electrostatic and electromagnetic propulsion for improved thruster life and performance. Research on auxiliary propulsion will develop concepts for control of space vehicles. Another high potential area involves the use of extremely high energy-density propellant combinations, such as liquid oxygen with metallized fuels, that offer promise of significantly potential performance gains. Progress continues to be made in several areas. Ion engine discharge chamber erosion rates have been reduced by a factor of 20 to 50 and a hydrogen arcjet was successfully demonstrated between 5 to 24 kilowatts at specific impulses over 1400 seconds. In addition, progress continues in advanced fluid film bearings, fiber-reinforced high heat-flux combustion devices, low leakage rotating seals, and high efficiency turbine stages, low cost manufacturing, and long lived combustion devices.

In the Propulsion Program for FY 1992, a propulsion evaluation system for advanced transportation vehicles will be implemented to better assess the potential payoffs of technology improvements in propulsion systems and innovative propulsion concepts. In Lunar and planetary propulsion, system level conceptual studies will identify exploration vehicle/propulsion concepts designed to use planetary-derived propellants. Advanced propulsion concept studies will continue so that fruitful areas for agency emphasis and the critical experiments necessary to demonstrate their potential benefits may be identified. Numerical modeling of innovative plasma rocket concepts will be completed and system level assessments will be conducted. In addition, electrodeless thruster concepts will be tested.

Materials and Structures

The Materials and Structures Program focuses on extended space durability and environmental effects, lightweight structures for space systems, and large space structures and advanced space transportation systems with significant improvements in performance, efficiency, durability, and economy. The objectives for materials technology include the following: to acquire a fundamental understanding of the processing, properties and behavior of advanced space materials; development of lightweight space-durable materials; computational methods in chemistry to enable the prediction of physical properties and environmental interactions involving materials in space or during reentry; nondestructive measurement science for advanced materials; tribological aspects of materials behavior in the space environment; and the development of a wide variety of metallic, intermetallic, ceramic and carbon-carbon materials for thermal protection systems. Structures technology focuses on the following: development of erectable and deployable structural concepts; methods for in-space construction; monitoring and repair of large complex structures; dynamics of flexible structures and vibration suppression; new structural concepts for active cooling of hot structures; cryogenic tanks for advanced Earth-to-orbit rocket propulsion systems; future space transportation vehicles; and orbital transfer vehicles, efficient analysis and design methodology for advanced space structures, including multidisciplinary analysis and optimization. During the past fiscal year, analysis of the data returned by the Long Duration Exposure Facility (LDEF) has improved the definition of the low Earth orbit environment, such as in debris and micrometeoroid modeling, and has proven valuable in directing the continued development of tailored polymers, advanced metals and composites. Also during the previous fiscal year, space structures research has successfully demonstrated in-space construction of a large truss in the laboratory, advanced fabrication methodology was developed for hot structures, and materials were evaluated for more durable thermal protection systems.

In 1992, the Materials and Structures Program will emphasize the evaluation of materials systems returned from the LDEF which will provide a baseline for assessing stability and long term durability of advanced materials and coating systems requiring a 20 year service life in both low Earth orbit and geosynchronous Earth orbit. Space environmental effects on materials, such as radiation and atomic oxygen effects, will be assessed using degradation models to describe environmental interaction and accelerated test methods to simulate the space environment. Computational chemistry will be used to model material interaction phenomena at the molecular level. Advanced materials and structural concepts will be explored for integral cryogenic tanks and thermal protection systems, including advanced metallic and composite cryogenic tank concepts and durable, woven ceramic thermal protection systems, for future space vehicles. The emphasis in space structural concepts will be on automated construction methods required for large orbiting scientific instruments and space platforms. The payoff will be to minimize astronaut EVA time and reduce mass and packaging volume, up to 50 percent, by enabling advanced design concepts. Research on deployable concepts for large area precision structures, such as antennas of the type needed for advanced Earth observing instruments, also will be continued. A new program in space mechanisms will be initiated within the Materials and Structures Program, and an increased emphasis will be placed on materials for space optical systems.

Information and Controls

The Information and Controls Program is comprised of five areas: computer science; advanced data concepts; photonics; communications; and, sensors and controls. In the computer science area, the research goals include: access to and management of very large scientific data sets; development of software engineering tools for generating significantly complex and reliable software; and innovative, but potentially, highly effective computational approaches such as neural networks. The communications area goals include development of Ka band deep space communications capabilities and development of the technology base for space-to-space and space-to-ground optical communication links.[2] The primary goal of the photonics research is to develop optoelectronic components and system concepts to enable high speed optical sensing and computing. The sensors research area is directed at innovative sensing and electronic devices for high energy (gamma, X-ray, ultraviolet) observation missions. In the controls and guidance area, the goal is to shorten by orders of magnitude the time to compute controls solutions for complex systems. New computational approaches have been developed and are being successfully integrated into advanced computational controls tools.

Priorities in FY 1992 in the Information and Controls Program have been identified in all five areas. In the area of computational and computer science, the emphasis will be on maintaining a solid university base. Photonic research will emphasize device development in optoelectronic integrated circuit technology for spaceborne optical electronic systems, such as optical computing. Data and communications research will be directed toward software engineering research, advancing electro-optic technology

[2] R&T in this area is being merged with the space communications R&T transferred from OSSA; an integrated discussion of the combined effort will be provided in the 1992 ITP.

for laser communications, and evaluating the potential impact of high temperature superconducting materials on future communications system components. Research on high efficiency monolithic millimeter-wave circuit technology and high performance electron beam technology will be pursued for advanced deep space and satellite communications. Sensor research will continue to concentrate on development of solid state laser systems for enhanced atmospheric science, ranging and altimetry, and other remote sensing applications. In the controls and guidance area, emphasis will be focused on the development of analytical tools for the design of control systems for precision pointing and control of large flexible spacecraft and for avionics systems technology for advanced transportation vehicles.

Human Support

In the Human Support Program, human factors research goals include the development of new technology to model human performance, including physical and cognitive capabilities of astronauts for zero-gravity. EVA operations will be aided by development of a new technology in high pressure EVA glove design. New thermal control methods for life support also will be developed. Closed loop life support chemical processing technologies will provide recycled air and water for crew consumption to eliminate or significantly reduce mission resupply requirements. Progress will continue in the development of a set of techniques, which collectively are called virtual interactive environment workstation or artificial reality. A data base for virtual exploration of the Mars surface and an Earth analog environment will be established.

The emphasis in the Human Support Program, during FY 1992, will be on the development of new methods for presenting visual information via computer-based displays and technology to visualize virtual environments for exploration missions. New methods for thermal management of zero-gravity suits will be tested to verify predicted performance gains. Advanced, expert system-based human/computer interfaces will be tested using actual data. In addition, technology requirements for in-space biomedical support will be defined. Research will continue on developing efficient air, water, and waste processing technologies, sensor and monitoring instrumentation and controls technology for air and water quality, as well as the development and validation of computerized simulation techniques to support and guide the research efforts.

Space Flight R&T and the In-Space Technology Experiment Program (IN-STEP)

The following section discusses the planned programs in Space Flight R&T and the In-Space Technology Experiments Program (IN-STEP). The IN-STEP program is a separate line item in the FY 1992 budget. However, as a part of the ITP process, IN-STEP and the continuing R&T Base Space Flight R&T Program will be better coordinated in the future. Therefore, the two activities are assessed together in this section.

Space Flight R&T

The Space Flight R&T Program provides the development, verification and evaluation of advanced technologies that require the actual space environment for validation. Flight data obtained from in-space research and experimentation will be used to validate and verify analytical models, prediction techniques, and ground test methods and facilities. This program encompasses the identification and definition of future in-space flight experiments generated within U.S. industries, universities and the government. It also includes the continued design, fabrication, and flight certification of several experiments in preparation for space validation that were initiated prior to FY 1990 (including the Light Detection and Ranging In-Space Technology Experiment (LITE), development of a space platform-mounted laser sensor to measure Earth atmospheric constituents and instrumentation for the Orbiter Experiments (OEX) mounted in the Space Shuttle; and the development of unique, special purpose experiment hardware systems to facilitate technology validation in the space environment. Thirteen flight experiments will finish their design definition phases. Those experiments are: Cryo-system; Permeable Membrane; Two

Phase Flow; Sodium Sulfur Battery; Inflatable Paraboloid; Jitter Suppression; Middeck Active Controls; Joint Damping; Hydrogen Maser Clock; Liquid Motion in a Rotating Tank; Tank Venting; Tank Pressure Control; and Electrolysis. Two other experiments, Optical Properties and Fire Safety, will complete feasibility studies. Several new experiments, initiated from a 1991 Announcement of Opportunity (AO-91), will begin their feasibility studies.

For FY 1992, funding for the space flight area will concentrate on the definition of 13 technology experiments selected as part of a November 1989 AO. An AO will be released in early FY 1991 to identify a new series of technology experiments that will provide solutions to critical technology needs identified at the 1988 IN-STEP Workshop. Feasibility studies will be conducted on a new series of experiments that respond to a FY 1991 AO. Assembly of the components for the LITE experiment will be initiated in preparation for a launch readiness date of 1993.

IN-STEP

The In-Space Technology Experiments Program (IN-STEP) provides for the definition and development of hardware and software for flight experiments to validate advanced space technologies already developed within NASA, industry or universities. Previous efforts in the R&T Base have identified and defined advanced technology concepts that require testing or validation in the actual space environment to reduce the risk of potential applications and to increase the rate of transfer of advanced technologies into future space missions. Examples of those technologies include the behavior of fluids in the microgravity environment, which is essential for the design of advanced thermal management systems; effects of the space environment on spacecraft; variable gravity effects on heat transfer; effects of contaminates on space systems; and in-space construction techniques (welding).

IN-STEP will coalesce many unique space technology concepts into defined flight experiments and will provide for the development of the flight hardware. The program concentrates on experiments performed primarily in the Shuttle mid-deck, "get-away special" (GAS) cans, or combined on cross-bay structures such as hitchhiker. Many of the experiments will serve as precursors to other experiments that will use the SSF facilities later in the decade. The two major elements of IN-STEP are: (1) industry/ university experiments; and (2) NASA in-house experiments.

NASA Experiments

Current NASA experiments include: REturn FLux contamination Experiment (REFLEX); the Thermal Energy Storage Materials Testing (TEST) experiment; the Debris Collision Warning Sensor (DCWS) experiment; and several innovative concepts currently in the definition phase. The REFLEX experiment will identify the types and quantities of contaminates surrounding the spacecraft. The TEST experiment will validate concepts for storage of energy on spacecraft for later use when normal energy sources (such as the sun) are unavailable. The DCWS experiment will validate a sensor concept which measures and identifies small debris in low Earth orbit that could be detrimental to spacecraft and space structures, and the safety of humans. Currently this debris is undetectable by ground radar and telescopes or by present space sensors.

Aerospace Industry/University Experiments

The industry and university technology experiments program was initiated in 1986 with a solicitation for flight experiments resulting in the identification of over 200 innovative space technology experiment concepts. Forty-one experiments were selected for definition or development. Five experiments have completed design studies and are initiating the detailed design, fabrication, and ground certification in preparation for flight testing. Examples of these five experiments are the Tank Pressure Control (TPC) and the Experimental Investigation of Spacecraft Glow (EISG) experiments. The TPC experiment will validate predicted mixing and thermal stratification characteristics of fluids in a zero-gravity environment influenced by jet-induced flow. The glow experiment will study the causes and effects of ram-induced radiation observed around certain materials in the space environment, which may reduce the erosion of space structures. The other thirty-six experiments have completed the definition phase and will compete in an AO with other industry and university concepts for continuation in the flight hardware design, fabrication, and testing phase.

In FY 1992, several of the experiments in NASA's IN-STEP will complete the hardware development phase. Also, the first IN-STEP joint industry and university experiment, the Tank Pressure Control (TPC), will provide flight results that may significantly reduce the cost and complexity of fluid tanks in future spacecraft. In FY 1992, two other experiments will be tested in the middeck of the Space Shuttle: the Heat Pipe Performance experiment (which will test performance under different extreme conditions that may occur in spacecraft applications); and the Middeck Zero-gravity Dynamics (MODE) experiment (which will provide basic information on the behavior of structures in microgravity reducing the risk for large systems).

Five experiments will complete their flight hardware fabrication and assembly: Thin Foil Mirrors (TFM); Laser Oscillator (SUNLITE); Glow (described above); Emulsion Chamber (ECT); and Solar Array Plasma Interaction (SAMPIE). TFM will test new types of protective coatings for x-ray mirrors. SUNLITE will validate an ultra-stable, solid state laser oscillator that can be used to improve frequency and time standards for global positioning systems. The Emulsion Chamber experiment will characterize the space radiation environment and will lead to improved performance of sensors and microcircuits. SAMPIE will evaluate the effects of low orbit plasma interference on on the effectiveness and lifetime of high voltage solar cells.

University Programs

The objective of the University Space Research Program is to enhance and broaden the capabilities of the Nations's engineering community to participate more effectively in the U.S. civil space program. It is an integral part of the strategy to strengthen the Nation's space research and technology base. The program elements include the following: the university space engineering research center program, which supports interdisciplinary research centers at nine universities; the university innovative research program, which provides grants to individuals with outstanding credentials; and the university advanced space design program, which funds advanced systems study courses at the senior and graduate levels. Significant technical, research and educational benefits have begun to be realized from the University Space Engineering Research Centers (USERCs), including attracting, retaining, and training graduate students and increased industry cooperation support.

In FY 1992, the University Space Research Program funding will continue to support the nine incumbent centers of the program. The current centers are the following:

- *University of Idaho* — Space Engineering Research Center for VLSI (Very Large Scale Integration) System Design
- *University of Michigan* — Center for Space Terahertz Technology
- *University of Arizona* — Center for the Utilization of Local Planetary Resources
- *North Carolina State University at Raleigh/North Carolina Agricultural and Technical State University* — Mars Mission Center
- *Rensselaer Polytechnic Institute* — Center for Intelligent Robotic Systems for Space Exploration
- *University of Cincinnati* — Health Monitoring Technology Center for Space Propulsion Systems
- *Massachusetts Institute of Technology* — Controlled Structures Technology Center
- *Pennsylvania State University* — Center for Space Propulsion Engineering
- *University of Colorado at Boulder* — Center for Space Construction.

Support also will continue for the eminent researchers selected in FY 1989 and FY 1990, to participate in the Space University Investigators Research Program, and additional three-year grantees will be included. Support for the Advanced Design Research Program also will continue. Finally, U.S. universities continue to be strong participants in IN-STEP.

SYSTEMS ANALYSIS

The goals of the Systems Analysis Program are to: (1) identify technology requirements for future mission concepts and technology opportunities to enable new and improved concepts; (2) integrate those technologies into a comprehensive set of technology planning options; and (3) generate candidate plans to develop those technologies in a timely manner. This effort is closely coordinated with the space flight mission program offices (e.g., OSSA, OSF, OEXP and OSC) to identify the technology requirements for their future mission concepts and the technology opportunities to enable new and improved mission approaches for space transportation, science spacecraft, and large space systems. Progress will continue in the following areas: defining the critical technologies associated with Earth science observations for understanding global change; defining technologies for future astrophysics missions beyond the Great Observatories; identification of high priority technologies that will increase reliability and reduce operations costs for the current Space Shuttle system (Shuttle evolution); and development of future unmanned launch vehicles and second generation manned vehicles.

The Systems Analysis Program in FY 1992 will continue supporting studies that identify technology needs and benefits for advanced transportation, space science and space platform systems. The emphasis of the transportation systems effort will be on launch vehicle concept design studies to assess technologies for the next generation of manned launch vehicles. The technology options to be studied address staged

Space Science Technology	Submillimeter Sensing	Direct Detectors	Laser Sensing	----	----	----
	Cooler and Cryogenics	Microprecision CSI	----	----	----	----
Planetary Surface Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	----	----
	----	----	Extravehicular Activity Systems	----	----	Laser-Electric Power Beaming
Transportation Technology	ETO Propulsion	Nuclear Thermal Propulsion	----	----	----	----
	----	Advanced Cryogenic Engines	----	Nuclear Electric Propulsion	----	----
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.	----	----	----	----
	----	----	----	----	----	----
Operations Technology	Space Data Systems	----	Artificial Intelligence	----	----	----
	----	----	TeleRobotics	----	----	----
	HIGHEST PRIORITY			2nd-HIGHEST PRIORITY		

and single-stage-to-orbit vehicles, horizontal and vertical takeoff vehicles, rocket and airbreathing vehicles, and combined engine concepts. For spacecraft systems, efforts will focus on the identification of critical technologies for science missions in the OSSA planning queue for the next several years, in the "pool" of next generation science mission options projected for 1998/1999 and beyond. Additionally, studies will be undertaken to gain a broader understanding of the critical technologies identified by OSSA needs.

FY 1992 Focused Programs Summary

The space R&T focused programs are based on requirements provided by the potential users of the technology. The goals of the focused programs are to develop technology for specific future applications and deliver products in the form of proven hardware concepts, software, and design techniques and data.[3] In FY 1992, a variety of specific element technology projects will be implemented, including efforts in each of the ITP's five technology thrusts. In addition, the FY 1992 space R&T budget included a line item for Exploration Mission Studies which was planned to continue to provide resources for the technical, programmatic, and cost analyses required to support a future national decision on a specific SEI architecture. (This part of the FY 1992 budget request is not assessed below.)

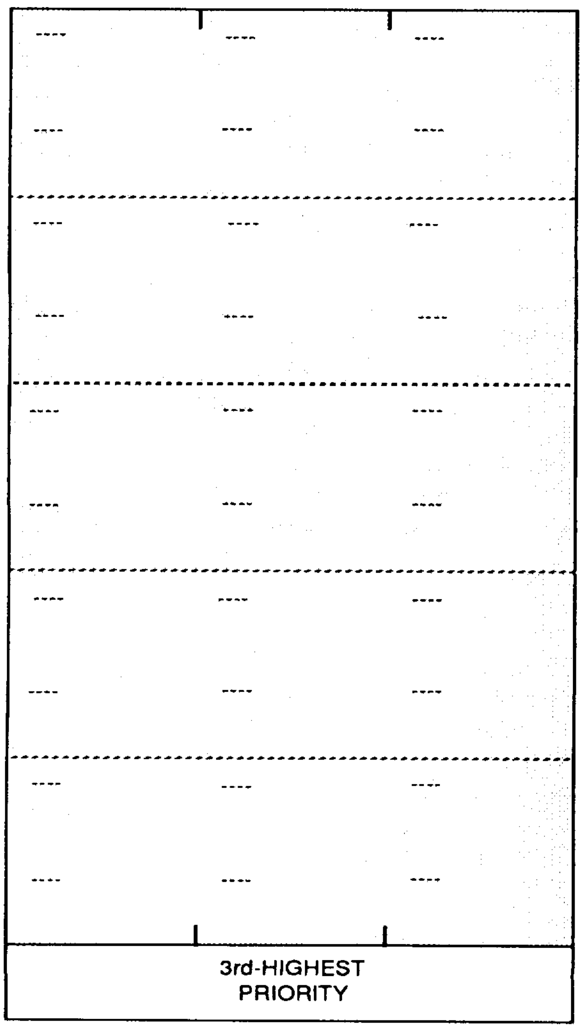

Figure 4-2 *1992 Space R&T Focused Programs*

In fiscal year 1992, only a select number of the highest priority elements in the overall ITP strategic plan priority matrix are funded. (Figure 4-2 presents a summary of this information.) However, in terms of the overall strategic plan, the FY 1992 program allows a reasonable effort in the majority of highest priority space technology research efforts, including both the R&T Base programs and focused program technology projects. Within the focused programs, efforts are underway in each of the major program thrusts of the ITP, including the following:

Space Science Technology

Five elements, each ranked in the highest priority in the ITP strategic plan, are funded in FY 1992, including: Submillimeter Sensing; Coolers and Cryogenics; Direct Detectors; Microprecision CSI; and Laser Sensing.

Planetary Surface Technology

Four elements from the highest priority ranking in the ITP strategic plan, are funded in FY 1992. These include: Radiation Protection; Regenerative Life Support (physical-chemical); Space Nuclear Power (SP-100); and Extravehicular Activity (EVA) Systems (Surface). Two elements from the second highest strategic ranking are funded: the High Capacity Power (an ongoing program): and Laser-Electric Power Beaming.

[3] Three fiscal year 1992 focused program line items are identified in the old program structure, including the Exploration Technology Program (ETP), the In-Space Technology Experiments Program (IN-STEP) and the Space Automation and Robotics (A&R) program (which was comprised of the telerobotics and artificial intelligence programs previously conducted as part of the CSTI program).

Transportation Technology

Three element programs ranked in the highest priority are supported in FY 1992, these include: ETO Propulsion; Advanced Cryogenic Engines; and Nuclear Thermal propulsion. In addition, one element project from the second highest priority is supported, Nuclear Electric Propulsion.

Space Platforms Technology

Two Space Platforms Technology Thrust elements are underway in FY 1992, both in the highest priority ranking: Platform Structures and Dynamics; and Platform Power and Thermal management (including solar dynamics).

Operations Technology

Three elements are supported in Operations Technology, both from the highest priority category in the ITP strategic plan prioritization matrix. These are: Space Data Systems; Artificial Intelligence; and Telerobotics.

In each thrust, those elements that are not funded in FY 1992, due to resource constraints, will be considered as candidates for initiation in future cycles of ITP planning (Figure 3-10 presents these elements). The following paragraphs provide brief summaries of the FY 1992 elements in each of the funded focused technology thrusts.

Space Science Technology

The Science Sensing area (including Direct Detectors, Submillimeter Sensing, and Laser Sensing) will develop additional advanced sensors to enable observation of Earth, the solar system, and the universe. The sensors can be characterized as having significantly increased sensitivity, resolution, and/or longer life than those previously available. In FY 1992, science sensor technology activities will continue to demonstrate detectors in the four to 20- microns wavelength region using multiple quantum-well and mercury zinc telluride devices, in the 30- to 300-microns region using blocked impurity band phenomena, and in the submillimeter wave region on quantum-well local oscillator and superconducting tunnel junction mixers. A solid-state laser technology for LIDAR applications will continue to be developed. In addition, in FY 1992, an augmented effort will begin to develop advanced mechanical coolers and infrared detectors with performance and lifetime characteristics required by future Earth observing missions.

The Precision Segmented Reflector (PSR) Program completed its scheduled period of performance in FY 1991. The goal of the PSR Program was to develop critical enabling technology for large orbiting astrophysical telescopes operating in the submillimeter spectrum. Advanced lightweight reflector panels were developed, panel control methodology was demonstrated, and a high-precision erectable support truss concept was designed, fabricated and tested.

Planetary Surface Technology

In the area of Surface Systems technology, research will continue in the Space Nuclear Power element, focused on refractory metal reactors, solid-state thermoelectric conversion, and thermal management technologies such as heat pipes. NASA's participation in the interagency space nuclear power program, SP-100, with the DOE and DOD, is supported through this effort. The High Capacity Power Program will provide the technology for advanced energy conversion systems, radiators, heat pipes, and power control components necessary to achieve a fivefold increase in the electrical power obtainable from the SP-100 reactor and will double the power-to-weight ratio of the current SP-100 system being developed as part of the tri-agency program. In this element, based on the completion of the linear alternator, an improved heater head, and other key component technologies were delivered (e.g., a Stirling engine will be fabricated and tested at 1050 degrees Kelvin in late FY 1992). In addition, testing of a multi-couple thermal electric conversion system at a projected figure of merit of .85 (as compared to the current .70) will be completed. Other technology activities include: testing of a water heat pipe at 450 degrees

Kelvin for use with a Stirling engine; testing of refractory liner material for a 850 degrees Kelvin carbon-carbon heat pipe; and completion of the feasibility demonstration of a lithium-sodium-potassium pumped-loop radiator at 550 degrees Kelvin.

In the area of Human Support technology, research will continue in Regenerative Life Support Systems technology, including air revitalization, water reclamation, environmental monitoring and control, and bioregenerative life support. Research efforts will also continue in the development of Extravehicular Activity Systems, including highly dexterous, high pressure gloves, suit end effecters and tools, and portable life support systems, including thermal management systems, and carbon dioxide removal. Research will continue in Radiation Protection technology, including the definition of radiation transport computer models, initial development of an experimental radiation transport database, and research in radiation protection shielding materials and structures.

TRANSPORTATION TECHNOLOGY[4]

The Transportation Technology Thrust consists of three program areas in the ITP strategic plan: Earth-to-Orbit (ETO) Transportation; Space Transportation; and Transportation Technology Flight Experiments. In FY 1992, four element programs are underway, one in ETO Transportation and three in Space Transportation.

The ETO Propulsion Program provides for both the acquisition and verification of need-focused advanced technologies for the evolution of future transportation propulsion systems. New analytical methodologies and design tools, validated experimentally in test rigs, large-scale combustion devices, turbopumps, and in the controls and monitoring test laboratory, will be made available to industry and government engineers and technicians for application to future flight hardware development programs. The ETO Propulsion Program is aimed at providing the technological know-how and those test-proven development tools needed for future safe and reliable, low cost and operationally efficient space transportation propulsion systems.

In FY 1992, the ETO Propulsion Program will focus on the emplacement of large scale technology validation testing facilities in each of three major areas: combustion devices; turbomachinery; and systems and controls monitoring. In parallel with these focused subsystems evaluation capabilities, in FY 1992, an estimated twelve to fifteen additional technology products are expected to be validated in the Space Shuttle Main Engine (SSME) technology testbed (TTB) at the Marshall Space Flight Center.

In the area of space transportation technology, the Advanced Cryogenic Engines Program will continue research and technology in areas such as advanced expander-cycle cryogenic (hydrogen-oxygen) engines for space transfer vehicles and for ascent/descent propulsion. This R&T will include development of a breadboard and the technology for high throttleability, long life with multiple firings, integrated engine diagnostics and controls, and design for engine space basing and servicing. In FY 1992, development of the Advanced Expander Cycle Testbed (AETB) will continue to be the primary objective of the program.

Within the Space Transportation area, in FY 1992, nuclear propulsion technology research will be supported in areas such as nuclear thermal rocket propulsion technologies, including several alternative solid core nuclear system and operational concepts, for systems capable of long life and multiple starts. Nuclear electric propulsion technologies will be also studied, including issues related to nuclear reactor power systems, and magnetoplasmadynamic (MPD) and high power ion thruster technologies for future deep space mission applications.

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[4] In FY 1992, the Aeroassist Flight Experiment (AFE), formerly funded in the Space R&T Program was terminated. AFE would have permitted the validation of computational fluid dynamics (CFD) codes necessary for the design of those vehicles and would have test materials and guidance and navigation techniques in the actual flight environment which cannot be adequately or fully simulated in ground tests. Future OAST Space R&T Planning will address how ITP strategic objectives vis-a-vis aerobraking technology development will be accommodated.

Space Platforms Technology

In the ITP strategic plan, the Space Platforms Thrust consists of four major program areas: Earth Orbiting Platforms; Space Stations; Deep Space Platforms; and, Space Platforms Technology Flight Experiments. In FY 1992, two elements within the Earth Orbiting Platforms program area are underway.

The Platform Structures and Dynamics program (formerly the Control/Structures Interaction (CSI) program) focuses on unifying the controls and structures disciplines into a multidisciplinary technology to enable accurate prediction of in-space behavior and maximize the performance of large flexible space structures. Program emphasis includes analysis and design methods, CSI concepts, verification test methods, qualification methods and on-orbit experiments. In FY 1992, the Platform Structures and Dynamics Program (a.k.a, the CSI Program) will initiate an effort to develop smart materials for vibration control and isolation and will enhance the development of technology focused on space interferometers and large Earth observing platforms.

In FY 1992, a new focused program in Earth orbiting Platform Power and Thermal Management was initiated. The FY 1992 focus of this program will be on solar dynamic power systems, including collectors, Brayton cycle thermal-to-electric conversion systems, thermal management systems and thermal energy storage. A major objective of the program will be to conduct an integrated sub-scale, ground test to evaluate subsystem-to-subsystem interactions and performance in a realistic breadboard environment.

Operations Technology

In the ITP strategic plan, the Operations Technology Thrust consists of four major program areas: Automation and Robotics; Infrastructure Operations; Information and Communications; and Operations Technology Flight Experiments. In FY 1992, three element programs are underway.

The Artificial Intelligence Program will exploit artificial intelligence (AI) for control of multiple subsystems with the capability for automated reasoning and recovery from unanticipated failures. This technology effort will focus on providing real-time, fault-tolerant control for flight critical systems and on developing, testing and validating increasingly complex autonomous systems, starting with automation of a single critical function and progressing to coordinated control of multiple critical functions. The application of this technology to future exploration, SSF, Space Shuttle and space science missions will result in higher degrees of onboard autonomy and reduction in manpower required in mission control. This technology will enable increased safety and likelihood of mission success by permitting more intelligent control and warning systems and by permitting the onboard system to dynamically replan around existing failures.

The Telerobotics Program will support the integration and demonstration of technology for space telerobotics to enhance operational capability and decrease cost of space operations. The program focuses on advanced teleoperations, robotics and supervisory control (telerobotics). One aspect of the program is a challenging sequence of demonstrations of telerobotics technology applied to processing of launch vehicles, which serve as a focus for research efforts in NASA, university and industry laboratories. Additional demonstrations will validate capabilities to service satellite and assemble space structures. In FY 1992, OAST's efforts in A&R were planned to include the technology demonstration elements of the flight telerobotic servicer program (previously conducted as part of SSF) and the Telerobotics and Artificial Intelligence Programs (previously conducted as part of the CSTI Program).[5]

The Space Data Systems Program (formerly High Rate/Capacity Data Systems) will assure the evolution of high speed, high volume data handling onboard spacecraft and in ground data analysis. The Space Data Systems Program will continue using four-processor, very high speed, integrated circuit multiprocessors and will continue development of a brassboard space flight optical disk recorder module. Preliminary design of experimental onboard digital processors and correlators will be continued.

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[5] The Flight Telerobotics Servicer (FTS) was funded under SSF in FY 1990 and FY 1991. The FTS detailed design of the first Development Test Flight (DTF-1), was transferred to OAST in FY 1991. Through the action of the Congressional Appropriation Conference Committee, the FTS program has been terminated in FY 1992.

The complexity, costs and risks of civil space program operations must be reduced in order to achieve our objectives during the coming decade. At the same time, data system capabilities and human operator efficiency must be increased dramatically. As illustrated in this artist's rendering, advances in artificial intelligence, robotics, data system, telecommunications and other technologies, will all be important to attaining these goals. The ITP's Operations Technology Thrust provides a roadmap for these vitally needed investments.

Chapter 5
Coordination of Civil Space Technology Development and Transfer

The coordination of space technology development among government institutions (and with industry and academia) and the successful transfer of technology are vital to the success of the civil space program. Several challenges must be addressed, including: (1) coordination of technology development and transfer between the OAST organization and its research teams and the NASA flight programs and their field center project offices; (2) coordination (and selected transfer) between NASA and other U.S. government technology development efforts; (3) transfer and dissemination of timely technology development information from NASA to the aerospace industry; and (4) technology transfer from the U.S. aerospace community to the broader U.S. economy.[1] This chapter reviews the major areas for development coordination, within NASA, between the agency and other parts of the U.S. government, and between NASA and the aerospace industry. The chapter also discusses principal issues, strategies, and participants involved in the transfer of technology.

NASA Programs

Office of Space Science and Applications

OSSA depends upon OAST for research and technology development across a wide range of spacecraft subsystems, instruments, infrastructure subsystems (e.g., onboard SSF), and indirectly for continuing support to low cost transportation to space. However, OSSA also conducts a family of advanced technology development (ATD) programs for the next planned major OSSA initiatives. OSSA's objective in conducting these ATD efforts is to ensure that mission-critical technologies are proven prior to initiation of full-scale development (FSD), thereby reducing cost and schedule risks.

In its 1991 Strategic Plan, OSSA identified ATD programs associated with the Space Infrared Telescope Facility (SIRTF); the Orbiting Solar Laboratory (OSL); and Gravity Probe-B. As a result of the 1991 Woods Hole Workshop on space science and applications strategic planning, the OSL new start has been deferred beyond the near term timeframe.

OSSA and OAST will work closely to coordinate their respective technology development activities in these areas during the coming year. In addition, planning is underway in several other space science areas (e.g., in solar system exploration) for advanced studies and ATD. OAST space R&T planning will also be linked to these efforts as they are defined and implemented. One area of particular interest is life sciences research.

[1] Coordination with — and assessment of — international space technology development activities also are aspects of the overall subject of technology transfer; they will be treated in future editions of the ITP.

The Life Sciences Program will conduct ground and in-space research programs during the next two decades that will provide an essential scientific foundation for space R&T efforts. As a result, this area represents a special set of challenges for advanced space R&T coordination. First, the results of life sciences research will define both requirements and boundaries for human support R&T (such as determining human limits for exposure to microgravity). Second, alternatives in the advance of technology will substantially affect the course of life sciences research (e.g., definition of artificial gravity concepts that are practical from an engineering standpoint). Finally, the overall framework for both life sciences research and human support R&T will be defined by the mission planners (e.g., through plans to use high performance nuclear propulsion and fast trip times to Mars rather than artificial gravity and slower transits).

The NASA OSSA Life Sciences Program represents a core of expertise that spans several NASA Centers, enjoys broad participation from academia, and is well coordinated with the DOE National Laboratories and the National Science Foundation (NSF), and the National Institutes of Health (NIH). Two areas of particular importance are the effects of long duration operations in microgravity[2] and issues associated with exposure to galactic cosmic radiation (GCRs) and solar particle events (SPEs). The Life Sciences Division is actively examining the strategic research options and priorities to satisfy the knowledge requirements of future deep space exploration missions. As this process continues, the ITP will evolve to best reflect refinements in life sciences program planning.

Office of Space Flight[3]

The Office of Space Flight (OSF) has responsibility for the continuing development and operation of the Space Shuttle, expendable launch vehicles (ELVs), and related systems (such as upper stages). OSF is also responsible for the development of SSF and for NASA's participation in the development of the National Launch System (NLS). The latter topic is addressed below in the section concerning major joint NASA-other government programs.

OSF works with OAST in the definition of technologies needed for manned Earth-to-Orbit (ETO) transportation systems, SSF, and future ELVs and upper stages and related ground operations. OSF plans and implements a series of advanced mission and system concept studies as well as selected advanced development (A/D) programs to support pre-project efforts for future flight programs. The R&T efforts planned within the ITP are being coordinated with those studies and A/D programs.

Office of Space Communications

The Office of Space Communications (OSC) has a strong, ongoing and continuing engineering development program (analogous to the A/D programs in the flight project offices) which addresses the next major enhancements planned for NASA telecommunications and mission operations systems. OAST R&T is targeted on the next generation system concepts identified by OSC.

[2] This includes planning for utilization of Space Station *Freedom* for extended microgravity research studies beginning in the mid- to late- 1990's.

[3] As the 1991 ITP was being completed, a significant reorganization of OSF was announced—involving the creation of a separate Office of Space Systems Development. Details regarding change will be incorporated in the 1992 ITP.

Office of Exploration[4]

NASA's Office of Exploration (OEXP) is leading the definition of the U.S. Space Exploration Initiative (SEI). The research and technology needs of SEI are discussed in some detail in Chapter 2. In addition, as planning for SEI matures, it is anticipated that a series of SEI advanced development activities will be initiated, including the demonstration of selected key capabilities for future SEI missions.

The OEXP is leading the coordination of SEI-related joint activities, between the National Science Foundation and NASA, related to the use of Antarctic research facilities as part of Lunar and Mars mission analog studies. Major efforts have not yet been initiated however, OAST and the space R&T program are participating in planning for this activity. Areas of particular interest include base and mobile power, life support systems, and human factors.

Office of Commercial Programs

The Office of Commercial Programs (OCP) is the focus within NASA for expanding the U.S. private sector investment and involvement in civil space activities (including higher-risk, higher-leverage advanced technology commercial ventures— in particular in commercial communications satellites) and the management of the Small Business Innovative Research Program. OCP also promotes the application of NASA-developed technologies in the general economy and helps to expand commercial access to available NASA capabilities and services. Continuing close interactions between these activities and those of OAST will be needed to ensure effective transfer to the general economy. The following section delineates three major OCP activities.

Small Business Innovative Research Program

The Small Business Innovative Research (SBIR) Program was initiated in 1983 by Public Law 97-219. The objectives of the SBIR Program are to stimulate technological innovation in the U.S. private sector, to strengthen the role of small business (including firms owned by minority or disadvantaged persons) in accomplishing federal R&T goals, and to enhance commercial applications of federally-supported R&T products. SBIR programs are supported in two phases. Phase I project objectives are to determine feasibility of research innovations meeting agency needs. Phase II continues development of the most promising Phase I projects for up to a two-year performance period. Selection criteria include technical merit and innovation, Phase I results, value to NASA, commercial potential and company capabilities.

Although the SBIR Program is managed by OCP, NASA Headquarters, Washington, D.C., all individual SBIR projects are managed by the nine NASA field centers. Some of the general topics addressed in the 1991 SBIR Program included:

- In situ science instrument R&T
- Regenerative life support systems technology
- High temperature superconductor materials
- Advanced space energy and thermal management
- Space sensors and detectors and fabrication
- Advanced space communications, data systems and component fabrication
- Artificial intelligences, expert systems and robotics
- Structures, dynamics and materials.

The SBIR Program is supported through contributions from many programs within NASA, however due to the R&D character of the program, coordination with the OAST Space R&T Program is particularly important.

[4] Also as a part of 1991 NASA organizational changes, the former OAET Space Exploration Directorate has been dissolved, OAET has been renamed OAST and a separate NASA Office of Exploration has been created. In order to provide better continuing, these changes have been incorporated into this document, the 1991 edition of the ITP.

Centers for the Commercial Development of Space

The OCP Centers for the Commercial Development of Space (CCDS) are consortia of university, industry and government. The purpose of the CCDS effort is the conduct of early research and testing of potential commercial products or services. Some of the general topics being addressed by the CCDSs include:

- Microgravity materials processing
- The Commercial Experiment Transporter (COMET) effort
- Space power systems technology.

Technology Utilization Program

The NASA Technology Utilization (TU) Program, is designed to promote the application of NASA developed technologies in the public and private sectors. The efforts of the program are comprised of several transfer strategies, grouped within three principle steps for transfer; these include: (1) new technology identification and documentation; (2) technology deployment (i.e., actively working with the public sector regarding technology opportunities); and (3) sponsorship of specific technology application/ demonstration projects to facilitate technology transfer.

New Technology Identification

To improve technology transfer, new opportunities must be discovered, characterized, evaluated and documented for easy access to potential commercial users. The process is a complex one in which the primary mechanisms are the efforts of individuals within the laboratory, often aided by external experts and consultants, and requiring close coordination with the center's patent counsel. To aid in this effort, however, dedicated Technology Utilization Officers are located at each NASA field center to assist in the coordination of technology transfer processes at their respective sites.

Technology Deployment

A network of six Regional Technology Transfer Centers (RTTCs) has been created to assist in the transfer of government-developed technology. The RTTCs — which cover the United States — will aid in establishing linkages between various state and local technology transfer programs and NASA centers or other government laboratories within their region of coverage. A central National Technology Transfer Center (NTTC) also has been created. Serving as a "hub" for the RTTC's, the NTTC serves as a national resource to assist all federal agencies in transferring technology (e.g., through national technology databases). In addition, NASA Tech Briefs magazine represents a valuable announcement mechanism for new technologies that are becoming available to the private sector. Through this means, industry is provided with a compendium of abstracts, announcements and full articles about emerging NASA technologies. Also, conferences, seminars and trade shows are used to communicate opportunities in NASA-developed technology. Beginning in 1990, NASA has sponsored an annual conference dedicated to highlight transferable technologies for industry. This effort includes not only NASA, but also other U.S. laboratories and agencies.

Applications Projects

As a third approach to facilitating transfer, several small, two to three year technology applications projects are conducted on a continuing basis. The projects are largely conducted in-house at NASA, by working researchers and engineers, and involve an effort to use NASA R&T results to address some of the technology needs faced by industry and government agencies. These projects are jointly funded efforts between NASA, government and industry partners.

Other U.S. Government Agencies

NASA has three types of relationships with other U.S. government agencies, with respect to space R&T: (1) as a partner in R&T execution (e.g., as in the case of the SP-100 program in which NASA, DOD and DOE are partners in the development of space nuclear power); (2) as a provider of new technologies to meet future civil space mission needs (e.g., as in the case of remote sensing technologies for NOAA); and (3) as a user of the technology developed by others (such as the use of DOD-developed space sensor technologies).[5] The following section delineates the major intra-government space R&T relationships that NASA has with other agencies.

Department of Energy

DOE represents a partner in the conduct of space R&T for future civil space mission applications. In addition, DOE provides selected advanced technology flight systems for use in NASA missions (e.g., radioisotope thermoelectric generators—RTG's). DOE, and its systems of national laboratories, represent a profound resource for the accomplishment of U.S. space objectives (both defense and civil).

Traditionally, DOE space activities have included space power and propulsion, and national security related programs. The current space goal of DOE is to focus on civil, commercial and national security objectives in space, while evolving from DOE terrestrial missions. That goal translates into a series of DOE plans in the area of space exploration (SEI), the U.S. Global Change Research Program (GCRP), as well as an increased emphasis on the development of space technology.

DOE is planning a "Space Technology Initiative" (STI) that will address: (1) nuclear energy-related technologies and applications, including both nuclear power (e.g., the tri-agency SP-100 Program) and nuclear propulsion (e.g., for SEI); (2) non-nuclear energy-related technologies and applications (including energy sources, energy storage and management, and power transmissions); (3) environmental assessment and monitoring (including remote sensing, environmental modeling, and the use of optoelectronics); (4) human health and life sciences (focusing on radiation effects and risk management); (5) manufacturing and construction (addressing materials, shielding and robotics applications); (6) high performance computing; and (7) science, mathematics and engineering education.

NASA and DOE are coordinating closely on the planning and implementation of space R&T. Memorandums of Understanding (MOU's) existing between DOE, DOE and NASA include agreements on the SP-100 Program and thermionics R&T. In addition, a blanket MOU has been established regarding DOE/NASA cooperation for SEI. Finally, the existing DOE/NASA Space Technology Interdependency Group (STIG—see the discussion below) may be extended to include DOE participation in the near future.

As a part of the annual cycle, the ITP will be updated to reflect the evolving status of both joint and parallel R&T efforts between NASA and DOE to assure optimal application of the skills and facilities of both organizations and their field centers in the achievement of civil space R&T objectives.

Department of Defense

The primary objective of the DOD in space technology is to assure that national security is preserved and enhanced through the effective of use of space assets in the future. However, due to the similarity between defense and civil engineering requirements for a wide variety of space systems, a high degree of synergism exists in a number of space research and technology areas between the needs of NASA and the DOD. This synergism has resulted in a strong and continuing coordination between the two organizations in the conduct of U.S. space R&T programs.

[5] Reference: National Space Policy context — see Chapter 1.

U.S. Air Force

NASA has a strong, ongoing working relationship with U.S. Air Force (USAF) in space technology development. The Space Technology Interdependency Group (STIG) represents the primary top-level forum for this coordination process. The STIG includes both executive review sessions annually, as well as a family of joint NASA-USAF technical committees that work to assure good coordination in detailed R&T efforts. R&T topic areas include: information collection; transfer and processing; propulsion; power; advanced vehicle concepts; flight dynamics and control; space materials and structures; operations; space environments and effects; and flight experiments planning.[6] Also, NASA has an ongoing working relationship with the USAF in the development of Earth-to-orbit transportation technologies.

Strategic Defense Initiative Office

The Strategic Defense Initiative Office (SDIO) was established in the early 1980's to conduct a broadly based research and development effort to determine the feasibility of effective ballistic missile defense. Three major SDIO program areas are of particular importance for civil space R&T: the small spacecraft technologies associated with the so-called "brilliant pebbles" concept; the transportation technology demonstrations planned to support single-stage-to-orbit vehicle development; and coordination and transfer of technology development related to high energy laser beamed power applications.

Single-Stage-To-Orbit

The SDIO has initiated a program addressing Single-Stage-To-Orbit (SSTO) vehicles using rocket propulsion systems. During the 1990's, the program is planned to focus on using already-developed technology in a vehicle demonstrator program which would begin with a sub-scale experiment and lead by the turn-of-the-century to a full-scale prototype vehicle. The SSTO activity is being coordinated with both of the joint NASA-DOD ETO technology development efforts — the NLS and the NASP Programs. NASA, although co-sponsoring this effort at this time, is nevertheless closely involved in its review. SSTO planning and progress will be assessed annually and incorporated into the ITP's strategic planning for ETO-related space R&T.

DARPA

The DOD Defense Advanced Research Projects Agency (DARPA) is responsible for pushing the state-of-the-art for advanced future defense systems, including developments for future defense satellites. The DARPA Advanced Space Technology Program (ASTP) is of particular importance to NASA. The goal of the ASTP is to develop key technologies to maximize the capabilities, performance, accessibility, and survivability of military space systems, while minimizing their cost, size, weight and power requirements. The ASTP is organized along three interrelated segments: launch vehicles; LightSat demonstrations; and advanced technology developments for spacecraft size reduction. For example, DARPA's ASTP sponsored the development of the *Pegasus* Air Launched Space Booster (first launched in 1990). Although many of DARPA's efforts are directed toward the development of technologies specific to defense sector needs, DARPA activities have been, and will continue to be, a primary target for close coordination in the development of civil space R&T within the ITP.

Other Interactions

In addition to NASA's major ongoing working relationships in space technology development with the USAF, SDIO and DARPA, NASA is also exploring a possible R&T partnership with the U.S. Army Corps of Engineers in the development of advanced space construction technologies that would be used for a Lunar outpost early in the next century. A similar interaction is possible between NASA and the Department of the Interior's Bureau of Mines in advanced technology for the mining and utilization of extraterrestrial resources.

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[6] During the coming year, extension of the STIG to include broader participation is planned. DoE participation is planned. Also, invited observers/associate members are planned from the other DoD services, from Strategic Defense Initiative Office (SDIO) and Defense Advanced Research Projects Agency (DARPA,) and from the DoC (e.g., National Institute of Standards and Technology (NIST) and NOAA).

Department of Commerce

Within the Department of Commerce (DOC) several agencies participate in the U.S. civil space program or in the development of related advanced technologies and standards. Of these, the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) are of particular interest in terms of space R&T.

NOAA

NOAA is responsible for both polar orbit and GEO operational Earth observing satellites and will also have several instruments on NASA's EOS platforms. NOAA is a significant non-NASA government potential user of advanced civil space technologies—in particular in the areas of remote sensing and space platform technologies.[7] The initial ITP planning effort has provide a preliminary assessment of NOAA technology needs; these are provided in Chapter 2 of this document. Future ITP planning cycles will assure that the space technology needs of NOAA are documented and addressed and that new technology developments are effectively transferred to NOAA applications.

NIST

The National Institute of Standards and Technology (NIST) is responsible for developing measurement and quality control standards across a broad spectrum of science and engineering fields.[8] NIST provides technical services in a variety of areas, including support for improvements in process design, process control systems, integrated process automation, characterization of new products and the development of standard testing procedures. The Institute is also responsible for research in measurement technology needed for U.S. industry quality assurance programs, as well as generic advanced research in emerging technology areas. Moreover, NIST represents a valuable National resource for future civil space technology and mission efforts. For example, NIST has participated in operational civil space programs (such as in spectrograph calibration on the Hubble Space Telescope) as well as in space technology research related activities (e.g., studies of high performance aerospace materials).

Closer coordination between the space R&T efforts at NASA field center efforts and related activities of NIST will be an objective of future cycles of the ITP. Close cooperation between NASA R&T efforts and NIST's strong in-house research capabilities is of vital importance. In addition, coordination with future activities within the NIST-sponsored Advanced Technology Program (ATP) will be needed. The ATP, initiated in fiscal year 1991, is designed to assist in research and development on precompetitive, generic technologies with wide potential commercial applications. Some specific areas include: chemical measurements and standards; bioprocess engineering; lightwave measurements; digital networks and computer security; advanced semiconductors, atomic-scale electronics, and high-temperature superconductors; intelligent control for materials processing and other manufacturing; and high-performance composite materials (e.g., materials performance measurement).

Major Multi-Agency Space Technology Development Programs[9]

Several technology development programs are jointly implemented by NASA and other U.S. Government Agencies—predominantly the DOD. Among these are the National Aerospace Plane (NASP), the National Launch System, and the High Performance Computing and Communications (HPCC) program. Each of these is described briefly in the following section.

[7] Reference: Mission Needs—see Chapter 2.
[8] NIST also conducts the annual Malcolm Baldridge National Quality Award program.
[9] The SP-100 Program, which is jointly funded by DOE, DOD and NASA is discussed in Chapter 4.

National Aerospace Plane

The National Aerospace Plane (NASP) program is a joint effort of NASA OAST and the Department of Defense (USAF) to conduct advanced research on hypersonic flight, scramjet propulsion systems, and ultra-high-temperature materials. The objective of the NASP Program is to develop and demonstrate an experimental hypersonic research plane, designated the "X-30," by the mid- to late- 1990's. The NASP Program and the X-30 could form the basis for a hypersonic vehicle approach to single-stage-to-orbit (SSTO) flight. (See the *DARPA* discussion above for an alternative, rocket propulsion-based approach to SSTO.) Key technology areas include: use of computational fluid dynamics (CFD) for vehicle flight analysis; advanced (slush) cryogenic hydrogen management techniques; air-breathing scramjet engines; low mass cryogenic tankage; and high-temperature (potentially actively-cooled) thermal protection systems.

National Launch System

The National Launch System (NLS) Program, jointly managed by NASA Office of Space Flight and the USAF, will develop a new, unmanned (but human-rateable) moderate to heavy lift launch vehicle (HLLV) for the U.S. during the 1990's. Advanced development for the NLS, conducted under the name Advanced Launch System (ALS) Program, has been underway for several years. The major investment in these efforts has been in the development of a new, primary cryogenic engine: the Space Transportation Main Engine (STME), which would be the workhorse for the NLS. Other advanced development efforts have included: avionics and software; structures, materials and manufacturing; and aerothermodynamics and recovery.

High Performance Computing and Communications

The High Performance Computing and Communications (HPCC) Program is a broad, government spanning initiative to sustain and strengthen U.S. leadership in a wide variety of key advanced areas of computing and network systems. Major program areas addressed by HPCC include: high performance computing systems; advanced software technology and algorithms; national research and education network; and basic research and human resources. The projected areas for future applications of HPCC research, described as "grand challenges" (with supporting technology studies) are equally broad these include the following areas:

- forecasting severe weather events
- cancer genes research
- predicting new superconductors
- modeling and predicting air pollution
- aerospace vehicle design
- energy conservation studies and modeling turbulent combustion
- microsystems design and packaging
- modeling the Earth's biosphere
- developing extremely high speed networks
- conducting education using the National Research and Education Network (NREN).

Participants in the HPCC effort include a panoply of government agencies: DARPA; DoE; NASA; NSF; NIST; NOAA, EPA, and the National Library of Medicine. The program, implemented through each of these agencies individually, but orchestrated at the national level through the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), will include a partnership between national centers, industry and academia.

Other Intra-Government Coordination

In addition to the specific areas listed above, the ITP will be actively coordinated with several other government activities. For example, although the Department of Transportation (DOT) is not a direct user of space technology, the Space R&T Program is also being coordinated with the DOT with regard to the identification of technology needs for ELVs in the commercial space sector. Also, coordinated R&T activities are being planned with the NSF (for example, see the discussion concerning Antarctic analog activities and SEI).

Coordination With U.S. Industry

Achieving the goals of the civil space program will depend upon an effective partnership between government, industry, and academia. In particular, close coordination between government and U.S. industry technology development efforts will be a cornerstone for the success of the ITP. A wide variety of technology development efforts are planned and implemented annually by the U.S. aerospace industry These include: independent research and development (IRAD); contracted research and development (CRAD); and corporate research and development. In each case, a number of potential relationships are possible. R&T efforts within the U.S. aerospace industry in most cases focus primarily on nearer term technical objectives.

Coordination with U.S. industry efforts will be achieved in a variety of ways. For example, as a part of the external review process for the ITP, industry technologists will play a leading role — including participation in the SSTAC and SSTAC/ARTS, as well as the National Research Council's Aeronautics and Space Engineering Board (ASEB). The Department of Transportation's Commercial Space Transportation Advisory Committee (COMSTAC) provides yet another forum for government-industry communications and coordination within one specific area. In addition, numerous opportunities exist at the working level for research-to-research communication (e.g., through workshops and symposia). This chapter concludes with a discussion of technology transfer strategies.

Space R&T: International Issues

Space operations, systems and technologies are no longer the province of one or two nations unlike the situation in the 1960's and early 1970's. A variety of reports have been released (e.g., the recent AIA report referenced in Chapter 1) that analyze the relative stature of an increasing number of national players in civil space endeavors. In addition, partnerships between companies based in multinational corporations have made the question of the flow of technology between nations an especially challenging topic. At this time, no formal strategy has been formulated for assessing and responding to international issues in U.S. civil space R&T (e.g., with regard to teaming between U.S. and foreign firms on technology development projects, or with regard to foreign graduate students in U.S. universities that participate in the civil space R&T program).

During the coming year, one of the primary objectives of OAST's continuing efforts to refine the ITP will be the identification of general topics related to international space research and technology efforts and the development of a strategic approach to deal with issues that arise in this arena.

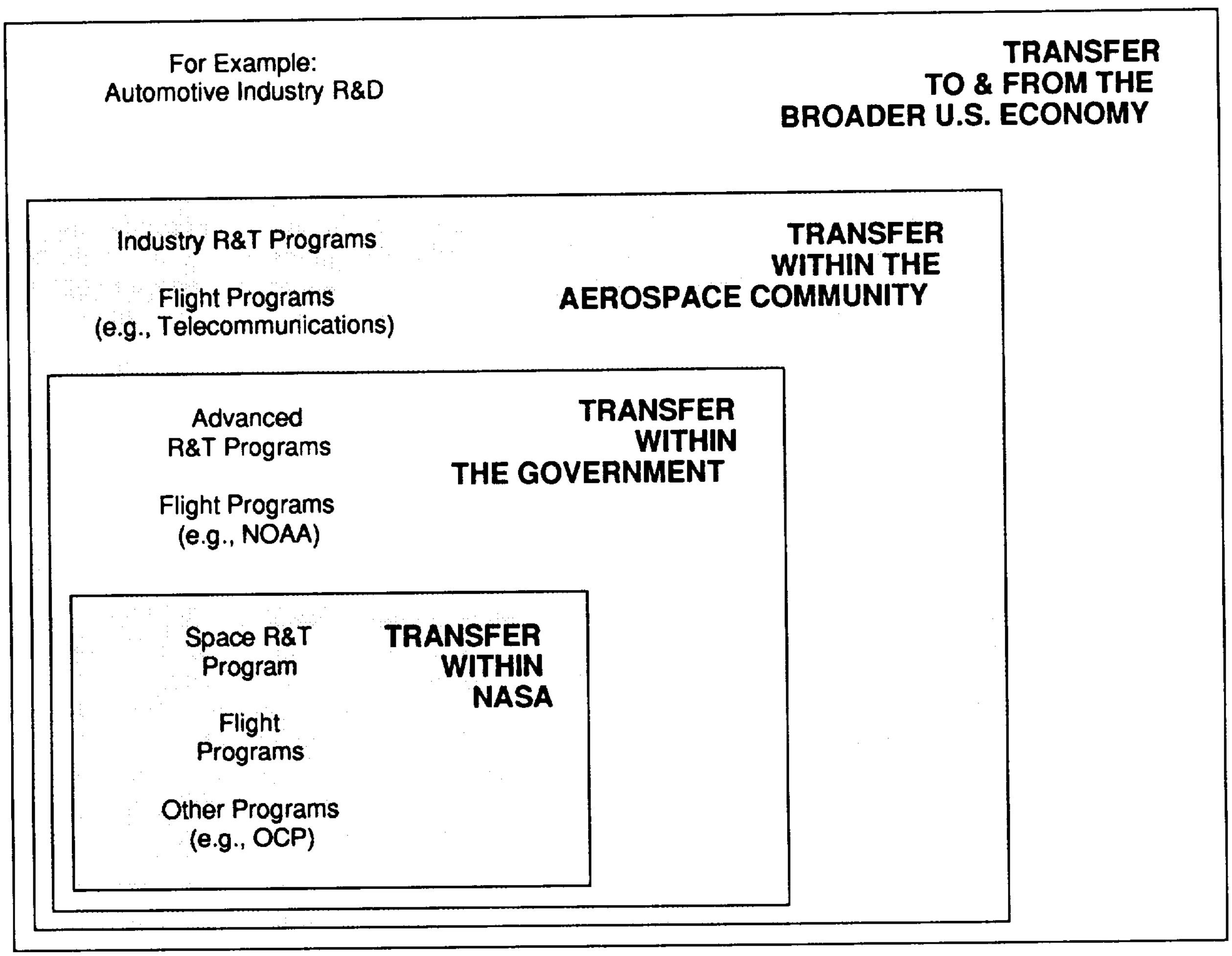
Technology Transfer: Strategies and Plans

The successful application of the products of NASA's space R&T efforts within NASA flight projects is one of the primary objectives of the ITP. The issue of technology transfer, however, is one of considerably broader import. Figure 5-1 illustrates the full scope of this challenge with respect to technology transfer within the U.S. as it relates to civil space R&T.

Four distinct arenas for technology transfer must be understood and facilitated to make the most effective use of the U.S. government investment in advancing the state-of-the-art in civil space technology. These include the following:

- Transfer within NASA — including transfer from advanced space R&T programs[10] to NASA flight programs (including advanced development programs and flight projects, as appropriate) and between the Space R&T Program and other NASA space R&T efforts (e.g., with OCP)
- Transfer within the government — including transfer from advanced Space R&T Programs to other government flight programs (including advanced development programs and flight projects, as appropriate), and between the NASA Space R&T Program and other U.S. government R&T efforts (e.g., with the DOE or DOC)

Figure 5-1
Arenas for Civil Space Technology Transfer



[10] In this context, "NASA advanced space R&T programs" is defined to include the efforts of: NASA Research Centers, NASA Flight or Science Center R&T teams and also university researchers supporting NASA.

- Transfer within the aerospace community — including transfer between NASA (and other government) advanced space R&T programs and aerospace industry R&T efforts, and transfer from government R&T efforts to aerospace industry/commercial flight programs (e.g., advanced telecommunications satellites)
- Transfer between (to/from) the aerospace community (including NASA, other government, universities, and the aerospace industry) and the broader U.S. economy.

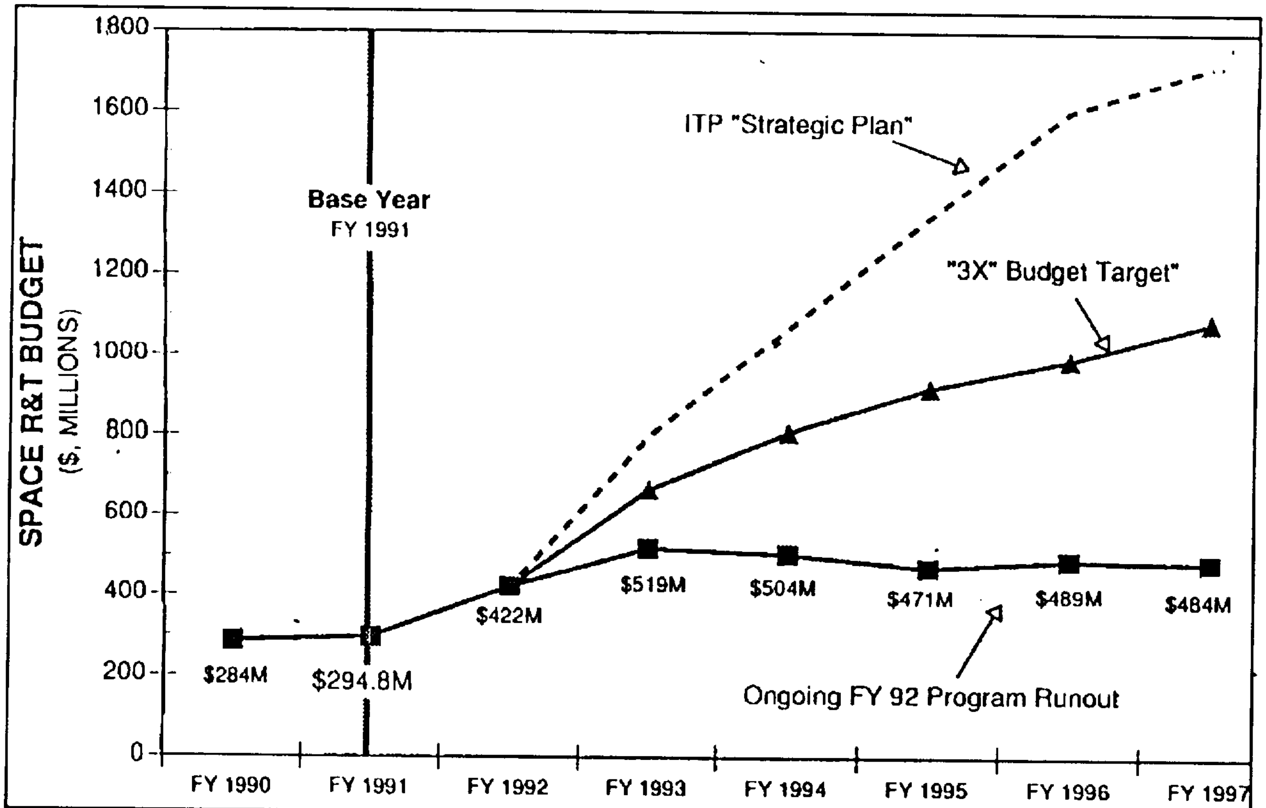
One of the primary objectives of OAST's continuing efforts to refine the ITP during the coming year, will be the development of more a formal set of national strategies that promote the effective and timely transfer of civil space technology advances in each of the cases listed.

A continuing research and technology base is a necessary foundation for long-term preeminence in civil space endeavors. Advanced missions, such as the extreme upper atmospheric probe depicted in this artist's concept, will be enabled by reliable, ongoing investments in a number of discipline research areas, such as aerothermodynamics, power, propulsion, thermal management, and information sciences.

APPENDIX A
BUDGET IMPLICATIONS

Using the program prioritization and budgeting strategies described in Chapter 3, OAET has constructed a number of planning options that examine the budgetary scope of a space R&T investment that can meet the technology needs of the nation's future civil space activities. For reference purposes, Figure A-1 illustrates: (1) the FY 1992 space R&T program budget level; (2) the growth curve and budget levels implied by a program that meets virtually all of the priority technology needs of the civil space program; and (3) a growth curve and budget level consistent with the 1990 Recommendations of the Advisory Committee on the Future of the U.S. Space Program.[1] These options make it clear that the current program level (FY 1992 budget) can accomplish only a limited subset of the R&T needs of the civil space program. Nevertheless, the ITP planning process provides the machinery needed to make decisions to establish the optimal components of the space R&T program at any given budget level of a specific fiscal year.

Figure A-1
Budget Implications



[1] Reference: See Chapter 1.

APPENDIX B
INSTITUTIONAL IMPLICATIONS

Planning for and implementation of space research and technology to support future civil space missions will depend upon the participation of NASA field centers, other government agencies and federal laboratories, U.S. industry and universities. Within NASA, OAST has direct management responsibility for three centers: the Langley Research Center (LaRC) in Virginia, the Ames Research Center (ARC) in California, and the Lewis Research Center (LeRC) in Ohio. In addition, the NASA space science and space flight field centers also play vital roles in the space research and technology program.

The following discussion of NASA center roles is intended to identify the nature of the major space R&T program activities at each center. It is not intended to be complete or to imply any limitation on future participation.

AMES RESEARCH CENTER

Building on its responsibilities in aeronautics technology, the Ames Research Center (ARC) has a strong base of expertise in the space technology areas of aerothermodynamics, thermal protection system (TPS) materials, and human factors research. ARC has lead center responsibilities in a number of areas. For example, ARC is lead for detector technology development and has been responsible for major advances in IR detectors for SIRTF. In addition, ARC has lead research responsibilities for OAST in the areas of artificial intelligence research and extravehicular activity (EVA)/extravehicular mobility unit (EMU) technology development, and has a major responsibility in the regenerative life support area.

Ames has a major role in planning, advocacy and implementation of advanced space technology development in several areas, such as aerothermodynamics (in the R&T Base) and aerobraking (in the Transportation Technology Thrust), as well as a supporting role for advanced cryogenic coolers (in the Space Science Technology Thrust).

LANGLEY RESEARCH CENTER (LARC)

LaRC has played an historic role in atmospheric physics, and they are responsible for several OSSA experiments (e.g., TOMS and AALOE). LaRC has a long-standing foundation of expertise in the areas of aerothermodynamics and materials and structures. In addition, LaRC was the lead center for the highly-successful Viking mission to Mars in the 1970s.

The center's responsibility extends to lead research responsibility in the areas of controls-structures interactions (CSI), aerobraking and in-space assembly and construction. Also, LaRC has a lead role in laser sensing technology, as well as being a major contributor to both passive microwave radiometry and to IR detectors R&T. Finally, LaRC also has a unique capability for aerospace vehicle concept analysis (including the integration of technology issues and design concepts). LaRC has played a central role in the strategic systems planning for Space Station *Freedom*, including initial systems with a very strong focus on evolution beyond the baseline.

Lewis Research Center

The major areas of technology research capability at the Lewis Research Center (LeRC) include space propulsion and space power systems technologies. In particular, LeRC has lead responsibilities in the propulsion technologies of cryogenic engines, cryogenic fluids management, nuclear thermal and nuclear electric propulsion, as well as in the areas of advanced space communications and electronics and advanced concepts studies. LeRC has space power and thermal management technology responsibilities in areas such as advanced solar arrays, solar dynamic power, high-efficiency thermal-to-electric energy conversion (including dynamic conversion), batteries and regenerative fuel cells, power management and distribution (PMAD) systems, and advanced space radiators.

In addition, LeRC plays a strong role in space power and thermal management technology application as one of the Space Station *Freedom* work package lead centers. LeRC also has a strong in-house capability in the area of advanced communications technology development and conducts communications-related advanced studies for the Office of Space Communications.

Goddard Space Flight Center (GSFC)

GSFC has extensive involvement in many of the activities of the OSSA, including management of major science and applications projects, instrument development, and related technology research and development, in astrophysics, space physics, and Earth science. GSFC has prime responsibility for the OSSA Earth Observing System (EOS). In addition, GSFC provides scientific management for a number of other science missions, including the Hubble Space Telescope (HST), the Gamma Ray Observatory (GRO) and the Upper Atmosphere Research Satellite (UARS). GSFC is responsible for orbital operations of these science satellites, for which automation technologies are being incorporated into their control centers, and for analysis of the resultant massive volumes of space science data. GSFC also operates — under the management of the NASA Office of Space Communications — the Tracking and Data Relay Satellite system (TDRSS) and the near-Earth tracking and data acquisition network.

GSFC is the lead center for development of advanced space data systems and high performance computing technology. R&T responsibilities also include advanced communications (in particular, optical communications) and science sensors, in which GSFC is lead center for cryogenic coolers and has active technology programs in LIDAR, optics and microelectronics. The most recent GSFC strategic plan identifies interferometers as an area of future focus. The center has an historic interest in x-ray astronomy and space-based plate tectonic research. GSFC currently provides strong support to the OAST technology flight experiments (TFEs) program by developing and management many TFEs and by developing the carriers and procedures for integrating them to the Shuttle orbiter.

Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) in Pasadena, California, is a space science NASA field center operated by the California Institute of Technology (CIT) for NASA. JPL has a long-standing role in OSSA's solar system exploration program and has been identified as a national resource in the development and operation of deep space missions. JPL is now developing the Mars Observer, the CRAF and the Cassini missions. Previous JPL deep space missions include the Viking Project Mars Orbiters, Voyagers 1 and 2, and the Magellan. In addition, JPL plays a strong role in astrophysics (providing the Wide Field Planetary Camera to the HST and being the lead center for the Space Infrared Telescope Facility), and Earth observing missions. JPL also has lead responsibility in submillimeter astronomy and as a prime participant in studies of future interferometer-based science missions. In support of the Office of Space Communications, JPL operates (including long-range planning and supporting development) the Deep Space Network (DSN) which provides worldwide tracking and communications capabilities for deep space missions. In support of SEI, JPL has conducted a series of studies of robotic Lunar and Mars exploration missions.

JPL has specific technology leadership responsibilities in the areas of telerobotics and planetary surface rovers and sample acquisition, analysis and preservation, and submillimeter detectors and sensor electronics. JPL also plays a substantial role in a variety of other technology areas including: microprecision CSI; precision segmented reflectors; communications, artificial intelligence; and space power and thermal management systems. JPL has a lead responsibility for the Department of Energy (DOE) in the management of the SP-100 space nuclear reactor power technology development project. Finally, the Center for Space Microelectronics at JPL provides the center with a unique capability within NASA in the in-house fabrication of microdevices and microsensors.

Johnson Space Center

JSC has a primary agency responsibility in manned space flight including both the lead for the Space Shuttle Program and one of the major work packages of the Space Station Freedom Program. Moreover, JSC has responsibility for overall mission concept engineering studies for SEI, as well as analysis and planning related to SEI planetary surface systems. Also, JSC has a strong role in OSSA life sciences research, including space and operational medicine and research into the effect of long duration space missions on astronauts. JSC also has an ongoing program using a KC-135 aircraft to conduct human factors research in simulated reduced gravity environments.

JSC has extensive laboratory and test facilities related to human support technologies. The center also has extensive faculties in other aspects of spacecraft design development and integration, such as avionics, communications, power, propulsion, and structures and mechanics. Also, facilities have recently been constructed for A&R research and development. Within the OAST Space R&T Program, JSC has lead center responsibility for several areas, including: autonomous rendezvous and docking and autonomous landing (FY 1991 focused technology projects); and *in situ* resource utilization and surface habitats and construction (pre-technology project research and studies). In addition, JSC plays a major role in both the regenerative life support and the EVA systems programs, and has a strong capability in thermal management technologies.

Marshall Space Flight Center

The Marshall Space Flight Center (MSFC) in Alabama has an historic role in the technology, design, development and operations support for large-scale, space transportation systems, including the Apollo program's Saturn V booster as well as major systems of the Space Shuttle. MSFC is responsible for analysis and plans related to transportation systems in support of SEI. MSFC also plays a major role in the National Launch System (NLS) advanced development program. In particular, MSFC is responsible for the development of the Space Transportation Main Engine (STME), for studies associated with a Cargo Transfer Vehicle (CTV) as a potential upper stage to the NLS. Similarly, Marshall has a major responsibility in the SSF program, as lead work package center for the habitation and laboratory modules. MSFC also has lead roles in the OSSA space science program. Marshall has lead responsibility for large telescope systems, including past programs such as development of the Hubble Space Telescope, and future programs such as AXAF development. MSFC also has a lead role in microgravity sciences research. MSFC is the lead center for laser system development and is currently working on the LAWS CO_2 instrument for OSSA.

Building on these flight program responsibilities, MSFC has a significant expertise and responsibility in several space R&T program areas. MSFC has lead responsibility for OAST research and technology efforts related to ETO Propulsion, in which engine component and technology testing (as opposed to development testing) is conducted at MSFC facilities.) Based on its SSF role, MSFC also has significant expertise in the life support systems and power management and distribution (PMAD) technology areas. MSFC also has capabilities in CSI and sensors.

Kennedy Space Center

The Kennedy Space Center (KSC) in Florida is predominantly NASA's ETO transportation operations center. Kennedy is responsible for processing the majority of spacecraft prior to launch on both Shuttle and ELVs and is responsible for coordinating NASA activities at the Vandenberg Air Force Base in California. KSC also plays a limited role in human support technology-related life sciences programs in the area of biologically-regenerative life support systems (i.e., CELSS). Moreover, MSFC supports planning for science payload physical integration for SSF. In addition, however, KSC plays a strong role in the definition of technology needs associated with launch operations, as well a serving as a potential test site for advanced operations technologies as they mature (e.g., in the areas of Space Shuttle processing robotics). KSC also plays a role in the NLS program, addressing issues associated with vehicle launch facilities and operations.

Stennis Space Center

The Stennis Space Center (SSC) has responsibility for development testing of the Space Shuttle Maine Engine (SSME) and the Space Transportation Main Engine (STME), which is under development for the NLS program, as well as a turbopump development test stand for the STME. The SSC also has minor roles in OSSA life sciences research, and in Earth science and applications, including responsibilities for the Earth Resource laboratory, which is involved in research in land/sea interactions and forest ecosystems.

Other Institutions

In addition to the NASA field centers, a variety of other U.S. R&T institutions play important roles in the development of technology for the civil space program. For example, the DOE operates several National Laboratories which provide a significant resource for space technology research, with a particular emphasis on issues associate with energy and nuclear power. These include Los Alamos National Laboratory in New Mexico, the Lawrence Livermore and Lawrence Berkeley Laboratories in California, the Idaho National Engineering Laboratory, the Brookhaven National Laboratory in New York state, Argonne National Laboratory, and others. The DOD has a robust laboratory system with considerable expertise in space systems and technologies. DOD Laboratories include: the Phillips Laboratory; Armstrong Laboratory; Rome Laboratory; Wright Laboratory; and the Naval Research Laboratory (including the Naval Center for Space Technology). The potential roles and activities related to civil space technology development at these and other National laboratory capabilities will be discussed in greater detail in the 1992 ITP.

Appendix C
Technology Validation

Technology validation is an essential part of the technology development and transfer process. Technology validation may consist of data collection to prove that an analytic prediction is in fact correct, or that a component or subsystem that works in the laboratory also works in the field. Two major strategies are available for validating advanced civil space technology: ground-based testbeds; and technology flight experiments.

National Testbeds

In the development of advanced technology for the civil space program, testbeds (and various facilities) play an important role. For example, some testbed functions include: (1) simulation of realistic and consistent environments; (2) support for test and evaluation of a specific class of technology components or subsystems; and (3) an opportunity to integrate components and subsystem by providing common interfaces and standards. The SSTAC-sponsored external review of the 1991 ITP recommended that "National Testbeds" be considered in a future ITP planning cycle. They justified this recommendation in two ways: first, a testbed can serve as an effective means of drawing together related smaller technology projects; and second, testbeds offer a means of demonstrating technology readiness for application. The latter function can be very important in the absence of technology flight experiment opportunities (which are discussed in more detail in the section that follows).

However, several issues must be addressed before proceeding with the definition of a cohesive testbed strategy for technology testbeds in the 1992 ITP. These include:

(1) Determination of what testbeds could best benefit industry
(2) Ensuring the appropriate levels industry and academic involvement in testbed development and operations
(3) Determination of when cooperative agreements with other government agencies for testbeds and facilities are appropriate
(4) Ensuring that appropriate mechanisms are provided to safeguard proprietary interests
(5) Developing a process for making decisions concerning entry of technology into testbeds, including contractual, costing and risk assignment relationships
(6) Because an increased emphasis on testbeds implies an increased investment in space R&T facilities, to succeed it is necessary to resolve an appropriate strategy, approved through NASA management, vis-a-vis OAST space R&T program construction of facilities (CofF) resources over a period of several years.

Testbeds may be used both nationally and within NASA to stimulate the development of a given class of technology. In addition, early development of appropriate testbeds can shorten the length of time required for technology development, as well as reducing design and development risks associated with using new technologies in flight systems. In this way, technology testbeds can function as "bridging" mechanisms that help build confidence in new technologies and move them closer to flight. Finally, appropriate government facilities and testbeds can allow industry to avoid the expense of implementing multi-duplicative facilities privately.

The 1991 ITP incorporates a number of individual technology validation testbeds, including: the ETO Propulsion Program use of the TTB; the AETB of the Advanced Cryogenic Engines Program; and a life support testbed at JSC that will support both R&T Base research and Planetary Surface Technology Thrust development in physical-chemical regenerative life support. During the preparation of the 1992 ITP, a focused effort will be made in the area of testbed planning, including: (1) an assessment existing testbeds and facilities planning; (2) a preliminary assessment of potential industry and university requirements for space R&T testbeds and facilities; and (3) assessment of ITP-supporting NASA CofF planning.

TECHNOLOGY FLIGHT EXPERIMENTS

In a wide variety of cases, the successful completion of space technology development demands some level of in-space experimentation or demonstration. For example, some physical phenomena depend directly on the absence of gravity. This is certainly the case in trying to understand, predict and control the behavior of cryogenic fluids in microgravity. In these cases, in-space experimentation may be essential to resolving key questions and developing a reliable (i.e., flight validated) data base. Moreover, in many cases the successful transfer of technology may depend on flight validation of a specific advanced technology subsystem or component (e.g., radiation-tolerant information systems). Therefore, in-space experiments are an integral part of the overall space R&T technology maturation strategy.

Potential technology flight experiment carriers include: the Space Shuttle; Space Station Freedom; independent expendable launch vehicles (ELVs); and piggy-back aboard available space on existing spacecraft. However, flight experiments are often regarded as expensive — in particular when compared to ground research costs. On the Space Shuttle, even a modest GAS can or middeck locker experiment can cost as much as $ 5 to 6 million.[1] Keeping these costs to a minimum will be essential to increase the level of technology flight experimentation. In addition, the length of time required to get a new technology from the laboratory to space has a direct influence on successful technology flight experimentation. Thus, in planning technology flight experimentation, a variety of factors must be balanced, including both cost versus benefits for the proposed experiment and the time required to reach flight.

A broad range of technologies will require in-space testing to assist their development and validation. General areas include: space structures; thermal management; propulsion systems; fluid management; power systems; humans in space systems; sensors; information systems; and selected automation and robotics operations. In addition, to better understand the environment within which systems will be required to operate, additional information on space environmental effects (including debris) are required. This range of potential technology flight experiments spans each of the five major thrusts of the ITP: space science; planetary surface technology; transportation; space platforms; and operations technology.

The 1991 ITP strategic plan includes both focused program (e.g., CONE) and R&T Base flight experiments (e.g., the IN-STEP program). During the preparation of the 1992 ITP, and in conjunction with testbed planning, an integrated assessment of civil space technology experimentation will be conducted, (including both an evaluation of systematic impediments to achieving the goal faster, lower-cost experimentation, as well as methods by which experiment costs can be more accurately predicted and managed).

[1] Of course, the cost of a technology flight experiment could be regarded as trivial when compared to the potential cost of a subsystem failure in an operational flight system.

APPENDIX D
SPACE TECHNOLOGY AND NATIONAL COMPETITIVENESS

As we enter the 21st century, a number of significant issues must be resolved for the U.S. to improve its competitive posture in the international marketplace. In order of priority (as determined in a result survey of senior U.S. R&T managers), those issues include: general management practices; external financial pressures; the changing global technology environment; technology management practices; and the technology policies of the federal government.[1] Within the area of general management practices, the key problems were associated with the failure to manage strategically with a long term view and an inability to effectively integrate new technology into business strategy. Although systemic issues were identified as foremost in improving our competitiveness, nevertheless the development and application of new technologies is a key requirement for the long term.

In addition to addressing the needs of future civil space missions for advanced technologies, NASA space R&T efforts are also a part of the nation's overall investment in strategically important technology research areas. An assessment has been made across the several focused technology thrusts and the R&T Base to determine how well the ITP addresses this strategically important technology areas. To facilitate that assessment, a set of "keystone technology areas" have been defined. (A "keystone technology" is one which is a necessary ingredient for future civil space mission success.) Figure D-1 provides a summary of the keystone technologies, including both the constituent R&T areas from which they are constructed, as well as the strategic future capabilities that the keystone technologies will make possible.

[1] American Institute of Aeronautics and Astronautics (AIAA)/National Center For Advanced Technology (NCAT) Conference on Technology Policy and Global Competitiveness (Washington, D.C.; September 5-6, 1991).

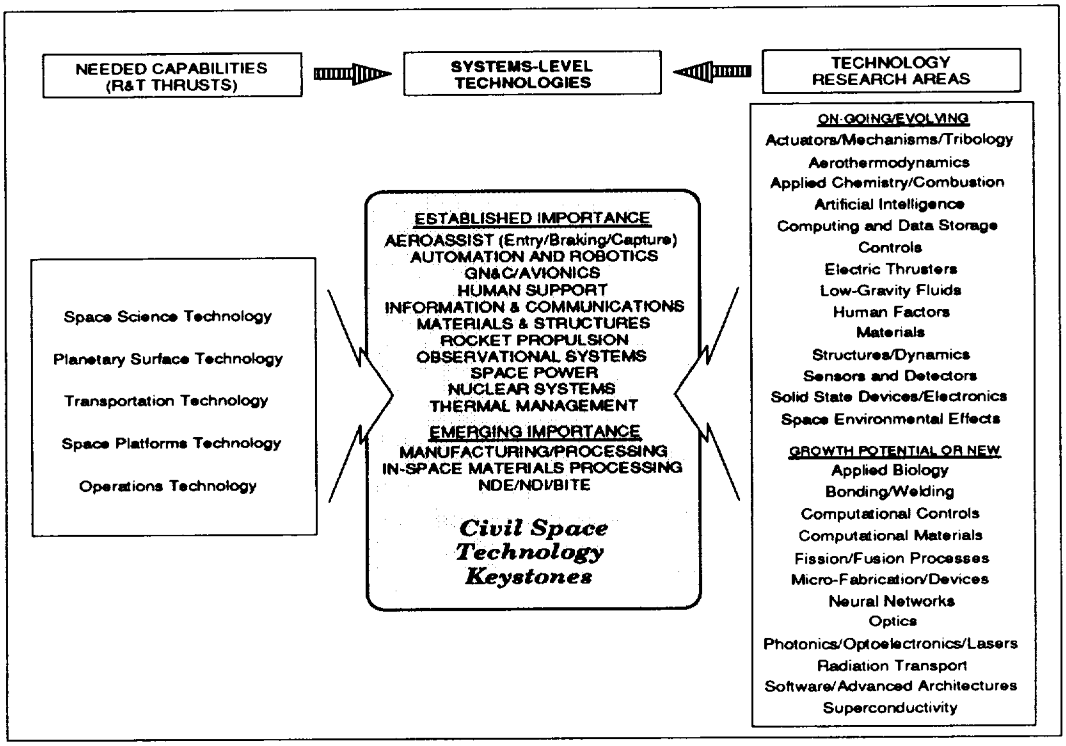


Figure D-1
Keystones for Future Civil Space Missions

❑ Partial Commonality With NASA "Keystones" ■ Strong Commonality With NASA "Keystones"

NASA Space R&T Technology "Keystones"	Office of Science and Technology Policy National Critical Technologies	Department of Defense Critical Technologies
AEROASSIST AUTOMATION & ROBOTICS GN&C/AVIONICS HUMAN SUPPORT INFORMATION & COMMUNICATIONS MATERIALS & STRUCTURES ROCKET PROPULSION OBSERVATIONAL SYSTEMS SPACE POWER NUCLEAR SYSTEMS THERMAL MANAGEMENT MANUFACTURING/SYSTEM PROCESSING (E) IN-SPACE MATERIALS PROCESSING (E) NDE/NDI/BITE (E) *(E) = "Emerging"*	❑ AERONAUTICS & SURFACE TRANSPORTATION Aeronautics Surface transportation technology ❑ BIOTECHNOLOGY & LIFE SCIENCES Applied molecular biology Medical technology ■ MATERIALS Materials synthesis & application Electronics & photonic materials Ceramics Composites High-performance metals/alloys ❑ MANUFACTURING Flexible computer integrated manufacturing Intelligent processing equipment Micro- & nanofabrication Systems mgt. technologies ■ ENERGY & ENVIRONMENT Energy technologies Polution minimization, remedia- tion, & waste management ■ INFORMATION & COMMUNICATIONS Software Microelectronics & optoelectronics High-performance computing & networking High-definition imaging & displays Sensors & signal processing Data storage & periperals Computer simulation & modeling	AIRBREATHING PROPULSION BIOTECHNOLOGY ■ COMPUTATIONAL FLUID DYNAMICS DATA FUSION ❑ FLEXIBLE MANUFACTURING ❑ HIGH ENERGY DENSITY MATERIALS ❑ HIGH PERFORMANCE COMPUTING ❑ HYPERVELOCITY PRO- JECTILES & PROPULSION ■ MACHINE INTELLIGENCE & ROBOTICS ■ COMPOSITE MATERIALS ■ SEMICONDUCTOR MATERIALS & MICRO- ELECTRONIC CIRCUITS ■ PHOTONICS PULSED POWER ■ SENSITIVE RADARS ■ PASSIVE SENSORS ❑ SIGNAL/IMAGE PROCESSING SIGNATURE CONTROL ■ SIMULATION & MODELING ■ SUPERCONDUCTIVITY ■ SOFTWARE ENGINEERING ■ WEAPON SYSTEM ENVIRONMENT

NASA's overarching requirement is to assure successful R&T for each of the keystone technologies and the demonstration of needed capabilities that build upon those keystones. The technology "keystones" for the civil space program identified in the ITP can be effectively compared against the technologies for the year 2000 identified by the Aerospace Industries Associations (AIA) — with the exception of Airbreathing Propulsion. There is a similar strong correlation with the key technology assessments of the Council on Competitiveness, the Department of Commerce and the Department of Defense. Finally, the ITP correlates reasonably well with three of the six major areas of the Office of Science and Technology Policy's (OSTP's) critical technologies report, and much more closely with the remaining three OSTP areas. Figure D-2 summarizes this assessment of the "keystone technologies" identified in the ITP against the various national level technology listings that have been developed over the past several years.

Department of Commerce Emerging Technologies	Council on Competitiveness Critical Technologies	Aerospace Industries Association (AIA/NCAT) Technologies for the Year 2000
■ ARTIFICIAL INTELLIGENCE ❑ BIOTECHNOLOGY ❑ DIGITAL IMAGING ■ HIGH-DENSITY DATA STORAGE ❑ FLEXIBLE COMPUTER INTEGRATED MFG. ❑ HIGH-PERFORMANCE COMPUTING ■ ADVANCED MATERIALS ■ OPTOELECTRONICS ■ ADVANCED SEMICONDUCTOR DEVICES ■ SENSOR TECHNOLOGY ■ SUPERCONDUCTORS ❑ MEDICAL DEVICES AND DIAGNOSTICS	❑ BIOTECHNOLOGIES Bioreactive/biocompatible mat'ls Bioprocessing Drug discovery techniques Genetic engineering ■ ELECTRONIC & PHOTONIC MATERIALS Display materials Electronic ceramics Electronic packaging materials Gallium Arsenide Magenetic materials Optical materials Photoresists Silicon Superconductors ■ ENVIRONMENTAL TECH. Emissions reduction Recycling/waste processing ■ ADVANCED STRUCTURAL MATERIALS Advanced metals Metal matrix composites Polymers Polymer matrix composites Structural ceramics	AIRBREATHING PROPULSION ■ ARTIFICIAL INTELLIGENCE ■ ADVANCED COMPOSITES ■ COMPUTATIONAL SCIENCE ■ ADVANCED METALLIC STRUCTURES ■ OPTICAL INFORMATION PROCESSING ■ ROCKET PROPULSION ■ ADVANCED SENSORS ■ SOFTWARE DEVELOPMENT ■ SUPERCONDUCTIVITY ■ ULTRA-RELIABLE ELECTRONIC SYSTEMS

Figure D-2
National Technologies Assessment

APPENDIX E
DETAILED STRATEGIC CIVIL MISSION FORECAST
(FOR TECHNOLOGY PROGRAM PLANNING PURPOSES)[1]

[1] Although developed in Spring, 1991, this forecast has been adjusted to accommodate late Summer changes in Space Science and Applications, Space Exploration Initiative, and Space Flight Planning.

TECHNOLOGY TIMEFRAME	MISSION PLANNING-DERIVED TECHNOLOGY STRATEGIC OBJECTIVES	PROJECTED LAUNCH TIMEFRAME
1992	*not applicable*	
1993	Science - Ground Based	
	Complete technology *[if any]* for TOPS-0 (e.g., "Toward Other Planetary Systems - Keck II)	[OPS~1996-1997+]
	Transportation - ETO	
	Complete technology development *[if any]* to support initial National Launch System (NLS) system options (except STME) (assumes 3-m shroud @ 35-75 MT capacity)	[LAUNCH~1999-2002+]
	Science - Earth Orbiting & MTPE	
	Complete technology development to support initial Earth Observing System spacecraft and instrument enhancements options (EOS initial spacecraft)	[LAUNCH~1998]
	Complete technology development *[if any]* to support Advanced X-Ray Astrophysics Facility (AXAF)	[LAUNCH~1998+]
1994	Science - Earth Orbiting & MTPE	
	Complete technology development *[if any]* to support Astromag	[LAUNCH~1999+]
	Complete technology development *[if any]* to support Gravity Probe-B	[LAUNCH~2000+]
	Science - Lunar/Planetary Surface & MFPE	
	Complete technology development *[if any]* to support Lunar Observer	[LAUNCH~1998-1999+]

1995	Transportation - ETO	
	Complete technology development to support space transportation main engine (STME) for NLS	[LAUNCH~2001-2004+]
	Deliver technology to support space transportation system (STS) evolution (if any) during the first five years of the 21st century	[LAUNCH~2001-2005+]
	Transportation - Upper Stages & Transfer	
	Complete technology development *[if any]* to support ground-based Cargo Transfer Vehicle (CTV) option	[LAUNCH~2001-2004+]
	Science - Earth Orbiting & MTPE	
	Deliver technology to support potential upgrades and/or evolution of Geosynchronous Operational Environmental Satellites (GOES)	[LAUNCH~2000++]
	Science - Lunar/Planetary Surface & MFPE	
	Complete technology development to support initial Mars landers/probes network mission 1st launch	[LAUNCH~1998 or 2001]

1996-1997	<u>Transportation - ETO</u>	
	Complete technology development to support ELV-launched personnel launch system (PLS) option	[LAUNCH~2002-2006+]
	<u>Transportation - Upper Stages & Transfer</u>	
	Complete technology development to support high-energy cryogenic upper stage (ground-based, for use with ELVs)	[LAUNCH~2001-2004+]
	<u>Space Station</u>	
	Complete technology development to support Space Station Freedom systems enhancement for LEO operations (e.g., Enhanced Operating Capability - EOC)	[LAUNCH~2003-2006+]
	<u>Science - Earth Orbiting & MTPE</u>	
	Complete technology development to support Space Infrared Telescope Facility (SIRTF)	[LAUNCH~2001+]
	Complete technology development to support EOS Synthetic Aperture Radar (SAR) mission	[LAUNCH~2001+]
	Complete technology development to support initial Second-Round EOS spacecraft and instrument enhancements options	[LAUNCH~2001+]
	Complete technology development to support Laser Atmospheric Wind Sounder (LAWS) instrument	[LAUNCH~2001-2002+]
	<u>Science - Deep-Space</u>	
	Complete technology development to support enhancements of Mariner Mark II spacecraft technologies for very long duration Outer Planet Missions (e.g., Neptune orbiter missions)	[LAUNCH~2002-2003+]
	Complete technology development to support initial miniaturized free-flying probe spacecraft (e.g., for Pluto flyby mission probe)	[LAUNCH~2002-2003+]

1996-1997 *(continued)*	<u>Science - Lunar/Planetary Surface & MFPE</u>	
	Complete technology development to support Lunar Transit Telescope	[LAUNCH~2002-2005+]
	Complete technology development to support upgrades and/or evolution of Mars network probes missions (including a micro-rover option)	[LAUNCH~2001 or 2003+]
	<u>SEI - Mission From Planet Earth (MFPE)</u>	
	Complete technology development to support initial Lunar outpost transportation system and surface systems	[LAUNCH~2003-2007+]

1998-1999	Transportation - ETO	
	Complete technology development to support advanced/integrated vehicle personnel launch system (PLS) option	[LAUNCH~2006-2008+]
	Deliver technology to support hybrid propulsion options to support commercial ELV advanced pre-planned product improvement (P3I) or space transportation system (STS) strap-on booster (SRB) upgrade/replacement	[LAUNCH~2003-2004+]
	Space Station	
	Complete technology development to support Space Station Freedom systems for advanced LEO operations (i.e., Lunar Vehicle Capability - LVC - for space-basing of Lunar transportation systems)	[LAUNCH~2007-2011+]
	Telecommunications - Earth Orbiting	
	Deliver initial technology to support advanced geostationary/commercial telecomunications satellites	[LAUNCH~2003-2005+]
	Science - Earth Orbiting & MTPE	
	Complete technology development to support TOPS-1 (Astrometric Imaging Telescope - AIT)	[LAUNCH~2005-2008+]
	Complete technology development to support Submillimeter Moderate Mission (SMMM)	[LAUNCH~2002-2003+]
	Science - Lunar/Planetary Surface & MFPE	
	Complete technology development to support initial Mars Sample Return Missions (including a local rover)	[LAUNCH~2005 or 2007+]

2000-2003	**Science - Ground Based**	
	Complete technology development to support Advanced Very Long Baseline Interferometer (VLBI)	[OPS~2007-2010+]
	Telecommunications - Ground Based	
	Complete technology development to support optical communications systems upgrades and/or evolution for DSN operations	[OPS~2007-2010+]
	Transportation - ETO	
	Complete technology development to support upgrades/evolution of initial NLS systems (assumes 8 to10-m shroud @ 75-150 MT capacity)	[LAUNCH~2005-2010+]
	Complete all technology development activities related to Space Shuttle evolution	[LAUNCH~TBD]
	Space Station	
	Complete technology development to support Space Station Freedom systems for extended LEO operations (e.g., for Extended Operating Capability - XOC)	[LAUNCH~2011-2013+]
	Science - Earth Orbiting & MTPE	
	Complete technology development to support 1st upgrades and/or evolution of Earth Observing System spacecraft & instrument enhancements options	[LAUNCH~2004-2006+]
	Complete technology development to support initial GEO Earth Observing System platforms	[LAUNCH~2006-2009+]
	Complete technology development to support Hard X-Ray Imaging Facility (HXIF)	[LAUNCH~2006-2009+]

2000-2003 *(continued)*	Complete technology development to support Large Deployable Reflector (LDR)	[LAUNCH~2008-2010+]
	Complete technology development to support Orbiting Solar Laboratory (OSL)	[LAUNCH~2008+]
	Complete technology development to support orbiting optical interferometer (OI) for astrophysics, and planetary science, including the TOPS-2 systems approach option	[LAUNCH~2006-2009+]
	<u>Science - Deep-Space</u>	
	Complete technology development to support Solar Probe (SP) mission spacecraft and/or instruments	[LAUNCH~2002+]
	Complete technology development to support Mercury Dual Orbiter (MDO) mission spacecraft	[LAUNCH~2007-2008+]
	Complete technology development to support upgrades and/or evolutionary enhancements of Mariner Mark II spacecraft (e.g. for advanced Uranus orbiter/probe mission)	[LAUNCH~2007-2010+]
	Complete technology development to support Jupiter Grand Tour Mission using nuclear electric propulsion (NEP)	[LAUNCH~2007-2011+]
	Complete technology development to support Multiple Main Belt Asteroid Rendezvous (M-MBAR) mission (with major NEP enhancement option)	[LAUNCH~2007-2011+]
	Complete technology development to support Comet Nuclear Sample Return (CNSR) mission	[LAUNCH~2008-2010+]
	<u>Science - Lunar/Planetary Surface & MFPE</u>	
	Complete technology development to support extended-range robotic Mars rover missions	[LAUNCH~2006-2010+]

2000-2003 *(continued)*	Complete technology development to support Lunar surface observatories for astrophysical, space physics and planetary science, including the TOPS-4 option (e.g., a surface optical interferometer (OI))	[LAUNCH~2007-2010+]
	SEI - Mission From Planet Earth (MFPE)	
	Complete technology development to support upgrades of initial Lunar outpost surface systems (e.g., in situ resource utilization systems)	[LAUNCH~2007-2010+]
	Complete technology development to support upgrades and/or evolution of initial Lunar outpost transportation systems (e.g., space-basing of systems)	[LAUNCH~2009-2014+]

2004-2007	<u>Transportation - ETO</u>	
	Complete technology development to support Advanced Manned Launch System (AMLS)	[LAUNCH~2013-2017+]
	<u>Space Station</u>	
	Complete technology development to support Space Station Freedom systems for Mars vehicle LEO transportation node operations (e.g., for Mars Vehicle Capability - MVC)	[LAUNCH~2015-2017+]
	<u>Science - Earth Orbiting & MTPE</u>	
	Complete technology development to support 1st upgrades and/or evolution of Second-Round EOS spacecraft and instrument enhancements options	[LAUNCH~2008-2010+]
	<u>SEI - Mission From Planet Earth (MFPE)</u>	
	Complete technology development to support initial human missions to Mars transportation vehicle systems and Mars surface exploration systems	[LAUNCH~2010-2017+]

2008-2011	<u>Transportation - ETO</u>	
	Complete technology development to support post-NLS, 2nd-generation Heavy Lift Launch Vehicle (HLLV) system (assumes 17 to 20-m shroud @ 150-225 MT capacity)	[LAUNCH~2016-2019+]
	<u>Science - Earth Orbiting & MTPE</u>	
	Complete technology development to support 2nd upgrades and/or evolution of Second-Round EOS spacecraft and instrument enhancements options (e.g., EOS-B series)	[LAUNCH~2011-2013+]
	<u>SEI - Mission From Planet Earth (MFPE)</u>	
	Complete technology development to support Mars outpost preparation human missions to Mars	[LAUNCH~2019+++]

Glossary of Acronyms

A&R	Automation and Robotics
AC	Alternating Current
ACRV	Assured Crew Return Vehicle
ACTS	Advanced Communications Technology Satellite
A/D	Advanced Development
AETB	Advanced Expander Cycle Testbed
AFE	Aeroassist Flight Experiment
AI	Artificial Intelligence
AIA	Aerospace Industries Association
a.k.a.	Also Known As
ALARA	As Low As Reasonably Achievable
AMAC	NAC Aerospace Medicine Advisory Committee
AMLS	Advanced Manned Launch System
AN&L	Autonomous Navigation and Landing
AO	Announcement of Opportunity
AOTF	Acousto-Optical Tunable Filter
APSA	Advanced Power Solar Array
AR&D	Autonomous Rendezvous and Docking
ARC	NASA Ames Research Center
ARTS	SSTAC Aerospace Research and Technology Subcommittee
ASEB	NRC Aeronautics and Space Engineering Board
ATD	Advanced Technology Development
ATDRSS	Advanced Telecommunications & Data Relay Satellite System
AXAF	Advanced X-Ray Astronomical Facility

CCD	Charged-Coupled Devices
CCDS	NASA OCP Centers for the Commercial Development of Space
CELSS	Controlled Ecological Life Support Systems
CFD	Computational Fluid Dynamics
CNSR	Comet Nucleus Sample Return
COHE	Cryogenic Orbital Hydrogen Experiment
COMSTAC	(DOT) Commercial Space Transportation Advisory Committee
CONE	Cryogenic Orbital Nitrogen Experiment
CO_2	Carbon Dioxide
CRAF	Comet Rendezvous/Asteroid Flyby
CSI	Controls-Structures Interactions
CSTI	Civil Space Technology Initiative
CTV	Cargo Transfer Vehicle
DARPA	Defense Advanced Research Projects Agency
DCWS	Debris Collision Warning System
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EDO	Extended Duration Orbiter
ELV	Expendable Launch Vehicle
EMA	Electromechanical Actuator
EMU	Extravehicular Mobility Unit
EOS	Earth Observing System
EOS/DIS	EOS Data and Information System
ETO	Earth-To-Orbit
ETP	Exploration Technology Program
EVA	Extravehicular Activity Systems
FEL	Free-Electron Lasers
FSD	Full Scale Development
FTS	Flight Telerobotic Servicer
GCR	Galactic Cosmic Ray

GCRP	Global Change Research Program
GEO	Geostationary Earth Orbit
GN&C	Guidance, Navigation and Control
GPS	Global Positioning System
GRO	Gamma Ray Observatory
GSFC	NASA Goddard Space Flight Center
GTO	GEO Transfer Orbit
HCI	Human-Computer Interaction
HEAb	High-Energy Aerobraking (Flight Experiment)
HLLV	Heavy Lift Launch Vehicle (a.k.a., Heavy Lift Vehicle, HLV)
H/O	Hydrogen/Oxygen
HST	Hubble Space Telescope
HTS	High Temperature Superconductivity
HXIF	Hard X-Ray Imaging Facility
IEHM	Integrated Engine Health Management
INS	Inertial Navigation System
IN-STEP	In-Space Technology Experiments Program
IR	Infrared
Isp	Specific Impulse
ISRU	*In Situ* Resource Utilization
ITP	Integrated Technology Plan
JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center
K	(degrees) Kelvin
kg	Kilograms
KSC	NASA Kennedy Space Center
kW	Kilowatts
kWe	Kilowatts-electric
kWt	Kilowatts-thermal
LaRC	NASA Langley Research Center
LAWS	Laser Atmospheric Wind Sounder
LCC	Life Cycle Cost

LDEF	Long Duration Exposure Facility
LDR	Large Deployable Reflector
LEM	(Apollo) Lunar Excursion Module
LEO	Low Earth Orbit
LeRC	NASA Lewis Research Center
LHC	Liquid Hydrocarbons
LH_2	Liquid Hydrogen
Li	Lithium
LIDAR	Light Detection and Ranging
LO	Lunar Observer
LOx	Liquid Oxygen
LLOx	Lunar Liquid Oxygen
m	Meters
MFPE	Mission From Planet Earth
μm	Micron
MLS	Microwave Limb Sounder
MMIC	Monolithic Microwave Integrated Circuit
MO	Mars Observer
MODE	Middeck Zero Gravity Dynamics Experiment
MOU	Memorandum of Understanding (a.k.a., Memorandum of Agreement—MOA)
MPD	Magnetoplasmadynamic
MSFC	NASA Marshall Space Flight Center
MTPE	Mission To Planet Earth
MTV	Mars Transfer Vehicle
NAC	NASA Advisory Committee
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NCAT	AIA National Center for Advanced Technology
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NEP	Nuclear Electric Propulsion (a.k.a., NEPS)

NIST	National Institute of Standards and Technology
NLS	National Launch System (a.k.a., Advanced Launch System—ALS)
NOAA	National Oceanographic and Atmospherics Administration
NRC	National Research Council
NTP	Nuclear Thermal Propulsion
NTR	Nuclear Thermal Rocket
OAET	NASA Office of Aeronautics, Exploration and Technology
OAET/RZ	OAET Space Exploration Directorate
OAST	Office of Aeronautics and Space Technology
OCP	NASA Office of Commercial Programs
OEIC	Optoelectronic Integrated Circuit
OEX	Orbiter Experiments
OEXP	Office of Exploration
OSL	Orbiting Solar Laboratory
OMB	Office of Management and Budget
OSF	NASA Office of Space Flight
OSMQ	NASA Office of Safety and Mission Quality
OSO	NASA Office of Space Operations
OSSA	NASA Office of Space Science and Applications
OSTP	White House Office of Science and Technology Policy
OTA	U.S. Congress Office of Technology Assessment
OTV	Orbital Transfer Vehicle
PIC	Power Integrated Circuit
PLS	Personnel Launch System
PMAC	Power Management and Conditioning
PMAD	Power Management and Distribution
PMC	Permanently Manned Capability
POINTS	Precision Optical Interferometry In Space
PSR	Precision Segmented Reflector
PV	Photovoltaic
R&T	Research and Technology
RF	Radio Frequency

RFC	Regenerative Fuel Cell
RMS	Remote Manipulator System
RLSS	Regenerative Life Support System
s	Seconds
SAR	Synthetic Aperture Radar
SATWG	Strategic Avionics Technology Working Group
SDIO	Strategic Defense Initiative Office
SEI	Space Exploration Initiative
SEPS	Solar Electric Propulsion System
SETI	Search for Extraterrestrial Intelligence
SIRTF	Space Infrared Telescope Facility
SMIM	Submillimeter Intermediate Mission
SODR	Space Optical Disk Recorder
SPE	Solar Particle Event
SSAC	NAC Space Science and Applications Advisory Committee
SSB	NRC Space Studies Board
SSC	NASA Stennis Space Center
SSF	Space Station *Freedom*
SSME	Space Shuttle Main Engine
SSTAC	NAC Space Systems and Technology Advisory Committee
SSTO	Single Stage To Orbit
STIG	Space Technology Interdependency Group
STME	Space Transportation Main Engine
STV	Space Transfer Vehicle (a.k.a. OTV, LTV, MTV)
TOPS	Toward Other Planetary Systems
TOPEX	Ocean Topography Experiment (a.k.a, Poseidon)
TR	Telerobotics
TSTO	Two-Stage-to-Orbit
TTB	Technology Test Bed
UARS	Upper Atmosphere Research Satellite
U/S	Upper Stage
USAF	United States Air Force

USERC	University Space Engineering Research Center
USRA	University Space Research Association
UV	Ultraviolet
VHM	Vehicle Health Management
VLBI	Very Long Baseline Interferometry (also Orbiting VLBI, O-VLBI)
VLSI	Very Large Scale Integration
VHM	Vehicle Health Monitoring
V&V	Verification and Validation
WBS	Work Breakdown Structure

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