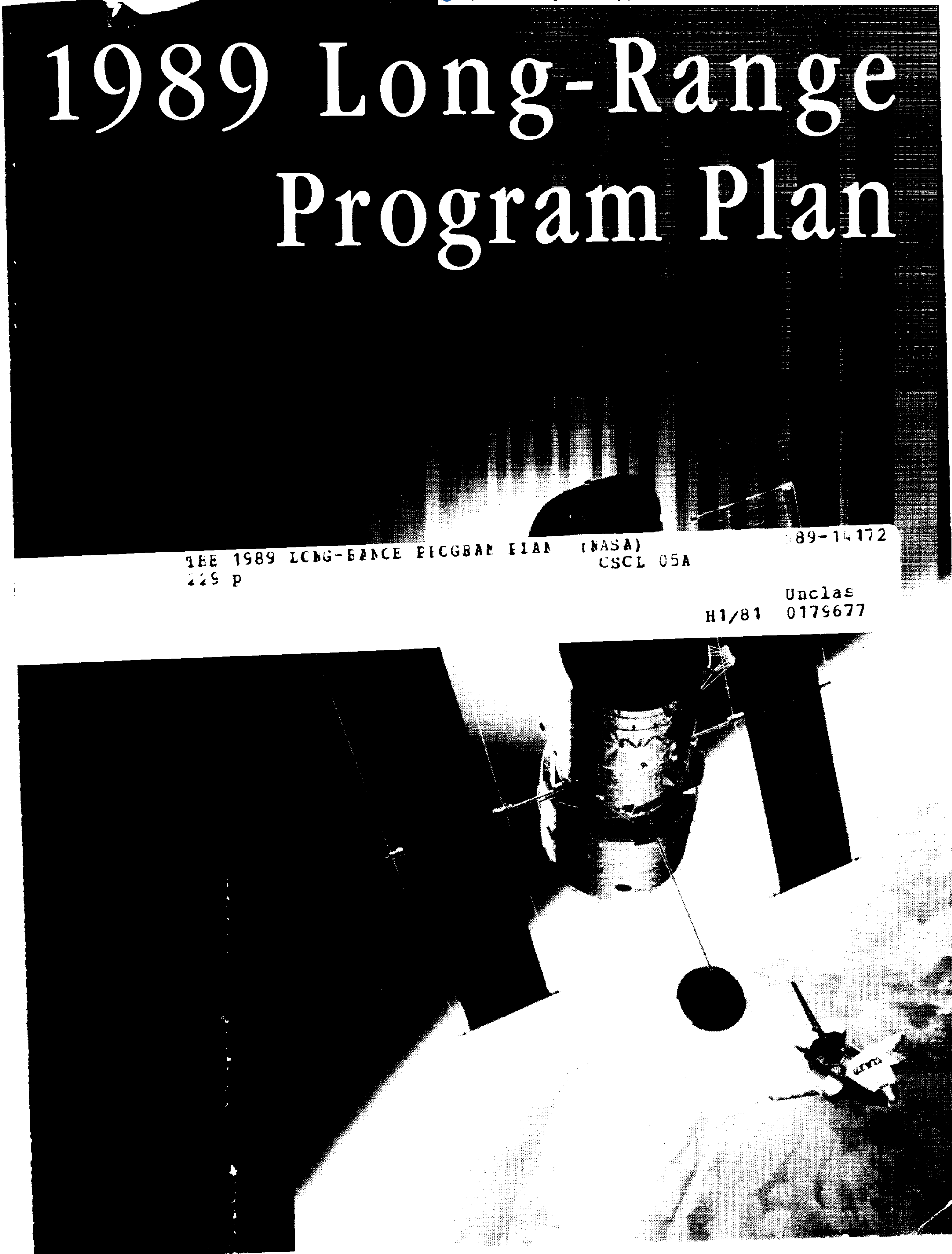
1989 Long-Range Program Plan



1989 LONG-RANGE PROGRAM PLAN

NASA
National Aeronautics and
Space Administration
Washington, D.C. 20546

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INTRODUCTION

Overview

The President's National Space Policy of 1988 reaffirms that space activities serve a variety of vital national goals and objectives, including the strengthening of U.S. scientific, technological, political, economic, and international leadership. The new policy stresses that civil space activities contribute significantly to enhancing America's world leadership. As the Nation's research and development organization for civil aeronautics and space activities, NASA must look continually to the future. Goals and objectives must be defined and redefined, and each advance toward a given objective must be viewed as a potential building block for future programs. This important evolutionary process for research and development is reflected in this report describing NASA's program planning for FY 1989 and later years.

This plan outlines the direction of NASA's future activities by discussing goals, objectives, current programs, and plans for the future. Normally an annual event, the plan was not published for two years (the last one was the 1986 Long-Range Program Plan) because of the Challenger disaster and continuing budget uncertainties. The 1989 plan is consistent with national policy for both space and aeronautics, and with the FY 1989 budget that the President submitted to Congress in February 1988.

This document is designed for agency-level planning purposes and does not represent the Administration's approval or support of any program not included in the President's budget request. Programs discussed in this document are subject to budget constraints and Administration approval.

Organization of the 1989 Long-Range Program Plan

Major features of NASA's goals, objectives, and programs are summarized in Chapter II and are described in detail in Chapters III through X. Abbreviations and acronyms are found in Chapter XI, and an index is available in Chapter XII.

Throughout this report, many descriptions of specific programs and ideas are highlighted by being placed in insets. This feature of the format enhances clarity and conciseness by concentrating information on a given topic in a particular location of the the report. Each inset appears as close as possible to the first discussion of the inset's topic within the chapter. The text provides cross-references to insets within a chapter, and to insets located in other chapters. The Table of Contents contains a list of all insets.

For Further Information

This report is a working document, summarizing the status of NASA's goals, objectives, and plans as of late spring of 1988. Comments and suggestions are welcome and will receive careful consideration.

To obtain copies of this report or general information about NASA's program planning, contact Thomas W. Chappelle, Code ADI-1, National Aeronautics and Space Administration, Washington, D.C. 20546. For up-to-date details on individual technical programs, get in touch with the appropriate program offices.

NASA's Office of Aeronautics and Space Technology annually updates the NASA Space Systems Technology Model described on page VII-7. A copy of the executive summary of that report can be obtained from Stanley R. Sadin, Code RS, National Aeronautics and Space Administration, Washington, D.C. 20546. The more detailed report volumes and the full data base constitute an extensive set of documents available to those who can demonstrate a need for them.

SUMMARY AND PERSPECTIVE

Introduction

Written on the eve of the Nation's return to space, this 1989 Long-Range Program Plan provides a general view of the goals, objectives, and programs of the National Aeronautics and Space Administration.

This chapter of the report provides an Agency-level perspective of NASA's activities, and offers brief summaries of the programs in eight major areas of NASA's technical program:

(1) Space Science and Applications,
(2) Space Flight,
(3) Space Station,
(4) Space Operations,
(5) Space Research and Technology,
(6) Aeronautical and Transatmospheric Research and Technology,
(7) Commercial Programs, and
(8) Exploration.

NASA's Mission

As charged by the National Aeronautics and Space Act of 1958, as amended, NASA's primary mission is to advance science and technology in the disciplines appropriate to aeronautics and space activities, to develop applications of aerospace technology, to explore space, and to develop and operate systems necessary to the furthering of space science, technology, applications, and exploration. NASA is also responsible for providing appropriate aerospace research and development support to other agencies of the U.S. government as they discharge their respective responsibilities, and to elements of the private sector in their commercial endeavors.

Background

In the last few years, NASA and the Nation have reevaluated the posture and the long-term direction of the U.S. civilian space program. The goals and strategies that have emerged from this evaluation are vital to the U.S. leadership role in space. Of the many complementary studies relevant to NASA's long-range goals, three in particular are discussed here.

The Presidential Commission on the Space Shuttle Challenger Accident (see page II-4) investigated the causes of the Challenger accident and made specific recommendations for technical and organizational improvements.

The National Commission on Space made broad and exciting recommendations (see page II-5) for advancing the Nation's civil space program into the 21st century.

A task force charged with defining and evaluating potential space initiatives observed that "the U.S. civilian space program is now at a crossroads, aspiring toward the visions of the National Commission on Space but faced with the realities set forth by the Rogers Commission. NASA must respond aggressively to the challenges of both while recognizing the necessity of maintaining a balanced space program within reasonable fiscal limits." The task force report provided guidelines (see page II-6) for this response.

The Rogers Commission Report

The Rogers Commission report presents the results of an official investigation into the space shuttle Challenger accident, which occurred on January 28, 1986, killing seven crew members. This commission, the Presidential Commission on the Space Shuttle Challenger Accident, was chaired by William P. Rogers. Its report, submitted to the Executive Office on June 6, 1986, set forth the following recommendations:

(1) Redesign the Solid Rocket Motor Joints, establish a NASA Independent Solid Rocket Motor Design Oversight Committee to monitor redesign and test, review and redefine the Shuttle Management Structure, and redefine the Program Manager's responsibilities;

(2) Encourage qualified astronauts to transfer into NASA management positions, and establish a Shuttle Safety Advisory Panel;

(3) Perform criticality reviews and hazard analysis before each flight to ensure mission success and flight safety;

(4) Establish an Office of Safety, Reliability, and Quality Assurance to be headed by an Associate Administrator reporting directly to the NASA Administrator;

(5) Improve communications in all levels of management;

(6) Improve landing safety;

(7) Implement launch abort and crew escape procedures;

(8) Regulate the shuttle's flight rate to be consistent with NASA's resources; and

(9) Implement rigorous maintenance procedures and safeguards.

The Report of the National Commission on Space

The National Commission on Space, chaired by Thomas O. Paine, was appointed by the President and charged by Congress with formulating a bold agenda to carry America's civilian space enterprise into the 21st century. After analysis, deliberation, and review of testimony from experts and a cross-section of citizens from across the country, the Commission completed its report Pioneering the Space Frontier in 1986, recommending the following broad program thrusts:

(1) Advancing Understanding of Earth, the Solar System, and the Universe

This understanding may be obtained in part through a sustained program to understand the evolution of the universe, a study of the evolution of the solar system, a global study of planet Earth, and a study of the sun and the vast region it influences. The Commission also recommended a continuing program to search for evidence that life exists—or has existed—beyond Earth, provision of state-of-the-art facilities for laboratory experiments on the ground and on the Space Station, and new research into the effects of different gravity levels.

(2) Exploring, Prospecting, and Settling the Solar System

This objective may be realized through continuing robotic precursor missions, missions to obtain samples, robotic and human exploration and surveying, and establishment of human outposts and bases.

(3) Stimulating Space Enterprises for the Direct Benefit of the People on Earth

It was recommended that the private sector be given the task of providing specified services or products in space, with the freedom to determine the most cost-effective ways to do so consistent with evolving federal regulations. In addition, the Commission recommended that NASA initiate research and development on systems and processes for application beyond low Earth orbit.

To accomplish these thrusts economically, the Commission recommended a long-range commitment by the United States to two additional thrusts:

(4) Advancing Technology to Ensure Timely Availability of Critical Capabilities

The Commission proposed a threefold growth in NASA's base technology budget, with special emphasis on intelligent autonomous systems. Demonstration projects were recommended in seven critical technologies: flight research on National Aerospace Plane propulsion and aerodynamics, advanced rocket vehicles, aerobraking for orbital transfer, long-duration for closed ecosystems, electric launch and propulsion systems, nuclear-electric space power, and space tethers and artificial gravity. The Commission also recommended satisfaction of three major transport needs: cargo transport to low Earth orbit, passenger transport to and from low Earth orbit, and round-trip transfer beyond low Earth orbit.

(5) Creating and Operating Systems and Institutions to Provide Low-Cost Access to the Space Frontier

The Commission recommended development of reliable, high-performance, electric propulsion systems, development of fully self-sustaining biospheres, and establishment of initial outposts and bases on the moon and Mars that combine a variety of long-range objectives.

The Ride Panel Report

In 1987, Dr. Sally Ride presented a report to the Administrator entitled Leadership and America's Future in Space. The report was the product of Dr. Ride's task group, which was charged with defining potential U.S. space initiatives and evaluating them in light of the Nation's current space program and its desire to regain and retain space leadership. The objectives of the study were to energize a discussion of the long-range goals of the civilian space program and to begin to investigate overall strategies to direct that program to a position of leadership.

The task group identified the following candidate initiatives, each building on NASA's achievements in science and exploration:

(1) Mission to Planet Earth,
(2) Exploration of the Solar System,
(3) Outpost on the Moon, and
(4) Humans to Mars.

The group developed each initiative in detail and assessed its implications and requirements. The conclusions reached included the following:

(1) A focal point should be established within NASA to fund, direct, and coordinate studies related to human exploration. (Recognizing this need, the NASA Administrator established the Office of Exploration, whose activities are described in Chapter X.)
(2) NASA's most urgent problem from now until the mid 1990s is Earth-to-orbit transportation. The Nation must develop a cadre of launch vehicles that can first meet the near-term commitments of the civilian space program and then grow to support projected programs or initiatives.
(3) Technology development and life sciences research are pacing elements in human exploration. Without advanced technology programs like Project Pathfinder, the exciting goals of human exploration will always remain 10 to 20 years in the future.
(4) NASA should embrace Mission to Planet Earth, a program using the perspective afforded from space to study and characterize Earth on a global scale.
(5) Robotic planetary exploration should be actively supported and nurtured through the 1990s. Planetary exploration is fundamental science that challenges the Nation's technology, extends human presence, and provides a glimpse of other worlds.
(6) Settling Mars should be an eventual goal, but not the next goal. The Nation should adopt a strategy to continue an orderly expansion outward from Earth. In particular, humans should learn to live and work on a hostile world beyond Earth by exploring the Moon first, in an evolutionary manner and on a time scale that is consistent with developing capabilities.
(7) Leadership does not require that the United States be preeminent in all areas and disciplines of space enterprise; in fact, the increasing number of spacefaring nations make it impossible for any nation to dominate in this way. The Nation must determine its priorities, make conscious choices to pursue a set of objectives that will restore its leadership status, develop a sound program of scientific research and technology development, and incorporate visible and significant accomplishments in the program.

1988 National Space Policy

In 1988 a new National Space Policy was set forth by the President in a comprehensive statement derived from a long and thorough review of previous Presidential directives, and of assessments of current and future opportunities in space. The policy, described in the inset below, included the national space goals shown in the first inset on page II-8.

The Nation's policy and major goals for aeronautics are described in the second inset on page II-8. They were developed and published by the Office of Science and Technology Policy, Executive Office of the President, in 1982.

The President's 1988 National Space Policy

On February 11, 1988, President Reagan issued a new National Space Policy designed to guide the United States' activities in space well into the future. This comprehensive "Space Policy and Commercial Space Initiative to Begin the Next Century" is intended to ensure United States space leadership.

The President's program has three major components:

(1) establishing a long-range goal to expand human presence and activity beyond Earth orbit into the solar system,
(2) creating opportunities for U.S. commerce in space, and
(3) continuing national commitment to a permanently manned Space Station.

The new policy and programs are contained in a National Security Decision Directive signed by the President on January 5, 1988; in the FY 1989 budget the President submitted to Congress; and in a 15-point Commercial Space Initiative.

To lay the foundation for the expansion of human presence and activity in the solar system, the President requested funds for a major new technology development program, Project Pathfinder, that will enable a broad range of manned and unmanned missions beyond Earth's orbit. Additional details on Project Pathfinder are to be found in Chapters VII and X.

The President's commercial space initiative has the goals of promoting a strong U.S. commercial presence in space, assuring a highway to space, and building a solid technology and talent base. These goals are reflected in NASA's commercial activities described in Chapter IX.

The President continued his commitment to the Space Station as a multipurpose facility for the Nation's science and applications programs. Details of the Space Station program are found in Chapter V.

National Space Goals

A fundamental objective guiding U.S. space activities has been, and continues to be, space leadership. Leadership in an increasingly competitive international environment does not require United States preeminence in all areas and disciplines of space enterprise. It does require United States preeminence in key areas of space activity critical to achieving national security and the Nation's scientific, technical, economic, and foreign policy goals.

The overall goals of U.S. space activities, as embodied in the 1988 Presidential directive on national space policy, are:

(1) to strengthen the security of the United States;
(2) to obtain scientific, technological, and economic benefits for the general population and to improve the quality of life on Earth through space-related activities;
(3) to encourage continuing U.S. private-sector investment in space and related activities;
(4) to promote international cooperative activities taking into account U.S. national security, foreign policy, scientific, and economic interests;
(5) to cooperate with other nations in maintaining the freedom of space for all activities that enhance the security and welfare of mankind; and
(6) as a long-range goal, to expand human presence and activity beyond Earth orbit into the solar system.

National Aeronautics Policy

The high-technology payoffs that result from advances in aeronautics are important national benefits that must be maximized by American enterprise. This maximization requires government and industry to combine their efforts toward aggressive technological goals with potential for broad future application. The major U.S. goals in aeronautics are as follows:

(1) Subsonics—to develop Trans-Century Renewal technology for a new generation of U.S. subsonic aircraft;
(2) Supersonics—to develop Long-Distance Efficiency technology for improved supersonic cruise; and
(3) Transatmospheric—by building on subsonic, supersonic, and hypersonic technology, to provide future options for cruising and maneuvering in and out of the atmosphere using conventional runways as bases.

NASA Goals and Objectives

NASA's goals are reviewed regularly and modified to meet national space and aeronautics requirements. The most recent set, together with a brief statement of the Agency's vision for the future, was announced by the NASA Administrator in December 1986 (see inset below).

To accomplish its mission, implement Administration policy, and achieve its goals, NASA is pursuing objectives in each of the eight program areas discussed in this report, as well as in the two additional areas of Institutional Management and Safety, Reliability, Maintainability, and Quality Assurance. Major objectives are shown in Table II-1; complete objectives are included in chapters III through X.

NASA Goals

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set a course into the 21st century and bring this vision to reality, NASA will pursue major goals which represent its aspirations in aviation and space. These goals are:

(1) advance scientific knowledge of the planet Earth, the solar system, and the universe beyond;

(2) expand human presence beyond the Earth into the solar system; and

(3) strengthen aeronautics research and develop technology toward promoting U.S. leadership in civil and military aviation.

Successful pursuit of these major goals requires commitment to the following supporting goals:

(1) return the space shuttle to flight status and develop advanced space transportation capabilities; and

(2) develop facilities and pursue science and technology needed for the Nation's space program.

As NASA pursues these goals, it will:

(1) promote domestic application of aerospace technologies to improve the quality of life on Earth and to extend human enterprise beyond Earth; and

(2) conduct cooperative activities with other countries when such cooperation is consistent with national space goals.

Table II-1. NASA Major Program Objectives

Advance Scientific Knowledge of the Planet Earth, the Solar System, and the Universe Beyond	Complete the group of astronomical facilities known as the Great Observatories to analyze the universe across the electromagnetic spectrum (i.e., Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, and Space Infrared Telescope Facility).
	Complete a detailed scientific characterization for virtually all of the solar system (e.g., Galileo, Magellan, Comet Rendezvous-Asteroid Flyby, Cassini, and Mars Observer).
	Quantitatively characterize the physical behavior of the sun, the origins of solar variability, the geospace environment, and the effects of solar processes on Earth (e.g., Ulysses, the Solar Heliospheric Observatory, and the International Solar-Terrestrial Program missions of Wind, Polar, Geotail, and Cluster).
	Establish a set of observing platforms to study the Earth system on a global scale (e.g., Earth Observing System, Shuttle Imaging Radar, and Topex-Poseidon Ocean experiments).
	Determine, develop, and exploit the unique capabilities provided by the Space Station and other space-based facilities to pursue microgravity studies (e.g., U.S. and International Microgravity Laboratory missions).
Expand Human Presence Beyond the Earth into the Solar System	Develop the scientific foundation to support the planning of human exploration beyond Earth (e.g., Spacelab Life Sciences study missions).
	Provide a permanent human presence in space by the 1990s that will enhance capabilities for space science and applications, stimulate advanced technologies, promote international cooperation, encourage private sector participation and use, and provide options for future endeavors in space.
	Provide alternatives and recommendations for initiatives in human exploration of the inner solar system to support an early 1990s Presidential decision.
Strengthen Aeronautics Research and Develop Technology Toward Promoting U.S. Leadership in Civil and Military Aviation	Build a technology basis for maintaining world leadership in civil and military aeronautics by emphasizing emerging technologies, strengthening systems technology development and validation in high payoff areas, and ensuring continued availability of critical facilities. Emphasis is to be placed on Subsonic Transport, Civil Tiltrotor, High Speed Civil Transport, High Performance Military Aircraft, and Wind Tunnel Modernization.

Table II-1. NASA Major Program Objectives (continued)

	Maintain a vigorous National Aerospace Plane program.
Return the Space Shuttle to Flight Status and Develop Advanced Space Transportation Capabilities	Return the space shuttle to flight status and attain safe, sustainable flight rates and capabilities that are compatible with payload requirements and program resources (e.g., pursue a robust test program, Advanced Solid Rocket Motor, replacement orbiter, etc.).
	Establish and employ a space transportation mixed fleet comprising the space shuttle and unmanned launch vehicles or procured commercial launch services to launch NASA and other civil government payloads (i.e., Scout, Delta, Atlas, and Titan classes).
	Ensure availability of a variety of upper stages, carrier systems, and automated robotic systems, to provide simple, flexible, reliable transportation between the shuttle, Space Station, and other payloads and systems in orbit and to support permanent manned presence in space (e.g., pursue the Transfer Orbit Stage, Orbital Maneuvering Vehicle, Tethered Satellite System, Spacelab recertification, etc.).
	Enhance current space transportation capabilities and operations through advanced development, and prepare for advanced missions by developing plans, concepts, and preliminary designs for advanced transportation systems that will enable human and robotic exploration beyond Earth orbit into the solar system (e.g., shuttle evolution, heavy-lift launch vehicle, next generation launch systems, satellite servicing, etc.).
Develop Facilities and Pursue Science and Technology Needed for the Nation's Space Program	Continue development of space leadership technology programs, such as the Civil Space Technology Initiative and Pathfinder, to provide research in space transportation, operations, life sciences, and exploration.
Promote Domestic Application of Aerospace Technologies to Improve the Quality of Life on Earth and to Extend Human Enterprise Beyond Earth	Expand U.S. private sector investment and involvement in civil space activities.
	Support new high-technology commercial space ventures.
	Transfer existing aeronautics and space technology to the private sector, for application there.
	Expand commercial access to available NASA capabilities and services.

(Table continued on next page)

Table II-1. NASA Major Program Objectives (continued)

Conduct Cooperative Activities with Other Countries When Such Cooperation is Consistent with National Space Goals	(Applicable to many of above objectives; mentioned specifically in seventh objective above.)
Goals in the Supporting Areas of Operations; Safety, Reliability, Maintainability, and Quality Assurance; and Institutional Management	Establish, operate, and sustain a highly robust Tracking and Data Relay Satellite System (TDRSS) space network to provide high quality user services at a reasonable cost. Provide a follow-on TDRSS space network to meet evolving user needs through the year 2010 in an efficient and cost-effective manner. Maintain the ground network's capacity to support NASA programs in order to complement the TDRSS capacity (e.g., pursue a second TDRS Ground Terminal and Customer Data and Operations System). Maintain the expert capabilities and the capacity of communications and data systems; provide a focal point for frequency allocation and standards, and for improvements in communications and data systems. Establish the Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) function as an aggressive contributor to the overall NASA operation. Develop a system for identifying problems and for subsequent analyses, corrective action, and communication up through all levels of management. Provide an independent assessment of the NASA program development and operating process—system design, development, manufacturing, procurement, test, and operations. Develop and ensure implementation of firmly defined policies and procedures for SRM&QA on a uniform basis throughout the Agency. Develop an SRM&QA work force that is staffed with qualified, properly trained and equipped people.

Table II-1. NASA Major Program Objectives (continued)

	Provide, at all times, oversight directed towards 100-percent operational success in a safe manner.
	Provide the leadership needed to maintain a highly effective work force, "world-class" facilities, state-of-the-art equipment and systems, and an environment emphasizing excellence.
	Establish a new multiyear Affirmative Employment program plan, actively pursue the implementation of an improved Discrimination Complaint Processing system, and continue NASA's outreach efforts to increase the number of minority, female, and handicapped scientists and engineers.
	Provide professional, technical, and functional management support to the NASA field installations and headquarters.
	Provide a quality work life for NASA personnel that includes a challenging career, equal opportunity, open communications, and recognition of employees based on their contributions.

Space Science and Applications Summary

To chart an enduring course that will make its vision a reality, the Office of Space Science and Applications (OSSA) has formulated a strategy that is the culmination of extensive interaction and collaboration with the scientific and applications communities, careful consideration of resource guidelines, and iterative reviews of pertinent issues and challenges.

The resulting strategy is constructed around five actions:

(1) establish a set of programmatic themes;
(2) establish a set of decision rules;
(3) establish a set of priorities for missions and programs within each theme;
(4) demonstrate that the strategy can yield a viable program; and
(5) check the strategy for the readiness of technology and for consistency with resource constraints such as budget, manpower, and launch vehicle availability.

Taken together, these five actions define a programmatic process by which OSSA is planning its activities and allocating its resources. The programmatic themes provide direction and balance to the program, the decision rules guide the selection of efforts among and within each theme, and the list of priorities determines the order in which the missions and programs within each theme will be pursued. The result is various plans for a Space Science and Applications program that then are checked for realism and for consistency with resource constraints. These actions, rather than defining a single plan, define a realistic and flexible process that provides the basis for making near-term decisions on the allocation of resources for future efforts.

OSSA pursues its program activities through an integrated sequence that includes:

(1) ground-based laboratory research and experimentation;
(2) suborbital flights of instruments on airplanes, balloons, and sounding rockets;
(3) flights of instruments on the shuttle-Spacelab system, commercially developed facilities, and the permanently manned Space Station; and
(4) the development and flight of automated Earth-orbiting and interplanetary spacecraft.

The program is conducted with the participation and support of all the NASA field centers, other government agencies and facilities, universities throughout the United States, and the aerospace industry. Substantial international participation occurs in many aspects of the program.

OSSA includes seven program divisions, each of which sponsors research within a specific scientific discipline to accomplish Space Science and Applications program goals. These discipline divisions are Astrophysics, Communications and Information Systems, Earth Science and Applications, Life Sciences, Microgravity Science and Applications, Solar System Exploration, and Space Physics.

Astrophysics

The highest priority for Astrophysics is the completion of the Great Observatories program, which will provide the backbone for a coordinated, multispectral observing program. The Great Observatories (Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, and Space Infrared Telescope Facility) will observe the universe with unprecedented completeness and sensitivity across the electromagnetic spectrum.

Current Programs. The Astrophysics program's one operating spacecraft, the International Ultraviolet Explorer, is in its tenth year of operation. Conducted in cooperation with the Netherlands and the United Kingdom, the project supports approximately 230 guest investigators per year.

The Hubble Space Telescope, the first of the Great Observatories, is scheduled for launch in early 1990. The Gamma Ray Observatory will be launched in 1990, as will two moderate astrophysics missions, the Cosmic Background Explorer and the Roentgen Satellite.

The Extreme Ultraviolet Explorer, to be launched in 1992, will be the first mission to be launched on the reusable Explorer platform. It will conduct the first high-sensitivity survey of the entire sky in extreme ultraviolet wavelengths. After two years of operation, it will be replaced with the X-Ray Timing Explorer (XTE), which also will be launched on the Explorer platform.

Planned Initiatives. The Advanced X-Ray Astrophysics Facility (AXAF), the third Great Observatory, is the highest priority new initiative in the astrophysics program. It will extend the spectral coverage of the Great Observatories into the X-ray region of the electromagnetic spectrum.

The next major initiative in the astrophysics program is the Space Infrared Telescope Facility (SIRTF), the fourth Great Observatory. It will complete the spectral coverage of the Great Observatories by extending high-sensitivity, high-resolution astronomical observations into the infrared.

Complementing AXAF with higher energy sensitivity and high time resolution, XTE will obtain important information by studying the time variations of astronomical emissions in the X-ray domain. XTE is currently in the definition phase; mission development is expected to begin in FY 1989.

NASA has selected four larger, Delta-class Explorer missions for study during the next year. The missions to follow XTE will be selected from them. The Far Ultraviolet Spectroscopy Explorer and the Nuclear Astrophysics Explorer are astrophysics missions; the remaining two—the Advanced Composition Explorer and the Mesosphere and Lower Thermosphere Explorer—are, respectively, space physics and Earth science missions.

In addition to using Delta-class Explorers, NASA expects to initiate a "Scout-class" of Explorers. Although the constraints on weight, telemetry, etc., for

Scout-class missions will be more stringent than those for Delta-class missions, it is anticipated that a significant number of scientifically exciting missions will be possible, and that they can be developed on a short time scale.

Activities also will be initiated to complete the general relativity investigation known as Gravity Probe-B. Plans are for this unique, moderate scale mission to have its integrated system test in 1989, and a space shuttle engineering test in 1993. Following administrative approval, the full spacecraft and experiment can be integrated and launched into a polar orbit, potentially as early as 1995.

The Japanese ASTRO-D, currently planned for launch in 1993, is an X-ray astronomy mission that NASA is currently investigating for potential U.S. cooperation.

Research Base. Space shuttle attached payloads continue to occupy a key position in the research base of the NASA astrophysics program. Two payloads—Astro and the Shuttle High Energy Astrophysics Laboratory — are planned for launch soon after the resumption of shuttle flights.

Two enhancements to the astrophysics research base are planned. The first enhancement is modification of a Boeing 747 aircraft to carry the Stratospheric Observatory for Infrared Astronomy (SOFIA). The result will be a significant increase in the capability to use suborbital observations to advance infrared astronomy and an opportunity for scientists to follow up on the exciting discoveries of the Infrared Astronomical Satellite in the interim until launch of SIRTF.

The second enhancement is the definition and implementation of the Astrophysics Data System, a system that will ensure the fullest access to and exploitation of various mission data sets. Emphasis will be given to the wealth of data to be returned by the Great Observatories, but data from the International Ultraviolet Explorer, the Infrared Astronomical Satellite, and the High Energy Astronomy Observatories continue to be of importance and will be included. An initial definition process involving extensive inputs from the astrophysics community has been completed, and installation of the principal elements of this essential system will begin in FY 1989.

Communications and Information Systems

The communications research program is structured around the development of advanced technology to use more effectively the electromagnetic spectrum and the geosynchronous orbit.

Current Programs. The Advanced Communications Technology Satellite program remains the centerpiece of NASA's communications activities in support of U.S. industry. In addition, NASA will continue to operate the Applications Technology Satellite, which provides vital support to many organizations through satellite voice and data links.

In the Satellite-Aided Search and Rescue program, a third U.S. satellite was placed in orbit in 1988. Fourteen local ground-station user terminals were in operation by the end of the second quarter of 1988. By the end of 1988, an experiment using geostationary satellites to provide more nearly instantaneous alerting and identification will be performed. Efforts will be continued in 1989 to improve the locating accuracy of the system, to make the service available to a broader spectrum of users, and to reduce false alarms and the cost-performance ratio of emergency beacons.

Essentially all of the technology developments for Mobile Satellite activities, which are undertaken in close coordination with industry, are scheduled for completion by the end of 1988. Some hardware is now undergoing field testing, with completion scheduled for FY 1989.

The Mobile Satellite program, including the effort to obtain operational frequencies, has served as a focal point to accelerate the introduction of mobile satellite service in the United States. A private consortium has been formed and currently is preparing a filing to the FCC to provide that service. Licensing approval to own and operate such a system could be granted within months, with satellite launch in the early 1990s.

Continuing Radio Science and Support Studies will provide the technical basis for developing national and international policies, regulations, and telecommunications standards to ensure the orderly growth of existing and new communications satellite services for U.S. and NASA science programs. The Agency has provided direct support to the Department of State, National Telecommunications Information Administration, and Federal Communications Commission.

In FY 1988, NASA completed development of a concept for allotment of the geostationary orbit arc as part of U.S preparations for the 1988 Space World Administrative Radio Conference. This arc allotment concept is unique and is essential to the growth of U.S. communication satellite service. In 1988, NASA will complete work on its method of planning the allotment of the geostationary orbit arc, and will provide key support at the second session of the Space World Administrative Radio Conference.

New Initiatives. Communications research will continue to focus on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. The development work, building on the technology for the Advanced Communications Technology Satellite and Mobile Satellite, will enable future satellite communications systems to provide high-capacity information services at lower costs to smaller terminals for both fixed and mobile commercial and scientific applications. In addition, the Agency plans to interconnect commercial satellite systems, and to expand optical link developments that have the potential to increase greatly the rate of information that can be returned from deep-space missions.

Research Base. The Optical Communications program will continue development of technology for optical communications to a mature operational status and will support adoption of optical communications by the space communications community.

The Multidisciplinary Information Systems program continues to support Space Science and Applications flight projects and science programs in three basic ways:

(1) by operating large-scale computational resources for use in data analysis,
(2) by working with discipline programs to establish data centers for managing and distributing data, and
(3) by developing computer networks and exploiting advanced technologies needed to access and process the massive amounts of data acquired from successful space missions.

Earth Science and Applications

Recent research has clearly demonstrated that land, atmospheric, ionospheric, oceanic, and biospheric processes are strongly coupled. To understand the environment, and ultimately to predict global change induced either naturally or by human activity, it is important to study Earth as a single coupled system, as well as to answer questions arising in such separate disciplines as ecology, biology, meteorology, hydrology, geology, oceanography, and atmospheric chemistry. Current programs in Earth science are yielding major steps forward in some of these areas.

Current Programs. In 1988, Critical Design Reviews will be held for the Upper Atmosphere Research Satellite (UARS) observatory and the Central Data Handling Facility, and environmental testing for all flight instruments will be completed. UARS is scheduled for launch in late 1991.

Work continues toward a December 1991 launch of TOPEX/Poseidon, which will map global ocean circulation, and toward development of the NASA Scatterometer, which will permit detailed study of the influence of winds on ocean circulation and thus on climate change.

Operation of currently orbiting spacecraft and the processing, validation, and analysis of data from them will continue. The Earth Radiation Budget Experiment continues to operate in Earth orbit and collect data on the Earth and on solar influences on Earth's environment. Other orbiting spacecraft include the Nimbus and Solar Mesospheric Explorer satellites, which continue to provide valuable information about the atmosphere and oceans. Correlative measurements collected by flights of rockets, balloons, and aircraft provide part of the Earth Science and Applications research base and will continue to support NASA's research in Earth science. Results from ozone instruments aboard National Oceanic and Atmospheric Administration satellites provide support for studies of the chemistry and dynamics of the stratosphere.

New Initiatives. In the mid-1990s, access to a new generation of advanced polar platforms will greatly extend research capabilities by providing an expanded set of co-located instruments. The opportunity to service, modify, and replace instruments on-orbit should make it possible to sustain consistent, uniformly calibrated, long-term measurements.

The Earth Observing System (Eos), to be mounted on the Space Station polar platforms, will, for the first time, allow acquisition of long-term, self-consistent data sets needed for understanding and predicting global change. Extensive discussions with working groups of the Earth System Science Committee indicate that the planned Eos instrument complement will meet the anticipated requirements of Earth system science in the 1990s. As a major future mission, Eos is under consideration as a potential new start candidate for FY 1991. The Earth System Sciences Committee has stated that Eos is the centerpiece of its strategy for NASA.

Concurrent with the release in mid January 1988 of the Announcement of Opportunity for Eos, the European Space Agency and the Science and Technology Agency of Japan released coordinated announcements soliciting payload development for, respectively, the European Polar Platform and the Japanese instruments to be mounted on the NASA Space Station platform. Instruments to fly as attached payloads on the manned Space Station also are being solicited by the Eos Announcement of Opportunity.

Missions such as the proposed Mesosphere and Lower Thermosphere Explorer would complement the observations carried out by the Eos. NASA's program for remote sensing of Earth by aircraft also has proven very useful, and expanded use and enhancement of the aircraft fleet's capabilities are planned.

To further complement the observations carried out by Eos, a series of Explorer-class Earth science missions, called Earth Probes, will be launched at regular intervals. For example, the Tropical Rainfall Measurement Mission and the Geopotential Research Mission are concepts for moderate size missions that may be proposed in future years as Earth Probe missions. They are currently being studied as part of the Atmospheric Dynamics and Radiation and the Geodynamics programs, respectively.

Research Base. The Research and Analysis program supports the basic scientific research in the various disciplines of Earth science, which in turn provides technological and conceptual advances in the application of remote sensing for social and economic benefit.

The foundation for large observatory missions is a direct heritage from development of aircraft and shuttle payloads. Sustained shuttle payload activity will continue. To prepare for reflight of instruments previously flown on the shuttle, refurbishments and modifications followed by requalification will be needed. For example, many early Spacelab solar and atmospheric experiments will refly on the Atmospheric Laboratory for Applications and Science, a series of shuttle missions that will fly approximately annually for about 10 years, beginning in 1990 or 1991.

NASA will continue to define, design, and construct advanced instruments such as the Shuttle Imaging Radar-C—which will be carried on the Shuttle Radar Laboratory, the Shuttle Imaging Spectrometer Experiment, and the Shuttle Light Intensity Detection and Ranging instrument for use in making global measurements of clouds and atmospheric aerosols.

Life Sciences

Individual elements of the life sciences program have been examined closely by external review panels, and long-term strategic plans for life sciences programs are being developed by a special committee of the NASA Advisory Council. Implementation of recommendations made by the panels has been initiated.

Current Programs. The Space Life Sciences program is involved in all major aspects of NASA's activities in space exploration. Major disciplinary areas addressed by the program include operational medicine, space medicine, space biology, global biology (biospherics), exobiology, and controlled ecological life support systems.

The Spacelab Life Sciences series of experiments will continue, with the first mission planned for flight in 1990 to conduct a variety of investigations into acute physiological responses and short-term adaptation to microgravity in humans and animals, and to investigate several significant problems in gravitational biology.

The life sciences program has depended upon international cooperation (in such areas as primate research facilities and unmanned biological satellites) to meet several of its objectives, and has developed active working relationships with Japan, West Germany, France, Canada, the European Space Agency, and the U.S.S.R.

New Initiatives. Space Station offers a unique opportunity to develop U.S. leadership in life sciences research. Its on-orbit life sciences facilities initially will focus on basic biomedical research to understand the various mechanisms active in adaptation to weightlessness and the physiological problems encountered upon return to Earth.

The Extended Duration Crew Operations project will allow development and verification of suitable countermeasures to enable routine long-duration spaceflight. The Space Station Space Biology project will consist of basic research in the areas of gravitational biology, space physiology, controlled ecological life support system, and exobiology.

Space Station facilities also will be used to confirm the feasibility of establishing a fully bioregenerative life-support system for use in the operations of lunar or Mars bases. As part of the Humans in Space element of the Office of Aeronautics and Space Technology's Pathfinder initiative, that office and the Office of Space Science and Applications are working together to develop "exploration technology" that will enable advanced missions such as establishing a lunar base or undertaking manned exploration of Mars. Covered under the Humans in Space program are advanced technologies such as remote medical care, artificial gravity, human behavior and performance, radiation shielding, bioregenerative life support systems, medical care technologies, and requirements for extravehicular activity suits.

Lifesat is being studied as a small, recoverable, and reusable orbiting spacecraft for use as an inexpensive platform to conduct life sciences (and possibly other) experiments. It would complement the continuing Spacelab series and the space biology facilities on Space Station, and could be launched on a variety of expendable launch vehicles to provide from 20 to 40 days of microgravity environment.

In FY 1989, the definition and design phase will continue in the Exobiology program's microwave observing project, which will conduct a high-resolution survey of signals in space that may be evidence of the development of technology by living organisms elsewhere in the galaxy.

Research Base. Life sciences will carry out fundamental research in exobiology and biospherics, using the Space Station, as well as the Earth Observing System, the Great Observatories, and solar system exploration missions. The science management infrastructure will be improved by establishing a dual system of independent Principal Investigator grants and critical-mass teams that will focus on special topics or facilities, both inside and outside NASA's laboratories and in cooperation with the National Institutes of Health.

Microgravity Science and Applications

The mission of the Microgravity Science and Applications Division is to foster development of near-Earth space as a national resource by exploiting the unique attributes of microgravity attainable in orbiting spacecraft. The Microgravity Science and Applications program has three major elements: Fundamental Sciences, Materials Science, and Biotechnology.

Current Programs. The current microgravity flight program uses three capabilities of the space shuttle for accommodation of flight experiments: the orbiter mid-deck, the Materials Science Laboratory, and Spacelab.

The United States Microgravity Laboratory (USML) series will provide a focus for microgravity materials processing technology, science, and research requiring the low-gravity environment of Earth orbit. Emphasizing government, commercial, and academic participation within the United States, up to half of each mission payload may involve commercial participation. In addition, the plan is flexible enough to make use of Spacehab and a Commercially Developed Space Facility, should they become available. The USML series will be complementary to the International Microgravity Laboratory (IML) series. First launch for the IML series is expected in 1991, and for the USML series in 1992.

New Initiatives. The future centerpiece for microgravity science and applications is the Space Station, which will serve as a national microgravity laboratory. For the first time, scientists will be able to conduct experiments in an interactive mode and feed the results of one set of experiments into the next set in a timely manner. Also for the first time, adequate power will be available to support materials science experiments involving high temperature and the growth of large diameter crystals. Six new facilities have been identified for Space Station Microgravity and Materials Processing experiments:

(1) Modular Multizone Furnace Facility,
(2) Modular Containerless Processing Facility,
(3) Advanced Protein Crystal Growth Facility,
(4) Biotechnology Facility,

(5) Fluid Physics/Dynamics Facility, and
(6) Modular Combustion Facility.

NASA will fly elements of these facilities on the space shuttle in advance of the Space Station, both to test and perfect the design of the facilities, and to provide new research results. While Spacelab continues to present opportunities to develop and refine Space Station capabilities, the Space Station itself will dominate the future of microgravity science.

Research Base. A number of recent NASA-sponsored program reviews have argued vigorously for an expanded ground-based program, a sounding rocket program, and the development of hardware that can be readily adapted to various platforms, including Spacelab, commercially developed space facilities, the Space Station, and possible free-flyers. In addition, OSSA has been charged with supporting user hardware development and with balancing flight manifesting priorities for both academic and industrial researchers.

During the delay in the flight program resulting from the Challenger accident, the microgravity program has been restructured. Much of the old hardware that had been adopted from the pre-shuttle sounding rocket program has been retired and new hardware development has been initiated. The flight program has been thoroughly reviewed by a committee headed by Nobel-Laureate Dr. Robert Schrieffer, and the highest quality experiments have been prioritized. A 10-year strategic plan has been formulated to guide evolutionary development of the microgravity program into the Space Station era.

Solar System Exploration

The Solar System Exploration Division's program is structured around the recommendations of the Solar System Exploration Committee (SSEC) of the NASA Advisory Council, which stress continuity, commonality, cost-effectiveness, and the use of existing technology. The core program recommended by the SSEC consists of:

(1) a continuing series of modest Planetary Observer missions to explore the inner planets and near-Earth asteroids using reconfigured off-the-shelf Earth-orbital spacecraft;
(2) a continuing series of Mariner Mark II spacecraft missions to explore the outer planets, comets, and asteroids, using a common spacecraft with evolving technological capabilities;
(3) development of a multimission spaceflight operations and data analysis capability; and
(4) strong foundations of ground-based research, analysis, and related activities funded at about 25% of the total program.

The SSEC separately, in 1986, recommended an augmented program of more challenging missions to return samples from a comet and from the surface of Mars, and to start searching for other planetary systems.

Current Programs. By the end of this decade, all the major planets and their satellites will have been studied at the reconnaissance (i.e., flyby) stage. The exploration phase has either been completed or has been established for every accessible major body of the solar system. Five spacecraft are still in operation—three Pioneers and two Voyagers. The Pioneer Venus Orbiter recently completed its 3,000th orbit of Venus. Voyager 2 is heading for an encounter with Neptune in August 1989, and then will travel on to study interstellar space, along with Pioneer 10, Pioneer 11, and Voyager 1.

In spite of the Solar System Exploration program's setback from the Challenger accident, no planetary missions have been cancelled, and three missions to explore the solar system are proceeding toward launch. The Magellan mission to map the cloud cover of Venus globally, and the Galileo mission to make detailed studies of Jupiter and its moons, are scheduled for launch in 1989.

The Mars Observer mission, the first of the new Planetary Observer series of spacecraft, will investigate the geologic and climatic evolution of Mars and is planned for launch in 1992.

New Initiatives. The Comet Rendezvous Asteroid Flyby (CRAF) is the highest priority solar system exploration mission. The first of the new Mariner Mark II missions, it will rendezvous with comet Kopff after exploring the asteroids. The second Mariner Mark II mission, Cassini, is potentially a cooperative mission with the European Space Agency. Cassini will conduct detailed investigation of Saturn and its rings and moons to follow up on the exploratory results from the Pioneer and Voyager programs.

The second Planetary Observer, the Lunar Observer, also is high priority and will be submitted for administrative approval following the CRAF mission.

Research Base. The strategy promulgated by the Solar System Exploration Committee and adopted by the Solar System Exploration Division calls for balanced emphasis on the terrestrial (Earth-like) inner planets, the giant (Jupiter-like) outer planets, and the small bodies (comets and asteroids) in the solar system. This theme is reflected throughout the research-base activities of the Division. Active research programs are in process in planetary astronomy, atmospheres, materials and geochemistry, and geology and geophysics. A vigorous research and analysis program, based chiefly in universities, is developing the next generation of planetary scientists and the instrumentation base needed for future missions. Research and analysis funds also are providing for effective analysis and exploitation of data from prior planetary exploration missions and for generation of corroborative ground-based data to reinforce results from space observations.

Spacecraft missions progress in an evolutionary series in which relatively simple reconnaissance missions, which provide a fundamental characterization of an object, are followed by more complex missions that provide increasingly detailed information. The highly visible spacecraft missions are supported by an essential foundation of diverse ground-based activities: mission operations and data analysis, scientific research and analysis, and advanced programs studies.

The Solar System Exploration program will take advantage of the Hubble Space Telescope in the near-term, and of the Space Station over the longer term. To promote effective use of the new capabilities the Space Station will provide in the mid 1990s, the program encompasses study of attached payloads that will yield new information about such major questions as what the origin of the solar system was and whether planets exist around other stars. The Cosmic Dust Collection Facility, which will collect small cosmic particles (possibly from comets), will be among the first Space Station attached payloads. The Astrometric Telescope Facility, which would conduct a decade-long search for large planets around other stars, is under active study for possible inclusion in the initial phase of the Space Station program.

Current and future plans place high priority on reduction of launch and mission risk; NASA has begun a policy of acquiring spare subsystems to enable rapid changeout during development testing to protect launch windows. In addition, future missions are being designed to provide the maximum possible backup for missions now under development. One example of this new approach is the purchase of spare components for the Mars Observer mission, not only to ensure timely launch of that mission but also to initiate subsequent Planetary Observer missions.

Advanced studies will continue to examine such missions as the Mars Rover Sample Return (see page X-9), a precursor mission to any manned Mars activity. In addition, major increases in research and analysis funding, especially to equip laboratories, are anticipated.

Space Physics

The space physics research community has approved flight programs for the next 5 to 10 years that will use a coordinated combination of space-flight capabilities to make in situ and remote measurements of a large number of space plasma and related parameters. Major flight missions will address broad, general questions about plasma systems of interest, while moderate missions will focus on specific processes within given systems.

Current Programs. At present, the following five satellites are returning measurements of the sun, the heliosphere, and Earth's magnetosphere and ionosphere:

(1) Solar Maximum Mission, which continues to operate successfully since its 1984 on-orbit repair, measuring the characteristics of solar energetic and steady state phenomena, and is expected to continue operating until its expected orbital decay in 1990, just before the peak of the next sunspot cycle;

(2) Interplanetary Monitoring Platform, IMP-8, which is the only spacecraft currently measuring the solar wind in the immediate vicinity of Earth;

(3) International Cometary Explorer, which is measuring the solar wind, energetic particles, and cosmic rays at Earth's orbital distance from the sun, but at a location far from Earth;

(4) Charge Composition Explorer, which continues to provide measurements of the equatorial radiation belts and ring current regions within Earth's magnetosphere; and
(5) Dynamics Explorer, which is providing both remote imaging of the global aurora and in situ polar magnetospheric measurements.

All of the geospace regions and phenomena being investigated by these five satellites respond dynamically to variations of the solar wind seen by IMP-8.

Information from the Pioneer and Voyager solar system exploration spacecraft about the solar wind and cosmic rays in the outer heliosphere is compared with data collected by the Solar Maximum Mission, International Cometary Explorer, and IMP-8 to build an integrated picture of the entire heliosphere in the sun's equatorial plane.

The next major flight program, the International Solar Terrestrial Physics (ISTP) program, is composed of two closely related parts: the Collaborative Solar Terrestrial Research (COSTR) program, and the Global Geospace Science (GGS) program. COSTR, initially funded in FY 1987, includes the Solar and Heliospheric Observatory (SOHO) and Cluster missions, both of which are jointly sponsored with the European Space Agency, and the Geotail mission, jointly sponsored with Japan's Institute of Space and Astronautical Science. SOHO will emphasize understanding of the sun's interior and the origin of the solar corona, while Cluster (a set of four identical spacecraft) will fly in close formation to measure micro-scale plasma processes in Earth's magnetosphere. Geotail will measure variations in Earth's extended magnetosphere. Approved in the FY 1988 budget for inclusion in the second half of the ISTP, GGS Wind and Polar spacecraft will, in combination with the Geotail mission, investigate geospace as a total integrated system. SOHO and Cluster will be launched about 1995. Geotail and Wind and Polar, which are to be launched in 1992 and 1993, will operate concurrently.

The moderate-sized Combined Release and Radiation Effects Satellite, scheduled for a 1990 launch, will provide mapping of the radiation belts during a solar maximum and will analyze the chemistry of the ionosphere and magnetosphere through numerous chemical releases.

The launch of Ulysses, which will study the heliosphere out of the ecliptic plane, is planned for 1990. Ulysses is a joint NASA-European Space Agency program. The spacecraft will carry a package of experiments to investigate the sun at high solar latitudes with the objective of understanding the sun's corona, the origin and acceleration of solar wind, and the composition and acceleration of energetic particles.

In 1991, the Tethered Satellite System will investigate the electrodynamic interaction between ionospheric plasma and a diagnostic satellite at the outer end of a conducting wire 20-km long deployed from the shuttle.

New Initiatives. The highest priority major mission for space physics is the Solar Probe, which will be humanity's first direct exploratory venture to the vicinity of the Sun. Currently in an early study phase, this mission offers a unique opportunity for leadership in this area. For that reason and because of its significant scientific benefit, the Solar Probe has been strongly endorsed by the scientific community.

The highest priority moderate mission for space physics is the Orbiting Solar Laboratory, a scientific platform for investigating the sun's fine-scale magnetic structures. This program is unusually mature in terms of hardware definition, and the provision of funding for its construction and implementation is critical.

Definition studies are under way for potential Space Station payloads, including the Plasma Interaction Monitoring System, the Solar-Terrestrial Observatory, Astromag, and the Pinhole Occulter Facility.

Research Base. As science moves beyond simple reconnaissance of various space plasma phenomena, support both of in-depth data analysis and of sophisticated theory building becomes increasingly important. Thirteen investigator groups will be supported at a significant level by the Solar-Terrestrial Theory program in FY 1989, and the Research and Analysis program funds nearly 300 investigator groups for data analysis modeling and theory tasks. These programs continue to provide the bedrock of support for many of the space science researchers in the United States.

Space Physics is a major user of NASA's Suborbital program. Cosmic ray measurements use about 30 of the 45 balloon flights conducted each year. Two-thirds of the 40 yearly sounding rocket flights are devoted to satisfying the need for solar fine-pointed instruments, in situ measurements in the middle atmosphere and auroral regions, and active space-plasma experiments.

The one Spartan mission still to be launched by the shuttle is designed to provide fundamentally new measurements of the temperatures and velocities of the plasma in the sun's inner corona, where the solar wind is formed. Further detailed measurements of the sun are planned—with Spartan-201's white-light coronagraph and ultraviolet coronal spectrometer in 1990-1991, and with the NASA-Japanese Solar-A, which will measure soft and hard solar X-rays.

It is anticipated that other programs, such as Space Station-attached payloads and Explorer missions, with support from rocket and balloon programs and theory and analysis programs, also will fulfill many space physics objectives.

Space Flight Summary

The Space Flight program supports the President's National Space Policy of February 1988 and NASA's commensurate goals for space transportation: a permanent presence in space and human expansion into the solar system. NASA is required to maintain a strong, responsive, reliable, and cost effective space transportation system, and this calls for the Space Flight program, as its main goal, to return the Space Transportation System (STS) to full flight status as soon as safely possible. Consequently, activities in the immediate future are focused on attaining a safe, sustainable shuttle flight rate, completing the development of the STS, making each mission safe and successful, reducing operational costs, and exploiting the STS' inherent capabilities.

Planned programs emphasize development of follow-on systems for space transportation and other large space systems, including support of the Space Station program, orbital platforms and facilities, and the test, transportation, and servicing systems required to support them.

The objectives associated with bringing the Space Transportation System to full operation will be achieved through completion of the current base-line system and demonstration that it is ready and available for safe, on-time use in its intended operational environment.

All Earth-to-orbit and return-to-Earth transportation needs will be met by a mixed fleet that consists of the space shuttle and expendable launch vehicles, supported by the Shuttle Production and Capability Development program and the procurement of ELV services from private sector operators. As a further part of the program, activities are focused on:

(1) developing the Inertial Upper Stage for launching major payloads from the shuttle,
(2) achieving full flight status for Spacelab,
(3) developing techniques and systems to satisfy more effectively the needs of future Spacelab users, and
(4) providing operational support services.

A proposed new initiative is to identify and demonstrate new or enhanced processes and technologies that can be applied to ground, flight, and on-orbit operations in order to reduce the operations costs, while ensuring safe and reliable operation, of space transportation systems. This initiative supports both the near-term objectives of space transportation operations and the long-term objective to establish a space infrastructure for permanent presence of humans in space and their expansion into the solar system.

Advanced program development will include planning and evolutionary development of follow-on programs to build upon the STS, definition of a heavy-lift cargo vehicle based on available technology, and development of a next-generation manned space launch system. These programs will provide an advanced space transportation infrastructure to support permanent presence of humans in space, and will increase space flight capabilities through development of advanced transportation and on-orbit services. Development of advanced vehicles, automated and robotic systems, and Earth return capabilities will enable human and robot exploration beyond Earth orbit into the solar system.

For the far term, the program will develop technology and techniques to construct, deploy, and assemble systems in space, and to test and service the systems on orbit.

The design and development of higher-performance and more versatile space transfer vehicles also constitute a long-range objective. Development of an automated satellite servicer system also will be supported.

NASA's in-house institutional base and system of industrial and other contractors required to achieve the goals of the Space Flight program will be maintained and strengthened.

Space Station Summary

The Space Station is planned as a permanently manned, multipurpose facility with a long operational lifetime. The Station will achieve operational status in the mid-1990s and will evolve on-orbit to accommodate changing user needs and to meet long-term goals of the United States. At the invitation of the President, Japan, Canada, and the European Space Agency have become partners with the United States in the development and operation of the Space Station.

The Space Station infrastructure, with a baseline created after three years of analyses by NASA and industry, includes a manned base in low-inclination orbit and at a nominal altitude of approximately 220 to 250 nautical miles. The manned base will feature a 360-foot transverse boom with four pressurized modules attached at its center. Photovoltaic arrays located at each end of the boom will generate a total of 75 kW of continuous power. Attachment points for mounting and operating externally mounted payloads will be provided along the boom.

The four pressurized modules of the Space Station include:

(1) a U.S.-provided laboratory module for microgravity materials and life sciences research,
(2) a U.S.-provided habitation module, and
(3) two laboratory modules, one from Japan and one from the European Space Agency.

Linking the pressurized modules will be "resource nodes"—interconnects between modules that provide extra space for equipment and 8,400 cubic feet of pressurized volume. The Space Station will have a total of approximately 31,000 cubic feet of pressurized volume, and will provide living quarters for up to eight crew members.

Systems will be available to provide the following functions: electrical power; thermal control; data management; communications and tracking; guidance, navigation, and control; extravehicular activity; environmental control and life support; fluid management; and human habitation and work productivity.

A Flight Telerobotic Servicer, provided by the United States, and a Mobile Servicing System, partially provided by Canada, will assist with Space Station assembly, with servicing of payloads, and with Station maintenance.

Also included in the Space Station program plans are two free-flying, unmanned platforms in polar orbit. One of these polar platforms will be developed by the United States, and the other by the European Space Agency.

The Space Station configuration is based on the use of the shuttle for transportation to and from low Earth orbit. The shuttle will:

(1) launch Space Station elements,
(2) provide a stable base from which astronauts can assemble the Station,
(3) resupply the Station through periodic logistics missions, and
(4) provide the means for crew-member travel to and from the Space Station.

Another space vehicle, the Orbital Maneuvering Vehicle, will be used for movement between the Space Station and other objects in space. Expendable launch vehicles are under study for resupply of consumables and for launching polar orbiting platforms. Also under study is enhancement of Space Transportation System capabilities by, for example, development of Advanced Solid Rocket Motors that would increase the mass the shuttle could place in orbit.

The Space Station program is using a 3-tiered management structure:

(1) Level I, the Office of Space Station located at NASA Headquarters in Washington, D.C., is responsible for policy direction, budget formulation, external liaison, and Space Station evolution;
(2) Level II, the Space Station Program Office in Reston, Virginia, is responsible for development of the Space Station and the operational capability of flight and ground systems; and
(3) Level III, consisting of the field center Project Offices, is responsible for engineering support, user operations integration, and the design, development, testing, and evaluation of hardware and software systems.

The U.S. Space Station elements will be developed by NASA field centers with overall program direction by the Space Station Program Office. Development will be supported by competitively selected contractor teams. The current Space Station program schedule is based on the goal of attaining a First Element Launch in the first quarter of 1995, with a permanently manned capability achieved in the fourth quarter of 1996.

A fundamental requirement of the Space Station program is the capability to evolve on-orbit, both in design and function, in order to satisfy evolving user needs in an environment of changing technologies and the changing long-term goals of the United States. The base-line Space Station will be designed with a capability to evolve in a cost-effective manner while causing a minimum of interruption to continuing operations.

In its reference evolutionary design, the Space Station would be expanded to the full "dual-keel" configuration originally conceived. That configuration includes the addition of a solar dynamic power system, upper and lower booms providing additional attached payload accommodations, a servicing bay, and a co-orbiting platform. In addition, the Mobile Servicing System would be completed.

Additions and enhancements might include accommodations for a space-based (rather than a ground-based) Orbital Maneuvering Vehicle and for a Space Transfer Vehicle able to transport payloads from the space Station's orbit to geosynchronous orbit, or to propel payloads to Earth escape velocities. The Station also may be used to assemble and launch larger and more complex spacecraft than will ever be possible from Earth.

The Space Station program serves as the focus and catalyst to bring to bear the diverse capabilities of NASA in meeting the Presidential directive to develop a permanent manned presence in space. With the Space Station, the U.S. civil space program will continue this country's leadership role in space.

Space Operations Summary

The Office of Space Operations supports the Nation's aeronautics and space missions by planning, developing, operating, and maintaining space and ground networks of tracking and data systems to support missions of unmanned and manned orbital spacecraft, deep space platforms, radio astronomy, sounding rockets, balloons, and research aircraft. The program consists of four basic elements: a space network, a ground network, communications and data systems, and advanced systems development.

Space Network

By the end of 1989, tracking and data acquisition facilities for spacecraft in near Earth orbit will have evolved from a worldwide network of ground tracking stations into a network of two Tracking and Data Relay Satellite System (TDRSS) satellites in geostationary orbit, an on-orbit spare, and a single ground terminal at White Sands, New Mexico. A network control center at Goddard Space Flight Center (GSFC) will control the system and manage network resources. The system will increase coverage of near Earth orbits from 15 percent to 85 percent. In addition, a second ground station, under construction at White Sands, New Mexico, will provide a backup to the present White Sands ground terminal to avoid a single-point failure in the space network system.

Ground Network

NASA will close the Hawaii, Ascension, Dakar, Guam, and Yarragadee ground stations while phasing TDRSS into operation, leaving only six locations fully operational. Three of these are under Jet Propulsion Laboratory management and three are operated by GSFC. The former will support deep-space missions and missions in geostationary and high Earth orbits; it will also support radar and radio science experiments. The stations managed by GSFC will provide primarily launch and early orbit support. Because NASA's new low-cost payloads have tracking and support requirements that are far more modest than those of previous missions, a study is now under way to identify potential low-cost ground station options.

Communications and Data Systems

To handle the substantial increase in data transfer and processing that TDRSS services will permit, greater use will be made of electronic data transfer and other automated features to reduce the need for human intervention and tape handling. Replacement of aged and obsolete computing systems for mission support will continue to increase reliability and reduce maintenance costs; more use will be made of microprocessors; and capacity will be greatly expanded to meet the needs of new missions starting in the 1990s, including both free-flyers and Space Station associated platforms.

Advanced Systems

Though relatively small, the Advanced Systems program is a vital part of the total program, providing a base for future planning and for development of cost-effective support capabilities. Its objectives are to increase abilities for communicating with spacecraft, improve navigation capabilities, increase the operational capabilities of ground stations and data handling and processing networks, and develop technology to facilitate use of the Space Network.

Future Space Operations

The TDRSS is expected to meet needs through most of the 1990s, but increases in data rates and volumes for missions planned after the 1990s will require new relay capabilities. More links and greater capacity will be needed. Studies already have examined some support needs and the new technologies that may satisfy them. Other studies are in process on technological problems related to a follow-on system for the TDRSS.

Rapid advances being made in telecommunications technology will have a profound effect on tracking and data acquisition support of deep-space missions in the coming decades by making possible, for example, a deep-space relay station. The Space Operations program will continue to look ahead and make plans to meet such challenges.

Space Research and Technology Summary

The Space Research and Technology plan is developed around three classes of systems: Space Transportation Systems, Spacecraft Systems, and Large Space Systems/ Space Infrastructure.

Space Transportation Systems. Low-cost access to space is the key to realization of the Nation's space objectives. A mixed fleet of transportation vehicles will be required to move people and cargo. It must be able to:

(1) provide rapid and flexible access to and from the Space Station;
(2) place heavy payloads in low Earth orbit;
(3) deploy and service satellites in both low Earth and geosynchronous orbits;
(4) serve polar platforms;
(5) provide rapid, routine, manned access to the Nation's space facilities; and
(6) provide a highly reliable space transport and return capability for piloted and robotic solar system exploration missions.

In order to reduce significantly the cost of access to space, the mixed fleet of transportation systems must be robust, operationally simple, and flexible. The vehicles in the fleet must provide the building blocks for a future lunar and planetary transportation infrastructure. Major advances are required in, for example:

(1) more efficient vehicle structures;
(2) more efficient propulsion systems and airbraking techniques;
(3) lighter weight and more durable thermal protection systems and materials;
(4) lightweight and long-life cryogenic tankage;
(5) autonomous systems to reduce the cost of both ground- and space-based operations;
(6) improved ability to predict aerodynamic and aerothermodynamic characteristics, and thereby to increase vehicle margins; and
(7) adaptive guidance, navigation, and control systems to provide reduced sensitivity to launch changes.

Spacecraft Systems. The potential users of spacecraft technology include space science and applications missions, such as planetary exploration, astrophysics, Earth science, space physics, and communications missions, as well as a spectrum of national security and commercial missions. In the next 20 years, spacecraft will, in addition to other activities:

(1) make initial observations of comets and asteroids;
(2) provide a continuous multispectral inventory of Earth processes;
(3) return samples from the surface of Mars, comets, and asteroids;
(4) record the birth and processes of stars and galaxies; and
(5) maintain a national preeminence in space communications.

The technology challenge is to enable the development and operation of these diverse spacecraft in an affordable manner.

Large Space Systems/Space Infrastructure. With its deployment and operation in the mid-1990s, the permanently manned Space Station will become the cornerstone for an expanding space infrastructure. The principal elements of the infrastructure may include:
(1) the evolutionary Space Station in low Earth orbit, complemented by co-orbiting man-tended platforms;
(2) man-tended platforms in polar low Earth orbits and geosynchronous Earth orbits;
(3) advanced Earth-to-orbit launch vehicles; and
(4) space-based, reusable, orbit-transfer vehicles.

Collectively, this infrastructure can be thought of in terms of "facilities" linked by communication and transportation systems.

Space operations supported by this infrastructure will include:

(1) scientific research;
(2) technology development;
(3) engineering demonstrations;
(4) assembly of large space structures;
(5) spacecraft inspection, servicing, and repair;
(6) transportation system operations, including cargo management, payload integration, payload deployment, and space-based launching; and
(7) commercial ventures, such as materials processing.

Ultimately this infrastructure will contain systems essential to expanded human operations in the solar system, including a lunar base and manned Mars missions.

Current Program Plan—Research and Technology Base

The Space Research and Technology base is structured around the following disciplinary elements:

(1) aerothermodynamics,
(2) space energy conversion,
(3) propulsion,
(4) materials and structures,
(5) space data and communications,
(6) information sciences,
(7) controls and guidance,
(8) human factors,
(9) space flight,
(10) systems analysis, and
(11) university space research.

Aerothermodynamics. The Aerothermodynamics program develops and validates a predictive capability for use in optimizing the performance of advanced vehicles entering and maneuvering in the atmospheres of Earth and the other solar system planets. The principal requirements are for aeroassisted orbital transfer vehicles (OTVs designed to employ aerobraking; i.e., employment of planetary atmospheres to achieve deceleration), advanced space transportation systems such as rocket and air-breathing advanced shuttle vehicles, and reusable heavy-lift launch vehicles.

Space Energy Conversion. For large manned space systems, small Earth-orbiting spacecraft, planetary exploration spacecraft, and other ambitious future space missions, the Space Energy Conversion program explores concepts and components to improve the performance, extend the lifetime, increase the cost effectiveness, and reduce the size and weight of power and life support systems.

This program provides the fundamental understanding and the technology basis for development of future space power systems ranging from those for spacecraft requiring only low power levels to those for large space systems requiring high-capacity, non-nuclear power.

Propulsion. The Propulsion program establishes a base of design concepts and analytical tools that will allow the design and development of advanced propulsion systems with the known performance, life, and operational characteristics essential for next-generation space transportation systems. This base will reduce the risk of costly, unanticipated design deficiencies and schedule delays during the development and certification of flight hardware.

Materials and Structures. The Materials and Structures program provides technology that will allow development of spacecraft, large-area space structures, and advanced space transportation systems with significant improvements in performance, efficiency, durability, and economy.

Space Data and Communications. The Space Data and Communications program develops advances in the ability to control, process, store, manipulate, and communicate space-derived mission data and enables new communications concepts.

Information Sciences. The Information Sciences program seeks advanced concepts, techniques, and system algorithms, and devises systems architectures, hardware devices and components, and software that will enable space information systems to be productive. Areas the program addresses include computer sciences and sensors.

Controls and Guidance. The Controls and Guidance program includes developing the means for:

(1) generating the practical design methods and techniques required to enable precise pointing and stabilization for future Agency spacecraft and payloads,
(2) precisely maintaining the structural shape of highly flexible large space systems, and
(3) guiding, navigating, and controlling advanced space transportation vehicles.

Human Factors. The Human Factors program provides the technology base for productivity, efficiency, and safety in the increasingly complex piloted space operations associated with the Space Station. The research is focused on crew-station design and productivity enhancements for extravehicular activity.

Space Flight. Using current facilities and, when they become available, future space facilities such as in-space research laboratories, the Space Flight program provides research-quality flight data supporting ground-based research and technology efforts related to development and operation of future space systems.

Systems Analysis. The Systems Analysis program includes the following activities:

(1) conducting systems analyses to identify technology requirements for spacecraft systems, space transportation systems, and large space systems for the national space program;
(2) integrating these requirements into a comprehensive technology plan; and
(3) providing data to establish the ability to develop these technologies in a timely manner.

University Space Research. The University Space Research program enhances and broadens the capabilities of the Nation's engineering community to participate more effectively in the U.S. civil space program.

Current Program Plan—Civil Space Technology Initiative (CSTI)

The program elements of CSTI are directed at technologies to enable efficient, reliable access to Earth orbit, and to enable operations and science missions therein. They are:

(1) automation and robotics,
(2) propulsion,
(3) vehicle,
(4) information technology,
(5) large structures and control, and
(6) power.

Automation and Robotics. The Automation and Robotics program exploits the potential of artificial intelligence and telerobotics to increase the capability, flexibility, and safety of space and ground operations while decreasing associated costs.

Propulsion. The Propulsion program conducts full-scale component and system tests to develop and demonstrate propulsion technology for main engines and boosters. This technology will enable the development of the next generation of Earth-to-orbit vehicles.

Vehicle. The Vehicle program investigates the critical technologies applicable to the design of an aeroassisted orbital transfer vehicle.

Information Technology. The Information Technology program develops materials, devices, and components that will enable productive detection, imaging, and data-storage systems for space and planetary missions in the next century. Development of systems to handle high data rates and volumes is directed toward maintaining U.S. preeminence in the collection and productive use of space-derived data.

Large Structures and Control. The Large Structures and Control program provides experimental validation of analytical methods for predicting the dynamics of coupled structures and their response to their structural controls. Of particular interest are complex, multibody space structures with flexible components, interfaces, and dissipative mechanisms.

Power. The Power program develops the technology needed to meet the requirements for high-capacity power systems for the evolutionary Space Station, lunar and planetary bases, and high-power-demand electric propulsion systems. Power levels of interest are greater than tens of kilowatts to multi-megawatts.

Current Program Plan—Pathfinder Program

Pathfinder is an essential prerequisite to any decision by the Nation's leadership to go forward with major civil space missions in the future. Pathfinder will enable or enhance a set of new mission scenarios: future robotic exploration of the solar system, an outpost on the moon, a piloted mission to Mars, and Earth orbit operations.

Project Pathfinder addresses technologies organized around four major program areas:

(1) surface exploration,
(2) in-space operations,
(3) humans-in-space, and
(4) space transfer.

Through the advances obtained in these program areas — and a strong partnership between NASA, industry, and universities — Pathfinder will lead U.S. space technology forward in the coming decade, much as the Apollo program did during the 1960s.

Current Program Plan—University Space Research Augmentation

In addition to increasing its emphasis on focused technology programs, NASA intends to bolster the Nation's civil space research and technology base by broadening and strengthening its partnership with academia. CSTI and Pathfinder will provide vital stimuli to augmentation of the space technology engineering-talent pool, both within the government and in the entire aerospace community. By providing a set of challenging future objectives for the civil space program, NASA will attract the interest and enthusiasm of the Nation's brightest and most energetic youth, and will encourage them to pursue careers in engineering. Nurture of this talent will ensure the Nation's future in space.

An integral part of NASA's strategy is to capitalize on this interest and enthusiasm by providing added support to the building of new partnerships with the university engineering community. With this in mind, NASA established in FY 1988 its university space engineering research center program with the initiation of eight research centers. This program is designed to advance the traditional space engineering disciplines and bring together the knowledge, methodologies, and engineering tools needed for future advanced space systems.

Future Initiatives

Within the restrictions imposed by the currently constrained budget environment, the Office of Aeronautics and Space Technology (OAST) is planning to undertake the future initiatives described below.

In-Space Engineering Research and Technology Experiments. A focused initiative will be sought for advanced technology projects that will achieve phase B and C/D maturity within the next five to ten years. It has been designed to establish a leadership role for OAST in the area of in-space engineering research and technology experiments. It encompasses all space sectors and will help to make space accessible to industry and the universities for technology experimentation and validation.

Global Change Technology Initiative. The objective of this new focused initiative is to develop and validate key technologies for advanced space-based observatories that will allow scientific study and understanding of Earth as a complete system. A broad-based program will be directed at developing a new generation of technologies that promote cost effectiveness and ultra-high reliability in space systems and their operations. Both extensive and intensive Earth orbit operations will be enabled for:

(1) space observations,
(2) support for in situ observations,
(3) platform services, and
(4) computational capabilities.

Technology for Outyear (1993-1994) Initiatives

It is anticipated that the Nation will decide in the early 1990s to undertake a bold new initiative, such as a lunar base or a mission to Mars. That decision will generate explicit requirements for technology development programs to support the selected mission or missions. Concurrent with its system definition studies, the Space Research and Technology program will conduct technology development programs jointly with other NASA program offices. Those programs will be designed to validate the readiness of technology to satisfy the specific requirements defined in mission studies. Programs such as test-bed demonstrations eventually will be transferred to user offices.

Space Research and Technology Beyond the Year 2000

Much of the current and planned Space Research and Technology program is already targeted at creating capabilities that will be applied to systems and missions that will evolve after the Space Station. Pathfinder, for example, emphasizes research needed for a lunar outpost mission and a sprint mission to Mars. Projected dates for these missions generally are in the first decade after the turn of the century. While it is premature to plan specific technology programs to enhance the performance of these missions or to provide follow-on missions, it is important to conduct studies anticipating the nature and potential impact of these missions.

Aeronautical and Transatmospheric Research and Technology Summary

The Aeronautics Research and Technology program consists of two major program areas:

(1) Research and Technology Base programs, which are discipline-oriented and are designed to establish and maintain a solid foundation of aeronautical technology embracing all of the relevant disciplines and areas of systems research; and
(2) Systems Technology programs, which exist to carry new and innovative technology from the laboratory environment into experimental- and verification-systems testing, and which provide for the analysis, design, fabrication, and testing of multidisciplinary aeronautical systems in order to reduce greatly the technical risks associated with their application.

Program Strategy

NASA has developed the following three-pronged strategy for its aeronautical research and technology development program:

(1) identify and emphasize emerging technologies having the potential for order-of-magnitude advances in capacity or performance that will enhance the national security and economic competitiveness of the United States,
(2) target and strengthen technology development and validation efforts in selected high-payoff areas, and
(3) ensure the continued health and productivity of critical national aeronautical research facilities.

A phased implementation of these three strategy elements is reflected in the current program plan and the planned initiatives.

Vehicle-Class Objectives

To help focus and integrate this research and development, and to respond to national aeronautical research and development goals, the Agency has established five "vehicle-class" objectives. These objectives target development of the fundamental knowledge base in critical technologies to provide effective options for U.S. industry's use in designing and building superior aircraft for global markets and national security applications.

Hypersonic Cruise/Transatmospheric Vehicles. The convergence of aeronautics and space technologies provides the potential for an entirely new class of vehicles for the next century, ranging from hypersonic aircraft to a single-stage-to-orbit space transportation system. These vehicles would have the ability to take off from and land on conventional runways, sustain hypersonic cruise flight (greater than six times the speed of sound) in the atmosphere, or accelerate into space. The transatmospheric capability made possible by this technology will greatly enhance the operational potential of both civil and military aircraft.

Long-range Supersonic Cruise Aircraft. Vehicles with long-range supersonic cruise capability will ensure a U.S. presence in this vital area. Passenger aircraft that feature 350-passenger capacity, trans-Pacific range, and cruise speeds of two to four times the speed of sound will link the farthest reaches of the Pacific Rim area in four to five hours. Military applications will provide vital mission enhancements in basing, long-distance responsiveness, and survivability.

Transcentury Subsonic Transport. Advances in technology for subsonic aircraft during the past 15 years have been predominantly evolutionary. To ensure that the United States retains its leadership role in the world marketplace, it is essential that NASA, in close coordination with manufacturers, airlines, and the FAA, accelerate the development of subsonic technology and ensure that its introduction is timely.

NASA's efforts in the subsonic transport area are focused on the technology required both to develop an entirely new generation of fuel-efficient, affordable aircraft and to improve the safety and capacity of the National Airspace System.

Advanced Rotorcraft. Advanced rotorcraft that combine the vertical takeoff and landing capability of conventional helicopters with the high forward speed capability of fixed-wing aircraft will make a major contribution in both the civil and the military sectors. Civil versions (the tiltrotor, for example) will operate in the vertical- or short-takeoff mode with the economy, productivity, and maintainability of fixed-wing passenger aircraft. Advanced craft of this kind can provide improved intercity and interregion transportation, reducing congestion in U.S. airports without requiring major investments in new runways.

High-Performance Aircraft. NASA's research program for high-performance aircraft is structured to develop and mature technologies that have important, long-term, military and civil applications.

Disciplinary Research Objectives

In addition to the vehicle-class activities described above, the Agency's aeronautical research and technology development program consists of fundamental, disciplinary research that either has broad application to the safety, efficiency, and performance of a wide range of aircraft types or has the potential to enable entirely new aircraft systems.

Facilities Objective

Many of NASA's aeronautical research facilities—including wind tunnels, simulators, and advanced computing facilities—are unique, national assets. In addition to supporting the work of NASA and its contract research, these facilities support research and development work being undertaken by the aerospace industry and other government agencies, including the Federal Aviation Administration, Department of Defense, and Department of Energy.

To continue meeting its obligations in this area, the Agency has the objective of enhancing the capability of its aeronautical facilities by improving the productivity and integrity of major facilities, and by extending that capability in critical areas.

Research and Technology Base

The R&T Base is composed of the following nine areas:

(1) Fluid and Thermal Physics,
(2) Applied Aerodynamics,
(3) Propulsion and Power,

(4) Materials and Structures,
(5) Information Sciences,
(6) Controls and Guidance,
(7) Human Factors,
(8) Flight Systems, and
(9) Systems Analysis.

Fluid and Thermal Physics. The Fluid and Thermal Physics program advances understanding of fundamental fluid mechanics phenomena and develops efficient tools for analyzing aerodynamics.

Applied Aerodynamics. The Applied Aerodynamics program generates advanced technology for improving the performance and flight dynamics of future aircraft and missiles through analytical and experimental programs.

Propulsion and Power. The Propulsion and Power program provides the understanding of the governing physical phenomena at the disciplinary, component, and subsystem levels that will support and stimulate future improvements in the performance capability, efficiency, reliability, and durability of propulsion systems.

Materials and Structures. The Materials and Structures program includes the following activities:

(1) investigating and characterizing advanced metallic, ceramic, polymer, and composite materials;
(2) developing novel structural concepts and design methods to exploit the use of advanced materials in aircraft;
(3) advancing analytical and experimental methods for determining the behavior of aircraft structures in flight and ground environments; and
(4) generating a research data base to reduce aircraft weights and to promote improvements in aircraft performance, safety, durability, and life-cycle costs.

Information Sciences. The Information Sciences program includes the following activities:

(1) increasing the Agency's capabilities in advanced aerospace computing;
(2) exploiting key computer science disciplines to meet the Agency's unique computing requirements; and
(3) establishing a technology base for cost-effective, reliable computing in complex, mission-critical hardware and software systems.

Controls and Guidance. The Controls and Guidance program includes the following activities:

(1) investigating emerging control, guidance, artificial intelligence, and display technologies that offer automation and systems integration contributing to aviation effectiveness and efficiency;
(2) developing architectures for flight-crucial systems for future aircraft and devising analytical techniques for assessing their reliability and performance;
(3) developing methods for airborne detection and avoidance to alleviate the threat of wind shear and heavy rain;
(4) developing advanced control theories, guidance theories, and analytical methods for extending the performance envelope and reliability of highly augmented future aircraft; and
(5) exploring new concepts for achieving integration of multidisciplinary technologies.

Human Factors. The Human Factors program provides the capability to design effective crew-cockpit systems using advanced cockpit automation technologies that will properly integrate the diverse systems, operators, and procedures consistent with the mission requirements and environment.

Flight Systems. The Flight Systems program provides the research and technology development required for an improved and validated base of advanced technology for application by industry to future generations of the entire spectrum of aircraft.

Systems Analysis. The Systems Analysis program provides a basis for effective long-range planning by developing performance data, conducting sensitivity analyses, and examining the technology needs and opportunities associated with future vehicle concepts. Systems analysis studies identify technologies that can lead to new plateaus or major improvements in the performance of civil or military vehicles, in the creation of new markets, and in economic benefits.

Systems Technology

Systems Technology consists of five areas:

(1) Materials and Structures,
(2) Rotorcraft,
(3) High Performance Aircraft,
(4) Advanced Propulsion, and
(5) Numerical Aerodynamic Simulation.

Materials and Structures. The Materials and Structures program develops advanced materials and structural concepts for future advanced aircraft propulsion systems and primary structures.

Rotorcraft. The Rotorcraft program advances the disciplines of rotorcraft acoustics, aerodynamics, and aeromechanics, and explores promising high-speed configurations to provide a technology base for advances in civil and military rotorcraft vehicles.

High Performance Aircraft. The High Performance Aircraft program generates validated engineering methods and design data applicable to the development of advanced high-performance, high-speed aircraft.

Advanced Propulsion. The Advanced Propulsion program explores and exploits advanced technology concepts for future aircraft systems in high-payoff areas by focusing fundamental research and technology efforts and by integrating advanced propulsion components.

Numerical Aerodynamic Simulation. As a necessary element in maintaining U.S. leadership in computational fluid dynamics and related disciplines, the Numerical Aerodynamic Simulation program establishes and maintains a pathfinding national computational capability available to the Agency, other federal research organizations, industry, and academia.

Transatmospheric Research and Technology

The Transatmospheric Research and Technology program, a part of the National Aerospace Plane program, seeks to demonstrate, by the mid-1990s, the following aerospace vehicle technologies:

(1) horizontal takeoff from, and landing on, conventional runways;
(2) sustained hypersonic cruise and maneuver in the atmosphere; and
(3) acceleration to orbit and return.

Development of critical technologies is being accelerated through a combination of computational efforts, ground-based experiments; and small-scale, hypersonic-technology flight experiments. Flight experiments will be conducted, as needed, on small, specially instrumented research vehicles in order to validate the predictions for high speed and altitude conditions that cannot be simulated adequately in ground facilities.

FY 1989 Augmentations and Initiative

Three research and technology development augmentations are planned for FY 1989 to accelerate key research and technology development activities. In addition, a major wind tunnel revitalization program will be initiated to ensure that critical facilities are available to support planned and future Agency research and industry development needs.

Advanced Composite Materials. The Advanced Composite Materials technology augmentation will emphasize development of tough, durable, more easily processed composite materials for use in temperatures as high as 600°F. In addition to developing and characterizing toughened thermosetting and thermoplastic resins, the research will concentrate on developing advanced materials and efficient material processing and fabrication technology.

Advanced Propulsion Concepts. This augmentation will provide high-leverage technology for advanced propulsion concepts that will form the basis for large improvements in propulsion capability for a broad range of applications. Enabling technologies will be developed that lead to:

(1) a 20-percent improvement in supersonic cruise aircraft range,
(2) a concept for a propulsion system that can operate efficiently from takeoff to Mach 6.0,
(3) a 20-percent improvement in fuel consumption for propulsion systems that must operate extensively at both subsonic and supersonic conditions, and
(4) a 25-percent improvement in the thermal efficiency of propulsion for subsonic transport aircraft.

Aviation Safety and Automation. One of the eight national aeronautics research and development goals endorsed by the Administration in 1987 was *to enhance the safety and capacity of the National Airspace System.* The aviation safety and automation augmentation will accelerate progress toward that goal through the integration of control and guidance, human factors, and artificial intelligence technologies into automated flight and Air Traffic Control (ATC) management systems.

Major Wind Tunnel Revitalization. NASA has prepared a comprehensive, 5-year plan to revitalize existing facilities and to construct vital new facilities. In addition to wind tunnels, this initiative addresses associated support facilities and data acquisition systems and equipment. Preliminary work has begun on revitalizing the 12-foot pressure wind tunnel at Ames Research Center. Work on other tunnels is scheduled to begin during FY 1989 and continue through FY 1993.

Future Initiatives

Several initiatives are planned as additions to the current aeronautics research and technology development program. Their initiation will depend on future budget levels and program priorities.

Subsonic Transport and Commuter Aircraft Technology. Propulsion efforts under this initiative will focus on development of technology for ultra-high-bypass-ratio ducted propulsors to improve fuel efficiency and reduce direct operating costs. Aerodynamics technology development will be directed at reducing both wing drag and fuselage turbulent skin friction drag to provide further reductions in direct operating costs.

High-Angle-Of-Attack and Supermaneuverability Technology. This initiative will seek an order-of-magnitude increase in advanced fighter maneuverability and agility, without degradation of supersonic cruise performance.

High-Speed Civil Transport Aircraft Technology. A concerted technology development initiative by NASA is required to satisfy airline requirements in speed, range, capacity, operating economy, and environmental impact. Primary emphasis for this initiative will be on establishing multidisciplinary research programs to develop critical technologies, and on systems integration studies to ensure that the full synergistic benefits of each technology advance are realized in any subsequent aircraft design process.

This initiative will be able to build on the strong technology base being developed under the National Aerospace Plane program. NASP research in areas of technological commonality—including high-temperature materials and structures, advanced cockpits, guidance and controls, and predictive computer codes—will advance the state of the art of areas in which technologies for high-speed civil transport aircraft will be developed.

Advanced Short Takeoff and Vertical Landing (ASTOVL) Technology. This initiative will develop, in a broad ground-based program, supersonic STOVL technology for use in selecting the most promising concepts for a flight vehicle. A secondary objective is to obtain for propulsive-lift aircraft the cruise data base needed for a new generation of high-performance fighters able to operate from a variety of surfaces, including damaged runways and the decks of small ships.

High-Speed Rotorcraft Technology. This initiative will investigate, and further develop, emerging technologies that offer truly revolutionary advances in rotorcraft performance. New rotary-wing vehicles will leapfrog current helicopter limitations, offering, for example, a 200- to 300-percent increase in speed. They will earn rotorcraft a much broader role in both civil and military applications.

Aeronautics Beyond the Year 2000

The benefits flowing from the current programs and proposed initiatives summarized above will continue to accrue to the U.S. aviation industry—and the Nation—well into the next century. Given the long lead-times required to move from research and technology development to the use of new technology, NASA is laying plans for advancing the frontiers of technology development so that it will be able to meet its challenging mission of ensuring the preeminence of U.S. civil and military aviation.

Commercial Summary

The functions of the Office of Commercial Programs (OCP) are divided into three broad working areas: Commercial Development, Technology Utilization, and Small Business Innovation Research.

Commercial Development

The Commercial Development element is responsible for stimulating and encouraging the interest of the U.S.

business community in commercially oriented space-related research and development. In this role, OCP supports industrial research activities and other initiatives that may benefit from collaboration with NASA research efforts. In addition, OCP develops programs to inform the private sector of opportunities for such collaboration.

Development of Commercial Expendable Launch Vehicle (ELV) Industry. In 1986 and 1987, NASA executed two first-of-a-kind ELV agreements. In 1986, it signed an agreement to allow use of its facilities for launching a privately developed expendable launch vehicle. In 1987, it signed the first U.S. government agreement transferring operation of a government-developed ELV to the private sector.

NASA currently is negotiating with additional firms for rights for them to manufacture another government-developed ELV commercially and for NASA support to several firms' commercial operations at NASA facilities.

Cooperative Agreements. Cooperative agreements between NASA and the U.S. private sector are the instruments through which NASA attempts to mitigate extraordinary up-front technical and financial risks the private sector may face in such capital investment projects. OCP employs six types of basic cooperative agreements:

1. Joint Endeavor Agreement,
2. Space Systems Development Agreement,
3. Technical Exchange Agreement,
4. Industrial Guest Investigator Agreement,
5. Memorandum of Agreement, and
6. Memorandum of Understanding.

Each of these types of agreements is designed to meet the requirements of specific types of private ventures, and each represents a varying degree of commitment on the part of both NASA and the private sector. NASA has entered into 77 such agreements to date.

Centers for the Commercial Development of Space (CCDS) Program. In 1987, OCP increased the number of CCDSs from 9 to 16. The 16 CCDSs include over 100 participating private entities. NASA's funding of each CCDS was planned to last 5 years in order to stimulate and stabilize CCDS' activities and to enable successful CCDSs to achieve self-sufficiency. However, because of the lack of flight opportunities resulting from the Challenger accident and the likelihood that research in process will lead to viable commercial applications, consideration is being given to extending this period.

Future Focus. OCP is cooperating with the Office of Space Science and Applications to develop multi-user, multi-use, government hardware that will reduce the experiment costs of individual entrepreneurs to an affordable level. This hardware includes various types of furnaces, materials processing equipment, and experiment-carrier supporting structures for use by private companies in their space experiments. Use of the hardware will provide access to microgravity through flights on the shuttle, NASA aircraft, and sounding rockets.

To maintain momentum in activities related to the commercial use of space, OCP will develop improved methods for facilitating private sector agreements and commitments to develop commercial opportunities in space. Institutions with strong research capabilities in science and engineering, in collaboration with industry and/or industrial associations, will be encouraged to participate in NASA-sponsored workshops and endeavors to accelerate U.S. commercial leadership in the use of space.

Through coordination with various industrial sectors and NASA program offices, OCP's efforts to enhance commercial research and development will include an increase in the availability of generic, multi-use research experimentation equipment. This equipment—as well as ground-based hardware, software, and analytical tools—will be developed to expand the research data base on the commercial uses of space. Support services, equipment maintenance, and studies and analyses also are elements of Commercial Development support.

Technology Utilization

The Technology Utilization element is responsible for dissemination to and secondary application by industry, academia, and other government agencies of NASA-developed technology. Information on the secondary application of NASA technology is disseminated through publications such as NASA Tech Briefs and Spinoff. Mechanisms such as NASA's Industrial Application Centers determine specific needs of businesses and, with the assistance of NASA field installations, identify the relevant NASA technologies that address those needs.

During the past year, NASA's Industrial Application Centers (IACs) have strengthened their relationships with state-sponsored institutions, universities, and federal laboratories through an expanded outreach program called the Industrial Applications Affiliates program. Under this program, a number of NASA's field centers have developed cooperative working relationships with state-sponsored business-assistance institutions. At present, 39 state institutions have established, or are in the process of establishing, affiliate status with the IACs. This program will result in a nationwide network for technology transfer, making NASA technology available to a wider range of U.S. industry.

In March 1987, NASA entered into an agreement with the Federal Laboratory Consortium to provide appropriate linkages between over 500 federal laboratories and NASA's nationwide transfer network. This network comprises NASA's IACs, NASA's field centers' technology utilization offices, expert technology counselors, and technology applications teams. It seeks to enhance the transfer of NASA and other federally developed technologies to U.S. industry and public organizations.

Future Focus. To accomplish its Technology Utilization goal, NASA has established and will continue to operate a number of technology transfer mechanisms to provide timely access to useful technologies by the private and public sectors of the economy. Almost every part of U.S. industry is affected by the technology transfer process, especially in such areas as automation, electronics, materials, and productivity. In the public sector, medicine, rehabilitation, transportation, and safety are areas in which aerospace technologies have been especially beneficial.

The NASA-sponsored IAC network has made significant strides in developing effective linkages with state-sponsored institutions engaged in industrial and economic growth. The broadening and strengthening is continuing to gather momentum, with nearly 40 of the 50 states now participating

The IACs intend to expand their relations further, to include specific technology-transfer arrangements with the Small Business Administration's Small Business Development Centers (SBDCs) throughout the Nation. They will service more than 570 SBDCs, linking the centers into all the federal research and development laboratories. Similar arrangements are being developed with the Department of Commerce to establish interfaces between its more than 120 Minority Business Development Centers nationwide and the technical resources and capabilities available in the National Aerospace Plane program and the federal research and development laboratories.

OCP plans continued strengthening of the Technology Counselor network at its field installations to provide for the expanded identification of NASA technical capabilities and expertise necessary for matching and cross-correlating NASA technology with industry needs specified by the IACs.

NASA has authorized experimental technology-transfer programs, involving both process and product, at its Jet Propulsion Laboratory as a means to enhance the access of small and large industrial firms to that Laboratory's technology. At present, 20 industrial firms are participating and 25 more are expected to join within the next 12 months.

As OCP's role in industrial outreach expands, additional emphasis will be required on development of program goals and objectives in terms of long-range plans for the Technology Utilization program. Some of the many management planning and support requirements that will be needed are as follows:

(1) focused efforts on assessing potential participants in U.S. industry,
(2) preparation of information guidelines to support cooperative relationships throughout the NASA technology transfer network,
(3) satisfaction of the anticipated increase in demand for Technology Utilization publications, and
(4) response to an increased number of program inquiries.

Small Business Innovation Research

The Small Business Innovation Research (SBIR) element is responsible for meeting NASA's requirements under the "Small Business Innovation Development Act of 1982." This law requires NASA, as a federal agency with a research and development budget exceeding $100 million, to set aside a percentage of its budget to fund small business research in aeronautics and space technology.

The SBIR program, now entering its 6th year, has been a popular and effective program in all the federal government agencies. In NASA's program, more than 7,000 Phase I and Phase II proposals have resulted in 755 Phase I and 299 Phase II awards. More than half the Phase II projects completed to date have yielded results that are in use or are planned for use by NASA, and more than 20 percent have found their way into commercial products and services. In 1986 Congress extended the SBIR program through September 1993, but will decide before then whether the program will be continued.

Future Focus. Interest from the private sector in the SBIR program has increased, resulting in a growth rate of 10 to 12 percent per year in proposals. NASA expects this rate to continue and expects to receive more than 2,000 Phase I proposals in FY 1988.

The primary objective of the SBIR program remains unchanged: increased participation of innovative, high-technology small businesses in NASA's aeronautics and space programs. However, OCP intends to place additional emphasis on selecting more SBIR projects that from their outset also have strong potential for yielding commercial applications, and to find mechanisms for encouraging and assisting small businesses to progress toward commercial markets for the results of their research.

Strategy

The Office of Commercial Programs has four general strategies for meeting its objectives:

Close Working Relations. NASA is working to strengthen its traditionally close relationships with the academic and industrial communities, particularly with nonaerospace sectors, which may have different concepts and proposals for commercial space projects. In addition to establishing closer working relationships with the academic community and the industrial sector, NASA will address private sector requirements to the maximum extent possible.

Private Sector Space Activities. To duplicate NASA's space and ground-based facilities is beyond the financial capability of many companies. These facilities should be viewed as national assets, and should be available to private organizations for their use and for national economic benefit. Private sector involvement in the commercial development of space could be considerably delayed without the availability of these unique resources. OCP, in cooperation with the NASA program offices and field installations, will make government facilities and capabilities available to U.S. private sector users as much as practical when that use does not interfere with approved NASA and other government programs.

Independent Private Sector Investment. Obligation of funds to projects by OCP generally requires prior commitment of resources by the private sector. However, programs funded by OCP's Technology Utilization and Small Business Innovation Research programs may be exceptions to this requirement. In projects administered by these two programs, NASA funds may be provided in the absence of a financial commitment by private sector participants.

Commercial Space Policy. OCP will strive to ensure that commercialization provisions of the National Space Policy are interpreted and administered in a consistent, dependable fashion, and will clarify and streamline NASA's coordination and decision-making processes pertaining to private sector requirements. Further, OCP will serve as the Agency's focal point for review and development of policies to meet the needs of the private sector.

Planned New Initiatives

OCP has initiated the following significant program of aggressive initiatives to improve and expand industry's interest in the commercial development of space:

(1) create an industry committee to provide advice on commercial space issues,
(2) develop and recommend a new pricing policy,
(3) develop a plan to manage and optimize the 31-percent allocation of secondary-payload space on space shuttle flights to commercial payloads,
(4) streamline the Joint Endeavor Agreement process,
(5) provide new opportunities for small business,
(6) enhance the development of the commercial infrastructure in support of the planning and implementation of spaceflight operations, and
(7) inventory the hardware facilities and services available for spaceflight activities.

Exploration Summary

The task force led by Dr. Sally Ride set forth four critical areas that require near-term investments:

(1) development of the necessary technology base;
(2) improvement of understanding and response to the biomedical, psychological, and human adaptation implications of long-duration space flight;
(3) development of a cadre of launch vehicles, for both people and cargo, that initially would meet the near-term commitments of the civilian space program and then grow to support projected programs; and
(4) early consideration of the demands that exploration initiatives will make on the Space Station.

To ensure progress beyond ad hoc study activities and task force exercises, the task force report recommended creation of the Office of Exploration, to serve as the focal point within the Agency for the study of human exploration initiatives. On June 1, 1987, NASA's Administrator, Dr. Fletcher, formally announced the establishment of the Office to "analyze and define missions proposed to achieve the goal of human expansion off the planet. It will provide central coordination of technical planning studies that will involve the entire agency."

Initiatives

Two initiatives, each involving various scenarios (mission techniques), are currently under study.

Lunar Base Initiative. The first is the Lunar Base initiative, whose scenarios emphasize (in priority order) science, resource development, and sustained human presence. The scenarios include:

(1) a robotic exploration phase for base site selection;
(2) an early outpost phase entailing emplacement of geological and astronomical science instruments and of a pilot plant for processing lunar resources; and
(3) a permanently inhabited phase during which potential "world class" science operations can be conducted.

Mars Initiative. The Mars initiative's scenarios emphasize (in priority order) science, human exploration, and resource development. This initiative also includes a robotic phase for scientific exploration and for gathering additional engineering data required before exploration by humans starts. Its second phase would encompass piloted landings, the establishment of an inhabited outpost with enhanced scientific exploration capabilities, and pilot processing plants for resource utilization. The third phase would include initiating establishment of a permanently inhabited base on Mars, using local resources to support transportation and habitation. A key tradeoff study related to the Mars initiative is of the potential necessity for prior establishment of a lunar base, to serve as a stepping stone for human voyages to Mars.

Prerequisite Programs in Support of Human Exploration

Life Science Research. Project Pacer, developed by NASA's Office of Space Science and Applications, is a program designed to develop an understanding of the physiological effects of the microgravity and radiation environments in space and to provide the physiological and medical foundation for extended spaceflight. Research performed under this program will be conducted in laboratories and on space shuttle missions in preparation for the critical long-term Space Station experiments mentioned in the paragraph that follows.

Space Station. Planning for the Space Station's evolution will include assessment of the implications of human exploration initiatives. Specific scenarios developed to serve as a basis for the assessments will provide results that will feed back into the original initiative scenarios. The Space Station is an enabling link to expanding the human exploration of space. It will be used to develop a capability for the long-term presence of humans in space. It also will be used as a development and test site for relevant robotic devices, crew aids, and tools. The Space Station can ensure that facilities exist to support relevant life sciences and materials sciences research; with proper allowances for evolution, it can grow into a low Earth orbit transportation node.

Earth-to-Orbit Transportation. Identified by the Ride study as NASA's most pressing problem, Earth-to-orbit transportation continues to receive considerable Agency attention. Vehicles under consideration include expendable launch vehicles and a shuttle-derived cargo vehicle.

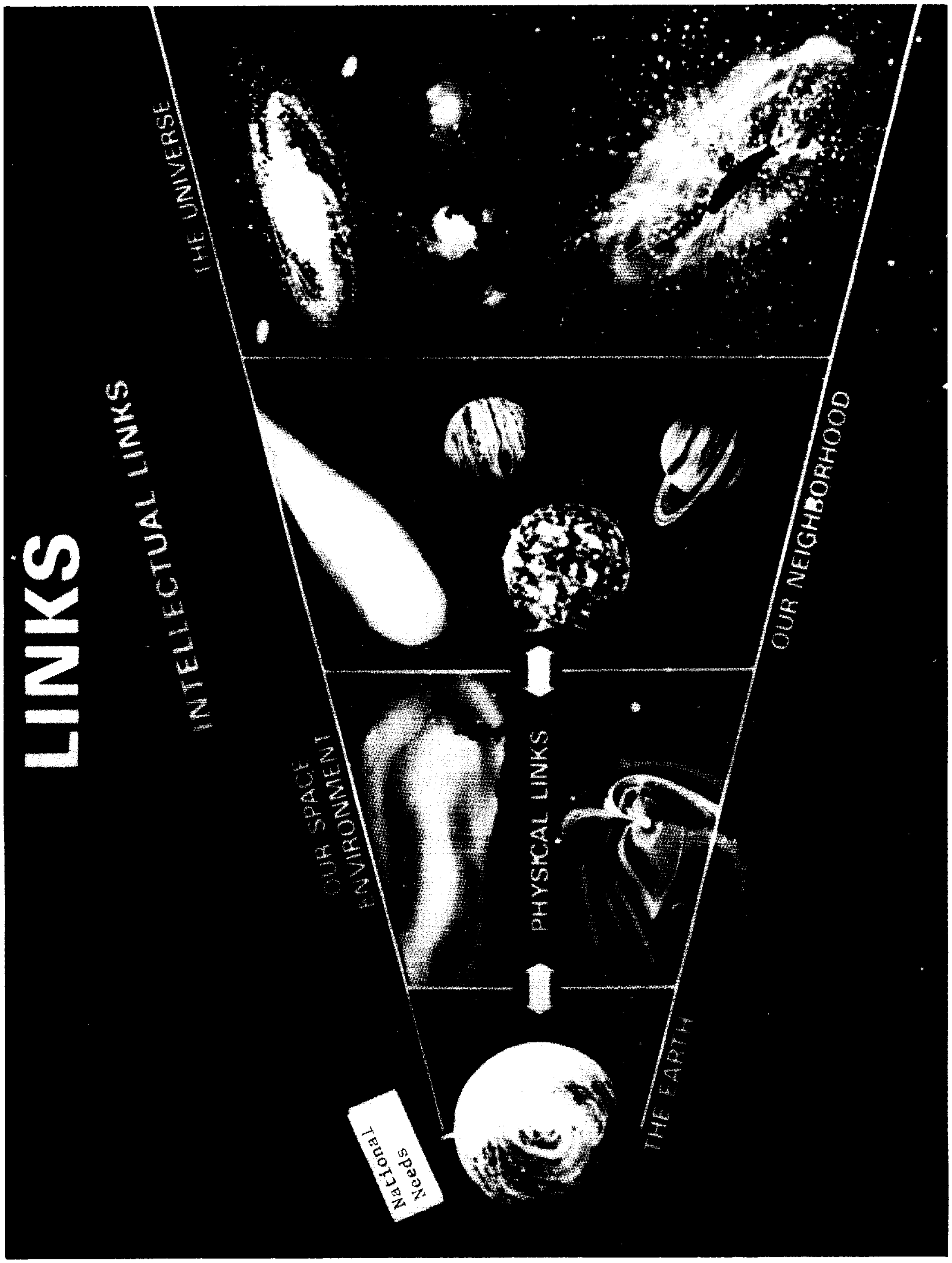
Science and Engineering Robotic Precursor Missions. Special studies, initiated by the Exploration program, will define the need for robotic precursor missions to enable or enhance human exploration activities. Such precursor missions are related to planetary science efforts to understand the surface environments of the moon and Mars, to perform resource surveys, and to explore bio-contamination issues. These missions would demonstrate key advanced technologies, such as those for aerobraking and autonomous roving vehicles. The Office of Space Science and Applications provides the key support for this activity by assessing the requirements and responding with an implementation plan for precursor missions.

Pathfinder Technology. Project Pathfinder, developed by NASA's Office of Aeronautics and Space Technology in conjunction with experts on the Lunar Base and Mars initiatives, will provide the technologies to enable missions beyond Earth's orbit. Pathfinder will develop technologies for autonomous systems and robotics, advanced propulsion systems for lunar and planetary spacecraft, extraction of useful materials from lunar and planetary surfaces, life support systems, and the human-machine interface. Emphasis is being placed on defining needs and examining the leverage that investments in advanced technologies can provide to enable human exploration initiatives.

Long Range Perspective

A NASA-wide organization and study process has developed a preliminary long-range milestone schedule, and an initiative definition exercise is now in process. In FY 1989, effort will be directed toward refining and validating required program dependencies and relationships across the agency. A national exploration decision will be made in the early 1990s.

SPACE SCIENCE AND APPLICATIONS


LINKS
INTELLECTUAL LINKS
THE UNIVERSE
OUR NEIGHBORHOOD
OUR SPACE ENVIRONMENT
PHYSICAL LINKS
THE EARTH
National Needs

Space Science and Applications

The Office of Space Science and Applications (OSSA) is responsible for planning, directing, executing, and evaluating that part of the overall NASA program that uses the unique characteristics of the space environment, and the vantage point of Earth orbit, to conduct scientific studies of the universe, to solve practical problems on Earth, and to provide a scientific research foundation for expanding human presence beyond Earth into the solar system. The OSSA program results in increased knowledge for all humanity. Its scope ranges from studies of the oceans and tectonic plates that make up the Earth to investigations of the upper reaches of the atmosphere, and from exploration of the solar system to investigation of distant galaxies. The pursuit of OSSA's program objectives results in the development of tools, techniques, and procedures that can aid in the solution of major national problems and can contribute to the economic health and development of the United States.

Introduction

The Space Science and Applications program is responsible for most of the Nation's scientific research in space, and for exploring ways in which space can be used in practical applications for materials processing, in the life sciences, and in research for monitoring and analyzing Earth's natural resources. The program includes observations and studies of the distant universe and of the fundamental physical laws that govern it, exploration of the solar system, and efforts to understand more about Earth's planetary features and environment. Its application programs include research in the life sciences to enable humans to function and work in space, experiments in materials processing in the microgravity environment of space, and the expansion and improvement of such services as satellite communications.

These program activities are pursued through an integrated sequence that includes:

(1) ground-based laboratory research and experimentation;
(2) suborbital flights of instruments on airplanes, balloons, and sounding rockets;
(3) flights of instruments on the shuttle-Spacelab system, commercially developed facilities, and the permanently manned Space Station; and
(4) the development and flight of automated Earth-orbiting and interplanetary spacecraft.

The program is conducted with the participation and support of all the NASA field centers, other government agencies and facilities, universities throughout the United States, and the aerospace contractor community. Substantial international participation occurs in many aspects of the program.

As shown in Figure III-1, OSSA includes seven program divisions, each of which sponsors research within a

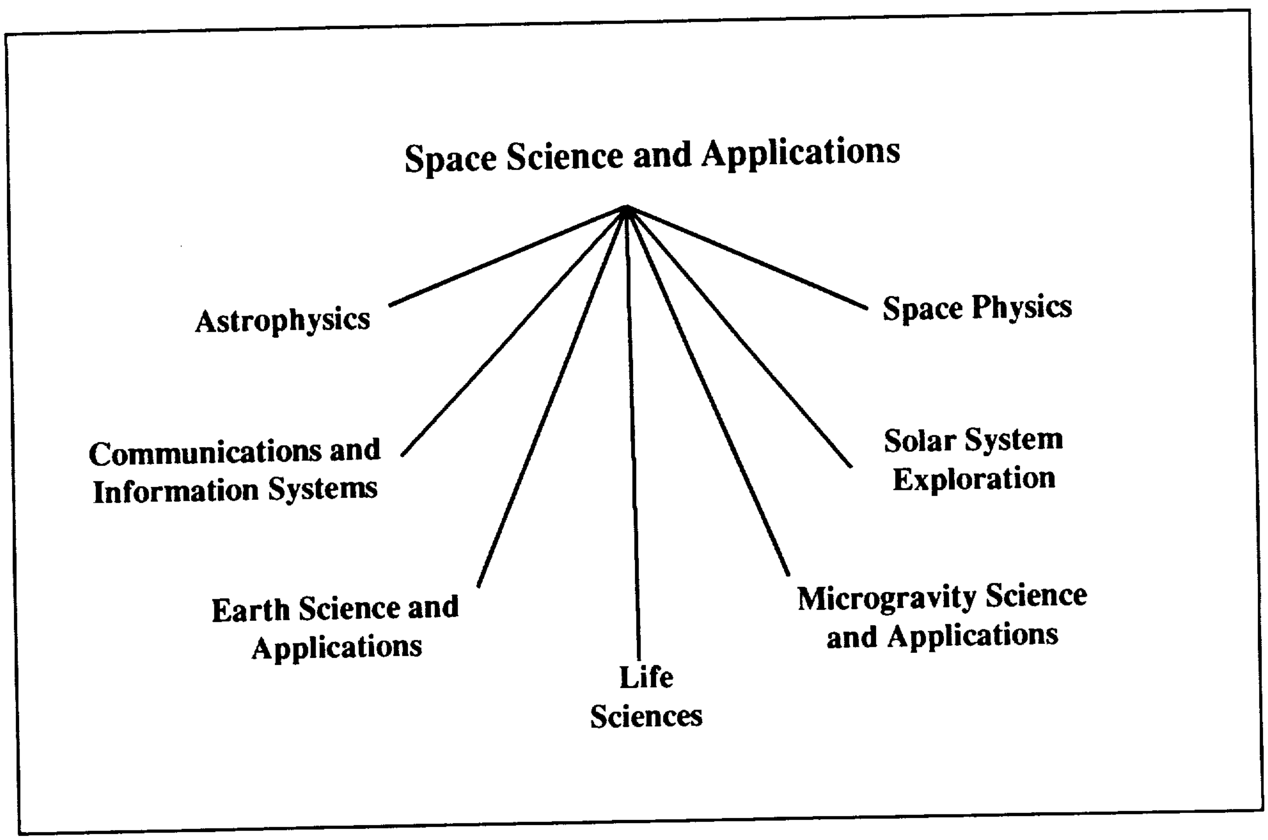


Figure III-1. Space Science and Applications Program Divisions

different scientific discipline to accomplish Space Science and Applications program goals. These discipline divisions include:

(1) **Astrophysics.** The Astrophysics program performs studies and investigations necessary to determine the nature of objects and the range of conditions existing within the universe, and to identify their place in and contribution to its evolution.
(2) **Communications and Information Systems.** The Communications research program focuses on developing high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of space communications systems. The information systems program applies information systems technologies to meet the unique needs of the Space Science and Applications program, the satellite communications industry, and the public sector.
(3) **Earth Science and Applications.** The Earth Science and Applications program establishes global observations and studies directed at understanding the physical, chemical, and biological processes that operate to unify Earth's environment as a system.
(4) **Life Sciences.** The Life Sciences program extends from basic research in life sciences to applied clinical practice. Major disciplinary areas of research include operational medicine, space medicine, space biology, global biology (biospherics), exobiology, and controlled ecological life support systems.
(5) **Microgravity Science and Applications.** The Microgravity Science and Applications program fosters development of near-Earth space as a national resource by exploiting microgravity and other attributes that may be attained in an orbiting spacecraft. It uses the unique characteristics of the space-flight environment to conduct basic research in physics and chemistry (with special emphasis on materials science); to understand the role of gravity in materials processing; and, where possible, to demonstrate the production of improved materials that have high technological utility.
(6) **Solar System Exploration.** The Solar System Exploration program embodies efforts to understand the formation and current state of all the planets in the solar system (including Earth), the comets, and other primitive solar system bodies.
(7) **Space Physics.** The Space Physics program conducts scientific investigations into the origin, evolution, and interactions of space plasmas in a wide variety of astrophysical settings.

Following a discussion of the goals, objectives, principles, and strategy of Space Science and Applications, this chapter contains descriptions of current programs, planned initiatives, and the research base for each of the seven disciplines (see Programs and Strategies by Discipline, page III-14). Next the programs are placed in the context of the programmatic themes developed as part of the OSSA strategy. This integrated view of the programs is presented first for 1989 (see page III-69), and then for 1990-1994 (see page III-71).

As in the other chapters of this document, details about specific programs are presented in insets. Each program inset appears as close as possible to the first reference to the program. Where clarity dictates, subsequent discussion of the program contains a reference to the program inset.

The chapter concludes with a section that describes Space Science and Applications beyond 1994, and a section discussing interrelationships with programs of other offices.

Goals

The traditional focus of the Space Science and Applications program has been advancement of scientific knowledge of the planet Earth, the solar system, and the universe beyond. This goal remains a major component of the program.

In addition, many current and future efforts will directly support NASA's goal of expanding human presence beyond Earth into the solar system by providing the scientific research foundation essential for planning major human-related initiatives. As discussed in Chapter X describing the Exploration program, this research foundation will be built by characterizing the surfaces of the Moon and Mars, by assessing the potential for using nonterrestrial resources in space, by developing a scientific basis for understanding the long-term effects of the space environment on human beings, and by developing appropriate countermeasures to prevent or ameliorate the adverse effects of this environment.

The goals of the Space Science and Applications program as a whole are reflected in each of the seven discipline areas, a summary of which appears in Table III-1.

Table III-1. Discipline Goals

Discipline	Goals
Astrophysics	1. Understand the origin and fate of the universe; 2. Understand the underlying fundamental laws of nature and physics that govern the universe; and 3. Understand the birth and evolutionary cycles of galaxies, stars, and planets.
Communications and Information Systems	1. Maintain U.S. technological and economic preeminence in space communications; 2. Enable innovative services in support of the satellite communications industry, NASA's needs, and the needs of the public sector; and 3. Establish a dynamic architecture and operating capability for the implementing a space science information system responsive to the needs of the scientific research and application community.
Earth Science and Applications	1. Obtain a scientific understanding of the entire Earth system on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales.
Life Sciences	1. Understand the origin, evolution, and distribution of life in the universe; 2. Understand the relationship between life and gravity and other planetary properties; and 3. Develop medical and biological systems that enable human exploration and habitation of space.

Table III-1. Discipline Goals (continued)

Microgravity Science and Applications	1. Advance understanding of the fundamental science that governs processes on Earth, in the solar system, and in the universe; 2. Increase understanding of the influence of gravity on Earth-based processes, leading to better control strategies to improve such processes; 3. Pursue limited production of exotic high-value materials with enhanced properties to serve as benchmarks for comparison with the products of Earth-based technologies or for use in highly specialized applications; 4. Evolve processes for the eventual commercial production of certain high-value-added products in space; and 5. Explore the possibility of processing extraterrestrial materials.
Solar System Exploration	1. Determine the present nature of the solar system, its planets, and its primitive bodies, in order to under stand how the solar system and its objects formed, evolved, and (in at least one case) produced environments that could sustain life; 2. Better understand planet Earth by determining the general processes that govern all planetary development and by understanding why the "terrestrial" planets of the solar system are so different from each other; and 3. Establish the scientific and technical data base required for undertaking major human endeavors in space by surveying of near-Earth resources, characterizing planetary surfaces, and searching for life on other planets.
Space Physics	1. Understand the ionosphere and magnetosphere of Earth and other planets, as well as the heliosphere, in their quiet (steady state) and dynamic configurations; 2. Understand the sun, both as a star and as the dominant source of energy, plasma, and energetic particles in the solar system; and 3. Understand the acceleration, transport, and propagation of energetic particles that originate both within the solar system and outside it (i.e., solar and galactic cosmic rays).

Objectives

OSSA has established a number of near-term objectives that will guide its plans and programs for the future. These include (not in priority order):

(1) complete the group of astronomical facilities commonly called the Great Observatories, which will observe the universe across the electromagnetic spectrum with unprecedented resolution and sensitivity;
(2) complete detailed scientific characterization of virtually all of the solar system, including the terrestrial planets, the primitive bodies, and at least the nearer parts of the outer solar system;
(3) quantitatively characterize the physical behavior of the sun, the origins of solar variability, the geospace environment, and the effects of solar processes on Earth;
(4) establish a set of observing platforms to study the Earth system on a global scale, to determine the long-term changes that can develop as a consequence of the interactions between the components of that system, and, eventually, to develop a capability to predict changes that might occur either naturally or as a result of human activity;
(5) determine, develop, and exploit the unique capabilities provided by the Space Station and other space-based facilities to study the nature of physical, chemical, and biological processes in a microgravity environment, and then apply the results of these studies to advance science and applications in such fields as materials science, plant and animal physiology, biotechnology, and fluid physics;
(6) develop a scientific foundation to support the planning of human exploration beyond Earth (see Chapter X) by developing an understanding of the effects of low gravity and of space radiation on humans, the nature of the surfaces of the moon and Mars, and the potential for using nonterrestrial resources in space; and
(7) develop and apply advances in communications and information systems technology to meet future needs of the Office of Space Science and Applications, the satellite communications industry, and the public sector.

The objectives of the seven individual discipline areas are summarized in Table III-2.

Table III-2. Discipline Objectives

Discipline	Objectives
Astrophysics	1. Establish permanent observatories for viewing the universe in four major wavelength regions of the spectrum (infrared, optical/ultraviolet, X-ray, and gamma ray); 2. Obtain crucial bridging and supporting measurements via directed-objective missions of intermediate and small scope; 3. Enhance scientific access to results of space-based research activities, including problem-oriented, multidisciplinary studies implemented through the Astrophysics Data System program; and 4. Develop and maintain the scientific/technical base for space astrophysics programs and mission via research and analysis and suborbital programs.

Table III-2. Discipline Objectives (continued)

Communications and Information Systems	1. Develop advanced technology to use frequencies and geosynchronous orbit more effectively; 2. Develop positions for and provide other support to U.S. and NASA interests in international and domestic communications regulatory forums; 3. Provide scientific computing and data management support through the NASA Space and Earth Sciences Computing Center and the National Space Science Data Center, both located at Goddard Space Flight Center; 4. Expand access to data and resource sharing via the development and dissemination throughout the science community of networking technology; and 5. Plan and develop information systems to meet scientific needs.
Earth Science and Applications	1. Establish global observations and studies directed at understanding the physical, chemical, and biological processes operating to unify Earth's environment as a system.
Life Sciences	1. Understand the physiological, sociological, and psychological implications of space flight and return to a gravity field; 2. Develop appropriate medical and bioregenerative life support technologies to enable human expansion into the solar system; 3. Understand the effects of gravity on the life cycles of animals and plants; 4. Characterize the combined effects of microgravity, space radiation, and other environmental stresses on biological systems; 5. Determine how biological and planetary processes interact; 6. Trace the history of biologically important molecules from synthesis to assimilation into planetary and living systems; and 7. Undertake a search for evidence of extraterrestrial life.

(Table continued on next page.)

Table III-2. Discipline Objectives (continued)

Microgravity	1. Perform investigations in fundamental science, including study of the behavior of fluids and of transport phenomena in microgravity; 2. Conduct experiments that use the enhanced measurement precision possible in microgravity to measure physical properties and to challenge contemporary theories of relativity and condensed-matter physics; 3. Perform investigations in materials science, including the processing of electronic and photonic materials, of glasses and ceramics, of polymers, and of metals, alloys, and composites; 4. Perform investigations in biotechnology, which primarily studies the growth of protein crystals and the development of separation techniques for biological materials.
Solar System Exploration	1. Conduct a continuing series of modest Planetary Observer missions to explore inner planets and near-Earth asteroids, using reconfigured off-the-shelf Earth-orbital spacecraft; 2. Conduct a continuing series of Mariner Mark II spacecraft missions to explore the outer planets, comets, and asteroids, using a common spacecraft with evolving technological capabilities; 3. Develop a capability for multimission spacecraft operations and data analysis; and 4. Develop strong foundations of ground-based research, analysis, and related activities.
Space Physics	1. Observe and obtain measurements of space plasma systems and plasma processes; 2. Conduct active plasma experiments both in the laboratory and in accessible space plasmas; and 3. Apply theory and computer simulations to synthesize measurements into a general understanding of space physics phenomena, including those related to geospace, solar-planetary interactions, the solar system, and the chemical evolution of the galaxy.

Program Principles

In the coming years, the Space Science and Applications program will continue to nurture the principles that have served it well in the past, including:

(1) constant emphasis on excellence and the continuation of U.S. scientific leadership;
(2) basic scientific goals and strategies defined by the scientific community;
(3) use of scientific peer review in all appropriate aspects of the program;
(4) balance among the various scientific disciplines;
(5) close communication with external scientific and applications communities, particularly as advisors;
(6) strong support for universities to maintain them as a source of essential long-term research talents;
(7) effective use of the NASA field centers in formulating and implementing the OSSA program;
(8) choice of appropriate mission approach in accordance with scientific and applications requirements; and
(9) maintenance of a strong research foundation for space applications.

Especially important in the past, and a major theme for the future, is the need for an increasingly interdisciplinary approach to major scientific problems. The importance of such an approach, to transcend some of the narrow and artificial boundaries between scientific disciplines, has become more compelling as the pursuit of solutions to major space research problems evolves. Such problems cannot be solved without applying data and insights from many different fields. The future will see a continuing application of multidisciplinary approaches to such questions as the origin of stars and solar systems, the origin and evolution of life, the understanding of processes that cause all planets—especially Earth—to form and change, and the gathering of information needed to plan long-term human voyages beyond Earth.

Program Strategy

To chart an enduring course that will make its vision a reality, the Office of Space Science and Applications has formulated a strategy that is the culmination of extensive interaction and collaboration with the scientific and applications communities, careful consideration of resource guidelines, and iterative reviews of pertinent issues and challenges.

The resulting strategy is constructed around five actions:

(1) establish a set of programmatic themes (see inset on page III-12);
(2) establish a set of decision rules (see inset on page III-13);
(3) establish a set of priorities for missions and programs within each theme;
(4) demonstrate that the strategy can yield a viable program; and
(5) check the strategy for the readiness of technology and for consistency with resource constraints such as budget, manpower, and launch vehicle availability.

Taken together, these five actions define a programmatic process by which the Office of Space Science and Applications is planning its activities and allocating its resources. The programmatic themes provide direction and balance to the program, the decision rules guide the selection of efforts among and within each theme, and the list of priorities determines the order in which the missions and programs within each theme will be pursued. The exercising of these actions provides various plans for a Space Science and Applications program, and the plans thus are checked for realism and for consistency with resource constraints.

An important point to note is that exercising the above actions does not, nor is it intended to, result in a single plan. Rather, these actions define a realistic and flexible process that provides the basis for making near-term decisions on the allocation of resources for planning future efforts. The least predictable constraint on program planning is the budget level that will be available. The process defined here allows adjustment to varying budget levels.

Programmatic Themes

Five basic themes drive the development of OSSA's strategy and provide a template on which the program is built. Ideally, at least one new initiative for each theme except the current program would be included each year, and the initiatives under each theme would be systematically pursued, in sequence, by priority.

(1) The Current Program

First and foremost for missions in the current program, the scheduling, resource allocations, and manifested slots on the Space Shuttle or an expendable launch vehicle must be protected and ensured. The same high level of priority applies to current research programs, to mission-operations activities, and to data-analysis activities.

(2) Leadership through Major and Moderate Missions

OSSA plans to move boldly forward to make fundamental and visible advances in key areas of space science, so as to ensure that U.S. world leadership is preserved in the future. Because major and moderate missions provide the largest leaps in the advancement of scientific knowledge and technological ability, the U.S. pursuit of leadership is most conspicuous through them.

(3) Increased Opportunity with Small Missions

Small missions are vital to the program because they can be accomplished relatively inexpensively, allowing consideration of ideas that are more innovative, and therefore of higher risk, and because they can be conducted on a short time scale, offering quick turnaround and continuing opportunity. The small missions are particularly important for the training of the next generation of scientists and engineers, since the missions are of a size that universities can develop, and the development and flight of small missions can occur in the same length of time as that required to earn a graduate degree.

(4) The Transition to Space Station

Beginning with Spacelab and other in-space facilities, it is time to move aggressively, but sensibly, to develop the principal areas of space science and applications that will take advantage of unique Space Station opportunities. These opportunities include pressurized laboratories for microgravity science and life sciences research, the multidisciplinary use of attached payloads, and polar platforms for Earth science research.

(5) The Research Base

OSSA's research and analysis program supports a vigorous and productive research community and presents a special opportunity for students to develop the skills that will enable them to conduct the programs of the future. Parts of the program need early enhancement, especially the replacement of aging laboratory equipment, the increase of theory and data-analysis funding in certain disciplines, and the ground-based and suborbital programs.

Decision Rules

In the event that the budget or other aspects of the external environment do not accommodate simultaneous enhancements in all areas, the following decision rules have been formulated to determine the mix of program elements that will be undertaken:

(1) Completion of the Current Program

Completion of the ongoing program always has the highest priority; no resources allocated to those programs already under way will be sacrificed or postponed in order to pursue new initiatives.

(2) Initiation of a Major or Moderate Mission Each Year

Major missions preserve and enhance U.S. leadership in key areas of space science and applications; they will be pursued whenever available resources allow. If an assessment of foreseeable expenditures for candidate missions, over both the near-term and the lifetime of the program, indicates that resources do not permit a major mission, a moderate mission will be pursued.

(3) Initiation of Small Missions in Addition to Major or Moderate Missions

In all cases, the program will endeavor to start a small mission or a small-mission program every year, in conjunction with either a major or a moderate mission.

(4) Determination of Space Station Initiatives by Scientific Discipline Pace and Balance, Relevance to Space Station, and Technological Maturity

The Office of Space Science and Applications will move forward systematically to provide a complete set of fully developed facilities and instrumentation for the Space Station.

(5) Seeking Research Base Augmentations Whenever they Are Warranted

The need for research-base augmentations is determined by the impact of the rest of the program on discipline stability, progress, and future needs.

Programs and Strategies by Discipline

Developing a strategy for the future program of OSSA and its discipline divisions begins in the scientific research community, where active collaboration between OSSA and the community translates goals into the program strategy for each discipline division. Several committees of the National Academy of Sciences and the NASA Advisory Council advise OSSA about broad issues of the overall Space Science and Applications program: the Space Science Board, the Space Applications Board, the Space Science and Applications Advisory Committee, and the Aerospace Medicine Advisory Committee. These standing committees and special ad hoc advisory bodies also specifically address the challenges and charters of each of the scientific disciplines that fall under OSSA's umbrella. Focused groups, such as scientific working groups and project definition teams, provide more specific recommendations regarding near-term strategies.

With the recommendations of these advisory groups as detailed objectives, and with the overall goals for Space Science and Applications providing the framework, each scientific discipline formulates specific program plans designed to focus on a particular aspect of the Space Science and Applications program. Each division strives to complement the other six, and each formulates a strategy that can be integrated into a comprehensive, cohesive plan. The plan then provides a context for decision-making within OSSA.

In this section, which comprises pages III-14 through III-69, each discipline is addressed individually. For each discipline, current programs are summarized, and then the strategy guiding the discipline's future activities is discussed. The integration of these individual plans is the basis of the overall strategy for Space Science and Applications.

Astrophysics

The astrophysics program seeks to understand the origin and fate of the universe; to understand the birth and evolution of the large variety of objects in the universe, from the most benign to the most violent; and to probe the fundamental laws of physics by examining their behavior under extreme physical conditions. These goals are pursued through contemporaneous observations across the entire electromagnetic spectrum, and through theoretical interpretation of radiation and fields associated with astrophysical systems.

The astrophysics program is structured around its four primary objectives:

(1) establishment of permanent observatories for viewing the universe in four major wavelength regions of the electromagnetic spectrum (infrared, optical/ultraviolet, X-ray, and gamma-ray bands);
(2) obtainment of crucial bridging and supporting measurements via directed-objective missions of intermediate and small scope conducted within the Explorer and Spacelab programs;
(3) enhancement of scientific access to results of space-based research activities, including problem-oriented, multidisciplinary studies implemented through the Astrophysics Data System program; and
(4) development and maintenance of the scientific/technical base for space astrophysics programs and missions via research and analysis and suborbital programs.

In addition, an advanced planning activity is conducted to identify and direct the early definition of new mission candidates.

The highest priority for Astrophysics is the completion of the Great Observatories program, which will provide the backbone for a coordinated, multispectral observing program. The Great Observatories (Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, and Space Infrared Telescope Facility) will observe the universe with unprecedented completeness and sensitivity across the electromagnetic spectrum.

Current Programs. The astrophysics program's one operating spacecraft, the International Ultraviolet Explorer, is in its tenth year of operation. Conducted in cooperation with the Netherlands and the United Kingdom, the project supports approximately 230 guest investigators per year.

**International Ultraviolet Explorer (IUE)
(Astrophysics)**

The IUE was developed to measure ultraviolet spectra of astronomical objects. It consists of a small (0.45-meter diameter) ultraviolet telescope, spectrographs, and a camera. IUE was placed in geosynchronous orbit in 1978. It is a cooperative mission between NASA, the European Space Agency, and the Science and Engineering Research Council of the United Kingdom. The observing time and spacecraft control are shared by the sponsoring agencies. After ten years of continuous operations in orbit, IUE is still producing valuable scientific results and has become one of the most productive scientific instruments ever created.

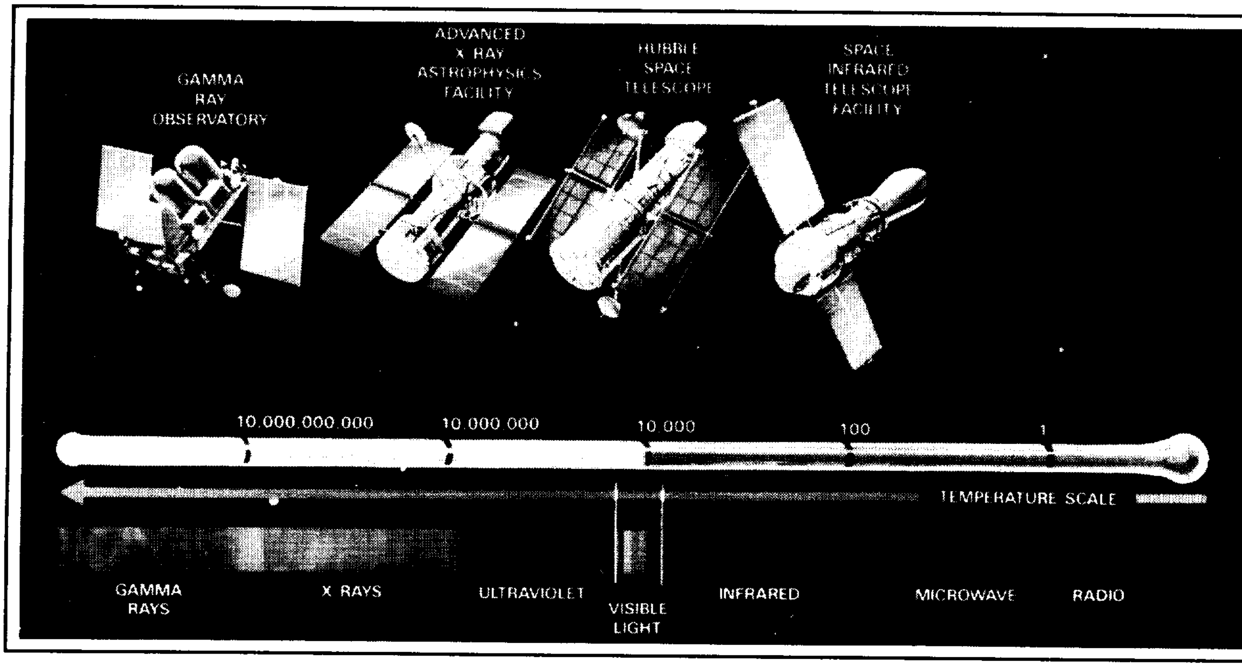


Figure III-2. The Great Observatories

The Hubble Space Telescope, the first of the Great Observatories, is scheduled for launch in early 1990. The Gamma Ray Observatory, second of the Great Observatories, will be launched in 1990. In addition to the Gamma Ray Observatory mission, two moderate astrophysics missions, the Cosmic Background Explorer and the Roentgen Satellite, are scheduled for launch in 1990. The Cosmic Background Explorer will investigate the creation of the universe using the oldest information—the cosmic microwave background radiation believed to be a remnant of the big bang explosion that created the universe.

The Roentgen Satellite (ROSAT) is a cooperative X-ray astronomy mission with the Federal Republic of Germany, with whom the data obtained will be shared. NASA is providing the Delta launch vehicle and a high-resolution X-ray imaging instrument. Development of the high-resolution imager is complete and initial integration with the spacecraft has been accomplished.

Figure III-3. Hubble Space Telescope

Hubble Space Telescope (HST)
(Astrophysics)

HST is the visible-light element of the Great Observatories program that will provide coverage of the visible and ultraviolet portions of the spectrum. It will be a free-flying observatory with a 15-year operational lifetime achieved through on-orbit servicing via the Space Transportation System or the Space Station. HST will have a mass of 11,600 kg, and will fly in a 28.5-degree inclination, 600-km circular orbit. It carries a 2.4-meter optical telescope with a cluster of five Principal Investigator-developed instruments at its focal plane. The European Space Agency has provided one science instrument and the solar arrays. HST science instruments are replaceable, to achieve state-of-the-art performance throughout HST's operational lifetime. A later payload may include cryogenically cooled detectors to extend HST's operational range into the near infrared.

HST will investigate the constitution, physical characteristics, and dynamics of celestial bodies. It will determine the nature of processes occurring in stellar and galactic objects, study the history and evolution of the universe, and confirm the universality of physical laws.

Gamma Ray Observatory (GRO)
(Astrophysics)

GRO, the gamma ray element of the Great Observatories program, will be a free-flying observatory with an operational lifetime of four years. This lifetime can be extended to eight years through reboost of the spacecraft and refueling of its Multimission Modular Spacecraft modules. GRO will cover a wavelength range of 0.05 to 30,000 Mev, and its 15,790-kg mass will orbit at an altitude of 350-450 km and an inclination of 28.5 degrees. Its complement of science instruments, developed by Principal Investigators, includes an oriented scintillation spectrometer experiment, a Compton telescope, an energetic gamma ray experiment, and a burst and transient source experiment. The Compton telescope has been developed in the Federal Republic of Germany.

Launched by the space shuttle, the Gamma Ray Observatory will:

(1) study gamma ray emitting objects originating in our galaxy and beyond;
(2) investigate evolutionary forces in neutron stars and black holes;
(3) search for evidence of nucleosynthesis; and
(4) search for primordial black hole emissions.

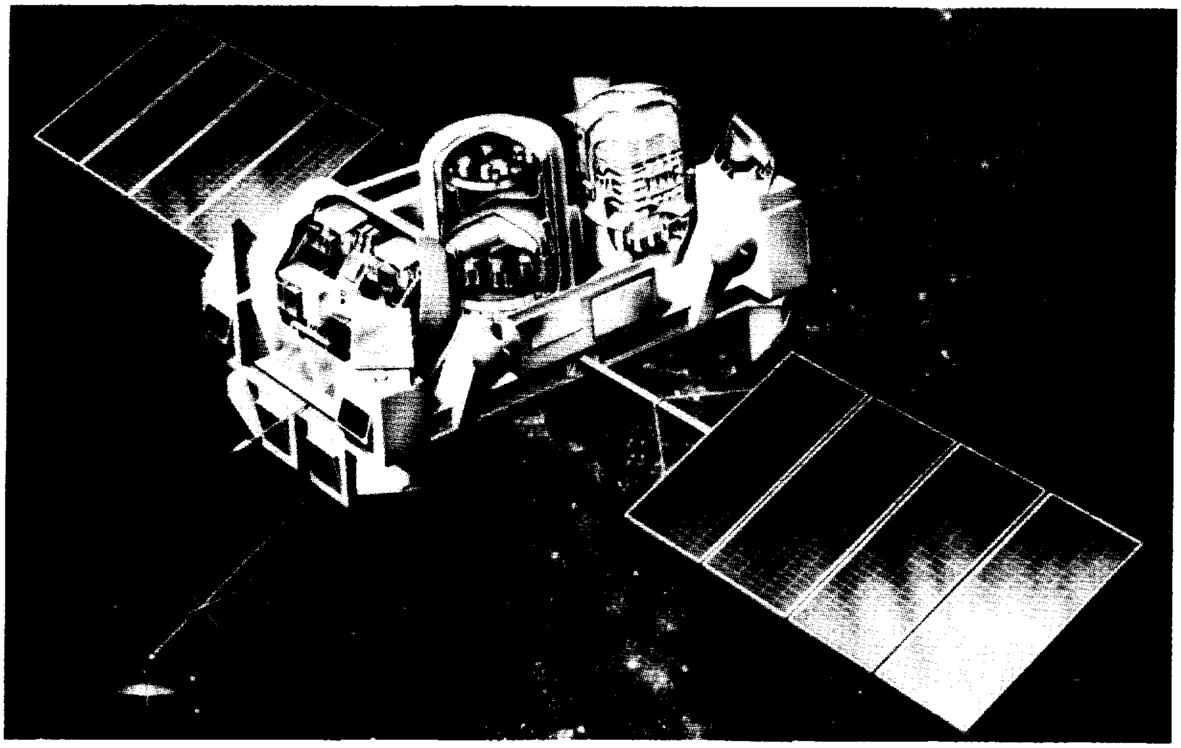


Figure III-4. Gamma Ray Observatory

Cosmic Background Explorer (COBE)
(Astrophysics)

COBE is a free-flying Delta-class Explorer to be launched into a near-polar orbit at a mission altitude of 900 km. It will perform measurements in the wavelength range of 1 micrometer to 10 millimeters, using a cryogenically cooled telescope with focal plane instruments developed by Principal Investigators: the Far Infrared Absolute Spectrophotometer, the Differential Microwave Radiometer, and the Diffuse Infrared Background Experiment.

COBE will measure the presence of the 3-degree Kelvin, cosmic background radiation as a remnant of the primeval explosion (the Big Bang), and will detect accumulated light from the very first stars and galaxies. It will confirm the spectral predictions and the suspected brightness anisotropy of the background radiation, and will provide the most comprehensive observations to date of the radiative energy content of the universe. COBE will also investigate the presence of dark matter in the universe, the nonuniform distribution of galaxies, the age of the universe, and the fate of the universe.

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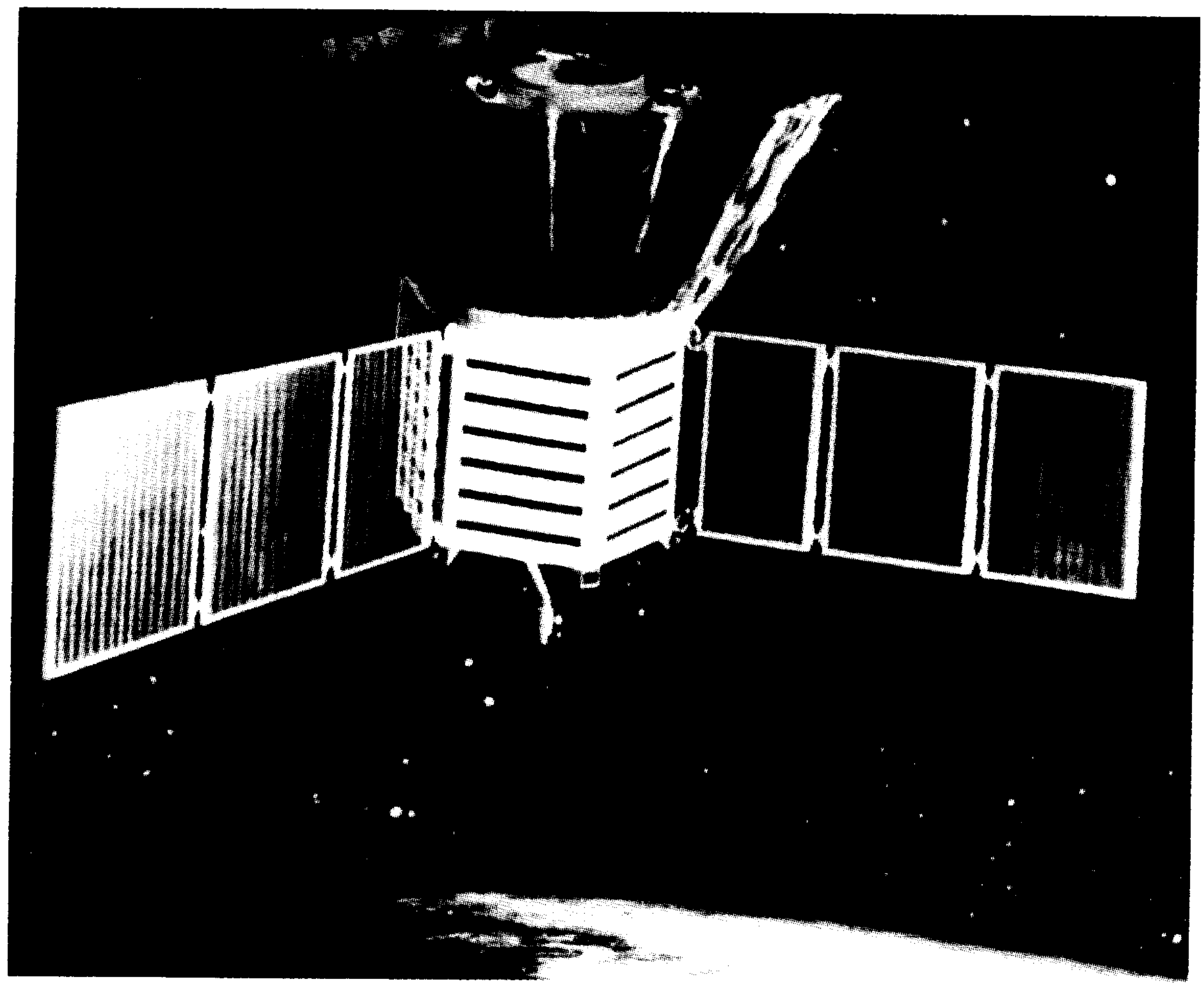

Figure III-5. Cosmic Background Explorer

Roentgen Satellite (ROSAT)
(Astrophysics)

ROSAT is an Earth-orbiting X-ray observatory that will fly at a 57-degree inclination and 430-km altitude. It has a fourfold, nested, grazing-incidence mirror system with an 83-cm aperture and a 240-cm focal length, and covers the wavelength range from 0.1 to 2.0 keV. Its expected operational lifetime is approximately three years. It is a cooperative NASA/Federal Republic of Germany X-ray astronomy mission viewed by NASA as a stepping stone toward the Advanced X-ray Astrophysics Facility. Germany is providing the spacecraft and main telescope, NASA the high resolution imager and launch services. Operations and data analysis will be shared.

The ROSAT objectives are to:

(1) study coronal X-ray emission from stars of all spectral types,
(2) detect and map X-ray emission from galactic supernova remnants,
(3) evaluate the overall spatial and source count distributions for various X-ray sources,
(4) perform detailed study of various populations of active galaxy sources (Seyferts, QSOs, etc.),
(5) perform morphological studies of X-ray emitting clusters of galaxies, and
(6) perform detailed mapping of the local interstellar medium.

Launched on an expendable Delta launch vehicle, ROSAT will be a key link between the spectacularly successful X-ray astronomy mission of the High Energy Astronomical Observatory-2 and the much more powerful Advanced X-ray Astrophysics Facility mission.

The Extreme Ultraviolet Explorer (EUVE), to be launched on a Delta rocket in 1992, will be the first mission to be launched on the reusable Explorer platform. It will conduct the first high-sensitivity survey

Extreme Ultraviolet Explorer (EUVE)
(Astrophysics)

EUVE will consist of four grazing incidence telescopes and a variety of optical filters. It will be mounted on an Explorer Platform. It will map approximately 95% of the sky in 0.1-degree increments for an all-sky survey. A subsequent deep survey, in the extreme ultraviolet region of the spectrum, will scan a region 2 degrees wide by 180 degrees long along the ecliptic, again in 0.1-degree increments.

Launched on a Delta vehicle, EUVE will be placed in a circular orbit at a 500-km altitude and 28.5-degree inclination. The mission duration will be at least 30 months. At the end of its lifetime, it will be exchanged for a new payload, the X-Ray Timing Explorer, via in-orbit servicing. The primary responsibility for the EUVE payload rests with the University of California at Berkeley.

The EUVE objectives are to:

(1) produce the first peripheral sky map in the 800- to 900-Angstrom portion of the spectrum,
(2) perform follow-up spectroscopic observations on bright extreme ultraviolet point sources,
(3) study stellar evolution and the local stellar population,
(4) perform spectral emission physics investigations, and
(5) study ionization and opacity of the interstellar medium.

of the entire sky in extreme ultraviolet wavelengths. After two years of operation, it will be replaced with the X-Ray Timing Explorer, which will be carried into space aboard the space shuttle.

Explorer Platform (Astrophysics)

Explorers are free-flying scientific spacecraft that may be solar-, celestial-, or Earth-pointing. Explorer Platform missions will include missions like the Extreme Ultraviolet Explorer and the X-Ray Timing Explorer.

The Explorer Platform is a reusable spacecraft based on the Multi-mission Modular Spacecraft (MMS) and an equipment deck. The MMS, which has been used for both solar- and Earth-pointing missions, provides all utilities for its payloads and can be serviced in-orbit. The Platform can be launched on either a Delta-class expendable launch vehicle or the space shuttle. When launched on a Delta-class vehicle, it can carry a 4,000-lb payload; when launched on the space shuttle, it can carry more than 10,000 pounds. It is designed to have a 10-year operational lifetime, assuming on-orbit servicing and an occasional reboost. To accommodate more than one mission, it may be converted on orbit and reused . A typical scenario involves retrieval of the Explorer Platform, changeout of its science payload, and then redeployment.

A payload module is connected to an MMS through a standard platform equipment deck. The Platform includes the following:

(1) a standard triangular MMS structural subsystem,
(2) one high gain antenna,
(3) an MMS Modular Power Subsystem module,
(4) an MMS Communications and Data Handling module,
(5) an MMS Modular Attitude Control Subsystem module, and
(6) a platform equipment deck with solar arrays and six equipment drawers.

X-Ray Timing Explorer (XTE) (Astrophysics)

XTE will probe the physics of cosmic X-ray sources by making sensitive measurements of their rich temporal variability over time scales ranging from milliseconds to years. Their time behavior is the source of important information about processes and structures in white-dwarf stars, X-ray binaries, neutron stars, pulsars, and black holes. For studying known sources and detecting transient events, observations are required over an extended period with instruments sensitive to X-ray energies from 2,000 to 10,000 electron volts.

The objectives of XTE are to investigate:

(1) periodic, transient, burst, and white-noise fluctuations in X-ray emissions,
(2) relaxation times for the interior structure of neutron stars,
(3) binary stellar masses, separation distances, and orbit eccentricities, and
(4) mass exchange between ordinary and degenerate stars in binary systems.

XTE will be placed on an Explorer Platform through an on-orbit changeout procedure.

Planned Initiatives. The Advanced X-Ray Astrophysics Facility (AXAF), the third Great Observatory, is the highest priority new initiative in the astrophysics program. AXAF will extend the spectral coverage of the Great Observatories into the X-ray region of the electromagnetic spectrum. Development of the high-resolution mirror, to begin in FY 1989, will make possible a full-up spacecraft development start in FY 1992 and a launch in 1996.

The next major initiative in the astrophysics program is the Space Infrared Telescope Facility (SIRTF), the fourth Great Observatory. It will complete the spectral coverage of the Great Observatories by extending high-sensitivity, high-resolution astronomical observations into the infrared. Definition studies of SIRTF, currently in process, are directed toward receiving administrative approval for development in the early 1990s.

The second mission for the Explorer platform will be the X-Ray Timing Explorer (XTE). Complementing AXAF with higher energy sensitivity and high time resolution, XTE will obtain important information by studying the time variations of astronomical emissions in the X-ray domain. XTE is currently in the definition phase; mission development is expected to begin in FY 1989.

Advanced X-Ray Astrophysics Facility (AXAF)
(Astrophysics)

AXAF is a telescope facility designed to observe the universe in the X-ray region of the electromagnetic spectrum. Launched on the shuttle, AXAF will be a free-flying observatory with an operational lifetime of 15 years and a science payload unit developed by Principal Investigators. The AXAF telescope consists of a nested array of grazing incidence mirrors, up to four focal plane science instruments, and two sets of objective gratings. With a geometric collecting area of 1,700 square cm and a 0.5-arcsecond angular resolution, the AXAF telescope will provide a 100-fold increase over its predecessor, the High Energy Astronomical Observatory-2. AXAF will have 1,000 times more capability for spectroscopy than any previous or planned X-ray mission.

The objectives of AXAF are as follows:

(1) obtain high-resolution X-ray images and spectra in the 0.1 to 10 keV wavelength range,
(2) investigate the existence of stellar black holes,
(3) study the contribution of hot gas to the mass of the universe,
(4) investigate the existence of dark matter in galaxies,
(5) study clusters and superclusters of galaxies,
(6) investigate the age and ultimate fate of the universe,
(7) study mechanisms by which particles are accelerated to high energies,
(8) confirm the validity of basic physical theory in neutron stars, and
(9) investigate details of stellar evolution and supernovae.

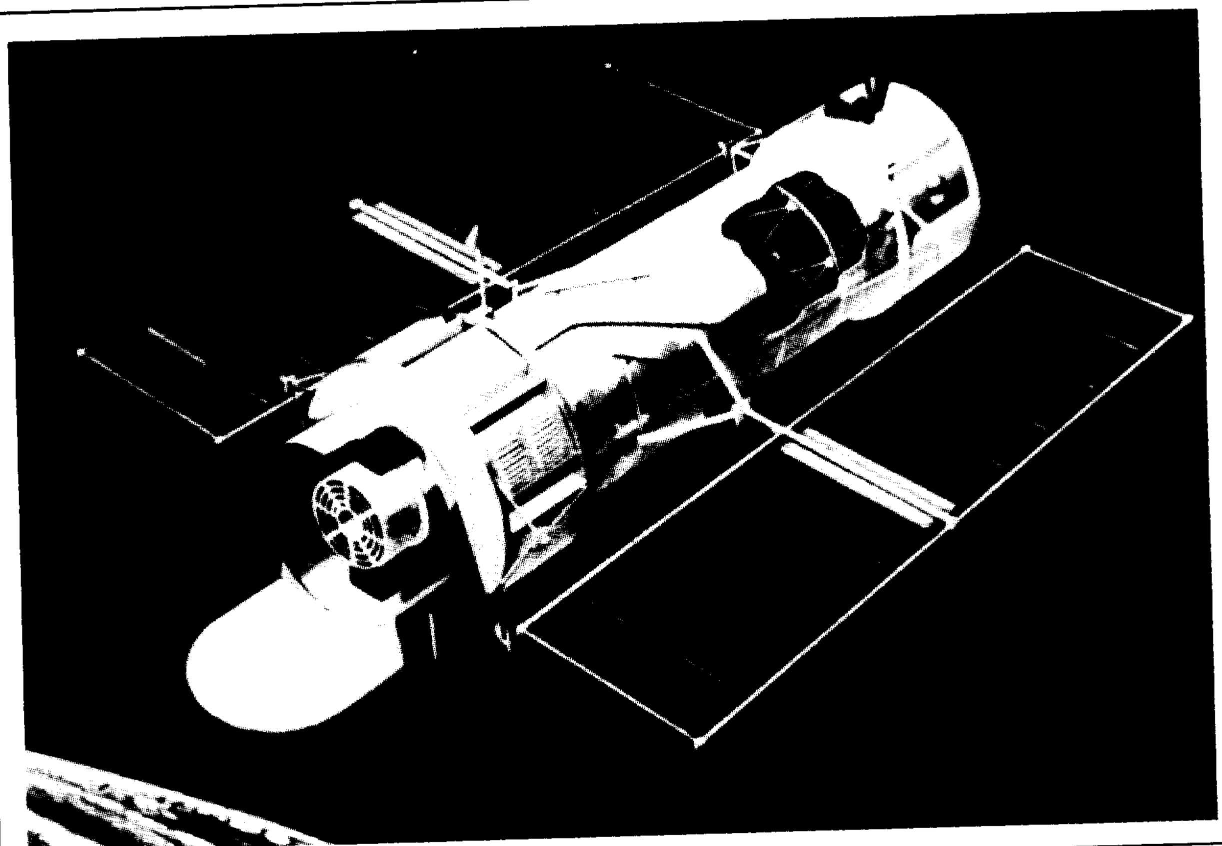

Figure III-6. Advanced X-Ray Astrophysics Facility

Space Infrared Telescope Facility (SIRTF)
(Astrophysics)

Originally planned as a Spacelab facility, SIRTF has been redesigned to be the fourth Great Observatory. It will provide unprecedented spatial and spectral resolution in the infrared region of the electromagnetic spectrum. To achieve this resolution, its complement of four science instruments will be cryogenically cooled. This long-lived, meter-class, infrared observatory will study the very cold regions of space. It will be launched by the space shuttle and serviced by the shuttle and the Space Station.

Regions and objects the facility will study are:

(1) locations where the cosmic gas and dust condense into stars;
(2) cool objects in the solar system—planetary systems, asteroids, and comets; and
(3) infrared-emitting extragalactic objects.

SIRTF will be 1,000 times more sensitive than the Infrared Astronomical Satellite. One of its major applications will be to obtain detailed infrared spectrometry of the faint infrared sources that the Infrared Astronomical Satellite discovered but could not observe in detail.

NASA has selected four larger, Delta-class Explorer missions for study during the next year. The missions to follow XTE will be selected from them. The Far Ultraviolet Spectroscopy Explorer and the Nuclear Astrophysics Explorer are astrophysics missions; the remaining two—the Advanced Composition Explorer and the Mesosphere and Lower Thermosphere Explorer—are, respectively, space physics and Earth science missions.

Far Ultraviolet Spectroscopy Explorer (FUSE) (Astrophysics)

FUSE will be a 1-meter class telescope equipped for very-high-resolution spectroscopy in the spectral region from 900 to 1,200 Angstroms. Its objectives are to expand the preliminary studies initiated by the third Orbiting Astronomical Observatory and to act as a scientific complement to the Hubble Space Telescope and planned X-ray missions. Information on many spectral features that lie in the 900- to 1200-Angstrom band is essential to an understanding of the interstellar gas, extended stellar atmospheres, supernova remnants, galactic nuclei, and processes in the upper atmospheres of planets. FUSE will rely on short-wavelength gratings to disperse the spectrum.

Nuclear Astrophysics Explorer (NAE) (Astrophysics)

The Nuclear Astrophysics Explorer is a Delta-class, Explorer-Platform mission that will use nine cooled germanium detectors to make high-resolution ($E/\Delta E \sim 1000$) observations of gamma ray lines at a sensitivity 100 times better than that of previous instruments for the purpose of studying nucleosynthesis, supernova dynamics, neutron stars, and black holes.

In addition to using Delta-class Explorers, NASA expects to initiate a "Scout-class" of Explorers. Although the constraints on weight, telemetry, etc. for Scout-class missions will be more stringent than those for Delta-class missions, it is anticipated that a significant number of scientifically exciting missions will be possible, and that they can be developed on a short time scale. An Announcement of Opportunity for this small-Explorer class of missions was issued in May 1988. A peer review of proposals is expected to result in the selection of several missions for development. An initial launch can occur as early as 1990. While management responsibility for the Explorer program resides within the Astrophysics Division, the program supports scientific requirements of a broader scientific community that includes Astrophysics, Space Physics, and parts of Earth Science and Applications.

Activities also will be initiated to complete the general relativity investigation known as Gravity Probe-B. Plans are for this unique, moderate scale mission to have its integrated system test in 1989, and a space shuttle engineering test in 1993. Following administrative approval, the full spacecraft and experiment can be integrated and launched into a polar orbit, potentially as early as 1995.

The Japanese ASTRO-D, currently planned for launch in 1993, is an X-ray astronomy mission that NASA is currently investigating for potential U.S. cooperation.

Gravity Probe-B
(Astrophysics)

The Gravity Probe-B mission will investigate the structure of space and time through the theory of general relativity. Gravity Probe-B is an orbiting, cryogenically cooled gyroscope experiment designed to test a fundamental concept of general relativity by measuring the precession of orbiting gyroscopes as they move through a gravitational field twisted by Earth's rotation (relativistic spin-spin coupling). This twisting of a gravitational field acts as a force that is to gravity what magnetism is to electricity. The effect is very small and the experiment can be carried out only in space. The required technology has been under development since 1965.

Research Base. Space shuttle attached payloads continue to occupy a key position in the research base of the NASA astrophysics program. Two payloads—Astro and the Shuttle High Energy Astrophysics Laboratory — are planned for launch soon after the resumption of shuttle flights. Astro, planned for a Spacelab flight in early 1990, will contain three ultraviolet instruments, and efforts are under way to investigate the possibility of adding the Broad Band X-Ray Telescope instrument to conduct wide-band observations of Supernova 1987a at a key stage in its early evolution. The Shuttle High Energy Astrophysics Laboratory (SHEAL) will carry two X-ray astronomy instruments and is scheduled for flight in 1991 or 1992.

Two enhancements to the astrophysics research base are planned. The first enhancement is modification of a Boeing 747 aircraft to carry the Stratospheric Observatory for Infrared Astronomy (SOFIA). The result will be a significant increase in the capability to use suborbital observations to advance infrared astronomy and an opportunity for scientists to follow up on the exciting discoveries of the Infrared Astronomical Satellite in the interim until launch of SIRTF.

Astro
(Astrophysics)

Astro consists of a complement of three ultraviolet instruments that will provide unique imaging, polarimetric, and spectroscopic observations of cosmic sources in the important spectral region from 500 to 3,000 Angstroms. This region lies between the spectral coverage of the Hubble Space Telescope and the Advanced X-ray Astrophysics Facility. The instruments, mounted on two pallets, will complement and extend the capabilities of the International Ultraviolet Explorer and the Hubble Space Telescope by providing spectral coverage in the far ultraviolet, by observing circular as well as linear polarization, and by employing a much wider field of view (up to 40 arcmin).

Astro will study the behavior of quasars, galaxies, and active galactic nuclei in the far ultraviolet. With its broad field of view, Astro will investigate the behavior of hot stars and galaxies in broad ultraviolet wavelengths. It also will explore polarization characteristics of hot stars, galactic nuclei, and quasars.

Shuttle High Energy Astrophysics Laboratory (SHEAL) (Astrophysics)

The SHEAL program consists of a series of shuttle-Spacelab flights using two X-ray instruments that will use specialized techniques for investigations in high-energy astrophysics.

The two SHEAL instruments are the Diffuse X-ray Spectrometer, which will probe the origin of the hot interstellar medium via high-resolution spectroscopy of the soft X-ray background, and the Broad Band X-Ray Telescope, which will provide high-sensitivity, moderate-resolution spectroscopy of discrete sources in the spectral region that includes the important features due to fully ionized iron.

Stratospheric Observatory for Infrared Astronomy (SOFIA) (Astrophysics)

SOFIA is a telescope in the 3-meter class planned for flight in a modified Boeing 747 airplane to observe, with good angular resolution at infrared wavelengths inaccessible from the ground, sources identified by the Infrared Astronomical Satellite. A facility with tremendous potential for science, SOFIA will offer an improvement in resolution over the 0.9-meter Kuiper Airborne Observatory. Like the Kuiper, SOFIA will be readily available to the scientific community. It will have a short turnaround time, and will be flown on a reliable, reusable vehicle.

The second enhancement is the definition and implementation of the Astrophysics Data System, a system that will ensure the fullest access to and exploitation of various mission data sets. Emphasis will be given to the wealth of data to be returned by the Great Observatories, but data from the International Ultraviolet Explorer, the Infrared Astronomical Satellite, and the High Energy Astronomy Observatories continue to be of importance and will be included. An initial definition process involving extensive inputs from the astrophysics community has been completed, and installation of the principal elements of this essential system will begin in FY 1989.

The unexpected appearance of Supernova 1987a has provided the opportunity and impetus for a special study in the astrophysics research and analysis program. This program has provided basic support for the development of the infrared, ultraviolet, X-ray, and gamma-ray instruments that are being flown on balloons and rockets to observe the supernova, and for the formulation of theoretical models of the expected light curve, which have provided invaluable assistance in planning an optimal observing program.

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Communications and Information Systems

The communications research program focuses on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. It is structured around the development of advanced technology to use more effectively the electromagnetic spectrum and the geosynchronous orbit. This research reduces industry's adoptive risk and improves the Nation's competitive posture in the world marketplace. The use of sophisticated communications technology also enables scientific advancement through extremely efficient, wideband space communications. Scientific advancement, in turn, enables and enhances future near-Earth and space exploration missions.

The communications program develops positions to take, and supports U.S. and NASA interests in, international and domestic communications regulatory forums. It also uses NASA's resources to provide consultation, perform system studies, and plan and conduct space experiments in support of other Government agencies.

Current Programs. The Advanced Communications Technology Satellite program remains the centerpiece of NASA's communications activities in support of U.S. industry. In addition, NASA will continue to operate the Applications Technology Satellite, which provides vital support to the National Science Foundation, the National Oceanic and Atmospheric Administration, the Department of Defense, the Department of the Interior, the Drug Enforcement Agency, a number of universities,

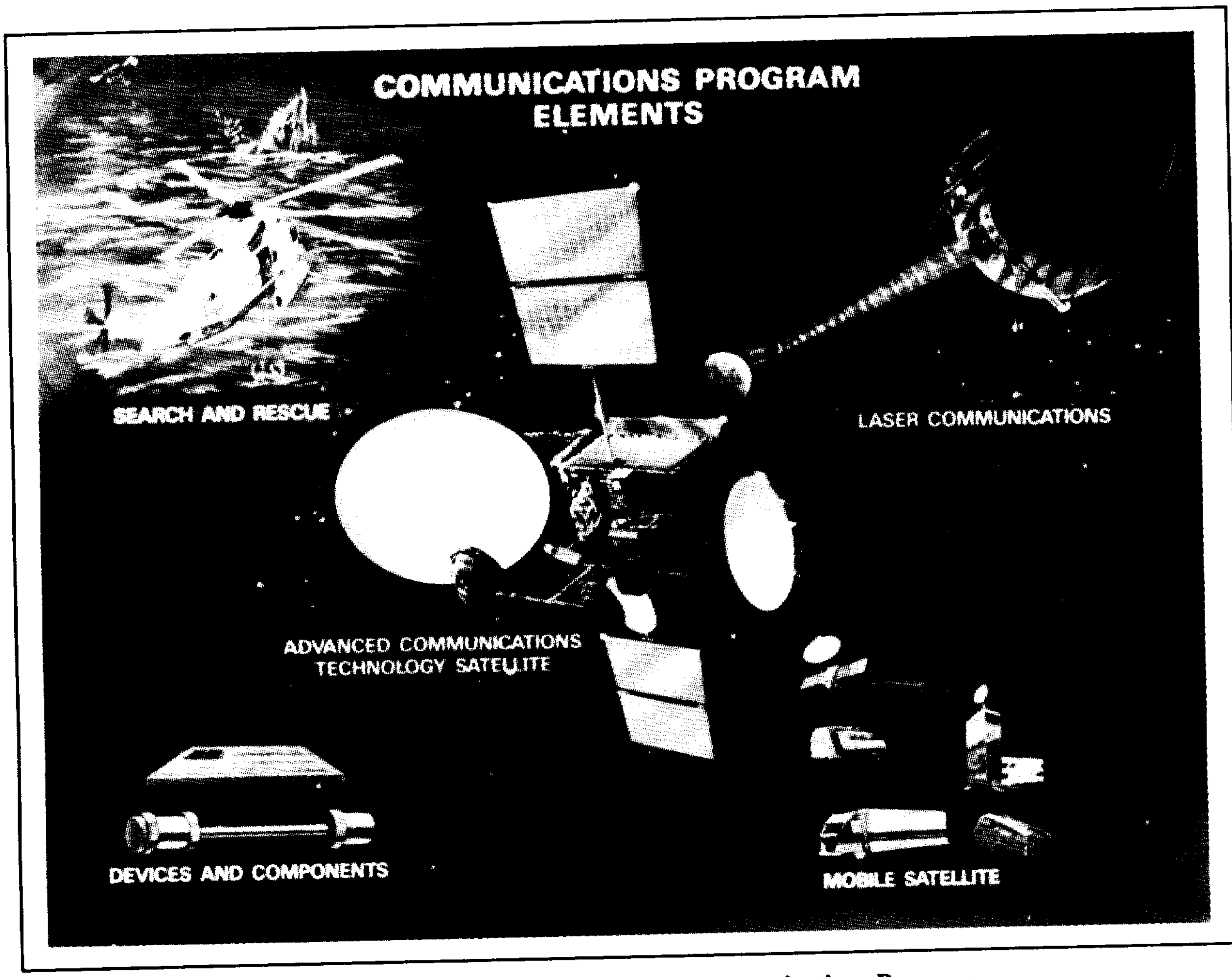

Figure III-7. Major Features of Communications Program

C-2

Advanced Communications Technology Satellite Program (ACTS) (Communications and Information Systems)

The ACTS system includes revolutionary technologies that will lay the foundation for the next generation of commercial communications service. Its steerable and spot-beam antennas, together with on-board processing, will provide full networking flexibility throughout the hemisphere and provide a capability for high bit rate communications to small terminals. To be built by RCA Corporation, teamed with TRW, Inc. and COMSAT Corporation, ACTS will be applicable to a wide range of communication systems in the 1990s.

ACTS program goals are to:

(1) develop the high-risk advanced communications technology required for future satellite systems,
(2) promote effective use of the frequency spectrum and growth in communications capacity, and
(3) ensure continuous U.S. preeminence in the satellite-communications industry.

The ACTS spacecraft will be launched from the shuttle via a Transfer Orbit Stage into geostationary orbit. Following launch and checkout, a 2-year program is planned for user-funded experiments. The objective of the experiments will be to test, demonstrate, and evaluate the key technologies of the ACTS system.

Application Technology Satellites (ATSs) (Communications and Information Systems)

The ATSs of the 1966-1974 era were precursors to current maritime, land, and aeronautical mobile satellite services. ATS-1, in orbit since the 1960s, was the backbone of southern Pacific Island communications. ATS-6 and the joint Canadian-NASA Communication Technology Satellite provided the basis for today's new broadcast satellite service industry. ATS-6 also provided the first tests of educational instruction via satellite transmissions and supplied the means for conducting signal and propagation experiments at 20 and 30 GHz. The Communication Technology Satellite opened the door to a whole new generation of fixed-service satellites operating in the 12 GHz band.

state and local governments, and domestic and international disaster relief organizations. That support, provided through satellite voice and data links, has been given to experiments in North and South America, most of the eastern Pacific Ocean, Hawaii, and Antarctica. The experiments relate to communications applications in science, education, and disaster relief.

In the Satellite-Aided Search and Rescue program, a third U.S. satellite was placed in orbit in 1988. Fourteen local ground-station user terminals were in operation by the end of the second quarter of 1988. By the end of 1988, an experiment using geostationary satellites to provide more nearly instantaneous alerting and identification will be performed. Efforts will be continued in 1989 to improve the locating accuracy of the system, to make the service available to a broader spectrum of users, and to reduce false alarms and the cost-performance ratio of emergency beacons.

Satellite Aided Search and Rescue Program (SARSAT) (Communications and Information Systems)

The SARSAT program is the U.S. part of the international satellite-aided search and rescue program, which has already been credited with saving over 1,000 lives. The U.S. program is a joint effort of NASA, the National Oceanic and Atmospheric Administration, the Coast Guard, and the Air Force. NASA is responsible for research and development activities. Five satellites are now in service, two from the U.S. and three from the U.S.S.R. The current SARSAT ground system consists of six mission control centers in the U.S., Canada, France, Norway, the U.S.S.R., and Great Britain.

Essentially all of the technology developments for Mobile Satellite activities, which are undertaken in close coordination with industry, are scheduled for completion by the end of 1988. Some hardware is now undergoing field testing, with completion scheduled for FY 1989. In addition to its relationship with industry, NASA will be working closely with over 25 other government agencies in a joint experimental program. The Agency also will investigate the feasibility of a flight experiment to validate the technology for large, multibeam antennas needed for satellite services supporting future mobile and personal communications. Such an endeavor has been strongly supported by industry and could be carried out in conjunction with the Space Station. A major government-industry conference to facilitate the transfer of technology was held in May 1988.

The Mobile Satellite program, including the effort to obtain operational frequencies, has served as a focal point to accelerate the introduction of mobile satellite service in the United States. A private consortium has been formed and currently is preparing a filing to the FCC to provide that service. Licensing approval to own and operate such a system could be granted within months, with satellite launch in the early 1990s.

Mobile Satellite Program (MSAT) (Communications and Information Systems)

MSAT is a joint NASA-industry program to accelerate the introduction of mobile satellite service in the United States and to develop the enabling technologies needed for effective use of the spectrum and for future growth. The first-generation system will be paid for and built by industry, will be launched by NASA, and will contain a small amount of channel capacity to carry out U.S. Government experiments. Launch will be by the shuttle or an expendable vehicle.

MSAT, an approved flight program since 1985, has objectives to:

(1) develop high-risk technology to enable commercial mobile satellite service,
(2) facilitate development of new markets for satellite and ground terminal hardware,
(3) develop terminal hardware that is frequency and power efficient,
(4) develop networking techniques for use in experimental government applications, and
(5) promote growth of commercial services.

A successful mobile satellite system has the potential to satisfy unique public service needs, improve U.S. productivity, and create a new multibillion-dollar service and hardware industry.

Continuing Radio Science and Support Studies will provide the technical basis for developing national and international policies, regulations, and telecommunications standards to ensure the orderly growth of existing and new communications satellite services for U.S. and NASA science programs. The Agency has provided direct support to the Department of State, National Telecommunications Information Administration, and Federal Communications Commission.

In FY 1988, NASA completed development of a concept for allotment of the geostationary orbit arc as part of U.S preparations for the 1988 Space World Administrative Radio Conference. This arc allotment concept is unique and is essential to the growth of U.S. communication satellite service. During the latter part of 1987, the Agency participated in the World Administrative Radio Conference on mobile communications to support its land and aeronautical mobile satellite services, search and rescue, and science interests. With respect to the Land Mobile Satellite Service area, worldwide recognition and frequency allocations were obtained. This recognition was the culmination of more than 10 years of studies, experiments, and regulatory proceedings. The allocations of frequencies for this new service will help spawn a major new industry in the 1990s.

In 1988, NASA will complete work on its method of planning the allotment of the geostationary orbit arc, and will provide key support at the second session of the Space World Administrative Radio Conference. The Agency also will continue to develop system concepts and techniques to maximize use of the scarce, finite, geostationary orbit arc and radio spectrum resources. It also will complete critical propagation experiments applicable to improving overall system performance. The propagation work supports activities of over a half dozen universities throughout the U.S. and is a major contributor to the U.S. position for the International Telecommunications Union in Geneva.

New Initiatives. Communications research will continue to focus on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. The development work, building on the technology for the Advanced Communications Technology Satellite and mobile satellite, will enable future satellite communications systems to provide high-capacity information services at lower costs to smaller terminals for both fixed and mobile commercial and scientific applications. In addition, the Agency plans to interconnect commercial satellite systems, and to expand optical link developments that have the potential to increase greatly the rate of information that can be returned from deep-space missions. It also will interconnect commercial satellite systems.

Personal access communication technology extends mobile communication to its ultimate form, i.e., direct to the person two-way data and voice communications, using a very low-cost hand-held transceiver. The implementation of this technology depends heavily on the development and checkout of large spacecraft antennas. The Space Station would be used as a staging base for deployment and checkout of the antennas before their placement in final orbit.

Research Base. The Optical Communications program will continue development of technology for optical communications to a mature operational status and will support adoption of optical communications by the space communications community.

The Multidisciplinary Information Systems program continues to support Space Science and Applications flight projects and science programs in three basic ways:

(1) by operating large-scale computational resources for use in data analysis,
(2) by working with discipline programs to establish data centers for managing and distributing data, and
(3) by developing computer networks and exploiting advanced technologies needed to access and process the massive amounts of data acquired from successful space missions.

Several major data processing systems used by researchers to make large-scale computations and to test complex scientific models are located at NASA's Goddard Space Flight Center. These include supercomputing and data analysis resources in the Goddard Space and Earth Science Computing Center. In addition, the Communications and Information Systems program is responsible for the National Space Science Data Center, which archives data from science missions and coordinates overall management of NASA data at distributed data centers. The Science Internet program develops computer networks and explores new technologies to improve access to computers, data bases, and collaborators.

Optical Communications Program (Communications and Information Systems)

The Optical Communications Program has as its focus the flight testing of systems to support future NASA missions as well as the space demonstration of this technology to reduce its adoptive risk by the American space communications industry. This technology will both enhance and enable new science through increased data gathering, transceiving, and processing capability. For example, optical communications, with the advantages of unused spectrum and virtually unlimited bandwidth, will enable the enhancement of both near Earth and deep-space exploration missions through the use of telescience (the process of performing scientific research by employing distributed resources and manpower, integrated by high-speed communication links). In addition, operating in the optical region of the electromagnetic spectrum, with its inherently narrow beams and lack of radio frequency interference, makes optical communications technology ideal for use in regions of high density radio frequency communications such as Space Station.

In 1988, an electronic master directory was completed for all NASA-acquired data at the National Space Science Data Center, and development of compatible on-line catalogs for all science data centers began. The Agency also established international electronic access to the distributed discipline-data centers. This capability was fully exploited during NASA's SN1987A campaigns by researchers worldwide. Through its data systems technology program, NASA developed new capabilities to access and manage data for the astrophysics, planetary, and land processes disciplines.

In FY 1989, NASA will continue to develop improved capabilities to archive and distribute space data. The Agency will improve mass storage capabilities in order to provide high-performance access to data and delivery of data via wideband network interconnections. NASA will emphasize improved access to data facilities via international networks, interoperable on-line catalogs, and international data standards. Close coordination with the astrophysics and Earth science programs will continue in the development of information systems for long-term interdisciplinary flight missions. This activity includes integrating widely separated data centers into a unified information network to support interdisciplinary research. Such a unified data management capability will be especially needed in the 1990s by major missions such as the Advanced X-Ray Astrophysics Facility and the planned Earth Observing System.

NASA will continue, in FY 1989, to work with the National Science Foundation, the National Oceanic and Atmospheric Agency, and the United States Geological Survey in areas such as networking and supercomputer applications. This cooperation will provide technical consultation in key areas, such as Earth science, planetary science, astrophysics, and Space Station studies.

Earth Science and Applications

The challenge to Earth sciences as a whole is to develop the capability to predict changes that will occur within Earth, on its surface, and in its atmosphere over the next decades, whether they derive from presumed natural causes or are linked to human activity in a favorable or adverse way. As a research organization, the Earth Science and Applications Division supports development and use of quantitative models of elements of the Earth environmental system that can be used to anticipate future global trends. As an applications organization, the Division also supports development of research and operational sensors with which applicable data sets can be derived, for assessment and transfer into the private sector or to more operationally-focused federal agencies. Available to support both research and development is a data and information system through which scientists and operational users can assemble the information essential both for research and for effective environmental decision-making. Long-term reliability,

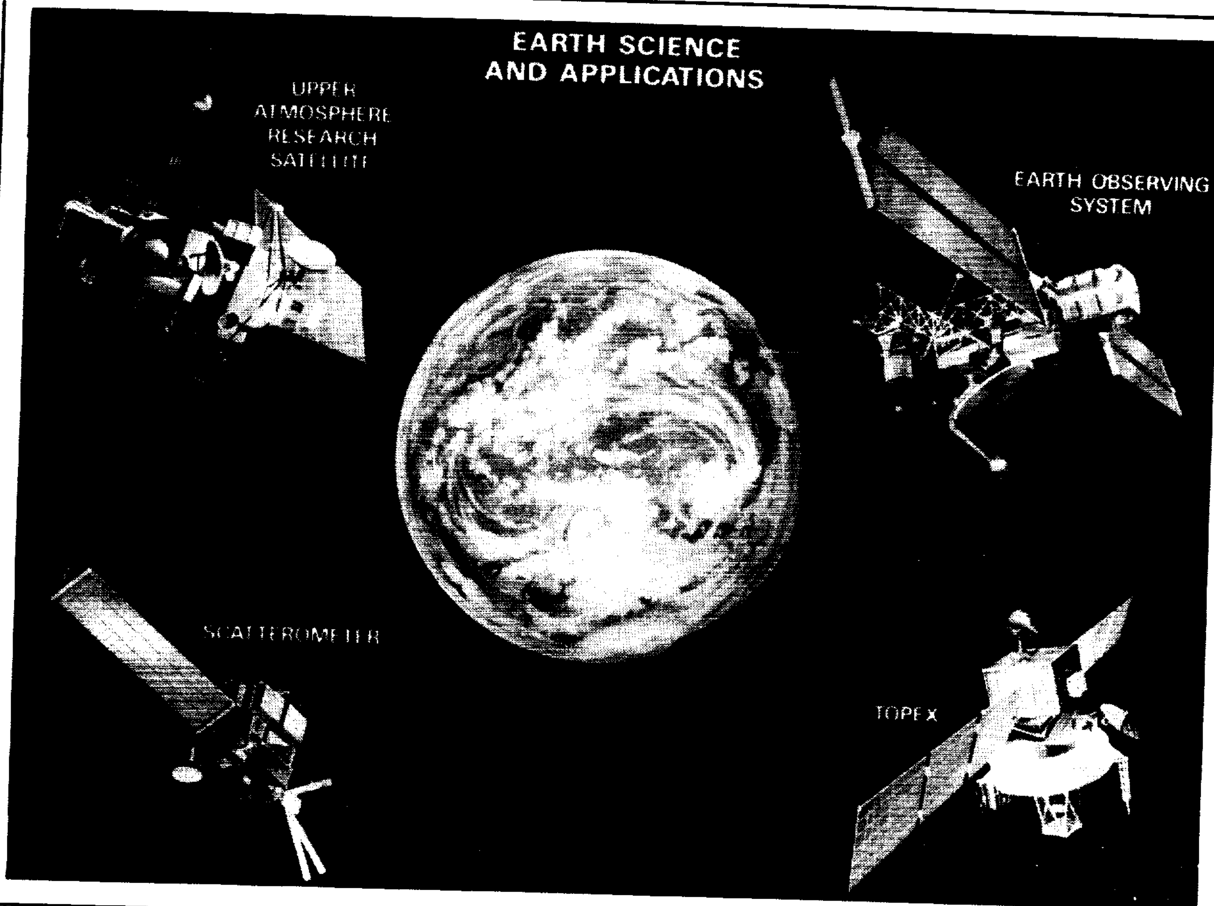

Figure III-8. Major Features of Earth Science and Applications Program

availability, and consistency in data sets are critical to research, operational, and commercial users of remote sensing.

Traditionally, Earth science disciplines have advanced through studies of the individual components: interior, crust, oceans and ice cover, biosphere, atmosphere, and ionosphere. Recent research has clearly demonstrated that land, atmospheric, ionospheric, oceanic, and biospheric processes are strongly coupled. To understand the environment, and ultimately to predict global change induced either naturally or by human activity, it is important to study Earth as a single coupled system, as well as to answer questions arising in such separate disciplines as ecology, biology, meteorology, hydrology, geology, oceanography, and atmospheric chemistry. Current programs in Earth science are yielding major steps forward in some of these areas.

Current Programs. In 1988, Critical Design Reviews will be held for the Upper Atmosphere Research Satellite (UARS) observatory and the Central Data Handling Facility, and environmental testing for all flight instruments will be completed. Delivery of instruments, including one British and one Canadian-French instrument, will be completed in 1989, and integration and test will begin. Also in 1989, software for data processing and interpretation will be delivered by the Principal Investigator teams. UARS is scheduled for launch in late 1991.

Upper Atmosphere Research Satellite (UARS)
(Earth Science and Applications)

The UARS observatory program is directly responsive to NASA's mandate to develop and implement a comprehensive program of research, technology, and monitoring of atmospheric phenomena. It will be the first satellite to simultaneously measure energy input, chemical composition, temperature, and winds of the upper atmosphere, including the stratospheric ozone level. The UARS objectives are to:

(1) understand the mechanisms that control the structure and variability of the upper atmosphere,
(2) understand the response of the upper atmosphere to natural and anthropogenic perturbations, and
(3) define the role of the upper atmosphere in climate and climate variability.

UARS consists of a shuttle-launched free-flying spacecraft with nine dedicated instruments and one flight-of-opportunity instrument.

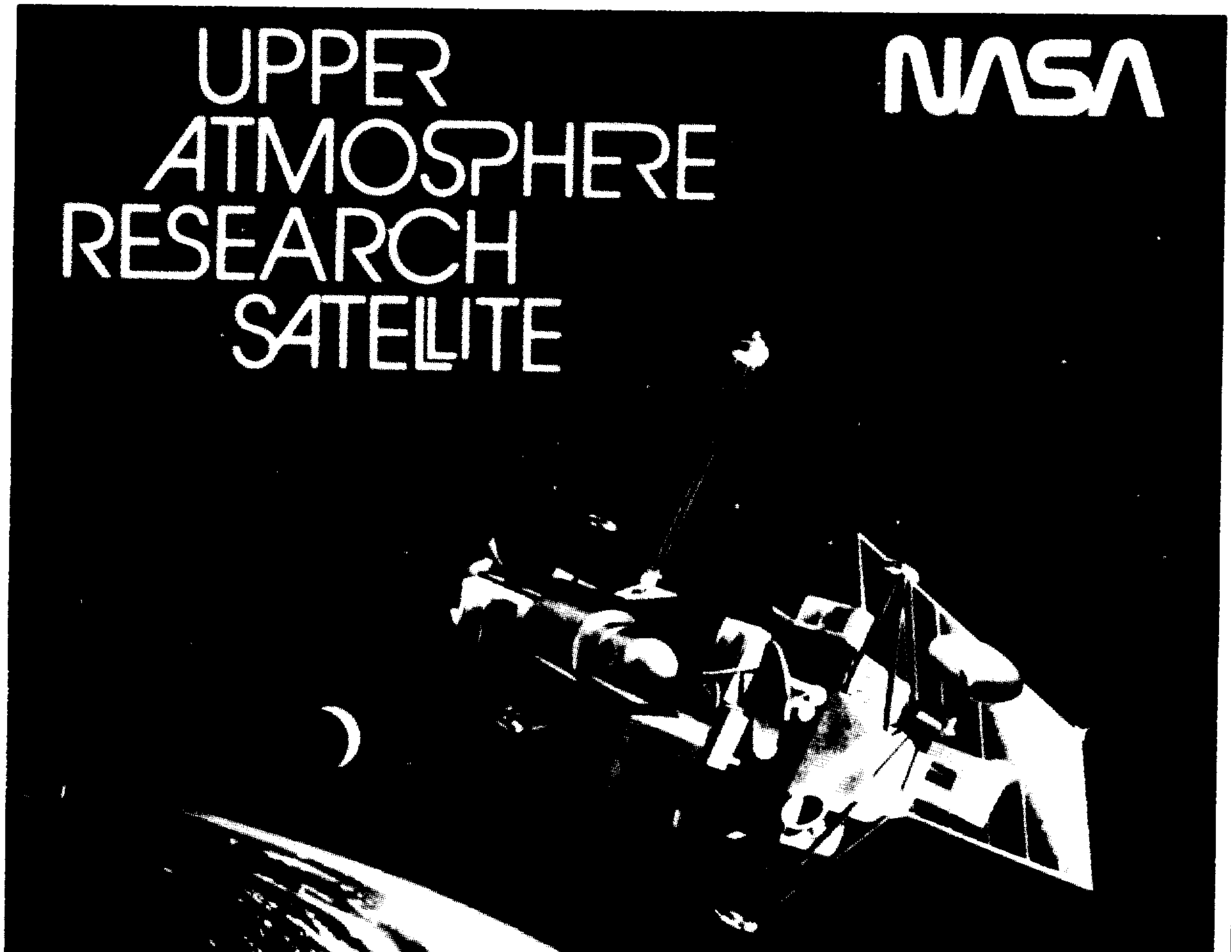

Figure III-9. Upper Atmosphere Research Satellite

Work continues toward a December 1991 launch of TOPEX/Poseidon, which will map global ocean circulation, and toward development of the NASA Scatterometer, which will permit detailed study of the influence of winds on ocean circulation and thus on climate change. Both TOPEX and the Scatterometer are critical components of the World Ocean Circulation Experiment and the Tropical Oceans Global Atmosphere experiment, which are elements of the World Climate Research program.

Ocean Topography Experiment (TOPEX/Poseidon)
(Earth Science and Applications)

TOPEX/Poseidon is a cooperative program between the United States and France intended to provide the measurement capability needed to determine the circulation of the global oceans and to study their influence on global climate. This project, to be launched on a French-provided Ariane vehicle, uses satellite radar altimetry and includes two French and five NASA instruments.

The objectives of TOPEX/Poseidon are to:

(1) use precise measurements of ocean surface topography to develop an understanding of the circulation of the global oceans, and the relationship of that circulation to climate change;
(2) make detailed maps of currents, eddies, and other features of ocean circulation; and
(3) increase knowledge of atmosphere-ocean interactions, including the exchange of heat and momentum.

NASA Scatterometer (NSCAT)
(Earth Science and Applications)

NSCAT is a radar instrument to be flown on the Space Station's polar platform to measure ocean winds.

Upper ocean currents, as well as surface waves, are generated by the stress that winds exert on ocean surfaces. As earlier instruments aboard aircraft and Seasat have shown, a scatterometer can measure the small-scale roughness of a sea surface; and the associated wind velocity, or stress, can then be calculated. Modern oceanographic measurements show that ocean currents are much more variable than they previously were thought to be. An ability to obtain wind velocities will permit calculation of the velocities of the time-dependent, wind-driven, upper ocean currents, and knowledge of those velocities will substantially improve understanding of the momentum coupling of the atmosphere and oceans. Scatterometer data provide a unique global view of the oceans, significantly improving understanding of how the oceans work.

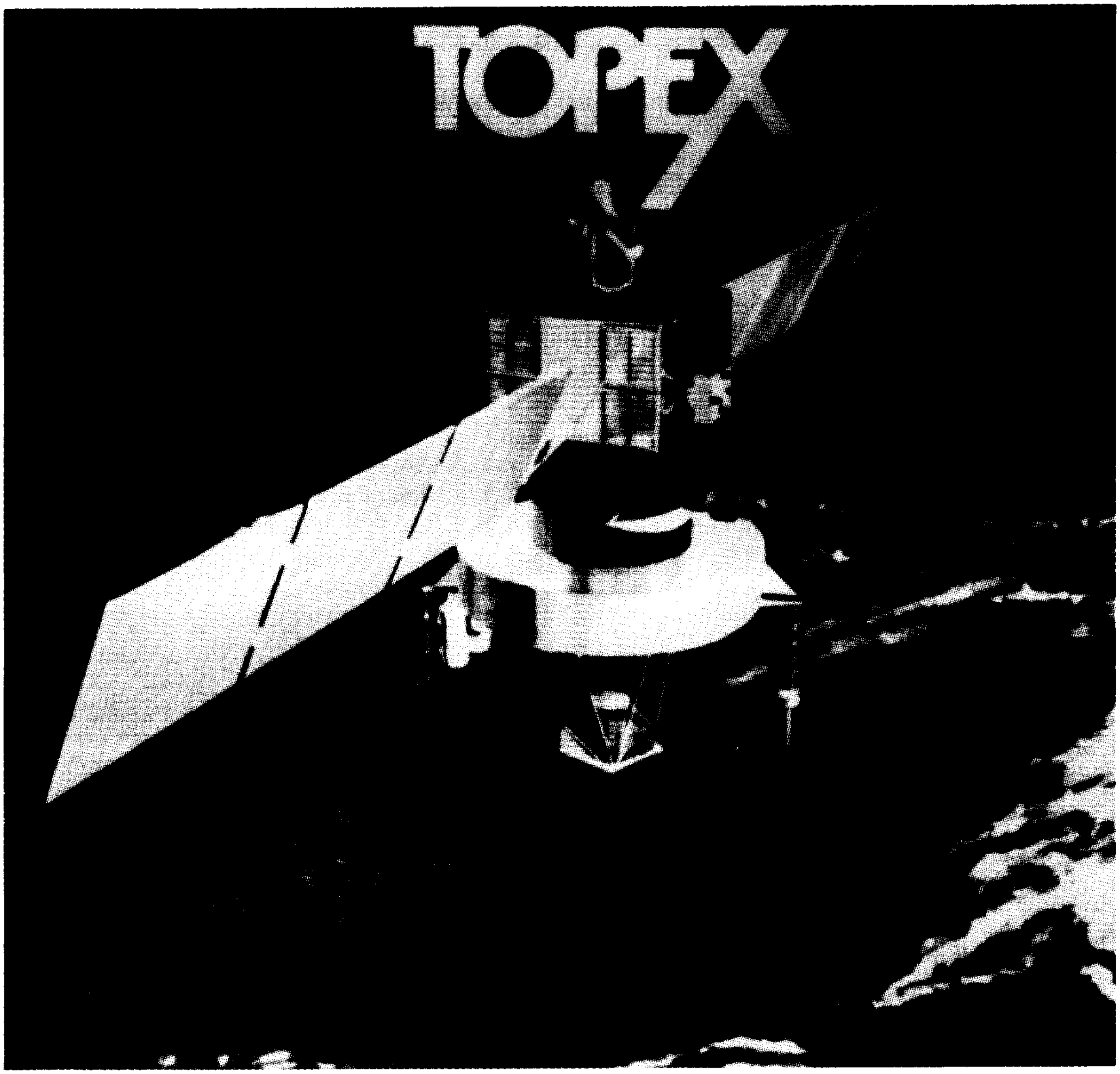

Figure III-10. TOPEX

Operation of currently orbiting spacecraft and the processing, validation, and analysis of data from them will continue. The Earth Radiation Budget Experiment continues to operate in Earth orbit and collect data on the Earth and on solar influences on Earth's environment. Other orbiting spacecraft include the Nimbus and Solar Mesospheric Explorer satellites, which continue to provide valuable information about the atmosphere and oceans. Correlative measurements collected by flights of rockets, balloons, and aircraft provide part of the Earth Science and Applications Research base and will continue to support NASA's research in Earth science. Results from ozone instruments aboard National Oceanic and Atmospheric Administration satellites provide support for studies of the chemistry and dynamics of the stratosphere.

Earth Radiation Budget Experiment (ERBE)
(Earth Science and Applications)

ERBE is a multisatellite system designed to measure Earth's radiation budget. Each of the three ERBE satellites carries two instruments—a scanner and a nonscanner—and a complete system for inflight calibration. The nonscanner has four Earth-viewing channels and a solar monitor similar to that flown on the Solar Maximum Mission; the nonscanner detectors are active cavity radiometers. The scanner contains three thermistor bolometers that scan the Earth in a direction perpendicular to the orbital track.

The study of possible changes in Earth's energy balance caused by changes in the flow of radiation is a cornerstone of modern climate modeling. Measurements of the radiation budget provide an important tool for validation of numerical models of the atmosphere and permit empirical studies of the sensitivity of the radiation budget to various perturbations.

New Initiatives. In the mid-1990s, access to a new generation of advanced polar platforms will greatly extend research capabilities by providing an expanded set of co-located instruments. The opportunity to service, modify, and replace instruments on-orbit should make it possible to sustain consistent, uniformly calibrated, long-term measurements.

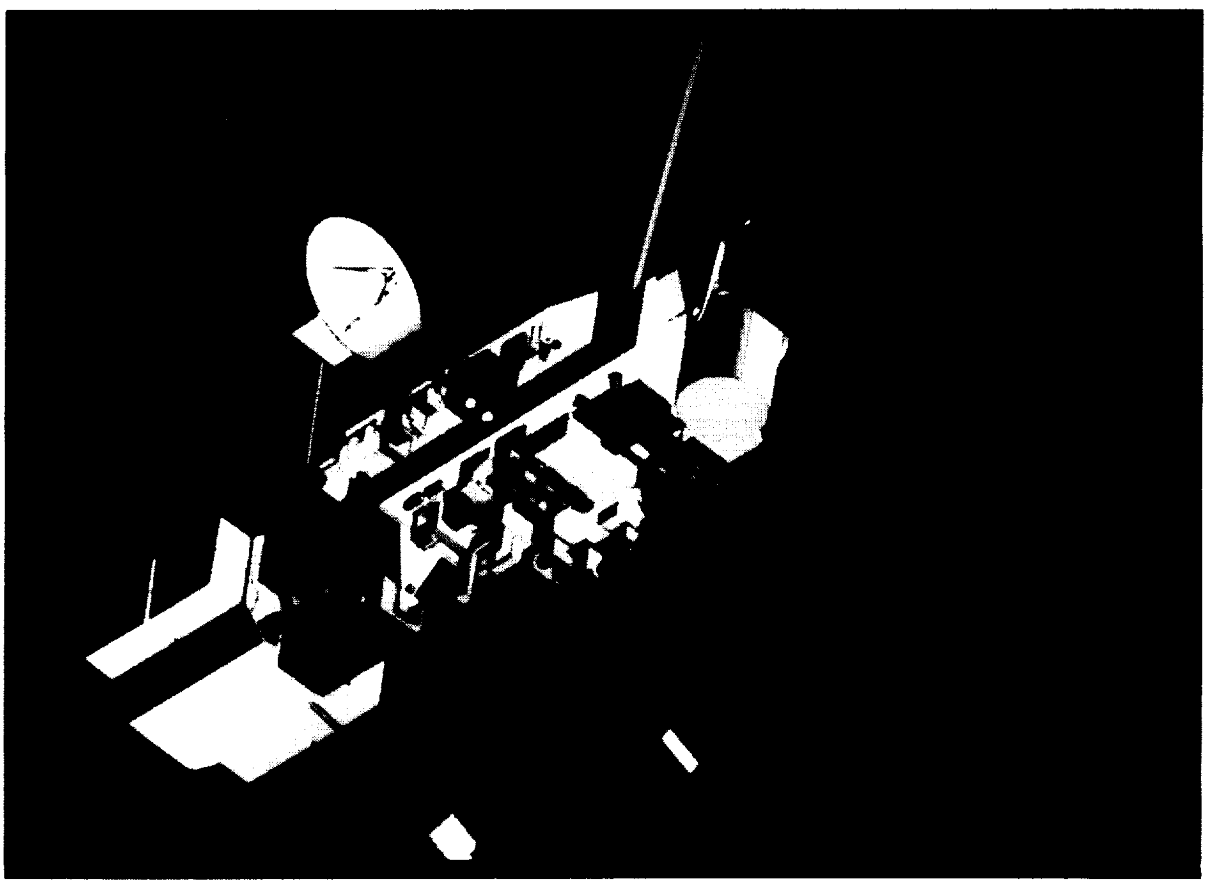

Figure III-11. Earth Observing System

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The Earth Observing System (Eos), to be mounted on the Space Station polar platforms, will, for the first time, allow the acquisition of long-term, self-consistent data sets needed for understanding and predicting global change. Extensive discussions with working groups of the Earth System Science Committee indicate that the planned Eos instrument complement will meet the anticipated requirements of Earth system science in the 1990s. As a major future mission, Eos is under consideration as a potential new start candidate for FY 1991.

The Announcement of Opportunity for Eos was released in mid January 1988. Concurrent with this release, the European Space Agency and the Science and Technology Agency of Japan released coordinated announcements soliciting payload development for, respectively, the European Polar Platform and the Japanese instruments to be mounted on the NASA Space Station platform. Instruments to fly as attached payloads on the manned Space Station also are being solicited by the Eos Announcement of Opportunity.

Eos is a major element in the U.S. contribution to the International Geosphere-Biosphere program. The Earth System Sciences Committee has stated that Eos is the centerpiece of its strategy for NASA. Eos provides a context within which to promote the more focused research projects that are necessary to maintain program vitality.

Earth Observing System (Eos)
(Earth Science and Applications)

Eos will place a suite of instruments in low-Earth orbit to make comprehensive observations of Earth's atmosphere, oceans, land surfaces, and biota. An integral part of the program is the collection, processing, analysis, interpretation, and archiving of the resulting data. Eos is the centerpiece of NASA's implementation of the Earth System Science Committee's strategy for integrated study of Earth and of global change. Long-term, consistent measurements are required for an understanding of global changes, and so the mission will study, for at least 15 years, the global-scale processes that shape and influence Earth as a system. The long-term (10-year) data sets provided by Eos will be used in Earth science studies in agriculture, forestry, hydrology, oceanography, snow and ice, atmospheric chemistry, atmospheric dynamics, and geology.

Eos will consist of four platforms (two provided by NASA, one by the European Space Agency, and one by Japan) containing a variety of instruments to carry out interdisciplinary Earth science studies. ESA, Japan, and others have indicated their intentions to provide significant components of the payload instrumentation and data handling systems. The Eos payloads are being designed for on-orbit servicing. It may be possible to transfer the National Oceanic and Atmospheric Administration's polar-orbiting operational meteorological payload to the Eos polar platforms to ease the use of operational data for research and research data for operations.

This study of global change is of fundamental importance to humanity's future on this planet. Mankind must apply the capabilities developed in space to understand Earth, and to safeguard it for coming generations.

Missions such as the proposed Mesosphere and Lower Thermosphere Explorer would complement the observations carried out by the Eos. NASA's program for remote sensing of Earth by aircraft also has proven very useful, and expanded use and enhancement of the aircraft fleet's capabilities are planned.

To complement the observations carried out by Eos, a series of Explorer-class Earth science missions, called Earth Probes, will be launched at regular intervals. For example, the Tropical Rainfall Measurement Mission and the Geopotential Research Mission are concepts for moderate size missions that may be proposed in future years as Earth Probe missions. They are currently being studied as part of the Atmospheric Dynamics and Radiation and the Geodynamics programs, respectively.

Mesosphere and Lower Thermosphere Explorer (MELTER) (Earth Science and Applications)

MELTER is a Scout-class mission that will carry a payload of nine instruments designed to explore the chemistry, energy balance, and global temperature structure of the mesosphere and thermosphere, and the distribution and transport of major and minor atmospheric constituents in them.

Tropical Rainfall Measurement Mission (TRMM) (Earth Sciences and Applications)

TRMM consists of a multichannel, scanning, passive radiometer; a multichannel visible/infrared radiometer; and a dual-frequency, microwave precipitation radar to be carried by a free-flying spacecraft, and possibly the Space Station. TRMM's overall objective is to measure rainfall in the tropics in order to increase understanding of the energetic and hydrologic processes there, especially as those processes pertain to the general circulation of the atmosphere and oceans. Specific TRMM objectives include the following:

(1) obtain a minimum 3-year data set of the monthly averages of estimated rainfall-rate probabilities;
(2) develop new techniques for measuring rainfall by combining the measurements from several instruments;
(3) develop data sets for studies of diabatic initialization of weather forecast models;
(4) validate general circulation models and climate models;
(5) develop techniques for studying and removing the diurnal cycle from temporally and spatially smoothed rainfall data obtained from a non-sun-synchronous orbit; and
(6) develop a comprehensive ground-truth program to be conducted, with international collaboration, both before and after launch.

Geopotential Research Mission (GRM) (Earth Sciences and Applications)

GRM's objective is to study Earth's gravity and magnetic fields, created within the Earth and imprinted with its characteristics. GRM will make the most accurate and the most detailed global survey yet of the geopotential fields, increasing knowledge in this area by an order of magnitude.

GRM will use two spacecraft at the same altitude, and in the same orbit except for an along-orbit adjustable separation of 100 to about 600 km. Measurements of Earth's gravity field will be derived by measuring relative velocity changes between the two spacecraft. Measurements of Earth's magnetic field will be made by boom-mounted magnetometers on one of the spacecraft. A complete global survey of Earth's gravity and magnetic fields will be completed in six months for every square degree of its surface.

Research Base. The Research and Analysis (R&A) program supports the basic scientific research in the various disciplines of Earth science, which in turn provides technological and conceptual advances in the application of remote sensing for social and economic benefit. The R&A program includes the following areas: geodynamics, land processes, ocean processes, atmospheric dynamics and radiation (which includes climate), and upper atmosphere/tropospheric chemistry. An additional program, the Interdisciplinary Research program, considers topics that cut across discipline areas. In addition to supporting basic research, the R&A program supports the space flight aspects of the Earth Science and Applications program by developing mission and instrument concepts, validating satellite data through ground-based measurement campaigns, and using satellite mission data in current research and analysis. All of the flight projects and missions in the Earth Science and Applications program discussed above have their roots in one or more of the R&A programs. More than 600 investigator groups are funded to perform science investigations in the R&A programs, an additional 200 in flight programs.

The foundation for large observatory missions is a direct heritage from development of aircraft and shuttle payloads. Sustained shuttle payload activity will continue. To prepare for reflight of instruments previously flown on the shuttle, refurbishments and modifications followed by requalification will be needed. For example, many early Spacelab solar and atmospheric experiments will refly on the Atmospheric Laboratory for Applications and Science, a series of shuttle missions that will fly approximately annually for about 10 years, beginning in 1990 or 1991.

NASA will continue to define, design, and construct advanced instruments such as the Shuttle Imaging Radar-C—which will be carried on the Shuttle Radar Laboratory, the Shuttle Imaging Spectrometer Experiment, and the Shuttle Light Intensity Detection and Ranging instrument for use in making global measurements of clouds and atmospheric aerosols.

Atmospheric Laboratory for Applications and Science (ATLAS)
(Earth Science and Applications)

ATLAS missions will form a continuing effort to monitor variations in the total solar irradiance and the solar spectrum with state-of-the-art precision, and to characterize the response of Earth's atmosphere to changes in the incident solar energy. As planned, ATLAS will consist of a series of flights, ideally about 12 months apart, so that similar measurements can be made over a complete 11-year cycle of solar activity.

The objectives of the ATLAS missions are to:

(1) measure long-term changes in the total energy radiated by the sun,
(2) determine variability in the solar spectrum,
(3) measure the global distribution of key molecular species in the middle atmosphere,
(4) differentiate human-made from natural perturbations in Earth's atmosphere, and
(5) provide absolute calibrations for solar monitoring instruments on free-flying spacecraft.

ATLAS missions have a core payload of six proven instruments, and will be launched by the shuttle.

Life Sciences

The life sciences program seeks to understand the origin, evolution, and distribution of life in the universe; to understand the relationship between life and gravity, and other planetary properties; and to develop medical and biological systems that enable human exploration and habitation of space. It combines Earth-based laboratory research with on-orbit basic and applied research on a variety of animal and plant species, as well as on human beings. The Earth-based research is conducted in NASA laboratories and in extramural programs centered on individual university-based principal investigators and on Centers of Research Excellence.

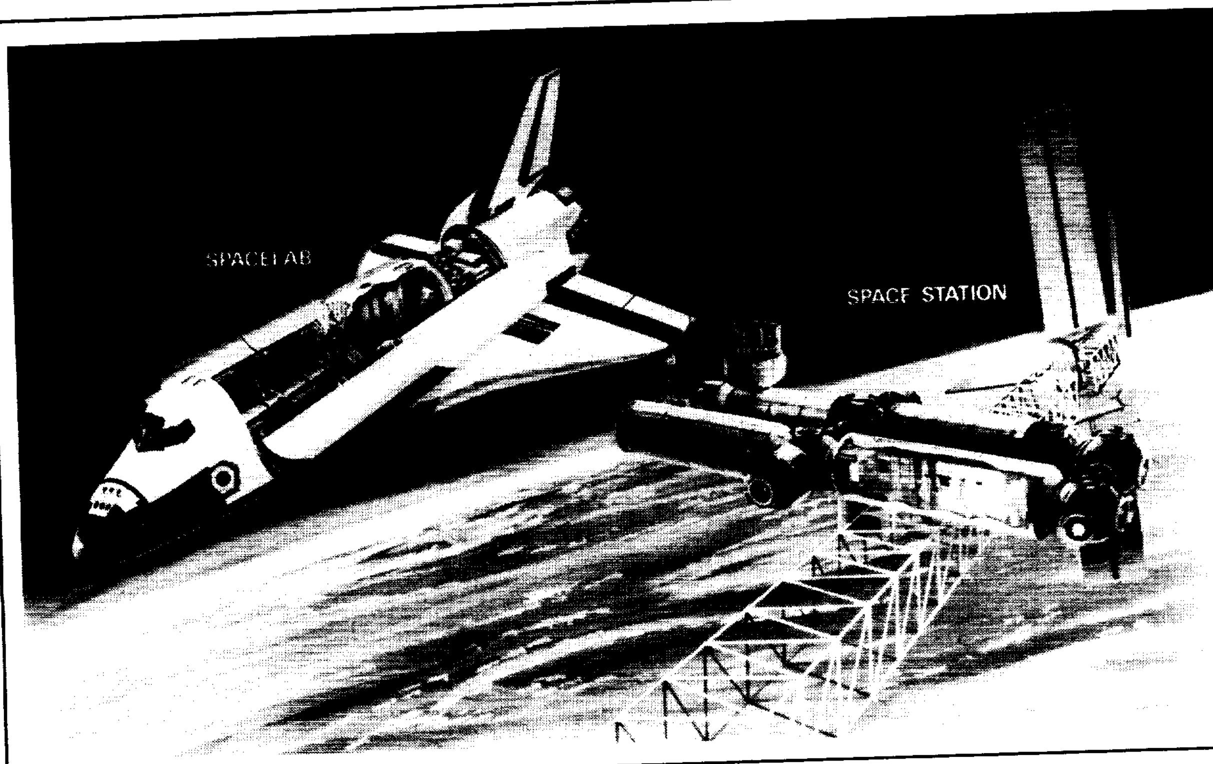

Figure III-12. Facilities for Life Sciences and Microgravity Investigations

Recently, the individual elements of the life sciences program have been closely examined by external review panels, and long-term strategic plans for life sciences programs are being developed by a special committee of the NASA Advisory Council. Implementation of recommendations made by the panels has been initiated.

Current Programs. The Space Life Sciences program is involved in all major aspects of NASA's activities in space exploration. Major disciplinary areas addressed by the program include operational medicine, space medicine, space biology, global biology (biospherics), exobiology, and controlled ecological life support systems.

The Spacelab Life Sciences series of experiments will continue, with the first mission planned for flight in 1990 to conduct a variety of investigations into acute physiological responses and short-term adaptation to microgravity in humans and animals, and to investigate several significant problems in gravitational biology.

The life sciences program has depended upon international cooperation (in such areas as primate research facilities and unmanned biological satellites) to meet several of its objectives, and has developed active working relationships with Japan, West Germany, France, Canada, the European Space Agency, and the U.S.S.R.

New Initiatives. Space Station offers a unique opportunity to develop U.S. leadership in life sciences research. The Space Station's on-orbit life sciences facilities initially will focus on basic biomedical research to understand the various mechanisms active in adaptation to weightlessness and the physiological problems encountered upon return to Earth.

The Extended Duration Crew Operations project will allow development and verification of suitable countermeasures to enable routine long-duration spaceflight. This project is necessary to the optimization of crew on-orbit operations. Detailed investigations are required so that the countermeasures developed will be based on sound physiological principles. To meet the Agency's operational objectives, an extended-duration crew-certification program extending crew stay times on the Space Station to six months or more will make the

Spacelab Life Sciences (SLS) Series
(Life Sciences)

The SLS series focuses on life sciences experiments that use the low-gravity environment provided by the Spacelab. The investigations emphasize the understanding and development of effective countermeasures for the known problems of manned space flight. Principal investigations involve cardiovascular adaptation, space adaptation syndrome, muscle atrophy, bone demineralization, early anemia in weightlessness, and the effects of weightlessness on plants and animals.

The objectives of the SLS series are to:

(1) conduct life sciences research related to the safety, well-being, and productivity of humans in space;
(2) conduct a set of coordinated and complementary investigations that focus on observations of early physiological responses to weightlessness, such as acute fluid shifts, cardiovascular adaptation, and space sickness; and
(3) improve the capability to estimate physiological effects of sustained weightlessness.

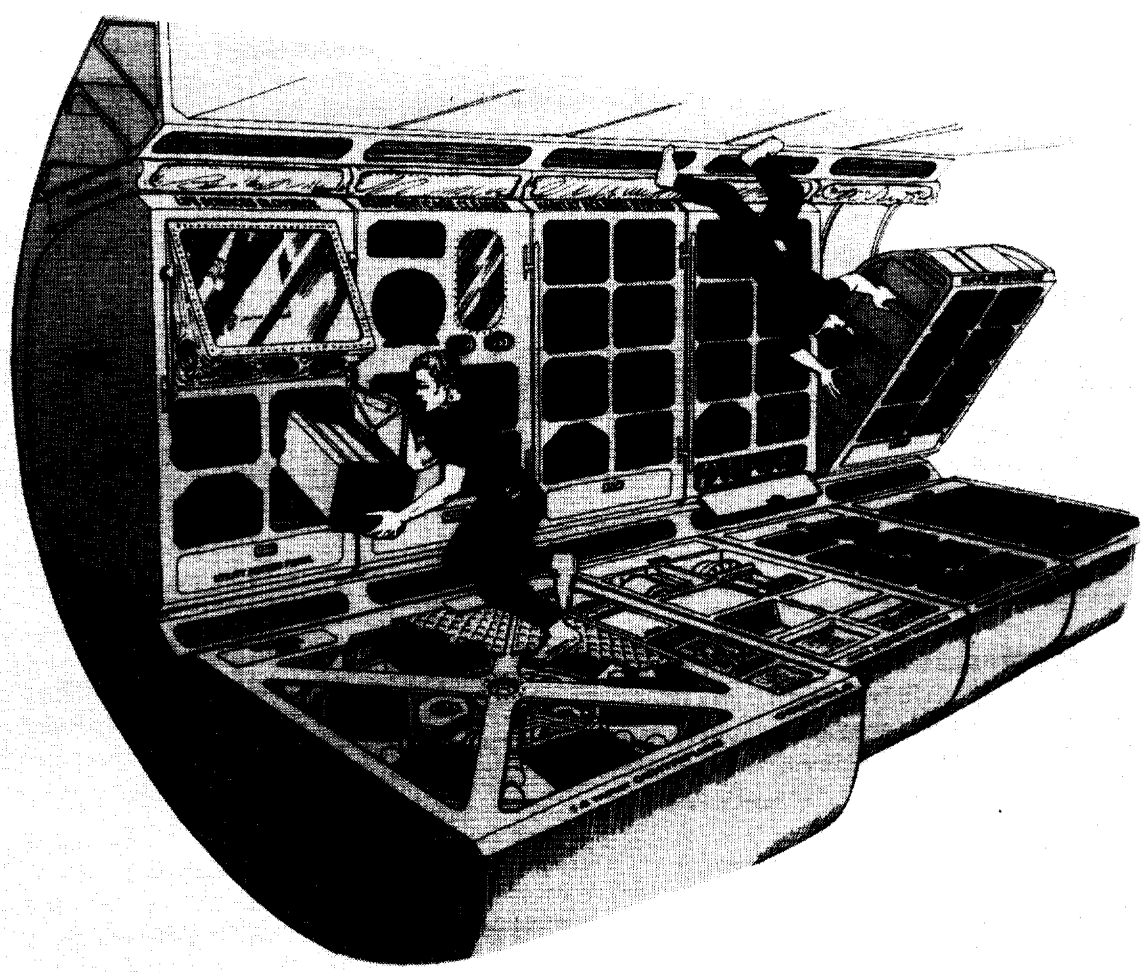

Figure III-13. Space Life Sciences (SLS) Spacelab countermeasures developed by the Extended Duration Crew Operations project fully operational.

The Space Station Space Biology project will consist of basic research in the areas of gravitational biology, space physiology, controlled ecological life support system, and exobiology. The project's definition phase will determine its resource requirements, including those for on-orbit pressurized volume, equipment, crew time and expertise, logistics, and ground support capabilities. Centrifuges to create artificial gravity on orbit will enable research using animals and small plants, and initiation of variable-gravity studies. They also will provide an opportunity to test artificial gravity as a possible countermeasure for human physiological deconditioning during long-duration spaceflight. The focal point of this initiative is development of a 1.8-meter centrifuge facility that will provide access to a range of gravity, from ambient on-orbit gravity to Earth's gravity under fully controlled conditions, for extended periods, and for a broad range of living species. For the first time it will be possible to expose living specimens to artificial gravity for periods necessary for understanding the nature of the specimens' response to gravity.

1.8-Meter Centrifuge (Life Sciences)

The 1.8-meter centrifuge facility will provide an ability to vary the gravitational force on a broad range of living species, under fully controlled conditions, for extended periods. For the first time it will be possible to expose living specimens to artificial gravity levels up to Earth's gravity for periods long enough to understand the nature of the species' response to gravity. The biological structures responsible for gravity perception and their threshold sensitivities will be approachable through controlled, replicative studies. It also will be possible to develop effective countermeasures against the negative effects of piloted space flight and to verify their efficacy on the basis of experimental results.

Many of the physiological alterations experienced in space have Earth-based equivalents (e.g., bone structure changes and cardiovascular deconditioning) and are of interest to a broad range of biomedical specialists. The 1.8-meter centrifuge will facilitate studies of acute transition responses and of the effects of repeated cycling between gravity levels. The ability to maintain on-orbit, one-gravity controls for the range of species will "harden" this science, allowing clear distinction among variables.

This facility will initially be flown on Spacelab missions.

Space Station facilities also will be used to confirm the feasibility of establishing a fully bioregenerative life-support system for use in the operations of lunar or Mars bases. As part of the Humans in Space element of the Office of Aeronautics and Space Technology's Pathfinder initiative, that office and the Office of Space Science and Applications are working together to develop "exploration technology" that will enable advanced missions such as establishing a lunar base or undertaking manned exploration of Mars. Covered under the Humans in Space program are advanced technologies such as remote medical care, artificial gravity, human behavior and performance, radiation shielding, bioregenerative life support systems, medical care technologies, and requirements for extravehicular activity suits.

Lifesat is a small, recoverable, and reusable orbiting spacecraft that can be used as an inexpensive platform for conducting life sciences (and possibly other) experiments. It is being studied as a complement to the continuing Spacelab series and the space biology facilities on Space Station. This combination of research opportunities would result in the elaboration of a rigorous program of basic biological science matched with optimum flight capability. Lifesat could be launched on a variety of expendable launch vehicles and provide from 20 to 40 days of microgravity environment. This program provides a particularly attractive opportunity for international cooperation.

In FY 1989, the definition and design phase will continue in the Exobiology program's microwave observing project, which will conduct a high-resolution survey of signals in space that may be evidence of the development of technology by living organisms elsewhere in the galaxy. The Astronomy Survey Committee of the National Academy of Sciences recommended a moderate endeavor in this area because of its potentially high scientific return. Certainly, successful detection of other advanced civilizations in the galaxy would have profound scientific and societal effects. In addition, the project has significant potential for spinoffs in communications and signal processing, and may uncover previously unknown astrophysical phenomena. It is likely to become a particularly fruitful area for international cooperation. Its proposed signal processing systems will be used with existing radio astronomy facilities and NASA's Deep Space Network antennas around the world.

Research Base. Life sciences will carry out fundamental research in exobiology and biospherics, using the Space Station, as well as the Earth Observing System, the Great Observatories, and solar system exploration missions. Basic research on problems concerning human health, safety, and performance must continue with an augmented base, both on the ground and in space; and the intramural and extramural base in fundamental basic research must be improved. The science management infrastructure will be improved by establishing a dual system of independent Principal Investigator grants and critical-mass teams that will focus on special topics or facilities, both inside and outside NASA's laboratories and in cooperation with the National Institutes of Health.

Microgravity Science and Applications

The mission of the Microgravity Science and Applications Division is to foster development of near-Earth space as a national resource by exploiting the unique attributes of microgravity attainable in orbiting spacecraft. The Microgravity Science and Applications program has three major elements:

(1) Fundamental Sciences—This element includes the behavior of fluids, transport phenomena in microgravity, and experiments that make use of the enhanced measurement precision possible in microgravity to measure physical properties and to challenge contemporary theories of relativity and condensed-matter physics;

(2) Materials Science—This area includes the processing of electronic and photonic materials; metals, alloys, and composites; glasses and ceramics; and polymers. The primary objective is to obtain a better understanding of the role of gravity-driven convection in the processing of such materials, with the goal of effecting better control strategies on Earth. Just as the development of precise temperature control has greatly enhanced science's ability to improve the properties of materials, the ability to control convective transport during processing should provide improvements in properties that are even more dramatic. The experiments conducted should evolve new processing technologies that take full advantage of the microgravity environment. Production of limited quantities of exotic new materials, with superior properties, that can serve as bench marks or be used for certain strategic applications, should be possible. Eventually, such efforts could lead to commercially viable enterprises; and

(3) Biotechnology—The primary focus of the microgravity program in biotechnology is the growth of protein crystals. In some very simple experiments on shuttle flights, evidence was obtained that superior ordering of the crystalline lattice could be achieved in microgravity. Since the only direct source of knowledge of the molecular structure of complex proteins is derived from X-ray diffraction data obtained from crystallized proteins, space-grown protein crystals could have enormous implications for understanding the biological function of important proteins at the molecular level. In addition to this fundamental knowledge, such information provides the basis for rational drug design, the development of new vaccines, and protein engineering. The Microgravity Science and Applications program is continuing to explore the possible advantages of cell culturing, cell separation, and cell fusion in microgravity.

Current Programs. The current microgravity flight program uses three capabilities of the space shuttle for accommodation of flight experiments: the orbiter mid-deck, the Materials Science Laboratory, and Spacelab. Although the general public and Congress are very interested in the scientific, technological, and commercial potential of the space environment, past budgets, priorities, and lack of flight opportunities have severely restricted the microgravity program. Renewed emphasis within NASA and competition from programs supported by foreign governments have provided a challenge to aggressively pursue development of the space environment as a national resource.

At the recommendation of a NASA task force led by Dr. Bonnie Dunbar, the microgravity program is initiating a series of Spacelab flights to regain the U.S. competitive advantage and to evaluate Space Station hardware concepts. The United States Microgravity Laboratory (USML) series will provide a focus for microgravity materials processing technology, science, and research requiring the low-gravity environment of Earth orbit. Emphasizing government, commercial, and academic participation within the United States, up to half of each mission payload may involve commercial participation. In addition, the plan is flexible enough to make use of Spacehab and a Commercially Developed Space Facility, should they become available. The USML series will be complementary to the International Microgravity Laboratory (IML) series. First launch for the IML series is expected in 1991, and for the USML series in 1992.

New Initiatives. The future centerpiece for microgravity science and applications is the Space Station, which will serve as a national microgravity laboratory. For the first time, scientists will be able to conduct experiments in an interactive mode and feed the results of one set of experiments into the next set in a timely manner. Also for the first time, adequate power will be available to support materials science experiments involving high temperature and the growth of large diameter crystals. Six new facilities (described in the inset on pages III-46

United States Microgravity Laboratory (USML) (Microgravity Science and Applications)

The USML series will focus on microgravity science and applications experiments as well as technology development experiments using the low-gravity environment provided by Spacelab. The series will include U.S. investigators from government, academia, and industry. NASA will provide flight opportunities, define and integrate the payloads, and maintain responsibility for mission management. The experiments are essential to test hardware developed for the Space Station and operational procedures for scientific and commercial experiments to be flown during the Space Station era.

The objectives of USML are to:

(1) focus on low-gravity materials science and on research in materials processing technology;
(2) emphasize U.S. commercial, government, and academic participation within the United States; and
(3) develop a science and technology base for Space Station applications.

USML missions, which will be launched on the shuttle, are envisioned to be complementary to the International Microgravity Laboratory series of missions. Planned to be launched at intervals of 12 to 18 months, they are expected to continue even after the Space Station is in operation to test new technologies and new hardware to be installed on the Station, and to be flown on free-flyers that are to be part of the ongoing program.

International Microgravity Laboratory (IML) Series (Microgravity Science and Applications)

The IML series will focus on materials and life sciences, two disciplines needing access to a laboratory in reduced gravity. IML Spacelab missions will fly at 18- to 24-month intervals so that scientists, building upon results from previous investigations, may prepare for the Space Station era. NASA will provide the flight opportunities, define and integrate the payloads, and maintain responsibility for mission management. IML is derived from a concept whereby multiple application research instruments in complementary fields fly together frequently with minimal disassembly and rework between missions. In many investigations, the payload crew will be actively involved as trained scientists, performing experiments on orbit and providing immediate scientific analysis of experiment progress to investigators on the ground.

The objectives of IML are to:

(1) establish a space laboratory program with long-term continuity to conduct high-quality science investigations for disciplines that require access to the microgravity environment of space,

(2) offer U.S. scientists access to flight hardware developed independently by NASA and other nations, or

(3) give the international scientific community access to Spacelab and its capabilities.

and III-47) have been identified for Space Station Microgravity and Materials Processing experiments:

(1) Modular Multizone Furnace Facility,
(2) Modular Containerless Processing Facility,
(3) Advanced Protein Crystal Growth Facility,
(4) Biotechnology Facility,
(5) Fluid Physics/Dynamics Facility, and
(6) Modular Combustion Facility.

NASA will fly elements of these facilities on the space shuttle in advance of the Space Station, both to test and perfect the design of the facilities, and to provide new research results. While Spacelab continues to present opportunities to develop and refine Space Station capabilities, the Space Station itself will dominate the future of microgravity science.

Several individual microgravity experiments are currently being developed to provide critical tests of fundamental concepts of chemistry and physics. They will investigate, for example, the equivalence principle, which is the fundamental assumption in Einstein's theory of relativity, and will test Wilson's recent Nobel prize theory of the universality of the behavior of condensed matter near a second-order phase transition. These experiments eventually may require a drag-free, free-flying satellite to realize their ultimate accuracy. However, short-duration tests on the USML series and longer-duration tests on the Space Station or a Commercially Developed Space Facility are essential steps toward the evolutionary development of such experiments before they would be able to take advantage of expensive drag-free satellite technology.

Research Base. A number of recent NASA-sponsored program reviews have argued vigorously for an expanded ground-based program, a sounding rocket program, and the development of hardware that can be readily adapted to various platforms, including the Spacelab, commercially developed space facilities, the Space Station, and possible free-flyers. In addition, OSSA has been charged with supporting user hardware

Microgravity and Materials Processing Facilities (Microgravity Science and Applications)

The following six facilities will accommodate most of the experiments identified for Space Station:

Modular Multizone Furnace Facility

The highest priority is the Modular Multizone Furnace Facility, which will consist of a collection of furnaces for growing high-quality semiconductor crystals and for solidifying various alloys and composites. A small-diameter (approximately 1.5 cm) version of the crystal growth furnace and of the alloy solidification furnace is being developed for use on the United States Microgravity Laboratory (USML) series of flights. These furnaces will be modular in nature and able to be reconfigured on orbit to accommodate different experiment requirements. In addition to providing an early scientific return, they will be used to evaluate modular design concepts that will be needed when the furnace facility remains in orbit for extended periods on the Space Station.

Modular Containerless Processing Facility

The Modular Containerless Processing Facility will accommodate a variety of experiments that require the positioning and manipulation of samples without physical contact. Acoustic, electromagnetic, and electrostatic fields will provide the forces required to manipulate the sample and to overcome residual spacecraft accelerations in order to maintain the sample's position during processing. Experiments to be conducted in the Modular Containerless Processing Facility range from tests of theories that describe the behavior of liquid drops to the processing of molten materials at high temperatures. Two experiment modules that eventually will go into this facility, the Drop Physics Module and the Acoustic Levitation Furnace, are being developed for the USML series of flights. In addition to an early science return, this series of flights will allow development of levitation and heating techniques for very high temperatures, as well as of the measurement technology needed for the more ambitious experiments planned for Space Station.

Advanced Protein Crystal Growth Facility

The Advanced Protein Crystal Growth Facility will incorporate technology being developed in ground-based research programs related to sensing and controlling nucleation and growth of protein crystals. To eliminate spurious nucleation sites, techniques are being explored to suspend and deploy droplets of growth medium electrostatically and without physical contact. The objective is to limit nucleation in the protein droplet so that a single crystal develops, and then to grow that single crystal under carefully controlled conditions to obtain the highest degree of long-range order in the crystalline lattice. Long-range order determines the precision with which X-ray crystallographers can determine the structures of these complex, biologically active molecules.

(continued...)

Biotechnology Facility

The Biotechnology Facility will consist of one or more bioreactors designed to keep various living cells in suspension for long periods with a minimum of shear flows. This suspension will allow a detailed study of the response of various cells to microgravity under carefully controlled conditions, making possible resolution of some of the provocative results obtained by the Soviets on Salyut and the Germans on the shuttle D-1 flight. Those results indicated dramatic changes in cell function in microgravity. The bioreactors also will serve as cell maintenance systems to support advanced cell-separation and cell-fusion processes that can take advantage of microgravity.

Fluid Physics/Dynamics Facility

The Fluid Physics/Dynamics Facility will accommodate a variety of experiments in fluid flow and transport phenomena. An experiment module to study convection driven by surface tension without the complicating effects of buoyancy-driven convection is being developed for a series of experiments to be started on the USML flights. Other experiments being considered for the facility involve flow and property measurements of multiphase fluids, electrohydrodynamics, the behavior of fluids near their critical phase transitions, and tests of various stability criteria. Such experiments will enhance understanding of the behavior of fluids in microgravity—understanding essential to the development of processes that will take full advantage of the microgravity environment.

Modular Combustion Facility

The Modular Combustion Facility will provide suitable containment and diagnostics for studies of combustion phenomena in microgravity. Such studies are essential for developing appropriate fire-safety criteria for manned laboratory operations and to determine the best methods for dealing with a fire, should one develop. Experiments will allow the study of fundamental phenomena involved in combustion under diffusion controlled transport, which vastly simplifies measurement and analysis. They will include solid-surface combustion, smoldering combustion, pool burning, droplet combustion, and particle-cloud combustion. Preliminary combustion experiments are being developed for the shuttle's mid-deck and Spacelab. In addition to providing early data, these experiments will develop concepts for a Space Station facility that will permit interactive experimentation.

There are two possible additional areas of experimentation, polymer science and fundamental physics and chemistry. These areas include relativity, critical phenomena, and measurement of fundamental properties. Consideration is being given to these areas to determine if the experimentation could be accommodated in existing facilities or if new facilities will be required.

Note: A facility is defined as an assembly of subsystems that can support various experiment modules having common requirements. An experiment module is designed to conduct a series of experiments to specifications provided by the various Principal Investigators. This modular approach allows retention of the flexibility required to accommodate new scientific requirements as they evolve during the lifetime of the facility.

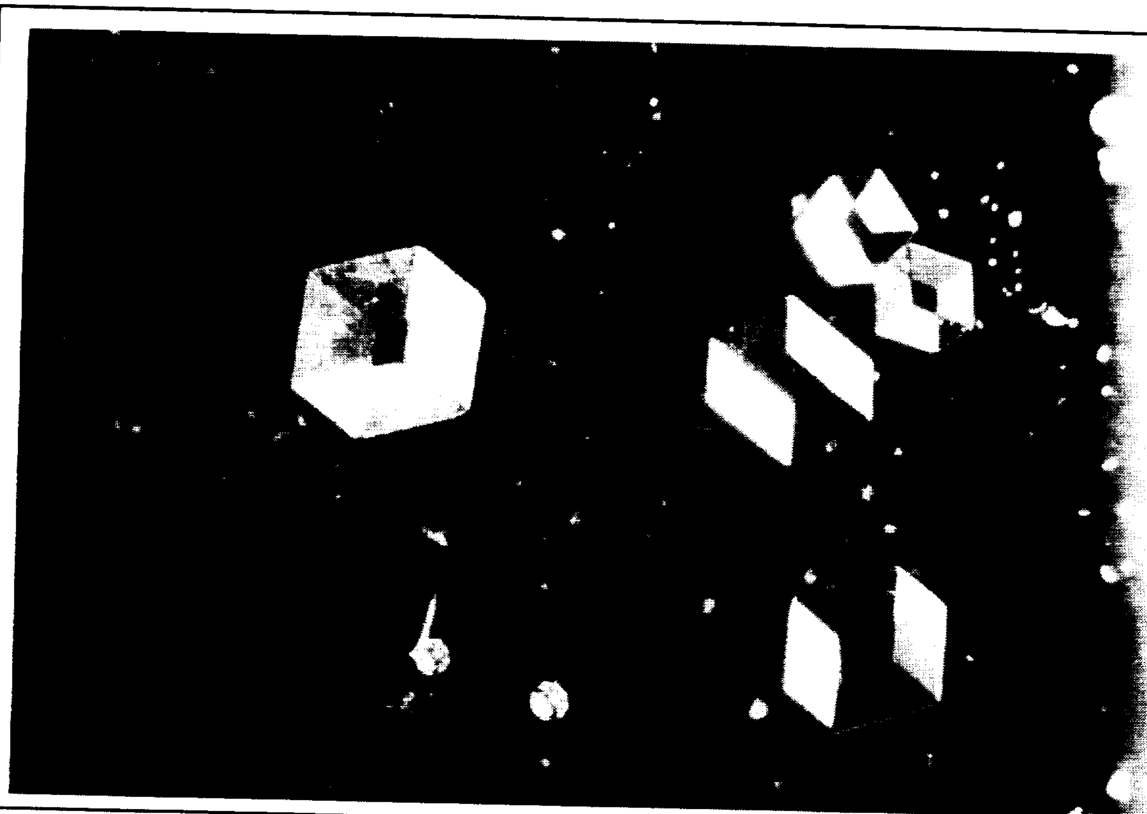

Figure III-14. Crystals of the Jack Bean Seed Protein Canavalin Grown in Space

development and with balancing flight manifesting priorities for both academic and industrial researchers.

During the delay in the flight program resulting from the Challenger accident, the microgravity program has been restructured. Much of the old hardware that had been adopted from the pre-shuttle sounding rocket program has been retired and new hardware development has been initiated. The flight program has been thoroughly reviewed by a committee headed by Nobel-Laureate Dr. Robert Schrieffer, and the highest quality experiments have been prioritized. A 10-year strategic plan has been formulated to guide evolutionary development of the microgravity program into the Space Station era.

All of the facilities that accommodate experiments requiring more than a few days of microgravity will be designed to operate in a man-tended mode so that they can be flown during the build-up phase of Space Station—or on a Commercially Developed Space Facility, should it be available at an earlier date.

Recently, to increase their understanding of processes carried out on Earth, polymer scientists have begun to take an interest in microgravity research. For example, they would like to be able to measure directly the extensional viscosity of a variety of polymers that behave as non-Newtonian fluids. Extensional viscosity is important in many processes ranging from the pulling of fibers to ink-jet printing and paint spraying, most of which evolved from years of empirical cut-and-try methods. Knowing the extensional viscosity and how to control it would enable plant engineers to design more efficient processes. The crystallization of certain polymers is an area that shows promise in the search for non-linear optical material for optical logic devices and other advanced applications. It is thought that the microgravity environment might provide better control in the polymer crystallization process, thereby producing crystals that are more homogeneous and have fewer defects. Experiments planned for the USML series will evaluate some of the above concepts and will determine whether future experiments can be carried out in presently identified facilities, or if a new facility will be required for polymer science.

To delineate the potential advantages and limitations of the space environment, a fundamental requirement is to establish a data base that is both relevant and accessible to the user community. Furthermore, to ensure a broader perspective and enhance the quality and reliability of results, the user community should be expanded to include researchers sponsored by other government agencies and industry. Expansion of the ground-based research program also would increase the base of information for a high-quality scientific program.

Solar System Exploration

The Solar System Exploration Division is responsible for scientific exploration of the planets; their moons, comets, and asteroids; and the interplanetary medium. The Division's program is structured around the recommendations of the Solar System Exploration Committee (SSEC) of the National Academy of Sciences, which stress continuity, commonality, cost-effectiveness, and the use of existing technology. The core program recommended by the SSEC consists of:

(1) a continuing series of modest Planetary Observer missions to explore the inner planets and near-Earth asteroids using reconfigured off-the-shelf Earth-orbital spacecraft;

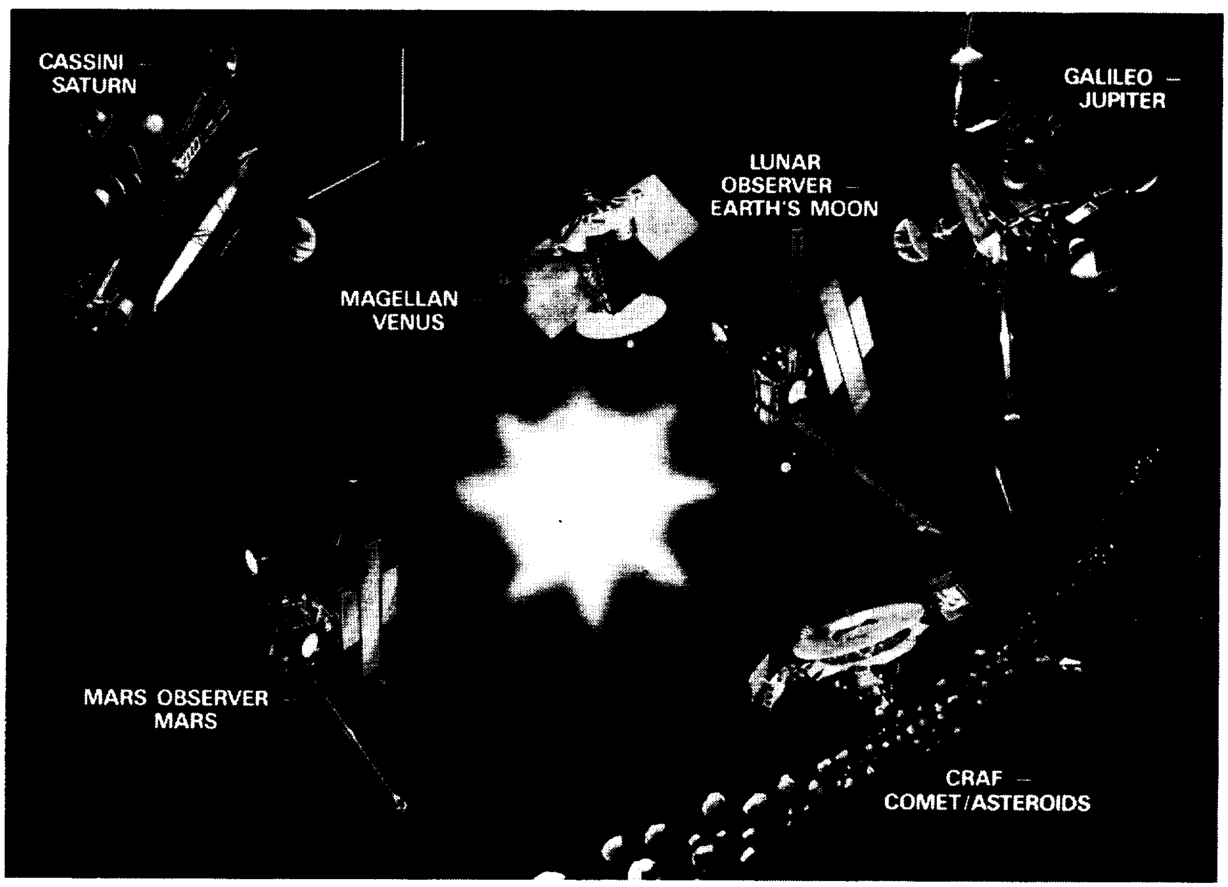

Figure III-15. Major Features of Solar System Exploration Program

(2) a continuing series of Mariner Mark II spacecraft missions to explore the outer planets, comets, and asteroids, using a common spacecraft with evolving technological capabilities;
(3) development of a multimission spaceflight operations and data analysis capability; and
(4) strong foundations of ground-based research, analysis, and related activities funded at about 25% of the total program.

The SSEC separately, in 1986, recommended an augmented program of more challenging missions to return samples from a comet and from the surface of Mars, and to start searching for other planetary systems.

Current Programs. By the end of this decade, all the major planets and their satellites will have been studied at the reconnaissance (i.e., flyby) stage. The exploration phase has either been completed or has been established for every accessible major body of the solar system. Five spacecraft are still in operation—three Pioneers and two Voyagers. The Pioneer Venus Orbiter recently completed its 3,000th orbit of Venus. Voyager 2 is heading for an encounter with Neptune in August 1989, and then will travel on to study interstellar space, along with Pioneer 10, Pioneer 11, and Voyager 1.

In spite of the Solar System Exploration program's setback from the Challenger accident, no planetary

Pioneer Venus Orbiter (PVO)
(Solar System Exploration)

PVO carries a payload of twelve scientific instruments designed to perform a comprehensive study of Venus' surface, gravity field, and atmosphere, and the interaction of its atmosphere with the solar wind. The spacecraft and instruments have performed almost flawlessly for over nine years, permitting observation of changes in the Venus environment over nearly a full solar cycle.

The PVO objectives are to:

(1) conduct a detailed study of Venus and its environment;
(2) observe solar-cycle effects on Venus' atmosphere and ionosphere;
(3) monitor long-term changes in Venus' atmospheric circulation, cloud morphology, and high altitude haze;
(4) obtain unique ultraviolet spectrometer observations of a "comet of opportunity" (Encke, Halley, Giacobini-Zinner, Wilson, and NTT have already been observed);
(5) conduct studies of solar corona disturbances within 0.3 AU of the sun using radio science techniques during a superior conjunction;
(6) support other NASA missions (e.g., provide solar wind monitoring for International Ultraviolet Explorer observations of the Jovian aurora and Venus gravity field data for Magellan);
(7) continue monitoring the characteristics and source(s) of gamma ray bursts;
(8) resume, during final low-altitude mission phases, in situ measurements of Venus' atmosphere, radar studies of its surface, and mapping of its gravity field.

PVO was launched on May 20, 1978. From December 1978 to July 1980, it provided radar mapping of the Venusian surface and sampling of Venus' atmosphere. Currently (until May 1992) data collection continues, with a changing PVO orbit relative to Venus. From May 1992 to August 1992, PVO will study southern portions of the Venusian surface until it enters Venus' atmosphere.

Voyager
(Solar System Exploration)

There are two operating Voyager spacecraft. Each has a mass of 825 kg, is powered by a nuclear-electric system, contains about 5,000,000 equivalent electronic parts, and uses onboard computer fault detection and response to protect itself. Both were launched in 1977, with identical complements of 10 science instruments.

The primary objectives of the Voyager missions were to investigate and compare the Jupiter and Saturn planetary systems, and to study the interplanetary medium between Earth and Saturn. All primary objectives have been met. An extension of the Voyager investigations to the Uranus planetary system also has been completed successfully and another objective—to investigate the Neptune planetary system—has been added.

Over 60,000 images and much additional scientific data have been obtained from flybys of Jupiter, Saturn, and Uranus; and Voyager 2 will be the first spacecraft to explore Neptune. As they leave the outer planets, both Voyager spacecraft will monitor the space environment and search for the heliopause—the interface between the solar system and galactic space.

missions have been cancelled, and three missions to explore the solar system are proceeding toward launch. The Magellan mission to map the cloud cover of Venus globally, and the Galileo mission to make detailed studies of Jupiter and its moons, are scheduled for launch in 1989.

The Mars Observer mission, the first of the new Planetary Observer series of spacecraft, will investigate the geologic and climatic evolution of Mars and is planned for launch in 1992.

Magellan
(Solar System Exploration)

The Magellan mission will provide global radar image maps of the cloud-shrouded surface of Venus, including its land forms and geological features.

Using a synthetic aperture radar to penetrate the planet's opaque atmosphere, Magellan will achieve a resolution sufficient to identify small-scale features (0.25- to 0.5-km wide) and to address fundamental questions about the origin and evolution of the planet. Magellan will also obtain altimetry and gravity data to accurately determine the planet's gravity field and detect internal stresses and density variations. By obtaining data on the morphology of Venus and by identifying its geologic characteristics, the Magellan mission will enable the evolutionary history of Venus to be compared with that of Earth.

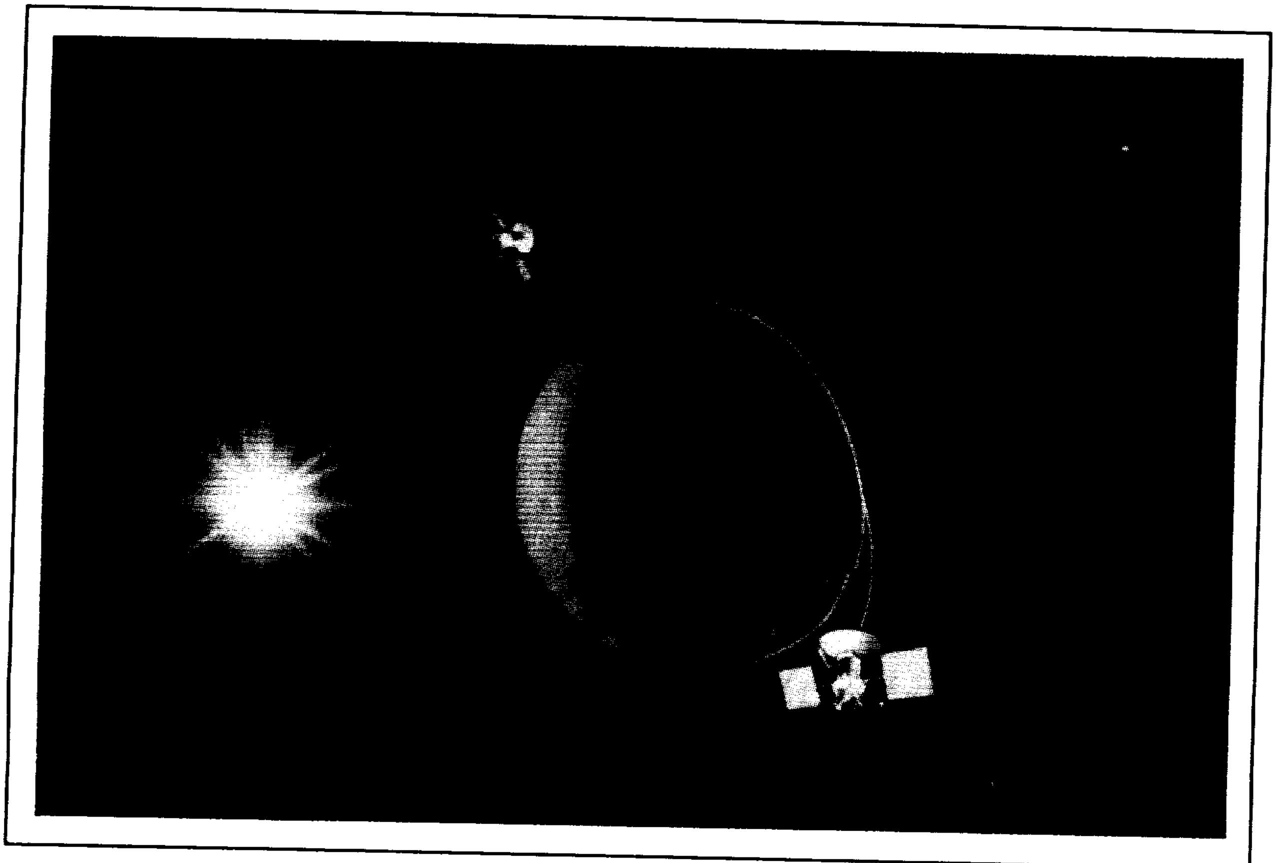

Figure III-16. Magellan

Galileo
(Solar System Exploration)

The Galileo mission will make detailed explorations of Jupiter and its satellites and detailed studies of its four major satellites—Io, Europa, Ganymede, and Callisto. The comprehensive science payload carried by Galileo will extend knowledge of Jupiter and its system of satellites well beyond the profound discoveries of the preceding Voyager and Pioneer missions.

During its 22 months of operation in the Jovian system, the Galileo orbiter will inject an instrumented probe into Jupiter's atmosphere to make direct analyses. The probe will take measurements for 60 minutes, down to a pressure level of 10 bars, and relay its data to the orbiter for real-time transmission to Earth. The orbiter will be able to make as many as ten close encounters with Jovian satellites.

The Galileo mission objectives are to make scientific measurements and significantly advance knowledge in the areas of:

(1) the chemical composition and physical state of Jupiter's atmosphere,
(2) the chemical composition and physical state of the Jovian satellites, and
(3) the structure and physical dynamics of the Jovian magnetosphere.

Figure III-17. Galileo

Mars Observer
(Solar System Exploration)

The Mars Observer will follow up on the earlier discoveries of the Mariner 9 and Viking programs, emphasizing the geologic and climatic evolution of this complex planet. It will provide a spacecraft in orbit around Mars from which the entire Martian surface and atmosphere may be mapped for at least one Martian year (687 Earth days).

The objectives of the mission are to:

(1) determine globally the elemental and mineralogical character of surface materials;
(2) define globally the topography and gravitational field;
(3) establish the nature of the magnetic field;
(4) determine the time and space distribution, abundance, sources, and sinks of volatile material and dust over a seasonal cycle; and
(5) explore the structure and aspects of the circulation of the atmosphere.

Figure III-18. Mars Observer

New Initiatives. The Comet Rendezvous Asteroid Flyby (CRAF) is the highest priority solar system exploration mission. The first of the new Mariner Mark II missions, it will rendezvous with comet Kopff after exploring the asteroids. The second Mariner Mark II mission, Cassini, is potentially a cooperative mission with the European Space Agency. Cassini will conduct detailed investigation of Saturn and its rings and moons to follow up on the exploratory results from the Pioneer and Voyager programs.

The second Planetary Observer, the Lunar Observer, also is high priority and will be submitted for administrative approval following the CRAF mission.

Research Base. The strategy promulgated by the Solar System Exploration Committee and adopted by the Solar System Exploration Division calls for balanced emphasis on the terrestrial (Earth-like) inner planets, the giant (Jupiter-like) outer planets, and the small bodies (comets and asteroids) in the solar system. This theme is reflected throughout the research-base activities of the Division. Active research programs are in process in planetary astronomy, atmospheres, materials and geochemistry, and geology and geophysics. A vigorous research and analysis program, based chiefly in universities, is developing the next generation of planetary scientists and the instrumentation base needed for future missions. Research and analysis funds also are providing for effective analysis and exploitation of data from prior planetary exploration missions and for generation of corroborative ground-based data to reinforce results from space observations.

Comet Rendezvous Asteroid Flyby (CRAF)
(Solar System Exploration)

CRAF is a Mariner Mark II free-flying mission that will include a close flyby of a main belt asteroid followed by an extended multiyear rendezvous with a short-period comet, Kopff. It will make a 3-year, detailed study of the comet's nucleus, dust, and atmosphere at close range under both quiescent and active conditions. The asteroid flyby part of the CRAF mission will allow study of the asteroid's physical properties and chemical make-up. The objectives of the comet rendezvous part of the mission are to better understand:

(1) the origin and evolution of the solar system,
(2) the creation and evolution of pre-life organic chemicals, and
(3) the various astrophysical processes in plasma and dust clouds.

To meet those objectives, CRAF will:

(1) image the entire comet nucleus at high resolution;
(2) determine the comet's chemical, isotopic, and mineral composition;
(3) observe the coma and its interaction with the solar wind and magnetic field;
(4) collect dust boiled off from the comet and examine it with an electron microscope; and
(5) penetrate the comet nucleus with a probe that will take a direct sample and analyze its composition.

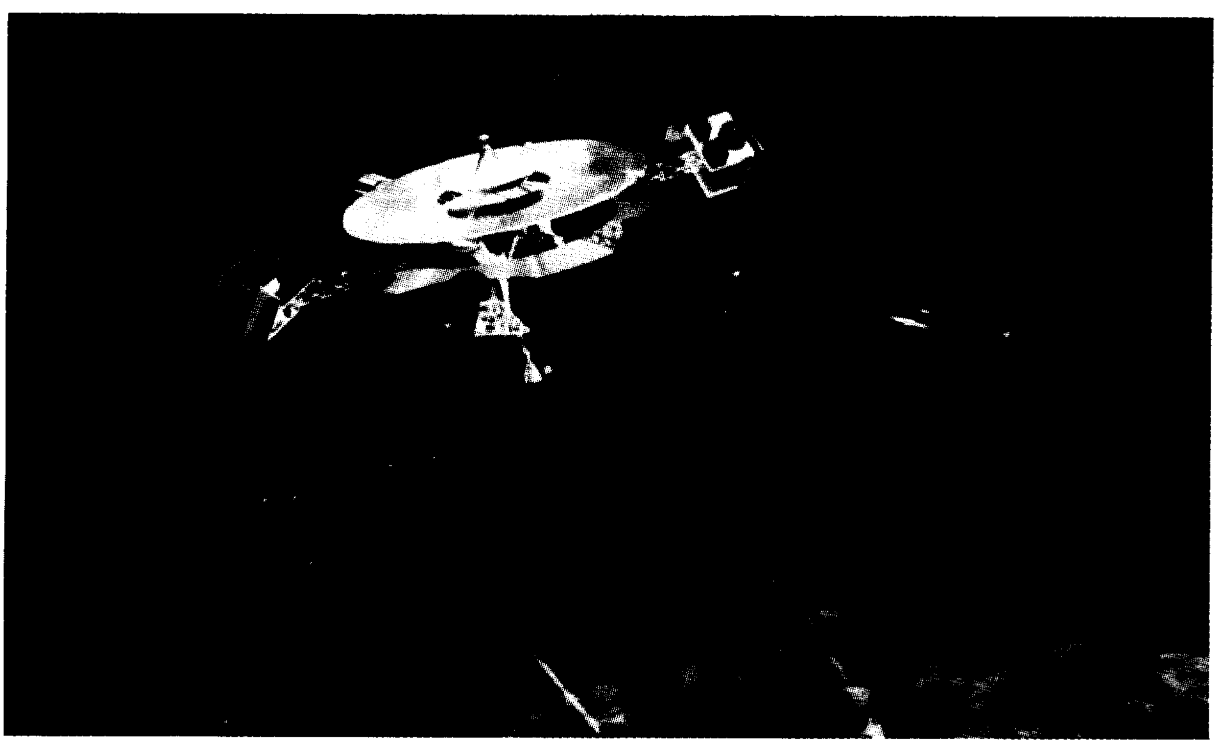

Figure III-19. Comet Rendezvous Asteroid Flyby

Cassini
(Solar System Exploration)

The Cassini mission, named for the 17th century discoverer of Saturn's moon Titan, is potentially a cooperative project with the European Space Agency. It will conduct a comprehensive scientific investigation of Saturn, its rings and moons, the surface and atmosphere of its principal moon, Titan, and the nature of fields and particles in Saturn's magnetosphere.

Cassini will be a Mariner Mark II orbiter with a scan platform and a spin table. It will have long- and short-focus cameras with charge-coupled-device detectors having much greater sensitivity and wavelength range than the Voyagers' cameras possessed. It will have a near-infrared spectrometer to measure surface composition, a far-infrared instrument to study the composition and structure of the atmospheres of both Saturn and Titan, a synthetic-aperture radar to pierce Titan's haze layer and map its surface, and a full complement of fields and particles instruments to map the properties of Saturn's magnetosphere in space and time. An instrument to image Titan's surface and a near-infrared spectrometer are possible additions to make measurements of surface characteristics complementing those provided by the synthetic-aperture radar.

Figure III-20. Cassini

Lunar Observer
(Solar System Exploration)

The second mission in the Planetary Observer program, the Lunar Observer will be constructed from Mars Observer spares. Its objective will be to conduct a 1-year polar mapping mission to measure the mineral and elemental composition of the moon's global surface, to assess global topography, and to measure magnetic and gravitational fields. In addition to the valuable scientific information this mission will provide, the Lunar Observer will provide data that will contribute to NASA's goal of preparing the way for a possible human outpost on the moon (see Chapter X).

Spacecraft missions progress in an evolutionary series in which relatively simple reconnaissance missions, which provide a fundamental characterization of an object, are followed by more complex missions that provide increasingly detailed information. The highly visible spacecraft missions are supported by an essential foundation of diverse ground-based activities: mission operations and data analysis, scientific research and analysis, and advanced programs studies.

The Solar System Exploration program will take advantage of the Hubble Space Telescope in the near-term, and of the Space Station over the longer term. To promote effective use of the new capabilities the Space Station will provide in the mid 1990s, the program encompasses study of attached payloads that will yield new information about such major questions as what the origin of the solar system was and whether planets exist around other stars. The Cosmic Dust Collection Facility, which will collect small cosmic particles (possibly from comets), will be among the first Space Station attached payloads. The Astrometric Telescope Facility, which would conduct a decade-long search for large planets around other stars, is under active study for possible inclusion in the initial phase of the Space Station program.

Cosmic Dust Collection Facility (CDCF)
(Solar System Exploration)

CDCF is a facility that will collect and retrieve extraterrestrial material and measure the orbital parameters associated with the material. It will be a modular system on which various types of collectors and detectors can be mounted. The initial CDCF configuration consists of nine 1-meter-square modules up to 100 centimeters in depth. Two types of collection devices are planned: Type A (capture cells) and Type B (porous media). These devices will be clustered into replaceable units that can be readily exchanged in orbit. Both passive and electronically active arrays are planned, and power and data buses are part of the structure. Self-contained electronics will collect time, direction, and velocity data on impacts. The impact data then will be combined with data on Space Station orientation, position, and time, and will be telemetered periodically to the ground. Individual impacted cells will be replaced and returned to Earth for chemical, physical, and petrographic analysis, initially every 180 days but with a possible subsequent increase in frequency (replacement every 90 days).

The CDCF objective is to determine the parent objects, nature, abundance, distribution, and physical and chemical characteristics of cosmic dust particles by actually collecting such particles and measuring their trajectories.

Astrometric Telescope Facility (ATF)
(Solar System Exploration)

ATF consists of a prime-focus optical telescope with a Ronchi ruling at the focus to modulate star signals, a multichannel astrometric photometer to detect the modulated signals, and associated electronics equipment. For on-orbit operations of ATF, additional electronics in the Space Station pressurized module will supplement the Space Station standard display and control console.

The primary objective of ATF is to search for planetary systems outside the solar system. It will accomplish this objective by precisely measuring changes in the relative positions of target stars with respect to reference stars. ATF is designed to detect Neptune- and Uranus-class planets out to 10 parsecs. It also will be able to support many other astrophysics research activities.

Current and future plans place high priority on reduction of launch and mission risk; NASA has begun a policy of acquiring spare subsystems to enable rapid changeout during development testing to protect launch windows. In addition, future missions are being designed to provide the maximum possible backup for missions now under development. One example of this new approach is the purchase of spare components for the Mars Observer mission, not only to ensure timely launch of that mission but also to initiate subsequent Planetary Observer missions.

Progress toward realizing the basic premise of the Solar System Exploration Committee—national commitment to a level of program activity that is continuous, but also modest in cost—has been slow. Only the first two recommended missions, Magellan and Mars Observer have been approved for project start. Advanced studies will continue to examine such missions as the Mars Rover Sample Return (see page IX-9), a precursor mission to any manned Mars activity. In addition, major increases in research and analysis funding, especially to equip laboratories, are anticipated.

Space Physics

The mission of the Space Physics Division is to understand the origin, evolution, and interactions of plasmas in a wide variety of space settings. In-situ probes measure natural plasma systems and processes within accessible plasma systems, such as Earth's planetary magnetosphere and the heliosphere, while remote sensing techniques must be used for regions not directly accessible to probes, such as the sun's atmosphere, or for regions that require a global view, such as Earth's auroral ionosphere. Passive and active measurements are obtained using the full range of currently available space research techniques and platforms: free-flying satellites, shuttle-attached payloads, Spartan missions deployed and recovered by the shuttle, sounding rockets, and stratospheric balloons. Measurements also are made, to a lesser extent, by ground-based observatories.

The space physics research community has approved flight programs for the next 5 to 10 years that will use a coordinated combination of space-flight capabilities to make in-situ and remote measurements of a large number of space plasma and related parameters. Major flight missions will address broad, general questions about plasma systems of interest, while moderate missions will focus on specific processes within given systems.

Current Programs. Space-flight programs sponsored by OSSA and foreign space agencies have provided opportunities for initial reconnaissance of a variety of planetary atmospheres, ionospheres, and magnetospheres; the heliospheric region; and the layers of the solar atmosphere. Measurements from a survey, now nearly complete, have been made over wide ranges of wavelength, energy, and field strength. They have led to the identification and classification of many plasma phenomena, and to some understanding of cause and effect relationships.

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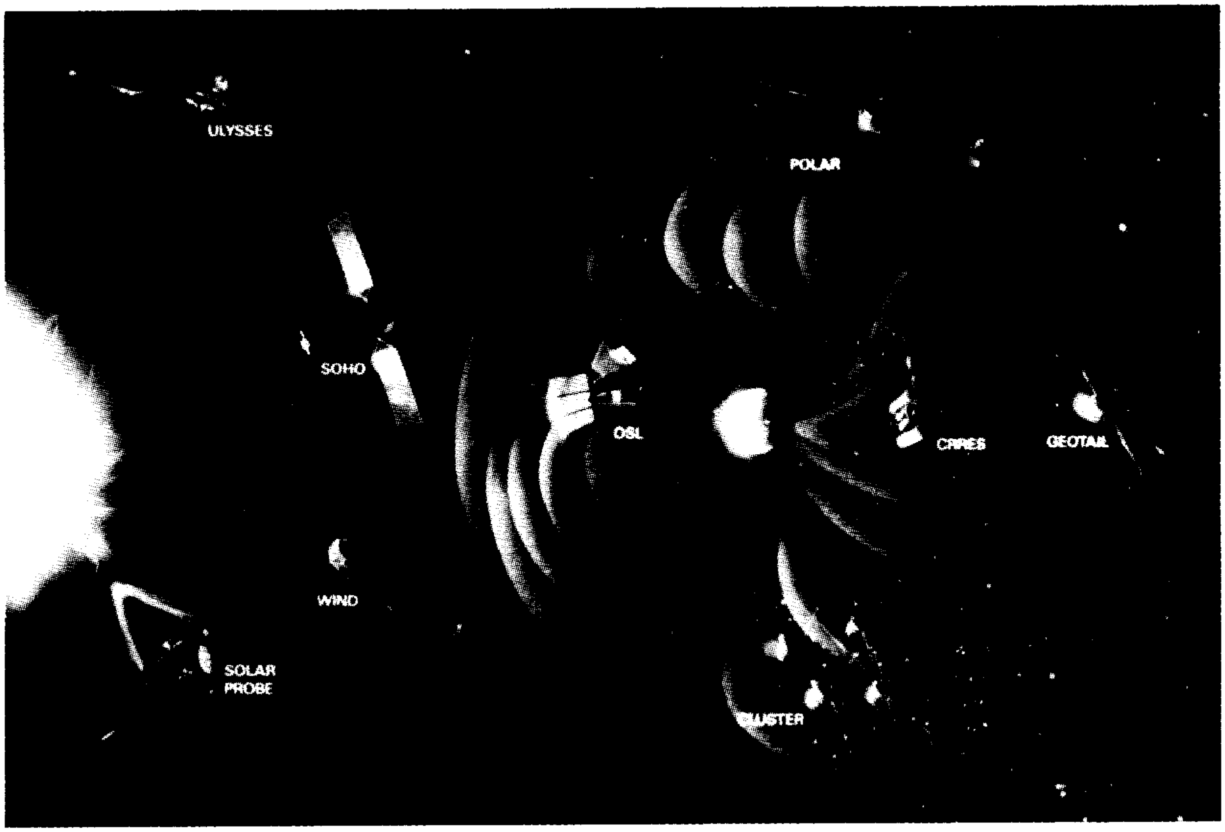

Figure III-21. Major Features of Space Physics Program

At present, the following five satellites are returning measurements of the sun, the heliosphere, and Earth's magnetosphere and ionosphere:

(1) Solar Maximum Mission, which continues to operate successfully since its 1984 on-orbit repair, measuring the characteristics of solar energetic and steady state phenomena, and is expected to continue operating until its expected orbital decay in 1990, just before the peak of the next sunspot cycle;
(2) Interplanetary Monitoring Platform, IMP-8, which is the only spacecraft currently measuring the solar wind in the immediate vicinity of Earth;
(3) International Cometary Explorer, which is measuring the solar wind, energetic particles, and cosmic rays at Earth's orbital distance from the sun, but at a location far from Earth;
(4) Charge Composition Explorer, which continues to provide measurements of the equatorial radiation belts and ring current regions within Earth's magnetosphere; and
(5) Dynamics Explorer, which is providing both remote imaging of the global aurora and in situ polar magnetospheric measurements.

All of the geospace regions and phenomena being investigated by these five satellites respond dynamically to variations of the solar wind seen by IMP-8.

Information from the Pioneer and Voyager solar system exploration spacecraft about the solar wind and cosmic rays in the outer heliosphere is compared with data collected by the Solar Maximum Mission, International Cometary Explorer, and IMP-8 to build an integrated picture of the entire heliosphere in the sun's equatorial plane.

Solar Maximum Mission (SMM)
(Space Physics)

Activity in stars, including the sun, is most easily studied by observing the ultraviolet light and X-rays they emit. However, because of the sun's proximity to Earth, its flares also can be imaged with hard X-rays and the products of nuclear collisions in its atmosphere can be observed. SMM has obtained the most comprehensive observations to date on solar flares. Its simultaneous observations over a broad band of the electromagnetic spectrum have yielded a reliable model of flare phenomena. Since SMM's on-orbit repair in 1984, its observations have had the goal of discovering how flares are triggered.

Interplanetary Monitoring Platform (IMP)
(Space Physics)

The IMP series of spacecraft has been one of the most scientifically productive series of spacecraft ever launched. Explorer 18, which was the first of the IMP series, verified that the magnetosphere was separated from the solar wind by a standing shock wave in the solar direction. Beginning with Explorer 18, the IMPs systematically mapped Earth's radiation environment, the near-Earth solar wind, and the details of the magnetospheric collisionless shock wave. IMP spacecraft have been placed in deep interplanetary Earth orbits and IMP-E (Explorer 35) was put into orbit around the moon, thereby providing detailed observations of the moon's particles and fields environment. The IMPs also explored the tail of Earth's magnetosphere to better understand the flow of plasma and magnetic fields around and away from Earth. The IMP series of Explorers consisted of 10 spacecraft, all of which were exceptional scientific successes.

International Cometary Explorer (ICE)
(Space Physics)

ICE is a renamed International Sun Earth Explorer (ISEE) spacecraft. The ISEE series consisted of a group of three spacecraft designed to investigate, in a coordinated manner, the solar wind's energy input into the outer and intermediate magnetosphere, and the resulting changes deeper in the magnetosphere. The ISEE series was a cooperative undertaking with the European Space Agency.

ISEE-3, an exceedingly versatile mission, was originally designed to remain in deep space, outside the magnetosphere, to measure the solar input to Earth's magnetosphere. However, after its launch in 1978, scientists at NASA's Goddard Space Flight Center realized that by redirecting the spacecraft into a near lunar flyby, it could be accelerated onto a trajectory to encounter the comet Giacobini-Zinner. After its fifth lunar flyby, on December 22, 1983, it was accelerated out of the Earth-moon system on a trajectory toward Giacobini-Zinner. During that final lunar flyby, ISEE-3 passed within 120 kilometers of the lunar surface and was renamed the International Cometary Explorer (ICE). On September 11, 1985, ICE passed through the tail of Giacobini-Zinner and measured the particles, waves, and fields there.

Charge Composition Explorer (CCE)
(Space Physics)

CCE is one of three spacecraft launched in 1984 that constitute the Active Magnetospheric Particle Tracer Explorer (AMPTE). Each of the three spacecraft was designed and built by a different nation—the United States, the Federal Republic of Germany, and the United Kingdom. The mission of the CCE, the U.S. 242-kilogram (533-pound) spacecraft, is to detect and study "tracer" ions released by the German satellite after the ions have entered Earth's magnetosphere. CCE's ion-detection instruments include the Hot Plasma Composition Experiment, the Charge Energy Mass Spectrometer, and the Medium Energy Particle Analyzer. In addition, CCE carries magnetic field and plasma wave experiments.

The AMPTE principal goals are to:

(1) study the entry of ionized particles from the sun into the region of space dominated by Earth's magnetic field (the magnetosphere) and understand transport and acceleration processes that produce high-energy particles in Earth's radiation belts;
(2) study the interaction between an artificially injected cold plasma and the naturally flowing space plasmas; and
(3) establish the composition, charge state, and energy spectrum of the natural particle populations of the magnetosphere.

Dynamics Explorer (DE)
(Space Physics)

The DE mission, which consisted of two spacecraft, was launched in 1981. Its objective was to better understand the direct energy coupling between Earth's immediate space environment and the sun's energy output. The two DE spacecraft were launched into co-planar orbits, one with an apogee of 24,775 kilometers and the other with an apogee of 999 kilometers, thereby enabling complementary data to be obtained at different altitudes. DE investigated the interactive coupling processes between Earth's magnetosphere, ionosphere, and atmosphere.

The next major flight program, the International Solar Terrestrial Physics (ISTP) program, is composed of two closely related parts: the Collaborative Solar Terrestrial Research (COSTR) program, and the Global Geospace Science (GGS) program. COSTR, initially funded in FY 1987, includes the Solar and Heliospheric Observatory (SOHO) and Cluster missions, both of which are jointly sponsored with the European Space Agency, and the Geotail mission, jointly sponsored with Japan's Institute of Space and Astronautical Science. SOHO will emphasize understanding of the sun's interior and the origin of the solar corona, while Cluster (a set of four identical spacecraft) will fly in close formation to measure micro-scale plasma processes in Earth's magnetosphere. Geotail will measure variations in Earth's extended magnetosphere. Approved in the FY 1988 budget for inclusion in the second half of the ISTP, GGS Wind and Polar spacecraft will, in combination with the Geotail mission, investigate geospace as a total integrated system. SOHO and Cluster will be launched about 1995. Geotail and Wind and Polar, which are to be launched in 1992 and 1993, will operate concurrently.

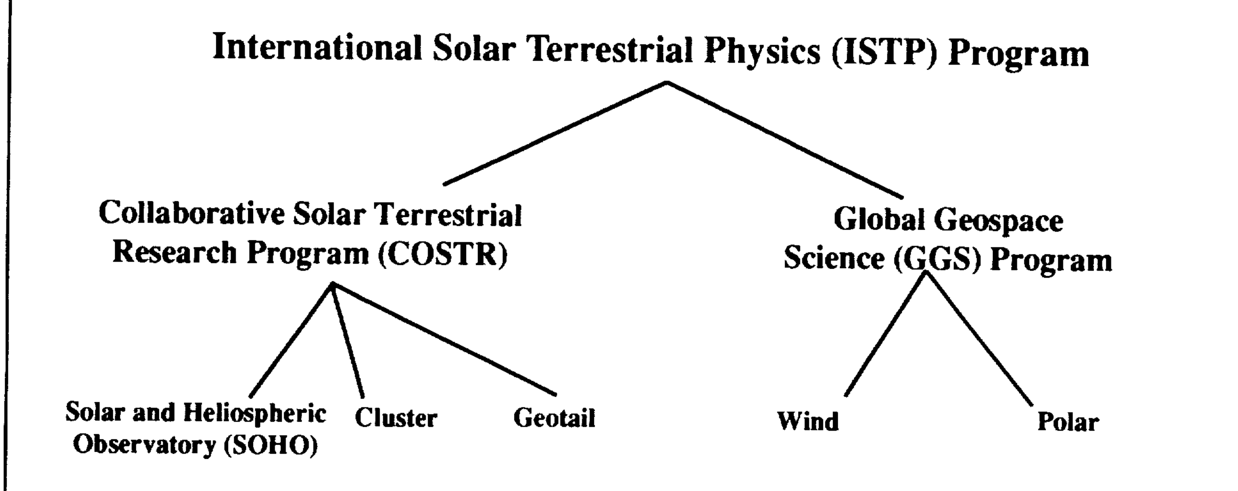

Figure III-22. Organization of the International Solar Terrestrial Physics Program

Solar and Heliospheric Observatory (SOHO)
(Space Physics)

SOHO, a 3-axis stabilized spacecraft equipped with shared European Space Agency-NASA solar physics and plasma physics fields and particles instrumentation, is to be launched by NASA into a sun-Earth orbit. Its objective is to perform remote measurements of the solar interior, the solar corona, and the solar wind in order to characterize the structure of the solar interior, the dynamics of coronal plasma, and the origin of the solar wind.

Cluster Mission
(Space Physics)

Cluster will consist of four identically instrumented, spin-stabilized spacecraft built and launched by ESA with a full range of shared European Space Agency-NASA plasma physics fields and particles instrumentation. Its objective is to perform 3-dimensional studies of the microphysical properties of different plasma states in Earth's magnetosphere.

Geotail Mission
(Space Physics)

Geotail will be a spin-stabilized spacecraft provided by the Japanese Institute of Space Astronautical Sciences (ISAS) and launched by NASA into a complex orbit that takes it deep into the tail of Earth's magnetosphere. It will have a full range of shared NASA/ISAS plasma physics fields and particles instrumentation. Its objective is to characterize energy storage in Earth's geotail and mid-magnetosphere region through measurements in the tail plasma sheet and measurements of plasma entry and transport in the magnetospheric boundary layer.

Global Geospace Science (GGS) Program: Wind Mission
(Space Physics)

Wind will be a spin-stabilized NASA spacecraft equipped with a full range of plasma physics instrumentation to investigate fields and particles. Its objective is to determine solar wind properties, including plasma waves, energetic particles, and electric and magnetic fields.

Global Geospace Science (GGS) Program: Polar Mission
(Space Physics)

Polar will be a spin-stabilized NASA spacecraft equipped with a full range of plasma physics instrumentation to investigate fields and particles. Its objectives are to:

(1) characterize the energy input to the ionosphere;
(2) determine the role of the ionosphere in substorm phenomena and in the overall energy balance of the magnetosphere;
(3) measure the complete plasma, energetic particles, and fields in the high-latitude polar regions, and the energy input through the dayside cusp;
(4) determine the characteristics of ionospheric plasma outflow;
(5) study the characteristics of the auroral plasma acceleration regions; and
(6) provide global multispectral auroral images of the footprint of magnetospheric energy deposition into the ionosphere and upper atmosphere.

The moderate-sized Combined Release and Radiation Effects Satellite, scheduled for a 1990 launch, will provide mapping of the radiation belts during a solar maximum and will analyze the chemistry of the ionosphere and magnetosphere through numerous chemical releases.

The launch of Ulysses, which will study the heliosphere out of the ecliptic plane, is planned for 1990. Ulysses is a joint NASA-European Space Agency program. The spacecraft will carry a package of experiments to investigate the sun at high solar latitudes with the objective of understanding the sun's corona, the origin and acceleration of solar wind, and the composition and acceleration of energetic particles.

In 1991, the Tethered Satellite System (see page IV-18) will investigate the electrodynamic interaction between ionospheric plasma and a diagnostic satellite at the outer end of a conducting wire 20-km long deployed from the shuttle.

Combined Release and Radiation Effects Satellite (CRRES) (Space Physics)

As satellite systems become more complex, with sophisticated electronics and sensors, they become increasingly susceptible to damage by the hostile radiation environment found hundreds of miles above Earth. CRRES is a joint program of NASA's Marshall Space Flight Center and the Department of Defense's Air Force Space Test Program, designed specifically to address this problem. The scientific instruments and investigations for CRRES are being supplied by scientists from institutions throughout the United States, Europe, and South America. The CRRES program is the latest in a new generation of space research missions using a synergistic combination of active probing and passive observations to study the complexities of the Earth-space environment.

CRRES will perform investigations in the ionosphere and the magnetosphere. Chemical tracer releases will briefly "paint" magnetic field lines and waves with luminous particles of calcium, barium, lithium, strontium, or europium so they can be studied by instruments on the ground, in specially equipped aircraft, and by CRRES. By observing the natural environment before, during, and after active experiments, scientists gain new insights into the conditions that naturally influence and perturb Earth's magnetic field. NASA's phase of the CRRES mission will take place in an elliptical orbit at an altitude of approximately 400 kilometers by 35,800 kilometers at 18 degrees inclination. The complement of 24 canisters will be expelled in brilliantly visible releases over ground observation sites in the Caribbean and South Pacific, with the objectives of tracing low-altitude electric fields and studying ion transport along magnetic flux lines. In addition, artificial ionospheric instabilities will be induced chemically, and the effects on ground-to-satellite communications will be studied. Attempts will be made to induce holes in the ionosphere and to use those holes to focus low-frequency radio waves. The effects of heating ion clouds using ground-base high frequency transmitters also will be studied. Nineteen additional chemical releases will be launched on a Scout ELV and a series of sounding rockets to complement the CRRES releases.

Ulysses
(Space Physics)

Ulysses, formerly known as the International Solar Polar Mission, is a cooperative undertaking by the European Space Agency and NASA to reconnoiter the solar wind and other interplanetary phenomena perpendicular to the sun's equatorial plane. It will consist of a single spacecraft provided by the European Space Agency and instruments supplied by both participants. U.S. scientists are Principal Investigators for five of the nine experiments to be conducted and are serving as co-investigators for some of the European Space Agency experiments. The United States will provide the radioisotope thermoelectric generator, launch services, and tracking and data acquisition services.

The objectives of the Ulysses mission are to investigate, as a function of solar latitude:

(1) the properties of the solar corona,
(2) the solar wind,
(3) the structure of the sun-wind interaction,
(4) solar and nonsolar cosmic rays,
(5) solar radio bursts and plasma waves, and

New Initiatives. The highest priority major mission for space physics is the Solar Probe, which will be humanity's first direct exploratory venture to the vicinity of the Sun. Currently in an early study phase, this mission offers a unique opportunity for leadership in this area. For that reason and because of its significant scientific benefit, the Solar Probe has been strongly endorsed by the scientific community.

The highest priority moderate mission for space physics is the Orbiting Solar Laboratory, a scientific platform for investigating the sun's fine-scale magnetic structures. This program is unusually mature in terms of hardware definition, and the provision of funding for its construction and implementation is critical.

Definition studies are under way for potential Space Station payloads, including the Plasma Interaction Monitoring System, the Solar-Terrestrial Observatory, Astromag and the Pinhole Occulter Facility.

Solar Probe
(Space Physics)

Solar Probe will study the unexplored region of the solar atmosphere between 4 and 60 radii from the sun's visible surface, where the solar wind begins to flow at supersonic speeds. It will measure the electromagnetic fields and study the particle populations close to the sun; make fundamental measurements relating to the sun's internal structure, gravitation, and relativity; and observe with exceptionally high spatial resolution the structure of the solar atmosphere from the photosphere to the corona.

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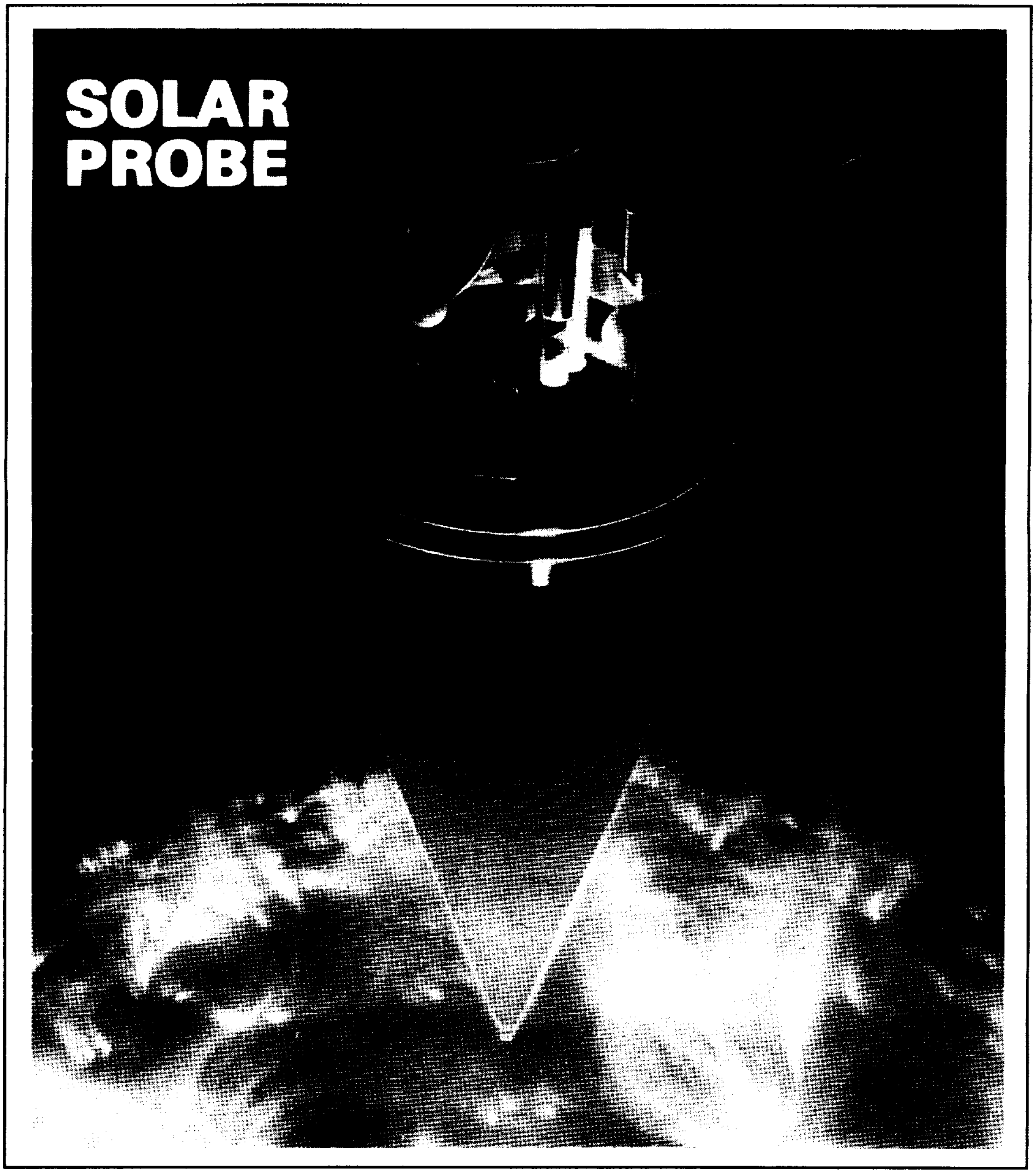


Figure III-23. Solar Probe

Orbiting Solar Laboratory (OSL)
(Space Physics)

OSL, formerly known as the High Resolution Solar Observatory, has the objective of studying in visible light, at the limits of spatial and temporal resolutions at which they actually occur, the fundamental magnetohydrodynamic processes of the sun's surface atmosphere.

Plasma Interaction Monitoring System (PIMS)
(Space Physics)

PIMS is a system of distributed, autonomous instrument packages, each of which consists of a full set of common modules assembled in a building-block approach. Its objective is to measure the induced space environment around the Space Station and the interactive effects between the Space Station and this environment. The individual instrument packages will be outfitted to measure, at a minimum, magnetic and electric fields; neutral particle masses and densities; ion masses and densities; and electron densities, temperatures, and pitch angles. The packages will be distributed on the Space Station so that a comprehensive model of the Space Station's environment can be developed. Candidate locations for the packages include the ends of the transverse boom, the vicinity of the external attach points, the solar panels (or their booms), and the laboratory modules.

Solar Terrestrial Observatory (STO)
(Space Physics)

The STO program consists of a group of missions that require instruments placed both in polar orbit and in the Space Station's low inclination orbit. The objective of this program is to obtain knowledge about solar activity and to study, through observation and active experimentation, the physical processes that couple the atmosphere, the magnetosphere, and the sun. The Space Station portion of STO consists of four groups of instrument packages: the Solar Instrument Group, the Plasma Instrument Group, the Waves in Space Plasma Package, and the Tethered Satellite System.

Astromag
(Space Physics)

The Astromag facility, a Space Station payload, will be built around charged particle track detectors and a powerful superconducting magnet. Capable of being reconfigured and augmented to support a wide range of studies, Astromag will measure the charge-to-mass ratios of subatomic particles.

The primary scientific objectives of Astromag are to:

(1) study the origin and evolution of matter in the Milky Way galaxy by directly sampling galactic material,
(2) support cosmological models by searching for antimatter and dark matter candidates, and
(3) study the origin and acceleration of the relativistic particle plasma in the galaxy and its effects on the dynamics and evolution of the galaxy.

Pinhole Occulter Facility (POF)
(Space Physics)

POF will use X-ray and coronagraphic equipment to study nonequilibrium plasma dynamics in the solar corona, and to investigate the acceleration of nonthermal particles in coronal disturbances. It will use a retractable boom to separate an occulting mask from an array of detectors and telescopes. An array of pinholes in the mask will allow only X-rays to pass through to produce high-resolution images of the sun on the X-ray detectors. The mask will serve a second function by eclipsing the sun for coronal studies.

Research Base. As science moves beyond simple reconnaissance of various space plasma phenomena, support both of in-depth data analysis and of sophisticated theory building becomes increasingly important. Because movement is increasing within the space physics field, from simple data collection into synthesis and model building, a need will grow over the next five years for enhanced support of theory activities, for development of new instruments, and for development of scientific investigators.

Thirteen investigator groups will be supported at a significant level by the Solar-Terrestrial Theory program in FY 1989, and the Research and Analysis program funds nearly 300 investigator groups for data analysis modeling and theory tasks. These programs continue to provide the bedrock of support for many of the space science researchers in the United States. Through the application of theory and computer simulation techniques, space measurements are synthesized into models that allow comparison of the differing plasma systems. General understanding of the accessible space physics systems can be applied both to remote astrophysical settings, for which direct measurement is not possible, and to related laboratory processes.

Space Physics is a major user of NASA's Suborbital program. Cosmic ray measurements use about 30 of the 45 balloon flights conducted each year. Two-thirds of the 40 yearly sounding rocket flights are devoted to satisfying the need for solar fine-pointed instruments, in-situ measurements in the middle atmosphere and auroral regions, and active space-plasma experiments.

The one Spartan mission still to be launched by the shuttle is designed to provide fundamentally new measurements of the temperatures and velocities of the plasma in the sun's inner corona, where the solar wind is formed. Further detailed measurements of the sun are planned—with Spartan-201's white-light coronagraph and ultraviolet coronal spectrometer in 1990-1991, and with the NASA-Japanese Solar-A, which will measure soft and hard solar X-rays.

It is anticipated that other programs, such as Space Station-attached payloads and Explorer missions, with support from rocket and balloon programs and theory and analysis programs, also will fulfill many space physics objectives.

Plan for 1989

The five programmatic themes and the rules for decision-making detailed on pages III-12 and III-13 were followed in constructing the Space Science and Applications program plan for 1989 described in this chapter. That plan and the post-1989 plans presented in the following sections represent the integration of the individual strategies presented in the preceding section.

Current Program

In accordance with the Space Science and Applications program's first theme, (see page III-12), the 1989 plan includes sufficient resources to keep each current flight program on schedule for launch in its manifested slot on the space shuttle or an expendable launch vehicle. The long hiatus in Space Science and Applications launches is drawing to a close and 1989 promises to be an exciting year, with expected launch of the following:

(1) Cosmic Background Explorer,
(2) Magellan, and
(3) Galileo.

In August 1989, Voyager 2 will encounter Neptune, a major milestone in outer solar system exploration, and one that surely will return a wealth of scientific information.

Development will continue on an impressive array of major, moderate, and small missions, to be launched from 1990 through 1993. Those not addressed below are described in the earlier section of this chapter entitled Current Programs and Strategies by Discipline, on pages III-14 through III-69.

In addition to support for flight projects, resource support will be continued for current program elements in research and analysis, suborbital observations, theory and modeling, laboratory and supporting observations, and mission operations and data analysis for current operating missions.

New Major and Moderate Missions

The second programmatic theme listed on page III-12 addresses major and moderate missions. The Space Science and Applications plan for 1989 makes a bold statement that the United States will pursue world leadership in space science in 1989 through a major initiative in astrophysics. The Nation is poised for an accomplishment unique in the history of humankind — to observe the physical universe with unprecedented completeness and resolution. The key to realizing this ambition is the Advanced X-Ray Astrophysics Facility (AXAF). The United States has demonstrated its ability to construct such high-technology orbiting telescopes that can observe the universe in all forms of electromagnetic radiation, and it has the unique ability to maintain these telescopes on-orbit with the space shuttle and, eventually, the Space Station.

If it can be launched by 1995, AXAF will provide an additional benefit by taking advantage of a scientific opportunity that is unlikely to be repeated for many generations. The closest supernova to occur near Earth since the invention of the telescope 400 years ago was sighted in 1987. AXAF can study it, provided that AXAF's launch occurs before the X-rays emitted by the supernova fade. Supernovae are the origin of all the heavier elements in the universe, including those essential for life.

Small Missions

The third programmatic theme involves small missions. A clear need exists for stimulating the research community, particularly at universities, with exciting new opportunities that will attract new scientists and engineers to space science. Over the years, the Explorer program, with its frequent launches of small payloads, has been one of the means NASA has used to provide such opportunities. To maintain the continuity and vigor of the Explorer program, the Space Science and Applications plan includes an augmentation for it in FY 1989. This augmentation, building on the augmentation provided by Congress in FY 1988, will support development of additional small payloads that can be launched on Scout-class expendable launch vehicles. These payloads are sufficiently small that they can be built and launched within three years, yet are sufficiently capable to accomplish first-class science in astronomy, space physics, and upper atmospheric physics. An Announcement of Opportunity was released in May 1988 to solicit proposals for payloads the augmentation could support.

Space Station Utilization

The fourth programmatic theme concerns the Space Station. It is time to begin aggressive development of the principal areas of Space Science and Applications that will take advantage of the unique opportunities that the Space Station will provide. Four such areas—microgravity science, life sciences, multidisciplinary attached payloads, and Polar Platform-based Earth science payloads—are being developed, and each area has an individual strategy.

Microgravity Science. The Space Station will provide a laboratory in which scientists will be able to conduct and continually interact with a broad range of microgravity experiments in materials science, fluid physics, and biotechnology. These experiments will advance basic knowledge in physics, chemistry, and biology, and will be directly applicable to improving the understanding of processes that occur on Earth and in space.

To use the Space Station as a microgravity laboratory, NASA will develop six facilities (see page III-45):

(1) Modular Multizone Furnace Facility,
(2) Modular Containerless Processing Facility,
(3) Advanced Protein Crystal Growth Facility,
(4) Biotechnology Facility,
(5) Fluid Physics/Dynamics Facility, and
(6) Modular Combustion Facility.

The plan for microgravity science provides for full development of all six of these facilities and allows for flight testing them on a Spacelab mission and/or a commercially developed space facility. The plan leads to full instrumentation of the Space Station for microgravity science by the time a human-tended capability becomes available. A full discussion of the Space Station program constitutes Chapter V of this report.

Life Sciences. Life sciences research also will be an important Space Station activity. NASA is conducting studies on precisely how that research will be accommodated on the Space Station, and is developing one of the facilities certain to be required—the 1.8-meter centrifuge. This facility is essential to biological research in space. As with the six microgravity facilities, the centrifuge will be flown and tested on a Spacelab mission and/or a commercially developed space facility before its use on the Space Station.

Multidisciplinary Attached Payloads. The Space Station also will provide opportunities for flying attached payloads in a broad range of science and applications disciplines. The strategy in this area is to begin with attached payloads that are not overly demanding on the environment and pointing capabilities of the Space Station. Evolution to more sophisticated attached payloads will occur as knowledge of the Station and its full capabilities increases. NASA will release an Announcement of Opportunity soliciting: (1) proposals for attached payloads to be carried on the Space Station during its initial one to three years of operation and (2) proposals defining more ambitious investigations with attached payloads to be flown later. Payloads under study for possible inclusion in the initial phase of the Space Station include:

(1) Cosmic Dust Collection Facility,
(2) Astrometric Telescope,
(3) Astromag,
(4) Plasma Interaction Monitoring System,
(5) Solar-Terrestrial Observatory, and
(6) Pinhole Occulter Facility.

Earth Science from the Polar Platform. The Polar Platform of the Space Station will provide an opportunity for detailed observations of Earth, including observations of how Earth is evolving on a global scale and of how humans are influencing that evolution. A recent Announcement of Opportunity, released jointly with the Europeans and the Japanese, will enable selection of Earth sciences investigations for the Earth Observing System, which is to fly on the Polar Platform, and of potential attached payloads to fly on the manned base. The Earth Observing System is a candidate new start for FY 1991, and this payload selection is part of the normal process of preparing a mission for new start consideration. Also planned are resources for advanced technology studies to define instruments and information systems for the Earth Observing System.

These four parts of the Space Station initiative—the development of microgravity facilities, the development of the centrifuge and the planning for other life sciences facilities, the development of attached payloads, and the selection and study of Earth observing instrumentation for the Polar Platform—form a comprehensive plan to begin to make full use of the unique opportunities that the Space Station will provide.

Research Base

The fifth and final theme is the Research and Analysis program, which is the vital underpinning to the Space Science and Applications program. Augmentations to this program will: continue the present rocket and balloon campaign to study and understand the recent supernova before the Great Observatories become available to observe and study it; complete the purchase of a new high-flying aircraft to conduct remote sensing of Earth; and provide additional resources to take maximum advantage of the approaching encounter of the Voyager spacecraft with Neptune. The plan also provides for continuing the development of advanced technology for the Mariner Mark II missions (Comet Rendezvous Asteroid Flyby and Cassini).

Five-Year Strategy (FY 1990 through 1994)

Beginning with the all-encompassing goals for NASA articulated in the President's National Space Policy and working through the Office of Space Science and Applications' goals and objectives, the themes and decision rules cited earlier (pages III-12 and III-13) form the basis for the Office's strategy for FY 1990 through 1994.

Current Program

Each succeeding year, the flight projects and research programs started the previous year combine with those that already were under way to form the current program. The highest priority of the Office of Space Science and Applications' strategy is to carry out the current program. The Hubble Space Telescope and the Astro Spacelab mission, both to be launched in early 1990, are examples of flight projects receiving high priority during this period.

Major and Moderate Missions

All the major flight projects in the FY 1989 current program will be launched by 1993. A new major flight project requires four to six years to develop. Thus, pursuit of leadership in key areas requires early selection and initiation of successors to the current program.

Several criteria drive decisions about the selection and sequence of major and moderate missions. First, missions of the highest scientific priority, as identified by the National Academy of Sciences and the NASA Advisory Council, are regarded as candidates. Second, the candidate missions are assessed for the degree of technological readiness to pursue them; this determines the degree of understanding of cost and schedule risk for them. Third, the order in which major and moderate missions are pursued is governed by the need to pace the implementation of discipline-specific plans at a rate of approximately one major or moderate new start every five years in each of the seven disciplines; this pace keeps all the discipline programs moving forward and maintains their vigor. All missions are viewed in the context of the recommendations for mission selection that the NASA Space and Earth Science Advisory Committee elucidated in its report *The Crisis in Space and Earth Science.* The report describes guidelines for the following criteria:

(1) scientific merit,
(2) programmatic considerations, and
(3) societal and other implications.

Another selection guideline is that there should be one major or moderate new start per year. While circumstances may present occasions when more than one major or moderate mission new start is possible, and others when no new start is possible, an average pace of one per year is necessary to meet the goal of leadership in key areas and to ensure vigor and continuity. On the other hand, a realistic estimate of resource constraints indicates that more than one new start per year cannot always be expected, since resources for small missions and for research and analysis must be preserved. In any event, in order to preserve and enhance U.S. leadership, major missions will be pursued whenever resources permit. Major missions, in order of priority, are as follows:

(1) Comet Rendezvous Asteroid Flyby and Cassini mission,
(2) Earth Observing System,
(3) Space Infrared Telescope Facility, and
(4) Solar Probe.

Joint Comet Rendezvous Asteroid Flyby (CRAF) and Cassini Mission. The CRAF and Cassini missions have long been established as endeavors of high scientific priority. Combined, they will address the fundamental goal of determining the origin and evolution of the solar system and of life. The large planets preserve unprocessed elemental and isotopic matter; and scientists believe, for example, that in Titan's atmosphere, chemical and physical reactions similar to those that led to the origin of life on Earth may now be taking place. The primitive bodies, comets and asteroids, preserve relatively unprocessed molecular and organic material from the interstellar medium and the solar nebula. Studying the outer solar system and the primitive bodies provides information about the early history of the solar system, and about the origin, evolution, and distribution of prebiotic organic materials.

Because of their shared scientific goals and the complementary nature of their objectives, and also because they both use the same Mariner Mark II spacecraft design, CRAF and Cassini have been combined into a joint program. This initiative has the highest priority for major missions because development must be started now to ensure a robust solar system exploration program at the end of this century, and to continue the U.S. tradition of leadership in exploring the outer solar system.

Earth Observing System. The Earth Observing System (Eos) is recommended for an early start in order to satisfy the accelerating need for information about the rapid evolution Earth's environment is undergoing, and to prepare to make timely use of platforms the Space Station will provide. Phase B studies are expected to be completed in 1990 and development then should start as soon as possible.

NASA has issued an Announcement of Opportunity for Eos soliciting proposals for science investigations, including the provision of instruments. The intent is to ensure full participation by the science community in the further planning and development of this mission. NASA will fund the initial study phases of the investigations selected and will support further studies of major instruments, the Eos Data and Information System, and the Eos mission as a whole. The Space Station program is already developing, as part of Work Package 3, the Polar Platform on which Eos will be mounted; and NASA's Office of Space Operations is defining and developing the space and ground segment elements required to relay Eos data.

NASA is studying the Mission to Planet Earth recommended in Dr. Ride's report as one of the four major long-range initiatives NASA should be considering. Eos is the first major element of that mission, and NASA is taking the appropriate steps to prepare for it.

Space Infrared Telescope Facility. The Astronomy Survey Committee of the National Academy of Sciences recommends the Space Infrared Telescope Facility as a high-priority mission. This facility, the fourth of the four Great Observatories, will view the very cold regions of the universe in the infrared region of the electromagnetic spectrum.

Solar Probe. Because the Solar Probe offers a unique opportunity for leadership in exploration of the heliosphere and has been cited by the scientific research community as a high-priority program, it has been established as the fourth major mission in this Space Science and Applications 5-year plan.

In the event that resources do not permit implementation of a major mission, the following moderate missions will be pursued, in the order of priority shown:

(1) Orbiting Solar Laboratory/High-Resolution Solar Observatory,
(2) Lunar Observer, and
(3) Gravity Probe-B.

Orbiting Solar Laboratory/High-Resolution Solar Observatory. The High-Resolution Solar Observatory program has been endorsed repeatedly as the highest priority of the Nation's space solar physics discipline and, as such, has received the highest recommendations from the relevant committees of the National Academy of Sciences.

Lunar Observer. To ensure an efficient and cost-effective transition to the Lunar Observer using spares from the Mars Observer, the Lunar Observer will begin in 1992. Therefore, at that time, the Lunar Observer will become the highest priority moderate mission, even if the Orbiting Solar Laboratory has not been started.

Gravity Probe-B. The technologies required for Gravity Probe-B have been under development since 1965. Systems analysis and technology development now under way will integrate the resulting component technologies to provide a functioning prototype that will be tested on a space shuttle flight in preparation for flight of this mission.

Small Missions

The missions in this category are essential to sustaining the vigor of the Space Science and Applications program. They can be launched more frequently than major or moderate missions, perhaps as often as every two years per discipline. They can provide opportunities comparable to those the Explorers provide. Currently identified small missions in the 5-year plan include Earth Probes and Lifesat.

Space Station Utilization

During FY 1990 through 1994, the Space Science and Applications program will begin the space biology counterpart to the 1989 microgravity initiative. The goal of space biology research is to use the unique characteristics of the space environment, especially microgravity, to understand life and its processes, and to understand how gravity affects and has shaped life on Earth. The objective of the research, which encompasses both plants and animals, is to: understand the mechanisms by which organisms perceive gravity and transmit the information to a responsive site; determine the role of gravity in reproduction, development, maturation, and function; and understand the mechanisms by which environments, in conjunction with microgravity, affect living systems.

The development of second-generation attached payloads for a variety of disciplines also will need to begin during this 5-year period.

A key factor in OSSA's preparation for Space Station will be the continued use of Spacelab, the space shuttle mid-deck lockers, and other appropriate carriers to develop, test, and verify new and improved instrumentation for subsequent use on the Space Station.

Research and Analysis

The highest priority in this area is to augment the research and analysis base. In particular, laboratory equipment and facilities need to be upgraded, and enhancements in funding need to be provided for new instrument development, data analysis, theoretical studies, and more capable information systems and computational facilities. Further, the suborbital program needs enhancement in balloons and rockets and in areas such as those described below.

Stratospheric Observatory for Infrared Astronomy (SOFIA). Since the Space Infrared Telescope Facility will not fly until the late 1990s, SOFIA is needed so that scientists can follow up on the exciting discoveries of the Infrared Astronomical Satellite in the interim. In addition, SOFIA will complement the Space Infrared Telescope Facility when it becomes operational.

New Aircraft for Earth Remote Sensing. Observations of Earth from instrumented aircraft complement those taken from space and on the ground, and provide critical flight demonstration tests of advanced remote sensing technologies. Currently, four aircraft—one DC-8, two ER-2s, and a C-130—support this program. Since aircraft observations provide a method for uncomplicated launch and fast turnaround, NASA will update the fleet with aircraft that are more capable and more sophisticated.

Summary

Table III-3 graphically summarizes the strategy that will guide the Space Science and Applications program from 1989 through 1994. The strategic approach described earlier, including consistent programmatic themes and decision rules, will continue to provide a methodology for planning the program in the future.

Table III-3. Space Science and Applications Strategy

	1989	1990 through 1994
Current Program	Research and Analysis Mission Operations and Data Analysis Flight Projects Spacelabs and Other Carriers	
Major and Moderate Missions	Advanced X-Ray Astrophysics Facility	CRAF/Cassini OSL Eos Lunar Observer SIRTF Gravity Probe-B Solar Probe
Small Missions	Scout-Class Explorers	Earth Probes Lifesat
Space Station Utilization	Microgravity Facilities Attached Payloads Eos Payload Definition	Space Biology Facilities Second Generation Attached Payloads
Research Base Enhancements	SETI Mission Operations and Planning CRAF/Cassini Advanced Technology Development SN 1987a Suborbital Observations ER-2 Purchase	Laboratory Facilities Mission Operations and Data Analysis Theory Suborbital

Beyond 1994

The current and planned programs discussed above will successfully push back the frontiers of space and further exploration and understanding of the universe. OSSA expects Space Science and Applications to be even more rewarding, exciting, and challenging at the dawn of the 21st century than it is today.

The four Great Observatories—the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility—will be operating together to observe the universe across the entire electromagnetic spectrum. With the information these observatories reveal, a deeper understanding will be gained of man's role and place in the universe. The revolution in thinking that this understanding causes will rival the one that occurred when the early astronomer Copernicus showed that the Earth was not the center of the universe. Many totally unexpected scientific discoveries are sure to be made; nature, unfettered by the limitations of human imagination, will continue to surprise.

Man's image of his uniqueness in the universe will be changed by good estimates of how many stars have planetary systems and by successful imaging of at least one planet in orbit around a star other than the sun.

The question of whether the universe is expanding indefinitely, or will at some time begin to contract, should have been answered. With the distance scales and the rate of expansion known with much greater precision, theorists, by combining data from the Great Observatories with experiment results from Earth-based particle accelerators, will develop models for the origin and fate of the universe that include unification of physical laws. Man's understanding of the laws of physics will be undergoing revision to accommodate new insights gained from studies of relics from the creation of the universe and from observations of matter reacting to pressures and magnetic fields unimaginable in the vicinity of Earth, but common near compact objects such as neutron stars and black holes.

The matter currently of unknown form that constitutes 90 percent of the near and far universe should be known. This matter may be composed of new fundamental particles such as "axions" and "photinos," or of new classes of astronomical objects such as brown dwarfs, or of unexpected concentrations of hot pervasive gases.

The Great Observatories will be visited by the space shuttle and the Orbital Maneuvering Vehicle for routine servicing and instrument exchange and, as needed, taken into thermally controlled enclosures at the Space Station for more extensive servicing. Scientists, from workstations at their universities, will browse astronomical data from the Observatories; and data sets with appropriate analytical software are going to be quickly and conveniently accessible on optical disks. The combination of data from the entire electromagnetic spectrum will be used to build total physical understanding of exotic phenomena such as quasars and supernovas. The United States will be perceived as leading a worldwide effort to understand the place of humanity in the universe.

Robotic spacecraft will have flown past all the planets and moons of the solar system, except Pluto and Charon, sending back the images that fill the world with awe and wonder and that build a solid foundation of scientific understanding. Spacecraft will have orbited every solar system body that is accessible to Earth, and will have mapped the surface of Earth's sister planet Venus, substantially augmenting the information base necessary for comparative study of the terrestrial planets: Mercury, Venus, Earth, Mars, and the moon. The history and future of this planet will have become clearer through increased understanding of its solar system neighbors.

The moon's global surface mineral and elemental composition will have been measured, and an assessment completed of its resources, including a search for frozen volatiles at the poles. Combined with what already has been learned about the moon, this information is expected to facilitate preparations for the return of human beings to the moon to build an outpost from which its resources can be explored and exploited.

Mars, the only other planet in the solar system besides Earth with the potential for human habitability, will have been studied in greater detail to determine its geochemistry and climatology. These studies will help in the development of plans for a human expedition to Mars, a journey expanding human presence farther into space than it has ever been before.

Solar system scientists will have peered back into the early history of the solar system by studying its most primitive, unaltered bodies—comets and asteroids.

A spacecraft will have flown in formation with a comet, and have studied an asteroid at close range. Solar system missions will have flown by asteroids whenever possible, to reconnoiter the resources these primitive bodies may hold.

Traveling into the outer solar system, a spacecraft orbiting Saturn will have released a probe into Titan's thick, murky atmosphere and sensed its surface with radar. In the atmosphere of this largest moon of Saturn, a complex process of chemical evolution has occurred and continues to occur. This evolution is worthy of study, for it may be repeating some of the earliest steps in the processes that led to the appearance of life on Earth.

Closer to home, the Earth Observing System and a variety of other instruments in space are expected to have been producing information about Earth for several years. Combined with ground-based measurements and observations, this information will advance understanding of the Earth system on a global scale, with the scientific community's having begun to make progress toward describing how Earth's intimately connected component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales. Earth system science should be well on the way to developing a capability to predict changes that will occur in the future, both naturally and in response to human activity.

Measurements taken over a long, continuous period, from the unique perspective of low-Earth orbit, will have enabled scientists to begin to quantify and understand global change on the planet. The nature and dynamics of the myriad components of the Earth system—core, mantle, crust, solid surface, soils, land masses, vegetation and forestation, oceans, cloud cover, and the layers that comprise the atmosphere—will have been observed and measured. The information generated will have been integrated into a comprehensive data system that scientists can access and use to understand and describe Earth's global character.

The knowledge gained through Earth observations provides continuing benefits to humanity. Increasing predictive ability will have brought Earth and atmospheric scientists closer to being able to alleviate some of the detrimental effects of climatological and geological occurrences. Scientists should have begun to achieve a comprehensive understanding of ocean dynamics and processes by determining the three-dimensional structure of the planet's ocean currents; and an improved understanding should have been gained of the coupled chemistry and dynamics of the stratosphere and mesosphere, the role of solar radiation in these processes, and the susceptibility of the upper atmosphere to long-term changes in the concentration and distribution of key atmospheric constituents, particularly ozone and the greenhouse gases. By coming to understand Earth's present condition, perhaps scientists may have developed techniques to safeguard its future.

The sun, whose light sustains life on Earth, will have been studied both as a star and as the dominant source of energy, plasma, and energetic particles reaching Earth, bringing about a fuller determination of the effects of solar processes on Earth. Solar scientists will have begun to understand the sun's interior and the origin of the solar wind, and will have flown multiple spacecraft in close coordination to measure the total energy budget of plasma processes in Earth's magnetosphere. A probe from Earth is expected to be speeding toward the inner heliosphere, the unexplored region between 4 and 60 radii from the sun, where the solar wind first flows at supersonic speeds. Scientists will have begun to be able to predict the behavior of this star, most central to the destiny of the solar system and of humanity. Quantitative study of the geospace environment, the area between Earth's surface and high Earth orbit, should be progressing toward a full-scale predictive stage.

Astrophysicists will be well on their way to understanding how the complex plasma phenomena in different regions of the solar system and the Milky Way Galaxy are related to the characteristics of the larger systems themselves.

Life scientists expect to know and understand the effects of long-duration spaceflight on the most precious of resources, human life. They will have completed an evolutionary study—starting with data gathered on Skylab, through the space shuttle, through Spacelab, to the Space Station—of the reaction of biological systems, including human beings, to low gravity and space radiation. They expect to have determined and developed measures to ameliorate or prevent the physiological and psychological detrimental results of long-term exposure to the space environment, and of the relative isolation that space travel necessarily imposes on explorers.

Hand in hand with academia and industry, NASA should have determined, developed, and begun to exploit the unique capabilities provided by the Space Station and other space-based facilities to study the nature of physical and chemical processes in a microgravity environment and to apply the results of the studies to advance science and applications in such areas as materials science, combustion science, medicine, biotechnology, and fluid physics. The Space Station, an operational national laboratory, will have enabled great strides in microgravity research.

Advanced communications technologies and information management and computational facilities are expected to be operating to support the transmission, acquisition, archiving, and analysis of the tremendous volume of data returning from instruments in space. These new communications capabilities will be orders of magnitude faster and more efficient than systems in use today, allowing a significant acceleration in progress.

In universities, industries, and federal laboratories, scientific research and analysis of the data flowing from space will be proceeding at a pace commensurate with that of the exploration being conducted. The research conducted in scientific laboratories can be expected to continually yield new insights to prove, disprove, or apply theories. The success of the U.S. space program is going to be a source of great national pride, and to attract youth in ever-greater numbers to develop the skills and knowledge needed to carry on the program in the future. Other nations will be drawn to participate with the United States in its accomplishments, perhaps with the setting aside of old rivalries for the sake of the mutual benefits to be gained by joining forces for scientific advancement.

Interrelationships with Programs of Other Offices

The Space Science and Applications program substantially influences the programs of NASA and other agencies (domestic and international) by generating demands and opportunities in a variety of areas. Within NASA, the appropriate allocation of resources among the Agency's various program areas will, therefore, be essential to the success of NASA's overall program.

Outside NASA, domestic and international science and applications communities are expected to respond to the leadership embodied in the direction and scope of OSSA's strategy. In addition, the opportunity for NASA to complement its programs through cooperative efforts is expected to continue to grow in areas defined by the strategy.

A summary assessment of the implications of the strategy on other NASA program areas follows.

Transportation

The Space Science and Applications program assumes that NASA will implement its current plans for a mixed fleet of launch vehicles, including the current space shuttle and the full range of existing expendable launch vehicles. A critical performance parameter for the space shuttle's Spacelab missions is the maximum permitted downweight. The current strategy assumes the availability of the space shuttle with 230,000 pounds of downweight, which enables Spacelab missions of up to 10 days on the orbiter Columbia, the only orbiter currently equipped for a 10-day mission. Launch rates for the space shuttle for Spacelab pressurized module missions will be two to three per year and, for pallet missions, one to two per year.

Regarding expendable launch vehicles, implementing the Space Science and Applications program requires the availability of "small" (Scout-class), "medium and intermediate" (Delta-, Atlas/ Centaur-, Titan III-class), and "large" (Titan IV-class) vehicles. Launch rates for expendables will average approximately two small and two to four medium or intermediate per year, and one large every two to three years.

The rate at which OSSA's strategy can be achieved can be enhanced substantially by the availability of the

Advanced Solid Rocket Motor, which will allow significantly heavier payloads to be delivered to the Space Station manned base during the assembly phase. Without this capability, delivery of user equipment to the Space Station will be delayed or additional shuttle flights required. The Advanced Solid Rocket Motor also is intended to permit shuttle-based servicing of polar platforms, provided that shuttle operations begin at the Western Test Range.

Probably the most substantial current deficiency in transportation services for OSSA payloads is the absence of a capability equivalent to that of the cancelled Centaur upper stage used in conjunction with the shuttle. This capability is required to relieve planetary mission designers of the need to compensate for its lack with multiple gravity-assist swingbys of Venus and Earth, with the attendant costly inefficiency. Until either a heavy-lift launch vehicle equipped with a cryogenic upper stage or some version of an orbital transfer vehicle and a capability for space-based assembly become available, planetary orbiters will not be able to achieve efficient direct transfers between Earth and the bodies in the outer solar system.

OSSA, in conjunction with NASA's Office of Space Flight, is engaged in a continuing assessment of civil space transportation needs as part of a larger national effort focused on space transportation architecture studies.

On-orbit Infrastructure

Development of the Space Science and Applications program assumes that the Phase 1 Space Station will be available in the mid-to-late 1990s. The early 1990s will be devoted to preparing for the Space Station through experiment and instrument development in space. At present, however, the only capability available for manned space operations is the Space Transportation System and its associated Spacelab systems. This matched system enables Spacelab module missions of up to 10 days only three times in a 12-month period, and then only on Columbia. Although this capability appears to provide adequate capacity for continuing Spacelab activity after deployment of the Space Station, demands by both U.S. and foreign users are such that a near-term shortfall in capacity could delay preparations for the Space Station without an increase in the availability of in-orbit time provided by giving the shuttle an extended-duration capability and by augmenting the Spacelab system.

Several potential enhancements, possibly including the Extended Duration Orbiter and commercially developed space facilities, will not be available until 1991 or 1992. Studies currently under way are focused on identifying optimal configurations for these enhancements, for use in conjunction with the Space Transportation System to both extend and increase the frequency of manned scientific operations in space. Use of commercially developed space facilities in a crew-operated mode could increase the number of equivalent annual Spacelab flights. In addition, the duration of man-tended missions aboard Spacelab or commercially developed space facilities could be extended to at least 20 and possibly as many as 30 days.

With regard to the Space Station itself, recent OSSA assessments indicate that OSSA could fully subscribe the Station's planned resources, even assuming the availability of five to six shuttle flights per year and of 45 kilowatts of power with the three laboratory modules in the base line. Future OSSA programs are likely to benefit from, and indeed may require, the availability of the coorbiting platform elements of the Space Station. Additional activities are currently under way as part of the Space Station Program Requirements Review to understand and resolve any issues.

The deferral of servicing for free-flying spacecraft and of some capabilities for attached payloads is one issue. Planned Space Station use would be enhanced substantially by reinstatement of the Space Station-based Orbital Maneuvering Vehicle for retrieving co-orbiting spacecraft, along with some limited capability at the manned base for changing out orbital replacement units on free-flyers and for replenishing fuel and cooling cryogens on free-flyers and attached payloads. Efforts are under way to further define these needs.

Telecommunication and Information Systems

Development of the Space Science and Applications program assumes that the full range of telecommunications and data systems will be provided by the Offices of Space Operations and Space Station. These services include the Tracking and Data Relay Satellite System, the Deep Space Network, the Program Support Communications Network, and the Space Station Information System.

OSSA information-systems activities enhance the scientific productivity of research programs through the application of advanced information technology. The information-systems program provides an effective scientific computing environment and a comprehensive scientific data service to OSSA's widely distributed research community. Key elements of the program include scientific computing and data management support through the NASA Space and Earth Sciences Computing Center and the National Space Science Data Center, both at the Goddard Space Flight Center. Another fundamental element of the program is networking to expand access and resource sharing throughout the community. To develop generic tools and capabilities for subsequent application across Space Science and Applications disciplines, research continues in advanced technologies and techniques.

The information-systems program has collaborated with individual research disciplines to design and build data systems for the oceans, climate, planetary, and land communities. Some scientific disciplines have already begun to develop disciplinary and interdisciplinary information systems for planned missions, such as the Earth Observing System's information system.

Data and information systems will continue to grow in importance as a vital support element for scientific programs. The Space Station betokens an era of increasingly complex, sophisticated missions comprised of multiagency, international activities. Achievement of the full scientific objectives of the era will require advanced information systems to satisfy the unique needs generated by these missions.

OSSA intends to evolve from the mode of designing and developing essentially independent data systems for individual flight projects to the broader mode of designing systems and evaluating tradeoffs that span payloads, projects, and scientific disciplines. This mode will require a consistent planning model, along with a methodology that can accommodate change to exploit advances in technology throughout the life cycle of very-long-duration future flight missions and science campaigns.

The Science and Applications Information strategy is the basis of a strategy for planning and developing future information systems to meet the objectives of all OSSA scientific disciplines. It is composed of four key activities, all of which are conducted in close coordination and cooperation with the scientific discipline programs:

(1) An overall architecture and planning model that meets the basic requirements of OSSA programs will be defined. This model must support a highly adaptable environment to permit the incremental, modular evolution of system components.
(2) OSSA information system requirements will be synthesized so that they can be clearly represented in the design and development phases of the Space Station Information System and other flight-mission data systems.
(3) A testbed program will be developed to explore, evaluate, and demonstrate new and emerging technologies that will support the telescience and other operational scenarios envisioned for the Space Station era. Where appropriate, the technologies will be integrated into current development efforts.
(4) Tools and information system capabilities that can be applied to all of OSSA's areas will be developed.

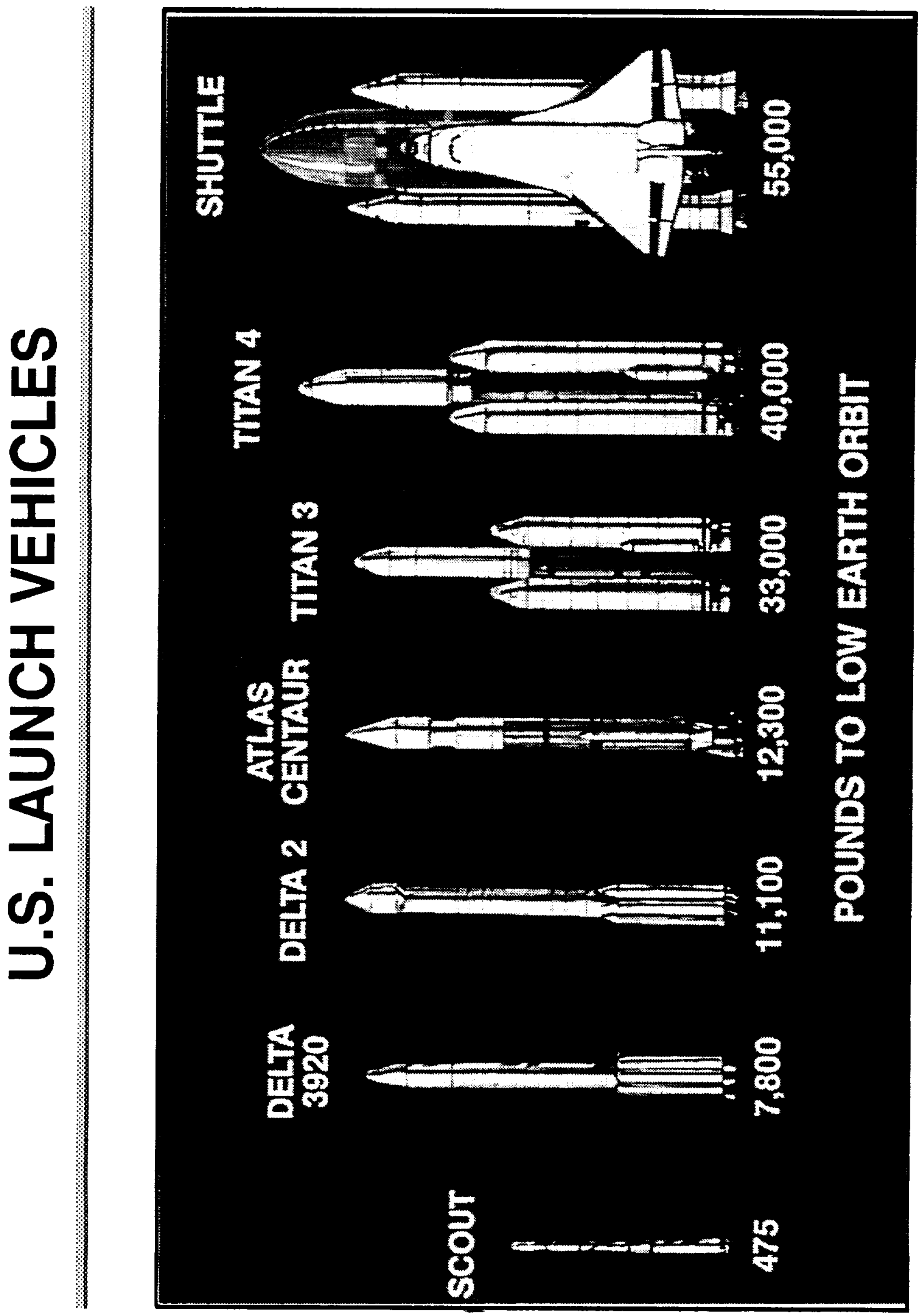
Technology

Development of the Space Science and Applications strategy has assumed the availability of technology that is currently state-of-the-art or near that level. In addition to depending upon continued efforts by the Office of Aeronautics and Space Technology in a wide range of spacecraft and instrument subsystems, OSSA is developing advanced technology for the next four major Space Science and Applications initiatives—the Advanced X-Ray Astrophysics Facility, the Mariner Mark II Program (starting with the Comet Rendezvous-Asteroid Flyby and Cassini missions), the Earth Observing System, and the Space Infrared Telescope Facility. The Solar Probe also will present significant new challenges, especially in the area of thermal protection systems; therefore, advanced technology studies in support of this candidate major mission will need to be initiated. Advanced development of technology will ensure the timely availability of critical technologies well before they are needed for full-scale development. This approach to risk and cost reduction is an important element in the Space Science and Applications program.

Future OSSA programs will benefit substantially from technologies generally associated with sensors, information systems, automation and robotics, and artificial intelligence. Anticipated applications for these technologies include ultrahigh-density data storage on Space Station, autonomous experiment-systems operations, "telescience," and telerobotic servicing. All these technologies will enhance productivity and will help to extend human presence in low Earth orbit and, eventually, in geosynchronous orbit.

OSSA is currently involved with NASA's Office of Aeronautics and Space Technology (OAST) in planning the scope and content of activities within the OAST program that are of direct interest to OSSA. A Memorandum of Understanding between OSSA and OAST outlines the responsibilities of the two offices in the humans-in-space element of OAST's Project Pathfinder.

SPACE FLIGHT



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SPACE FLIGHT

The Office of Space Flight develops space transportation capabilities and supports space flight operations. Its responsibilities encompass the return of the space shuttle to flight status as well as the establishment of a mixed fleet capability that includes shuttle and unmanned launch vehicle services. In addition, the Office of Space Flight actively supports the commercial use of space and the privatization of space transportation systems in accord with the President's National Space Policy of February 1988. It also conducts planning and development to provide an advanced space transportation infrastructure supporting manned and unmanned exploration of the solar system and permanent presence of humans in space.

Introduction

During the calendar year before the Challenger accident on January 28, 1986, there were 10 successful flights of the space shuttle, the key element of the Nation's Space Transportation System (STS). Those flights included the first two flights of the fourth Orbiter, Atlantis, the first "impromptu" satellite repair attempt, the first dedicated DOD mission, and three flights of the European-developed Spacelab, including the first dedicated foreign Spacelab mission.

With its 24 successful flights before the accident, the STS had begun to change the traditional view, that space activities are merely idiosyncratic activities of and for a limited few, to the forward looking view, that they are an integral part of human activity and of great benefit to all of society. When it returns to flight status after an extensive modification and improvement program, the STS will provide reliable, economical transportation between Earth's surface and low Earth orbit through the 1990s.

The plan described in this chapter is designed to meet U.S. space transportation goals and objectives through at least the end of the century. However, the STS, as presently defined and approved, will not meet requirements for the more distant future. As space becomes more and more a part of our daily life, new space transportation capabilities will be required.

The program of the Office of Space Flight (OSF) has three major components: Space Transportation, Flight Systems, and Advanced Program Development. In addition, OSF actively supports and encourages the commercial use of space and the privatization of space transportation systems, as directed by the President's National Space Policy. That policy addresses privatization of space transportation systems such as expendable launch vehicles and upper stages for the shuttle, and includes the procurement of launch vehicle services to meet unmanned payload requirements for NASA and other civil government users. Phase II of OSF's expendable launch vehicle (ELV)-Mixed Fleet program involves commercial development and operation of ELVs; and several private firms currently are considering commercial development of upper stages.

The space transportation component of OSF's program consists of acquisition, testing, production, and continuing improvement of space vehicles and the services they provide. In particular, it encompasses the return of the space shuttle to flight status and the addition of a replacement orbiter, as well as the establishment of a mixed fleet capability comprising the shuttle and unmanned launch vehicle services.

Space flight operations include pre-launch, launch, flight, landing, and post-landing activities. Concomitant

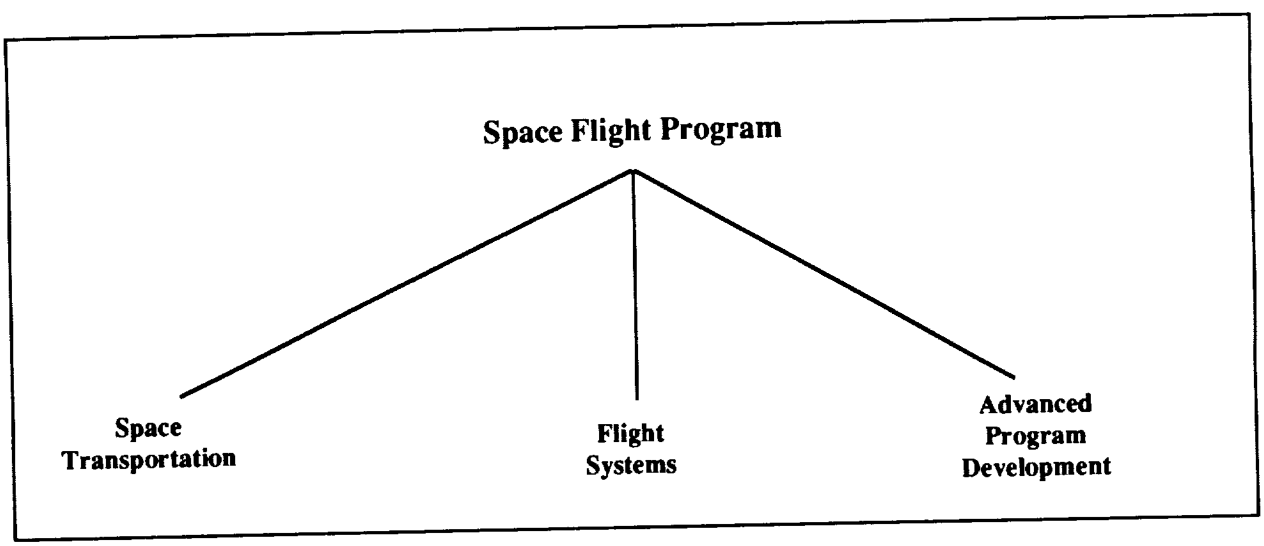


Figure IV-1. Space Flight Program Components

customer services, including the attainment of safe, sustainable shuttle flight rates, fall into this category, as does development of capabilities compatible with payload requirements and program resources.

The advanced program development component of the program includes planning and evolutionary development of follow-on programs to build upon the STS, definition of a heavy-lift cargo vehicle based on available technology, and development of a next-generation manned space launch system. These programs will provide an advanced space transportation infrastructure to support permanent presence of humans in space, and will increase space flight capabilities through development of advanced transportation and on-orbit services. Development of advanced vehicles, automated and robotic systems, and Earth return capabilities will enable human and robot exploration beyond Earth orbit into the solar system.

Space Flight Goals

The President's National Space Policy commits NASA to maintain world leadership in selected critical areas of space flight, particularly in manned space flight, by developing and employing space transportation systems able to meet appropriate national needs. Three of the Agency's top-level goals are relevant to that commitment, namely:

(1) return the space shuttle to flight status and develop advanced space transportation capabilities,
(2) develop facilities and pursue science and technology needed for the Nation's space program, and
(3) conduct cooperative activities with other countries when such cooperation is consistent with our national space goals.

Progress in meeting these goals requires that the Space Flight program maintain strong, responsive, reliable, and cost-effective space transportation systems. To do so, the program has adopted the following goals:

(1) return the space shuttle to flight status and attain safe, sustainable shuttle flight rates and capabilities that are compatible with payload requirements and program resources;
(2) establish and employ a mixed launch vehicle fleet comprising the space shuttle and unmanned launch vehicles or procured commercial launch services, to launch NASA and other civil government payloads;
(3) ensure the availability of a variety of upper stages, carrier systems, and automated and robotic systems, to provide simple, flexible, reliable transportation among the shuttle, Space Station, and other payloads and systems in orbit, and to support permanent manned presence in space;
(4) enhance current space transportation capabilities and operations through advanced development, and prepare for advanced missions by developing plans, concepts, and preliminary designs for advanced transportation systems to enable human and robotic exploration beyond Earth orbit into the solar system; and
(5) ensure the availability of a work force and support systems of the highest degree of excellence to ensure NASA's continued world leadership in space.

Space Flight Objectives

The goals presented above require objectives extending into the 1990s that can serve as a basis for initiatives to be undertaken in the near term. The objectives set for the Space Flight program are listed in Table IV-1, keyed to the five program goals listed above. The major objectives for each of the three components of the Space Flight program are summarized below.

Table IV-1. Space Flight Objectives

Goal	Objectives
Space Shuttle	Complete the implementation of the recommendations of the Presidential Commission on the Space Shuttle Challenger Accident Complete the implementation of STS hardware redesign, certification, and testing, and the review and updating of operational procedures and plans leading to the return of the STS to flight Successfully launch the STS-26 flight and re-initiate the STS flight program at the earliest possible date consistent with full safety and program operational rigor Ensure that adequate government manpower is available to properly manage and supervise the STS' day-to-day operational activity; that adequate sustaining engineering support is available to the STS program from the STS prime contractor and NASA field center organizations, including support to the operations activities at the launch site or sites; and that adequate government and contractor support is available to STS engineering activities and operations in the area of safety, reliability, maintenance, and quality assurance Ensure that program planning is consistent with resource availability and that a proper balance of resources is maintained among the various program elements Provide for a replacement orbiter, main engines, and associated equipment to support the Agency's flight rate and transportation requirements and commitments Provide for continued support of the STS flight manifest and new Agency mission and cargo objectives to fully support NASA's overall space transportation mission, and for STS capability upgrades to adequately support a flight rate of at least 14 flights per year by 1994 Continue an aggressive program of in-flight instrumentation and data gathering, and of associated shuttle vehicle and orbiter loads analyses to fully define and achieve potential shuttle ascent and landing performance capabilities Maintain continued vigilance over the shuttle's most critical systems:

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
	Solid Rocket Booster—Pursue current program of product and manufacturing process quality assessments and upgrades including evaluation of flown hardware and periodic Production Verification Motor full-scale firings Space Shuttle Main Engine (SSME)—Provide for robust ground-based, single-engine test program to complement and support increasing flight engine experience; continue SSME Phase II plus, external heat exchanger, and alternate turbopump programs leading to SSME configurations that are more durable and have additional performance margin Space Shuttle Avionics and Flight Software—Provide for continued strong technical support, assessment, and rigor in developing, controlling, and testing flight-to-flight software products and required avionics system and software changes; continue practice of extensive test demonstration of these products and changes in multiple avionics test and simulation facilities Orbiter Thermal Protection System (TPS)—Provide for attention to and scrutiny of TPS installation and rework activities on flight orbiters by design engineering and processing teams; maintain focused program to assess aging and use effects on the orbiter TPS system as the STS program continues to mature Orbiter Structure—Provide for an appropriate program of inspection for the structural features of the orbiter to assess, understand, and correct, if necessary, aging and multiple flight effects on the orbiter structural system Pursue implementation of an Advanced Solid Rocket Motor to provide increased manufacturing quality, producibility, and resultant safety margins, and to enable the shuttle to deliver approximately an additional 12,000 pounds of payload to orbit Continue efforts leading to definition and implementation of crew escape systems that could be effective during shuttle powered-flight ascent Continue implementation and utilization of an automated closed-loop problem reporting, tracking, and trend analysis system that supports and interconnects all STS program elements

(Table continued on next page)

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
	Continue efforts to improve the orbiter landing system by implementing, assessing, and flight testing orbiter and landing field upgrade features, and by considering additional improvements as appropriate Provide for continued rigor and maintenance of the STS program's technical and documentation data base so that the data base will continue as an accurate, living data base in support of the STS program Provide shuttle support for Space Station integration activities in the areas of Station assembly (cargo packaging and manifesting), Station transportation, flight crew support and government-furnished equipment, and Station up/down logistics
Mixed Fleet	Successfully launch NASA's remaining inventory of Expendable Launch Vehicles (ELVs): carry out 6 successful ELV missions in FY 1988 (4 Scout, 1 Delta, 1 Atlas), 3 in FY 1989 (1 Delta, 1 Atlas, 1 Atlas-Centaur), 5 in FY 1990 (3 Scout, 1 Atlas, 1 Atlas-Centaur), and 4 in FY 1991 (3 Scout, 1 Atlas-Centaur) Establish and employ a balanced ELV/services capability as part of the STS/ELV Mixed Fleet Program: Initiate Phase I of the Mixed Fleet Program and successfully launch six near-term payloads transitioned from the STS to ELVs (ROSAT, EUVE, CRRES, TDRS-F, Mars Observer, and a planetary backup payload) Initiate Phase II of the Mixed Fleet Program by competitively selecting private sector operators to provide commercial launch services in four performance classes to support civil government payload launch requirements: 2 launches per year of small (Scout class) ELVs, 3 to 5 medium (Delta class), 1 to 2 intermediate (Atlas-Centaur/Titan III class), and 1 large (Titan IV/Heavy Lift Launch Vehicle class—to be obtained from DOD until available commercially) When possible, require that payloads with critical launch schedules be compatible with both ELVs and the STS to maximize flexibility and the capability for providing timely launch Coordinate the scheduling of government-mission launch requirements so as to facilitate the cost-effective planning of a

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
	broad-based ELV launch capability from the aerospace commercial sector, and to ensure that the launch requirements of U.S. civil-government payloads are satisfied Support national space policy guidelines requiring U.S. Government encouragement of commercialization of ELVs through continued coordination of NASA's commercialization activities with similar activities of the U.S. Air Force and the Departments of Transportation and Commerce
Flight Systems	Continue support of the Solid Propulsion Integrity Program for development of technical data bases for solid rocket motors When feasible, continue to use commercially developed upper stages, such as the Transfer Orbit Stage, for government payloads launched on both the STS and ELVs Coordinate planning with the Air Force so that its Inertial Upper Stage will be available as required to support specific assigned civil-government missions on both the STS and ELVs Continue development of the Orbital Maneuvering Vehicle as part of the STS and Space Station infrastructure Complete recertification and return to operational status of Spacelab in support of science and Space Station experiments Continue to develop, maintain, and sustain the Spacelab module, to support a wide range of NASA, DOD, foreign government, and commercial and scientific users Continue to develop and maintain an adequate inventory of partial-payload carriers to support user missions, including the Hitchhiker carrier system for secondary payloads Develop the Tethered Satellite System (TSS), as a cooperative program with Italy, to make possible entirely new and unique scientific experiments and technical applications; use the TSS to conduct electrodynamic experiments in FY 1991 Evaluate the potential for using ELVs and the Orbital Maneuvering Vehicle for Space Station operations

(Table continued on next page)

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
Advanced Transportation Systems	Vigorously pursue studies, advanced development, and flight demonstrations in support of next-generation launch and orbit-transfer systems, satellite servicing systems, an assured crew return capability, and advanced operations support systems Maintain a data base of civil space-mission needs for the next 20 to 25 years as a planning tool for future civil requirements for a space launch and transportation infrastructure In conjunction with DOD and NASA's Office of Aeronautics and Space Technology, support space-technology initiatives and develop focused technologies; support the joint efforts of NASA and DOD to develop the Advanced Launch System, to be operational by 1998 Initiate and participate in concept definition efforts that could lead to new support and launch concepts, including a heavy-lift cargo capability, to improve the cost effectiveness, responsiveness, capability, reliability, and flexibility of launch systems Identify and initiate studies and advanced development activity to support the long-range evolution and enhancement of the shuttle's capability and operational effectiveness: Define a cargo element as part of the STS (Shuttle C) Plan for the next-generation manned launch system, considering both evolutionary approaches and new vehicle alternatives Develop and demonstrate operations technologies to improve STS operations and to support future launch vehicles and upper stages Develop transportation concepts and planning information to support future civil space initiatives; develop an integrated transportation strategy that defines a space transportation infrastructure including Earth-to-orbit, space-transfer, and other transportation vehicles, and automated and robotic systems to support national mission requirements and enable human and robotic exploration beyond Earth orbit into the solar system Plan for and develop, by the late 1990s, high-performance space transfer vehicle(s) complementary to the shuttle and the Space Station for transportation to, between, and beyond Earth orbits to meet the needs of potential new initiatives and other advanced missions

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
	Support development of a prototype automated satellite servicer system and facilitate satellite servicing capabilities by ensuring that transportation systems support access of satellite servicer systems to the operational orbits of missions requiring servicing capabilities Plan for and develop a capability for assured crew return from Earth orbit Investigate man-rating the Orbital Maneuvering Vehicle to meet the needs of planned and prospective spacecraft, platforms, and facilities for maneuvering in and between Earth orbits Develop a program for monitoring orbital debris and recommend Agency policy in this area Continue development of the Aeroassist Flight Experiment and other technology demonstrations applicable to space transfer vehicles Facilitate and support the establishment of a commercially developed space facility Continue demonstrating the abilities of the STS in servicing satellites in order to emphasize this operational capability, thereby influencing systems design and operations adopted by users

Institutional Excellence	Establish an institutional framework for space flight activities that meets civil and defense needs, appropriately utilizes industry capabilities, and fosters and facilitates international cooperation
	
	Maintain a capable, experienced Civil Service work force and provide additional Civil Service manpower to strengthen the program management, systems engineering and integration, and safety, reliability, and quality assurance functions essential to safely returning the space shuttle to flight:
	
	    Continue building the highly skilled, knowledgeable work force to accomplish the sustained STS mission
	
	    Vigorously pursue a high standard of excellence in all endeavors, with emphasis on safety, reliability, and quality assurance

(Table continued on next page)

Table IV-1. Space Flight Objectives (continued)

Goal	Objectives
	Continue to emphasize a team approach that recognizes individual abilities and contributions from all elements Encourage participative management at all levels Provide and maintain institutional facilities and equipment that will enable NASA to be recognized as the premier U.S. agency in aeronautics and space, and to support on-going research and development programs: Vigorously pursue a program to ensure that facilities and equipment needs are identified and facilities and equipment are available to support program and project requirements on time Address the urgent need for adequate on-site housing for the NASA work force, as well as on-site warehouse space for storage of supplies and equipment Ensure that facility infrastructures, such as those for utility systems, propellant systems, roads, and roofs, are adequately maintained and refurbished where needed Continue to emphasize environmental compliance and restoration requirements, encouraging budget support that will be adequate to correct deficiencies Vigorously support inhouse systems-level test beds and prototype large-scale demonstrations to more effectively transfer the latest technologies being developed under the Office of Aeronautics and Space Technology's CSTI and Pathfinder programs: Reestablish the "hands on" skills of the NASA field centers as an aid in the quest for regaining the Nation's leadership in space Provide the Agency with future options

Space Transportation

The major objective for Space Transportation in the near term is to return the space shuttle safely to flight status and, for the longer term, to achieve a flight rate of 14 safe and successful STS missions per year by 1994, with progressively lower operational costs and turn-around times.

In addition, the program envisions completion of the development, acquisition, and upgrading of the STS. This objective requires maintaining the production schedule, acquiring a replacement orbiter, developing an advanced solid rocket motor, and returning Spacelab to operational status.

Another near-term objective is to encourage and facilitate development and establishment of a balanced, robust, commercial expendable launch vehicle capability by the U.S. private sector as part of NASA's mixed fleet strategy.

Flight Systems

The program will continue to demonstrate the abilities of the STS in servicing satellites in order to emphasize this new operational capability, thereby influencing systems designs and operations adopted by users.

By FY 1991, the program will develop a tethered satellite system for the controlled deployment, on-orbit stabilization, and retrieval of science and applications satellites tethered above and below the orbiter.

Another major near-term objective is to help the Space Station Program Office meet its objective of developing and putting into routine operation by the mid-1990s a manned permanent facility (the Space Station) in low Earth orbit for operations, construction, and research in space. The development of assured crew return capabilities is part of this effort.

For the far term, the program will develop technology and techniques to construct, deploy, and assemble systems in space, and to test and service the systems on orbit.

Advanced Program Development

One objective of the Advanced Program Development component of the Space Flight Program is to conduct advanced development that will ensure the long-range evolution and enhancement of the shuttle's capability and operational effectiveness. One activity under that objective will be development of a capability for assured crew return from Earth orbit. Later, attention will be focused on development of the next-generation manned launch system.

Another objective is to define, design, and provide a cargo element as part of the STS and, later, to design and develop, in conjunction with DOD, an advanced cargo vehicle.

An important objective is to define a space transportation infrastructure that includes Earth-to-orbit, space-transfer, and other transportation vehicles, and provides all the automated and robotic systems required to support national mission requirements and enable human and robotic exploration beyond Earth orbit into the solar system.

The design and development of higher-performance and more versatile space transfer vehicles also constitute a long-range objective. Development of an automated satellite servicer system also will be supported.

Current Space Flight Programs and Plans

This section addresses the current activities and plans of the Office of Space Flight in two program components: Space Transportation and Flight Operations.

Space Transportation: Shuttle Production and Capability Development

Orbiters. In the Challenger accident of January 28, 1986, one of the four orbiters was lost. The replacement orbiter was ordered in August 1987 and is being built using structural spares, which will be replaced with a new set of structural spares. Fabrication will be completed in FY 1991.

Work continues in response to recommendations made by the Rogers Commission (see inset, Page II-4) following its investigation of the Challenger accident. Key issues include:

(1) improvement in landing and deceleration;
(2) crew escape;
(3) redesign of propulsion and power equipment to enhance reliability and performance while providing increased and better-defined safety margins; and
(4) achievement of greater productivity for missions.

Measures under examination to improve landing and deceleration include the addition of a drag chute and fail-operate/fail-safe nose wheel steering. Carbon brakes are being used to provide increased energy margin, decrease thermal brake damage, and provide more flexible braking procedures.

Methods of crew escape under other than controlled flight conditions are also being examined.

In the area of on-board power, the propulsion and power equipments are being upgraded to increase life, reduce turnaround time, and eliminate turbine wheel blade cracks. Measures under consideration include:

(1) redesign of the Power Reactants Storage and Distribution system on the orbiter Columbia to add a 5th cryogenic tank set that will provide a 10-day mission capability;
(2) improvement of the main propulsion system's gaseous helium pressure regulator;
(3) upgrade of the standard pyrotechnic initiator;
(4) improvement of the propellant valve for the reaction control system's primary thruster to reduce its sensitivity to leakage and susceptibility to uncommanded opening; and
(5) redesign of the 17-inch disconnect between the external tanks and the orbiter to remove the flow control device from the flow stream.

Pre-development work is under way on a pump-fed engine for the uprated orbital maneuvering system to increase its payload delivery capability. Development and qualification, with subsequent incorporation into the fleet, are being considered. In addition, to enhance safety, improvements in detection and control techniques for hazardous propellant leaks and spills are planned.

A planned measure for greater mission productivity is the continuation of developments to extend the orbiter's stay-time in orbit to 16 days. Current work includes improvements in the waste management system and carbon dioxide removal system.

Other major orbiter systems currently being improved include the inertial measurement unit and computer system, the fuel cells, and the extravehicular activity (EVA) systems. The general purpose computer has been upgraded to increase reliability, speed, and memory size. The multiplexer/demultiplexer has been redesigned to reduce cost, increase reliability, and reduce obsolescence. An improved mass memory unit will extend the error-free life of tape and eliminate nonrepetitive intermittent errors. In the area of EVA systems, in order to maximize commonality of flight equipment between the STS and the Space Station, a commonality working group has been established to set appropriate policy. The extravehicular mobility unit (EMU) is being modified to reduce its operational costs and increase its utility to the Space Station program. An EMU to replace the one lost in the Challenger accident will incorporate selected improvements such as operation at 8 psi to eliminate prebreathing requirements. Demonstration of a high-pressure (8 psi) glove was a significant technology milestone.

Propulsion System. The Space Shuttle Main Engine (SSME) program has four major areas of endeavor, all of which are integrated to support the program's total requirements:

(1) near-term flight support,
(2) near-term improvements,
(3) long- term overhaul requirements and margin improvements, and
(4) technology support.

Near Term Flight Support. In the aftermath of the Challenger accident, more than 25 mandatory changes were incorporated into the SSME and will be certified for flight. Increased awareness of some concerns has led to limitation of the life of the high-pressure pumps and possibly other parts. The current goal is to certify the SSME for use in 30 flights. Certification will require that at least two engines be tested to 60 equivalent flights. One engine has already met this requirement, and the second engine is under test.

Near Term Improvements. An external heat exchanger is being developed. It will be certified in 1988 and will be installed in the fleet in 1989 and 1990. A development program for improved high-pressure pumps was contracted for in August 1986. Component testing of the pumps should start in early 1989, and certification should start in 1990, with fleet introduction following soon thereafter.

Long-Term Overhaul Requirements and Margin Improvements. The first overhaul of an SSME following its prescribed 30 flights is scheduled for 1991. Installation of an improved flow powerhead and other measures to improve operating margins will be incorporated during that overhaul.

Technology Support. The SSME Technology Test Bed program was initiated in 1983 and will start testing in the summer of 1988. The technology challenges to the SSME program have been many. The test-bed program was established so that it will be possible for candidate design changes for improving the engine to be evaluated off-line from the mainline program. Three of the early test objectives are:

(1) high instrumentation of the engine,
(2) alternate high pressure turbopumps, and
(3) means for monitoring and diagnosing the SSME's health.

The Solid Rocket Boosters have been redesigned, with major changes in the Solid Rocket Motor's case joints, nozzle-to-case joint, and nozzle components. Evaluation of full-scale-short-duration and full-scale-full-duration tests of production verification motors will continue for several years. Static firing, refurbishment, and modification of solid motors produced prior to the Challenger accident will be started.

Design and development of a new, reusable Advanced Solid Rocket Motor (ASRM) are planned to begin early in FY 1989 to extend the capability of the shuttle system, to increase safety and reliability, and to replace the current redesigned motor. Specifically, the new ASRM will be designed to enhance safety by eliminating asbestos-bearing materials, to improve shuttle performance by increasing payload capability by 12,000 pounds, and to enhance producibility by applying production automation and state-of- the-art process control. The first flight of the ASRM is planned for early 1994.

Solid Propulsion Integrity Program. The five-year plan and objective of the Solid Propulsion Integrity Program is to establish the engineering capability necessary for improving the success rate of U.S.-built solid rocket motors. This program will improve understanding of materials, analytical tools, manufacturing processes, optimization, and control. Product evaluation and verification also will be improved. Initial efforts, to begin in 1988, will involve examination of motor bondlines and nozzles by industry teams. The intent will be to place solid motor design, manufacture, and evaluation on a scientific basis and to instill scientific methods into the community culture and infrastructure.

Aeroassist Flight Experiment. The first major milestone for the Aeroassist Flight Experiment (see inset on the following page) is the Project Requirements Review, scheduled to be completed by July 1988. The Preliminary Design Review is scheduled for April 1989, and the Critical Design Review for April 1990. Delivery of the spacecraft to Kennedy Space Center is planned for October 1992, for a launch readiness date of September 1993.

Upper Stages. STS upper stages are propulsive systems for boosting shuttle payloads to orbits and on trajectories beyond those the shuttle can fly, primarily geosynchronous orbits and planetary mission trajectories. Upper stages in process under government sponsorship are the Inertial Upper Stage (IUS) and the Orbital Maneuvering Vehicle (OMV). In addition, industry has undertaken development of four solid-propellant upper stages and has several additional upper stages under consideration or in the initial stages of definition and development.

Aeroassist Flight Experiment (AFE)

The AFE will investigate critical vehicle design technology issues applicable to aeroassist vehicles. Aerodynamic braking maneuvers occur in upper regions of the Earth's atmosphere at or near geosynchronous return velocities, producing aerothermodynamic environments that cannot be simulated in ground facilities or modeled using existing analytical techniques. The AFE will carry a number of experiments designed to gather data required for understanding the aerothermodynamic environments. That understanding is critical to the design of lightweight heatshields, including the selection of materials and heatshield thickness. Therefore, the AFE will use a conservatively designed, sufficiently instrumented heatshield to obtain data that will permit critical environments to be measured.

The AFE will be delivered to a low Earth orbit (LEO) by the orbiter. At the proper time, the AFE will be checked out and separated from the orbiter. After approximately one orbit, the AFE's solid rocket motor will ignite to drive the spacecraft into Earth's upper atmosphere. The aerobrake will slow the spacecraft and provide lift to ensure that the spacecraft can return to LEO. The orbiter will retrieve the spacecraft from LEO and return it to Earth. The mission duration deployment to retrieval will be approximately 30 hours. Although the AFE will simulate return from geosynchronous orbit, it will not provide data for the higher velocities associated with planetary return missions.

Payload Assist Module (PAM). The PAM upper stage is used to boost satellites to geosynchronous transfer orbit or other higher energy orbits after their deployment from the STS.

Inertial Upper Stage. The IUS is scheduled to be the upper stage to place two TDRS satellites into geosynchronous orbit in 1988 and 1989 and to support three major planetary missions (Magellan, Ulysses, and Galileo—see Chapter III) in 1989 and 1990.

Payload Assist Module (PAM)

Formerly called the Spinning Solid Upper Stage, PAM is designed and built by McDonnell Douglas Astronautics Company. It is designed to boost satellites deployed in near-Earth orbit to higher altitudes. The PAM-D is capable of launching satellites weighing up to 2,750 pounds, the PAM-DII up to 4,150 pounds, and the PAM-A up to 4,400 pounds. They are used for inserting satellites into geosynchronous transfer orbit, and also into non-geosynchronous transfer orbits.

Inertial Upper Stage (IUS)

The U.S. Air Force is developing the IUS, a two-stage, solid-propellant vehicle capable of boosting into geosynchronous orbit 2,270 kilograms from the shuttle and 1,910 kilograms from the Titan III expendable launch vehicle. The IUS has been flown on both of those vehicles. Its first use on the shuttle was to launch the first Tracking and Data Relay Satellite. NASA, the Department of Defense, other government agencies, and commercial organizations will use the IUS to transport heavy payloads from low Earth orbits to high Earth orbits.

Transfer Orbit Stage (TOS). The TOS upper stage is scheduled to place the Advanced Communications Technology Satellite into geosynchronous transfer orbit in May 1992 and to launch the Mars Observer spacecraft in September 1992.

Transfer Orbit Stage (TOS)

A new medium-capacity upper stage, TOS was developed commercially by Orbital Sciences Corporation for use in placing satellite payloads weighing 6,000 to 13,000 pounds into geosynchronous transfer orbit or other high-energy trajectories. Capable of being launched from the STS, Titan III, or Titan IV, TOS was designed to fill the performance gap between the PAM and the IUS.

Orbital Maneuvering Vehicle (OMV). The OMV development program was initiated in 1986 with the selection of TRW as the prime contractor. The first flight is projected for 1993. Early planned uses of the OMV are to reboost the Hubble Space Telescope when required because of orbital decay due to atmospheric drag, to support the assembly and logistics operations of the Space Station, to retrieve plasma experiments, and to service and reboost the Gamma Ray Observatory.

A long-term (up to 20 years) goal is an operations program in which there will be multiple OMVs, some based at the Space Station and others launched from the Eastern Space and Missile Center and the Western Space and Missile Center, either by the shuttle or by expendable launch vehicles. Many forms of spacecraft services will be possible. For example, the OMV will be used to return spacecraft to the shuttle or the Space Station for maintenance and resupply.

In addition, the OMV will be able to perform remote and in-situ maintenance, using special purpose mission kits both to exchange spacecraft modules that have failed and to replenish onboard expendables.

Kits also will be provided to:

(1) capture unstable spacecraft, inactive spacecraft, and certain classes of debris; and
(2) allow remotely controlled recovery of disabled and non-controllable tumbling satellites.

Another future upgrade is to expand the OMV's capabilities by installing a larger propulsion module. With larger tanks, the OMV will be able to carry out missions in much higher orbits and perform remote servicing on communications satellites at geosynchronous altitude.

Other Stages. In January 1984, the Orbital Sciences Corporation contracted to develop the Transfer Orbit Stage (TOS) for use in missions requiring propulsion capabilities less than those of the IUS. TOS will be able to place payloads weighing 2,725 to 5,910 kilograms into geotransfer orbit. Its planned availability is late

Orbital Maneuvering Vehicle (OMV)

The OMV is a special type of upper stage—a reusable, remotely controlled, free-flying vehicle able to perform a wide range of on-orbit missions and services in support of orbiting spacecraft. It will be capable of satellite delivery, retrieval, reboost, controlled de-orbit, viewing, and subsatellite support. It will be an important extension of the STS and a key element of Space Station operations. It will be able to operate from the shuttle, from the Space Station, or from a space-based position.

The basic OMV is not being designed to ferry humans; however, preliminary studies have shown that man-rating it is feasible. A man-rated OMV could be used, for example, to ferry crews between two physically separate elements of the Space Station, such as the initial space station and a transportation depot.

1989. Uses for TOS include launching the Advanced Communication Technology Satellite (see inset III-28) to geosynchronous orbit and the Mars Observer (see inset III-53) on its planetary mission. Both of these launches are planned for 1992.

Three other private firms have solid-propellant upper stages under development and several are considering commercial development of upper stages to provide propulsion from the shuttle's orbit for payloads with various propulsion requirements.

Tethered Satellite System. The Tethered Satellite System program is a cooperative one with Italy, which is responsible for developing the satellite and for instrument and experiment integration. The United States is responsible for developing the deployer, providing overall program management, and integrating the system with the orbiter. Work to prepare the system for its first flight was initiated in FY 1984, to yield an initial operational capability in FY 1991. The Italian government has appropriated all the funds necessary for its activities associated with the development and first flight of the satellite.

Spacelab. NASA plans to use the Spacelab system to support experiments for the DOD, and the German and Japanese governments. Also planned are missions during the next five years to support materials science, microgravity, life sciences, astronomical, and atmospheric research.

Spacelab Capability Development. Spacelab offers a wide range of capabilities to users. Techniques and systems to satisfy more effectively the many needs of users have been demonstrated or are being developed. For example, several methods for manifesting in the mixed cargo mode have been developed, and a new payload operations control center has been established at Marshall Space Flight Center.

Many flight opportunities for Spacelab payloads will be available on shuttle flights whose primary purpose is to deploy satellites and upper stages. For mixed-cargo missions requiring Spacelab's full data-management capability, an expanded Spacelab carrier system, called the Spacelab pallet system, is being developed. The Spacelab pallet system includes the Multiplexer/Demultiplexer (MDM) pallet system, the Igloo pallet system, and the enhanced MDM pallet/Space Technology Experiments Platform (STEP) pallet system. The Spacelab pallet system will enable the flying of a mixed cargo in the orbiter bay. Development of the MDM and Igloo pallet systems is complete. The MDM pallet system has been flown several times and the Igloo pallet system is awaiting its first flight, ASTRO-1, scheduled

Tethered Satellite System

The Tethered Satellite System is a reuseable facility consisting of a satellite attached by a cable to a deploying mechanism mounted on a pallet in the cargo bay of the orbiter. The deployer will include a reel mechanism and an extendable boom for deploying, operating, and retrieving the satellite. The satellite can weigh up to 500 kilograms and may be deployed downward or upward (toward or away from Earth) to distances up to 100 kilometers from the Shuttle.

The Tethered Satellite System will make possible entirely new electrodynamic experiments, in situ observations in hitherto inaccessible regions; and a unique approach to significant scientific objectives such as observation of important atmospheric processes occurring within the lower thermosphere, observation of crustal geomagnetic phenomena, and direct observation of processes coupling the magnetosphere, ionosphere, and upper atmosphere in the 125- to 150-kilometer region of the lower troposphere. It also will provide a means for long-term scientific experimentation not previously possible, in operations such as emergency power generation, propulsionless reboost and transfer, long-wave communications, Mach 25 flight, and the clustering and station-keeping of platforms around a space station.

Spacelab

Spacelab is a versatile facility that, installed in the cargo bay of the shuttle orbiter, affords scientists the opportunity to conduct experiments in the unique environment of space. The program includes habitable, pressurized modules; experiment pallets; the Instrument Pointing System; and ground support, including hardware-integration and payload-operations-control facilities. It is the result of a highly successful cooperative venture by the European Space Agency and NASA.

Two Spacelab pallets carrying scientific instruments were flown during the shuttle's Orbital Flight Test program, one in November 1981 and one in March 1982. The verification flight of the Spacelab module configuration was conducted during a dedicated shuttle flight in November 1983, and the first operational flight of the Spacelab pallet system was flown in October 1984 in a mixed cargo configuration. Spacelab provided the experiment support structure for missions flown in August and October 1984, and Spacelab pallets were used in the November 1984 recovery by the shuttle of two communications satellites. The Spacelab-3 mission, flown in April 1985, successfully demonstrated Spacelab's capabilities for multidisciplinary research in micro-gravity. During the July 1985 Spacelab-2 mission, verification flight testing of the Instrument Pointing System continued. Spacelab successfully supported the German Spacelab D-1 mission in October 1985.

for FY 1989. The enhanced MDM pallet and STEP pallet systems are under development and will be available to support the Tethered Satellite System and STEP missions in FY 1991.

Development of the across-the-cargo-bay Hitchhiker system and the side-mounted Hitchhiker system has been completed. These systems provide a simple interface between small experiments and the shuttle, making integration for flight easier and less costly. The two developed versions have added to Spacelab's capability and flexibility. The time from selection of an experiment for flight to its flight can be as short as six to eight months. The Hitchhikers are designed to reduce experimenters' costs and to optimize shuttle load factors. The first Hitchhiker was flown on shuttle mission 61-C in January 1985.

Space Flight Operations

Launch and Mission Support. At Kennedy Space Center (KSC), modifications to major facilities and launch site equipment now under way will provide more efficiency and reliability in launch processing operations; for example, permanent weather protection modifications to Launch Complex 39's Pad A will be completed in FY 1989. Also, equipment being procured for installation into the Orbiter Modification and Refurbishment Facility will provide orbiter safing and deservicing, development of the Digital Operational Intercom System will continue, and fiber optics will be incorporated to improve KSC on-site communications between facilities.

The principal KSC initiative to ensure facility readiness for planned flight rates beyond 12 per year is construction of an additional Orbiter Processing Facility . Test and checkout requirements added since the Challenger accident have increased vehicle processing times. Consequently, the processing of four orbiters and effective use of the fleet requires the addition of this third Orbiter Processing Facility to the two existing ones and the Orbiter Modification and Refurbishment Facility. Construction is scheduled to begin in 1990, with completion approximately one year later.

Upgrading of the Mission Control Center and Shuttle Mission Training Facility is included in activities that Johnson Space Center plans to conduct in support of flight rate increases. Under the Mission Control Center upgrade, replacement of the host computer was completed in April 1987, with additional hardware delivery and software upgrades scheduled for completion in late

1993. Under the Shuttle Mission Training Facility upgrade, computers for the shuttle mission simulators are being upgraded and their software is being rehosted. Other hardware replacement, training capacity augmentation, and software upgrades are scheduled through completion of the Training Facility upgrade in 1994.

NSTS Transportation Services. The primary program objective of the National Space Transportation System (NSTS) program is to complete the return to safe shuttle flight activities. Many of the program's activities center on returning the STS to operational status. A concerted effort is being made to provide the Agency and the general public combined shuttle and expendable launch vehicle manifests. Reevaluation of the shuttle program in the wake of the Challenger accident prompted a major assessment of launch requirements. The results of this assessment are reflected in recent manifests. The reevaluation led to a more realistic STS flight rate (see Space Shuttle Operations, below) and emphasized the need to use expendable launch vehicles.

STS missions are currently planned for NASA, the Department of Defense, other U.S. government agencies, domestic commercial organizations, and international organizations. Twenty-four missions were successfully flown between April 1981 and January 1986 (see Table IV-2). Current plans call for one flight in FY 1988, 7 flights in FY 1989, 10 flights in FY 1990, 11 flights in FY 1991, and 12 flights in FY 1992.

As a result of recent policy changes, the important class of secondary payloads now is defined to include large microgravity payloads, life sciences research, technology development experiments, and early design-related Space Station experiments. STS space is being allocated to these classes of payloads on the basis of their relative priority and value to the Nation.

Space Shuttle Operations. Operational support for the space shuttle in the NSTS program includes producing external tanks and solid rocket boosters; providing, overhauling, and repairing operational spares; and furnishing manpower, propellants, and other materials for flight, launch, and landing operations.

At Kennedy Space Center, operations have been streamlined by consolidating related program functions under single management contractors. A Base Operations Contract has been in force since December 1982 for all shuttle, payload, and institutional support; and a Shuttle Processing Contract has been in effect since September 1983 for all STS launch and landing operations. A third and final major consolidation contract, the Payload Ground Operations Contract, went into effect in January 1987.

At Johnson Space Center, mission operations have been streamlined by consolidation of related program functions under a single management contract, the Space Transportation System Operations Contract, which has been in effect since January 1986 to provide operations support for each STS mission.

Expendable Launch Vehicle/Mixed Fleet Program. The Expendable Launch Vehicle/Mixed Fleet program was initiated in FY 1987 as a result of a detailed study of NASA's space transportation requirements that recommended that U.S. civil government spacecraft be launched using a balanced mixed fleet to provide increased access to space, to ensure continuity of space operations, and to enhance mission flexibility. Accordingly, NASA has revised its space flight manifest plans for civil government payloads based on a mixed fleet concept consisting of the space shuttle and expendable launch vehicles (ELVs). Desciptions of U.S. ELVs are contained in Table IV-3. The ELV portion of the mixed fleet program has two phases.

Phase I encompasses the transition of six near-term shuttle payloads to ELVs that will be acquired by sole source procurements. The Roentgen Satellite (ROSAT—see inset on page III-20) and the Extreme Ultraviolet Explorer (see inset on page III-20) are scheduled to fly on Delta II launch vehicles in 1990 and 1991, respectively. A 1990 mission in the planning stage, the Combined Release and Radiation Effects Satellite is split between three launch vehicles: an Atlas/Centaur and two Scouts. The Agency plans to acquire Titan III launch vehicles commercially for launching the next Tracking and Data Relay Satellite as early as 1991 and the Mars Observer (see inset on page III-53) in 1992. The sixth transition to ELVs involves using a Titan IV to back up the planetary Galileo, Magellan and Ulysses missions scheduled to fly on the shuttle in 1989 and 1990. The Titan IV launch vehicle is expected to be available as early as May 1991. It, as well as the two Delta II vehicles, will be acquired through the DOD under a quid pro quo arrangement.

Phase II of the ELV portion of the mixed fleet program encompasses competitive selection of private-sector

Table IV-2. Space Shuttle Flights 1981-1986

ORBITER	DATE	PAYLOAD
1. COLUMBIA	APRIL 12, 1981	FLIGHT INSTRUMENTATION
2. COLUMBIA	NOVEMBER 12, 1981	OSTA-1, FIRST RMS, FLIGHT INSTRUMENTATION
3. COLUMBIA	MARCH 22, 1982	OSS-1, FLIGHT INSTRUMENTATION
4. COLUMBIA	JUNE 27, 1982	DOD, FLIGHT INSTRUMENTATION
5. COLUMBIA	NOVEMBER 11, 1982	SBS-C, TELESAT-E
6. CHALLENGER	APRIL 4, 1983	TDRS-A
7. CHALLENGER	JUNE 18, 1983	SPAS-01, OSTA-2, TELESAT-F, PALAPA-B1
8. CHALLENGER	AUGUST 30, 1983	PDRS/PFTA, OIM, INSAT 1B
9. COLUMBIA	NOVEMBER 28, 1983	SPACELAB 1
10. CHALLENGER	FEBRUARY 3, 1984	SPAS-01A, PALAPA-B2, WESTAR-6
11. CHALLENGER	APRIL 6, 1984	[illegible] SMM REPAIR
12. DISCOVERY	AUGUST 30, 1984	[illegible] SBS-D, TELESTAR 3-C, SYNCOM IV-2
13. CHALLENGER	OCTOBER 5, 1984	[illegible] LFC/ORS
14. DISCOVERY	NOVEMBER 8, 1984	[illegible] TELESAT-H, SYNCOM IV-1
15. [illegible]	JANUARY 24, 1985	[illegible]
16. DISCOVERY	APRIL 12, 1985	TELESAT-I, SYNCOM IV-3
17. [illegible]	APRIL 29, 1985	SPACELAB 3
18. DISCOVERY	JUNE 17, 1985	SPARTAN, MORELOS-A, ARABSAT-1B, TELESTAR 3-D
19. CHALLENGER	JULY 29, 1985	SPACELAB 2
20. DISCOVERY	AUGUST 27, 1985	AUSSAT-1, ASC-1, SYNCOM IV-4
21. ATLANTIS	OCTOBER 3, 1985	DOD
22. CHALLENGER	OCTOBER 30, 1985	SPACELAB D-1
23. ATLANTIS	NOVEMBER 26, 1985	EASE/ACCESS, MORELOS-B, SATCOM KU-2, AUSSAT-2
24. COLUMBIA	JANUARY 12, 1986	MSL-2, SATCOM KU-1, GAS BRIDGE
25. CHALLENGER	JANUARY 28, 1986	TDRS-B, SPARTAN-HALLEY

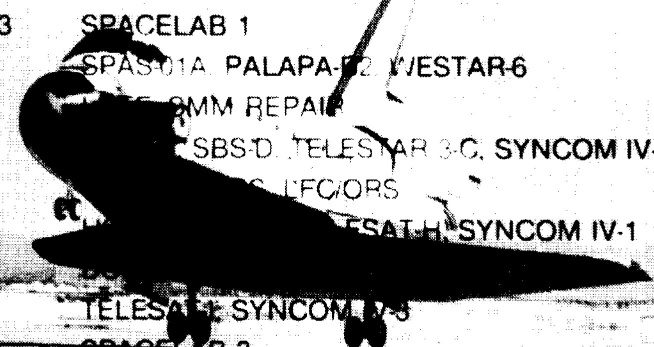


Table IV-3. U.S. Expendable Launch Vehicles

VEHICLE	AVAILABILITY	PERFORMANCE ($i = 28°$) LBS			PAYLOAD FAIRING DIAMETER	ESTIMATED VEHICLE LAUNCH SERVICES COSTS 1988 $
		LEO	GTO	GSO		
SCOUT - ETR - WTR	NOW	570 460			2.9 AND 3.5 FT	$10-20M
DELTA II MODEL 6925 MODEL 7925	OCTOBER 1988 JUNE 1990	8,780 11,110	3,190 4,010	1,600 2,000	8 AND 9.5 FT 10 FT (FEBRUARY 1990)	$40-50M
ATLAS I	NOW	13,000- 12,550	5,150- 4,950		11 AND 14 FT	$65-70M
ATLAS II	EARLY 1991	14,950	6,100- 5,900		11 AND 14 FT	$70-80M
TITAN II (WTR)	AUGUST 1988	4,200			10 FT	$30-35M
TITAN III WITH SRMU	JULY 1989 LATE 1991	30,500 38,000			13.1 FT	$130-145M
TITAN III / TOS	JULY 1989		13,000		13.1 FT	$145-200M
TITAN III / IUS WITH SRMU	JULY 1989 LATE 1991			4,200 5,000	10 FT	$145-200M
TITAN IV / NUS WITH SRMU	OCTOBER 1988 MID 1991	39,000 49,000			16.7 FT	$175-230M
TITAN IV / IUS WITH SRMU	OCTOBER 1988 MID 1991	49,000	5,000	5,200 6,600	16.7 FT	$230-300M
TITAN IV / CENTAUR WITH SRMU	MAY 1990 MID 1991			10,200 12,700	16.7 FT	$230-300M

operators to provide commercial launch services with four classes of vehicles: small, medium, intermediate, and large. NASA currently is developing the necessary procurement strategy and documentation. Selection of the small- and medium-class operators is expected to occur in early FY 1989. The small-class vehicles will carry NASA's Explorer-type missions starting in 1991. The medium class will support larger science payloads, such as the International Solar Terrestrial Physics program's missions, starting in 1992. Procurement of launch services employing intermediate- and large-class vehicles will not start in FY 1988, since payloads for them are not projected to require launching until after FY 1994.

Advanced Program Development

The advanced program development component of the Office of Space Flight program conducts advanced studies and advanced development activities to focus new technologies for incorporation into future vehicle designs. Its strategic goal is to define a future space-transportation infrastructure and the associated system elements needed to ensure safe, reliable, and cost-efficient access to and operations in space for the next 20 years. The program seeks to improve the reliability, reduce the operational costs, and enhance the performance of current systems through advanced development activities. The elements and activities addressed include advanced transportation systems, advanced operations support, satellite services, transportation-related tether application studies, and orbital debris studies. The Civil Needs Data Base is key to advanced program planning.

Advanced Transportation Systems. Advanced transportation systems studies are directed toward defining concepts for enhancements to the space transportation infrastructure. Cargo vehicle concepts being studied include both evolutionary vehicles such as the Shuttle-C and new vehicles such as the Advanced Launch System. Evolutionary approaches for manned space transportation systems and space transfer vehicles also are being assessed. The major current studies described below have evolved directly from or are continuations of past studies.

Shuttle-C. NASA plans to begin in 1988 the second phase of Shuttle-C definition studies to help define the optimum approach to a more robust national launch posture.

Civil Needs Data Base (CNDB)

The CNDB is a compilation of civil space-mission needs from 1990 to 2010. It is a primary tool for planning the civil space-transportation infrastructure. The data in the base are used both for NASA's transportation planning and inputs to Department of Defense planning.

Data in the base include total mass to orbit by year, as well as a top-level description of payload servicing requirements. Requirements can be examined by user, by destination of payload, and by the number of space shuttle equivalent flights that would be required.

The current data base consists of three models: constrained, nominal growth, and modest expansion. The models are updated annually in parallel with the budget cycle. The next update will include an aggressive growth model addressing possible manned lunar or manned planetary advanced missions.

Shuttle-C Program

For several years, NASA has studied concepts for a heavy-lift launch vehicle to meet a potential national need to boost payloads of 100,000 pounds or more into low Earth orbit. The studies culminated in a concept for an unmanned Shuttle-derived cargo vehicle called Shuttle-C. Definition study contracts for Shuttle-C were initiated in 1987. The studies, led by NASA with Air Force participation, focus on maximum use of shuttle hardware and facilities. It appears that Shuttle-C could provide an affordable and reliable near-term heavy-lift capability, and would furnish assured access to space at a limited flight rate for planetary and national security payloads that currently require launching by the STS or the Titan IV/Centaur.

Advanced Launch System (ALS). On January 4, 1988, President Reagan signed a report to Congress creating a joint Department of Defense (DOD) and NASA program for development of the ALS. DOD will manage systems engineering and integration and development of the vehicle, logistics, and payload modules. NASA will manage development of liquid engine systems and focused technology. Work in all areas will be performed by an appropriate mix of DOD and NASA organizations. The Defense Acquisition Board, with NASA as a participating member for all ALS reviews, will provide major policy and program direction. An Executive Committee made up of representatives from DOD and NASA will provide management oversight. The ALS goal is to have an operational capability no later than 1998.

In FY 1989, NASA will conduct system definition studies for a civil Advanced Launch System (ALS/Civil), building upon the ALS base-line design. The studies will examine vehicle systems and propulsion systems that could satisfy unique civil requirements—specifically, requirements for orbital insertion, on-orbit stabilization, maneuvering, proximity operations, and multiple-payload pointing and dispersion. Emphasis will be on accommodating possible advanced missions. The ALS/Civil studies will identify requirements for upper stages or kick stages for the ALS and define any required modifications to existing stages or to the basic ALS design to provide additional services for civil payloads.

Space Transfer Vehicle (STV). The objective of current studies of the STV is to define a plan and a schedule for developing an operational STV by 1998. The studies will define the STV's detailed characteristics, but the vehicle is expected to be cryogenic, space-based, and reusable.

Man-rated Orbital Maneuvering Vehicle. Studies on man-rating the Orbital Maneuvering Vehicle will continue in 1988, with the objective of identifying features in the basic design that would allow the addition of a capsule for intra-orbit transfer of humans.

Assured Crew Return Capability (ACRC). Definition studies for ACRC were initiated by the Space Station program in 1987 and are continuing as part of the Office of Space Flight's Advanced Program Development.

Support for Advanced Operations. Advanced operational support is a relatively new area of emphasis within Advanced Program Development. The additional emphasis results from recognition of the importance of ground and flight operations in achieving access to

Advanced Launch System

The Advanced Launch System is intended to provide a heavy-lift launch system that:

(1) meets national space launch needs;
(2) is flexible, robust, and reliable; and
(3) significantly lowers the cost of getting payloads into space.

Reduced costs will be sought in launch vehicle development and manufacturing, launch processing, logistics, data management, and automation. Concepts are being studied for both expendable and reusable vehicles with a payload capability range from 85,000 lbs to 150,000 lbs. Development of the Advanced Launch System is being funded by DOD, with NASA participation.

Assured Crew Return Capability (ACRC)

The ACRC studies will focus on definition of means to return astronauts safely to Earth in the event that a significant anomaly occurs and the space shuttle is not available within the required time. The goal is to have the capability by the time the permanently manned Space Station is available. In addition, the studies will be broadened to assess the feasibility of developing such a capability for other near- and long-term applications. The ACRC has the potential to be part of an alternative space transportation system in the near term and to support potential advanced missions in the long term.

Space Transfer Vehicle (STV)

Future advanced missions to geosynchronous orbit and to lunar or planetary surfaces will require an advanced upper stage for transportation from low Earth orbit to the payload destination. The STV is NASA's concept for this advanced upper stage. It is an expansion of the Orbital Transfer Vehicle concept that NASA has studied in previous years. While previous Orbital Transfer Vehicle studies were directed primarily to supporting payload delivery to geosynchronous orbit, STV studies have been expanded to develop concepts for supporting any of the new advanced mission initiatives under study. The STV studies will assess whether one basic design (with evolutionary capabilities) can perform such varied tasks as the delivery to orbit of the geosynchronous platform required for the Planet Earth initiative (see Chapter X—Exploration), delivering large automated planetary payloads to Earth-escape orbits, transporting humans and cargo to and from the moon, and supporting human exploration of the moon.

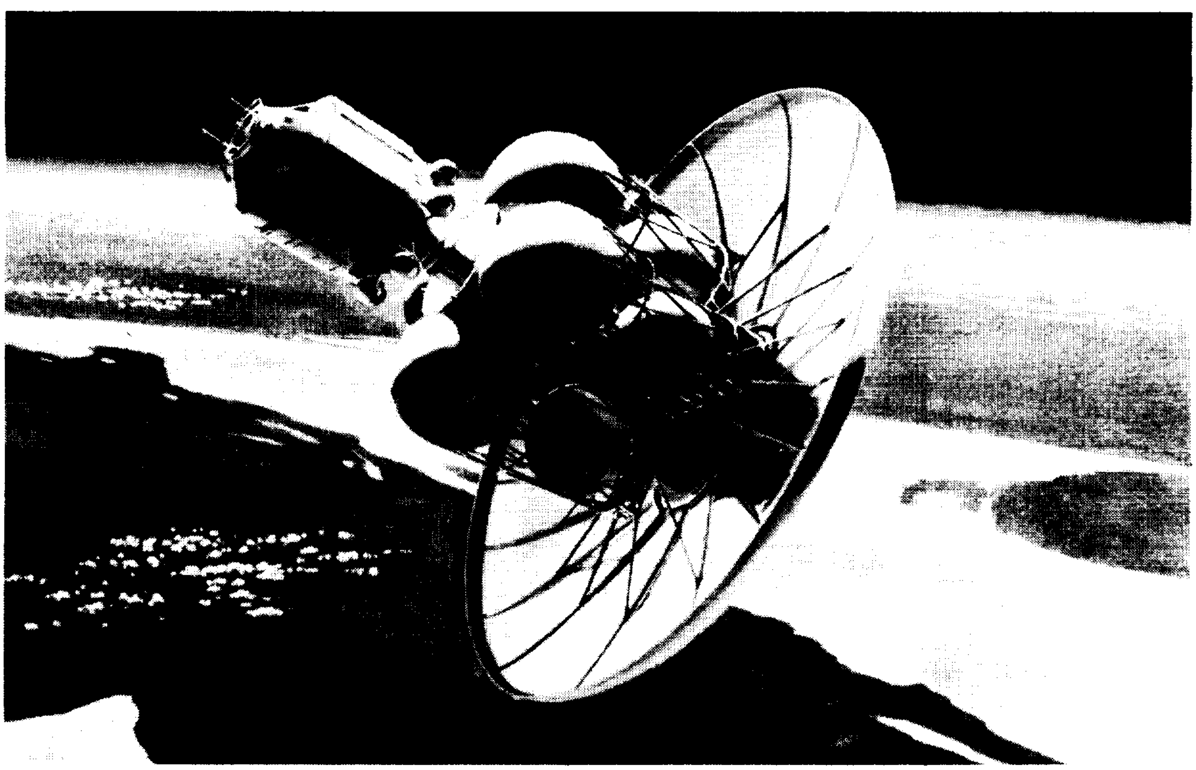


Figure IV-2. Space Transfer Vehicle Concept

space economically and an awareness of the potential for improving operational efficiencies through the application of technology. Past studies related to operations support have defined areas that can be improved. Continuing studies of this nature will guide advanced development activity in ground and flight operations.

The Advanced Operations Effectiveness Initiative (described in more detail later, under Advanced Development and New Initiatives) is an effort to expand operations-oriented technology efforts and target high leverage opportunities. It will build upon the efforts already under way to apply new and enhanced technologies to solve operational problems and improve operational efficiencies.

Expert systems, robotics, and automation are instrumental to achieving improvements and will be a major emphasis of the initiative. However, activity will not be limited to these technologies. Other operations-oriented studies and advanced development, spanning a broad spectrum of activity, will also continue. Continuing activity includes development of test and measurement instrumentation; generation of advanced software-engineering concepts; and development of graphics interfaces to improve human factors, hazard elimination, and others.

Satellite Servicing. Satellite servicing is an emerging capability in the early stages of development focusing primarily on definition of systems and procedures designed to use space shuttle capabilities.

General Services. NASA on-orbit repair and servicing experience early in the manned space program (Gemini, Apollo, and Skylab) evolved with the successful repair activity on the Solar Maximum Mission spacecraft and the retrieval of the Palapa and Westar satellites, establishing the validity of satellite servicing. Satellite servicing systems will be compatible with the Space Station and the Orbital Maneuvering Vehicle.

Satellite services near the space shuttle include placement, assembly, retrieval, maintenance, and repair, as well as replenishment of consumables. Initial

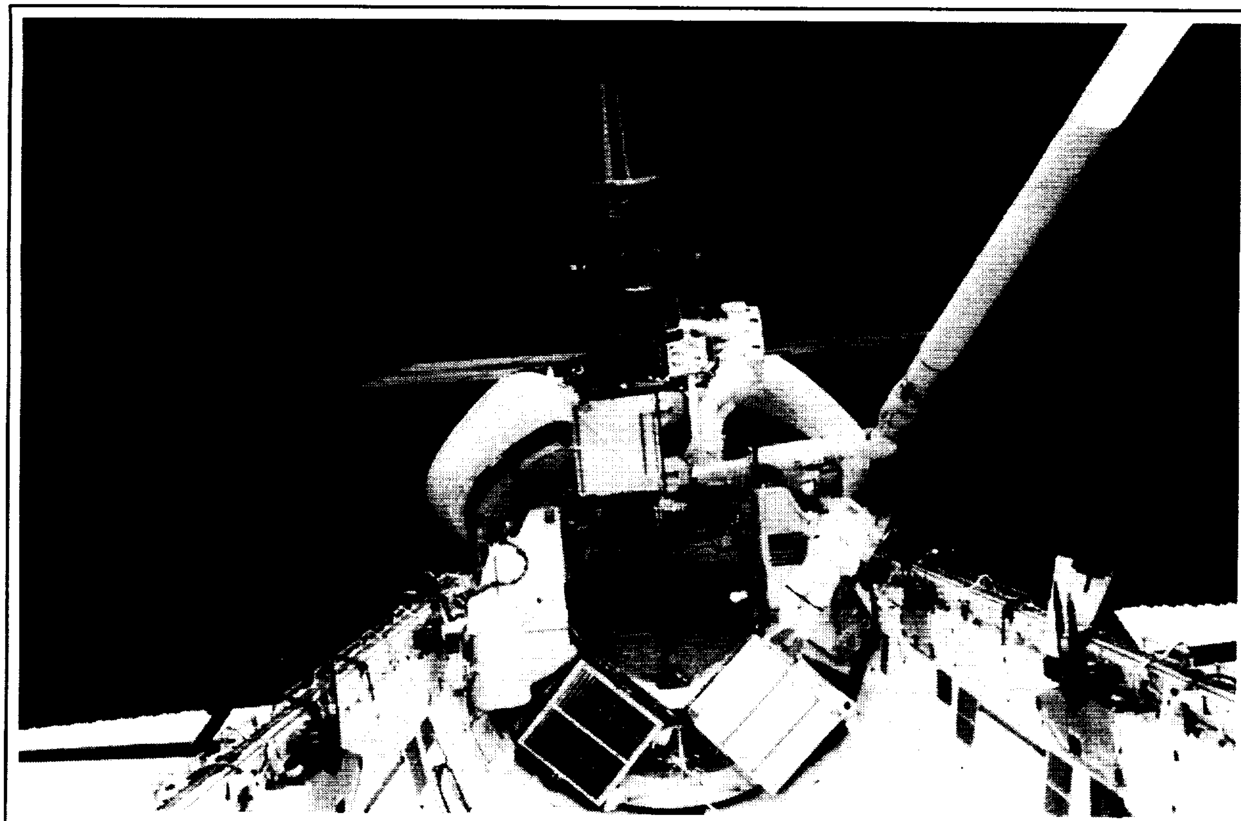


Figure IV-3. Satellite Servicing (Solar Max Repair)

capabilities for placement and limited retrieval of satellites were provided by the orbiter-mounted Remote Manipulator System, the Manned Maneuvering Unit, the integrated space suit and backpack known as the Extravehicular Mobility Unit, and the early tools developed for extra-vehicular activity. Those systems and tools have been demonstrated on shuttle missions. However, new and improved devices and techniques will be needed for such systems as the Hubble Space Telescope, Advanced X-Ray Astrophysics Facility, Space Station, and space platforms. The required equipment includes holding and positioning tools, maintenance and repair tools, berthing platforms, refueling tools and techniques, end effectors ("hands") for the Remote Manipulator System, versatile television systems, and equipment for assembling and supporting large structures.

By the mid-1990s, retrieval of stabilized satellites near the orbiter should be possible with the use of the Orbital Maneuvering Vehicle equipped with special front end kits. Studies to define tankers, couplings, telerobotic servicing aids, and servicing procedures are in process. They support servicing near the orbiter and remote servicing operations using the Orbital Maneuvering Vehicle. Long-term efforts to achieve extended operational lifetimes and mission flexibility through the use of on-orbit servicing are reflected in the plans of major science programs, including the Great Observatories (Hubble Space Telescope, Gamma Ray Observatory, Advanced X-Ray Astrophysics Facility, and Space Infra-Red Telescope Facility). Further development and flight experiments will increase system efficiency and crew productivity. Flight experiments awaiting a launch opportunity include the following:

(1) use of voice commands to augment manual control of closed circuit television cameras;
(2) use of a secure, infrared communications system to improve the space shuttle voice and data systems; and
(3) conducting a proof-of-concept test of a plasma motor generator.

Flight demonstrations of the following are under development:

(1) force-feedback end effector to improve the dexterity of the Remote Manipulator System;
(2) on-orbit transfer of superfluid helium;
(3) high-bandwidth fiber-optic communications link through the orbiter aft flight deck window to a payload in the cargo bay;
(4) laser docking sensor to provide highly accurate range, rate, and orientation data for eventual use in automated docking systems; and
(5) small tether-based expendable deployment system.

Tether Applications in Space. The Tethered Satellite System described earlier is an innovative concept that will provide a unique, reusable capability to conduct aggregated experiments at distances up to 100 km from the shuttle orbiter and the Space Station. It was approved as a new initiative in FY 1984. The following advanced tether uses are under investigation:

(1) propulsion and electrical power generation in space by electrodynamic tethers,
(2) provision of artificial gravity and transportation,
(3) kinetic isolation and contamination control,
(4) cryogenic propellant storage, and
(5) aerothermodynamic experiments and demonstrations.

Complementary definition studies conducted under a Letter of Agreement between the United States and Italy are also in process. They could lead to cooperative flight demonstrations and experiments in the future.

Orbital Debris. The global nature of orbital debris and its potential damaging effects on access to and operation in space are of great concern to NASA. Studies in the following areas currently are being conducted to assess damage potential and protection techniques:

(1) improved analytical models for hypervelocity impacts;
(2) penetration-effect simulation, modeling, and mitigation;
(3) advanced materials and shielding;
(4) test methodology for evaluation and qualification;
(5) detection and avoidance techniques; and
(6) flight experiments demonstrating concepts for protection from debris.

An improved definition of the orbital-debris environment is being developed. Key to the definition is an improved capability to measure debris. Studies have been initiated to define an orbital debris radar capable of measuring particles with a diameter as small as one centimeter. Data will be maintained in a data base to allow analytical study and continual monitoring.

NASA is formulating options for managing orbital debris to minimize and reduce debris accumulation. NASA also is working with other government agencies that are showing increasing interest in the control and management of orbital debris.

Planned Study Activities

The two significant advanced transportation system studies described below will be initiated in FY 1989.

Shuttle Evolution/Next-Generation Manned System

Systems studies beginning in FY 1989 will concentrate on determining the optimum path for upgrading and updating the Space Transportation System's capabilities and for reducing its operational costs. Concept definition studies will consider evolutionary changes to the current shuttle and the design for a next-generation vehicle. Shuttle evolution includes at least two levels of changes: (1) near-term subsystem improvements such as upgrading the fuel cells, and (2) major block changes such as changing to the advanced solid rocket booster or liquid rocket booster. Key issues to be considered with respect to the evolutionary upgrades include operating-cost reductions, reliability, effect on hardware availability, and commonality of parts with other systems. Options for the next-generation system include a dedicated personnel carrier and a combination personnel and cargo carrier. The objective is to be in a position to select an evolutionary approach in the early 1990s.

Transportation Infrastructure Study

Definition of transportation elements to support future missions will be a major part of advanced transportation planning in 1989 and the early 1990s. Advanced missions, which will involve transporting people and/or large cargos to low Earth orbit and beyond, may include large geosynchronous platforms for Earth observation, automated exploration of the outer solar system, and human exploration of the moon and Mars. The Transportation Infrastructure Study will concentrate on understanding and developing concepts for the complete transportation system required to support any combination of those missions. Study objectives will include assessment of the use of existing launch systems; evaluation of the applicability of new systems currently under study, such as the Advanced Launch System; and development of new concepts, if required. The infrastructure will include Earth-to-orbit vehicles, space transfer vehicles, and any specialized vehicles that are required to support advanced missions. The study will be closely related to the definition of new initiatives. As mission concepts and requirements are developed by the Office of Exploration and the Office of Space Science and Applications, concepts for a transportation infrastructure to support those missions will be developed so that the total mission/transportation infrastructure requirements can be evaluated.

Advanced Development and New Initiatives

In addition to advanced studies, Advanced Program Development conducts advanced development activities that focus generic technologies so that they can be incorporated into specific systems. Advanced development activity identifies and matures, through systematic use of test beds and subsystem demonstrations, selected technologies that potentially could strengthen and enhance both the overall Space Transportation System and future space transportation and servicing systems.

In preparation for the Advanced Operations Effectiveness Initiative, which will begin in FY 1989, advanced development work is under way in a number of areas where improved technology offers the potential to improve operations. Current activity includes the application of new technology in the areas of measurement and test instrumentation, integrated management information systems, built-in testing, and automatic software.

Advanced Operations Effectiveness Initiative

The Advanced Operations Effectiveness Initiative emphasizes the demonstration and application of technology to ground- and flight-operations support. It represents an effort to solve existing problems or to avoid future problems by demonstrating technology readiness for existing and future systems. Reduction of life-cycle costs is a key objective. Continuing emphasis on advanced development will increase efforts across the spectrum of advanced transportation systems, advanced operations support, and satellite servicing.

The primary goal of the Advanced Operations Effectiveness Initiative is to identify and demonstrate new and enhanced processes and technologies that can be applied to ground, flight, and on-orbit operations to reduce the operations costs of space transportation systems while ensuring safe and reliable operation. Near-term efforts will reduce the cost of ground and flight operations through selective application of expert systems, robotics, automation, and other evolving technologies to existing labor-intensive or hazardous operations. Longer-term activity will emphasize identification and demonstration of technologies and processes whose application during the design and development of future vehicles and systems will reduce overall costs.

The Advanced Operations Effectiveness Initiative will build on work already underway and concentrate on high-leverage opportunities. It will provide a technology transfer mechanism by helping ensure that technology development efforts elsewhere in the Agency and in industry are applied in the area of operations. Operations technology requirements identified through the initiative will be fed back to appropriate offices to be considered for future development.

Interrelationships With Other Programs

Space Flight/Space Station Integration

The objective of this activity is integration of the Space Station and its unique requirements into Space Transportation support systems.

The shuttle provides proven capabilities for manned flight; is an extravehicular activity base; and has the ability to rendezvous, to perform station keeping, to manipulate payloads remotely, and to remain in orbit for several days. Recent studies have concluded that these features suit the shuttle uniquely for the assembly and logistics requirements of the Space Station program. Existing expendable launch vehicles could accomplish limited cargo delivery tasks; and a heavy-lift launch system, once developed, could perform large-scale delivery operations. Station assembly and operations planning can accommodate the use of potential transportation systems and the incorporation of improvements into the shuttle without major changes in the Space Station program.

The Offices of Space Flight and Space Station have designated contacts to manage and coordinate integration activities related to technical and programmatic interfaces between the two programs. The Space Flight/Space Station Steering Group and its associated subgroups provide support to integration studies, analyses, and reports. The Office of Space Flight and the NSTS program provide representation to the Space Station Control Boards and subpanels.

In accord with the Nation's goal of building a permanently manned Space Station, the Office of Space Flight established, in 1987, a new program organization designed to facilitate integration of the Space Station's unique requirements into the Space Transportation support system. The new organization coordinates the exchange of information between the two programs and serves as a forum for presenting and resolving issues related to technical, programmatic, management, and policy interfaces. Recent activities have included performing a major transportation study and preparing a report to Congress in cooperation with the Space Station program. Both the study and the report examined transportation capabilities, including expendable launch vehicles, proposed heavy lift launch vehicles, space shuttle enhancements, and increased on-orbit stay times for Station crews. They identified improvements that are being incorporated into planning for the NSTS, life sciences, and Space Station to reduce shuttle flight-rate requirements and increase the weights the Space Station can support.

Present Space Flight/Space Station integration activities include performing studies and analyses related to the planning of operations and utilization support, transportation capabilities, and advanced program development.

Major programmatic and policy issues being addressed include the following:

(1) Space Flight/Space Station documentation;
(2) Station reimbursement/pricing policies;
(3) Station manifesting processes;
(4) ground, flight, and user operations policies;
(5) common flight-support equipment;
(6) shared use of STS facilities;
(7) construction of facilities prioritization;
(8) common safety requirements;
(9) Station precursor experiments;
(10) flight crew management;
(11) assured crew return;
(12) satellite servicing program development;
(13) orbital debris environment definition;
(14) Orbital Maneuvering Vehicle development;
(15) heavy-lift launch vehicle development; and
(16) Station extravehicular-activity capability development.

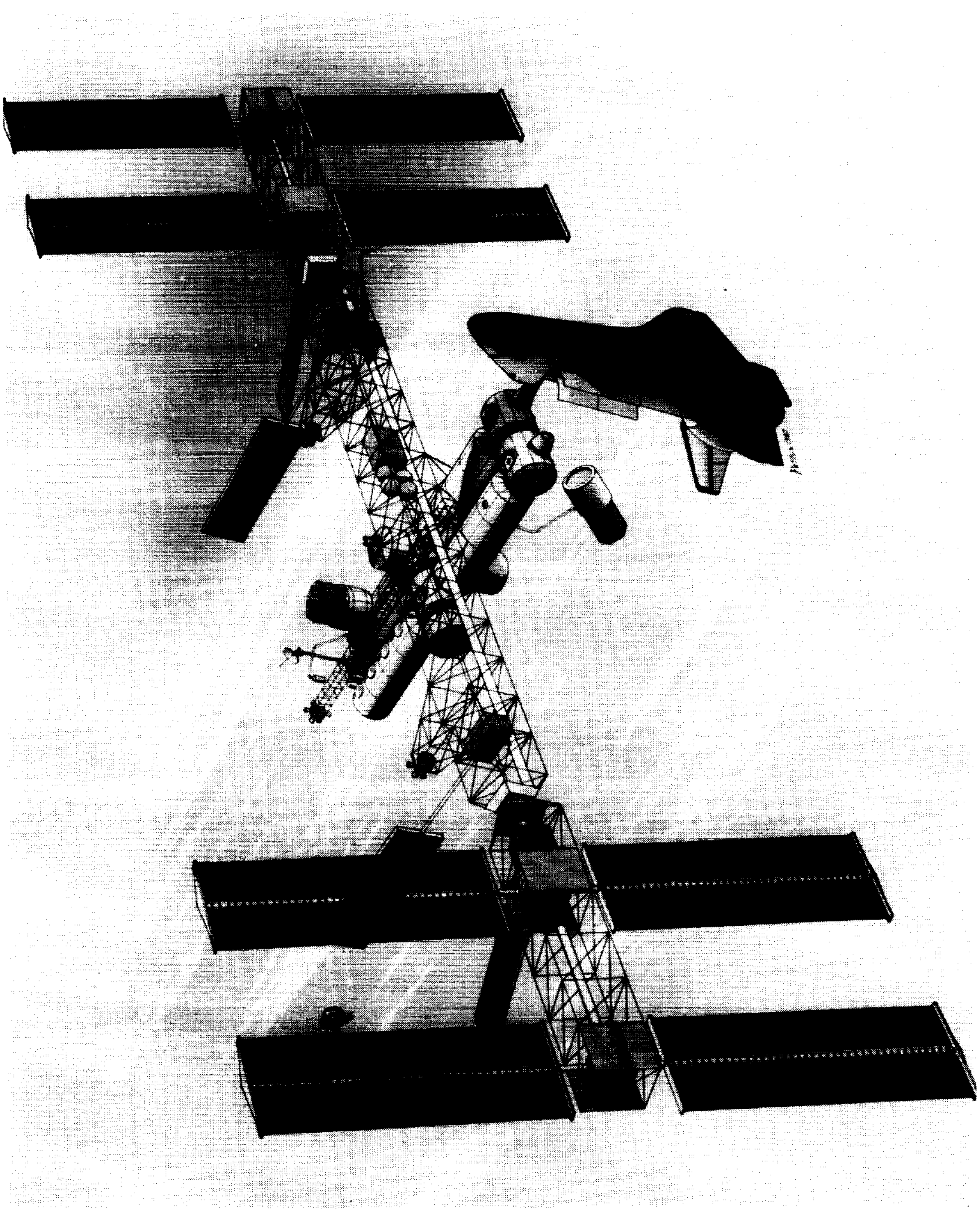
The NSTS program has initiated several integration and operations activities to ensure compatibility between shuttle capabilities and Space Station requirements. The NSTS and Space Station programs are preparing program management plans and Station launch and assembly plans to use in their internal planning and development activities. They are starting to study and analyze Space Station cargo integration and flight integration, as well as shuttle capability development. NSTS capabilities studies are in process on the following:

(1) shuttle/station docking systems,
(2) proximity-operations/docking sensor,
(3) crew transportation,
(4) upgrading of the Remote Manipulator System,
(5) control of Station manipulators from the orbiter,
(6) integration and utilization of the Flight Telerobotic Servicer, and
(7) transfer of utilities between the orbiter and the Space Station.

Other Transportation Integration

Transportation services activities focus on the responsibilities of personnel of the Office of Space Flight as user representatives to the STS program. As user representatives, they are the primary liaison between the STS and the user community, the DOD, other NASA organizations, and other civil agencies. They coordinate and manage the interface functions between the users and the STS at all levels. The interface functions include integration of user requirements (launch date requests, STS services, etc.) within the Level I program and management of interface activities between the users and the NASA field centers. The user-field center interface functions consist of coordinating the technical support necessary to meet the payload-integration milestones required for launch.

SPACE STATION



SPACE STATION

The Office of Space Station is engaged in a development that will become the largest and most complex task in NASA's history—the construction and operation of a permanently manned space station. The Space Station program, essential to realizing the national goal of maintaining U.S. leadership in space, will provide users with manned and unmanned capabilities necessary to achieve this goal.

Introduction

A goal of the National Aeronautics and Space Administration (see NASA goals inset, page II-9) is to expand human presence beyond Earth into the solar system. To accomplish this goal, NASA has undertaken the largest and most complex task in its history—the construction and operation of a permanently manned space station.

The idea of a space station has been the subject of dreams and conjecture for over 75 years, and the subject of NASA studies dating back to the 1960s. In the early 1970s, NASA orbited a manned facility, Skylab, that made possible the first U.S. experiments in long-duration manned space flight. However, Skylab was not intended to be permanently manned; it was not equipped for routine resupply of key expendable items, and thus could not be used over a multi-year period. During the early 1980s, NASA focused its attention on the possibilities of a permanently manned space station. On January 24, 1984, following several years of requirements studies, in-depth reviews, and Presidential briefings, President Reagan, in his 1984 State of the Union address, directed NASA to undertake the next logical step for the U.S. space program—the building of a permanently manned space station. The President also invited U.S. friends and allies to participate in this undertaking as a sign of international cooperation.

Space Station Goals

On January 5, 1988, President Reagan issued a revised national space policy that reaffirmed the Nation's commitment to develop the Space Station and achieve a permanently manned operational capability by the mid-1990s. This policy states that the Space Station will:

(1) contribute to U. S. preeminence in critical aspects of manned space flight;
(2) provide support and stability to scientific and technological investigations;
(3) provide early benefits, particularly in materials and life sciences;
(4) promote private sector experimentation preparatory to independent commercial activity;
(5) allow evolution in keeping with the needs of Station users and the long-term goals of the United States;
(6) provide opportunities for commercial sector participation; and
(7) contribute to the longer term goal of expanding human presence and activity beyond Earth orbit into the solar system.

NASA has completed Phase A conceptual design studies and Phase B definition studies, and is now entering the design and development phase for the base-line Space Station with seven, competitively selected, major aerospace teams comprising over a dozen large firms. This chapter provides a brief overview of the current Space Station program and NASA's strategy and plans for this permanently manned space base.

The Space Station will add new momentum to the civil space program and is essential to realizing the national goal of maintaining U.S. leadership in space.

Space Station Objectives and Requirements

Program Objectives

The objectives of the Space Station program are to:

(1) establish in low Earth orbit by the mid-1990s a permanently manned research facility with the capability to evolve to meet future needs;
(2) enhance and evolve mankind's ability to live and work safely in space;
(3) stimulate technologies of national importance, especially automation and robotics, by using them to provide Space Station program capabilities;
(4) provide cost-effective operation and utilization of continually improving facilities for scientific, technological, and operational activities enabled or enhanced by the presence of humans in space;
(5) promote substantial international cooperative participation in space;
(6) create and expand opportunities for private sector activity in space;
(7) provide for evolution of the Space Station program to meet future needs and challenges; and
(8) provide unmanned platforms for long-duration scientific and operational observations.

The combination of manned, unmanned, and automated systems will establish a broad spectrum of capabilities responsive to both the currently identified needs and the evolutionary requirements of space science, technology, and commerce.

The Space Station Program

The Space Station program encompasses a permanently manned base, unmanned polar platforms, a man-tended free-flyer to be serviced at the manned base, and the associated ground-based infrastructure. The major physical elements provided by the United States will include:

(1) pressurized habitation and laboratory modules with a shirt-sleeve environment for crew habitation,
(2) accommodations for microgravity experimentation,
(3) resource nodes for command and control,
(4) airlocks for extravehicular activity,
(5) accommodations for attached payloads,
(6) the Flight Telerobotic Servicer,
(7) a polar orbiting platform, and
(8) logistics elements.

Elements to be provided by the program's international partners are:

(1) the Japanese Experiment Module, which includes a pressurized laboratory, an exposed facility for payloads, and a logistics module;
(2) the Canadian Mobile Servicing System; and
(3) the European Space Agency (ESA) pressurized laboratory, polar orbiting platform, and man-tended free flyer.

The Space Station will be able to support a crew of eight and, using photovoltaic arrays, provide a total average power level of not less than 75 kW.

The ground-based infrastructure needed for Space Station operational capability will include facilities for mission control, logistics support, launch processing, training, testing, and user operations.

Program Requirements

The Space Station is composed of basic building blocks referred to as:

(1) elements, and
(2) distributed systems.

A Space Station element is a major piece of hardware that is part of the Space Station. Space Station elements comprise the hardware of the Station not involved with distributing a utility or service. An example of a Space Station element is the U.S. laboratory. Space Station elements are discussed in more detail starting on page V-22.

A Space Station distributed system is one that is required by two or more elements and provides an end-to-end function. The electric power system is an example of a distributed system. The Station will have a number of distributed subsystems that will provide data management, thermal control, communications, tracking, guidance, navigation, control, environmental control, human life support, and fluid management. A more comprehensive functional and physical description of Space Station distributed systems is provided starting on page V-28.

Space Station elements will be delivered to orbit by the space shuttle. ESA will deliver the ESA polar platform and man-tended free flyer by the Ariane launcher. The Space Station's on-orbit capabilities will increase during the assembly sequence, with emphasis placed on achieving an early man-tended operational capability.

Utilization

User Requirements. Utilization of the Space Station has been the focus of multi-year conceptual and definition studies that have identified, reviewed, and compiled descriptions of over 300 potential payloads into the Mission Requirements Data Base (MRDB).

Candidate payloads for the initial phase of the Space Station have been recently identified by the Office of Space Science and Applications, the Office of Aeronautics and Space Technology, and the Office of Commercial Programs. These payloads will be maintained as a near-term mission subset. Additional subsets containing candidate payloads to be accommodated in later program phases will also be developed. The subsets will be used in detailed accommodations studies for the early phase of the Space Station development program.

User Accommodations. Space Station user accommodations were initially identified and integrated into Space Station systems and configuration designs based on extensive analyses of the MRDB. Detailed accommodations studies will be required during the development phase to confirm the adequacy of user accommodations and to assess the Station's ability to support new payload requirements . These studies will assess candidate sets of payloads and develop potential manifests. Both U.S. and international payloads will be included in these activities.

International Participation

In his January 1984 State of the Union message, the President invited friends and allies of the United States to participate in the development and use of the Space Station. In the spring of 1985, agreements that set the framework for cooperation in the definition phase were signed with Canada, ESA, and Japan. These agreements for preliminary design and definition studies established a process for identifying elements of the Space Station that could be developed by the partners.

The approach for international cooperation in the Space Station program is based upon successful practices followed by NASA in more than 25 years of cooperative international activities. Negotiations have been completed on three bilateral Phase C/D/E memoranda of understanding and a single multilateral Intergovernmental Agreement to cover design, development, operation,

Mission Requirements Data Base (MDRB)

The Mission Requirements Data Base is a computerized data base that will be updated throughout the life of the Space Station to assess the adequacy of payload accommodations and to evaluate the need for evolution of Space Station accommodations. The MRDB currently has descriptions of over 300 payloads.

and utilization. Full international participation is now an integral part of the Space Station program, and program activities will be conducted with the cooperation of all partners and within the management framework established in the international agreements. The capabilities of the operational Space Station will be enhanced by the participation of the international partners.

While NASA retains overall program direction, the international participants will have a major role in Station development and operations. The long-term nature of the Space Station program dictates additional considerations; for example, the partners are developing long-term utilization plans and will be responsible for selecting and prioritizing their own users. They will remain responsible for the elements they provide and will maintain and support the operations of their respective elements. Special care will be taken to ensure that no unwarranted transfer of technology occurs. International partners will provide personnel to serve as crew members and will share the operations costs of the Space Station.

Growth and Evolution

The Space Station will be considered complete when the base-line elements have been assembled. Future program and budget decisions could provide direction for evolution of the base-line capability. Evolution, the process of increasing the capability or capacity of the Space Station after completion of the base-line system, may include increases in productivity and efficiency, increases in resources, and the addition of new functional capabilities.

Although evolution of the Space Station will ultimately be determined by user demand, U.S. space policy, and budgetary decisions, the Space Station base line will be designed to facilitate evolution.

Implementation

Development Strategy

The purpose of the Space Station program is to provide an operational capability consisting of Earth-orbiting manned and unmanned facilities and the requisite ground operation and support systems.

The Space Station will provide the United States and its international partners with a facility capable of supporting a permanent, manned presence in space that is both affordable and attractive to a large group of users. The NASA plan will result in a manned base that can accommodate user elements provided by NASA and the international partners, unmanned orbiting platforms, and development of an operational capability. Inherent in the current revised base-line design are provisions for growth of the Station, concurrent with its initial operations, into a configuration with greatly increased capacity to support payloads and provide services to its users.

The program guidelines encourage U.S. industry investment in development and operation of the Station. These guidelines are directed to U.S. commercial enterprises that seek to develop, with private funds, Space Station systems and services. The guidelines provide for appropriate incentives as well as protection of commercial proprietary rights.

Program Definition (Phase B). A major feature of NASA's development strategy for the Space Station program was to conduct a comprehensive program definition. This recently completed phase relied heavily on NASA's past experience in program management and on the technical expertise of NASA field centers and U.S. industry. Advice was actively solicited from outside communities on key matters such as user requirements, configuration, program management, evolution, technical risk, safety, commercial and international participation, and projected program costs. Throughout Phase B, NASA involved the user community in all major aspects of the planning process. Mission requirements were solicited from federal, scientific, international, and commercial sources and reviewed by various advisory groups. The user community will continue to have representation at all levels of the program.

Design and Development (Phase C/D). The U. S. elements of the Space Station will be developed principally by five NASA field centers, with the remaining field centers providing support. Overall program direction is from the Office of Space Station (Level I) in Washington, D.C. The Space Station Program Office (Level II), located in Reston, Virginia, is responsible for development and System Engineering and Integration of the Space Station program. The Space Station Program Office is supported by contractor teams.

NASA's development strategy for the Space Station deliberately precluded use of a single prime contractor because, for a program of such extended duration, dependency upon one company was considered not to be in the best interest of the government. Moreover, the "work package" approach better utilizes NASA expertise at the field centers and fosters greater competition within U.S. industry. An essential component of this strategy is NASA's responsibility for the overall system engineering and integration of the program. For assistance in this function, the Space Station Program Office has procured the services of Grumman Aerospace Corporation as the Program Support Contractor.

In late 1986 and early 1987, before release of the Requests For Proposals for major hardware items, NASA reviewed the Space Station's configuration and capabilities, as well as the projected program costs. The review produced a revised base-line configuration that will provide:

(1) a permanently manned system with pressurized laboratory and living space,

Space Station Phase C/D Reviews

Program Requirements Review (PRR)

The PRR will evaluate the status of the program and define actions to be accomplished before detailed design and release of fabrication requirements can proceed. The PRR will consider:

(1) program content, milestones, schedules, and plans;
(2) the Work Breakdown Structure; and
(3) the unique requirements of potential projects, including technical ground rules, waivers, and agreements with other organizations.

Preliminary Design Review (PDR)

The PDR will serve as an intermediate status check to verify that the design being implemented does in fact meet program requirements. It will provide a critical review and assessment of the Space Station system's design.

Critical Design Review (CDR)

A CDR will be performed for each of the Space Station elements. CDRs provide assurance that the detailed designs of flight and ground systems satisfy program requirements. The primary product of a CDR is an approved set of engineering documentation defining the design of selected contract specified end items to be released to manufacturing. As a result of the CDRs, authority will be granted to proceed to completion of fabrication and certification of the station hardware and software. Plans will be finalized for assembly, checkout, launch, on-orbit assembly, system verification, and operation.

(continued . . .)

Design Certification Review (DCR)

Near completion of fabrication, a DCR will be held. A DCR is a formal technical review to certify the design of the contract-specified end items for flight worthiness and manned flight safety. The review will specifically address certification requirements, plans, methods, results, and the certification status of flight hardware and software. Concurrently, the final details associated with pre- and post-launch assembly and check-out will be base lined, and final plans will be established for validating that the as-built hardware conforms to the as-certified design.

Preflight Operations Readiness Reviews (PORR)

As part of the activity to establish flight readiness, a series of reviews of the operations aspects of the program will be performed. These reviews, called Preflight Operations Readiness Reviews, will ensure the status of crew and ground support team training, flight and ground console operations, the Space Station Control Center, program and user support facilities, and the NSTS interfaces relative to Station crew and cargo.

Flight Readiness Review (FRR)

An FRR will be performed during the assembly phase before each launch to certify the flight readiness of hardware and software. It will include assembly hardware, crew equipment, flight support equipment , associated support hardware, payload support equipment, and other elements as specified by the Director of the Space Station Program.

Operational Readiness Review (ORR)

After on-orbit integration, assembly, and checkout have been completed, the final step in the development program will be the ORR. As a result of this review, the actual hardware and software performance and capability will be determined and certified, and the initial detailed operational procedures for the program at that phase will be base-lined.

(2) accommodations for attached payloads,
(3) a polar orbiting platform,
(4) accommodations for potential international elements, and
(5) allowances for growth.

During the course of Phase C/D, several reviews will help Space Station management monitor and manage the progress and direction of the Space Station program. Those reviews are summarized in the inset. A detailed table of milestones appears on page V-21.

System Engineering and Integration (SE&I). Space Station SE&I controls the definition of elements and distributed systems, which are the fundamental building blocks of the Space Station described on page V-6.

Space Station program-level SE&I includes the following:

(1) analysis of the Space Station's overall performance,
(2) optimization of user support,
(3) definition of the Space Station's configuration and supportability,
(4) apportionment of performance requirements among elements and subsystems,
(5) control of the design process,
(6) system integration planning, and
(7) performance of on-orbit assembly and test.

Testing and delivery of the elements and distributed systems will be performed by the participating field centers or the appropriate international partner.

A principal SE&I function is to conduct tests of the assembled Space Station on orbit and to validate and document the "as built" configuration to provide a reference for fuuure maintenance, modification, and operation of the completed Space Station.

NASA has defined a strategy for the design, development, verification, integration, assembly, launch, and on-orbit validation of the Space Station's systems. The strategy involves the following:

(1) verification of all systems and elements before launch;
(2) ensuring commonality of test requirements and procedures across work packages;
(3) Phase C/D contractor execution of verification testing (mandatory accountability);
(4) design of simple interfaces to facilitate verification;
(5) design for a minimum of on-orbit assembly;
(6) design for maintainability and minimum life cycle costs;
(7) ensuring commonality across work packages in standards, hardware, and procedures to simplify orbital verification and to minimize cost;
(8) extensive use of simulators to verify interfaces; and
(9) early integration of application software into flight hardware.

Information Systems Development. NASA has placed significant emphasis on system engineering and integration of the Space Station program's information systems, including the Technical and Management Information System, the operational Space Station Information System, and the Software Support Environment system (see Figure V-1 and insets below and on page V-11).

Transportation. The configuration of the Space Station is based on STS capabilities for transportation to and from low Earth orbit. The shuttle will launch Space Station elements, provide a stable base from which astronauts can assemble the Station, resupply the Station through periodic logistics missions, and provide the means for crew members to travel to and from the Space Station.

Another space vehicle, the Orbital Maneuvering Vehicle (OMV), will provide additional capability to the Space Station program and increase the utility of the Station. The OMV, which is described on page IV-17, will be capable of functions that greatly enhance the Space Station, such as retrieving satellites to the Station for servicing, returning satellites to operational orbits after servicing, and remotely servicing satellites in nearby

Technical and Management Information System (TMIS)

In view of the distributed nature of the Space Station development program and the numerous technical and organizational interfaces, the Space Station program will implement TMIS to improve program efficiency and data reliability, and to support timely decision making. The TMIS will include a backbone data-communications network, data processing systems, integrated software tools, and program-wide data bases that will provide both technical and management users with ready access to information.

NASA intends to use TMIS throughout the life of the Space Station program as the primary mechanism for maintaining, distributing, and archiving controlled data among the three levels of NASA Space Station management and the Program Support Contractor. TMIS will also provide information system interfaces with the international partners, the development contractors, and Space Station operators and users. TMIS will be developed incrementally, to support the definition, design, development, test, and operational phases of the Space Station program. Incremental implementation of TMIS will allow NASA to avoid technical obsolescence by incorporating into the TMIS architecture newly emerging technology as it becomes commercially available.

Space Station Information System (SSIS)

The SSIS will provide the infrastructure for operational, end-to-end command, control, and informational flow between the on-board and ground-based control and data processing systems. It will provide information processing, archiving, retrieval, and exchange services to on-board payloads, sensors, and mechanisms.

The SSIS will integrate all the data systems and information services required to manage information flow, as follows:

(1) within the Space Station;
(2) among customers, crew members, and ground support personnel; and
(3) between ground-based functions.

The primary engineering and integration task for SSIS is to ensure that the on-board systems, such as the Data Management System and the Communication and Tracking System, function properly with:

(1) the NASA space and ground-based communication networks;
(2) the Space Station manned base and platform control centers; and
(3) the space science payload data processing, archiving, and retrieval system.

Software Support Environment (SSE) System

The primary goal of the SSE system is to help minimize development and operational costs and risks. Achievement of this goal will depend on a software development and maintenance environment standardized for the program. The major components of the SSE system are software tools, the SSE Development Facility, and the Software Production Facilities.

The SSE Development Facility will develop and maintain the SSE's software requirements, design and test tools, compilers, debuggers, models, and simulations. Each Software Production Facility will use SSE software tools to develop, integrate, and maintain the program's ground and flight software. The SSE System will be developed incrementally, with its capabilities phased to meet essential program needs.

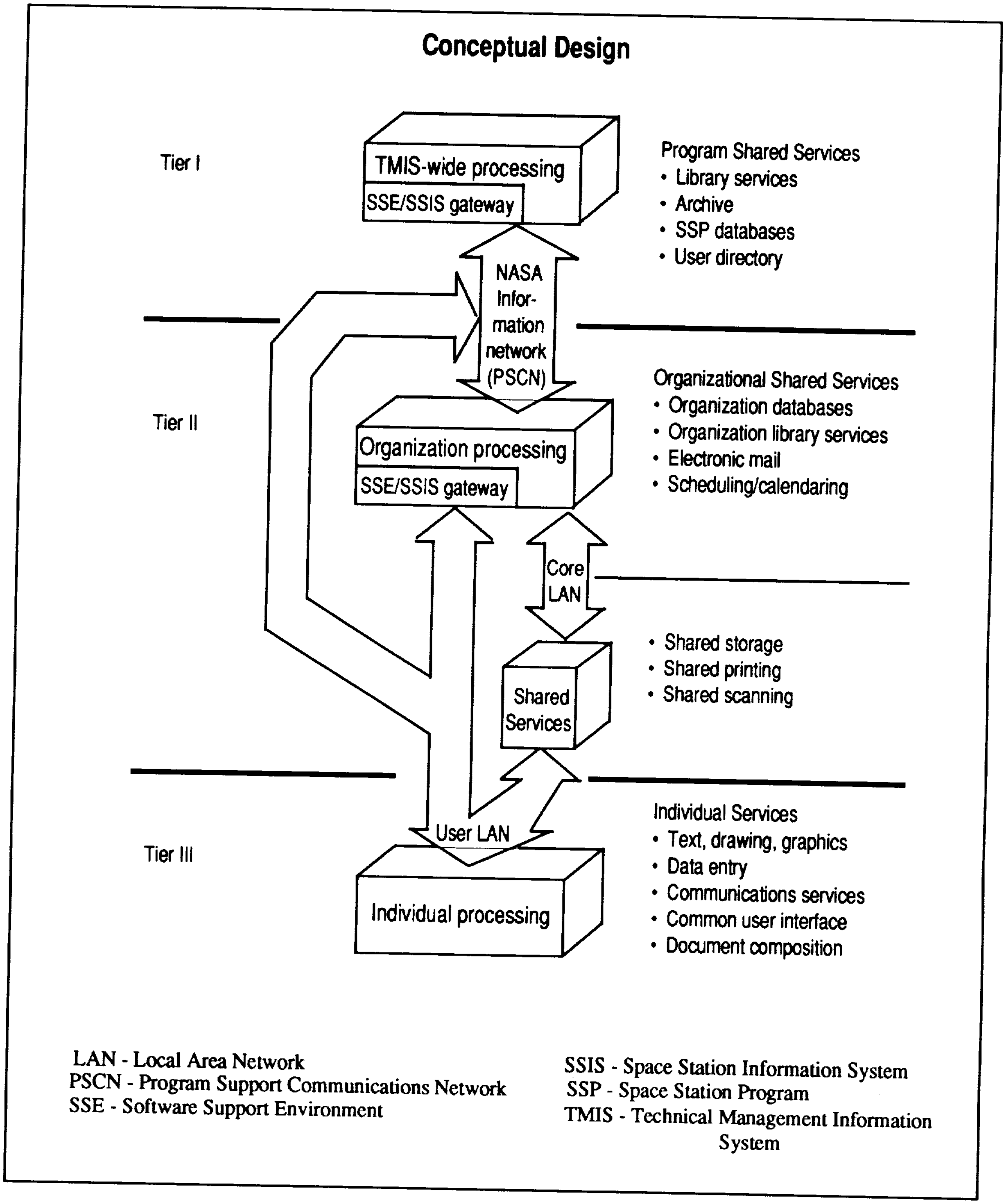


Figure V-1. The Software Support Environment

orbits. The shuttle will carry the OMV to the Station and return it to the ground for refurbishment after completion of its mission.

NASA is studying the potential of expendable launch vehicles (ELVs) for resupplying consumables and launching polar orbiting platforms. ELVs would complement the projected NASA base line of five shuttle flights to the Space Station per year during mature operations. Logistics elements launched by ELVs could rendezvous with an OMV to be ferried to the Station. Also under study is the use of Advanced Solid Rocket Motors to increase the shuttle's mass-to-orbit capability and thereby decrease the number of flights required in constructing and resupplying the Station.

Operations Capability. Space Station operations encompass all activities required to assemble and maintain the Space Station and its associated platforms for their planned lifetimes, including the following:

(1) pre-launch and post-landing processing,
(2) crew and ground personnel training,
(3) tactical and incremental planning,
(4) onboard and ground support of station operations,
(5) resupply and return logistics operations,
(6) communications and data management,
(7) trajectory maintenance, and
(8) rendezvous and proximity operations for vehicles and free-flyer satellites.

Also provided is support to user operations, including familiarizing users with the program.

In the development phase of the program, an operations infrastructure will be developed concurrently with the flight hardware and software. This infrastructure will consist of a management structure, a trained work force, and a set of unique support facilities. It will be based on recommendations of the Space Station Operations Task Force chartered by the Office of Space Station.

Space Station Operations

Space Station operations include the safe operation and maintenance of the Space Station to provide resources and capabilities for users. Planning and real-time support for space systems operations will be provided by a centralized organization supported by engineering and maintenance expertise at a number of NASA installations and in the organizations of international partners.

The Space Station Control Center (SSCC) will be supported by Engineering Support Centers at the work-package centers, and in Europe, Canada, and Japan. During on-orbit verification, these engineering centers of expertise will :

(1) maintain a real-time capability to monitor and analyze hardware and software,
(2) support the SSCC in troubleshooting problems,
(3) develop maintenance procedures, and
(4) perform sustaining engineering.

User planning and integration activities are distributed throughout many countries, government organizations, private companies, and universities. For near-term planning and real-time operations, user activities are coordinated and supported by the Space Station program.

The Payload Operations Integration Center (POIC) at Marshall Space Flight Center will be able to support various levels of computerized payload planning and will serve as the users' interface to the SSCC. Users and user sponsors will develop their own infrastructure. The Space Station Platform Control Center, located at Goddard Space Flight Center, will perform the POIC and

(continued...)

Space Station Operations (continued)

support functions for the NASA platform associated with the Space Station. ESA is providing control centers for its polar platform and man-tended free-flyer.

Pre-launch processing of Space Station hardware elements, platforms, and logistics carriers will be carried out at the launch site. Post-landing operations for logistics carriers and cargo are the responsibility of the launch center. The Space Station Processing Facilities will be located at Kennedy Space Center and will integrate and test the interfaces between system elements. Payloads and Station cargo will be physically integrated with the logistics carriers at the Kennedy Space Center.

Integrated logistics planning will be conducted at the launch site, and work package groups and contractors will be responsible for logistics management. A phased transfer of logistics management responsibility from the developing center to the launch site will take place. Initially, existing facilities at Kennedy Space Center will be used for logistics operations, and a logistics information system will be developed to support full-time logistics operations.

Numerous means for crew training will be used, including the following:

(1) part-task systems trainers,
(2) manipulator and proximity operations simulators,
(3) one-G mockups and trainers, and
(4) neutral buoyancy facilities.

Space Station systems operations and ground controller training will be centralized at the Space Station Training Facility at Johnson Space Center. The training facility will train crews and ground controllers for nominal Space Station proximity and manipulator operations, as well as for response to off-nominal situations. Trainers and simulators will be linked with STS facilities to conduct integrated nominal and contingency simulations during assembly. Joint on-board and ground simulations may be conducted during mature operations phases to maintain crew and ground controller readiness. Element-specific operations training will be conducted primarily by the partner providing the element, at appropriate centers of all the partners.

Space Station Evolution. In the Space Station program, the capability to evolve is a fundamental requirement, and has been since the earliest stages of Station concept definition. This important design requirement has recently been re-emphasized by the President's National Space Policy, which states that "the Space Station will allow evolution in keeping with the needs of Station users and the long-term goals of the U.S." The Space Station program has established activities required to ensure that the Space Station design can evolve in a cost-effective manner with a minimum of interruption to current operations.

In Fiscal Year 1988, transition definition of the Space Station program was initiated. The overall objective of this activity is to define, develop, and implement a program to enable Space Station evolution in keeping with the needs of users and the long-term goals of the United States. Specific objectives are to:

(1) define Space Station evolution options consistent with user requirements and program constraints;
(2) define, recommend, and advocate base-line design accommodations to satisfy evolution requirements; and
(3) define, develop, and implement an advanced technology program that ensures the readiness of technology to enhance Space Station capabilities and enable Space Station evolution.

Management Approach

In 1986 General Samuel C. Phillips, former Apollo Director, led a special team to study, and advise NASA on, a management approach to build the Space Station. He recommended, and NASA accepted, a management structure for the Space Station program that differs significantly from those previously used by NASA to develop large space systems.

Space Station Program Management Structure

The Space Station program is using a 3-tiered management structure, as follows:

Level I - the Office of the Associate Administrator for Space Station at NASA Headquarters in Washington, D.C.;
Level II - the Space Station Program Office in nearby Reston, Virginia; and
Level III - the field center Project Offices.

This structure is shown in Figure V-2.

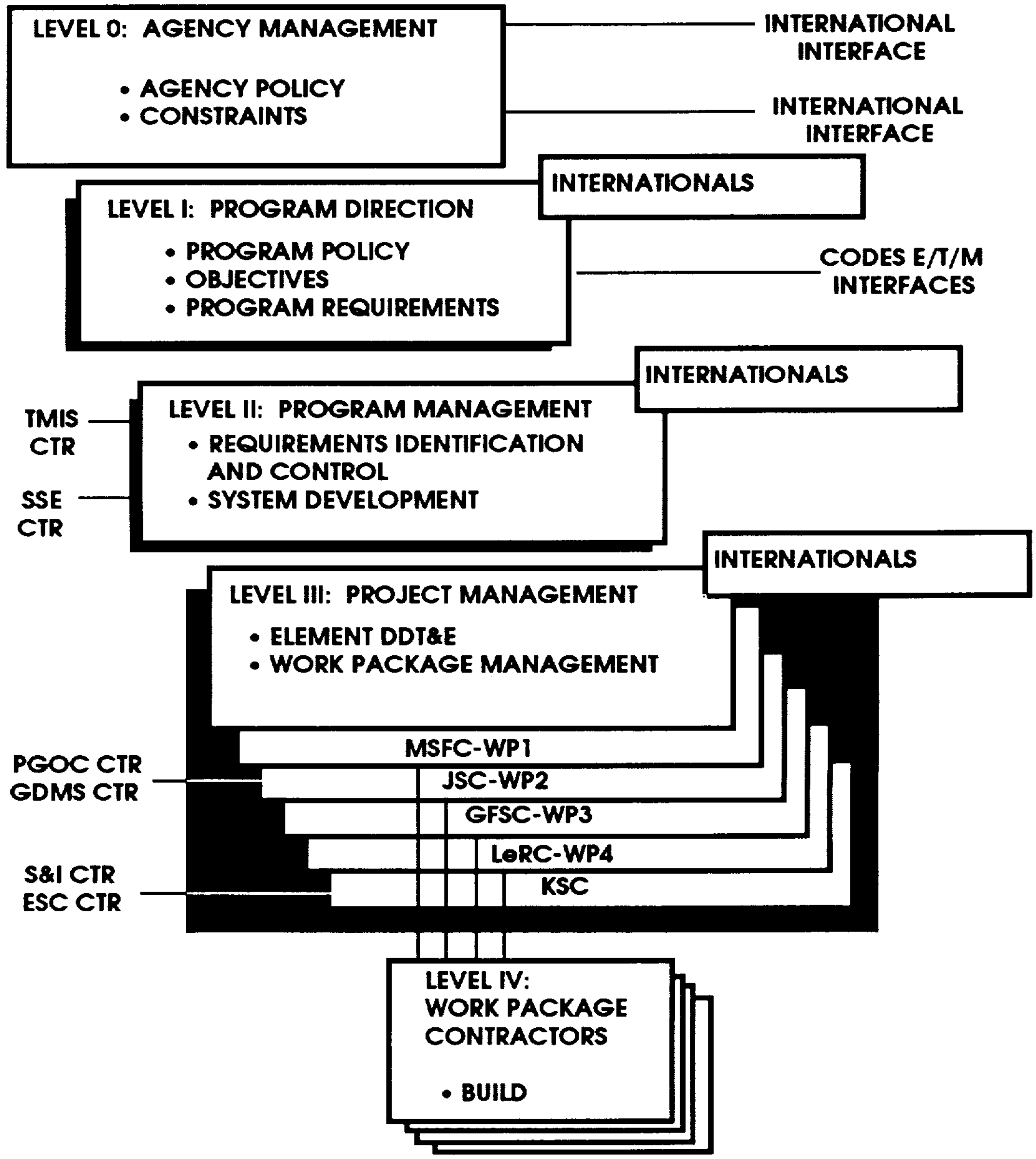
The Associate Administrator for Space Station at NASA Headquarters, Level I, is responsible for the Space Station program. His responsibilities include policy direction, budget formulation, external liaison, and Space Station evolution. He establishes and controls Level I technical and management requirements, milestones, budget allocations, and forecasts. He also coordinates external affairs with the legislative and executive branches, user communities, international partners, and other NASA Headquarters program offices that support the program.

The Space Station Program Office, Level II, is responsible for development of the Space Station and the operational capability of flight and ground systems. Principal responsibilities include system engineering and analysis, program planning and resource control (for both the development and the operations phases), configuration management, and integration of elements and payloads into an operating system. This Office is headed by the Director, Space Station program, who is responsible for its day-to-day management. The Space Station Program Office is assisted by the Program Support Contractor and by the Technical and Management Information System and Software Support Environment contractors. The Jet Propulsion Laboratory provides an independent program requirements and assessment function.

Level III consists of the Space Station Project Offices at the field centers. These offices are responsible for:

(1) design, development, testing, and evaluation;
(2) operation of hardware and software systems; and
(3) integration of element evolution, engineering support, and user operations. (The Project Managers of these Offices report to the Director, Space Station program, and programmatically to their Center Directors.)

Center Directors advise the Associate Administrator for Space Station on technical and management issues. They also participate as members of a Space Station Management Council, and ensure institutional excellence and support for their portions of the program.



Code E	Space Science and Applications
Code T	Space Operation
Code M	Space Flight
DDT&E	Design, Development, Test and Evaluation
GSFC	Goddard Space Flight Center
JSC	Johnson Space Center
KSC	Kennedy Space Center
LeRC	Lewis Research Center
MSFC	Marshall Space Flight Center
WP	Work Package
CTR	Center
PGOC	Payload Ground Operations Center
GDMS	Ground Data Management System
S&I	Systems and Integration
ESC	Engineering Support Center
TMIS	Technical Management Information System
SSE	Software Support Environment

Figure V-2. Space Station Program Management Structure

Work Package Center Responsibilities. The Phillips Committee's recommendations on management structure and work package responsibilities were structured to maintain contractor accountability for Phase C/D. Accountability is essential to cost control and demands clearly definable deliverable items that can be integrated and checked out independently. It also requires the assignment of the entire design and development responsibility for each deliverable item to a single contractor.

Further review in the fall of 1986 resulted in refinement of the field centers' development responsibilities recommended by the Phillips Committee. The inset below summarizes the current work package assignments.

International. Management of the potential international elements will be conducted within the framework of the multilateral Intergovernmental Agreement and the agency-to-agency memoranda of understanding (MOUs). The MOUs set forth the management structure, as well as specific documentation plans and major reviews. The international partners will be technically and financially responsible for the development of their respective Space Station hardware. Management mechanisms will be established to coordinate activities of all partners.

Three bilateral Program Coordination Committees, established during the definition phase, will meet during the design and development phase to review the design and development activities. As a result, decisions will be made to ensure implementation of the cooperative activities of the international partners. The Associate Administrator for Space Station and his international counterparts will co-chair each committee, and the co-chairs will each designate his or her respective members. A multilateral Coordination Board chaired by the Associate Administrator for Space Station, with his counterparts as members, will plan and coordinate Space Station operation and utilization activities

Liaison activities with international partners will be conducted under the direction of the Office of Space Station. Under the terms of applicable agency-to-agency MOUs, each partner may provide representatives to the Office of Space Station to coordinate cooperative program activities. Likewise, NASA is entitled to such representation at the respective partner's Headquarters site.

Work Package Assignments

Work Package 1
Marshall Space Flight Center is responsible for the Station laboratory, habitation module, logistics elements, and fabrication of the resource node's primary structure, as well as for technical and management responsibility for the engine elements of the Station's propulsion system. Boeing Aerospace Company is the prime contractor.

Work Package 2
Johnson Space Center is responsible for the external truss, distributed subsystems, EVA systems, airlock, and resource node design and outfitting. It also is responsible for the manned space subsystems through special provisions within the Marshall and Johnson contracts. McDonnell Douglas Astronautics Company is the prime contractor.

Work Package 3
Goddard Space Flight Center is responsible for Space Station platforms, attached payload accommodations, the Flight Telerobotic Servicer, and NASA's role in servicing. The prime contractor is the Astro-Space Division of General Electric Company.

Work Package 4
Lewis Research Center is responsible for the power system, and has as its prime contractor the Rocketdyne Division of Rockwell International.

Program Control. Program control (schedules, resources, and configuration control) will be implemented by the Space Station Program Office (SSPO) and the Project Offices.

The management of schedules will be implemented through establishment of milestones at various levels of the program. Each milestone will be assessed continuously by the field center Project Offices and the SSPO. Any change to the milestones will require formal approval. The program has established an intersite delivery schedule that establishes when specific hardware is required to be delivered from one Project Office to another to meet scheduled milestones. The intersite delivery dates are established by the Space Station Schedules Working Group, chaired by the SSPO with representation from each of the field center Project Offices. This working group will review the intersite delivery schedules continually to assess potential problem areas and required adjustments.

The SSPO also will review technical changes submitted to the configuration control process for their effects on development and operations costs and schedule.

Change Control. The change process will be handled at each level through a formal documentation and board structure. Top level program requirements are established by Level I and recorded in the Program Requirements Document. These requirements will be controlled by the Program Control Board (see inset on page V-19), chaired by the Associate Administrator. Level II program and technical requirements, including content, schedule, and interface requirements, are contained in the Program Definition and Requirements Document and related sub-tier documents. These documents add technical detail to the Level I requirements. The process for establishing and controlling these documents is founded on a formal configuration management discipline using a Level II Space Station Control Board, as shown in the inset on page V-19.

Program Support Contractor. NASA has awarded the Grumman Aerospace Corporation a level-of-effort, task-order contract to provide necessary skills to support the Space Station Program Office in Reston, Virginia, and at the participating field centers. The scope of the contract is broad and includes support for both programmatic and technical activities in all Level II functional areas. The principal effort, however, will be to assist NASA in essential systems engineering and integration functions, including analysis and assessment of program requirements, systems engineering and analysis, distributed systems integration, technical integration, and element and launch package integration. The support contractor will provide additional support in areas such as design of the ground-communication and ground-to-space communication links, the planning of interfaces with users, and the development of concepts and facility plans for the use and operation of the Space Station.

Operations Management. Because of the breadth, duration, and international nature of Space Station

Program Requirements Document (PRD)

The Space Station PRD establishes the highest level requirements associated with the Space Station program. Its purpose is to set forth the objectives, requirements, budgets, and milestones controlled by Level I of the Space Station program. The PRD addresses both technical and management requirements.

The PRD defines Space Station program Level I requirements necessary to establish Level II detailed requirements to design, develop, and establish the operational capability of the ground and space systems that comprise the Space Station.

Level I requirements are established and approved by the Associate Administrator for Space Station. The PRD contains both directives and constraints related to the Space Station program at the Agency and national level, and to the relevant international agreements.

Program Control Board (PCB)

The Space Station PCB is a forum where information relevant to change requests (CRs) submitted in response to the Level I Program Requirements Document (PRD) is discussed and reviewed. The PCB is chartered as a non-voting, advisory board to the Associate Administrator for Space Station. Members of this board include the Deputy Associate Administrator for Space Station, Special Assistant to the Associate Administrator, Level I Division Directors, the Chief Scientist, the Senior Engineer, and appropriate Level II managers.

The Associate Administrator for Space Station is the PCB chairman. He will review all information concerning CRs brought forward at scheduled PCB meetings, and will dispose of all PRD CRs brought before the Board. The decisions of the Associate Administrator are final and determinative.

operations, a unique organizational structure has been recommended for effectively managing utilization and operations activities. Its primary feature is a strong, centralized, technically competent operations planning and integration activity. The activities will be strategically managed and tactically integrated in Washington, D.C., with international participation. Support and implementation will be at the field centers. Figure V-3 illustrates the planning process.

For the U.S. allocation of Space Station resources, the Space Station Users Board will conduct utilization planning for the next five years. The Board will include membership from NASA organizations that sponsor users (Office of Space Science and Applications, Office of Aeronautics and Space Technology, Office of Commercial Programs, etc.), other government agencies, and commercial users. Each Space Station partner will submit its own 5-year plan. The Multilateral Coordination Board, supported by the User Operations and System Operations Panels (established by memoranda of understanding), will produce the upcoming 5-year Consolidated Operations and Utilization Plan (COUP).

The COUP will then be used by the Space Station Program Office to generate a Tactical Operations Plan (TOP). Tactical operations planning covers a 2-year period and includes manifests, milestones, payload integration, safety reviews, documentation, installation, test, checkout procedures, ground flow, and logistics support. The development of the TOP will be supported by a Space Station Users Working Group and other Station-accommodations working groups.

Space Station Control Board (SSCB)

The SSCB is chaired by the Director, Space Station program, and its membership includes the functional directors of the Space Station Program Office, the Level III Project Managers, other NASA offices, and the international participants. In practice, the board is the top-level authority for reviewing and controlling the program base line.

The Level II SSCB is supplemented by other SSCB chartered boards and panels to handle work activity in various areas. Space Station program Level II base-line documentation is formally controlled, and is maintained by the Space Station Program Office. At each field center Level III project, a similar process is in place, with the Project Manager chairing a Configuration Control Board to control changes within the project.

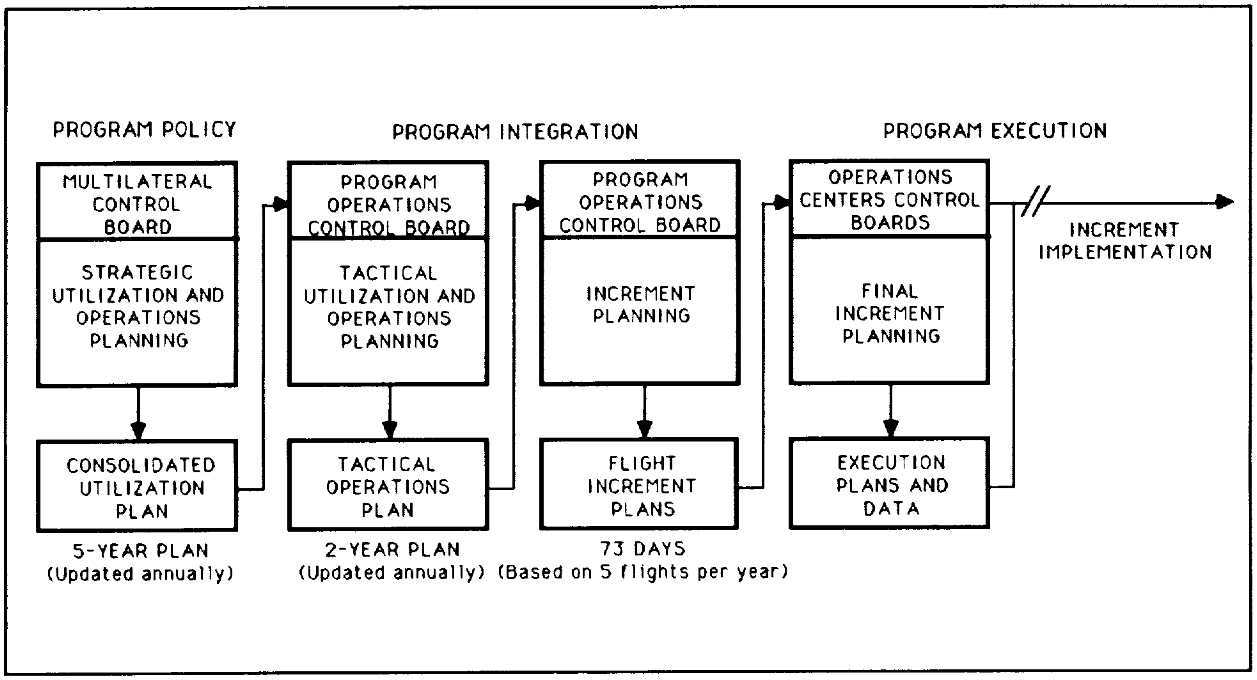


Figure V-3. Space Station Operations Planning Process

A Payload Accommodations Manager will be assigned to each payload in the COUP, and will be a single point of contact for an individual user of the Space Station.

The approved TOP will be the basis for generating multiple increment plans, where increment activities are defined as those occurring between STS visits to the Station. Specified increment plans also will cover activities associated with STS visits. NASA field centers, international partners, and user operations facilities will execute the increment plans, in addition to supporting the integrated tactical management functions.

Operations Cost Management. NASA recognizes that cost-effective operation of the Space Station, both manned base and platforms, is essential. Key features of the management plan are:

(1) an organizational structure facilitating management of operations costs;
(2) identification and control of significant cost drivers;
(3) implementation of tools, procedures, and processes for managing costs; and
(4) innovative, evolutionary application of automation and robotics.

A clearer focus on operations costs is being provided through the establishment of a separate line item for operations in the Space Station budget. A model developed for use in estimating categories of operations costs (e.g., logistics, ground operations) will be used to predict and assess the effects of program changes on operations costs.

Construction of Facilities. The field centers submit facility construction requirements to the Space Station Facility Review Board, which is chaired by the Space Station Program Office. This board provides recommendations to the Director, Space Station program, who provides a complete facility program recommendation to the Associate Administrator for Space Station. Requirements for out-years are reviewed annually and adjusted to meet programmatic changes.

Program Schedule and Milestones

The current Space Station program schedule is based on the goal of launching the first element in the first quarter of 1995, with a permanently manned capability achieved in the fourth quarter of 1996. The contract start date for Phase C/D detailed design and hardware development occurred in December, 1987. The top-level Space Station milestones are shown in Table V-1.

These milestones and a more detailed set of supporting milestones have been designated controlled milestones. They are incorporated in the Program Definition and Requirements Document and come under the formal change control procedures of that document. Distributed development responsibilities within the program dictate the need for clear accountability and scheduling of element and system components as they move through the integration process. The interdependence of hardware and software schedules requires careful integration. A key component is the intersite delivery schedule. For each deliverable end item, this schedule lists the flight assignment, the work package or entity responsible for delivery, the launch date, and intermediate deliveries necessary to complete assembly, integration, and verification.

Table V-I. Space Station Program Milestones

Milestone	Time
Phase C/D Contract Start Date	Dec 87
Preliminary Requirements Review	2nd Qtr 88
Initial Systems Preliminary Design Review	1st Qtr 90
Preliminary Design Review—Man-Tended Capability (MTC)	3rd Qtr 90
Preliminary Design Review—Permanently Manned Capability (PMC)	1st Qtr 91
Initial Systems Critical Design Review	2nd Qtr 91
Critical Design Review—MTC	3rd Qtr 92
Critical Design Review—PMC	2nd Qtr 93
Space Station Training Facility—Operational Readiness Date (ORD)	2nd Qtr 93
Space Station Control Center—ORD	4th Qtr 93
Design Certification Review—MTC	1st Qtr 94
Payload Operations Integration Center—ORD	2nd Qtr 94
Space Station Processing Facility—ORD	3rd Qtr 94
Operational Readiness Review	4th Qtr 94
First Flight Readiness Review	1st Qtr 95
Design Certification Review—PMC	1st Qtr 95
First Element Launch	1st Qtr 95
U.S. Polar Platform	4th Qtr 95
Early Man-Tended Capability	4th Qtr 95
Permanently Manned Capability	4th Qtr 96
Assembly Complete	1st Qtr 98

NOTE - All program milestones under review (4/1/88)

Space Station System Overview

The Space Station's base-line design, portrayed on page V-2, includes a manned base in low-inclination orbit, featuring a 110-meter (360-foot) transverse boom with four pressurized modules attached in the middle. Photovoltaic arrays for electrical power are located at each end of the boom, and attachment points for external payloads are provided along the boom. A Mobile Servicing System and a Flight Telerobotic Servicer will assist in Space Station assembly and in servicing payloads.

The four pressurized modules of the Space Station include a laboratory module and a habitation module to be provided by the United States, and laboratory modules to be provided by Japan and the European Space Agency. Linking the pressurized modules are resource nodes—pressurized passageways outfitted with racks providing 238 cubic meters (8,400 cubic feet) of extra space for equipment. The Space Station will have approximately 878 cubic meters (31,000 cubic feet) of pressurized volume.

Microgravity research is one of the important benefits the Space Station will provide. By combining extended time on orbit with the availability of human interaction, the Station is expected to advance significantly the fields of materials and life sciences. For this reason, the United States is developing a microgravity laboratory module outfitted to provide users with resources that will make possible a variety of materials processing and life sciences experiments. Virtually the entire human presence aboard the Space Station will be an experiment in how the human body reacts to long-term exposure to the environment of space.

Included in the Space Station program concept are free-flying, unmanned platforms. These platforms, envisioned as bases to support attached payloads, will provide a different set of capabilities from those of the Station. Two such platforms, both to be flown in polar orbit, are included in the base-line program. One will be developed by the United States, the other by ESA.

The Manned Base

The Space Station will be designed to operate at altitudes from 241 km (150 nautical miles) to 434 km (270 nautical miles) at a 28.5 degree inclination. The nominal operating altitude will be approximately 354 km (220 nautical miles) to 402 km (250 nautical miles). In flight, the Station's transverse boom will be perpendicular to the velocity vector.

Four pressurized cylindrical modules will be attached to the center of the boom. One of the modules, the habitation module, will provide living quarters for up to eight crew members. Pressurized and unpressurized logistics carriers will provide the Station with supplies and equipment. Electrical power will be provided by two modules attached to the two ends of the boom with alpha joints, which will rotate to point the modules' solar arrays toward the sun. With the power modules, the Station will have a total length of 155 meters (508.5 feet).

The boom will be equipped with attachment points providing power and other utilities to accommodate a variety of external scientific payloads.

Other features of the Space Station will include a Mobile Servicing System, partially supplied by Canada. This system will be used to assist in the assembly of the Station and for a number of servicing tasks. There will also be a Flight Telerobotic Servicer, which will be used to service payloads and assemble the Station.

Space Station Elements

Space Station elements are the major assemblies for the Station. They are not involved with distributing a utility or service.

Transverse Boom. This 110-meter (360-foot) long truss assembly will give structural stiffness and dimensional stability to the entire Space Station. It also will provide the structure for integration and installation of all the elements and systems, including the modules, that make up the Space Station's manned base, or core.

The core truss will be a framelike structure made up of longerons, battens, and diagonal struts designed to be assembled in space. These members, made of composite materials, will be attached to corner fittings forming a beam truss of sequential cubic bays measuring five meters wide from strut centerline to strut centerline.

The overall truss assembly will include the core truss structure, extravehicular activity truss equipment to facilitate crew movement about the Station, an external lighting system, utility distribution trays, resource pallets, and the alpha joints and their drive mechanisms for positioning the photovoltaic power modules. The utility distribution trays will house all the subsystem distribution lines for the Station: thermal, power, fluid, and data management. Utility ports, equipped with common interfacing hardware, will be provided for external attached payloads.

U.S. Laboratory Module. The U.S. laboratory module, shown in Figure V-4, will be used to conduct basic microgravity materials and life science research. The experiments conducted will be those requiring low gravity levels over long periods, and extensive human control and monitoring. The commercial potential of materials processes in microgravity will also be investigated.

The module will be located below the lower face of the transverse boom, and will be attached perpendicular to, and slightly to the right of center. It will be a pressurized cylinder 4.3 meters (14 feet) in diameter and approximately 13 meters (44 feet) in length. The ports at either end of the module will be 2 meters (7 feet) in diameter. The ends of the module will attach to Nodes 1 and 3 (see the subparagraph "Resource Nodes", below).

The module will be composed of two basic structures. The primary structure will consist of a pressure shell, meteoroid shield, and radiation protection, and will have space shuttle attachment provisions, viewports, and grapple fixtures. The secondary structure will be an inner wall that provides rigidity for attaching experiment racks and other equipment. Utility lines also will be mounted to this structure.

The laboratory module will be pressurized at 14.7 psi (sea-level pressure), and will be able to accommodate up to 42 cubic meters (30 double racks) of payloads and payload support equipment along its port and starboard walls. The Environmental Control and Life Support System, other distributed system components, laboratory outfitting equipment, and storage lockers will be placed along the floor and ceiling.

Habitation Module. The habitation module will be the living quarters for the crew. It will be where the crew eats, sleeps, engages in recreational activities, and receives medical care when necessary. It will be designed to include safe-haven emergency supplies and provisions to allow its isolation from the other modules.

The habitation module will be identical in size and structure to the U.S. laboratory module and will be located parallel and next to it. Like the laboratory, the habitation module will have both a primary and a secondary structure. The interior will be outfitted with the facilities for cooking, eating, personal hygiene, and other human needs. Exact outfitting equipment has not yet been specified. The floor and ceiling will contain stowage areas for spares, consumables, trouble-shooting equipment, and tools for subsystem maintenance.

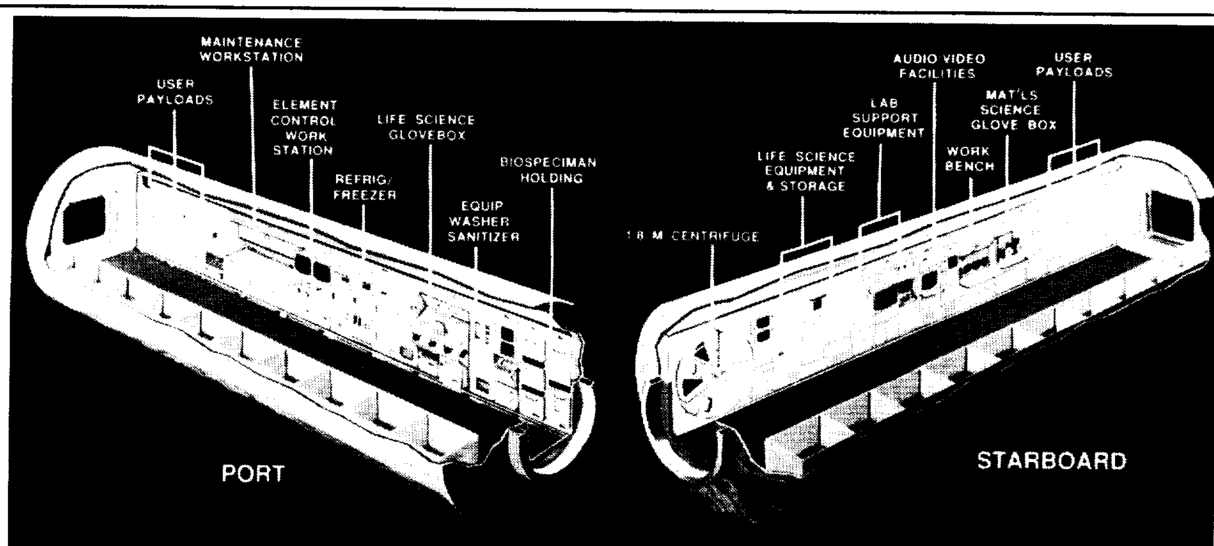


Figure V-4. The U.S. Laboratory Module

European Attached Pressurized Laboratory Module. The European module will be a permanently attached, pressurized laboratory module developed and funded by the European Space Agency. The module, 12.5 meters (41 feet) in length and 4.3 meters (14 feet) in diameter, will be composed of four segments of all-welded primary structure with an axially mounted Station-compatible docking port at each end. The internal, secondary structure will include removable single and double racks for accommodation of subsystems and payloads. The module also will contain an airlock to permit temporary exposure of experiments to a vacuum and transfer of tools and equipment to support external activities.

Japanese Experiment Module (JEM). Japan will provide the JEM, consisting of a permanently attached, pressurized laboratory module, an exposed facility, and an Experiment Logistics Module. The pressurized module will be 10.7 meters (35 feet) long and 4.3 meters (14 feet) in diameter. The exposed facility will be 7.6 meters (25 feet) long. The pressurized portion of the JEM will have a structure similar to that of the U.S. modules. The exposed facility will consist of an open truss and provisions for equipment attachment. An airlock will provide access between the pressurized module and the exposed facility. The Experiment Logistics Module will provide transportation and storage of supplies, and potentially could serve as a safe haven for two crew members.

Resource Nodes. The Space Station will have four resource nodes, one of which will be located at each end of the habitation module and the U.S. laboratory module. The nodes will be pressurized cylinders that will serve as command and control centers, and as pressurized passageways to and from the various modules. They will be approximately 4.3 meters (14 feet) in diameter and 5.2 meters (17 feet) long. They will be like the modules, with a primary and secondary structure and with accommodations for distributed systems. The nodes will contain docking equipment and hatches, and certain nodes will contain berthing mechanisms for temporary attachment of the space shuttle or the logistics modules. The nodes also will have attaching devices to connect them to the truss and modules. One or more cupolas may be attached to node ports to allow direct viewing of external activities.

Logistics Carrier. There will be pressurized and unpressurized carriers, both of which will be used to transport equipment and fluids to the Space Station and to return experiment results, equipment, and waste products back to Earth. They will be carried in the orbiter's payload bay. The pressurized carriers will transport equipment and supplies that require a pressurized, protected environment, while unpressurized carriers will be used for liquids and equipment that need no pressurization. Both kinds will be reusable.

Airlocks. There will be three airlocks on the Space Station: two pressurized at normal sea-level pressure, and one hyperbaric airlock capable of functioning at higher pressures. The airlocks will allow a suited astronaut to exit and reenter the protected environment of the Space Station. They will provide depressurization and repressurization, extravehicular activity (EVA) system checkout, service and maintenance equipment, and EVA system storage. The airlock will have access to all the distributed systems and utilities provided to other pressurized areas of the Space Station.

The hyperbaric airlock will be a variable pressure airlock for use in the event that a crew member needs medical attention for conditions such as altitude decompression sickness or pulmonary embolism (the "bends"). Provisions will be provided for passing items to and from the vacuum of space without loss of pressure in the Space Station. Both kinds of airlocks will have structures like those of the other pressurized modules.

Mobile Servicing System (MSS). The MSS will be an automated tool used for assembly, routine servicing, and maintenance of the Space Station and attached payloads. It will consist of the U.S. Mobile Transporter (MT) and the Mobile Servicing Center (MSC) to be developed by Canada. The MT will ride along rails mounted on the truss, providing mobility for the MSC. The MT will generate its own utilities and data, or will throughput Space Station distributed utilities and data. The base of the MT will measure approximately 4.9 x 6.1 meters (16 x 20 feet). The height has not yet been determined.

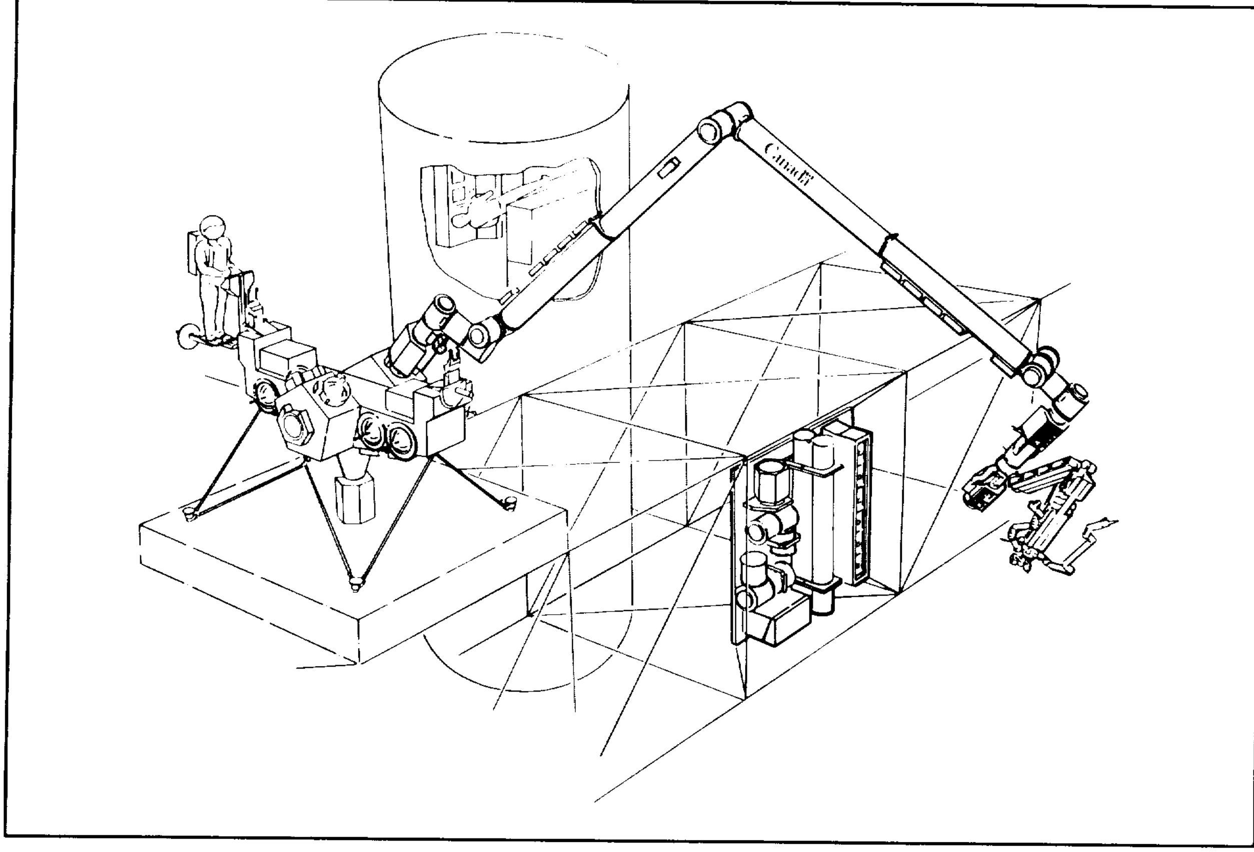


Figure V-5. Mobile Servicing System

The MSC will consist of a base structure mounted on the MT, a Remote Manipulator System (RMS), similar to the one on the orbiter, an Astronaut Positioning System, and a Special Purpose Dextrous Manipulator (SPDM), that acts as the "hands" of the system. The Astronaut Positioning System will be similar to the RMS, except that it will have additional restraints designed to interface with a suited astronaut. The SPDM will be designed to change-out Space Station orbital replacement units and attached payloads.

Flight Telerobotic Servicer (FTS). The FTS will be a highly automated telerobotic device capable of precise manipulations in space. It will perform routine and hazardous tasks, thereby reducing extravehicular activity time and risk. Proposed initial tasks include installation of truss members, installation of fixtures on the truss, change-out of Space Station orbital replacement units, mating of the Space Station thermal utility connectors, and inspection tasks.

Astronauts will operate the FTS using both direct manipulator control and programmed command sequences. The FTS will be designed to be operable from several different work stations. Its hardware and software will be modular to ensure serviceability, and its configuration will be flexible enough to facilitate its technological upgrading.

Attached Payload Accommodations Equipment. Attached Payload Accommodations Equipment (APAE) is the equipment that will be used to mount and operate external scientific payloads. It will include a structural interface between the Space Station and the payloads, and distributed systems outlets to supply the payloads with power, fluids, energy, and data links. It will be designed to accommodate a variety of external payloads, from pre-integrated instrument pallets to single instruments requiring gimbaled pointing. Typical Attached Payload Accommodations are shown in Figure V-7.

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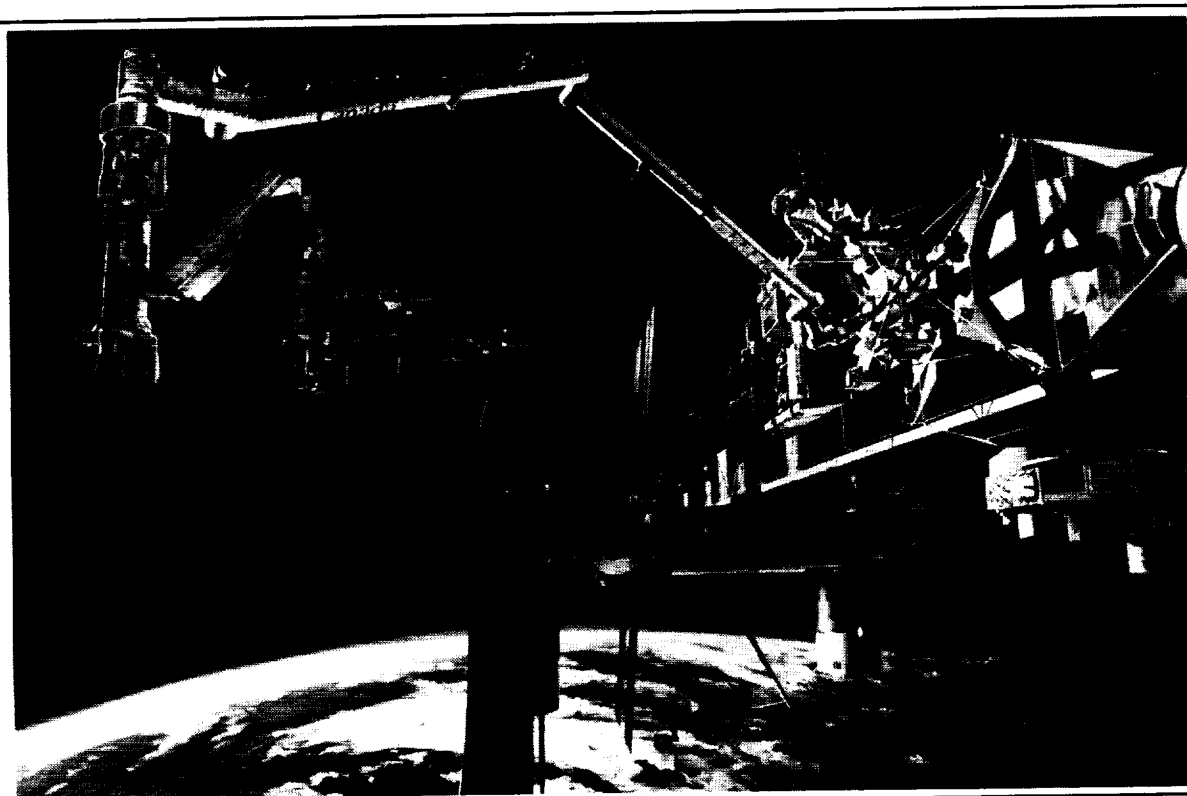

Figure V-6. Special Purpose Dextrous Manipulator

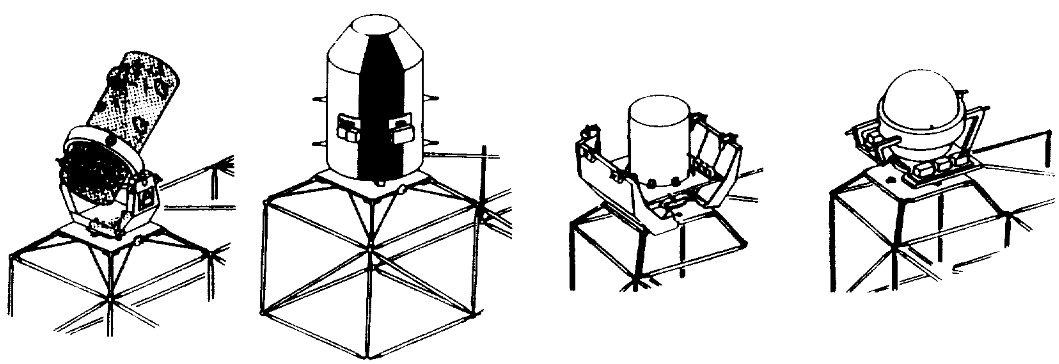

Figure V-7. Attached Payloads Accommodations Equipment

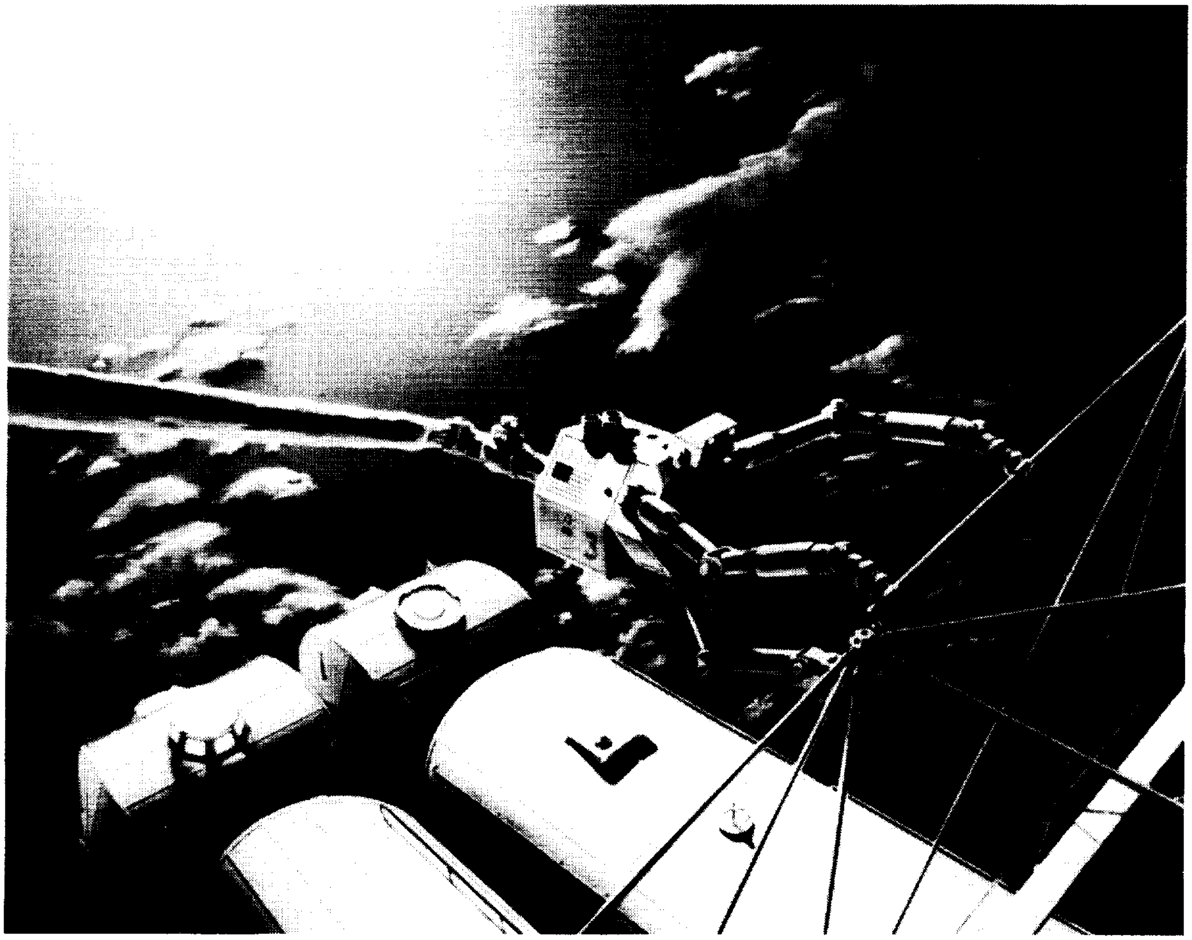

Figure V-8. Flight Telerobotic Servicer Performing an Assembly Task

There will be two sets of APAE hardware, usuable at any of the four utility ports (also called attach points) located along the transverse boom. In addition, there will be one precision pointing mount attachable at any of the four locations for instruments that must be oriented continuously in a specific direction.

Propulsion Assembly. The propulsion assembly will provide thrust for orbit maintenance and 3-axis thrust for attitude stabilization and reorientation. Three-axis thrust will be used to desaturate the Control Moment Gyroscopes, which are the primary attitude actuators of the Stabilization and Control System.

The propulsion system will consist of four propulsion modules, a tank farm, and a fuel distribution system. Each module will contain fuel tanks, plumbing and valving, a fuel pump, and two types of jet actuators—hot gas actuators to provide thrust for orbit maintenance and smaller engines to provide vernier control. The former will be in the 25- to 40-pound thrust range and will be fueled by a hydrogen-oxygen mixture. The latter will be resistojets in the 1-pound thrust range. The tank farm will consist of tankage, valving, and a distribution system.

Distributed Systems

Distributed systems provide end-to-end functions required by two or more Space Station elements.

Electrical Power System. The electrical power system will generate and distribute 75 kW of electrical power at 20 kHz to the Space Station housekeeping functions and users. It will consist of two power modules and a distribution and management system.

The power modules will be located at each end of the transverse boom. The primary structure of the power module will be a truss whose construction will be similar to that of the boom. Attached to the truss will be two pairs of photovoltaic solar arrays, each array consisting of two panels of photovoltaic cells. The truss will be attached to the boom with a rotating mechanism, the alpha joint, which will provide 360 degrees of rotation to angle the solar array panels toward the sun as the Station revolves around Earth. Each solar array will be attached to the truss with a beta joint that will provide a second degree of freedom necessary to permit the solar panels to track the sun. Each panel will be approximately 27 meters (88.5 feet) long, and the four panels on each side of the truss will span approximately 10.5 meters (34.5 feet).

Thermal Control System. This system will control the temperature and heat distribution throughout the Space Station, and will vent the heat produced by onboard systems. It will be composed of two parts, a Passive Thermal Control System and an Active Thermal Control System. The passive system will consist of thermal blankets and reflectors that will isolate Station components from the temperature extremes of the space environment.

The active system, which will supplement the passive one, will collect, transport, and reject waste heat from the manned modules and other Space Station elements. The thermal bus approach to heat collection and transport will be employed. The thermal bus will use a 2-phase working fluid to transport heat by evaporation and condensation.

Data Management System (DMS). The DMS will be a distributed system of the Space Station, and an integral part of the Space Station Information System concept. It will be an onboard computer system with two primary functions:

(1) to provide the hardware and software resources necessary to support the data processing and local communications needs of Space Station systems, elements, and payloads; and
(2) to function as an integrating entity that provides a homogeneous operating environment and human-machine interfaces (standardized for both the Station crew and the ground operators) for operating and controlling the Space Station.

The DMS will include an assembly called the Multipurpose Application Console that will be the electronic core of the Space Station work station. Consoles will provide access into operational monitoring, training, testing, caution and warning displays, and crew operations. Some consoles will be fixed in place; others will be portable. At least one multipurpose application console will have hard-copy capability.

Communications and Tracking (C&T) System. The C&T system, an integral part of the infrastructure of the Space Station Information System concept, will provide all the communications services necessary to support Space Station and payload operations. These services will include command and control, audio, video, and telemetry communication and tracking, both space-to-space and space-to-ground.

The C&T system will be divided into six subsystems, each representing a major class of service or function:

(1) a space-to-space communication subsystem to provide communication with astronauts performing EVA, the space shuttle, the Orbital Maneuvering Vehicle, the Mobile Servicing Center, the Flight Telerobotic Servicer, and the free-flying platforms;
(2) a space-to-ground subsystem to provide communication via the Tracking and Data Relay Satellite System to the ground data networks;
(3) an audio subsystem to provide all the voice communications on the Space Station;
(4) a video system to provide for all the internal and external video requirements on the Space Station;
(5) a tracking subsystem, which will consist of a Global Pointing System receiver-processor to provide the information necessary for accommodating future laser docking and radar requirements; and
(6) a control and monitoring subsystem to manage all C&T resources and distribute the C&T data.

Guidance, Navigation, and Control System. The Guidance, Navigation, and Control System will be the core system for control and traffic management. It will supply attitude and orbital maintenance, support the pointing of the photovoltaic power arrays and the thermal radiators, accomplish periodic reboost maneuvers, and provide Station attitude and state information to other systems and users. The System's traffic management function will control incoming, outgoing, and Station-keeping traffic within the vicinity of the Station. It also will control docking and berthing operations, monitor the trajectories of vehicles and objects that may intersect the orbit of the Space Station, and support flight planning.

Extravehicular Activity System. The EVA system will provide crew members with the ability to perform routine tasks in the unpressurized environment on and about the Space Station. The system will support assembly, maintenance, repair, inspection, and servicing of Station and user systems.

The EVA system will consist of a number of subsystems, including the following:

(1) Extravehicular Mobility Units, which will be central to the EVA system and will consist of a space suit, equipment for communications and physiology monitoring, and an autonomous life support system that will be carried as a backpack;
(2) a service and performance checkout subsystem;
(3) EVA translation and mobility aids such as handrails, slide mechanisms, and tethers;
(4) servicing provisions for EVA crew and equipment retrieval systems and subsystems;
(5) EVA lighting;
(6) generic tools;
(7) miscellaneous support equipment and lockers;
(8) extravehicular contamination detection and decontamination equipment; and
(9) systems interfaces for the airlock, Environmental Control and Life Support System, thermal control, and power utilities.

These components and subsystems of the EVA system will be stowed throughout the Space Station elements, with the majority of the equipment located within the airlocks. Various tools, restraints, and work platforms will be located on the Mobile Servicing Center. Mobility and translation aids will be placed on the truss.

Environmental Control and Life Support System (ECLSS). The ECLSS will provide a habitable environment both for the crew and for biological experiment specimens. It will maintain atmospheric temperature, humidity, pressure, and air composition in the pressurized modules. It also will supply potable and personal hygiene water, and will process and store biological waste. It will be able to detect and suppress fires.

Fluid Management System. The Fluid Management System will supply and dispose of Space Station fluids, including nitrogen, water, and waste fluids.

The Integrated Nitrogen System will consist of the hardware and software required to resupply, transfer, store, condition, distribute, control, and monitor nitrogen for the Space Station. The resupply subsystem will include the tankage, mounting hardware, conditioning, thermal control, transfer, monitoring, and control hardware necessary to deliver nitrogen to the Station.

Conceptually, the Integrated Water System will be similar to the nitrogen system. It will contain all the hardware necessary to receive, store, monitor, and control the water supply aboard the Station. The storage system, located in the nodes, will be able to accept water from the orbiter payload bay, the Space Transportation System water scavenging system, and the ECLSS.

The Integrated Waste Fluid System will consist of a collection/distribution subsystem, a storage subsystem, and a vacuum vent subsystem. To accommodate gas mixtures and water, these subsystems will contain all the hardware and software required to provide for fluid transfer, storage, conditioning, disposal, control, and monitoring. The collection/distribution subsystem will receive fluids discarded by the users, transferring them to the storage subsystem or to the vent subsystem. The storage subsystem will receive most of the fluids and will retain them for periodic transfer to the disposal interface. The vacuum vent subsystem will receive a small amount of the fluids for disposal in a location that minimizes contamination of the Station environment.

Man Systems. The Man Systems will provide all the hardware and systems necessary for crew habitation and a productive working environment. They will be distributed throughout the pressurized modules, but most will be in the habitation module. Crew quarters will provide accommodations for sleep, rest, and relaxation. Each crew compartment will have some storage space for clothing and personal equipment, and will be designed to allow crew members to have a private space away from the open area of the habitation module. The open area will contain galley and health care units. The galley will contain all equipment necessary for the preparation of, and clean-up after, meals. Ninety days of consumables and supplies will be stored in the habitation and logistics modules. Safe-haven emergency supplies for 45 days also will be provided.

A health-care subsystem will provide equipment and supplies to support all medical, health care, exercise, and environmental health needs. The Health Maintenance Facility will be installed in a dedicated area, and will be tied into the Data Management System and the Communications and Tracking System. A hyperbaric airlock will be a part of the health-care system. An environmental health subsystem will allow assessment of water quality, air quality, and contamination.

U.S. Polar Orbiting Platform

The U.S. Polar Orbiting Platform will be a self-contained, free-flying spacecraft operating in a sun-synchronous orbit at 90 degrees inclination. It will perform Earth geological and oceanographic observations, lower- and upper-atmospheric monitoring and research, solar observations, and plasma physics measurements.

The U.S. platform will consist of a propulsion module, a primary carrier, and supplemental carriers as required to support user needs. Its approximate diameter will be 14.3 meters (46.9 feet) and its approximate length 12 meters (39.4 feet). The primary and the supplemental carriers will accommodate payloads and orbital replacement units (ORUs) for resources. However, the primary carrier may contain resources not supported by supplemental carriers. It will house all the power generation equipment (solar arrays and drives) and the standard communications and tracking resources. It also will be

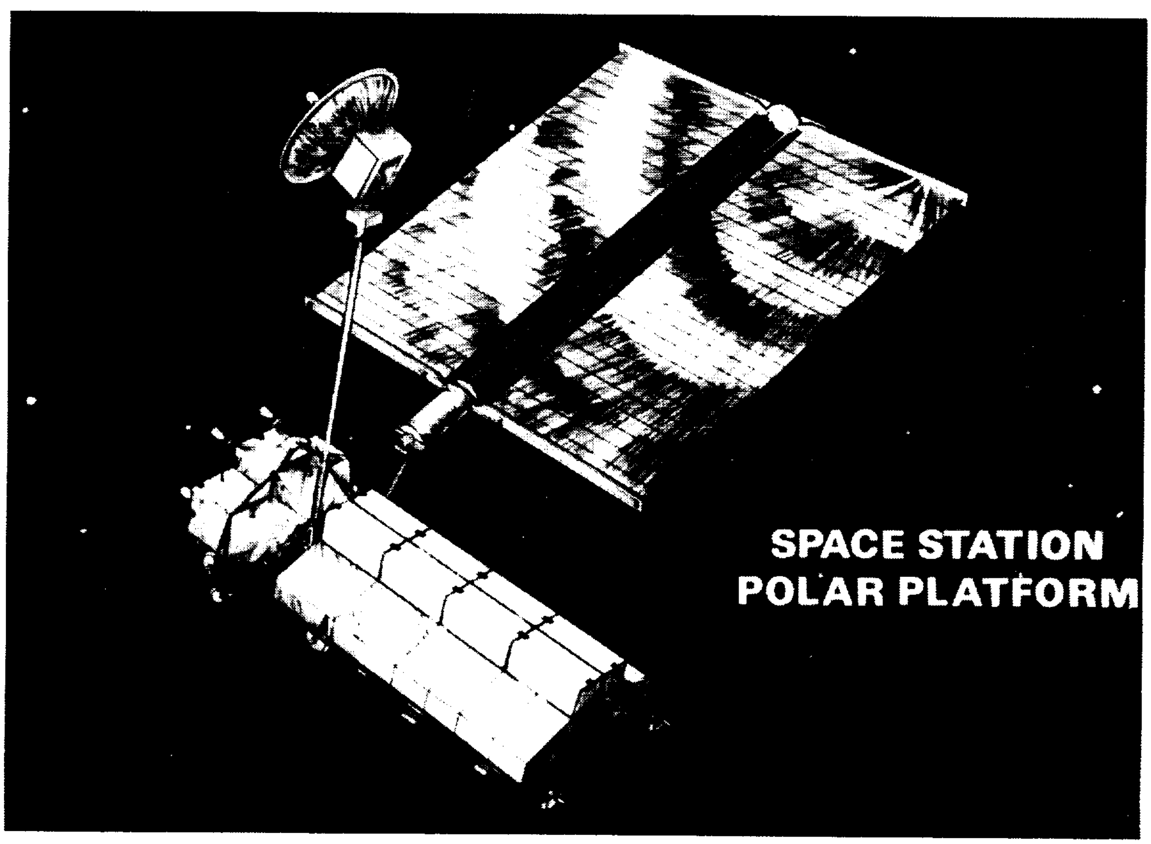

Figure V-9. U.S. Polar Orbiting Platform

the interface to the propulsion module. The supplemental carrier will carry payloads and additional resources, such as batteries and data-storage ORUs. Power and data systems will be distributed across the Platform's carriers. The thermal system of each carrier will be separate, with each one thermally self-sufficient. ESA will fund a polar platform to work together with the U.S. Polar Orbiting Platform.

Space Station Evolution

Planning for Space Station evolution is a strategic management process to facilitate change and protect future decisions. The objective is not to forecast the future, but to understand the future options and the implications of those options on today's decisions. The challenge is to understand the probable evolutionary paths and modes to the extent that current resources can be wisely allocated to the necessary provisions for evolutionary changes (hooks and scars) in the base-line Station and to appropriate technology development efforts. This requires close coupling of evolution planning with mission planning, space and ground infrastructure planning, and technology development, as well as with the design and development activities for the base-line Space Station.

A principal emphasis of current transition-definition activities is identification and definition of hooks and scars to be incorporated into the base-line design. The scope of this task recently has been broadened by a decision to phase the development program and revise the base line. Specific objectives are to:

(1) define user requirements,
(2) define potential growth scenarios and paths,
(3) define optional evolution concepts and the associated hooks and scars, and
(4) analyze those hooks and scars to develop recommendations for the base-line design.

An additional objective is to analyze various subsystems to ensure that their designs can accommodate technology upgrades during the long operational lifetime of the Space Station. Candidate hooks and scars for the base-line design (including technology transparency and advanced automation scars) have been defined, and their locations and characteristics will be selected through the Program Requirements Review process.

Reference Evolutionary Design

In its reference evolutionary design, the Space Station would be expanded to the full "dual-keel" configuration (see Figure V-10) originally conceived. This configuration includes the addition of a solar dynamic power system, upper and lower booms providing additional attached payload accommodations, a servicing bay, and a co-orbiting platform.

The solar dynamic power system would supply an additional 50 kW of power and therefore allow a much larger complement of experiments and payloads. Since the efficiency of dynamic conversion is much higher than that of photovoltaic conversion, a solar dynamic power system can be much smaller than photovoltaic arrays for the same level of power generation in low Earth orbit.

The ability to accommodate attached payloads on the upper and lower booms is an important feature of the dual-keel configuration. In addition to the extra space they provide, the booms offer positioning advantages for certain payloads. The upper boom is an ideal location for astronomical science experiments, and the lower boom is well suited to Earth-science experiments.

The Canadian Mobile Servicing System, partially completed in the base-line program, would be completed in the evolutionary phase. With its completion and the addition of the servicing bay, the Space Station would be fully equipped to service other spacecraft.

The co-orbiting platform would provide a base for additional payloads in low-inclination orbit. The payloads could be moved periodically between the Space Station and the platform by an Orbital Maneuvering Vehicle (OMV) for servicing, or they could be serviced by the OMV remotely from the Station.

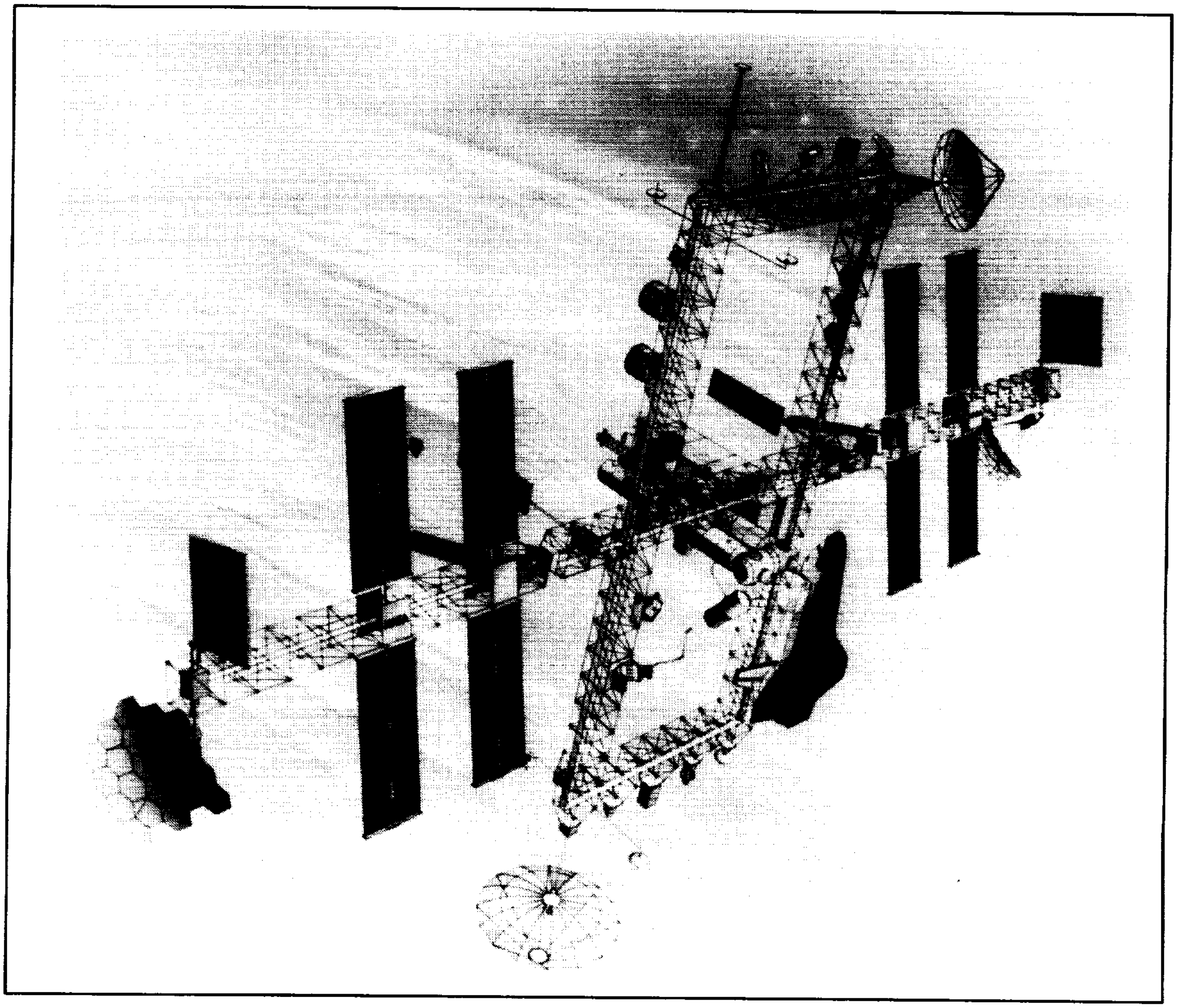

Figure V-10. Space Station Dual Keel Configuration

Additions to the Space Station might include accommodations for a space-based (rather than ground-based) OMV. The number of shuttle launches needed to support the Station and its associated payloads would decrease if the Station were able to repair, service, and refuel the OMV.

Another Station enhancement could be the inclusion of accommodations for a Space Transfer Vehicle able to transport payloads from the Space Station's orbit to geosynchronous orbit, or to propel payloads to Earth escape velocities. The logical extension of this concept is the use of the Station to support robotic and human missions to the moon and the planets.

The Station also may be used to assemble and launch larger and more complex spacecraft than will ever be possible from Earth.

Advanced Studies Program

A central aspect of the strategic planning process for Space Station evolution is the study of paths, modes, and options to support possible new space initiatives. As discussed on page X-4, four new initiatives covering a broad spectrum of future options currently are under study within NASA. Identification and study of such options are central to the Space Station evolution process. Options under study include expansion of multi-discipline Station accommodations, as well as specific growth paths to support new initiatives such as a piloted Mars mission or the establishment of a lunar base. Initially, each option is studied independently to determine the infrastructure required, the technology needs, and the hooks and scars on the base-line Space Station that will enable future exercise of the option. Subsequently, the results of the independent studies are examined as a group in order to identify the high-leverage technologies that must be developed and to identify actions that must be taken now to protect the future options.

Evolution Advanced Development Program

The Evolution Advanced Development program for the Space Station is the technology bridge between the genesis of new technologies and their mature development for use in an evolutionary Space Station.

Within NASA, the Office of Aeronautics and Space Technology (OAST) has primary responsibility for identifying and developing the broad range of new technologies that will enable and enhance future systems such as the Space Station. However, OAST does not in all cases pursue the technology needed for a specific application. Thus, the Space Station Evolution Advanced Development program is responsible for identifying and advocating technologies required for the Space Station's development beyond its base-line configuration so that it can support new national objectives and continue to increase its productivity and capability. Working with OAST and other program offices, this program will both support and advocate the development of selected technologies to a mature state for use in the evolution of the Space Station.

Relationship to Other NASA Offices

The Space Station program is of sufficient scope and breadth to involve nearly all the program offices within the Agency. Its major activities include interaction with the:

(1) Office of Aeronautics and Space Technology for development of technology to support the base-line Space Station and future options for growth and evolution,
(2) Office of Space Science and Applications for definition of science objectives and experiments,
(3) Office of Commercial Programs for identification of the requirements of private industry users,
(4) Office of Space Flight for construction and operational support,
(5) Office of Space Operations for space communications, and
(6) Office of Exploration for definition of future space initiatives involving the Space Station.

The Space Station program serves as the focus and catalyst in bringing to bear the diverse capabilities of NASA to meet the Presidential directive on developing a permanent manned presence in space.

SPACE OPERATIONS

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Space Operations

The Office of Space Operations supports the Nation's aeronautics and space missions by planning, developing, and operating space and ground networks of tracking and data systems. Space Operations supports missions of unmanned and manned orbital spacecraft, deep-space and planetary probes, radio astronomy, sounding rockets, balloons, and research aircraft.

Space Operations Goals

The primary goal of the Office of Space Operations is to provide tracking and data acquisition support to the Nation's space missions. This program plans, develops, and operates the space and Earth-based tracking and data systems required to support the inflight missions of automated and manned orbital spacecraft; deep-space probes, orbiters, and landers; sounding rockets; balloons; and research aircraft. The program comprises four basic elements:

(1) a space network;
(2) a ground network;
(3) the related communications, control, and data systems; and
(4) studies and development of advanced systems.

The first three are operational elements; the last provides the technology base from which future operational elements will be derived. The program also provides responsive management of NASA's program support communications and allocation of the radio frequency spectrum.

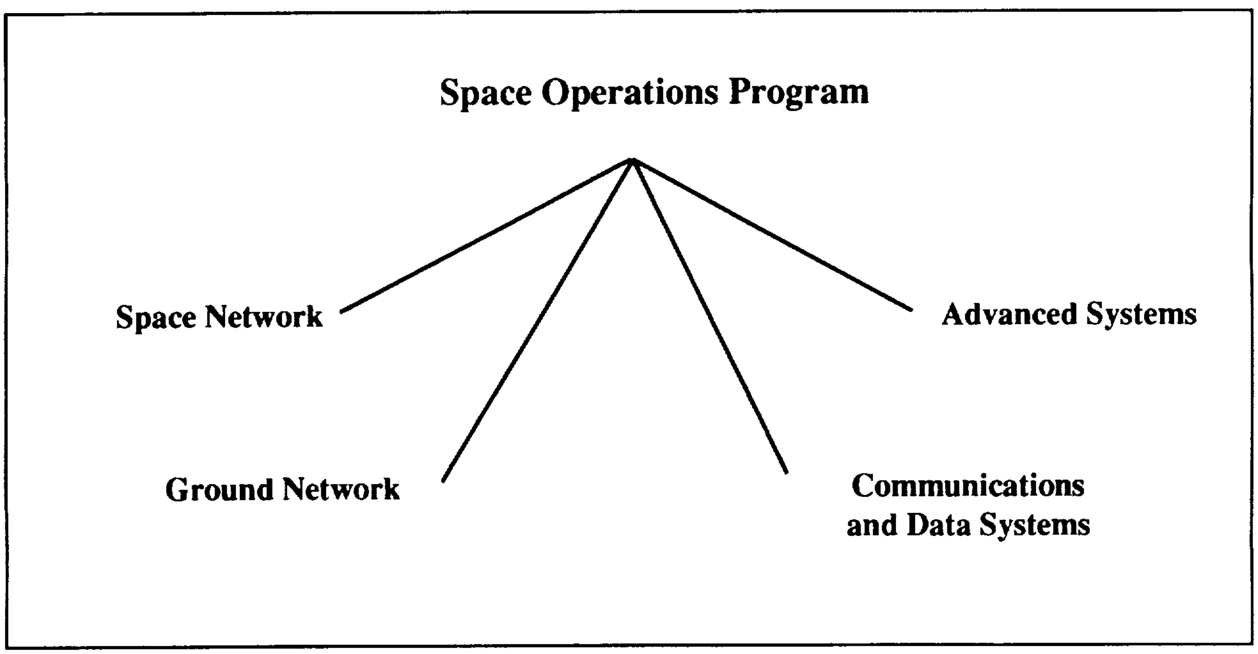

Figure VI-1. Space Operations Program Elements

Space Operations Objectives

Space Network

The Space Operations program's most important objective is to implement the Tracking and Data Relay Satellite System (TDRSS) for full operation. For the combined support workload created by low Earth orbit systems anticipated for the last decade of the century, the space network must have two supporting satellites and an operational spare. The network will require additional satellites as more users are included. An additional space network objective is to plan for a follow-on system for the TDRSS.

Ground Network

Following the phase-down of ground stations in the Spaceflight Tracking and Data Network, the ground network will consist of three Deep Space Network complexes and a minimum of three launch support stations. The objectives of this network are to provide:

(1) tracking and data support for all current and approved deep-space missions and missions in geostationary and high Earth orbits;
(2) launch and limited emergency support for certain missions in low Earth orbit, such as those of the space shuttle; and
(3) continuing support to the aeronautics, sounding rocket, balloon, and geodynamics programs and an increase in the support capacity of the aerodynamics test range.

Communications and Data Systems

Communications and Data Systems objectives are to:

(1) improve efficiency and economy in processing large volumes of data;
(2) upgrade the communications support capability of NASCOM (the NASA network of communications services for operational data flow between stations, control facilities, and users) to meet the demands of NASA missions with high data rates;
(3) provide support for controlling new space systems, including the Hubble Space Telescope; and
(4) improve, and increase the efficiency of, NASA's program support communications.

Other Objectives

Other important objectives for Space Operations are to:

(1) develop technology to facilitate use of the space network, and
(2) participate in the definition of Space Station requirements and prepare for support of the Space Station.

NASA Communications (NASCOM)

NASCOM is a generic term referring collectively to a global system of switching, terminal, and control facilities and circuits established and operated by NASA. NASCOM provides operational communications support to all NASA projects, including switching, multiplexing/demultiplexing, data communications, TV or analog sensor data transport, voice communications, and teletype communications.

NASCOM technical control facilities aid in scheduling, configuring, and reconfiguring of circuits and system components. It also aids in troubleshooting, monitoring, and expediting restoration of circuits. NASCOM also provides for data systems using voice bandwidth channels.

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Space Operations Current and Planned Program Elements

Space Network Program Elements

From the current network of ground tracking stations located around the world, NASA's tracking and data acquisition facilities that serve spacecraft in near Earth orbit will be replaced initially with a network of two TDRSS satellites in geostationary orbit, an on-orbit spare, and a single ground terminal at White Sands, New Mexico. That network configuration will evolve to include up to four operational TDRSS satellites. A single satellite currently is operating in Earth orbit; the system is expected to become fully operational in 1989 with launch of the next two satellites. To avoid a single-point failure in the space network system, NASA has colocated a communications terminal to interface with the TDRSS ground terminal at White Sands. The Space Network Control Center at Goddard Space Flight Center manages network resources. The space network system will achieve extensive coverage of near-Earth orbits: approximately 85 percent compared with the 15 percent provided by the ground stations. Therefore, even with a majority of ground stations phased out, space systems using TDRSS — including the space shuttle, Spacelab, and Hubble Space Telescope — will be able to communicate with their mission control centers almost continuously, if necessary.

The capabilities of the Space Network will be augmented in the 1990s. Support of current missions will continue, and expected increases in the number of spacecraft transmitting wideband data will demand more capability than the present four single-access relay links

Figure VI-2. Tracking and Data Relay Satellite System

Tracking and Data Relay Satellite System (TDRSS)

NASA's near-Earth orbit tracking and data acquisition activities are evolving from a network of ground stations located in the United States and around the world to a network based upon geosynchronous orbit. Satellites and their associated ground terminals constitute the Tracking and Data Relay Satellite System (TDRSS), whose services are leased from the Space Communications Company. The NASA TDRSS network includes the satellites and a number of supporting ground elements, configured to meet the tracking and data acquisition requirements for a variety of Earth-orbiting spaceflight missions.

Figure VI-2 shows a TDRSS satellite relaying data from the Hubble Space Telescope to the Space Telescope Science Institute in Baltimore, Maryland, via the tracking and data relay satellite terminal at White Sands, New Mexico, a domestic satellite, and Goddard Space Flight Center's network control center .

can provide. Therefore, plans are to replace the Tracking and Data Relay Satellites at the end of their useful lives, to increase the number of operating orbital spacecraft, and to increase the capacity for data capture, processing, and distribution on the ground. The interim requirements of the Space Station are expected to remain within the data rate capabilities of the current Tracking and Data Relay Satellite.

Ground Network Program Elements

NASA will close the Hawaii, Ascension, Dakar, Guam, and Yarragadee ground stations while phasing TDRSS into operation. After this phasing out of most of the ground stations in the Spaceflight Tracking and Data Network, the ground network will consist of three Deep Space Network (see inset on page VI-8) complexes, managed by the Jet Propulsion Laboratory, and at least three launch support stations. The network will continue to support deep-space activities and spacecraft not compatible with TDRSS. The major objective of the network will be to provide tracking and data support for all current and approved deep-space missions and missions in high Earth and geostationary orbits, as well as backup support for certain missions in low Earth orbit such as the space shuttle and the Hubble Space Telescope. The Deep Space Network is shown in Figure VI-3.

Even though several of the ground stations will be phased out when TDRSS becomes fully operational, the role of the ground network in support of NASA's space program will increase significantly. The Deep Space Network is being enhanced to provide support to Voyager's 1989 encounter with the planet Neptune (see page III-50). The enhancements will also support the resurgence of deep-space exploration activity beginning in 1989, including the Galileo mission to Jupiter (see page III-52), Magellan's mapping of the surface of Venus (see page III-54), the Ulysses exploration of solar out-of-ecliptic regions (see page III-65), and the radar mapping by Mars Observer (see page III-53). The solar system radar at Goldstone, California, will be upgraded to one megawatt to map the surface of Venus, study the rings of Saturn, and search for near-Earth asteroids and other celestial bodies.

Aeronautics, Balloons, and Sounding Rockets

To sustain NASA's flight tests aboard sounding rockets, research aircraft, and balloons, the Space Operations program includes a phased activity to upgrade and replace equipment for the domestic and mobile tracking and data acquisition facilities operated by NASA's Wallops Flight Facility and Dryden Flight Research Facility. The program includes: development at Dryden of a capability to support multiple missions; tracking and data acquisition support for the National Scientific Balloon Facility at Palestine, Texas; and improvement of the impact prediction system and fixed radar capabilities at Wallops.

Deep Space Network (DSN)

The DSN consists of multimission telecommunications and radiometric data facilities used to support NASA's exploration of space, research in space science, and advanced technology investigations. The network supports spacecraft in deep space and high Earth orbits that are outside the view constraints of TDRSS. It also provides transfer orbit injection support for some missions, support for existing missions not compatible with TDRSS, and space shuttle landing support. The DSN has facilities located on three continents, with tracking complexes located about 120 degrees (in longitude) apart, providing nearly continuous coverage of spacecraft at ranges of several thousand kilometers and beyond. These facilities are located at Goldstone, California; Madrid, Spain; and Canberra, Australia.

The DSN's basic services are:

(1) reception of telemetry from and transmission of commands to spacecraft;
(2) measurement of radiometric data for spacecraft navigation and radio science measurements; and
(3) use of the available radio links to probe the media and determine effects that characterize fields, particles, and objects in the path between Earth and the spacecraft.

The DSN additionally supports tasks requiring similar capabilities, such as radio astronomy, searches for extraterrestrial intelligence, and solar system radar studies.

Communications and Data Systems Program Elements

New flight missions and science instruments will be accompanied by a substantial increase in the rates and volumes of data to be transferred and processed. Cost effectiveness and improvements will be obtained through actions such as the following:

(1) increased electronic transfer of data at the higher data rates needed, to reduce the need for human intervention and tape handling;
(2) automated alerts and alarms;
(3) control of data quality and use of data standards; and
(4) standard data formation and labeling among data bases.

Replacement of aged and obsolete computing systems for mission support will continue to reduce downtime and maintenance costs. Increased use of microprocessors will improve quality and efficiency.

In 1988, mission scheduling and control systems will be ready to support the launch of the Hubble Space Telescope. The corresponding Space Telescope Control Center in shown in Figure VI-4. Current programs will also provide mission control systems for new spacecraft such as the Upper Atmosphere Research Satellite (see page III-33), the International Solar Terrestrial Physics program satellites (see page III-62), the Gamma Ray Observatory (see page III-17), and the Cosmic Background Explorer (see page III-18). The trend toward increased automation of control facilities will continue and will be treated as a factor in studies of the architecture for the Space Station's data system. Support of Space Station platforms in the 1990s will be a major step forward in expanding the capacity of communications and data systems.

Currently, most of NASCOM's circuits can accommodate data rates as high as 50 megabits per second. To meet future requirements for even higher data rates (i.e., hundreds of megabits), plans for NASCOM include

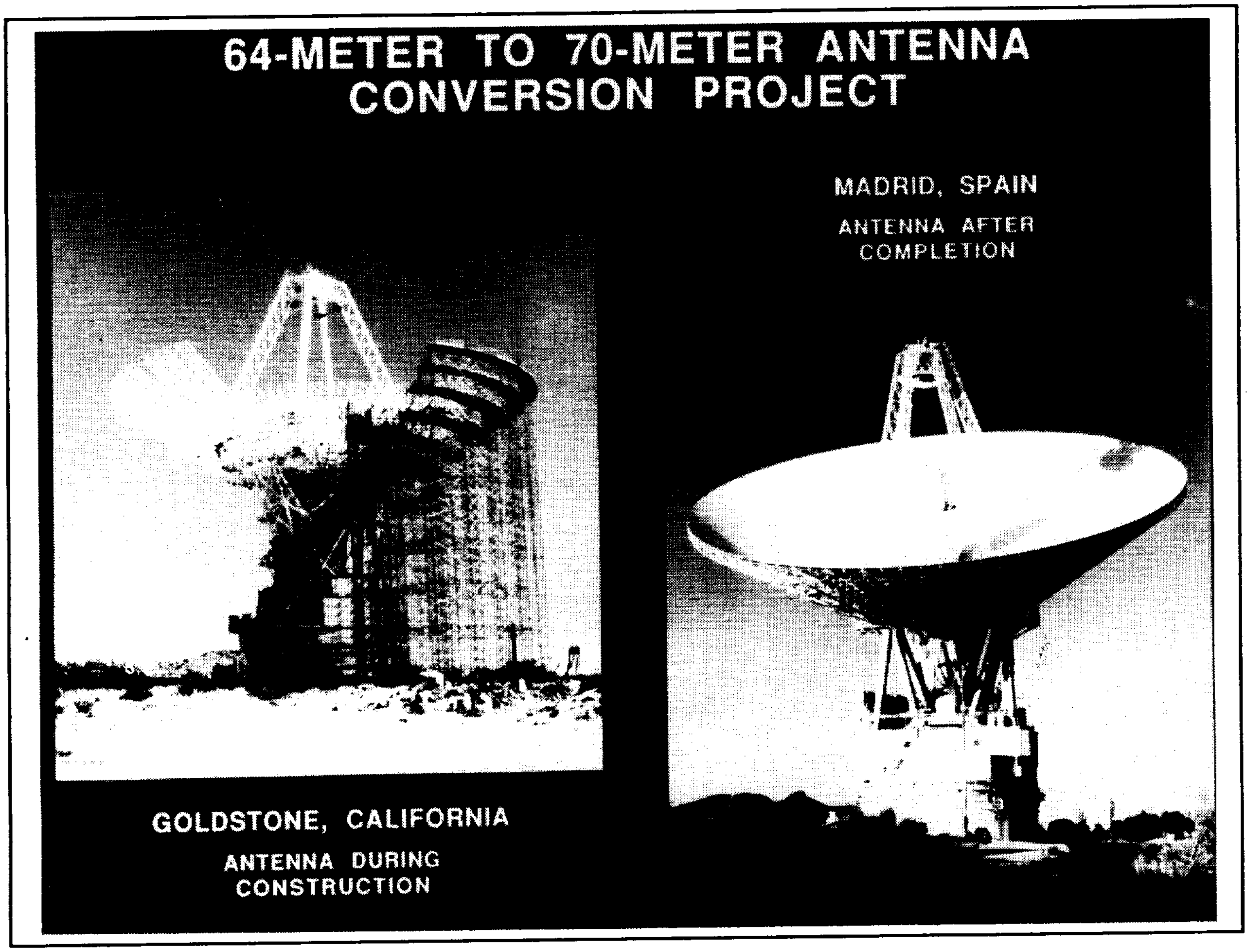


Figure VI-3. Deep Space Network (DSN)

digital voice circuits, satellite links from overseas stations, greater use of fiber optics for local links between NASCOM and satellite ground terminals, and store-and-forward remote facilities that will complement direct satellite paths from network stations to user centers. Also, NASA will introduce into NASCOM during the next two to three years a capability for dynamically assigning bandwidth among remote locations as a function of their changing demands.

Continued growth will be maintained within the Program Support Communications Network, which handles the more routine administrative communications. This growth will include a greater capacity for video teleconferencing, data transfer, and nodal connectivity.

Figure VI-4. Space Telescope Control Center

Advanced Systems Program Elements

The Advanced Systems program, a relatively small but vital portion of the total Space Operations program, consists of studies and developments in advanced technology. It provides a base for future planning and for development of cost-effective support capabilities. The program recognizes the dramatic changes taking place in telecommunications and computer technology and the ever increasing need to assess and apply advances in those areas to improve tracking and data acquisition capabilities for future missions. The following are examples of the objectives of the Advanced Systems program:

(1) increase the ability to communicate with spacecraft, using means such as a 34-meter diameter K-band antenna for deep-space missions and millimeter waves and optics for telecommunications;
(2) improve navigation capability, using the Global Positioning System to track Earth-orbiting missions with decimeter precision;
(3) develop techniques for using ground-based navigation systems to measure the angular directions of deep-space missions to an accuracy of 5 nanoradians;
(4) improve ground station and data handling and processing operations, using automation and new technologies such as custom VLSI (Very Large Scale Integration); and
(5) develop technology, such as that for onboard recorders with high-data-rate, steerable-beam antennas, that will facilitate TDRSS use.

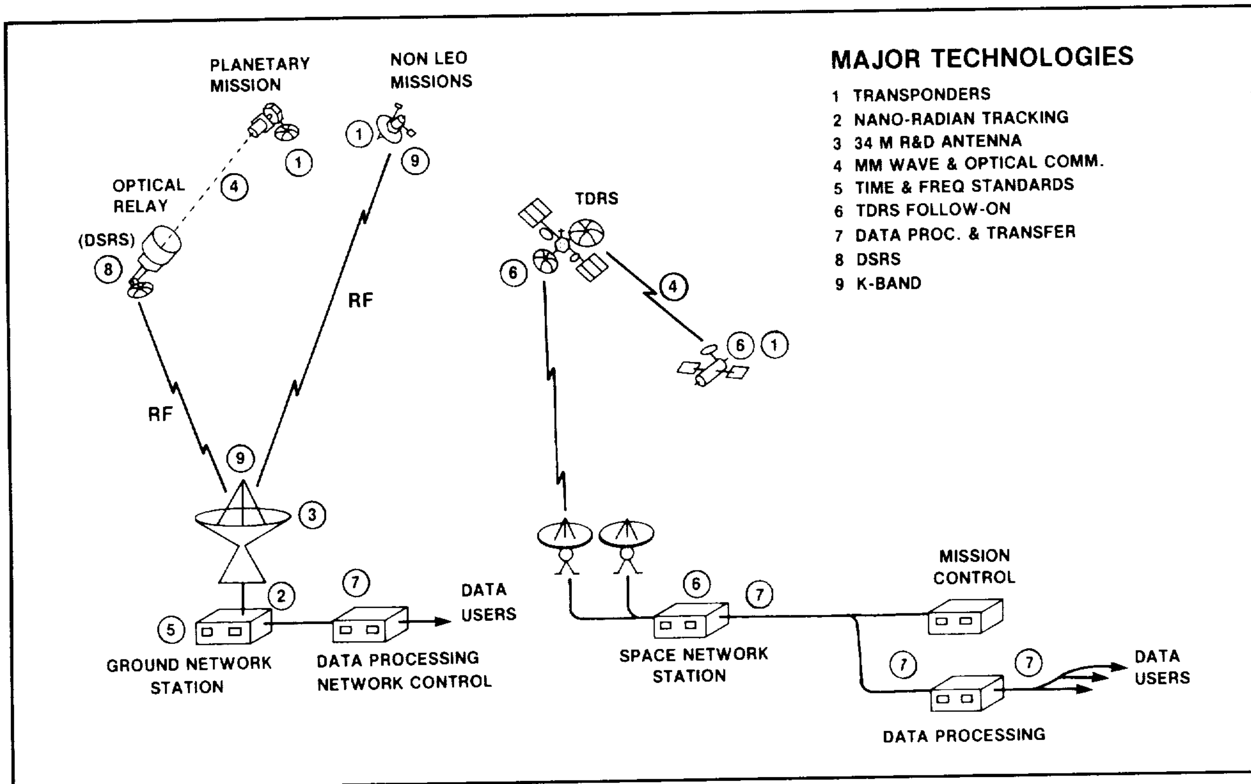


Figure VI-5. Advanced Systems Activities

Tracking and Data Acquisition System for the 1990s

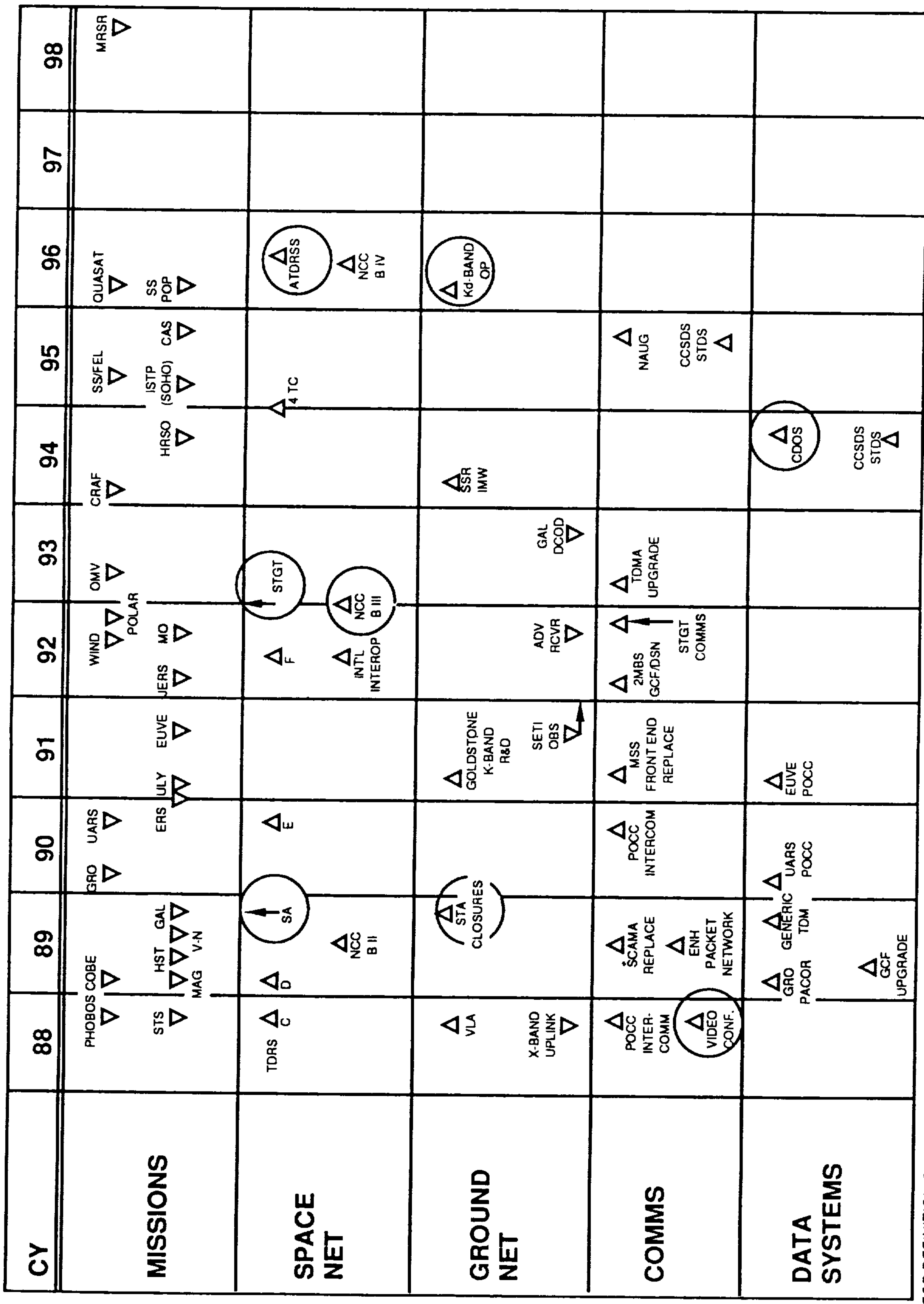
The TDRSS, including needed replacement satellites, is expected to meet the requirements of the space program through most of the 1990s. However, increases in the volume of data that missions will generate after the 1990s will require greater capabilities in the space network. Under consideration for the next-generation system, the Advanced Tracking and Data Acquisition System, are more links, data rates of gigabits per second, a relay-spacecraft to relay-spacecraft link, direct relay-to-ground links, and ground-station automation with distributed command management. Long lead-time technology and functional designs are under study, with the objective of initiating systems definition in the early 1990s.

Orbiting Deep Space Relay Station

Rapid advances in telecommunications technology are expected to have a profound effect on tracking and data acquisition support of deep-space missions in the next decades. For example, a deep-space relay satellite in geostationary orbit using an outward-looking optical receiver may increase dramatically the information and science return from NASA's planetary missions. The Space Operations program will continue to examine the feasibility of promising concepts and will study technologies and tradeoffs for such relay satellites.

Summary

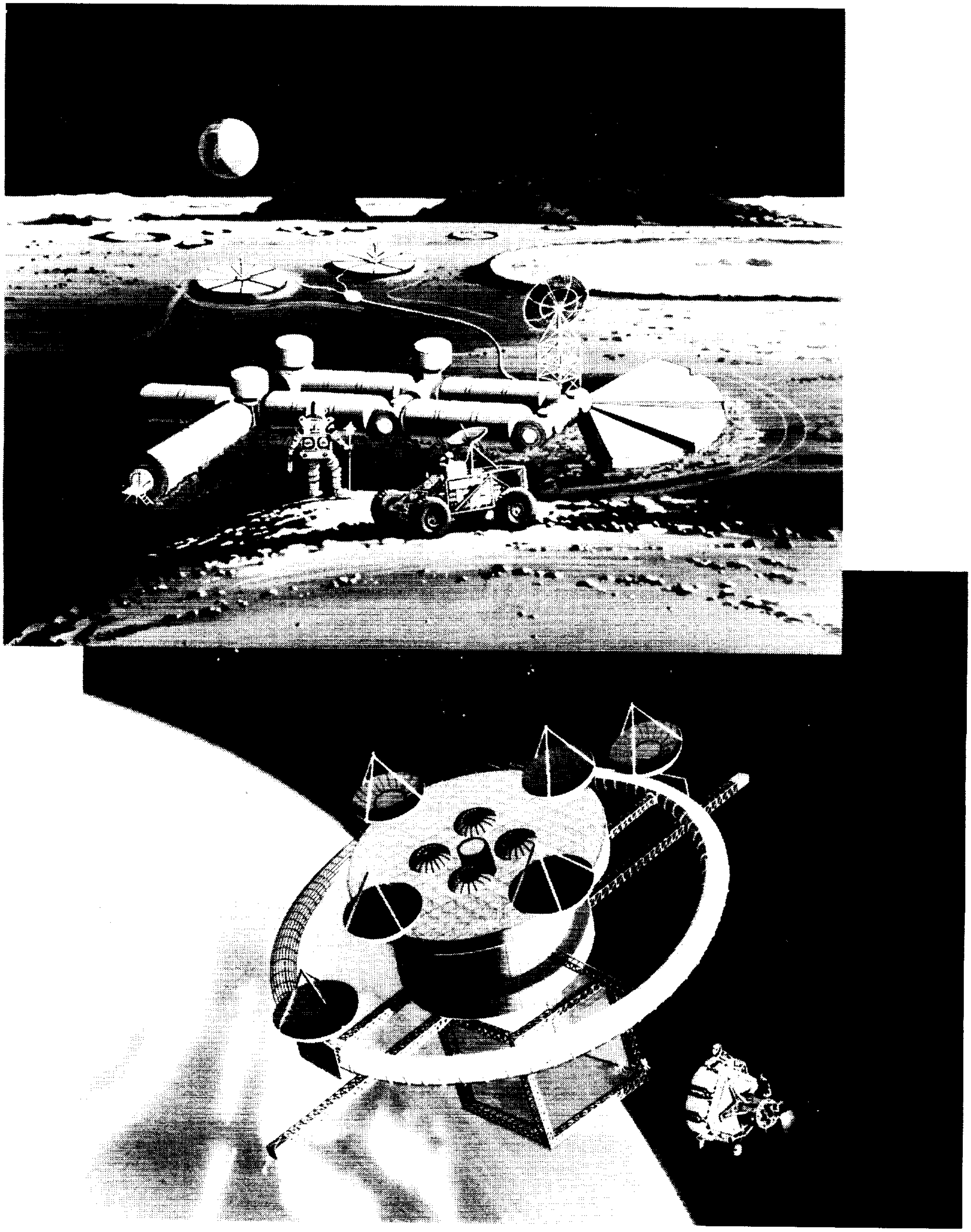
The Office of Space Operations planning schedule for the activities described above is summarized in Figure VI-6, which relates the planned developments to the Agency's mission field.



FOR DEFINITION OF ACRONYMS, SEE CHAPTER XI

Figure VI-6. Space Operations Planning Schedule

SPACE RESEARCH AND TECHNOLOGY



Space Research and Technology

The Office of Aeronautics and Space Technology conducts the Space Research and Technology program to provide advanced technology in support of continued U.S. leadership and security in space. This program provides the wellspring of innovative and fundamental research for the future space missions that will achieve the goals of the new National Space Policy. Within the program, high leverage technological concepts are brought to the level of demonstrating proof of principle. The program also acts as a seedbed for generating more highly mission-focused advanced development programs.

Introduction

The Space Research and Technology program, conducted by the Office of Aeronautics and Space Technology, consists of the Research and Technology Base and Focused Technology programs. This relationship is shown in Figure VII-1, where the elements of both subprograms are listed.

The Research and Technology Base program is a fundamental effort that provides research in emerging technologies and feasibility exploration, including proof-of-concept verification.

The current focused technology program, the Civil Space Technology Initiative (CSTI), is intended to fill critical technological gaps and to restore and enhance the Agency's and the Nation's technical strength. CSTI, created in FY 1988, is the first major focused Space Research and Technology program intended to deliver

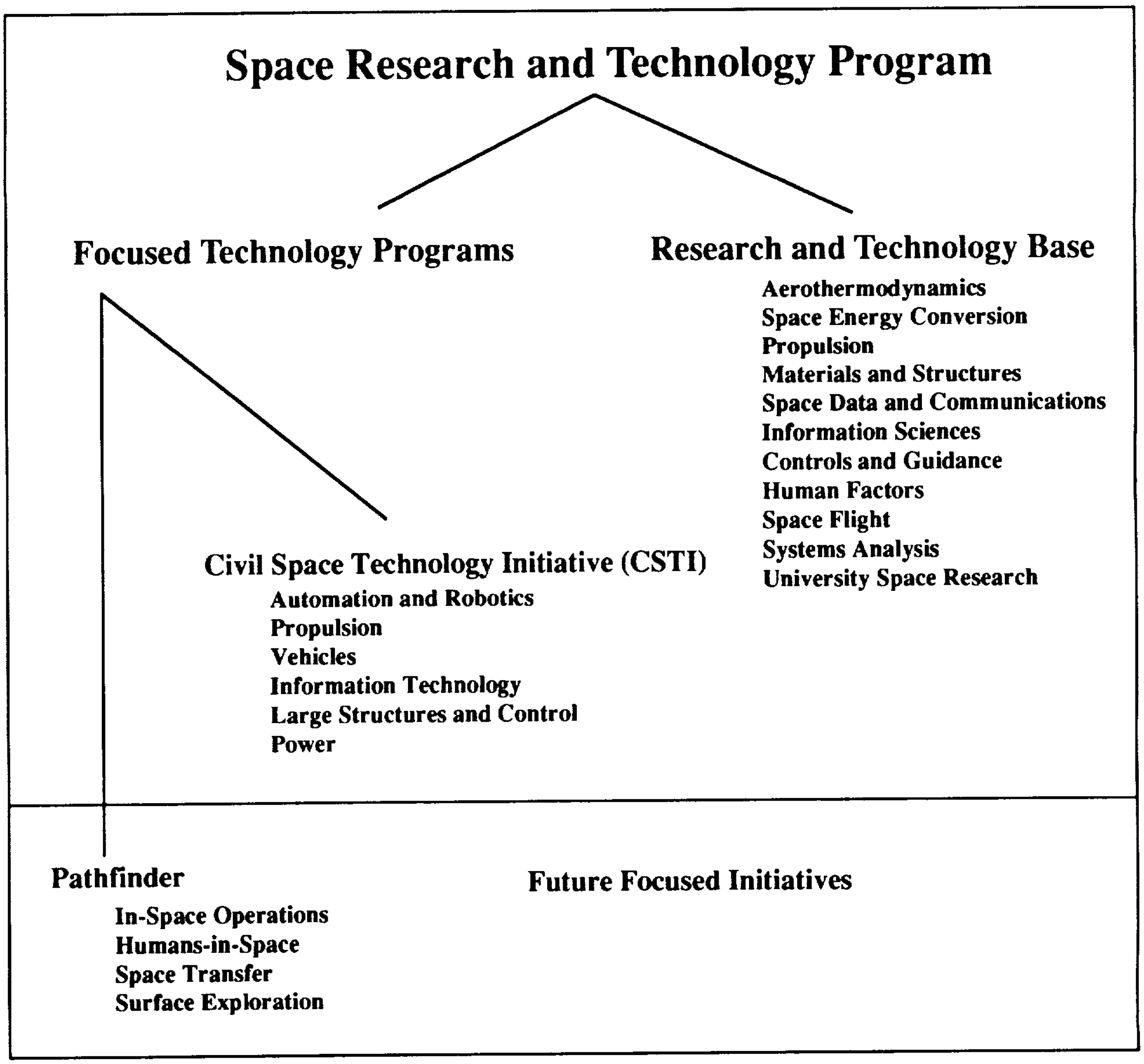


Figure VII-1. Space Research and Technology Program Elements

products in the form of proven hardware, software, and design techniques and data to flight system users. As a future augmentation to the CSTI, the Pathfinder initiative will provide the technologies to enable bold missions beyond Earth's orbit. These focused programs are developed and implemented with the participation of the user program offices.

Mission

The overall mission of the Space Research and Technology program is to provide advanced technology that contributes materially to continued U.S. leadership and security in space. This mission directly supports the goals of the new National Space Policy recently announced by President Reagan (see page II-7). It also requires a commitment to maintaining the Agency's research and technical strengths in the engineering sciences and disciplines required for future national programs in the exploration and exploitation of space. Advancements in technology are essential for the design, development, and operation of future space systems and missions, including those for transportation, spacecraft, platforms, stations, outposts, and bases. The technology also is intended to serve the long-term needs of other civil, commercial, and military uses of space.

Goals and Objectives

The primary goal of the Space Research and Technology program is to provide enabling technologies, validated at a level suitable for user-readiness, for future national space missions. This goal, established as a framework for the development of the technical program areas, is directed at maintaining the relevance of Space Research and Technology activities to Agency missions and to improving the effectiveness of technology transition to flight program use.

Two corollary goals accompany the above principal goal:

(1) ensure that the external community contributes to and benefits from the Agency's technology development role by increasing cooperative programs with industry, universities, other civil agencies, commercial users, and the Department of Defense; and
(2) become the national focal point for in-space engineering research and technology.

The first corollary goal addresses interactive mechanisms through which collaborative planning and joint activities are carried out. The second corollary goal addresses continuing use of the capability to conduct research and technology in space, use of the shuttle, use of other space platforms, and eventual use of the Space Station, which can serve as a national space-based engineering research and technology laboratory.

The program objective involved in realizing the primary goal is to identify and develop selected technologies critical for enabling specific priority missions or for establishing an important capability. This overall objective gives rise to the specific objectives shown in Table VII-1 associated with the primary goal. Table VII-1 also lists the specific objectives for both subgoals. The specific objectives for the primary and corollary goals guided the development of the current program plan described below.

Table VII-1. Space Research and Technology Goals and Objectives

Goals	Objectives
Primary Goal Provide enabling technologies, validated at a level suitable for user-readiness, for future national space missions.	(1) Conduct continuing studies and analyses to identify technology needs and opportunities for major national programs; (2) develop necessary programs, and maintain a model set of technology driver missions to provide a planning focus; (3) ensure a vigorous and innovative research and technology program including exploratory research and mission-enabling research; (4) effectively transfer technology to mission application through focused programs, such as the Civil Space Technology Initiative and Pathfinder, and (5) establish an in-space engineering research and technology program to exploit a growing space infrastructure containing, for example, Space Station.
Corollary Goal 1 Ensure that the external community contributes to and benefits from the Agency's technology development role by increasing cooperative programs with industry, universities, other civil agencies, commercial users, and the Department of Defense.	(1) Provide access to NASA's ground and in-space facilities for use by industry, universities, other civil agencies, commercial users, and the DOD in the conduct of space research and technology; (2) maintain a continuing University Design Program to provide academia the opportunities to understand and contribute to NASA's future missions and technology needs and research opportunities; (3) expand university centers of space engineering research and technology in areas of national technology needs to provide opportunity for collaborative research efforts among NASA, universities, and industry; (4) maintain a vigorous DOD interdependency activity through the Research and Technology Panel of the Aeronautics and Astronautics Coordinating Board and the NASA/USAF Space Technology Interdependency Group; and (5) pursue joint research and technology projects with the DOD in technology areas, with initial emphasis on support of advanced space transportation systems.
Corollary Goal 2 Become the national focal point for in-space engineering research and technology.	(1) Exploit the use of the space shuttle to perform in-space research; (2) conduct major new in-space R&T efforts, as related to CSTI and the planned Pathfinder program, such as those related to control of flexible structures, the aeroassist flight experiment, and the cryogenic fluid management flight experiment; (3) establish a national leadership role for Space Station-based in-space engineering research and technology programs; (4) identify opportunities for and conduct cooperative in-space research programs with industry, universities, and other national agencies; and (5) explore and conduct with foreign space agencies, on a mutually beneficial basis, cooperative in-space research programs.

Strategy

Because it can take as long as 20 years to develop and apply a new technology, a long-range mission model is used to help focus the Space Research and Technology program. The mission model, derived from the Agency's Space Systems Technology Model and validated by flight program managers, consolidates forecast technology trends, estimated user needs, and projected budgets. Figure VII-2 shows this mission model. Systems analysis studies of the depicted missions are conducted to identify needs and opportunities for developments in enhancing and enabling technologies. The disciplinary priorities for technology development programs are based on these system analyses.

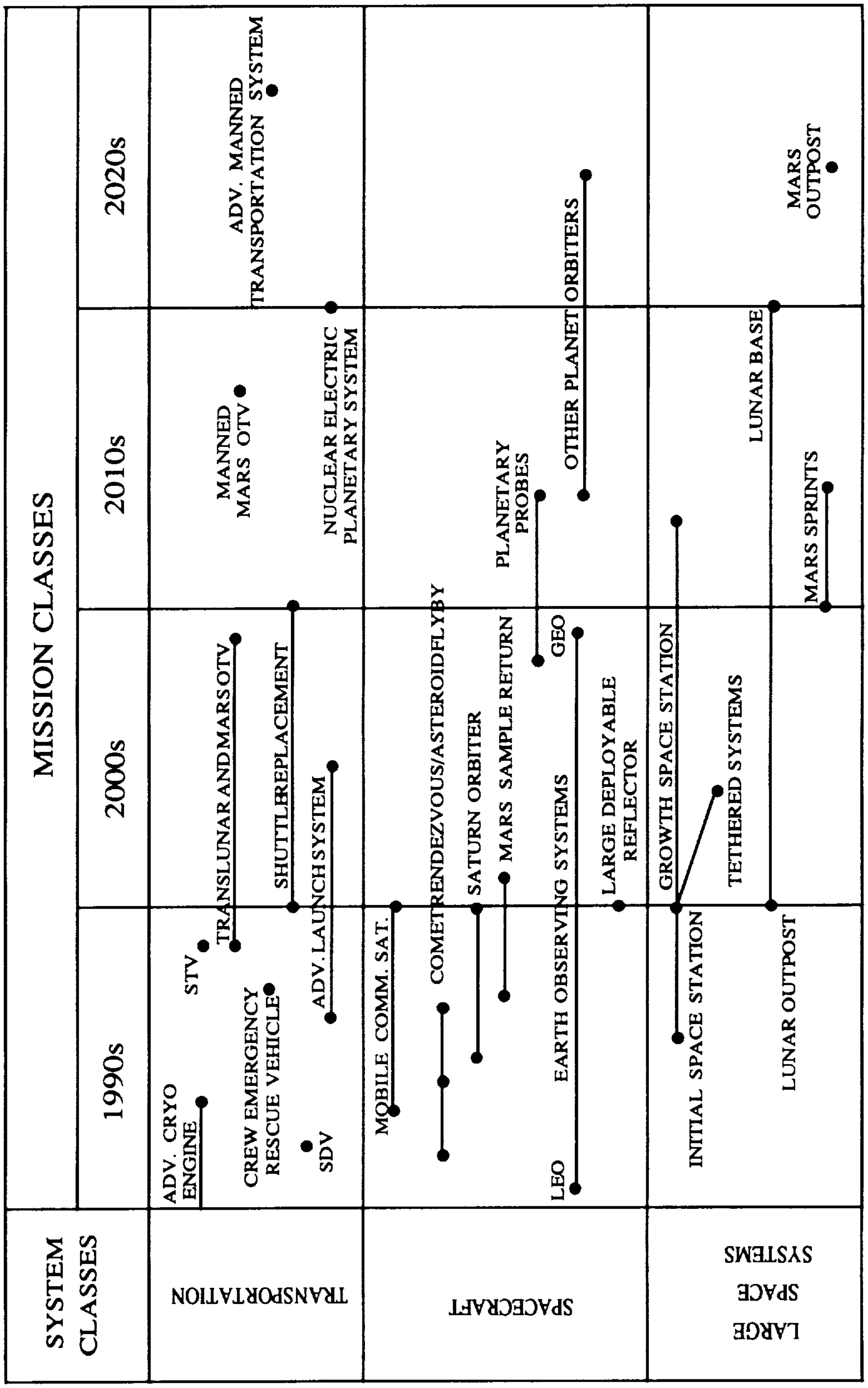
To provide the scope and direction for its programs, the Space Research and Technology plan is developed around three classes of systems: Space Transportation Systems, Spacecraft Systems, and Large Space Systems/ Space Infrastructure. Each mission in the long-range mission model is assigned to one of these system classes.

Space Systems Technology Model

The NASA Space Systems Technology Model is a compilation of anticipated NASA system and program requirements, technology trends, and forecasts for space technology. It is a reference for use in identifying technologies required for future missions, planning and assessing space research and technology programs, and forecasting the availability of technology for use in mission planning. The system technology needs and requirements it presents do not constitute official agency plans. However, it contains a broad menu of candidate and opportunity missions and programs unconstrained by current funding expectations and, therefore, is a valuable source document for NASA's long-range planning.

The Model summarizes NASA mission and payload systems under consideration for implementation. It identifies NASA programs and includes system and program objectives, start and launch dates, and system-level performance requirements. It also contains an overview of trends, and it forecasts the availability of space technology. It quantifies current and projected capabilities in the form of figures of merit for each technology discipline of interest. It compares the projected capabilities with future system needs and highlights critical technologies needed for near-term and far-term space missions that are under consideration. Trends and forecasts in this data base are drawn from throughout the U.S. space community, both civil and military. In addition, the Air Force produces a classified technology plan that provides comparable information for military space systems.

The Model's data base is updated annually and is maintained in two forms: printed reports and computer files. In printed form, it occupies three volumes that, although intended primarily for use by NASA mission planners and technologists, also is available in a limited number of copies to serve other government agencies. The computer files reside in the VAX computer system at NASA Headquarters. Those files contain more complete information than the reports do on mission and payload systems and technology trends and forecasts. Access to the data base in the VAX may be requested from the Office of Aeronautics and Space Technology by U.S. government agencies, industry, and universities that have VAX-compatible remote terminals and can justify adequately their need for access.



ADV = Advanced
GEO = Geosynchronous Earth Orbit
LEO = Low Earth Orbit

OTV = Orbital Transfer Vehicle
SDV = Shuttle Derived Vehicle
STV = Space Transfer Vehicle

Figure VII-2. Space Systems Mission Model

Space Transportation Systems

Low-cost access to space is the key to realization of the Nation's space objectives. A mixed fleet of transportation vehicles will be required to move people and cargo. It must be able to:

(1) provide rapid and flexible access to and from the Space Station;
(2) place heavy payloads in low Earth orbit;
(3) deploy and service satellites in both low Earth and geosynchronous orbits;
(4) serve polar platforms;
(5) provide rapid, routine, manned access to the Nation's space facilities; and
(6) provide a highly reliable space transport and return capability for piloted and robotic solar system exploration missions.

In order to reduce significantly the cost of access to space, the mixed fleet of transportation systems must be robust, operationally simple, and flexible. The vehicles in the fleet also must provide the building blocks for a future lunar and planetary transportation infrastructure. Major advances are required in technology areas such as:

(1) more efficient vehicle structures;
(2) more efficient propulsion systems and airbraking techniques;
(3) lighter weight and more durable thermal protection systems and materials;
(4) lightweight and long-life cryogenic tankage;
(5) autonomous systems to reduce the cost of both ground- and space-based operations;
(6) improved ability to predict aerodynamic and aerothermodynamic characteristics, and thereby to increase vehicle margins; and
(7) adaptive guidance, navigation, and control systems to provide reduced sensitivity to launch changes.

Spacecraft Systems

The potential users of spacecraft technology include space science and applications missions, such as planetary exploration, astrophysics, Earth science, space physics, and communications missions, as well as a spectrum of national security and commercial missions. In the next 20 years, spacecraft will (in addition to other activities):

(1) make the initial observations of comets and asteroids;
(2) provide a continuous multispectral inventory of Earth processes;
(3) return samples from the surface of Mars, comets, and asteroids;
(4) record the birth and processes of stars and galaxies; and
(5) maintain a national preeminence in space communications.

The technology challenge is to enable the development and operation of these diverse spacecraft in an affordable manner.

Large Space Systems/Space Infrastructure

With its deployment and operation in the mid-1990s, the permanently manned Space Station will become the cornerstone for an expanding space infrastructure. The principal elements of its infrastructure may include:

(1) the evolutionary Space Station in low Earth orbit, complemented by co-orbiting man-tended platforms;
(2) man-tended platforms in polar low Earth orbits and geosynchronous Earth orbits;
(3) advanced Earth-to-orbit launch vehicles; and
(4) space-based, reusable orbit transfer vehicles.

Collectively, this infrastructure can be thought of in terms of "facilities" linked by communication and transportation systems. A detailed discussion of the Space Station program can be found in Chapter V.

Space operations, in support of this infrastructure, will include:

(1) scientific research;
(2) technology development;
(3) engineering demonstrations;
(4) assembly of large space structures;
(5) spacecraft inspection, servicing, and repair;
(6) transportation system operations, including cargo management, payload integration, payload deployment, and space-based launching; and
(7) commercial ventures, such as materials processing.

Ultimately this infrastructure will contain systems essential to expanded human operations in the solar system, including a lunar-base mission and a manned Mars mission.

Current Program Plan

Research and Technology Base

The Space Research and Technology base is structured around the following disciplinary elements:

(1) aerothermodynamics,
(2) space energy conversion,
(3) propulsion,
(4) materials and structures,
(5) space data and communciations,
(6) information sciences,
(7) controls and guidance,
(8) human factors,
(9) space flight,
(10) systems analysis, and
(11) university space research.

Aerothermodynamics. The Aerothermodynamics program develops and validates a predictive capability for use in optimizing the performance of advanced vehicles entering and maneuvering in the atmospheres of Earth and the other solar system planets. The principal requirements are for aeroassisted orbital transfer vehicles (OTVs designed to employ aerobraking; i.e., employment of planetary atmospheres to achieve deceleration), advanced space transportation systems such as rocket and air-breathing advanced shuttle vehicles, and reusable heavy-lift launch vehicles. The program is seeking to achieve the following:

(1) development of advanced numerical algorithms for the whole range of continuum, transitional, and rarefied flow regimes;
(2) development of accurate and detailed finite-rate chemistry and turbulent flow models;
(3) establishment of benchmark-quality experimental data for code validation and verification;
(4) correlation of calculations with experimental data from ground tests and flight (shuttle orbiter) experiments;
(5) establishment of a detailed aerothermal-loads data base and development of integrated analysis techniques; and
(6) provision of an integrated aerospace-vehicle design and analysis capability to support future vehicle and mission requirements.

Space Energy Conversion. For large manned space systems, small Earth-orbiting and planetary-exploration spacecraft, and other ambitious future space missions, the Space Energy Conversion program explores concepts and components to:

(1) improve the performance,
(2) extend the lifetime,
(3) increase the cost-effectiveness, and
(4) reduce the size and weight of power and life support systems.

This program provides the fundamental understanding and the technology basis for development of future space power systems ranging from those for spacecraft requiring only low power levels to those for large space systems requiring high-capacity, non-nuclear power. Technology development for photovoltaic power will focus on improving the efficiency and reducing the degradation rate of photovoltaic cells through improvment of designs and materials. Technologies related to high-efficiency thermal-to-electric conversion, high-temperature thermal storage, and lightweight high-concentration-ratio solar collectors are being developed for solar dynamic systems. The goal is to provide a 25-percent reduction in collector area and a substantial reduction in weight in comparison with current high-capacity systems.

Propulsion. The Propulsion program establishes a base of design concepts and analytical tools that will allow the design and development of advanced propulsion systems with the known performance, life, and operational characteristics essential for next-generation space transportation systems. This base will reduce the risk of costly, unanticipated design deficiencies and schedule delays during the development and certification of flight hardware. The activities of this program include the following:

(1) developing a broad base of knowledge in, and a sound understanding of, the area of predicting and extending the life of reusable engine components;
(2) improving the models in use for studying the performance, stability, heat transfer, and cooling involved in high-pressure ignition and combustion;
(3) developing unique, non-intrusive, diagnostic sensors for use in systems for monitoring and controlling interactive engine conditions;
(4) establishing an understanding of the chemical and physical processes associated with very high performance, low-thrust propulsion systems, as well as developing corrosion-resistant high-temperature materials necessary for achieving extremely long life and reliability; and
(5) evaluating potential breakthrough propulsion concepts and related research and technology issues that could lead to quantum leaps in future propulsion capabilities.

Materials and Structures. The Materials and Structures program provides technology that will allow development of spacecraft, large-area space structures, and advanced space transportation systems with significant improvements in performance, efficiency, durability, and economy. For materials, the major technical areas of emphasis include the following:

(1) fundamental understanding of the properties and behavior of advanced space materials,
(2) characterization of the effects on materials of long-duration exposure to the space environment,
(3) development of computational chemistry for predicting the fundamental properties of materials and their interaction with the space environment, and
(4) development of ceramic, metallic, and advanced carbon-carbon thermal protection systems.

Structures technology focuses on the the following:

(1) concepts for erectable and deployable structures;
(2) efficient and reliable methods for erection, deployment, monitoring, maintenance, and repair of space structures;
(3) new concepts for structures and cryogenic tanks for advanced Earth-to-orbit rockets, hypersonic vehicles, and orbital transfer vehicles; and
(4) efficient analysis methods for designing and evaluating advanced space structures, including analysis and design optimization methods related to integrated structures and controls.

Space Data and Communications. The Space Data and Communications program develops advances in the ability to control, process, store, manipulate, and communicate space-derived mission data and enables new communications concepts. Data systems research provides the technology for onboard computing systems needed for new classes of data systems that will make future Agency missions with challenging computing requirements possible and affordable. New architectures now being developed will provide dramatic increases in performance and reliability. Increased emphasis is being placed on enhancing software reliability while also reducing its cost. The communications technology effort is directed toward maintaining and ensuring U.S. preeminence in satellite communications, as well as toward providing the technology necessary for future reliable data-communication links that will be required by ultra-high data-generation-rate missions, such as the Earth Observing System (see page III-37), the Large Deployable Reflector, and the Mars Rover (see page X-9).

Information Sciences. The Information Sciences program seeks advanced concepts, techniques, and system algorithms and devises systems architectures, hardware devices and components, and software that will enable productive space information systems. Areas the program addresses include computer science and sensors. In the computer science area, the selection of Ada as the programming language for Space Station has provided a focal point for the development of improved techniques for developing and managing large-scale software projects. Emphasis also will continue to be placed on concurrent processing as a means for improving physical simulations and visualization of scientific data. Sensor research will concentrate on the use of artificial intelligence techniques in autonomous onboard data analysis. Investigation of new materials, devices, and analytical models leading to the development of improved sensor systems also will continue.

Controls and Guidance. The Controls and Guidance program includes developing means for:

(1) generating the practical design methods and techniques required to enable precise pointing and stabilization for future Agency spacecraft and payloads,
(2) precisely maintaining the structural shape of highly flexible large space systems, and
(3) guiding, navigating, and controlling advanced space transportation vehicles.

The program emphasizes two areas:

(1) advancing the methodology for combining both ground-based testing and future space-based testing with modern control theory to validate advanced flexible-body modeling techniques and control laws; and
(2) providing advanced guidance, navigation, and control algorithms combined with real-time, fault-tolerant, distributed control architectures and validation and reliability tools.

Human Factors. The Human Factors program provides the technology base for productivity, efficiency, and safety in the increasingly complex piloted space operations associated with the Space Station. The research is focused on crew-station design and productivity enhancements for extravehicular activity (EVA). The objective of the crew-station design effort is to determine the requirements for effective interfaces between human operators and advanced automation. Increasing levels of machine intelligence and autonomy sought by system designers have made this issue very challenging. Instead of being a performer of low-level sensor integration and a reader of actuator positions, the human operator is becoming a supervisor of intelligent systems. Thus, a major goal of the crew-station research and technology program is to ensure the effective information transfer between the system and the operator that is fundamental to the operation of highly automated systems.

Increased EVA capability can be achieved by developing high-pressure suits and gloves that are comfortable, durable, and maintainable in space, and by introducing EVA electronic information displays that provide flexibility and rapid access to information.

Space Flight. Using current facilities and, when they become available, future space facilities such as in-space research laboratories, the Space Flight program provides research-quality flight data supporting ground-based research and technology efforts related to development and operation of future space systems. Data obtained from these efforts support the development and verification of analytical theories, as well as the verification of ground facility performance, test methods, and techniques. This program encompasses the design, development, and flight test of experiments and the development of special purpose, reusable, flight research facilities for use in space. The associated Outreach program provides leadership and funding support to the aerospace industry and university communities to improve their use of the potential of space for technology development. Efforts under Outreach include initiation of experiment definition and development activities.

Systems Analysis. The Systems Analysis program includes the following activities:

(1) conducting systems analyses to identify technology requirements for spacecraft systems, space transportation systems, and large space systems for the national space program;
(2) integrating these requirements into a comprehensive technology plan; and
(3) providing data to establish the ability to develop these technologies in a timely manner.

Close coordination with Agency program offices and other users will be maintained to ensure proper prioritization of enabling and high-leverage technologies.

Spacecraft systems analysis is concentrated in five science and application areas: astrophysics, space physics, Earth science, communications, and solar system exploration. Space transportation systems analyses are focused in three areas: advanced Earth-to-orbit vehicles, aeroassist orbit-transfer vehicles, and conceptual design and analysis methods for advanced space transportation systems. In addition, options will be studied for a crew emergency rescue vehicle and a down cargo vehicle (a vehicle for returning cargo from space). In the area of large space systems, both manned and unmanned, the focus of the analysis program is on technology for the evolutionary Space Station and the associated space infrastructure.

University Space Research. The University Space Research program enhances and broadens the capabilities of the Nation's engineering community to participate more effectively in the U.S. civil space program. It is an integral part of the strategy to rebuild the space research and technology base. The program is intended to remedy the decline in the availability of qualified space engineers by making a long-term commitment to universities aspiring to play a strong engineering role in the civil space program. The program includes:

(1) the university space-engineering research program, which supports interdisciplinary research centers;
(2) the university investigators research program, which provides grants to individuals with outstanding credentials; and
(3) the university advanced design program, which funds advanced systems study courses at the senior and graduate levels.

Civil Space Technology Initiative (CSTI)

The program elements of CSTI are directed at technologies to enable efficient, reliable access to Earth orbit, and to enable operations and science missions therein. They are:

(1) automation and robotics,
(2) propulsion,
(3) vehicle,
(4) information technology,
(5) large structures and control, and
(6) power.

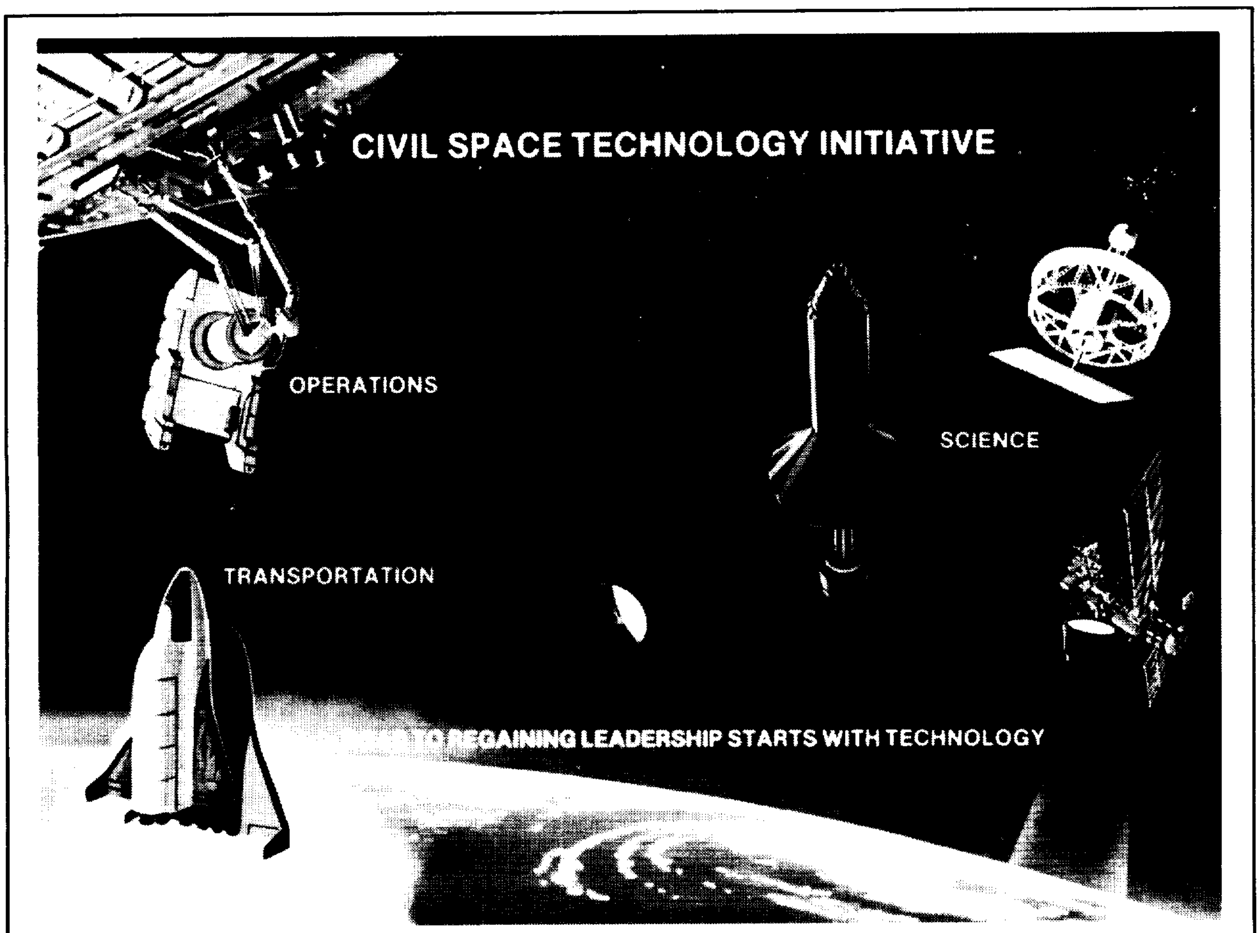


Figure VII-3. Civil Space Technology Initiative

Automation and Robotics. The Automation and Robotics program exploits the potential of artificial intelligence and telerobotics to increase the capability, flexibility, and safety of space and ground operations while decreasing associated costs. Specifically, the objectives of the robotics part of the program are to:

(1) increase the level of autonomy of remote operations from teleoperation to robotics, and
(2) increase the remote manipulation capability from its current embodiment as a crane on the shuttle orbiter to a device capable of on-orbit assembly, servicing, and repair.

These increased capabilities also would play a key role in planetary exploration.

The objectives of the autonomous systems part of the program are to:

(1) reduce the size of the ground control and operations crew, and
(2) automate control of appropriate subsystems aboard the Space Station, spacecraft, and transportation vehicles.

Long range goals of the automation and robotics program are to:

(1) replace 50 percent of extravehicular activity with telerobotics;
(2) decrease mission operations manpower by 60 percent; and
(3) reduce by 50 percent the manpower required to do routine housekeeping aboard spacecraft.

Propulsion. The Propulsion program conducts full-scale component and system tests to develop and demonstrate propulsion technology for main engines and boosters. This technology will enable development of the next generation of Earth-to-orbit vehicles. The program will verify the design and analysis tools developed with laboratory-scale and subscale test hardware in the research and technology base program and will demonstrate their ability to predict performance under large-scale, hot-fire engine environments. The validated analytical techniques then will become the basis for the design and development of advanced, reusable, high-performance, Earth-to-orbit propulsion systems. The design and analysis tools will be generalized to accommodate both hydrogen and high-density propellant engine systems for broad application and operating conditions. The booster technology part of the program will develop concepts for the space shuttle booster. Both solid-liquid hybrid boosters and pressure-fed bi-propellant liquid boosters will be considered.

Vehicle. The Vehicle program investigates the critical technologies applicable to the design of an aeroassisted orbital transfer vehicle. The technology areas that will benefit from the Aeroassist Flight Experiment (see page IV-16) are categorized into environmental and vehicle design technologies. The environmental technologies include nonequilibrium heating (radiative and convective), wall catalysis, and real gas aerodynamics. Vehicle design technologies involve thermal protection materials, structural loads, avionics, and guidance and control. The vehicle design technologies are strongly influenced by the variations associated with the upper atmosphere.

Information Technology. The Information Technology program develops materials, devices, and components that will enable productive detection, imaging, and data-storage systems for space and planetary missions in the next century. Development of systems to handle high data rates and volumes is directed toward maintaining U.S. preeminence in the collection and productive use of space-derived data. The work will enable a new generation of smart onboard information systems that will increase the return of scientific information from space. Science-sensor development concentrates on visual and infrared scanning and imaging instruments and radar and optical surface-mapping instruments. Onboard artificial intelligence to manage instrument operation will improve significantly the use of both classes of instruments. Smart instruments could be taught to look for particular features or events and transmit only data of interest.

Large Structures and Control. The Large Structures and Control program provides experimental validation of analytical methods for predicting the dynamics of coupled structures and their response to their structural controls. Of particular interest are complex, multibody space structures with flexible components, interfaces, and dissipative mechanisms. As the Agency initiates planning and implementation of large space systems (Space Station, space platforms, and large antennas), there are basic unknowns in the areas of structural dynamics, controls, structural interaction, structural performance, and deployment dynamics that must be resolved so that this new class of spacecraft can be developed with assurance that it will meet safety, performance, and cost goals. The size and flexibility of these systems require development of analysis and test methods and a space-based experiment activity addressing the key technology unknowns through graduated testing of flexible elements. The research data base will allow the design and development of integrated complex control systems and structural configurations for future large spacecraft. Study of the control of flexible structures is a comprehensive research activity that includes development of analytical methods, ground-based testing, and in-space experiments.

Power. The Power program develops the technology needed to meet the requirements for high-capacity power systems for the evolutionary Space Station, lunar and planetary bases, and high-power-demand electric propulsion systems. Power levels of interest are greater than tens of kilowatts to multi-megawatts. NASA's broad-based SP-100 advanced technology program has been highly successful in identifying potential component and subsystem improvements and in developing solutions for non-nuclear technology areas critical to successful development and application of high-capacity, nuclear reactor, space power systems.

FY 1989 New Initiatives and Augmentations

Pathfinder Program

The President's new National Space Policy establishes, for the first time, that the United States has a long-range civil space goal of expanding human presence and activity beyond Earth orbit into the solar system. The policy then directs the development of critical technologies that will allow future Administrations to act with confidence in choosing space mission strategies. To implement the new National Space Policy, the Office of Aeronautics and Space Technology has proposed initiation of the Pathfinder program in FY 1989. Pathfinder is an important new program to develop a broad set of technologies that will enable future space missions. Next in the sequence of focused space research and technology programs, Pathfinder will augment CSTI in strengthening the technology foundation for the civil space program and the Nation's technology leadership.

Pathfinder is an essential prerequisite to any decision by the Nation's leadership to go forward with major civil space missions in the future. The Ride report on space leadership (see page II-6) observed that the goals of human exploration will always remain 10 to 20 years in the future until key technologies (such as those to be addressed by Pathfinder) are developed. Pathfinder will enable or enhance a set of new mission scenarios: future robotic exploration of the solar system, an outpost on the Moon, a piloted mission to Mars, and Earth orbit operations.

Project Pathfinder addresses technologies organized around four major program areas:

(1) surface exploration,
(2) in-space operations,
(3) humans-in-space, and
(4) space transfer.

Through the advances obtained in these program areas — and a strong partnership between NASA, industry, and universities — Pathfinder will lead U.S. space technology forward in the coming decade, much as the Apollo program did during the 1960s.

Surface Exploration. The technologies to be developed in the exploration area are related to the gathering of scientific knowledge and technical understanding at possible mission sites on the moon and Mars. Specific goals are the capabilities needed for:

(1) piloted flights to Mars, and
(2) construction of a lunar outpost.

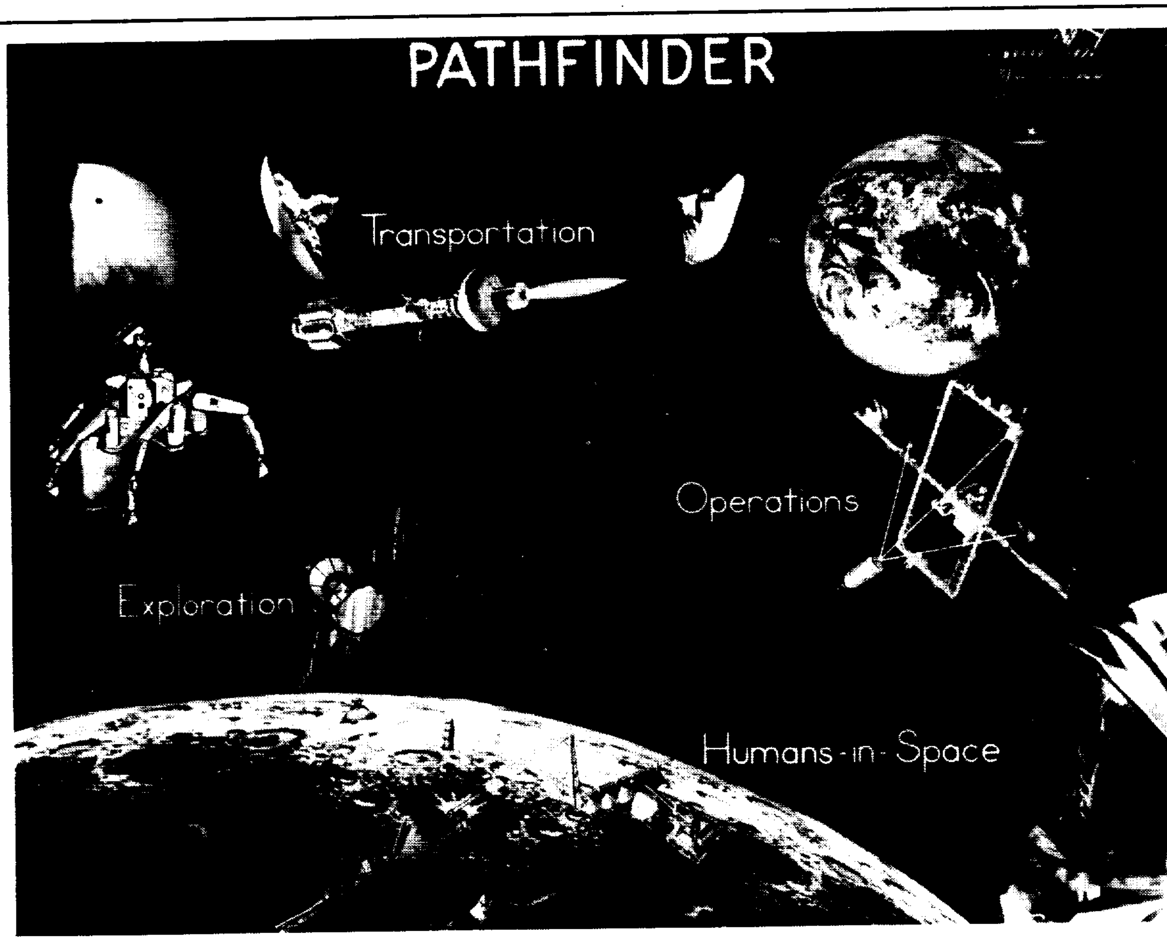


Figure VII-4. Project Pathfinder Technologies

The program objectives include:

(1) development of a planetary rover;
(2) acquisition, analysis and preservation of samples;
(3) generation of power at mission sites;
(4) development of autonomous landing capabilities; and
(5) research and development of photonics.

These objectives have been selected to provide critically needed capability, while reducing cost and risk, for the advanced space systems essential to future robotic and piloted exploration of the solar system.

In-Space Operations. The space operations area deals primarily with the lunar outpost, piloted missions to Mars, and operations in Earth orbit. For the lunar and Mars missions, this program will address critical technologies for departing Earth orbit, performing mission tasks at lunar and Martian surface sites, and safely returning from the moon and Mars. For Earth orbit operations, it will greatly extend NASA's ability to maintain an infrastructure for and provide support to major new science missions. Specific goals are extensive capabilities for:

(1) in situ materials processing;
(2) fabrication, assembly, and repair of massive and complex systems in Earth, lunar, and Martian orbits and at lunar and Martian surfaces.

The program objectives are:

(1) autonomous rendezvous and docking,
(2) resource-processing pilot plant,
(3) in-space assembly and construction,

(4) cryogenic fluid depot,
(5) space nuclear power, and
(6) use of optical communications.

Humans-in-Space. The humans-in-space area will address technology for making it feasible and productive to send astronauts on lengthy missions. Specific goals are:

(1) improving astronaut productivity,
(2) maintaining the health of the astronauts in space, and
(3) minimizing dependence on resupply of expendables.

The program objectives are:

(1) extravehicular activity (EVA) suit,
(2) human performance,
(3) closed loop life support, and
(4) life sciences research.

These objectives have been selected to provide the engineering systems essential to effective performance and good health during long-duration space missions.

Space Transfer. The transfer vehicle area will provide technology for transportation to and from geostationary Earth orbit, the moon, Mars, and other planets. Specific goals are:

(1) significant reduction in the mass that missions require for in-transit movement and launch into low Earth orbit, and
(2) reductions in the time required for transit.

The program objectives are:

(1) chemical transfer propulsion,
(2) cargo vehicle propulsion, and
(3) high-energy aerobraking.

Using the exploration scenarios identified in the Ride report (see page II-6), mission studies will identify, define, and analyze future space missions and their enabling technologies. These studies will lead to future refinement of the Pathfinder program to ensure that critical, long-lead technologies are receiving proper attention.

University Space Research Augmentation

In addition to increasing its emphasis on focused technology programs, NASA intends to bolster the Nation's civil space research and technology base by broadening and strengthening its partnership with academia. CSTI and Pathfinder will provide vital stimuli to augmentation of the space technology engineering talent pool, both within the government and in the entire aerospace community. By providing a set of challenging future objectives for the civil space program, NASA will attract the interest and enthusiasm of the Nation's brightest and most energetic youth, and will encourage them to pursue careers in engineering. Nurture of this talent will ensure the Nation's future in space.

An integral part of NASA's strategy is to capitalize on this interest and enthusiasm by providing added support to the building of new partnerships with the university engineering community. With this in mind, NASA established in FY 1988 its university space engineering research center program with the initiation of eight research centers. This program is designed to advance the traditional space engineering disciplines and bring together the knowledge, methodologies, and engineering tools needed for future advanced space systems. The research centers promote the kind of multidisciplinary teamwork demanded by technological systems problems, and bring individuals from a wide range of engineering and scientific fields into concentrated research endeavors. These partnerships provide the universities with broad charters for independent research and stimulate them to conceive new missions and technical alternatives that will broaden the options available to the Agency in selecting and defining future missions.

The planned FY 1989 augmentation of this program is required both for continuance of NASA's support of the incumbent centers and for increasing the number of centers. The enthusiastic response from universities, in both the number and the quality of their proposals, demonstrates the timeliness and value of the program. Many excellent proposals cannot be funded in FY 1988. The augmented program will allow the Agency to expand university participation and achieve a better technical balance.

Future Initiatives

The CSTI and Pathfinder initiatives constitute the emergence of a new direction for the Agency's advanced technology activities. Future initiatives will build upon these programs and will continue to reflect the objectives enunciated in the 1988 National Space Policy — that technology will make future decisions possible and will "enable a broad range of manned or unmanned missions." In the National Space Policy, the Agency's technology program is called upon, in the national interest, to build a solid base of capabilities and talent that will serve not only NASA's own future missions, but also those of the commercial sector and of all other sectors of the space program.

Within the restrictions imposed by the currently constrained budget environment, the Office of Aeronautics and Space Technology (OAST) is planning to undertake the future initiatives described below to support the objectives listed above.

In-Space Engineering Research and Technology Experiments

A focused initiative will be sought for advanced technology projects that will achieve phase B and C/D maturity within the next five to ten years. It has been designed to establish a leadership role for OAST in the area of in-space engineering research and technology experiments. It encompasses all space sectors and will help to make space accessible to industry and the universities for technology experimentation and validation.

The use of the shuttle for scientific experiments has demonstrated to the aerospace community that space is a valuable place for engineering research and technology development. As the sophistication level of future space missions increases, so will the need for advanced technologies whose feasibility has been demonstrated in the relevant space environment. In the course of conducting CSTI and Pathfinder, the need for in-space experiments will arise. OAST intends to conduct, as discrete initiatives, those flight experiments and, as needed, major ground demonstrations. OAST will assess CSTI and Pathfinder activities to anticipate the needs for major experiments and demonstrations, and will increase the use of in-space experimentation in response to the needs. All available carriers will be used in the next four years; and because the real payoff to technology development will be reached once the Space Station becomes operational, this initiative then will be expanded to accommodate Space Station experiments.

Global Change Technology Initiative

The objective of this new focused initiative is to develop and validate key technologies for advanced space-based observatories that will allow scientific study and understanding of Earth as a complete system. A broad-based program will be directed at developing a new generation of technologies that promote cost effectiveness and ultra-high reliability in space systems and their operations. Both extensive and intensive Earth orbit operations will be enabled for:

(1) space observations,
(2) support for in situ observations,
(3) platform services, and
(4) computational capabilities.

Space Observations. The specific research and technology elements for this area are:

(1) Earth sensors, optics, lasers, coolers, and radars;
(2) calibration (methods for obtaining measurements having long-term stability, reliability, absolute accuracy, and contamination control);
(3) stability and control for platforms and large structures (including large antennas for passive radiometers); and
(4) on-board data handling, processing and storage.

In Situ Support. The elements in this area are:

(1) tethers for upper atmospheric probes, and
(2) communications and control links for science networks and in situ instruments (such as probes, sounders, and penetrators for use in investigating atmospheres, oceans, remote locations, and volcanic eruptions).

Platform Services. This area includes spacecraft bus technologies (power, mass, and optical communications), on-orbit deployment or assembly, and servicing, with emphasis on reliability and fault-tolerance.

Computational Capabilities. Technology development in this area will address complex software systems for automation of on-board and ground-based operations and data processing.

Technology for Outyear (1993-1994) Initiatives

It is anticipated that the Nation will decide in the early 1990s to undertake a bold new initiative, such as a lunar base or a mission to Mars (see page X-7). That decision will generate explicit requirements for technology development programs to support the selected mission or missions. Concurrent with its system definition studies, the Space Research and Technology program will conduct technology development programs jointly with other NASA program offices. Those programs will be designed to validate the readiness of technology to satisfy the specific requirements defined in mission studies. Programs such as test-bed demonstrations eventually will be transferred to user offices.

In order that the evolving space-based infrastructure can be exploited fully for the new scientific ventures of the next century, many new enabling technologies will be required. The Space Station, its companion platforms, and the permanent presence of humans in space will enable a new class of scientific missions, such as the detection and characterization of planets outside of the solar system, using space or lunar-based interferometry. Unique technologies to be developed include those for large ultra-stable platforms, high-capacity power systems, precise (laser based) metrology, advanced construction techniques, and low contamination servicing.

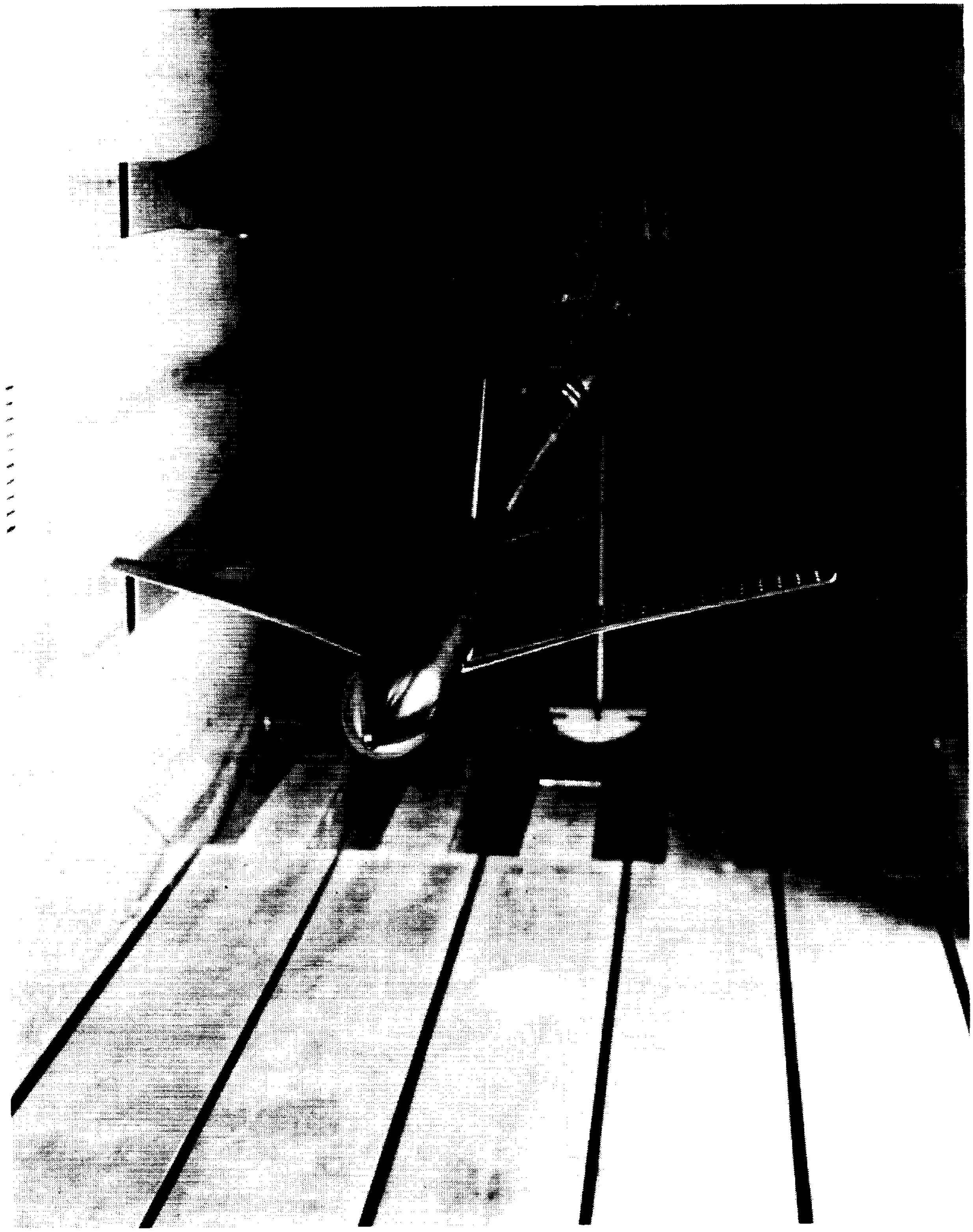
Space Research and Technology Beyond the Year 2000

Much of the current and planned Space Research and Technology program is already targeted at creating capabilities that will be applied to systems and missions that will evolve after the Space Station. Pathfinder, for example, emphasizes research needed for a lunar outpost mission and a sprint mission to Mars. Projected dates for these missions generally are in the first decade after the turn of the century. While it is premature to plan specific technology programs to enhance the follow-on performance of these missions or to provide follow-on missions, it is important to conduct studies anticipating the missions' nature and potential impact.

The lunar outpost, initially a host for science, engineering, and exploration sortie missions, will evolve into a lunar base with permanent human presence. Mars missions probably will follow along the logical, evolutionary pattern of the lunar program, with the Mars Sprint Mission being followed by a Mars Outpost. A new generation of Earth-to-orbit transportation systems and the infrastructure for an Earth orbital spaceport will emerge sometime beyond the current horizon for the CSTI program. For example, the potential for a hypersonic, single-stage-to-orbit aerospace plane could evolve from the National Aerospace Plane program (see page VIII-15).

It is essential to remain continually aware of, and to pursue, possible emerging technologies that may influence the design of future-generation systems. Superconductivitiy research is an excellent example. Much of the fundamental research conducted under the Research and Technology Base program shows promise of application in 10 to 20 years. Consequently, current fundamental research can be expected to lead to focused technology initiatives for application beyond the year 2000. Under a healthy Research and Technology Base program, current research should evolve and grow to provide the foundations for future development of the necessary technology.

Aeronautical and Transatmospheric Research and Technology



Aeronautical and Transatmospheric Research and Technology

The Office of Aeronautics and Space Technology (OAST) plans and manages NASA's aeronautics research and technology development program. The agency's three Research Centers–Langley, Lewis, and Ames (which includes Dryden Flight Research Facility)–conduct long-term, high-risk research and technology development in aerodynamics, propulsion, materials and structures, information sciences, guidance and controls, human factors, and flight systems. This advanced research guarantees a continuing wellspring of new discipline and systems technologies from which the U.S. aviation industry draws in developing safer, more efficient, and more effective generations of civil and military aircraft.

OAST also directs the Agency's program in transatmospheric research and technology development. Since 1986, this program has been focused on the National Aerospace Plane (NASP)–an initiative undertaken jointly by the government and industry to develop the technologies required for transatmospheric flight.

Aeronautical and Transatmospheric Research and Technology

Introduction

The fact that the U.S. aerospace industry registered, in 1987, a positive trade balance of over $15 billion—the largest of any U.S. export sector—is an indication that U.S. aircraft still maintain a broad base of technological advantage over foreign competitors. The margin of that advantage, however, has narrowed dramatically in recent years. This erosion of American preeminence implies major negative consequences for the vitality of U.S. industry in a changing global economy, as well as for U.S. leadership in global security.

Aggressive technology development is an essential element in maintaining U.S. competitiveness. Key technology opportunities are emerging that will enable the development of new generations of aircraft, making virtually all significant civil and military aircraft operational today obsolete.

In recognition of these trends, the White House Office of Science and Technology Policy (OSTP) chaired, during the past several years, a series of comprehensive, multi-agency studies on the role of the federal government in aeronautical research and technology development. These studies have clearly reinforced the importance of aeronautics to the Nation, strongly emphasized the necessity for a research and technology base to support the development of superior U.S. aircraft, and explicitly reaffirmed the traditional roles of government agencies in aeronautics.

Subsequently, OSTP's Aeronautical Policy Review Committee (APRC) established three specific national goals to focus the skills and energies of all sectors of American aeronautics toward the highest-payoff technology areas:

(1) Subsonics Goal: To build "trans-century" renewal—by advancing the technology for an entirely new generation of fuel-efficient U.S. aircraft operating in a modernized National Airspace System;
(2) Supersonics Goal: To attain long distance efficiency—and enable the development of civil and military aircraft featuring sustained supersonic cruise capabilities; and
(3) Transatmospherics Goal: To secure future options—and exploit the convergence of aeronautics and space technology in developing the capability to routinely cruise and maneuver into and out of the atmosphere, with takeoff and landing from conventional runways.

The APRC also outlined a comprehensive action plan for a concerted effort by government, industry, and the Nation's universities to realize these goals, maintain U.S. competitiveness in the world aeronautics marketplace, and ensure our national security.

The Agency's long-range planning for aeronautics and transatmospheric research and technology, presented in the following sections, is responsive to the Policy Review Committee's, and others', assessments of national needs, is designed to maximize the payoff from new technological opportunities, and is grounded in a realistic context of resource availability. Successful implementation of this plan will ensure a continuing, significant NASA contribution to revitalizing U.S. economic competitiveness, maintaining a secure national defense, and solidifying U.S. technological leadership well into the next century.

Goals

The Agency's aeronautical research and technology development activities date back to the founding in 1917 of the National Advisory Committee on Aeronautics (NACA). To ensure the continuation of the highly successful partnership between government and industry established by the NACA and maintained by NASA, the Agency's program goals for aeronautical and transatmospheric research and technology development are to:

(1) conduct effective and productive fundamental and systems-oriented aeronautics research to develop and validate emerging technologies that contribute materially to the enduring preeminence of U.S. civil and military aviation;
(2) ensure the excellence of NASA's Aeronautical Research Centers by maintaining critical national facilities, by acquiring necessary advanced

scientific and engineering computational capabilities, and by enhancing the technical excellence of its staff by selecting highly qualified personnel and providing them with challenging career opportunities;

(3) ensure the timely and efficient transition of research results to the U.S. aeronautics community through reports, conferences, workshops, and the active participation of industry in cooperative research programs;

(4) ensure the strong involvement of universities in NASA's program to broaden the Nation's base of technical expertise and innovation; and

(5) provide technical expertise and supporting facilities to U.S. industry, the Department of Defense, the Federal Aviation Administration, and other government agencies.

Objectives

Vehicle-Class Objectives

As mentioned above, the agency conducts a vigorous program of advanced research and technology development across a wide range of relevant aeronautical disciplines. To help focus and integrate this research and development, and to respond to the APRC's national aeronautical research and development goals, the Agency has established five "vehicle-class" objectives. These objectives target development of the fundamental knowledge base in critical technologies to provide effective options for U.S. industry's use in designing and building superior aircraft for global markets and national security applications. Each of the five vehicle classes is described below, including information on the needs each will satisfy and the potential benefits of each.

Hypersonic Cruise/Transatmospheric Vehicles. The convergence of aeronautics and space technologies provides the potential for an entirely new class of vehicles for the next century, ranging from hypersonic aircraft to a single-stage-to-orbit space transportation system. These vehicles would have the ability to take off from and land on conventional runways, sustain hypersonic cruise flight (greater than six times the speed of sound) in the atmosphere, or accelerate into space. The transatmospheric capability made possible by this technology will greatly enhance the operational potential of both civil and military aircraft.

Key to this vehicle class is the development of technology for air-breathing propulsion systems providing horizontal takeoff, acceleration through the transonic and supersonic speed ranges, and sustained operation at hypersonic speeds. Other crucial technology challenges include new high-temperature materials, actively cooled thermal structures for peak and sustained heat loads, revolutionary concepts for highly integrated airframe and propulsion systems, and advanced computational methods to address complex flow, structures, and integration phenomena associated with very high speed vehicles.

Long-range Supersonic Cruise Aircraft. Strategically and economically, U.S. trade and alliances in the Pacific have major implications for the future. U.S. trade with the Pacific community has increased dramatically, accelerating well beyond the volume of trade with Europe. Mutual security bonds are also of increasing significance.

Vehicles with long-range supersonic cruise capability will ensure a U.S. presence in these vital areas. Passenger aircraft that feature 350-passenger capacity, trans-Pacific range, and cruise speeds of two to four times the speed of sound will link the farthest reaches of the Pacific Rim area in four to five hours. Military applications will provide vital mission enhancements in basing, long-distance responsiveness, and survivability.

A major technology challenge in this area is to develop variable cycle propulsion that will provide noise levels acceptable to the community, a substantial reduction in fuel consumption, and extended life at high, sustained engine-operating temperatures. Other challenges include reducing the airframe structures weight fraction, increasing the cruise lift-to-drag ratio through improved aerodynamics (including supersonic laminar flow), and developing technologies to achieve environmental compatibility.

Transcentury Subsonic Transport. Advances in technology for subsonic aircraft during the past 15 years have been predominantly evolutionary. To ensure that the United States retains its leadership role in the world marketplace, it is essential that NASA, in close coordination with manufacturers, airlines, and the FAA, accelerate the development of subsonic technology and ensure that its introduction is timely.

NASA's efforts in the subsonic transport area are focused on the technology required both to develop an entirely new generation of fuel efficient, affordable aircraft and to improve the safety and capacity of the National Airspace System.

Key technology challenges involve the reduction of fuel consumption by the use of advanced turboprop propulsion systems, the reduction of viscous drag through control of laminar flow and turbulence, the reduction of structural weight by the use of advanced composite materials and concepts, and the full integration of flight controls and operating systems that interface with a flexible and modernized National Airspace System.

Advanced Rotorcraft. Advanced rotorcraft that combine the vertical takeoff and landing capability of conventional helicopters with the high forward speed capability of fixed-wing aircraft will make a major contribution in both the civil and the military sectors. Civil versions (the tiltrotor, for example) will operate in the vertical- or short-takeoff mode with the economy, productivity, and maintainability of fixed-wing passenger aircraft. Advanced craft of this kind can provide improved intercity and interregion transportation, reducing congestion in U.S. airports without requiring major investments in new runways.

NASA's objective in this area is to provide validated technology for the development of quiet, jet smooth, highly automated helicopters and revolutionary new rotorcraft with unprecedented high-speed capabilities for both civil and military roles.

Technology challenges include reduction of external noise and airframe vibrations through the use of validated prediction and design methods; reduction of crew workload in performing complex piloting tasks through cockpit automation and emerging concepts in man-machine interfaces; and integrating new enabling technologies in materials, controls, and aerodynamics into innovative configurations that combine the utility of the low-disk-loading rotor with the high-speed capability of a fixed wing.

High-Performance Aircraft. NASA's research program for high-performance aircraft is structured to develop and mature technologies that have important, long-term, military and civil applications. Specific technology programs are carefully selected to demonstrate significant improvements in performance or new capabilities that potentially have high payoff.

The Agency's objective in this area is to develop the technologies required to enable an entirely new generation of fighter aircraft with unprecedented maneuverability and agility, sustained supersonic cruise, and short takeoff and vertical landing capabilities.

Key technology challenges include achieving effective low-speed control at angles of attack above 70 degrees, increasing propulsion system thrust-to-weight, increasing aircraft range, and developing a supersonic short takeoff and vertical landing capability with minimum performance penalty.

Disciplinary Research Objectives

In addition to the vehicle-class activities described above, the Agency's aeronautical research and technology development program consists of fundamental, disciplinary research that either has broad application to the safety, efficiency, and performance of a wide range of aircraft types or has the potential to enable entirely new aircraft systems. Objectives for this research include:

(1) validate computational methods for analyzing and predicting complex external and internal flows, structural mechanics, control theoretics, and their interactions in order to enable confident, practical application of those methods to aircraft and engine design;
(2) provide design and validation methods for highly reliable, integrated, and interactive control of aerodynamics, structures, and propulsion to achieve optimum configurations;
(3) develop technology for human-error-tolerant and computer-aided piloting systems and for windshear modeling and detection;
(4) develop methodologies for designing sophisticated, intelligent, automated systems to enhance crew

performance of complex tasks and provide dramatic advances in vehicle performance and agility; and
(5) develop design methodologies and life-prediction modeling techniques for advanced high-temperature materials such as ceramics, ceramic composites, carbon-carbon and metal-matrix composites for use in lightweight airframes and high-performance, uncooled turbine engines.

Facilities Objective

Many of NASA's aeronautical research facilities—including wind tunnels, simulators, and advanced computing facilities—are unique, national assets. In addition to supporting the work of NASA and its contract research, these facilities support research and development work being undertaken by the aerospace industry and other government agencies, including the Federal Aviation Administration, Department of Defense, and Department of Energy.

To continue meeting its obligations in this area, the Agency has the objective of enhancing the capability of its aeronautical facilities by improving the productivity and integrity of major facilities, and by extending that capability in critical areas.

Program Strategy

Successful realization of all of the objectives outlined above will require a sustained and focused research effort well into the next century. To help in assigning priorities to its research efforts, and to ensure a continued leading-edge contribution in the current environment of constrained budgets, the Agency has developed the following three-pronged strategy for its aeronautical research and technology development program:

(1) identify and emphasize emerging technologies having the potential for order-of-magnitude advances in capacity or performance that will enhance the national security and economic competitiveness of the United States,
(2) target and strengthen technology development and validation efforts in selected high-payoff areas, and
(3) ensure the continued health and productivity of critical national aeronautical research facilities.

A phased implementation of these three strategy elements is reflected in the current program plan and the planned initiatives described in the following sections.

Current Program Plan

Aeronautics Research and Technology Development

The Aeronautics Research and Technology program consists of two major program areas:

(1) Research and Technology Base programs, which are discipline-oriented and are designed to establish and maintain a solid foundation of aeronautical technology embracing all of the relevant disciplines and areas of systems research; and
(2) Systems Technology programs, which exist to carry new and innovative technology from the laboratory environment into experimental- and verification-systems testing, and which provide for the analysis, design, fabrication, and testing of multidisciplinary aeronautical systems in order to reduce greatly the technical risks associated with their application.

The Agency uses a variety of mechanisms—including information from industry, systems analysis studies, and in-house assessments of technology needs—to identify specific research needs in both of these program areas.

The needs are then detailed in the Program and Specific Objectives (PASO) document—the Agency's long-range program plan for aeronautical research and technology. The PASO document provides an assessment of the state-of-the-art in each program area, future technology needs, program and specific technology objectives, and milestone schedules for the program elements within both the Research and Technology Base programs and the Systems Technology programs.

The PASO document in turn provides the basis for preparing the related Research and Technology Objectives and Plans (RTOPs). These annual operating plans describe in detail research to be performed during the coming fiscal year.

The sections of this chapter that follow summarize the current program and specific objectives for each aeronautics program element and for transatmospheric research and technology activities, which are part of the National Aerospace Plane Program. Anyone interested in a more detailed accounting of current aeronautics activities is referred to the PASO document itself, or to the analogous NASP Technology Maturation Plan, and to appropriate RTOPs.

Research and Technology Base

The R&T Base is composed of the following nine areas:

(1) fluid and thermal physics,
(2) applied aerodynamics,
(3) propulsion and power,
(4) materials and structures,
(5) information sciences,
(6) controls and guidance,
(7) human factors,
(8) flight systems, and
(9) systems analysis.

Fluid and Thermal Physics. The Fluid and Thermal Physics program advances understanding of fundamental fluid mechanics phenomena and develops efficient tools for analyzing aerodynamics. Research is directed primarily at external aerodynamics, and includes efforts in fluid physics, computational fluid dynamics (CFD), CFD code validation, experimental aerodynamics, and viscous flow. The specific objectives for this area include:

Computational methods and applications: Increase the speed and efficiency of 3-dimensional flow solvers by two orders of magnitude

Flow modeling and verification: Develop accurate 3-dimensional turbulence models for attached and separated flows

Experimental and analytical aerodynamics: Extend the detailed aerodynamics data base for new configuration concepts

Drag reduction: Develop devices and design techniques to reduce aircraft drag by 50 percent.

Applied Aerodynamics. The Applied Aerodynamics program generates advanced technology for improving the performance and flight dynamics of future aircraft and missiles through analytical and experimental programs. Research in this area uses a broad variety of test facilities and is supported by continuing development of test techniques and instrumentation. In addition, the program includes aeroacoustics research that develops basic predictive capabilities and control techniques for specific noise problems, such as the effect of acoustic loads on the performance of aircraft structures and systems. The specific objectives for this area include:

Subsonic aircraft: Reduce cruise drag by 50 percent

Rotorcraft: Provide a noise-prediction accuracy of 1.5 EPNL and vibration of less than 0.05 g

Supersonic cruise: Increase the lift-to-drag ratio by 50 percent

High-performance aircraft: Double the transient maneuverability (including provision of controllability at angles of attack to 70+ degrees) and provide sustained supersonic cruise and short takeoff/vertical landing capabilities

Hypersonic/transatmospheric vehicles: Increase the hypersonic cruise lift-to-drag ratio by 40 percent

Test techniques: Improve test accuracy by an order of magnitude.

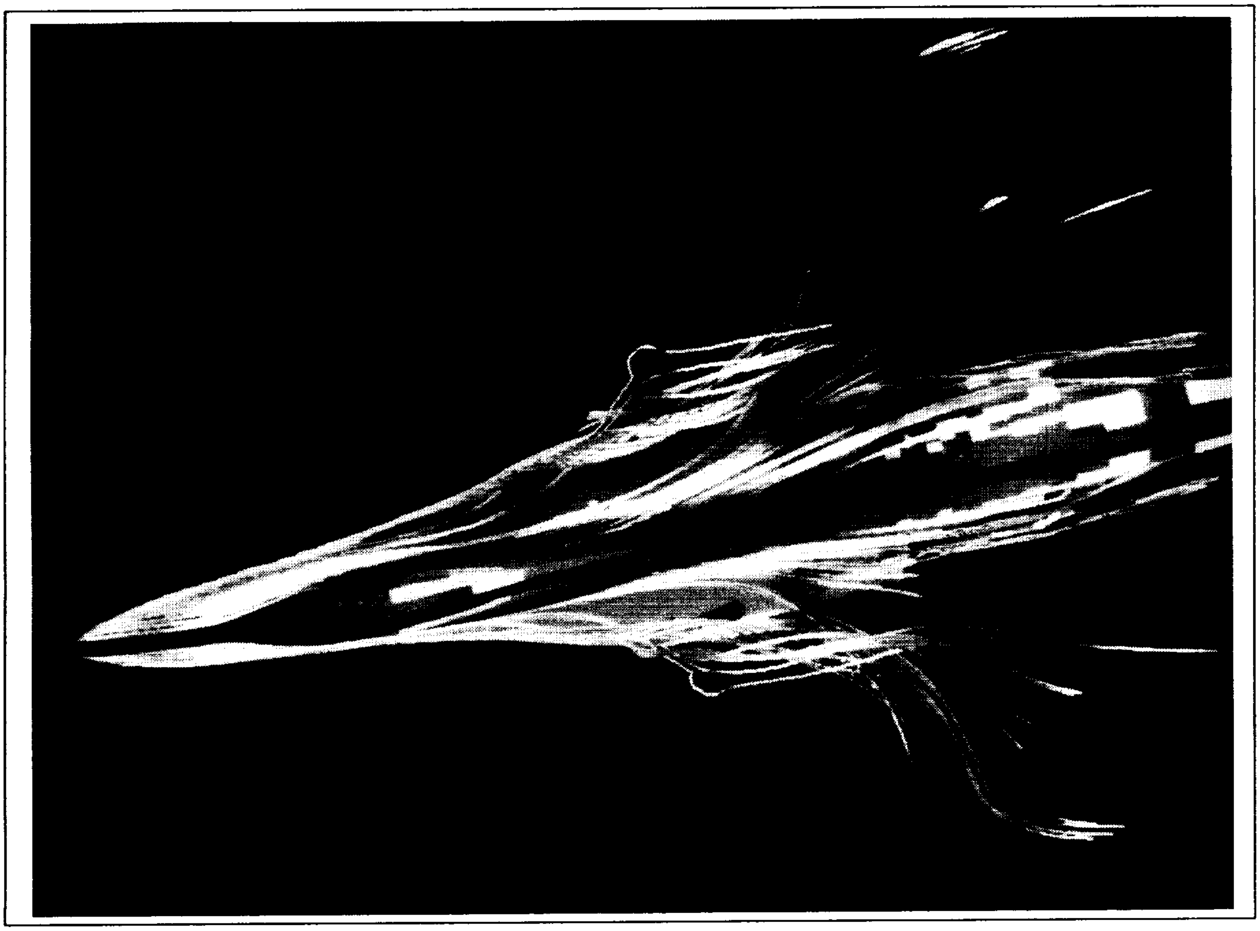


Figure VIII-1. Computer Generated Flowfield About an F-16 Aircraft

Propulsion and Power. The Propulsion and Power program provides the understanding of the governing physical phenomena at the disciplinary, component, and subsystem levels that will support and stimulate future improvements in the performance capability, efficiency, reliability, and durability of propulsion systems. Disciplinary research in instrumentation, controls, internal fluid mechanics, and aerothermodynamic concepts provides the foundation for continued advancement at the component and subsystem level. The specific objectives for this area include:

Controls and sensors: Develop minimally intrusive sensors for operation at 650°C to 1650°C, non-intrusive sensors for optical flow measurements in operating engine environments, optical sensors and data links for engine control, and high-temperature electronics capable of operation at 600°C

Internal computational fluid dynamics: Develop a validated predictive capability via improved physics modeling, advanced algorithms, and adaptive grids for facilitating resolution of complex, 3-dimensional, viscous, aeropropulsion internal flows, while reducing calculation times by a factor of 10

Supersonic cruise: Develop technology for, and establish the feasibility of, supersonic through-flow turbomachinery with the potential for a 15-percent reduction in fuel consumption

Small engines: Develop technology for a 40-percent improvement in turbine engine fuel consumption; and achieve a 40-percent reduction in fuel consumption, a 30-percent increase in power density, and a multifuel capability for rotary engines

Powered lift and control: Develop propulsion technology for short takeoff/vertical landing and highly maneuverable, propulsively controlled supersonic aircraft.

Materials and Structures. The Materials and Structures program includes the following activities:

(1) investigating and characterizing advanced metallic, ceramic, polymer, and composite materials;
(2) developing novel structural concepts and design methods to exploit the use of advanced materials in aircraft;
(3) advancing analytical and experimental methods for determining the behavior of aircraft structures in flight and ground environments; and
(4) generating a research data base to reduce aircraft weights and to promote improvements in aircraft performance, safety, durability, and life-cycle costs.

The specific objectives for this area include:

Composites: Develop 600°F thermoplastic polyimide composites, advanced structural design concepts providing up to 50-percent savings in weight, integrally stiffened structures using filament-winding and pultrusion technology, aeroelastic tailoring for high aspect-ratio wings, and carbon-carbon and ceramic matrix composites for high-temperature use up to 3000°F

Metallic materials: Develop aluminum-lithium alloys with a 10-percent reduction in weight and a 25-percent increase in strength; high-temperature (up to 900°F) aluminum alloys; and intermetallic and metal-matrix composites for engine and airframe applications

Structural concepts and analysis: Advance understanding of high-temperature structural concepts, flow and thermal analysis techniques, transient dynamic response, post-buckling behavior, failure analysis and life prediction, and stochastic modeling of structural response

Aeroelasticity: Develop accurate models of unsteady aerodynamics for use in flutter analysis and optimization techniques, and develop and validate the Computational Aeroelasticity Program-Transonic Small Disturbance code

Computational structural mechanics: Exploit advanced computer capabilities for analyzing complex structures, and improve structural analysis methods.

Information Sciences. The Information Sciences program includes the following activities:

(1) increasing the Agency's capabilities in advanced aerospace computing;
(2) exploiting key computer science disciplines to meet the Agency's unique computing requirements; and
(3) establishing a technology base for cost-effective, reliable computing in complex, mission-critical hardware and software systems.

The specific objectives for this area include:

Explore multiprocessor architectures, operating systems, programming languages, and algorithms for very high performance applications in computational physics and for aerospace applications requiring a mix of numeric and symbolic computation

Develop advanced computational concepts, system architectures, architectural design, and performance measurement methods for aeronautical applications and future missions

Investigate the theoretical basis underlying high-reliability and fault-tolerant systems, in order to provide insight into promising new algorithms, design methods, and architectural concepts

Develop techniques for realizing large-scale, complex, aeronautical computing systems that exhibit high reliability

Develop techniques for telescience, including improved communications, distributed data bases, man-machine interfaces, and computer graphics

Develop advanced technologies for distributed operating systems.

Controls and Guidance. The Controls and Guidance program includes the following activities:

(1) investigating emerging controls, guidance, artificial intelligence, and display technologies that offer automation and systems integration contributing to aviation effectiveness and efficiency;
(2) developing architectures for flight-crucial systems for future aircraft, and devising analytical techniques for assessing their reliability and performance;
(3) developing methods for airborne detection and avoidance to alleviate the threat of wind shear and heavy rain.
(4) developing advanced control theories, guidance theories, and analytical methods for extending the performance envelope and reliability of highly augmented future aircraft; and
(5) exploring new concepts for achieving integration of multidisciplinary technologies.

The specific objectives for this area include:

Flight crucial systems: Improve reliability by a factor of 1,000 by using fault tolerant architectures

Flight management: Develop flight controls and operating systems adapted to modernization of the National Airspace System in order to achieve more flexibility in the use of airspace, reduction of operationally caused accidents, and safer adverse weather operations

Artificial intelligence and expert systems: Improve the tactical maneuvering capabilities of aircraft

Control theory: Develop robust design methods and algorithms for superaugmented aircraft

Multidisciplinary integration research: Increase the mission effectiveness of military and civil aircraft.

Human Factors. The Human Factors program provides the capability to design effective crew-cockpit systems using advanced cockpit automation technologies that will properly integrate the diverse systems, operators, and procedures consistent with mission requirements and the environment. The specific objectives for this area include:

Intelligent cockpit systems: Achieve a 50-percent increase in operational capability

Human engineering methods: Achieve a 50-percent increase in operational safety by reducing automation induced errors; and develop predictive, integrated workload/performance measures for cockpit design and evolution.

Flight Systems. The Flight Systems program provides the research and technology development required for an improved and validated base of advanced technology for application by industry to future generations of the entire spectrum of aircraft. The specific objectives for this area include:

Aviation safety: Reduce aircraft accidents resulting from weather effects, including heavy rain and icing

Fighter/attack aircraft flight systems: Achieve a 70-degree angle-of-attack capability for maximum maneuverability

Technology for next-generation rotorcraft: Increase the operational capability of helicopter-type vehicles from 320 knots to transonic speeds

High-performance flight research: Validate promising technologies for application to future civil and military aircraft

Advanced short takeoff and vertical landing (ASTOVL) aircraft systems studies: Identify, in cooperation with DOD and the United Kingdom, gaps in today's technologies for pursuing advanced concepts.

Figure VIII-2. F-18 Vortex Flow Visualization

Systems Analysis. The Systems Analysis program provides a basis for effective long-range planning by developing performance data, conducting sensitivity analyses, and examining the technology needs and opportunities associated with future vehicle concepts. Systems analysis studies identify technologies that can lead to new plateaus or major improvements in the performance of civil or military vehicles, in the creation of new markets, and in economic benefits. Trade-off analyses determine the sensitivity of new vehicle concepts to proposed developments in aerodynamics, propulsion, materials, structures, and flight controls. The specific objectives for this area include:

Subsonic transport: Assess the ability of ultra-high-bypass propulsion systems to improve the efficiency of large, long-range transport aircraft

Rotorcraft: Identify advanced configurations and assess the effect of advanced technologies on high-speed rotorcraft for civil and military applications

High-speed civil transport: Identify the most promising vehicle and propulsion system concept for civil transports capable of speeds greater than Mach 2.0, and assess the effects of advanced technologies

High-performance aircraft: Identify and quantify the effects of technology developments on conceptual configurations of ASTOVL aircraft.

Systems Technology

Systems Technology consists of five areas:

(1) materials and structures,
(2) rotorcraft,
(3) high performance aircraft,
(4) advanced propulsion, and
(5) numerical aerodynamic simulation.

Materials and Structures. The Materials and Structures program develops advanced materials and structural concepts for future advanced aircraft propulsion systems and primary structures. The specific objectives for this area include:

Advanced high-temperature engine materials: Develop very high thrust-to-weight ratio (20 to 1) gas turbine engines with durable, long-life, hot-section components that can endure sustained operation without cooling air

Advanced composite materials: Incorporate new materials in optimally designed composite structures to achieve a 40- to 50-percent reduction in weight and a 25-percent reduction in cost, compared with current metallic structures.

Rotorcraft. The Rotorcraft program advances the disciplines of rotorcraft acoustics, aerodynamics, and aeromechanics, and explores promising high-speed configurations to provide a technology base for advances in civil and military rotorcraft vehicles. The specific objectives for this area include:

Increase speed and range by 100 percent

Establish world-wide self-deployment capability

Decrease noise and vibration by 80 percent

Reduce mission fuel requirements by 25 percent

Increase payload capacity by 100 percent.

High Performance Aircraft. The High Performance Aircraft program generates validated engineering methods and design data applicable to the development of advanced high-performance, high-speed aircraft. The specific objectives for this area include:

Validate the data base required to exploit fully the military potential of the high-angle-of-attack regime

Demonstrate and validate the cruise and maneuver performance benefits of the variable camber wing

Develop design tools and methodology for applying integrated flight/engine controls to future mission requirements

Validate wind-tunnel and systems-integration data on the vortex flap

Develop the technology data base required for short takeoff and vertical landing to be a design option

Demonstrate and validate performance improvements resulting from the advanced technologies incorporated into the X-29A Forward Swept Wing aircraft.

Advanced Propulsion. The Advanced Propulsion program explores and exploits advanced technology concepts for future aircraft systems in high-payoff areas by focusing fundamental research and technology efforts and by integrating advanced propulsion components. The specific objectives for this area include:

Advanced turboprop systems: Develop and verify methods for analyzing high-speed propellers, cabin environmental treatments, and propeller-airframe integration in order to continue providing a strong fundamental technology base for alternative applications, as well as for certification and refinement

General aviation and commuter aircraft technology: Develop advanced methods and concepts specifically aimed at reducing or eliminating size-dictated barriers to the improvement of the performance of small turbine engines.

Numerical Aerodynamic Simulation. As a necessary element in maintaining U.S. leadership in computational fluid dynamics and related disciplines, the Numerical Aerodynamic Simulation program establishes and maintains a pathfinding national computational capability available to the Agency, other federal research organizations, industry, and academia. The specific objectives for this area include:

Develop a computational capability of at least 4,000 million floating point operations per second (MFLOPS) for large computational aerodynamic modeling

Maintain a pathfinding role by supporting advances in computer architectures, high-speed networking, and graphics

Continue upgrades to NASA's computational processing capability to ensure maintenance of a state-of-the-art national resource for aeronautical research.

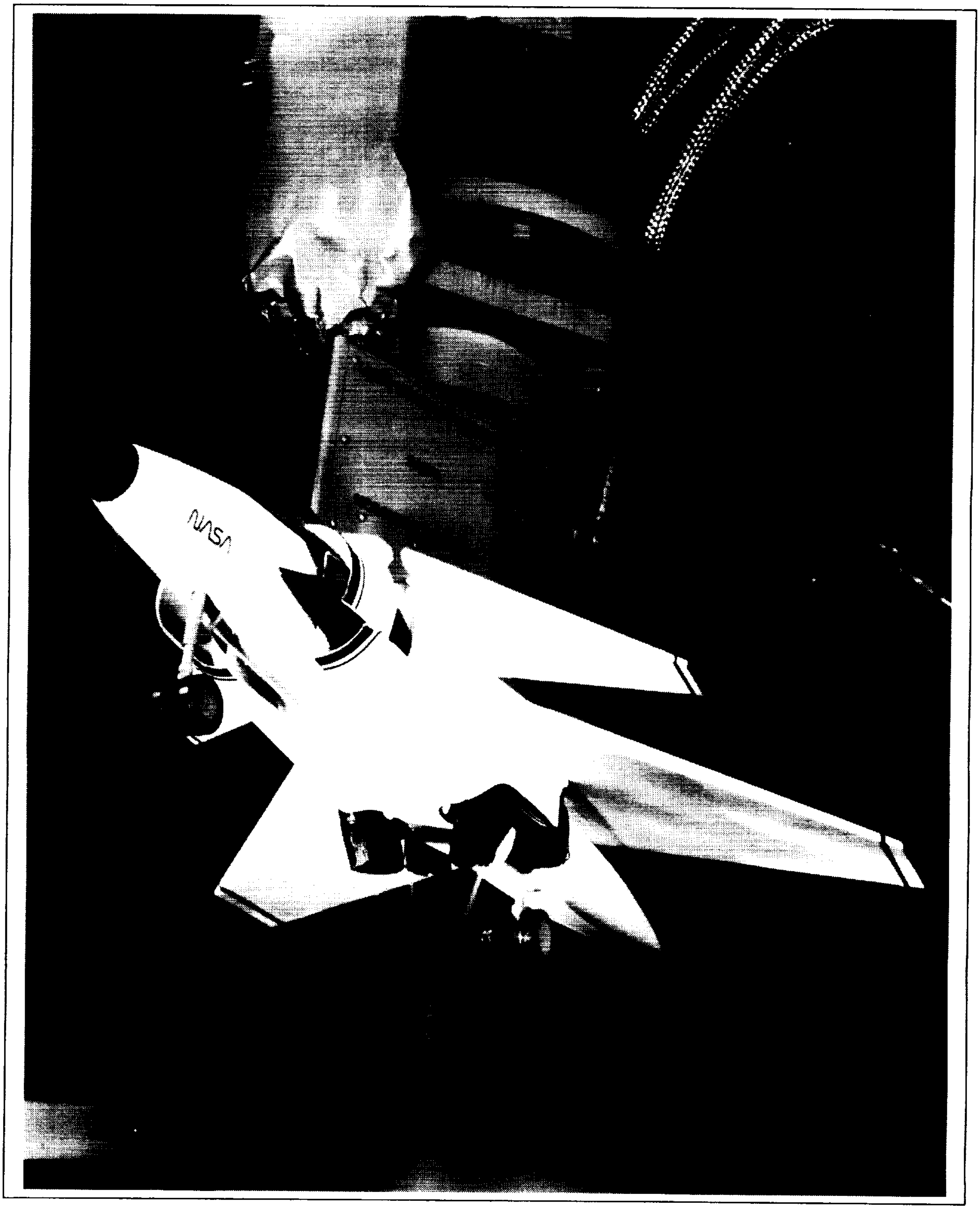


Figure VIII-3. STOVL Hot Gas Ingestion Model

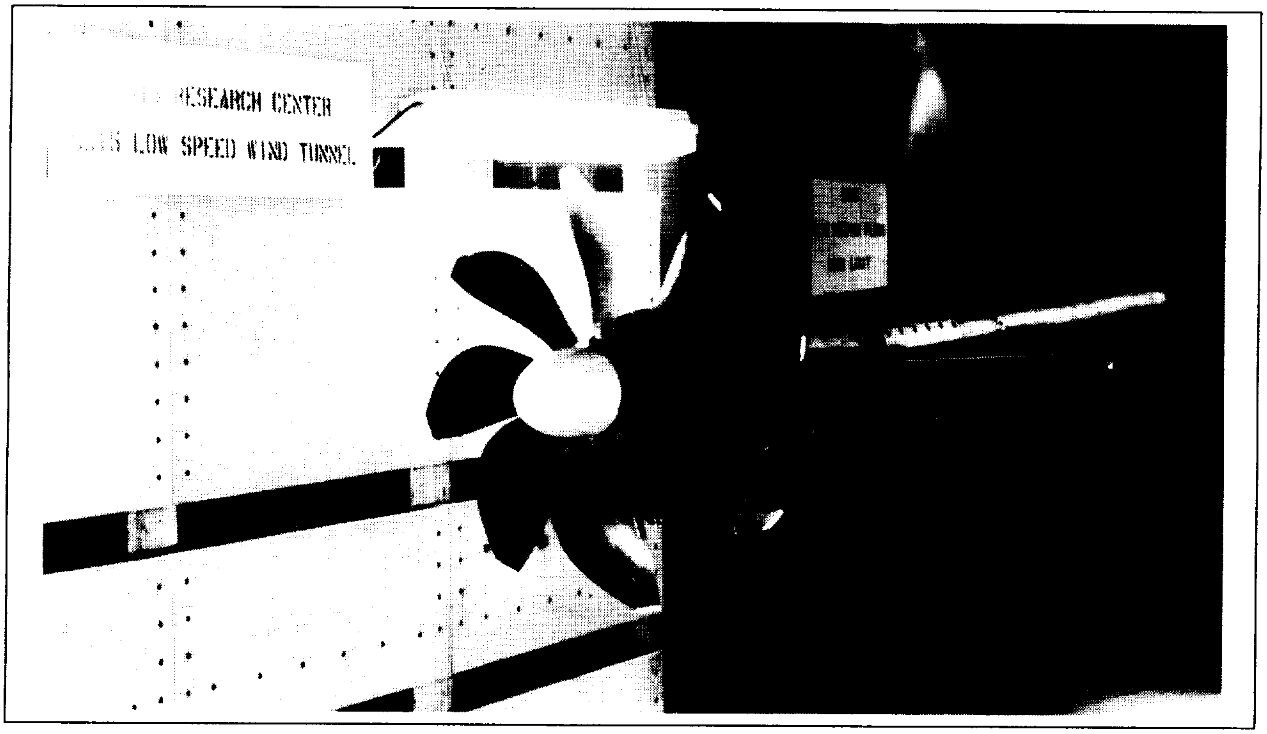


Figure VIII-4. Advanced Turboprop Wind Tunnel Test

Transatmospheric Research and Technology

The Transatmospheric Research and Technology program, a part of the National Aerospace Plane program, seeks to demonstrate, by the mid-1990s, the following aerospace vehicle technologies:

(1) horizontal takeoff from, and landing on, conventional runways;
(2) sustained hypersonic cruise and maneuver in the atmosphere; and
(3) acceleration to orbit and return.

Development of critical technologies is being accelerated through a combination of computational efforts, ground-based experiments, and small-scale, hypersonic-technology flight experiments. Flight experiments will be conducted, as needed, on small, specially instrumented research vehicles in order to validate the predictions for high speed and altitude conditions that cannot be simulated adequately in ground facilities.

Major emphasis is being placed on designing and experimentally determining the performance level and efficiency of several airbreathing propulsion systems. Integration of a small rocket also will be required for on-orbit and de-orbit operations. Both passively and actively cooled high-temperature engine and airframe structures, combined with cryogenic tankage structures, as appropriate, are being designed for repeated exposure to combinations of extreme peak heating during ascent and long-duration heat loads during cruise. The resulting designs will be fabricated, and their performance as reusable, lightweight, high-strength structures will be tested under simulated flight-loading conditions. Analyses of propulsion system-airframe integration characteristics will be conducted continually throughout the program in order to define a high-performance, minimum-weight configuration.

The progressive, continual output of these efforts will be integrated into the design, development, and testing of preliminary concepts for propulsion system modules and airframe components for an experimental vehicle, the X-30. A major technology readiness assessment is planned for FY 1989 to determine if sufficient progress has been made to proceed to design and fabrication.

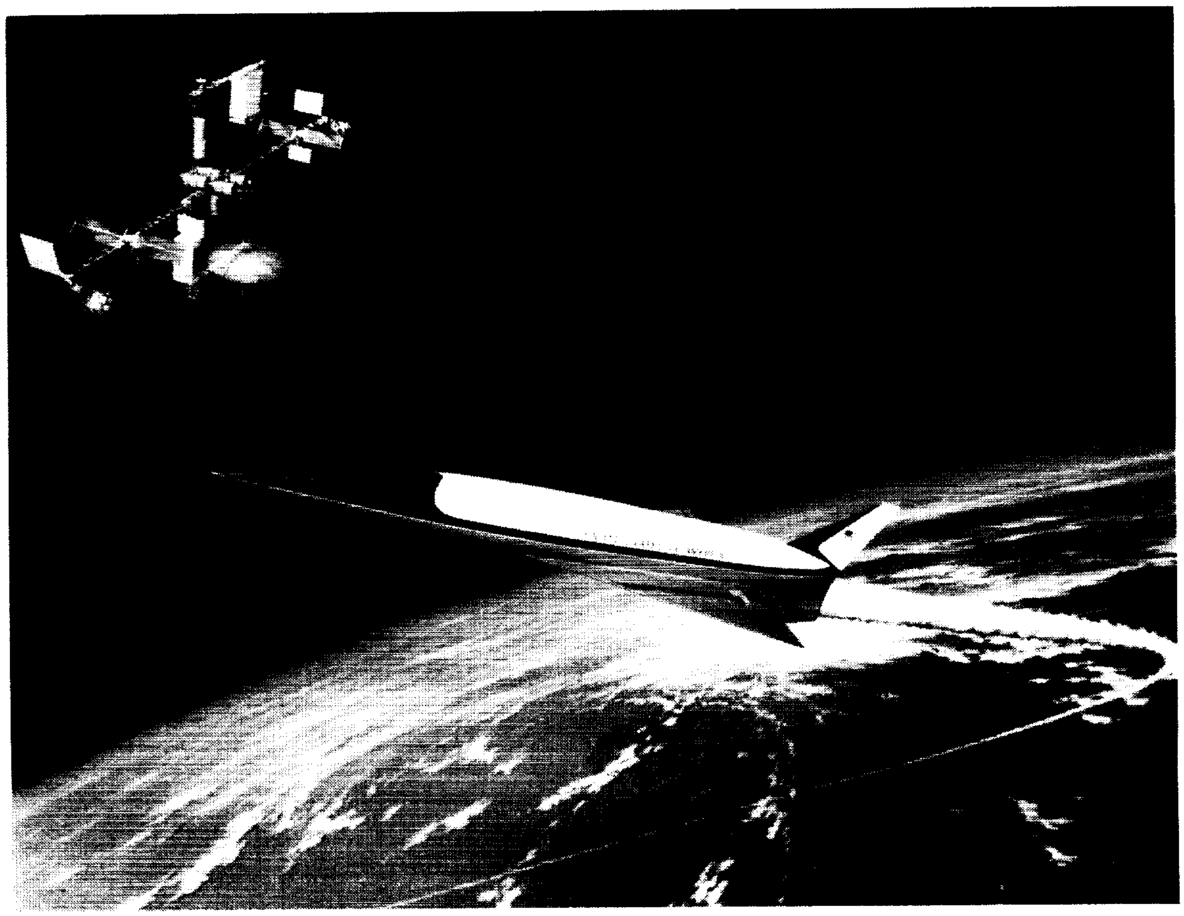


Figure VIII-5. National Aerospace Plane Concept

FY 1989 Augmentations and Initiative

Three research and technology development augmentations planned for FY 1989 to accelerate key research and technology development activities are described in succeeding paragraphs. In addition, a major wind tunnel revitalization program will be initiated to ensure that critical facilities are available to support planned and future Agency research and industry development needs.

Advanced Composite Materials

The Advanced Composite Materials technology augmentation will emphasize development of tough, durable, more easily processed composite materials for use in temperatures as high as 600°F. In addition to developing and characterizing toughened thermosetting and thermoplastic resins, the research will concentrate on developing advanced materials and efficient material processing and fabrication technology.

Innovative concepts for composite structures, including integral skin-stiffened wing and fuselage structures, will be explored using low-cost fabrication methods such as filament winding, thermoforming, and pultrusion (a process similar to extrusion except that the material is pulled, rather than pushed, through a die). Significant effort will be devoted to development and demonstration of concepts that effectively use the anisotropic properties of composites to realize the full potential of tailored composite structures. Subscale and large-scale testing will validate the structures and verify analytical predictions of structural performance and fatigue life, thereby providing the most efficient structural designs in terms of cost, weight, ease of fabrication, and improved performance.

Advanced Propulsion Concepts

This augmentation will provide high-leverage technology for advanced propulsion concepts that will form the basis for large improvements in propulsion capability for a broad range of applications. Enabling technologies will be developed that lead to:

(1) a 20-percent improvement in supersonic cruise aircraft range,
(2) a concept for a propulsion system that can operate efficiently from takeoff to Mach 6.0,
(3) a 20-percent improvement in fuel consumption for propulsion systems that must operate extensively at both subsonic and supersonic conditions, and
(4) a 25-percent improvement in the thermal efficiency of propulsion for subsonic transport aircraft.

Specific technology development areas include turbomachinery with high through-flows; compression systems able to operate over a wide range of flight Mach numbers; efficient multistream-mixing, variable-geometry components for cycle transition; and high-pressure radial turbomachinery for off-axis high-pressure-ratio core capability.

Emphasis will be placed on developing an analytical capability in computational fluid and structural mechanics that will allow evaluation of advanced concepts and verification of the feasibility of those concepts in small-scale or rig evaluations.

Aviation Safety and Automation

One of the eight national aeronautics research and development goals endorsed by the Administration in 1987 was to enhance the safety and capacity of the National Airspace System. The aviation safety and automation augmentation will accelerate progress toward that goal through the integration of control and guidance, human factors, and artificial intelligence technologies into automated flight and Air Traffic Control (ATC) management systems. These systems—designed to assist, not replace, aircraft crews and air traffic controllers—will improve situational awareness, reduce and eliminate the effects of human error, augment the handling of system contingencies, and improve the capabilities of air and ground systems.

The following three elements of the Aviation Safety and Automation program will combine to enable the development of major technologies, including those for ATC automation aids and an intelligent, error-resistant cockpit that will operate in an automated ATC environment:

(1) the Human-Automation Interface element, which addresses the role that humans play in an automated environment to ensure that tasks are allocated properly between the humans and the system in which they are operating;
(2) the Intelligent Error-Tolerant element, which focuses on the development of cockpit systems that intrinsically tolerate human error by passive and active means, and that provide flight crews with safe and effective methods to plan and replan flights, manage aircraft systems, and respond to aircraft-environment warnings; and
(3) the Aircraft-ATC element, which is aimed at the development and testing of controller-compatible ATC automation concepts and methods, their evaluation in both simulated and real environments, and their integration into the ATC system.

Major Wind Tunnel Revitalization

NASA's wind tunnels, like its other aeronautical research facilities, are used not only by the Agency's aeronautical researchers, but by its space researchers, industry, and other Federal agencies as well. The tunnels are unique national assets and provide specialized capabilities—including large scales, high Reynolds numbers, low turbulence, and high speeds—essential for conducting research and providing development support.

Many of the tunnels are over 30 years old, however, and have begun to deteriorate—the inevitable result of years of continuous operation. In addition, new testing capabilities will be required as generations of increasingly complex aircraft, including the National Aerospace Plane, enter development. And, reflecting the situation in the aerospace industry at large, other countries have developed similar—and in some cases superior—facilities, giving an edge to foreign competitors in aircraft development.

Figure VIII-6. 12-Foot Pressure Wind Tunnel

To address these problems, NASA has prepared a comprehensive, 5-year plan to revitalize existing facilities and to construct vital new facilities. In addition to wind tunnels, this initiative addresses associated support facilities and data acquisition systems and equipment.

Preliminary work has begun on revitalizing the 12-foot pressure wind tunnel at Ames Research Center. Work on other tunnels is scheduled to begin during FY 1989 and continue through FY 1993.

Future Initiatives

The initiatives described below are planned additions to the current aeronautics research and technology development program that will facilitate realization of the objectives outlined on pages VIII-5 through VIII-7. Their initiation will depend on future budget levels and program priorities.

A major component of several of these initiatives is an increased focus on technology validation. Validation, essentially the development of high-risk technologies to the point where they are proven to be reliable and ready to be used in actual aircraft design, is often the key to the acceptance and use of advanced technologies by the aerospace industry.

NASA has traditionally played a major role in bringing advanced ideas to this "technology readiness" stage. In recent years, however, validation efforts have lagged behind other critical research activities. To address this discrepancy, the Office of Aeronautics and Space Technology has recently completed, in close cooperation with industry, a multiyear plan that identifies critical technology development and validation requirements for civil aeronautics applications. The research and technology activities outlined in the plan are to be undertaken cooperatively by government and industry. NASA's planned support is reflected in several of the initiatives described below.

Subsonic Transport and Commuter Aircraft Technology

Despite inroads from foreign competition, the U.S. aerospace industry continues to contribute major surpluses to the Nation's balance of trade. However, as foreign manufacturers incorporate more and more advanced technology into their products, U.S. manufacturers have experienced a constant erosion of market share in two areas that produce the bulk of that surplus–large transport aircraft and engines.

The U.S. market share in jet transports dropped from 91 percent in 1969 to approximately 65 percent in 1987. Current forecasts predict that the U.S. share of the world transport market will fall to 55 percent or less by 1995. Similarly, U.S. manufacturers have retained only a 50-percent share of the market for propulsion systems for commuter aircraft as foreign competitors have captured a large share of worldwide sales of business jets and have almost totally dominated the light transport (20- to 60-seat) market.

Increased emphasis on key subsonic transport and commuter aircraft technologies could provide opportunities for improved U.S. products near the end of this century and provide new capabilities that would give the United States a competitive advantage in the following quarter century. In the subsonic transport area, propulsion efforts under this initiative will focus on development of technology for ultra-high-bypass-ratio ducted propulsors to improve fuel efficiency and reduce direct operating costs. Aerodynamics technology development will be directed at reducing both wing drag and fuselage turbulent skin-friction drag to provide further reductions in direct operating costs. Technology developments in electromotive actuation, fly-by-light, and associated flight-control systems and components can provide savings in weight, fuel, maintenance, and acquisition costs, as well as improved dispatch reliability. In the commuter aircraft propulsion area, technology development efforts will be directed at the unique requirements of small turbine engines to achieve significant improvements in fuel consumption and other performance characteristics. The transfer to industry of NASA's advanced computational techniques for analyzing fluid mechanics, as well as industry's use of the Agency's component diagnostic laboratories to test advanced components, will play key roles in these efforts.

High-Angle-Of-Attack and Supermaneuverability Technology

This initiative will seek an order-of-magnitude increase in advanced fighter maneuverability and agility, without degradation of supersonic cruise performance. Several years of research using simulators and free-flight wind tunnels have established the feasibility of propulsive flight control as a design option for future fighter aircraft. Evolving technologies—such as those for high thrust-to-weight engines, thrust vectoring controls, and design optimization through advanced computational capabilities—provide the potential for a revolutionary increase in the capabilities of advanced fighters. The integration of these technologies will allow previously unstable, highly efficient aircraft to achieve agile, safe, sustained supersonic, maneuvering flight at angles of attack above 70 degrees.

This initiative will emphasize flight-validated research in aerodynamics, controls, agility, and flight analysis. It will coordinate and correlate flight tests of an F-18 high-angle-of-attack research aircraft with wind tunnel tests, piloted simulator studies, computational fluid dynamics, and aircraft motion analysis. Its main elements will include:

(1) integrated thrust vectoring controls,
(2) tunnel-flight correlation,
(3) forebody aerodynamics,
(4) vortex flows,
(5) deep stall and wing rock,
(6) handling criteria and post-stall maneuver, and
(7) flight-dynamics analysis and motion prediction.

And its initial focus will be on:

(1) wind tunnel and analytical research to investigate the aerodynamic, propulsion system, and structures interactions resulting from multi-axis thrust vectoring;

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(2) simulator research to establish a data base for high-angle-of-attack controllability criteria; and
(3) simulator and design studies to develop a data base for integration of aerodynamic and propulsive flight controls on the F-18 research aircraft.

High-Speed Civil Transport Aircraft Technology

The growth of population and industry in the Pacific Basin, South America, Asia, and Africa, and the resulting increase in trade and multinational business, will create a significant market for over-ocean transportation with stage lengths considerably greater than North Atlantic stage lengths. These greater lengths, coupled with the large percentage of travel that will be business rather than tourist oriented, will increase the value of reduced trip time and increased productivity. Current studies indicate that a fleet of up to 300 supersonic transport aircraft could be in operation by the year 2000 and a fleet of 1,500 by the year 2025. The loss of this significant market to aggressive foreign competitors would damage severely the U.S. position in aerospace sales, balance of trade, and technology leadership.

A concerted technology development initiative by NASA is required to satisfy airline requirements in speed, range, capacity, operating economy, and environmental impact. Primary emphasis for this initiative will be on establishing multidisciplinary research programs to develop critical technologies, and on systems integration studies to ensure that the full synergistic benefits of each technology advance are realized in any subsequent aircraft design process.

Figure VIII-7. High-Speed Transport Concept

This initiative will be able to build on the strong technology base being developed under the National Aerospace Plane program. NASP research in areas of technological commonality—including high-temperature materials and structures, advanced cockpits, guidance and controls, and predictive computer codes—will advance the state-of-the-art of areas in which technologies for high-speed civil transport aircraft will be developed.

Critical technology for high-speed civil transport aircraft will be developed in programs focused on:

(1) advanced propulsion systems, including determination of the feasibility of the supersonic through-flow fan concept, emphasis on high-temperature materials, and investigation of variable geometry components;
(2) aerodynamics, including supersonic laminar flow and improvement of aerodynamic efficiency through fuselage shaping, wing-body blending, planform designs that minimize drag due to lift, and favorable integration of the propulsion system;
(3) materials and structures, including a broad-based examination of lightweight, temperature-resistant materials for airframes and of designs for structures embodying new materials; and
(4) advanced controls, including technology development for fiber optics, electrical flight controls, and an advanced cockpit featuring advanced sensor-produced displays.

Advanced Short Takeoff and Vertical Landing (ASTOVL) Technology

This initiative will develop, in a broad ground-based program, supersonic STOVL technology for use in selecting the most promising concepts for a flight vehicle. A secondary objective is to obtain for propulsive-lift aircraft the cruise data base needed for a new generation of high-performance fighters able to operate from a variety of surfaces, including damaged runways and the decks of small ships.

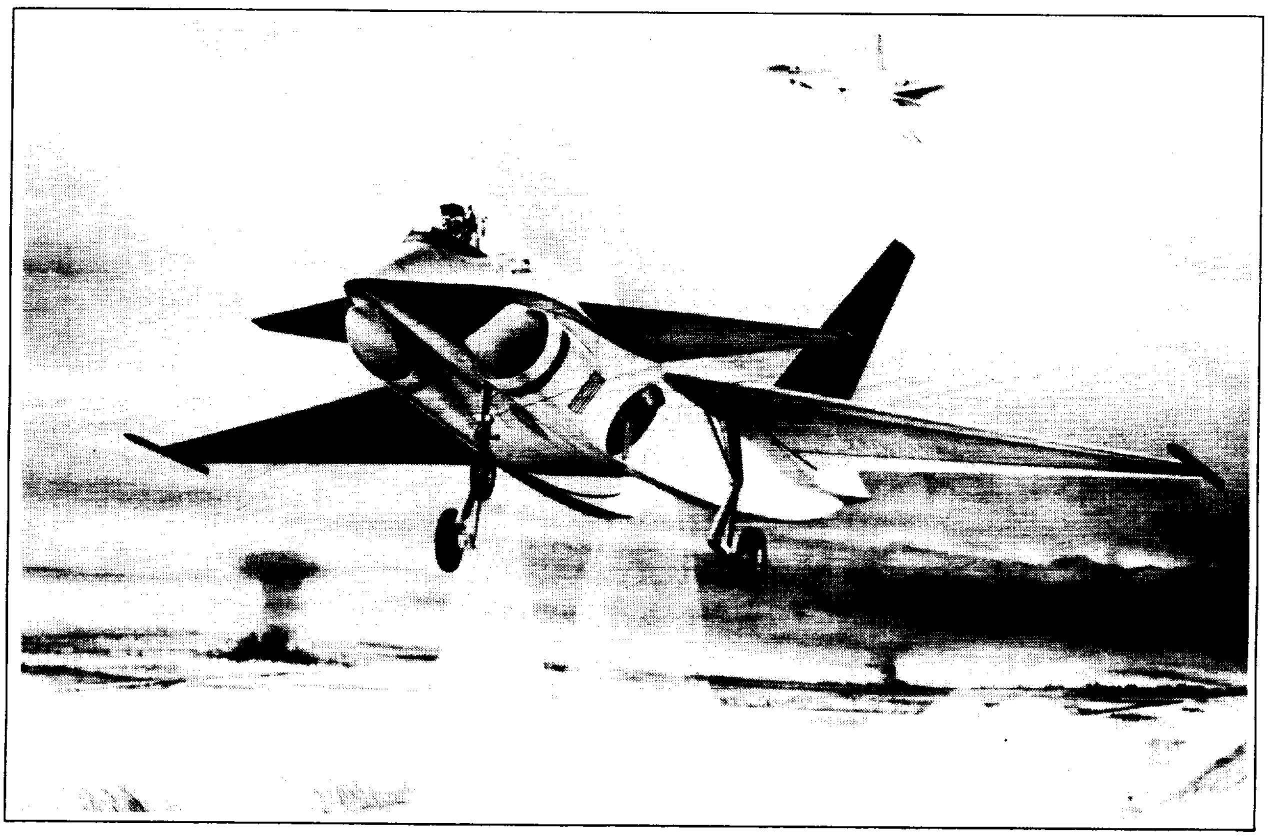

Figure VIII-8. STOVL Concept

Research will emphasize:

(1) development, fabrication, and test of small- and large-scale models and propulsion components;
(2) development, and test on a large-scale aircraft model, of a nearly full-scale, flight-like ejector-augmentor propulsion system with vectored core thrust;
(3) modification of an existing engine for use in demonstrating, on the ground, a concept for an advanced STOVL propulsion system;
(4) development of methodology for evaluating leading supersonic STOVL concepts and propulsion systems; and
(5) computational analyses of the cruise performance of propulsive-lift configured aircraft.

High-Speed Rotorcraft Technology

This initiative will investigate, and further develop, emerging technologies that offer truly revolutionary advances in rotorcraft performance. New rotary-wing vehicles will leapfrog current helicopter limitations, offering, for example, a 200- to 300-percent increase in speed. They will earn rotorcraft a much broader role in both civil and military applications.

Systems studies already are under way to define configurations and enabling technologies for high-speed rotorcraft of the future. Advanced configurations will have the fast, smooth, and efficient cruise characteristics of a subsonic jet airplane while retaining the excellent low-speed performance and agility of the helicopter. Improvements in cockpit-crew integration and mission

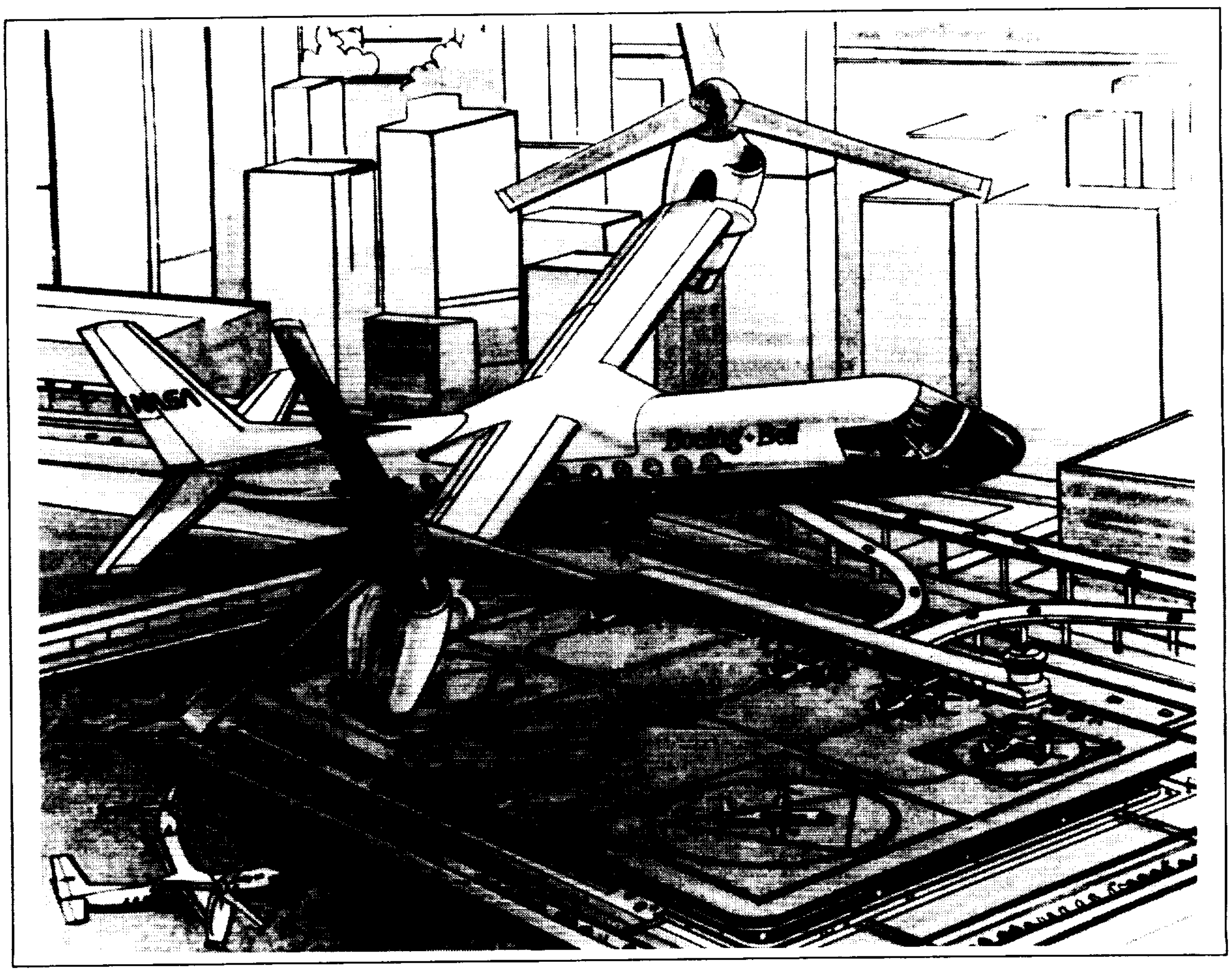

Figure VIII-9. Tiltrotor City-Center Concept

management technologies will allow the around-the-clock, zero-zero operations that will be required by both civil and military operators. As enabling technologies are developed and validated, military needs will provide the mission requirements for initial application and in-flight validation of integrated systems. Civil applications will follow as the National Airspace System is modified to best benefit from the enhanced safety and productivity of these high-speed rotorcraft.

Aeronautics Beyond the Year 2000

The benefits flowing from the current programs and proposed initiatives summarized above will continue to accrue to the U.S. aviation industry—and the Nation—well into the next century. Given the long lead-times required to move from research and technology development to the use of new technology, NASA is already laying plans for advancing the frontiers of technology development so that it will be able to meet its challenging mission of ensuring the preeminence of U.S. civil and military aviation.

Many of the tools and facilities that will be required to support research and technology development into the 21st century already exist or are under development.

An area of extreme importance is the growing dependence of aircraft and engine design on numerical simulation. By endorsing a research and development strategy for high-performance computing, the White House Office of Science and Technology Policy has taken a major step to ensure that advanced capabilities in this critical discipline will be available as needed. Based on its state-of-the-art capabilities in numerical aerodynamic simulation, NASA will assume a lead role in coordinating the development of hardware, software, and networking technologies to address major aeronautical research challenges—including fully interdisciplinary optimization of vehicle designs.

COMMERCIAL PROGRAMS

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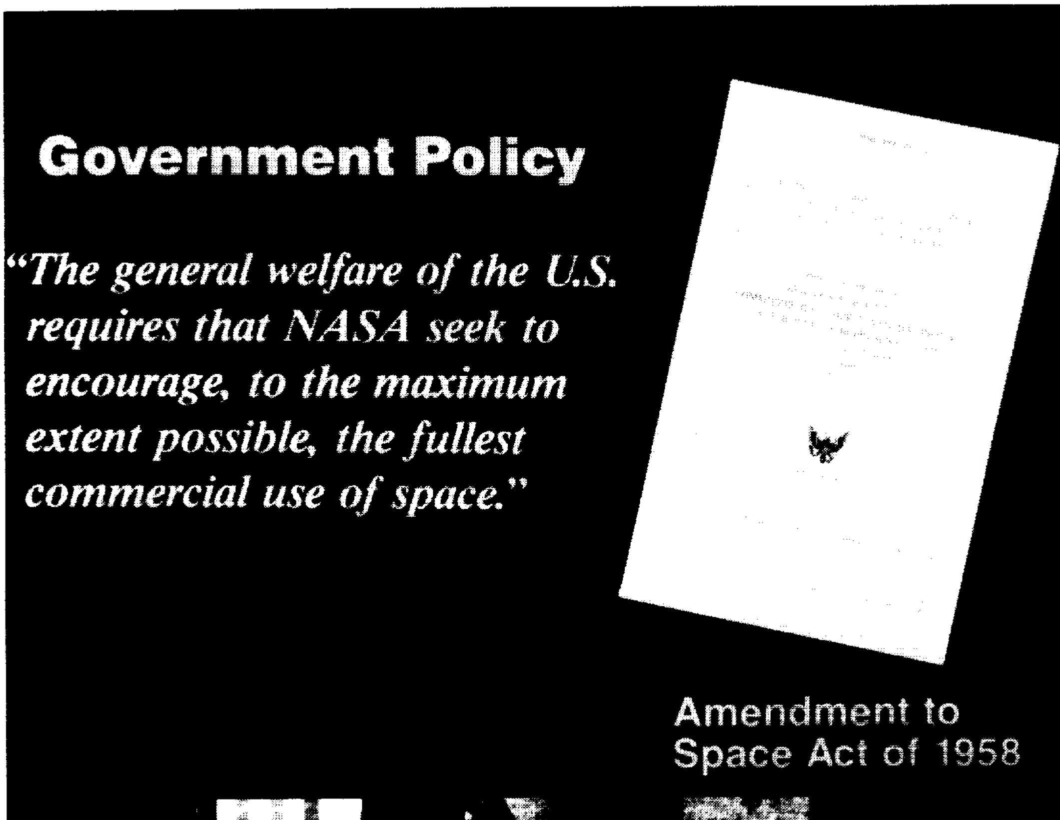

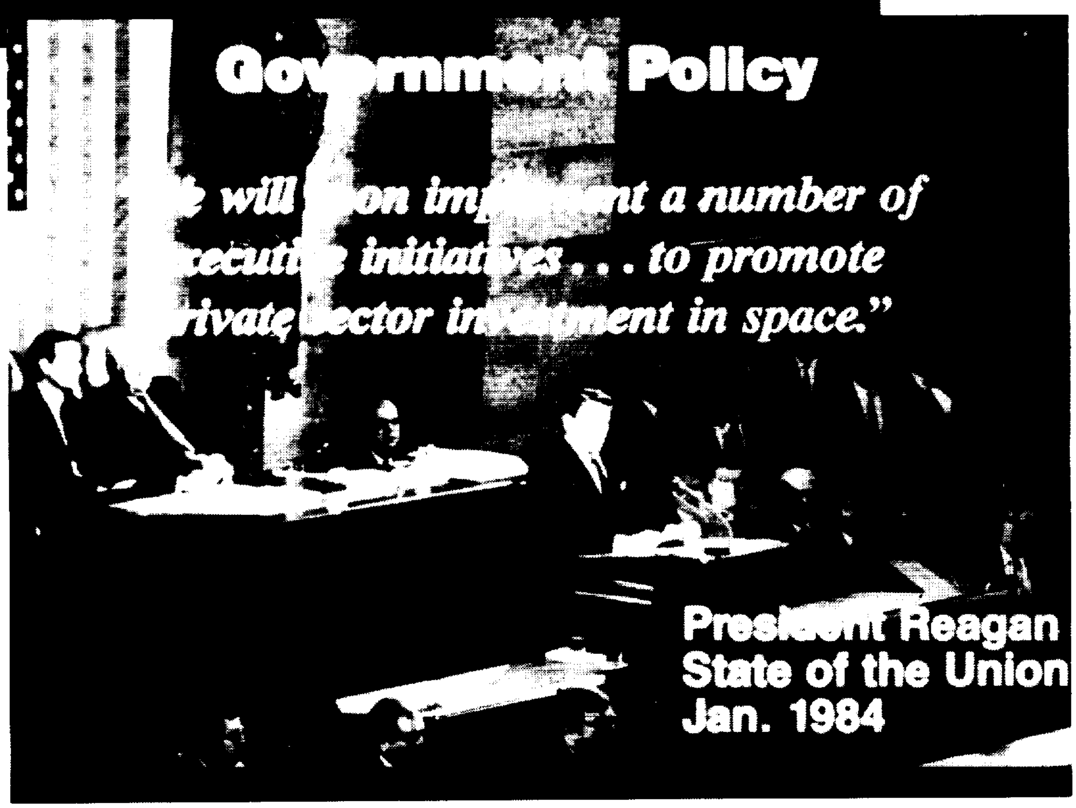

Commercial Programs

The Office of Commercial Programs (OCP) seeks, encourages, and facilitates the fullest commercial use of space. In this pursuit, OCP expands involvement of the private sector in civil space activities, supports new high-technology commercial space ventures, transfers existing aeronautics and space technology to the private sector, and expands commercial access to available NASA resources.

Introduction

The functions of the Office of Commercial Programs (OCP) are divided into three broad working areas: Commercial Development, Technology Utilization, and Small Business Innovation Research. This organization is shown schematically in Figure IX-1.

Commercial Development

The Commercial Development element is responsible for stimulating and encouraging the interest of the U.S. business community in commercially oriented space-related research and development. In this role, OCP supports industrial research activities and other initiatives that may benefit from collaboration with NASA research efforts. In addition, OCP develops programs to inform the private sector of opportunities for such collaboration.

Technology Utilization

The Technology Utilization element is responsible for the dissemination and secondary application of NASA-developed technology to industry, academia, and other government agencies. Information on the secondary application of NASA technology is disseminated through publications such as NASA Tech Briefs and Spinoff. Mechanisms such as NASA's Industrial Application Centers (see page IX-15) determine specific needs of businesses and, with the assistance of NASA field installations, identify the relevant NASA technologies that address those needs.

Small Business Innovation Research

The Small Business Innovation Research (SBIR) element is responsible for meeting NASA's requirements under the "Small Business Innovation Development Act of 1982." This law requires that NASA, as a federal agency with a research and development budget exceeding $100 million, set aside a percentage of its budget to fund small business research in aeronautics and space technology.

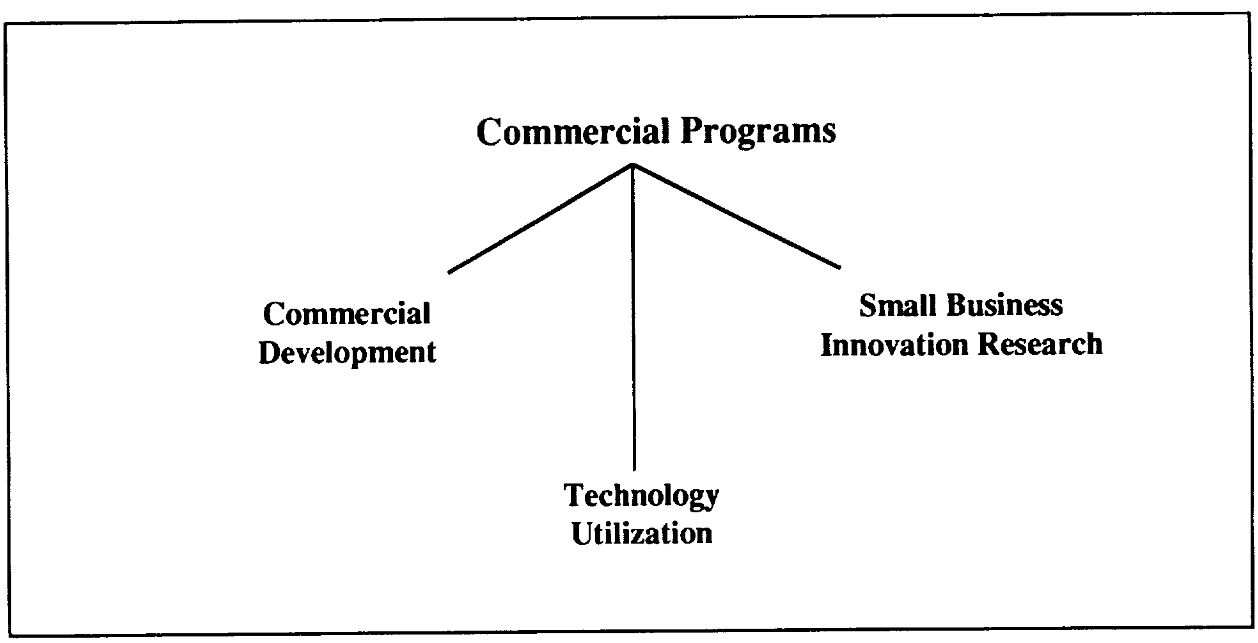

Figure IX-1. Elements of Commercial Programs

Goals

The goal of the Office of Commercial Programs is based on pronouncements issued by the President and then established by Public Law 98-361, the relevant portion of which states:

> "The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration seek and encourage to the maximum extent possible, the fullest commercial use of space."

Based on these directives, the mission of OCP is to provide a NASA program that will:

(1) expand U.S. private sector investment and involve ment in civil space activities;
(2) support new high-technology commercial space ventures;
(3) accelerate transfer, application, and use of existing aeronautics and space technology in the private sector; and
(4) expand commercial access to available NASA capabilities and services.

The goal of the Commercial Development program is to establish a national focus in support of opportunities for developing and expanding U.S. private sector investment and involvement in civil space activities.

The Technology Utilization program is designed to strengthen the national economy and industrial productivity through the transfer to and application in businesses of aerospace technology resulting from NASA's research and development programs. The technology NASA develops to meet its research goals and program needs is an important national resource. The goal of the NASA Technology Utilization program is to spread this valuable technology throughout the economy by working with U.S. industry to help it adapt the technology to meet its needs.

While the primary goal of the SBIR program is to use the innovative ideas of small, high-technology businesses to benefit NASA's aeronautics and space research and development programs, a second goal is to encourage commercial development of the products of the research conducted by the small businesses. Goals for the program in the future include development of opportunities for small business in the commercialization of space and the placing of greater emphasis on selecting for award SBIR proposals that show commitment to commercialization of the results of the NASA-supported research.

Objectives

Implementation of OCP's mission requires objectives to be undertaken in the near term to establish the framework for a long-range program plan. OCP's four major objectives are:

(1) establish close working relations with the private sector and academia to encourage use of and investment in space technology,
(2) facilitate private sector space activities through access to available U.S. government capabilities,
(3) encourage private investment independent of NASA funding, and
(4) develop and oversee consistent NASA-wide implementation of commercial space policy.

These major objectives have related objectives in each of the three working areas. Table IX-1 provides a summary of the area objectives.

Table IX-1. Commercial Programs Working Area Objectives

Working Area	Objectives
Commercial Development	(1) Establish close working relations with the private sector and academia to encourage investment in space technology and the use of the in situ attributes of space vacuum, microgravity, temperature, and radiation for commercial purposes; (2) facilitate private-sector space activities through improved access to available NASA capabilities and the development of new high-technology space ventures and markets; (3) encourage an increase in private sector investment in the commercial use of space independent of NASA funding; and (4) develop and implement commercial space policy throughout NASA.
Technology Utilization	(1) Accelerate and facilitate the application of new technology in the commercial sector, thus shortening the time between the generation of advanced aeronautics and space technologies and their effective use in the economy; (2) encourage multiple secondary uses of NASA technology in industry, education, and government, where a wide spectrum of technological programs and needs exist; and (3) develop applications of NASA's aerospace technology and unique facilities to priority nonaerospace needs of the Nation.
Small Business Innovation Research	(1) Continue to fund small, high-technology business in support of NASA missions; and (2) Develop mechanisms to foster commercialization by small businesses of the results of their SBIR research, including commercial use of the results in space.

Strategy

General strategies for meeting the four major commercial objectives are described in the following paragraphs.

Close Working Relations

NASA is working to strengthen its traditionally close relationships with the academic and industrial communities, particularly with nonaerospace sectors, which may have different concepts and proposals for commercial space projects. NASA builds the research and development foundation that will foster the commercial development of space and tries to accelerate the transfer of space technologies to the nonaerospace sector. The academic community can aid in expanding and extending NASA's basic research, while the industrial sector can ensure that significant space research leads to commercial applications.

In addition to establishing closer working relationships with the academic community and the industrial sector, NASA will address private sector requirements to the maximum extent possible. Active seeking of the private sector's recommendations for the most beneficial methods NASA can use in assisting the private sector has been an integral part of NASA's program since the inception of its commercial efforts in space. The major policy and program initiatives established by NASA in response to suggestions from industry are displayed in Table IX-2.

Private Sector Space Activities

To duplicate NASA's space and ground-based facilities is beyond the financial capability of many companies. These facilities should be viewed as national assets, and should be available to private organizations for their use and for national economic benefit. Private sector involvement in the commercial development of space could be considerably delayed without the availability of these unique resources.

OCP, in cooperation with the NASA program offices and field installations, will make government facilities and capabilities available to United States private sector users as much as practical when that use does not interfere with approved NASA and other government programs.

Independent Private Sector Investment

The Commercial Development program is one of many NASA programs competing for limited Agency resources. However, NASA resources allocated for commercial programs complement private sector funding, thereby accelerating the expansion of private sector investment in space research, while the private sector funding increases the resources available to NASA for other space research objectives.

Obligation of funds to projects by OCP generally requires prior commitment of resources by the private sector. However, programs funded by OCP's Technology Utilization and Small Business Innovation Research programs may be exceptions to this requirement. In projects administered by these two programs, NASA funds may be provided in the absence of a financial commitment by private sector participants.

Commercial Space Policy

The willingness of the private sector to invest in space endeavors depends, to a large extent, on its confidence that the federal government's actions relating to these investments will be consistent, dependable, and predictable. Concern over the possibility of changes in government policies and support for commercial development of space discourages and impedes private investment in commercial ventures.

OCP will strive to ensure that commercialization provisions of the National Space Policy are interpreted and administered in a consistent, dependable fashion, and will clarify and streamline NASA's coordination and decision-making processes pertaining to private sector requirements. Further, OCP will serve as the Agency's focal point for review and development of policies to meet the needs of the private sector.

NASA will meet challenges relating to space-based developments with practical approaches on many different fronts. It will work to lower business risks for private companies by minimizing capital costs. It will continue to provide facilities, both in space and ground-based, to accommodate industry needs. It makes its expertise available to private industry, as well as to government agencies and academia; and its technology is readily available for use in commercial applications. Through all of these means NASA will continue to function as a catalyst for innovative thought and will watch constantly for ways to reduce impediments to the commercial process. The five major categories of commercialization and their possible benefits to national economic growth are displayed in Table IX-3.

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Table IX-2. Commercial Initiatives Responsive to Industry Suggestions

WHEN SUGGESTED	WHEN IMPLEMENTED	1978-1982				1983-1985						1985 TO PRESENT									
	GOVERNMENT/NASA ACTIONS / INDUSTRY SUGGESTIONS FOR ASSISTANCE	SPACE ACT	NASA/INDUSTRY COOPERATIVE AGREEMENTS	SUPPORT FOR NASA FORTUNE-500 PROGRAM	USE OF NASA LAB FACILITIES	MATERIALS PROCESSING PROGRAM	OFFICE OF COMMERCIAL PROGRAMS	CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE	GENERIC PROCESSES, EQUIPMENT, AND CARRIERS	SPACE SYSTEMS DEVELOPMENT AGREEMENTS	ESTABLISHMENT OF SHUTTLE AUCTION PRICE	PRIVATIZATION OF ELVs	USE OF NASA LAUNCHING FACILITIES	OUTREACH PROGRAM	31% OF SECONDARY PAYLOAD CAPACITY ALLOCATION	INDUSTRIAL ADVISORY COMMITTEE	POST 51-L COMMERCIAL PRICING POLICY	AGREEMENT PROCESS STREAMLINING	COMMITMENT TO SPACE STATION	CONGRESSIONAL ACTIONS	OTHER AGENCY ACTIONS
1978	RECOMMENDATIONS FOR JOINT INITIATIVES	X	X																		
1983	AVAILABILITY OF BASIC RESEARCH AND EXPERIMENTAL FACILITIES		X	X	X																
	IMPROVED DISSEMINATION PROCESS						X														
	NASA SINGLE POINT OF CONTACT						X														
	NASA MARKETING OF ITS RESEARCH AND TECHNOLOGY MATERIALS			X										X							
	NASA RESEARCH ON PHENOMENOLOGY OF PROCESSING MATERIALS IN SPACE					X															
	PUMP-PRIMING MATERIALS PROCESSING RESEARCH							X													
	SIMPLIFICATION OF WAYS OF DOING BUSINESS WITH NASA						X									X		X			
	INDUSTRY ADVISORY COMMITTEE															X					
	"USER FRIENDLY" GENERIC RESEARCH FACILITIES								X												
	ESTABLISHMENT OF FIRM SHUTTLE PRICING POLICY										X										
POST-CHALLENGER	LONG-TERM CONSISTENT U.S. GOVERNMENT COMMITMENT												X				X		X		X
	GOVERNMENT ACTION TO EASE FOREIGN COMPETITION																				
	ACCESS TO SPACE ON TIMELY BASIS											X			X						
	FACILITIES TO SUPPORT LONG-TERM ON-ORBIT COMMERCIAL OPERATIONS																		X		
	ESTABLISHMENT OF FIRM PRICING POLICIES FOR START UP AND MATURATION OF COMMERCIAL OPERATIONS									X							X				

Table IX-3. Spectrum of Privatization/Commercialization Activities

TYPE	CHARACTERISTICS	TYPICAL EXAMPLES	ROLE OF U.S. GOVERMENT (USG)/NASA
PRIVATE SECTOR DEVELOPMENT FROM EXISTING NASA TECHNOLOGY FOR PRIVATE SECTOR USE	• MATURE INDUSTRY	• COMMUNICATION SATELLITES	• PRODUCER OF TECHNOLOGY • REGULATOR (DOT, DOD)
PURE PRIVATIZATION	• GOVERNMENT DEVELOPS SYSTEM TECHNOLOGY • PRIVATE SECTOR TAKES OVER DEVELOPED TECHNOLOGY	• EXPENDABLE LAUNCH VEHICLES (ELVs)	• PRODUCER OF TECHNOLOGY • REGULATOR (DOT, DOD) • OWNER/LESSOR OF ASSETS • FACILITATOR • CUSTOMER
PRIVATE SECTOR DEVELOPMENT FOR GOVERNMENT USE	• GOVERNMENT DEFINES REQUIREMENTS • PRIVATE SECTOR DEVELOPS NEW TECHNOLOGY	• TDRSS • PAM-D • TOS • CDSF	• DEFINER OF REQUIREMENTS • OWNER/LESSOR OF ASSETS • GUARANTOR • CUSTOMER
PRIVATE SECTOR DEVELOPMENT FROM NEW TECHNOLOGY FOR PRIVATE SECTOR USE	• GOVERNMENT DOES BASIC RESEARCH • GOVERNMENT PROVIDES INCENTIVES • PRIVATE SECTOR AND GOVERNMENT FORM PARTNERSHIPS (JEAs,CCDs) UNTIL PRIVATE SECTOR IS ESTABLISHED	• PHARMACEUTICALS • CRYSTALS • GEOSTAR	• CONDUCTOR OF RESEARCH • OWNER/LESSOR OF ASSETS • PROVIDER OF INCENTIVES
FULL COMMERCIALIZATION	• PRIVATE SECTOR DOES R&D, DEVELOPS, NEW SERVICES AND PRODUCTS, ETC. • GOVERNMENT MAY PROVIDE MINIMUM ASSISTANCE THROUGH TRANSPORTATION SUPPORT	• NEW MARKETS, PRODUCTS, AND SERVICES • RAW MATERIALS TRANSPORTED BY ELVs	• OWNER/LESSOR OF ASSETS

Current Program

Although the 2-year grounding of the shuttle has caused OCP to refocus its efforts, OCP has a variety of programs and projects designed to encourage and assist the private sector. Descriptions of some of OCP's major programs follow.

Commercial Development

Development of Commercial Expendable Launch Vehicle (ELV) Industry. In 1986 and 1987, NASA executed two first-of-a-kind ELV agreements. In 1986, it signed an agreement to allow use of its facilities for launching a privately developed expendable launch vehicle. In 1987, it signed the first U.S. government agreement transferring operation of a government-developed ELV to the private sector.

NASA currently is negotiating with additional firms for rights for them to manufacture another government-developed ELV commercially and for NASA support to several firms' commercial operations at NASA facilities.

Cooperative Agreements. Cooperative agreements between NASA and the U.S. private sector are the instruments through which NASA attempts to mitigate extraordinary up-front technical and financial risks the private sector may face in such capital investment projects. OCP employs six types of basic cooperative agreements:

(1) Joint Endeavor Agreement (JEA),
(2) Space Systems Development Agreement (SSDA),
(3) Technical Exchange Agreement (TEA),
(4) Industrial Guest Investigator Agreement (IGIA),
(5) Memorandum of Agreement (MOA), and
(6) Memorandum of Understanding (MOU).

Each of these types of agreements is designed to meet the requirements of specific types of private ventures, and each represents a varying degree of commitment on the part of both NASA and the private sector. NASA has entered into 77 such agreements to date.

The interactions that take place between NASA and industry to bring a commercial endeavor from the idea stage to full-scale production are depicted in Figure IX-2. An actual example of these procedures, the McDonnell Douglas Astronautics Corporation electrophoresis operation in space, is shown in Figure IX-3. Figure IX-4 shows Charles Walker of McDonnell Douglas conducting a hand-held crystal growth experiment, resting it against the continous-flow electrophoresis experiment equipment.

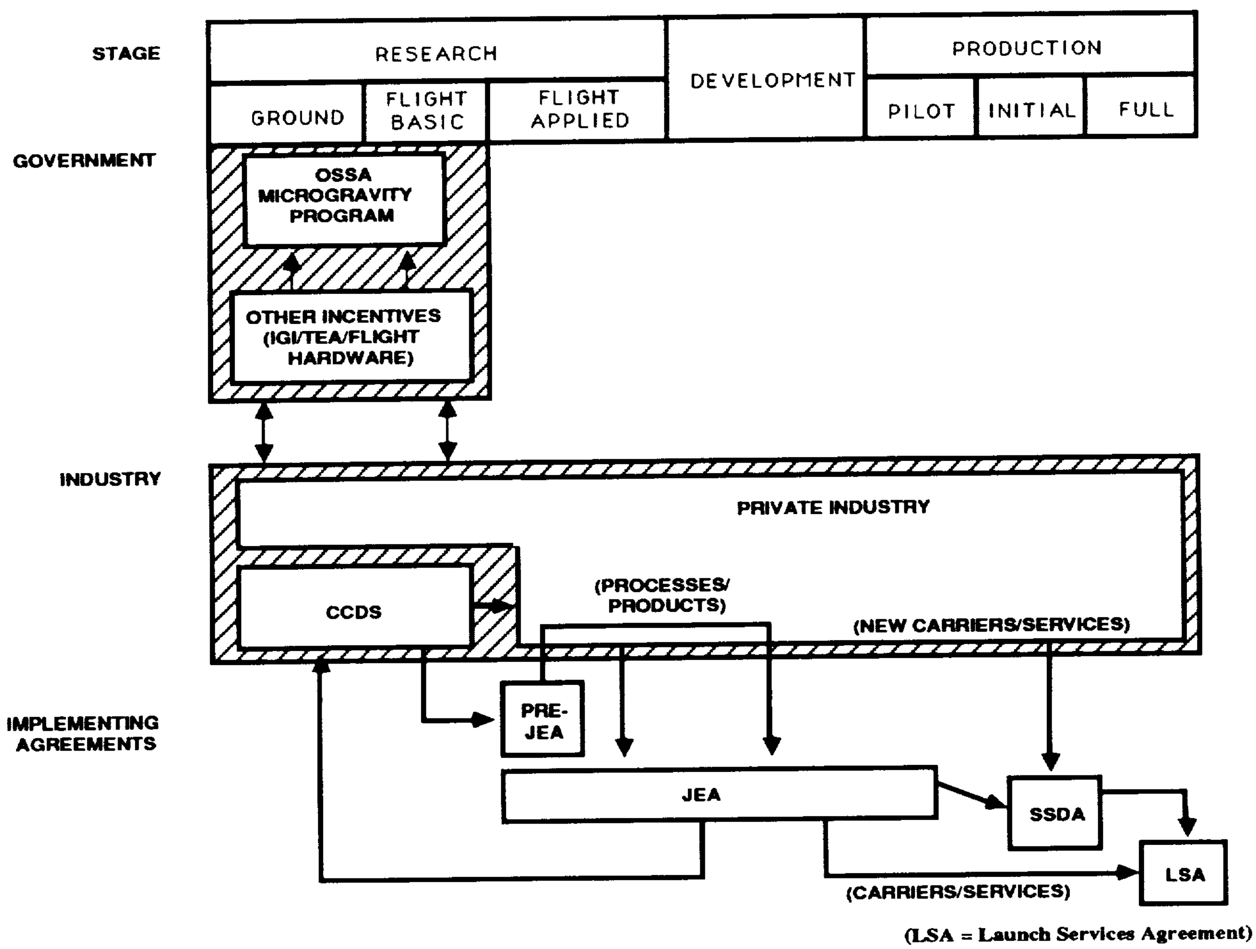

Figure IX-2. Commercial Development Interactions

Space Sytems Development Agreement (SSDA)

The SSDA, OCP's most recent innovation, has attracted significant private sector interest. A deferred payment provision for launch services, which can have many variations, is typically the primary characteristic of the SSDA. SSDAs are offered to eligible private sector concerns that are in the late development stage of research and development and intend to make revenue from the launch they plan to undertake. The fly-now, pay-later aspect of these agreements helps the concerns' cash flow problems while allowing NASA eventual recovery of costs. To be eligible for an SSDA, a company must submit a business plan that demonstrates a well thought-out venture and the expectation that NASA will be reimbursed in full for the launch services it provides. The project must be for the first flight(s) of a new industry promising significant national economic or other benefit.

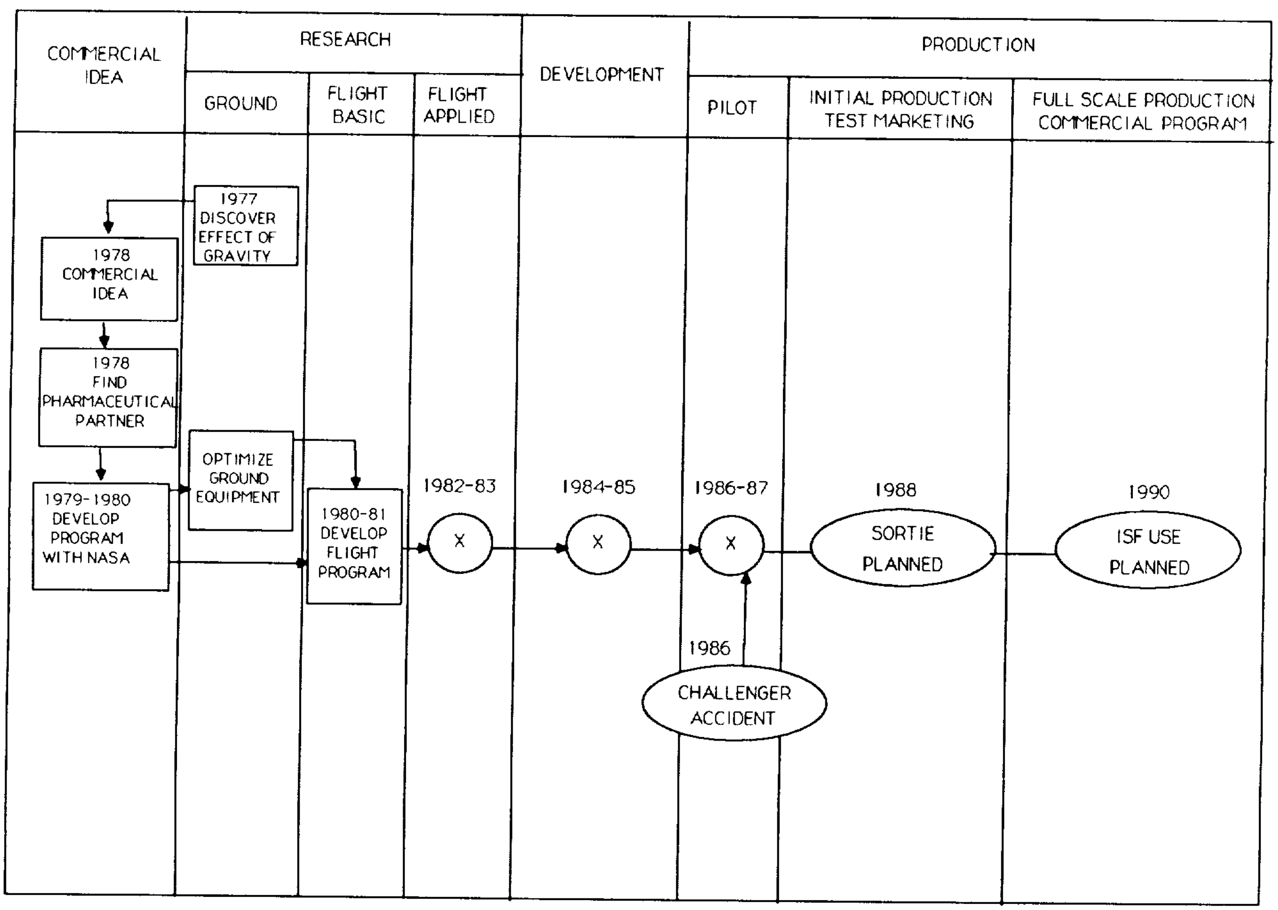

Figure IX-3. Commercialization Process for Electrophoresis Operations in Space

Figure IX-4. Crystal Growth and Electrophoresis Experiments Conducted in Space Shuttle

Centers for the Commercial Development of Space (CCDS) Program. In 1987, OCP increased the number of CCDSs from 9 to 16. The 16 CCDSs include over 100 participating private entities.

NASA's funding of each CCDS was planned to last 5 years in order to stimulate and stabilize CCDS' activities and to enable successful CCDSs to achieve self-sufficiency. However, because of the lack of flight

Centers for the Commercial Development of Space (CCDS)

The CCDS program was initiated in 1985 to stimulate interest and expand private sector investment in commercial space activities. CCDSs are not-for-profit consortia that represent undertakings involving U.S. companies, academia, and non-NASA government agencies. They are expected to stimulate high-technology, space-related research leading to development of new products and processes having the potential to contribute to new commercial ventures.

An example of a high-technology advance of interest to the CCDS program is the recent discovery of superconductors with higher transition temperatures. This technological breakthrough is of potentially immense social and economic benefit. It may have a positive impact on electrical and electronic subsystems in spacecraft. There is a possibility of further microminiaturization of components, which could result in more efficient systems requiring less power and less need for heat rejection.

Figure IX-5. Crystals Grown in Space Under the Centers for the Commercial Development of Space Program

opportunities resulting from the Challenger accident and the likelihood that research in process will lead to viable commercial applications, consideration is being given to extending this period.

A critical criterion in establishing a CCDS is maximization of the leveraging of NASA funds with a high percentage of funding by industry, university, and other institutional bodies. On the average, each NASA dollar is leveraged by approximately one and one-half dollars from consortia members; and their contribution should increase incrementally over the 5-year period, by the end of which each CCDS is expected to be self-supporting.

Technology Utilization

Technology Utilization at NASA is a program of long standing. For many years, NASA has maintained a systematic program for identifying space technologies that may have useful applications in the nonspace sector of the economy. The OCP Technology Utilization program involves both technology dissemination and technology application. Technology dissemination consists of identifying and gathering information on aerospace technologies that appear to have potential nonaerospace uses, and then making the technologies known to the private sector. Technology utilization is the use of the technologies in specific projects for public benefit.

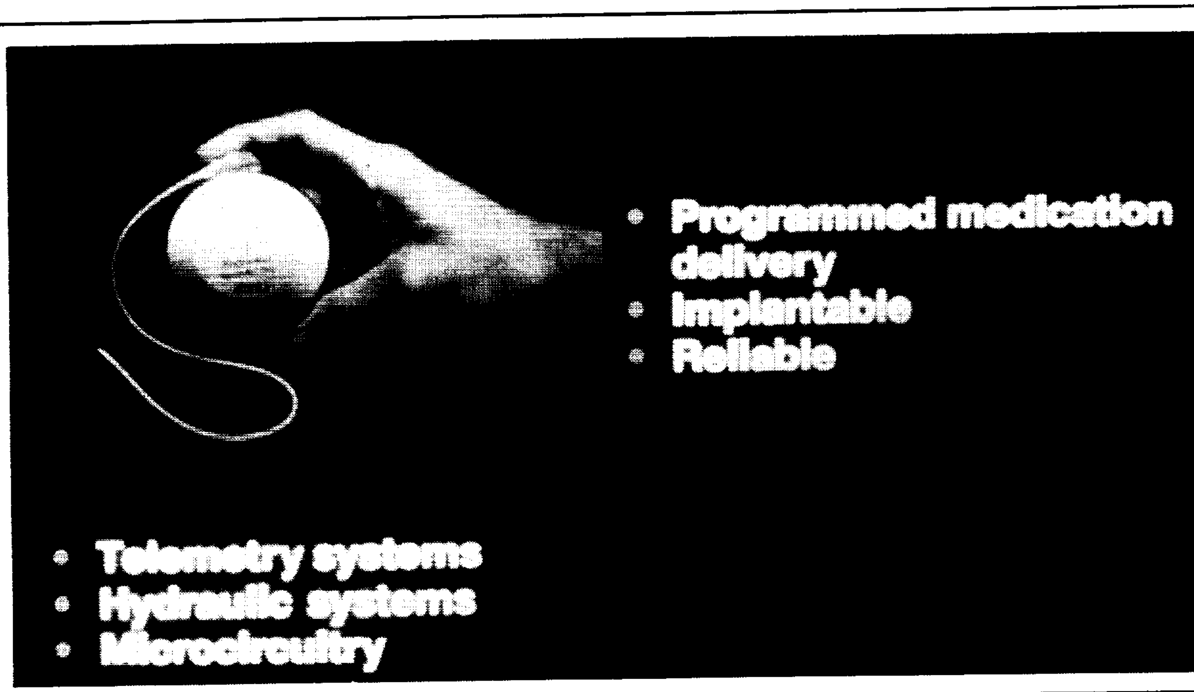

Figure IX-6. Programmable Implantable Medication System Derived from NASA Technology

During the past year, Industrial Application Centers (IACs) have strengthened their relationships with state-sponsored institutions, universities, and federal laboratories through an expanded outreach program called the Industrial Applications Affiliates program. Under this program, a number of NASA's field centers have developed cooperative working relationships with state-sponsored business-assistance institutions. At present, 39 state institutions have established, or are in the process of establishing, affiliate status with NASA IACs (see Figure IX-7). This program will result in a nationwide network for technology transfer, making NASA technology available to a wider range of U.S. industry.

In March 1987, NASA entered into an agreement with the Federal Laboratory Consortium to provide appropriate linkages between over 500 federal laboratories and NASA's nationwide transfer network. This network comprises NASA's Industrial Application

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Industrial Application Centers (IACs)

NASA's network of university-based IACs is the key component of the Technology Utilization information dissemination system. The IACs' computerized access to technical information has stimulated significant corporate interest in government-funded and government-derived advanced technologies. There are currently ten IACs across the United States. They cultivate strong ties with industry, identify their industrial clients' problems and technological interests, and assist the clients through exchange of technological information.

Centers, NASA's field centers' technology utilization offices, expert technology counselors, and technology applications teams. It seeks to enhance the transfer of NASA and other federally developed technologies to U.S. industry and public organizations. Access to unique technological resources and capabilities of the federal laboratories will be facilitated by this agreement. In turn, the commercialization of government-developed technology will be enhanced, improving productivity and creating a stronger U.S. industrial base.

Technology application requires interaction with private industries to learn of their specific needs or problems. Subsequently, aerospace-developed technologies are scrutinized for any that potentially can provide solutions. The technology applications activities of OCP include approximately 86 projects from the areas of automation, electronics, bioengineering, and rehabilitation and materials technology. To date, an estimated 30,000 spinoffs and applications of NASA-developed technology have resulted in the flow of new products and processes into the U.S. economy at an ever-increasing rate.

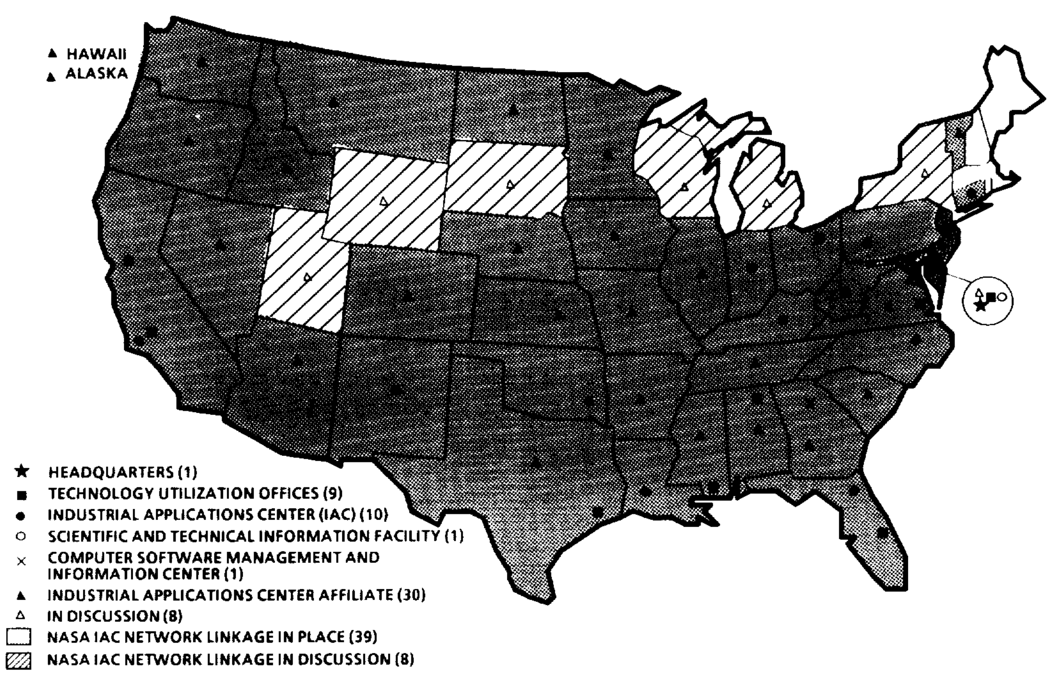

Figure IX-7. State Institutions Establishing Affiliate Status with NASA Industrial Application Centers

Status of Small Business Innovation Research (SBIR) Activities

The SBIR program, now entering its 6th year, has been a popular and effective program in all the federal government agencies. In NASA's program, more than 7,000 Phase I and Phase II proposals have resulted in 755 Phase I and 299 Phase II awards. More than half the Phase II projects completed to date have yielded results that are in use or are planned for use by NASA, and more than 20 percent have found their way into commercial products and services. In 1986 Congress extended the SBIR program through September 1993, but will decide before then whether the program will be continued.

Small Business Innovation Research (SBIR)

The SBIR Program is intended to increase participation of small, high-technology firms in NASA aeronautics and space research and development. The program is structured in three phases. Phase I consists of 6-month feasibility investigations of the most attractive innovations in response to an annual program solicitation. Phase II, the primary SBIR activity, develops the most promising ideas of those determined to be feasible during Phase I in projects that may extend for as long as 2 years. Phase III consists of commercial development by small business of the results of the Phase II research, or continued government-funded development or procurement under non-SBIR program funding.

The SBIR Program is funded at the level of 1.25 percent of the NASA research and development budget. Current legislation calls for the program to exist through 1992. At that time, Congress will determine if the program should be continued.

Planned New Initiatives

Since the Challenger accident, NASA's attention has been focused on returning the shuttle safely to flight and continuing the Space Station program. Shuttle flights will resume soon, the Space Station is moving steadily toward reality, and the time is nearing for commercial space operations to expand in scope and variety. Therefore, OCP has initiated the following significant program of aggressive initiatives to improve and expand industry's interest in the commercial development of space:

(1) create an industry committee to provide advice on commercial space issues,
(2) develop and recommend a new pricing policy,
(3) develop a plan to manage and optimize the 31-percent allocation of secondary-payload space on space shuttle flights to commercial payloads,
(4) streamline the Joint Endeavor Agreement process,
(5) provide new opportunities for small business,
(6) enhance the development of the commercial infrastructure in support of the planning and implementation of space-flight operations, and
(7) inventory the hardware facilities and services available for space-flight activities.

Industry Advisory Committee

NASA recently established the Commercial Programs Advisory Committee consisting of industry leaders who understand and are seriously interested in commercial space activities. Its purpose will be to advise NASA and help steer planning in such areas as research and the identification of the types of generic equipment that should be developed.

New Pricing Policy

NASA will develop a pricing policy for commercial customers, both for flight on the shuttle and for future use on the Space Station. New, creative approaches will be investigated to encourage policies that are broad and flexible and that will accommodate a spectrum of industries. The availability of such a policy is critical at this time to support industry planning through the next decade.

Space Allocation Management

OCD is developing a plan to manage and optimize the 31-percent allocation of secondary-payload space aboard the shuttle to commercial payloads. OCP will consider and investigate the capability and availability of all secondary payload opportunities.

In addition, NASA will develop and publish guidelines for the industrial community that will enhance flight opportunities and turnaround procedures for commercial payloads. Such guidelines will give commercial users the best possible chance of a timely flight for their payloads.

The Joint Endeavor Agreement Process

The Agency will develop a plan to streamline the agreement negotiation and settlement process. Doing business in a timely manner is critical to industry. OCP will determine how mutually beneficial agreements can be arrived at in the most businesslike manner possible.

New Opportunities for Small Business

OCP also will begin to include small business innovative research in its commercial programs to the extent possible. It will make every effort to support endeavors by small business communities oriented to space. These activities will add an important dimension to OCP's programs by bringing to the programs the innovation that America's small businesses have so amply displayed in the past.

Flight Operations Support

OCP is taking steps to enhance the support available to activities involved in flight operations for the commercial development of space. The support will include providing information on capabilities available commercially, as well as from NASA and other agencies, and on programs to focus such capabilities on planning and implementation. These steps are expected to improve the returns from space-flight operations related to both developmental and reimbursable commercial activities, and to develop the Nation's commercial infrastructure for space flight.

Commercial Space Users Catalog

NASA is developing a catalog to assist industry in the commercial development of space. The catalog will contain an inventory of hardware, facilities, and services available from the government and the private sector. In addition, it will serve as a general guide to accessing space and enable future commercial users of space to understand the process and requirements of space flight.

Future Focus

Commercial Development

Sixteen Centers for the Commercial Development of Space have been established since the start of the program. The average cost of a CCDS is just under $1 million per year. Several CCDSs have developed strong linkages with the private sector and are developing flight hardware for applied research in space.

OCP is cooperating with the Office of Space Science and Applications to develop multiuser, multiuse, government hardware that will reduce the experiment costs of individual entrepreneurs to an affordable level. This hardware includes various types of furnaces, materials processing equipment, and experiment-carrier supporting structures that private companies may use for space experiments. Use of the hardware provides access to microgravity through flights on the shuttle, on NASA aircraft, and on sounding rockets.

In order to maintain momentum in activities related to the commercial use of space, OCP will develop improved methods for facilitating private sector agreements and commitments to develop commercial opportunities in space. Institutions with strong research capabilities in science and engineering, in collaboration with industry and/or industrial associations, will be encouraged to participate in NASA-sponsored workshops and endeavors to accelerate U.S. commercial leadership in the use of space.

NASA's goal of expanding opportunities for U.S. private sector investment and involvement in civil space and space-related activities will be partially achieved by increasing the amount of space-related research conducted by the private sector, the number and type of NASA and private sector facilities available for space use, and the private sector's awareness of the opportunity to use NASA's terrestrial and space-based facilities for potential commercial research.

Through coordination with various industrial sectors and NASA program offices, OCP's efforts to enhance commercial research and development will include an increase in the availability of generic, multi-use research experimentation equipment. This equipment—as well as ground-based hardware, software, and analytical tools—will be developed to expand the research data base on the commercial uses of space. The private sector will require this data base for help in making economic decisions about committing to research and, potentially, to manufacturing. Emphasis will be accelerated to build the required technical infrastructure. The main thrust of the effort will be directed by the private sector in coordination with NASA field centers. Resources also will be made available to obtain hardware to support flight experiments conducted by industrial researchers. This hardware may include across-the-cargo-bay carriers, mid-deck accommodation racks, or supporting subsystems. It also includes possible leasing of hardware developed by the private sector to exploit commercial research and development of space.

Analytical and physical integration support are required for experiments conducted under JEAs. The support is intended to encourage and facilitate new private sector use of space and is directly proportional to the number of commercial research and development flight experiments scheduled. The use of ground-based research facilities, aircraft, and sounding rockets for commercial experimentation will be given emphasis in order to provide limited access to the microgravity environment for certain commercial experiments.

Support of the Commercial Development program requires a broad foundation. Ad hoc and continuing studies by experts are required to provide the direction and feedback needed by the program, especially when economic, commercial, and technical circumstances are changing rapidly. Study results assist in the development of short- and long-range plans and agency policy. Support services, equipment hardware maintenance, and studies and analyses also are elements of Commercial Development support.

Technology Utilization

To accomplish the Technology Utilization goal, NASA has established and operates a number of technology transfer mechanisms to provide timely access to useful technologies by the private and public sectors of the economy. Almost every part of U.S. industry is affected by the technology transfer process, especially in such areas as automation, electronics, materials, and productivity. In the public sector, medicine, rehabilitation, transportation, and safety are areas in which aerospace technologies have been especially beneficial.

NASA has continued its broad and comprehensive efforts to promote and encourage effective application and use of new innovative aerospace technologies throughout the public and private sectors of the U.S. economy. Of particular note is the upward growth of industrial and business subscribers to NASA Tech Briefs. The number of subscribers now exceeds 160,000. The 100-percent increase since January 1985 represents a growth rate averaging over 5,000 new subscribers per month and provides an effective measure of the importance and value U.S. industry places on new and emerging technologies.

The NASA-sponsored Industrial Application Center (IAC) network has made significant strides in developing effective linkages with state-sponsored institutions engaged in industrial and economic growth. This broadening and strengthening of the nationwide technology transfer network is continuing to gather momentum, with nearly 40 of the 50 states now being linked to transfer products and services available through the IAC efforts. NASA expects to continue this activity during the balance of FY 1988 and into FY 1989. An additional milestone was reached in late 1986 when the Federal Laboratory Consortium (FLC) for Technology Transfer (established under P.L. 99-502) and NASA elected to enter into an agreement in early 1987 that establishes formal linkages between the NASA IAC network and the various federal laboratories. Based on the successful completion of an experimental program between the NASA IAC at the University of Southern California and the FLC Far West Region, IAC industrial clients now will be able to gain controlled access to nationwide federal laboratories engaged in research and development activities of parallel commercial interest. This development of new linkages is spurring the acceleration of technology transfer and the application of federally-sponsored technologies in the mainstream of the U.S. economy. NASA also is seeking to familiarize and involve the private sector to a greater extent. The hiatus in shuttle flights caused by the Challenger accident has shifted the focus of NASA's commercial programs from in-space experimentation to ground-based opportunities and exploitation of available technology. The IACs are a natural focal point for increasing awareness of available technology and opportunities.

NASA has authorized experimental technology-transfer programs, involving both process and product, at NASA's Jet Propulsion Laboratory as a means to enhance the access of small and large industrial firms to that Laboratory's technology. (See inset below.) At present, 20 industrial firms are participating in RIMTECH programs and another 25 firms are expected to join within the next 12 months.

Based on the increasing demand for NASA Tech Briefs and the expanding IAC network, increases in identification and reporting of new technology are anticipated. Evaluation and packaging of these technologies for publication are expected to stimulate industrial interest and participation in NASA's Technology Utilization and Commercial Development programs.

OCP plans continued strengthening of the Technology Counselor network at its field installations to provide for expanded identification of NASA technical capabilities and expertise. This capability and expertise is necessary for matching and cross-correlating NASA technology with industry needs specified by the NASA IACs. To facilitate timely and efficient interaction between Technology Counselors, IACs, and other organizations in the NASA technology transfer network, a coherent, microcomputer-based communications system is planned for use with the NASA Technology Utilization infrastructure. Expansion of this communications system, increased effective communication, and data storage and retrieval systems will greatly enhance the overall capability of the network to coordinate technology transfer activities, and to respond to user needs efficiently and with minimum overlap and duplication of effort. Moreover, the network will enable technology transfer managers to maintain appropriate controls over the process to ensure overall program effectiveness and management accountability.

Research Institute for the Management of Technology (RIMTECH)

In May 1986, NASA entered into a cooperative agreement with the nonprofit California-based RIMTECH to introduce Jet Propulsion Laboratory (JPL) technology to industrial users in the Southern California area. For an entry fee, RIMTECH clients are offered NASA's technical assistance, information retrieval services, licensing rights, and the possibility of co-funding of projects in the development stage. NASA fulfills its charter and accrues the benefits of a broadened high-technology-base industry, incentives for JPL employee creativity, potential royalties from patent licensing, and reverse technology transfer to NASA/JPL from industry.

As OCP's role in industrial outreach expands, additional emphasis will be required on development of program goals and objectives in terms of long-range plans for the Technology Utilization program. Some of the many management planning and support requirements that will be needed are as follows:

(1) focused efforts on assessing potential participants in U.S. industry,
(2) preparation of information guidelines to support cooperative relationships throughout the NASA technology transfer network,
(3) satisfaction of the anticipated increase in demand for Technology Utilization publications, and
(4) response to an increased number of program inquiries.

Specific actions also are planned to strengthen program development, evaluation, and coordination on an internal as well as external basis to support the national technology transfer network and the emerging commercial use of space outreach efforts.

A broadening of application-team responsibilities is anticipated to help NASA IACs bring industrial client problems together with existing aerospace technologies, leading to project definition and industry-driven cooperative projects. This effort will result in increased tangible and meaningful applications of aerospace technology in the private sector, thus enhancing the productivity and competitive posture of U.S. industry.

NASA will use its existing dissemination network to acquaint U.S. industrial firms with opportunities to actively interact and participate with NASA in technology transfer and space commercialization. Contact on a face-to-face basis is envisioned, with appropriate follow-up (including seminars, conferences, and workshops) to explore more detailed characteristics of the "opportunities" for interaction. The NASA IACs are in a unique position to serve as NASA's surrogate in aligning U.S. industrial interests in space commercialization. The IACs also can focus interest on opportunities for terrestrial commercialization of advanced technologies derived from NASA's research and development programs. The technological needs of industry would benefit from this synergistic approach, designed to bring engineering resources of industry and NASA into closer proximity. Successful technology transfer occurs most frequently in an environment where knowledge is shared easily and where the advantages obtained through cooperative endeavors are explained and understood. It is this role that the NASA dissemination network can readily fulfill.

NASA's IACs intend to expand their relations further, to include specific technology-transfer arrangements with the Small Business Administration's Small Business Development Centers (SBDCs) throughout the Nation. The IACs will service more than 570 SBDCs, linking the centers into all the federal research and development laboratories. Similar arrangements are being developed with the Department of Commerce to establish interfaces between its more than 120 Minority Business Development Centers nationwide and the technical resources and capabilities available in the National Aerospace Plane program and the federal research and development laboratories.

Small Business Innovation Research

Interest from the private sector in the SBIR program has increased, resulting in a growth rate of 10 to 12 percent per year in proposals. NASA expects this rate to continue and expects to receive more than 2,000 Phase I proposals in FY 1988. Current budget levels permit funding approximately 200 Phase I proposals and 85 to 100 Phase II proposals per year. Since the SBIR program budget is based on a percentage of the total NASA research and development budget, the future number of awards cannot be estimated with confidence until the total research and development budget is known. It is possible that the program could double in size during the next 5 years.

The primary objective of the SBIR program remains unchanged: increased participation of innovative, high-technology small businesses in NASA's aeronautics and space programs. However, OCP intends to place additional emphasis on selecting more SBIR projects that, from their outset, also have strong potential for yielding commercial applications, and to find mechanisms for encouraging and assisting small businesses to progress toward commercial markets for the results of their research.

EXPLORATION

Exploration

The recently established Office of Exploration is responsible for developing alternatives and recommendations for a future national decision on a focused program for human exploration of the solar system. It will provide a central coordination point for technical planning studies undertaken by organizations throughout NASA and will initiate science-experiment and facility-definition studies to identify and define the science potential of and opportunities for human exploration programs. It also will initiate research studies for programs that can benefit from access to planetary environments and support from human presence. In all its activities, it must work in close accordance with NASA's overall plans, programs, and capabilities.

Introduction

In the fall of 1986, NASA Administrator James Fletcher asked astronaut Sally Ride to establish a task force to energize a discussion of long-range goals for the U.S. civilian space program. Dr. Ride and the task force recognized that the Nation's space program is faced with a dilemma; namely, that aspirations for the tremendous visions offered by the National Commission on Space (NCOS)—the Paine Commission—are constrained by fiscal realities and by the requirement outlined by the President's Commission on the Challenger Accident—the Rogers commission—that NASA return the shuttle fleet to flight status as its first priority.

To conduct the analysis, Dr. Ride's task force thoroughly reviewed four initiatives that, in its view, could serve as the basis for future space leadership. The initiatives spanned a broad spectrum of content and complexity and included both robotic and human exploration missions. They were the following:

(1) mission to planet Earth,
(2) robotic exploration of the solar system,
(3) lunar base, and
(4) humans to Mars.

The task force's intent was not to choose one initiative over the other three, but rather to understand the national benefits and implications such missions might have. The initiatives themselves, and the results of the study, were detailed in a report, Leadership and America's Future in Space, published in August 1987 (see inset on Page II-6).

In that report, the task force recommended that, before the nation commits to a specific long-range goal, it develop a strategy "...consistent with national aspirations and consistent with NASA's capabilities." To this end, the task force suggested adoption of a strategy of evolution and natural progression. This strategy

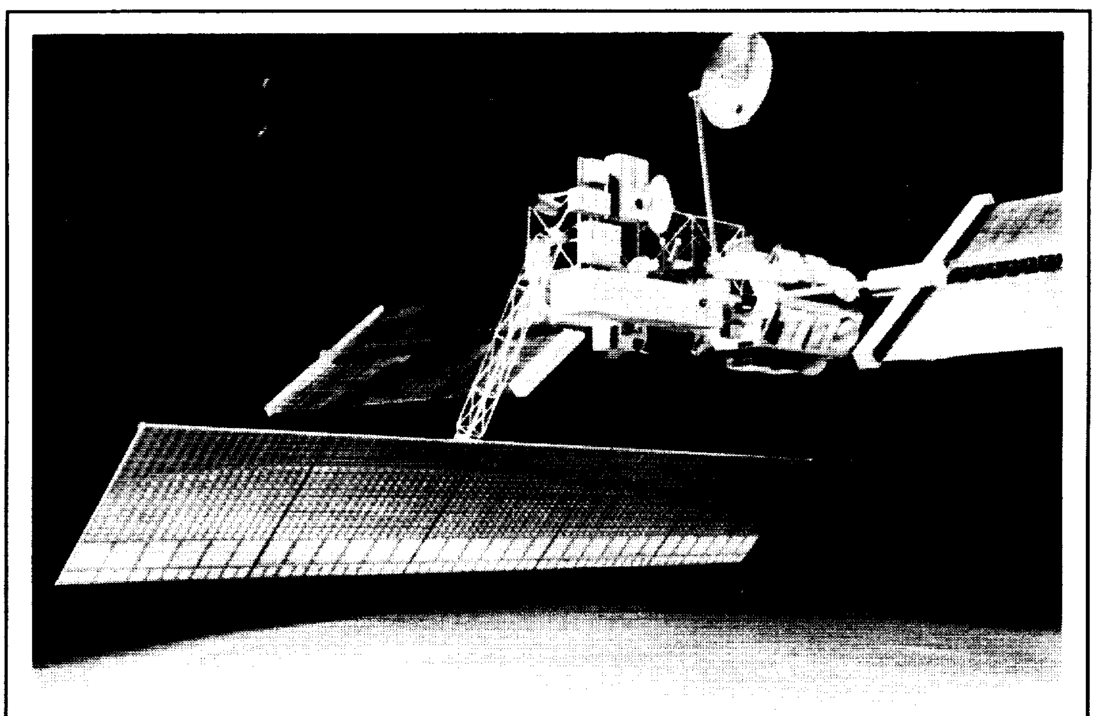

Figure X-1. Mission to Planet Earth

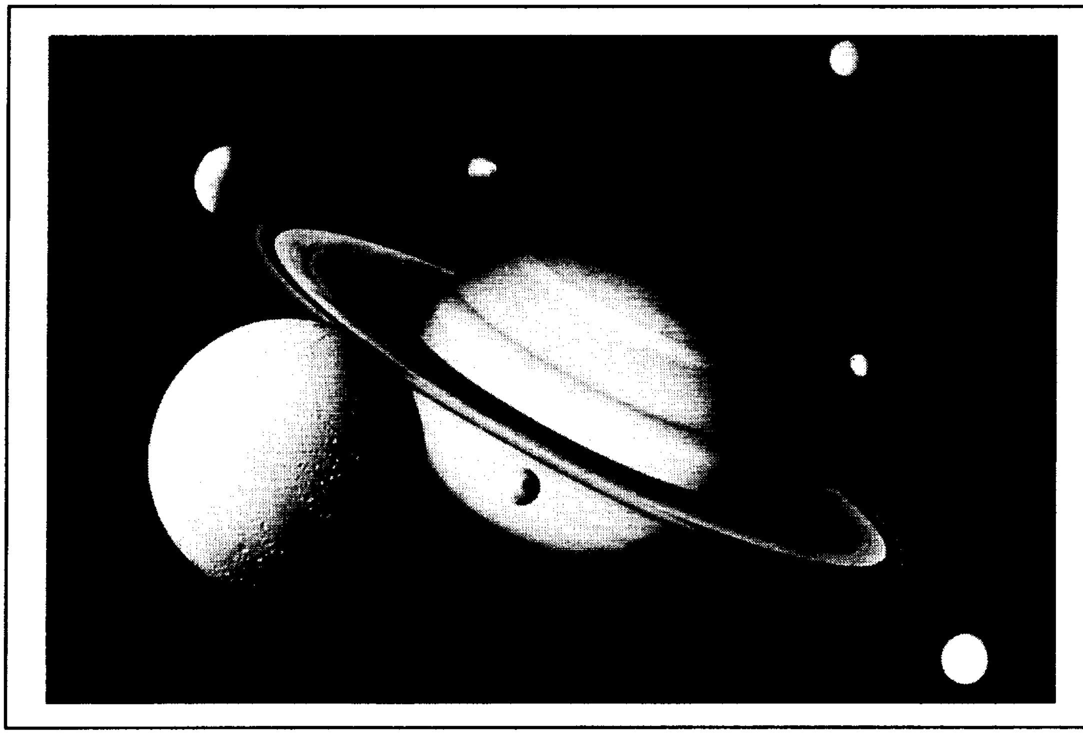

Figure X-2. Robotic Exploration of the Solar System

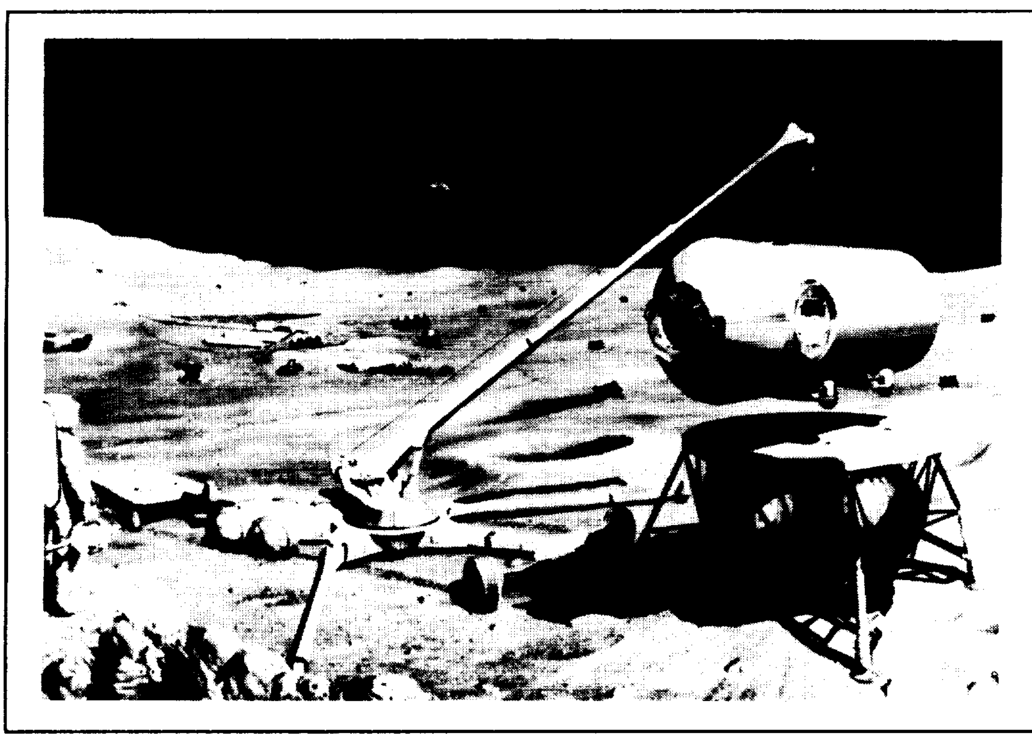

Figure X-3. Lunar Base

Figure X-4. Humans to Mars

originated in the realization that any "bold initiative," such as those listed above, must begin with today's capabilities. Four critical areas that require near-term investments were set forth.

The first critical investment proposed by the task force was development of the necessary technology base. As outlined in the NCOS report, technology is a key foundation for enabling "...science, exploration and enterprise" activities. The proposed investment responds to the NCOS' findings that the U.S. technology base has eroded and advanced technology research and development must receive immediate attention.

The second critical investment proposed was in life sciences research to improve understanding of and response to the biomedical, psychological, and human adaptation implications of long-duration space flight. As a Space Science Board study concluded, "...it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed. Not to do so would be imprudent at best, quite possibly irresponsible."

The third critical investment proposed related to the Nation's current launch capability. According to the task force's report, "...from now until the mid-1990s Earth-to-orbit transportation is NASA's most pressing problem." The report recommended that the Nation develop a cadre of launch vehicles, for both people and cargo, that initially would meet the near-term commitments of the civilian space program and then grow to support projected programs.

The fourth critical investment proposed was in the Space Station. The task force concluded that exploration initiatives will make large demands on the Space Station and must be addressed early in NASA's planning process. The capabilities the Space Station will provide to conduct life science research, to demonstrate technology applications, to gain operational experience, and to serve as the Earth-orbit "spaceport" are essential to human exploration ventures.

To move beyond the environment of ad hoc study activities and task force exercises, the task force report recommended creation of the Office of Exploration, to serve as the focal point within the Agency for the study of human exploration initiatives. On June 1, 1987, NASA's Administrator, Dr. Fletcher, formally announced the establishment of the Office to "analyze and define missions proposed to achieve the goal of human expansion off the planet. It will provide central coordination of technical planning studies that will involve the entire agency."

Exploration Program Goals and Objectives

The goal of the Exploration program is to develop alternatives and recommendations for a future national decision on a focused program for human exploration of the solar system.

In pursuit of this goal, the following objectives have been established:

(1) develop and analyze specific human exploration initiatives, concentrating on development of their scientific potential and economic benefits;
(2) identify the program requirements prerequisite to Earth-to-orbit transportation, human adaptation research, and Space Station capabilities needed for each initiative, and coordinate implementation with the NASA program offices;
(3) develop the requirements for science and engineering robotic precursor missions;
(4) refine the requirements for Pathfinder technology (see inset on page VII-16) necessary to enable and support a range of future exploration strategies; and
(5) organize the appropriate experts throughout the Agency and the Nation, and lead them in studying and developing potential exploration plans.

The Exploration program will initiate science-experiment and facility-definition studies to identify and define the science potential of and opportunities for human exploration programs. Access to planetary environments enables extension of current research capabilities in astronomy, planetary science, and life science, to name just a few. New science opportunities are anticipated in disciplines related to physics, cosmology, and materials research. The Exploration program will require science research activities that emphasize this unique environment and benefit from human presence and support.

Current Exploration Program

Initiatives Under Study.

Two initiatives, each involving various scenarios (mission techniques), are currently under study.

Lunar Base Initiative. The first is the Lunar Base initiative, whose scenarios emphasize (in priority order) science, resource development, and sustained human presence. The scenarios include:

(1) a robotic exploration phase for base site selection;
(2) an early outpost phase entailing emplacement of geological and astronomical science instruments and of a pilot plant for processing lunar resources; and
(3) a permanently inhabited phase during which potential "world class" science operations can be conducted.

Mars Initiative. The Mars initiative's scenarios emphasize (in priority order) science, human exploration, and resource development. This initiative also includes a robotic phase for scientific exploration and for gathering additional engineering data required prior to human exploration. Its second phase would encompass piloted landings, the establishment of an inhabited outpost with enhanced scientific exploration capabilities, and pilot processing plants for resource utilization. The third phase would include initiating establishment of a permanently inhabited base on Mars, using local resources to support transportation and habitation. A key tradeoff study related to the Mars initiative is of the potential necessity for prior establishment of a lunar base, to serve as a stepping stone for human voyages to Mars.

Prerequisite Programs in Support of Human Exploration

The human exploration implicit in the two initiatives, Lunar Base and Mars, will require the support provided by the prerequisite programs summarized in Figure X-5. Efforts to identify and satisfy these prerequisites are in process throughout NASA.

Life Science Research. Project Pacer, developed by NASA's Office of Space Science and Applications, is a program designed to develop an understanding of the physiological effects of the microgravity and radiation environments in space and to provide the physiological and medical foundation for extended spaceflight. Research performed under this program will be conducted in laboratories and on space shuttle missions in preparation for the critical long-term Space Station experiments mentioned in the paragraph that follows.

Space Station. Planning for the Space Station's evolution will include assessment of the implications of human exploration initiatives. Specific scenarios developed to serve as a basis for the assessments will provide results that will feed back into the original initiative scenarios. The Space Station is an enabling link to expanding the human exploration of space. It will be used to develop a capability for the long-term presence of humans in space. It also will be used as a development and test site for relevant robotic devices, crew aids, and tools. The Space Station can ensure that facilities exist to support relevant life sciences and materials sciences research; with proper allowances for evolution, it can grow into a low Earth orbit transportation node. Chapter V addresses the Space Station program in more detail.

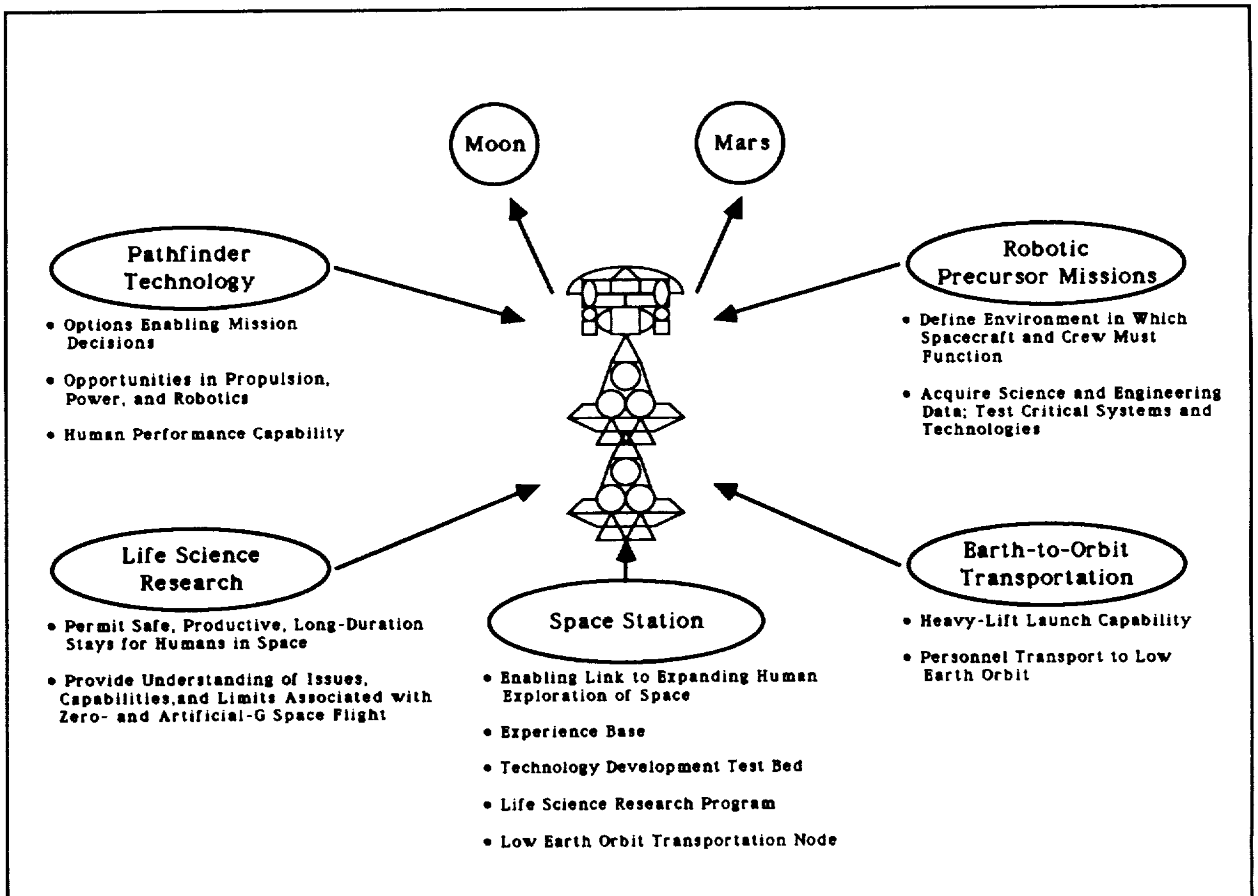

Figure X-5. Prerequisite Programs for Human Exploration

Earth-to-Orbit Transportation. Identified by the Ride study as NASA's most pressing problem, Earth-to-orbit transportation continues to receive considerable Agency attention. Development of a cadre of launch vehicles to meet the Nation's near-term and long-term commitments for the civilian space program is described in Chapter IV. Vehicles under consideration include expendable launch vehicles and a shuttle-derived cargo vehicle.

Science and Engineering Robotic Precursor Missions. Special studies, initiated by the Exploration program, will define the need for robotic precursor missions to enable or enhance human exploration activities. Such precursor missions are related to planetary science efforts to understand the surface environments of the moon and Mars, to perform resource surveys, and to explore bio-contamination issues. These missions would demonstrate key advanced technologies, such as those for aerobraking and autonomous roving vehicles. The Office of Space Science and Applications provides the key support for this activity by assessing the requirements and responding with an implementation plan for precursor missions. Examples of such precursor mission are the Mars Observer (see page III-53), the Lunar Observer (see page III-57), and the Mars Rover/Sample Return missions (see inset below and figure X-6).

Mars Rover/Sample Return Missions

A proposed pair of Mars Rover/Sample Return missions will :

(1) perform geochemical characterization of Mars;
(2) complete global mapping; and
(3) support landing site selection and certification for a manned mission.

In the first mission, a rover with a range of about 1,000 kilometers would collect samples and , at the same time, study Mars' surface. After dispatching its load of samples to Earth, it would continue exploring and collecting samples while a second rover and sample return mission was launched from Earth at the next opportunity. The second rover would embark on a different surface traverse, while the sample return vehicle could take from the first rover the additional samples it had collected and return them to Earth.

The currently envisioned mission strategy includes:

(1) deployment of payload elements by the space shuttle;
(2) on-orbit assembly of the full system;
(3) on-orbit fueling and injection into a Mars transfer trajectory;
(4) lander aerocapture and orbiter deployment;
(5) sample collection, launch, and orbital rendezvous and docking;
(6) return to Earth transfer, aerobraking, and Space Station rendezvous and docking; and
(7) shuttle transfer of samples to Earth's surface.

Figure X-6. Mars Rover/Sample Return

Pathfinder Technology. Project Pathfinder, developed by NASA's Office of Aeronautics and Space Technology in conjunction with experts on the Lunar Base and Mars initiatives, will provide the technologies to enable missions beyond Earth's orbit. Pathfinder will develop technologies for autonomous systems and robotics, advanced propulsion systems for lunar and planetary spacecraft, extraction of useful materials from lunar and planetary surfaces, life support systems, and the human-machine interface. Emphasis is being placed on defining needs and examining the leverage that investments in advanced technologies can provide to enable human exploration initiatives. Because the lead times for development are known to be long, Pathfinder is placing highest priority on trade-off studies that can force early identification of lead times. The Office of Aeronautics and Space Technology has produced and evaluated an initial set of requirements for technology, and will refine them continuously. Mission studies and technology program planning will be appropriately coupled, thus ensuring that the maximum potential that technology can provide will be realized in exploration programs.

Interrelationships with Programs of Other Offices

NASA now has in place an agency-wide organization to define, plan, and analyze potential exploration missions. This organization, led by the Office of Exploration, is composed of the Headquarters program offices and special organizations in the field centers.

With support from the major program offices, the Exploration Management Group has been formed to outline exploration concepts and to serve as a forum for integration of the needs of the Agency's existing programs for exploration initiatives. The Office of Exploration and the Exploration Management Group are providing top level guidance to the process, and the field centers are performing detailed definition and systems engineering studies for the human exploration initiatives. The field centers that directly support the Office of Exploration have formed exploration offices to conduct these studies. The centers are also conducting special assessment studies that deal with high-leverage technical areas. These studies develop techniques, approaches, configurations, and systems tradeoffs across a wide range of concepts that can significantly enhance the feasibility of mission scenarios. Figure X-7 schematically illustrates the distribution of Agency activities coordinated by the Office of Exploration.

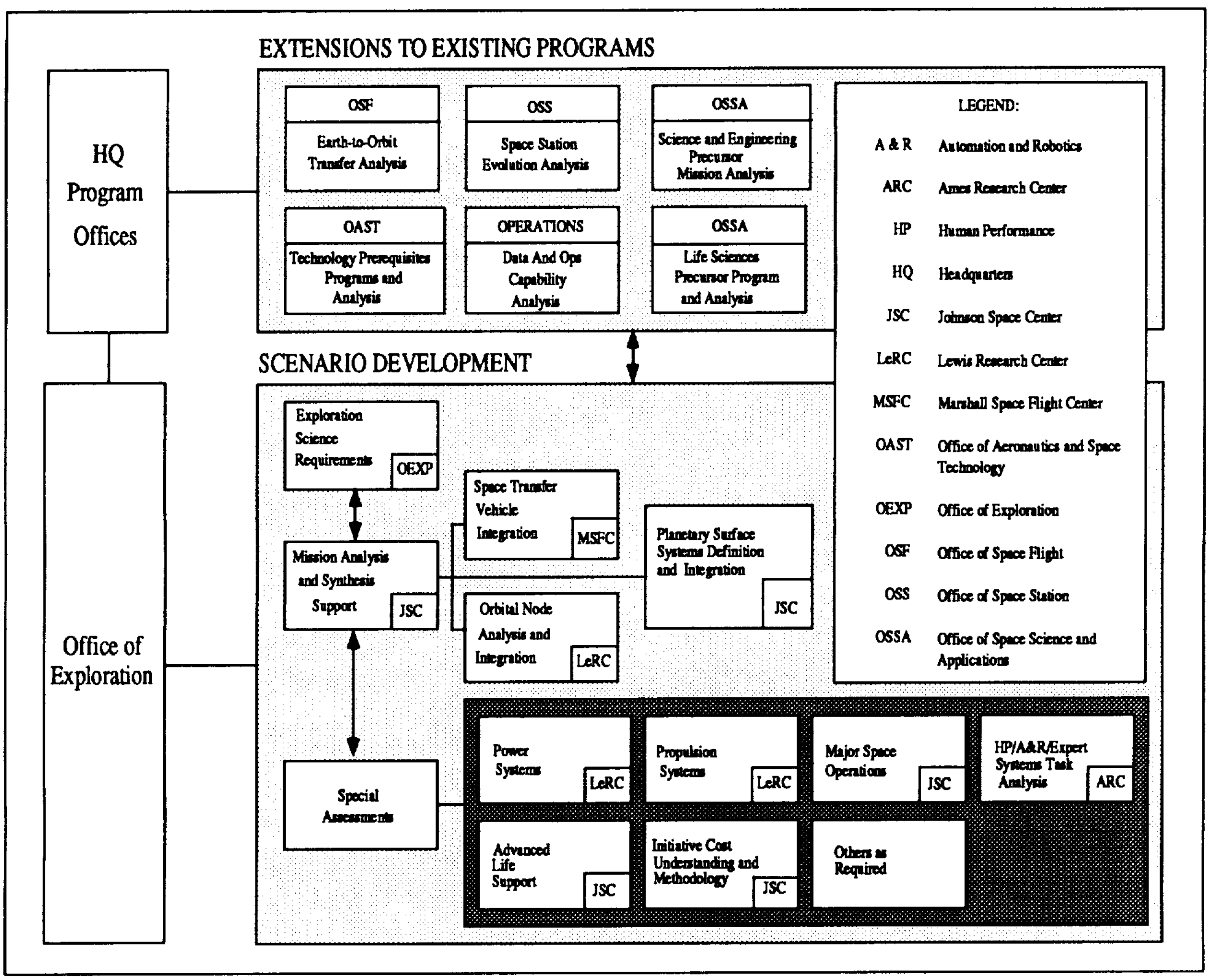

Figure X-7. Distribution of Exploration Activities

Due to the major implications human exploration has on NASA near-term programs, particular emphasis is being placed on defining the requirements that affect other NASA program offices. To coordinate and guide this activity, the agency-wide interactive process for planning, integration, and reporting illustrated in Figure X-8 has been established. Supporting this process, exploration scenario development groups at the field centers identify specific requirements related to transportation, technology, science, operations, human research, and the Space Station. The responsible Headquarters program offices, in turn, review these requirements and respond with an assessment of the impact on their plans. They also develop proposed implementation plans to provide the needed capabilities within the requested times.

The exploration scenario development groups examine these responses and adjust exploration mission concepts and planning where necessary. The groups also use the program office results to further define or narrow options for additional study. Substantial progress has been made in FY 1988 on the requirements definition process. An initial requirements document, based on the exploration scenarios under study, has been completed. The program offices have reviewed the requirements and provided an initial assessment.

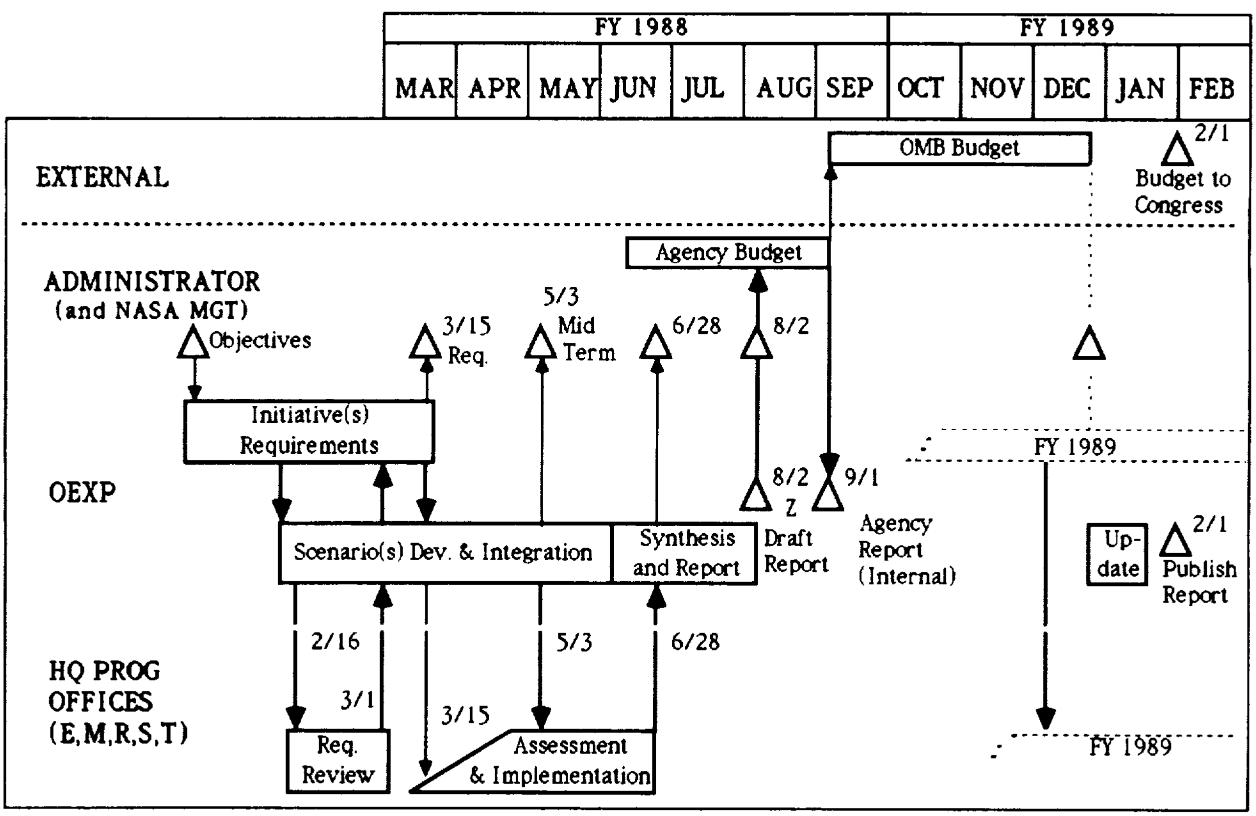

Figure X-8. Planning, Integration, and Reporting Process

Long Range Perspective

The NASA-wide organization and study process described above has developed the preliminary long-range milestone schedule illustrated in Figure X-9. The upper portion of Figure X-9 depicts the major milestones related to the initiative definition exercise now in process. The lower portion shows the milestones for prerequisite programs related to the supporting infrastructure, robotic precursor missions, and technology (Pathfinder) research programs described earlier. In FY 1989, effort will be directed toward refining and validating these required program dependencies and relationships across the agency. A national exploration decision will be made in the early 1990s.

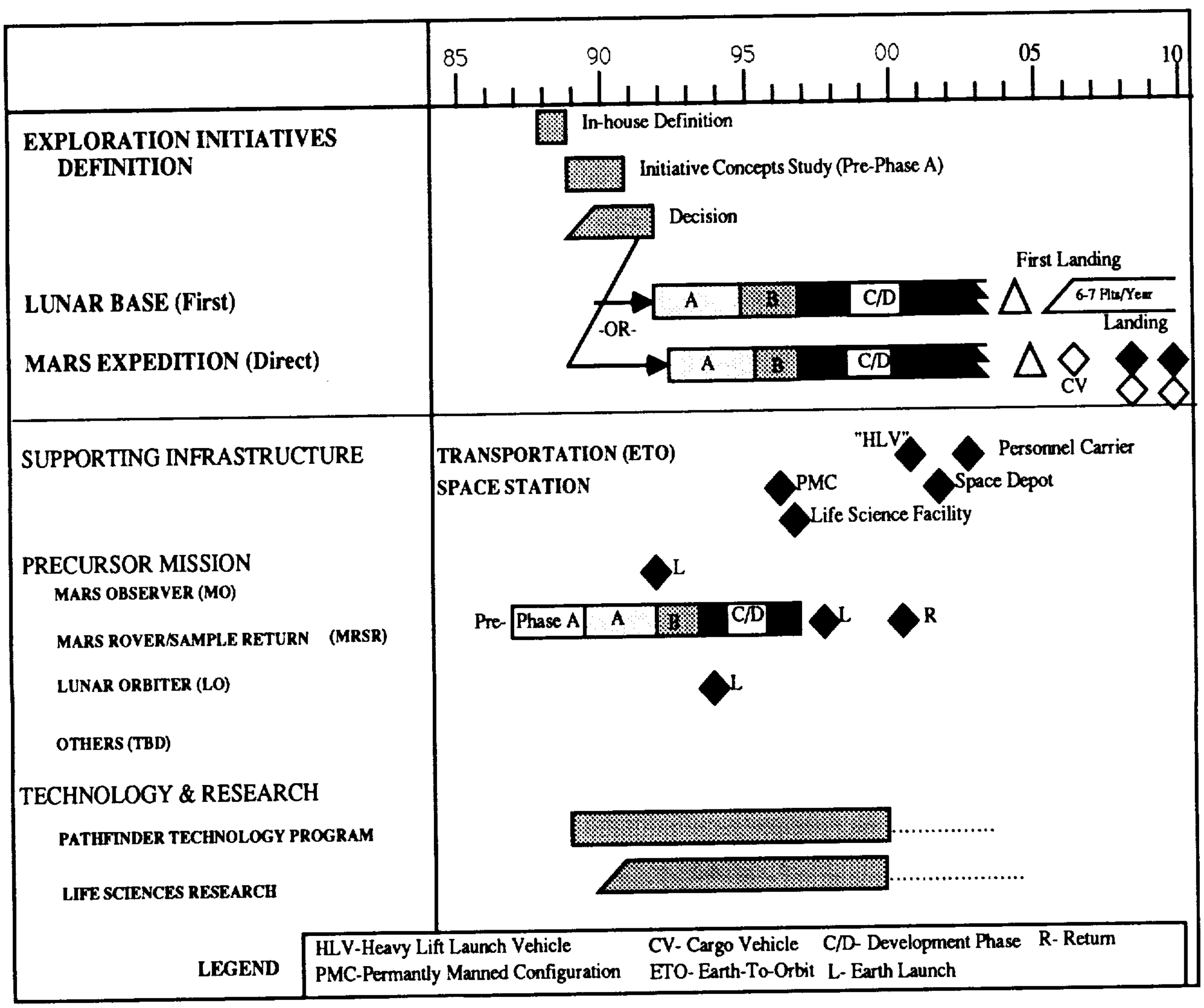

Figure X-9. Major Milestones for Initiative Definitions

ABBREVIATIONS AND ACRONYMS

ABBREVIATIONS AND ACRONYMS

A&R	Automation and Robotics
ACRC	Assured Crew Return Capability
ACTS	Advanced Communications Technology Satellite
ADV	Advanced
AFE	Aeroassist Flight Experiment
ALS	Advanced Launch System
AMPTE	Active Magnetospheric Particle Tracer Explorer
APAE	Attached Payload Accommodations Equipment
APRC	Aeronautical Policy Review Committee
ARC	Ames Research Center
ASRM	Advanced Solid Rocket Motor
ASTOVL	Advanced Short Take-Off/Vertical Landing
ASTRO	(Not an acronym)
ASTRO-D	(Not an acronym)
ASTROMAG	(Not an acronym)
ATC	Air Traffic Control
ATDRSS	Advanced Tracking and Data Relay Satellite System
ATF	Astrometric Telescope Facility
ATLAS	Atmospheric Laboratory for Applications and Science
ATS	Application Technology Satellite
AXAF	Advanced X-Ray Astrophysics Facility
BBXRT	Broad Band X-Ray Telescope
C&T	Communications and Tracking System
CAS	Cassini
CCD	Charge Coupled Device
CCDS	Centers for the Commercial Development of Space
CCE	Charge Composition Explorer
CCSDS	Consultative Committee for Systems Development Standards
CDCF	Cosmic Dust Collection Facility
CDOS	Customer Data Operations System
CDR	Critical Design Review
CDSF	Commercially Developed Space Facility
CELSS	Controlled Ecological Life Support System
CFD	Computational fluid dynamics
CNDB	Civil Needs Data Base

COBE	Cosmic Background Explorer
COSTR	Collaborative Solar Terrestrial Research
COUP	Consolidated Operations and Utilization Plan
CRAF	Comet Rendezvous Asteroid Flyby
CRRES	Combined Release and Radiation Effects Satellite
CSTI	Civil Space Technology Initiative
CV	Cargo Vehicle
DC	Direct current
DCOD	Decoder
DCR	Design Certification Review
DDT&E	Design, Development, Test, and Evaluation
DE	Dynamics Explorer
DMS	Data Management System
DOC	Direct operating costs
DOD	Department of Defense
DOT	Department of Transportation
DSN	Deep Space Network
DXS	Diffuse X-Ray Spectrometer
ECLSS	Environmental Control and Life Support System
ELV	Expendable Launch Vehicle
EMU	Extravehicular Mobility Unit
ENH	Enhanced
Eos	Earth Observing System
EPNL	Effective Perceived Noise Level
ERBE	Earth Radiation Budget Experiment
ERS	Earth Resources Satellite
ESA	European Space Agency
ESC	Engineering Support Center
ETO	Earth-to-orbit
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FLC	Federal Laboratory Consortium
FRR	Flight Readiness Review
FTS	Flight Telerobotic Servicer
FUSE	Far Ultraviolet Spectroscopy Explorer
FY	Fiscal year

GAL .... Galileo
GCF .... Ground Communication Facility
GDMS .... Ground Data Management System
GEO .... Geosynchronous Earth orbit
GGS .... Global Geospace Science
GP-B .... Gravity Probe-B
GRM .... Geopotential Research Mission
GRO .... Gamma Ray Observatory
GSFC .... Goddard Space Flight Center

HLV .... Heavy Lift Launch Vehicle
HP .... Human Performance
HQ .... Headquarters
HRSO .... High Resolution Solar Observatory
HSCT .... High Speed Civil Transport
HST .... Hubble Space Telescope

IAC .... Industrial Application Center
ICE .... International Cometary Explorer
IGI .... Industrial Guest Investigator
IGIA .... Industrial Guest Investigator Agreement
IML .... International Microgravity Laboratory
IMP .... Interplanetary Monitoring Platform
INTEROP .... Interoperability
ISAS .... Institute of Space Astronautical Sciences
ISEE .... International Sun Earth Explorer
ISF .... Industrial Space Facility
ISTP .... International Solar Terrestrial Physics
IUE .... International Ultraviolet Explorer
IUS .... Inertial Upper Stage

JEA .... Joint Endeavor Agreement
JEM .... Japanese Experiment Module
JERS .... Japanese Earth Resources Satellite
JPL .... Jet Propulsion Laboratory
JSC .... Johnson Space Center

kHz .... Kilohertz
km .... Kilometer
KSC .... Kennedy Space Center
kW .... Kilowatt

LEO .... Low Earth orbit
LeRC .... Lewis Research Center
LO .... Lunar Orbiter
LSA .... Launch Services Agreement

MAG .... Magellan
MDM .... Multiplexer/Demultiplexer
MELTER .... Mesosphere and Lower Thermosphere Explorer
MFLOPS .... Million floating point operations per second
MMPF .... Microgravity Materials Processing Facility
MMS .... Multimission Modular Spacecraft
MO .... Mars Observer
MOA .... Memorandum of Agreement
MOU .... Memorandum of Understanding
MRDB .... Mission Requirements Data Base
MRSR .... Mars Rover/Sample Return
MSAT .... Mobile Satellite
MSC .... Mobile Servicing Center
MSFC .... Marshall Space Flight Center
MSS .... Mass Storage Subsystem
MSS .... Mobile Servicing System
MT .... Mobile Transporter
MTC .... Man-Tended Capability

NAE .... Nuclear Astrophysics Explorer
NASA .... National Aeronautics and Space Administration
NASCOM .... NASA Communications
NASP .... National Aerospace Plane Program
NAUG .... NASCOM Augmentation
NCC .... Network Control Center
NCOS .... National Commission on Space
NSCAT .... NASA Scatterometer
NSESCC .... NASA Space and Earth Science Computing Center
NSSDC .... National Space Science Data Center
NSTS .... National Space Transportation System
NTT .... Nishikawa-Takamazawa-Tago

OAST .... Office of Aeronautics and Space Technology
OBS .... Observations
OCP .... Office of Commercial Programs

OEXP ....Office of Exploration
OMB ....Office of Management and Budget
OMV ....Orbital Maneuvering Vehicle
OP ....Operations
ORD ....Operational Readiness Date
ORR ....Operational Readiness Review
ORU ....Orbital replacement units
OSF ....Office of Space Flight
OSL ....Orbiting Solar Laboratory
OSS ....Office of Space Station
OSSA ....Office of Space Science and Applications
OSTP ....Office of Science and Technology Policy
OTV ....Orbital Transfer Vehicle

PACOR ....Packet Processor
PAM ....Payload Assist Module
PASO ....Program and Specific Objectives
PCB ....Program Control Board
PDR ....Preliminary Design Review
PGOC ....Payload Ground Operations Center
PIMS ....Plasma Interaction Monitoring System
PMC ....Permanently Manned Capability
POCC ....Payload Operations Control Center
POF ....Pinhole Occulter Facility
POIC ....Payload Operations Integration Center
PRD ....Program Requirements Document
PRR ....Program Requirements Review
PSCN ....Program Support Communications Network
psi ....Pounds per square inch
PVO ....Pioneer Venus Orbiter

QSO ....Quasi-Stellar Object
QUASAT ....(Not an acronym)

R&A ....Research and Analysis
R&D ....Research and Development
RCVR ....Receiver
RIMTECH ....Research Institute for the Management of Technology
RMS ....Remote Manipulator System
ROSAT ....Roentgen Satellite
RTOP ....Research and Technology Objectives and Plans

SA .... Service Acceptance
S&I .... Systems and Integration
SARSAT .... Satellite Aided Search and Rescue Program
SBDC .... Small Business Development Center
SBIR .... Small Business Innovation Research
SCAMA .... Switching, Conferencing, and Monitoring Arrangement
SDV .... Shuttle Derived Vehicle
SE&I .... System Engineering and Integration
SETI .... Search for Extraterrestrial Intelligence
SHEAL .... Shuttle High Energy Astrophysics Laboratory
SIRTF .... Space Infrared Telescope Facility
SLS .... Spacelab Life Sciences
SMM .... Solar Maximum Mission
SOFIA .... Stratospheric Observatory for Infrared Astronomy
SOHO .... Solar and Heliospheric Observatory
SPDM .... Special Purpose Dextrous Manipulator
SRM&QA .... Safety, Reliability, Maintainability, and Quality Assurance
SS POP .... Space Station Polar Orbiting Platform
SS/FEL .... Space Station First Element Launch
SSCB .... Space Station Control Board
SSCC .... Space Station Control Center
SSDA .... Space Systems Development Agreement
SSE .... Software Support Environment
SSEC .... Solar System Exploration Committee
SSIS .... Space Station Information System
SSME .... Space Shuttle Main Engine
SSP .... Space Station Program
SSPO .... Space Station Program Office
SSR .... Solar System Radar
STA .... Station
STDS .... Standards
STEP .... Space Technology Experiments Platform
STGT .... Second TDRSS Ground Terminal
STO .... Solar Terrestrial Observatory
STOVL .... Short take-off/vertical landing
STS .... Space Transportation System
STV .... Space Transfer Vehicle

TC .... TDRSS Constellation
TDM .... Time Division Multiplexer
TDMA .... Time Division Multiple Access

TDRS .... Tracking and Data Relay Satellite
TDRSS .... Tracking and Data Relay Satellite System
TEA .... Technical Exchange Agreement
TMIS .... Technical and Management Information System
TOP .... Tactical Operations Plan
TOPEX .... Ocean Topography Experiment
TOS .... Transfer Orbit Stage
TPS .... Thermal Protection System
TRMM .... Tropical Rainfall Measurement Mission
TSS .... Tethered Satellite System

UARS .... Upper Atmospheric Research Satellite
ULY .... Ulysses
USAF .... United States Air Force
USG .... United States Government
USML .... United States Microgravity Laboratory
UV .... Ultraviolet

V-N .... Voyager-Neptune encounter
VLA .... Very Large Array
VLSI .... Very Large Scale Integration

WP .... Work Package

XTE .... X-Ray Timing Explorer

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