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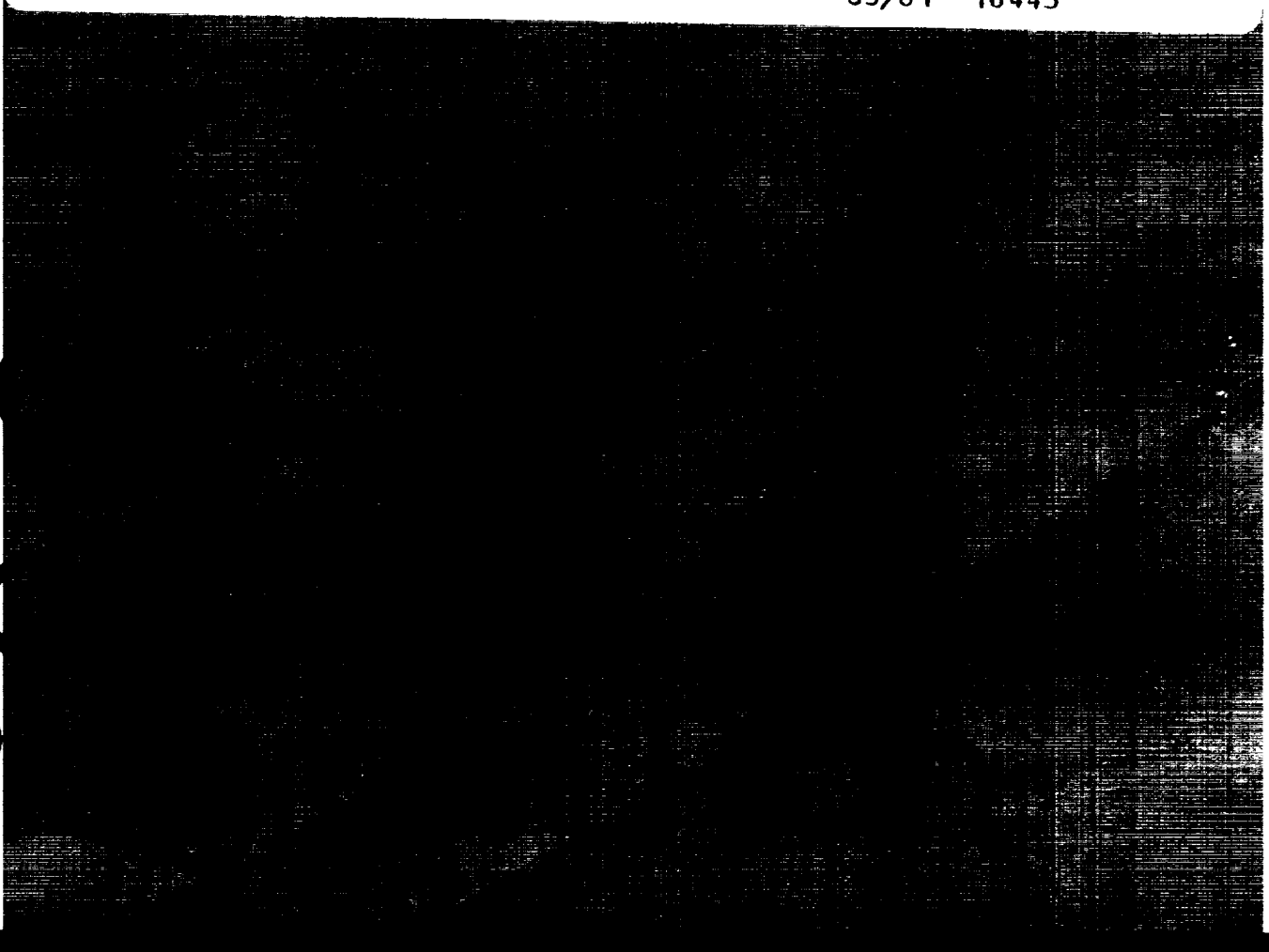
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NASA

1986 Long-Range Program Plan

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National Aeronautics and
Space Administration

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Introduction



I. INTRODUCTION

As the Nation's research and development organization for aeronautics and space, NASA must look continuously to the future. Long before a goal is reached, new goals must be defined. Each advance toward a program objective serves as a building block for future programs. That continual evolution of NASA's research and development is reflected in this report on the NASA program plan for FY 1986 and later years.

The plan outlines the direction of NASA's future activities. It is consistent with national policy for both space and aeronautics and with the FY 1986 budget the President submitted to Congress in February 1985. That modest, though forward-looking, budget reflects the President's determination that the United States will continue its leadership in space and advance toward its goal of developing, with international cooperation, a permanently manned space station. The budget will allow NASA to make solid progress in both space and aeronautics. It contains a new initiative, the Orbital Maneuvering Vehicle; funding to promote the commercial use of space; and in aeronautics, funding to continue advanced research and technology development and to develop the Advanced Turbo-prop Propulsion System for a new generation of fuel-efficient aircraft.

For the years beyond FY 1986, the plan consists of activities that are technologically possible and considered to be in the national interest. Its implementation will ensure logical and continued progress in reaching the Nation's goals in aeronautics and space, consistent with the responsibilities assigned NASA by the National Aeronautics and Space Act of 1958, as amended.

Chapter II of this report summarizes the major features of the programs described in greater detail in Chapters III through IX and projects the nature of the aeronautics and space programs beyond the year 2000. Chapter X lists the abbreviations and acronyms that appear in this report; and Chapter XI contains the report's index. Unless otherwise indicated, dates throughout are fiscal year dates, October 1 through September 30.

This report is a working document. It summarizes the status of NASA's plans at the time of its preparation, approximately the end of February 1985. Comments and suggestions are welcome and will receive careful consideration.

Because NASA's plans continually evolve, anyone desiring detailed information on a program should get in touch with the responsible program office. If he is working in areas related to NASA's programs and knowledge of the latest status of NASA's plans is important to his work, up-to-date information from the appropriate program offices is essential.

To obtain copies of this report or general information about NASA's program planning, contact Thomas W. Chappelle, Code LB, National Aeronautics and Space Administration, Washington, DC 20546.

NASA's Office of Aeronautics and Space Technology annually updates the NASA Space Systems Technology Model, described in section C.1. of chapter VII of this report. A copy of the executive summary of that report can be obtained from Stanley R. Sadin, Code RS, National Aeronautics and Space Administration, Washington, DC 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.

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Summary and Perspective



II. SUMMARY AND PERSPECTIVE

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II. SUMMARY AND PERSPECTIVE

A. Mission, Goals, and Objectives

The Reagan Administration assumed office in January 1981 committed to maintaining U.S. leadership in aeronautics and space. Toward that objective, it gave top priority to completing development of NASA's Space Shuttle and, with the Shuttle as the core element, to achieving full operational status for the Space Transportation System as an economically profitable and productive national resource. Advancement of those and other NASA space programs has benefited the economy and, at the same time, confirmed NASA's status as a world leader in science and technology. Space exploration has been and continues to be a catalyst for national progress and achievement.

The direction of NASA's mission and activities in space continues to reflect national policy and purpose as stated in the National Aeronautics and Space Act of 1958, as amended. A landmark achievement of the U.S. political system, that act directs NASA to explore space for peaceful purposes for the benefit of all mankind and to cooperate with other nations or groups of nations in pursuit of the Act's objectives. The President reaffirmed that commitment in his State of the Union address to Congress on January 25, 1984. He presented "four great goals to keep America free and secure in the eighties": "to ensure steady economic growth," "to build on America's pioneer spirit and develop our next frontier--space," "strengthening our community of shared values," and "a lasting and meaningful peace."

On August 15, 1984, the President approved a National Space Strategy designed to implement the national policy for space, as amended by Congress and as supplemented by his State of the Union address. The provisions of that strategy applicable to the civil space program are to:

- o Insure routine, cost-effective access to space with the Space Transportation System
- o Establish a permanently manned presence in space
- o Foster increased international cooperation in civil space activities
- o Identify major long-range national goals for the civil space program
- o Insure a vigorous and balanced program of civil scientific research and exploration in space
- o Encourage commercial Expendable Launch Vehicle activities
- o Stimulate private sector commercial space activities.

Development of the space frontier, the President's second goal, will affect, and contribute to achievement of, his other three goals; and the major new element in his strategy that will help to ensure meeting that goal is establishment of a permanently manned presence in space. Permanent manned presence in space will enable the Nation, he said, "to follow our dreams to

distant stars, living and working in space for peaceful, economic and scientific gain." The NASA program initiated to establish that permanent presence is the Space Station.

As currently perceived by NASA engineers and scientists, the Space Station will be evolutionary in concept and design to accommodate addition, modification, and in future decades, replication. It is to be a multipurpose facility in Earth orbit, permanently occupied by humans. A national research laboratory for both government and industry, it will serve, as well, as a repair and assembly station for satellites and space payloads. As it evolves, it ultimately will serve as a base for new operations and initiatives in space and, most important, will be valuable for the creation of new technologies and industries. Such a facility in full operation, the President pointed out, has "enormous potential for commerce." Research in space is expected to yield new products leading to new businesses. In addition, development and production of the Space Station will be a boost to the economy; and the new skills, advanced knowledge, and technology that result will be used in other areas of industry. Each new step in achieving aerospace goals has added new dimensions of excellence to industrial capabilities; and if past is prologue, this great enhancement of space capabilities certainly will contribute to economic growth.

Pioneering in space by building a permanent settlement in that vast frontier also has meaning with respect to the President's third and fourth goals: "strengthening our community of shared values" and "a lasting and meaningful peace." A community in space, with U.S. personnel working and functioning there, will reflect the shared values of a democracy in action for freedom and peace. The President intends the U.S. Space Station to be an instrument for peace. Other nations, he stated, will be invited to join the United States on the Station "so we can strengthen peace, build prosperity and expand freedom for all who share our goals."

Estimates are that the Space Station can be in orbit by the early 1990s, around the 500th anniversary year of America's discovery by Columbus. Now, as then, the discovery of a new frontier is prelude to its development. A new world emerged then; and mankind now may be on the threshold of building another new world or, at least, of extending Earth's limits into near space and beyond.

Support of the Space Station and of other anticipated activities will require definition, design, and acquisition of a second-generation space transportation system, including unmanned cargo vehicles and second-generation orbiters.

In extending Earth's limits, NASA has set for itself the following goals, each of which is in keeping with the mandates of the National Aeronautics and Space Act of 1958, as amended:

- o Provide for our work force a creative environment and the best of facilities, support services, and management support so that they can perform with excellence NASA's research, development, mission, and operational responsibilities. Provide for the development of employees so as to enhance and sustain an integrated work force of highest quality at NASA.

- o Make the Space Transportation System fully operational and cost effective in providing routine access to space for domestic and foreign, commercial, and Governmental users.
- o Develop within a decade a permanently manned Space Station.
- o Conduct an effective and productive aeronautics research and development program which contributes materially to the enduring preeminence of U.S. civil and military aviation.
- o Conduct an effective and productive Space and Earth Sciences Program which expands human knowledge of the Earth, its environment, the solar system, and the universe.
- o Conduct effective and productive space applications and technology programs which contribute materially toward U.S. leadership and security.
- o Expand opportunities for U.S. private sector investment and involvement in civil space and space-related activities.
- o Establish NASA as a leader in the development and application of advanced technology and management practices which contribute to significant increases in both Agency and national productivity.

The Administration's proposed budget for NASA for FY 1986 supports those goals, including sufficient funding for some new initiatives. It reflects the President's commitment to establishing a permanently manned space station and recognizes the importance of research and development for the well-being of the national economy. Flight activity will continue to increase to accommodate not only NASA payloads, but also those of paying customers, with plans calling for 10 Shuttle flights in FY 1985, 14 in FY 1986, and continued increases through the end of the 1980s.

The principal activities provided for are as follows:

- o Space Transportation--While moving forward on the Space Station program, top priority attention to achieving for the Space Transportation System the ability to fill space transportation needs through the 1980s and beyond
- o Space Science and Applications--Continued progress on approved projects, initiation of such programs as Upper Atmosphere Research Satellite, and further technology development and ground test and flight test programs for the Advanced Communications Technology Satellite
- o Space Research and Technology--Continued efforts in generic disciplinary base technology programs with modest expansion of system oriented efforts in platforms and Space Station technology, transportation systems, and spacecraft
- o Aeronautical Research and Technology--Additional work in aeronautical disciplines such as aerodynamics, structures, materials, propulsion,

and controls to provide technology for totally new aircraft systems, including rotorcraft, high performance and subsonic aircraft, and advanced propulsion systems

- o The Institution--Maintenance and improvement of NASA's professional work force of scientists, engineers, and technicians to ensure efficient, effective, and innovative progress in fulfilling program objectives.

B. Space Program Highlights to Year 2000

The subsections of this chapter that follow present the highlights of the programs NASA plans to conduct in the remaining years of the 20th century, including the programs' goals, objectives, and major new initiatives planned for the 10-year period beginning in FY 1986. Each program is described in greater detail in chapters III through IX of this report.

1. Space Science and Applications

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 by industry, in the life sciences, and in maintaining Earth's natural resources. It includes observations and studies of the distant universe and of the fundamental physical laws important to understanding the distant universe, exploration of the near universe, and efforts to understand more about Earth's planetary features and environment. Its applications programs include research in the life sciences to enable humans to function and work in space, experiments in materials processing in the microgravity of space, and expansion and improvement of such services as satellite communications.

Summaries of the six major areas of endeavor in space science and applications follow. Each area is described in greater detail in chapter III.

a. Study of the Distant Universe

As a result of NASA's program in space astronomy and astrophysics during the past two decades, a new view of the universe is emerging; and new discoveries are being made at an astonishing rate. Rocket and satellite observations at ultraviolet wavelengths reveal the ejection by many types of stars of enormous amounts of material at high velocities. A revolution is occurring in knowledge of the chemical composition and physical state of interstellar gas and dust. Entirely new types of celestial objects are being discovered. Explosive events of unimaginable violence that occur routinely in the universe are being observed. Studies of the sun, fundamental to interpreting the distant universe, may provide the first look into that star's interior. For assurance that this revolution in understanding of the universe will continue at the same rapid pace, new observing capabilities are planned.

In the current Astrophysics program, several research missions are providing diverse information and measurements on the nature of the universe. While each mission has a particular objective, the data it acquires may often be augmented substantially by data from one or more

other missions. For example, the objective of the Solar Maximum Mission is to observe solar flares, but data from several other missions add to understanding of flares on the sun and other stars.

The International Ultraviolet Explorer supplements the Solar Maximum Mission. The Space Telescope, scheduled for launch in 1986, is the first major astronomical observatory designed and built to be serviced and upgraded in orbit. It is planned to be in operation for two decades and will be able to make observations in the ultraviolet, visible, and infrared regions of the spectrum. The Infrared Astronomy Satellite was launched in 1983 in cooperation with the Netherlands and the United Kingdom. Analysis of its data continues to provide new discoveries in infrared astronomy. Under development and to be launched within this decade are the Roentgen Satellite, a cooperative program with the Federal Republic of Germany to investigate many phenomena discovered by the second High Energy Astronomy Observatory; the Gamma Ray Observatory, to investigate the highest energy reaches of the electromagnetic spectrum; the Cosmic Background Explorer, to measure precisely the spectral and directional distribution of cosmic microwave background radiation; and the Heavy Nuclei Collector, to detect charged particles such as the rare, heavy nuclei of uranium. The program also includes extensive theoretical and laboratory research and investigations to be flown on Spacelab.

The major initiative to be begun through FY 1990 is the Advanced X-Ray Astrophysics Facility, which will advance x-ray astronomy into the mature observatory stage. It will be as significant an advance in x-ray astronomy as the Space Telescope will be in optical astronomy. Other initiatives planned for the FY 1986 through FY 1990 period are principally investigations of the structure of space and time, the structure of the sun, the life cycle of stars and galaxies, and interstellar space. They include Gravity Probe-B, Space Infrared Telescope Facility, Solar Seismology Mission, Extreme Ultraviolet Explorer, X-Ray Timing Explorer, Far Ultraviolet Spectroscopy Explorer, Solar Corona Diagnostics Mission, and several Spacelab investigations.

In the period between FY 1991 and FY 1995, two mature observatories will enter development. The Advanced Solar Observatory will make coordinated observations of all aspects of the surface of the sun to study the evolution of solar features and observe events that are especially revealing. The Large Deployable Reflector will investigate the processes of birth of celestial bodies. Other planned initiatives are the High Throughput Mission, Very Long Baseline Radio Interferometry, and Starprobe. The Space Station will service those observatories during this "golden age" of astronomy.

b. Exploration of the Near Universe

The near universe includes all bodies in the solar system except the sun and Earth. Exploration of the near universe is vital to a full understanding of the relationship of Earth to the sun and other members of the solar system. Specific goals of the program are to understand the origin, evolution, and present state of the solar system; Earth through comparative planetary studies; and the relationship between the chemical and physical evolution of the solar system and the appearance of life.

In the years since the first flyby of Venus, planetary exploration has experienced a golden age. It has brought new knowledge and established U.S. leadership in this area of space science. U.S. spacecraft were the first to visit Mercury, Venus, and Mars. Only U.S. spacecraft have crossed the asteroid belt into the outer solar system; and only a U.S. spacecraft, Pioneer 10, has exited the solar system. All told, over two dozen bodies--planets and their satellites--have been explored at close range; and the interplanetary medium has been partially characterized.

The current solar system exploration program consists of three parts: planetary research and analysis, development flight projects, and mission operations and data analysis. Research and analysis and mission operations and data analysis ensure program continuity toward exploration goals. Flight projects currently progressing are the Voyager 2 extended mission, which is headed for encounters with Uranus in 1986 and Neptune in 1989, and continued operation of Pioneer Venus, Pioneers 6 through 11, Voyager 1, and the International Cometary Explorer (the retargeted International Sun Earth Explorer-3), which is on its way to an encounter with the comet Giacobini-Zinner in 1985. Approved flight projects in the pre-launch development stage include the ASTRO payload planned for flight on the Shuttle to observe Halley's Comet during its 1986 flight through the solar system; Galileo (Jupiter orbiter and probe), which is a cooperative project with Germany; International Solar Polar Mission, which is a cooperative project with the European Space Agency; the Venus Radar Mapper, the first of the moderate-cost missions recommended by the NASA Advisory Council's Solar System Exploration Committee; and the Mars Observer, the first of the Planetary Observers, to be launched in 1990 to investigate that planet's atmosphere, surface geochemistry, interior, and climate on a global scale.

The Solar System Exploration Committee has recommended a core program containing 13 exploration missions, including the Venus Radar Mapper and the Mars Observer, to be undertaken by the year 2000. In support of that program, four new initiatives are planned for the next five years. They will establish firmly the exploratory phase of exploration in all regions of the solar system. The first is the Comet Rendezvous and Asteroid Flyby, scheduled for launch in 1990. Its purpose will be to investigate the physical and chemical state of comets. The second is the Lunar Geoscience Observer scheduled for launch in 1991 to assess lunar resources and to extend the Apollo program's science investigations to a global scale. The third is Cassini (Saturn Orbiter and Titan Probe), to be launched in 1993 to investigate Saturn and the largest of its satellites, Titan, especially Titan's unique, dense atmosphere. The fourth is the Coma Atmospheric & Elemental Sampling and Return mission, whose objective will be to obtain both intact and plasmalized samples of comet coma materials and return them to Earth for detailed analysis.

The Committee also has recommended addition of one or more intensive study missions during the 1990s as resources then available permit. The core program was formulated under the constraint that no new enabling technologies be required for implementation. In contrast, the augmentation initiatives will require significant new enabling or strongly enhancing technologies.

c. Earth and Its Environment

The view of Earth from space has engendered a growing realization that a full understanding of Earth and its environment requires a strong global research program spanning the scientific disciplines associated with study of the whole Earth, including atmospheric physics and chemistry, oceanography, geology, geophysics, and the emerging science of the biosphere, global biology. NASA's program to study Earth is global, interdisciplinary, and integrated, with emphasis on understanding processes that affect Earth's habitability, particularly its biological productivity and air and water quality. The program involves coordinated observational, theoretical, and experimental investigations and development of future observing technologies. Those activities are complementary and together form a balanced program of system and process studies. The program consists of elements that range from the most fundamental Earth sciences studies from space, to experiments demonstrating how data from space concerning Earth's resources and environment can be used to benefit society.

The Earth resources part of the program uses multispectral (visible and near-infrared), thermal-infrared, and active-microwave remote sensing systems to collect data for research and to demonstrate the utility of remote sensing in agriculture, land-use analysis and planning, hydrology, and geology. Landsat spacecraft have been the principal vehicles for Earth resources observation. Landsat 4, launched in July 1982, carried the Thematic Mapper sensor into orbit for the first time. That sensor has about twice the spectral resolution, three times the spatial resolution, and four times the sensitivity of the Multispectral Scanner sensor carried by earlier Landsat spacecraft. Landsat 4 technical problems curtailed the sensor's operation; but Landsat D', launched in 1984, carries another Thematic Mapper. The Shuttle Imaging Radar-A and other experiments on the Shuttle also have provided much valuable and useful information. The current program includes experiments with an improved imaging radar system, SIR-B, which was first flown on the Shuttle in 1984.

The objective of the atmospheric science program is to increase understanding of atmospheric processes and their effects on weather, climate, and the global environment. The current program of observations to further that understanding uses sounding rockets; balloons; aircraft; free-flying satellites, such as the Earth Radiation Budget Experiment launched in 1984; and Shuttle-borne instruments. Programs are in process to study global biology, Earth's plasma envelope and its interaction with the sun, geodynamics, trace species in the troposphere, and the oceans.

Earth science programs planned for initiation by FY 1990 include the following: Shuttle-Spacelab Payloads--to study the basic processes by which electromagnetic energy and particle beams interact with plasmas in the universe and to acquire information on the behavior with time of the solar constant, the solar spectrum, and the upper atmosphere; Ocean Color Imager--to provide synoptic global measurements of chlorophyll concentration as a primary data base to which complementary ship, airplane, and buoy data can be added to yield primary productivity estimates of high accuracy for key oceanic regions; Tethered Satellite System--to develop with Italy a system to conduct Earth science and applications experiments in regions remote from the Shuttle; Topography Experiment for Ocean

Circulation--to improve significantly capabilities for observing the oceans on a global basis; Magnetic Field Satellite--to test results derived from Magsat-1 data and provide an updated survey for the 1990 reference field; Geopotential Research Mission--to provide the most accurate models yet available of the global gravity field, geoid, and crustal magnetic anomalies; and International Solar Terrestrial Physics Program--to attempt, for the first time, a quantitative study of the complete solar-geospace system.

Studies of Earth in the 1990s will focus on long-term physical, chemical, and biological trends and changes in the environment. They will assess the effects of natural and human activities and provide improved models for estimating the future effects of humans and other species on Earth's biological productivity and habitability. They will be interdisciplinary and require sophisticated supporting technologies, particularly for long-term data management.

d. Life Sciences

The Life Sciences program has two goals: to understand how life forms are affected by the environmental conditions they encounter in space and to find how life originated and evolved in the universe. Life in the universe is studied by basic research programs in exobiology--which considers the origin, evolution, and distribution of life and its chemical precursors, and in biospherics--which studies how biological processes interact with the global environment. The effects of space flight on humans are investigated in the biomedical research program, and a complementary gravitational biology program deals with effects on other life forms. All four of these programs pursue their objectives through combined ground-based research and experiments in space.

Applied work in the life sciences has the objectives of ensuring the health of spacecraft crews and of improving technology to support life and work in space. A medical program has been evolved to test operational countermeasures to mitigate undesirable effects of space flight and techniques for treating illness and injury in flight. Projects are conducted to develop technology for instrumentation, closed life support systems, spacecraft habitability, and simulation of human capabilities.

The current program includes extensive study of problems associated with maintaining the health and productivity of spacecraft crews, emphasizing particularly the Space Adaptation Syndrome that affects some crew members during the first few days of a mission, but also maintaining continuing emphasis on questions of cardiovascular deconditioning, bone demineralization, and other effects of long-term space flight. Also under study are the origin, evolution, and distribution of life and life-related molecules on Earth and elsewhere as part of the evolution of the cosmos; the effects of biological processes on global dynamics, including the atmosphere, oceans, and terrestrial ecosystems; and the effects of differing levels of gravitational force on Earth life forms. Both ground-based research and an extensive flight-experiment program are employed. These programs will be continued and augmented in the years ahead to ensure that the Life Sciences program's goals will be met. The activities associated both with the medical effects of space flight on

humans and with gravitational biology will be involved closely with the Space Station program through the next 15 years. The Space Station's operating plans call for flying a medically diverse population of government and private individuals routinely for periods as long as the longest Skylab mission, and also for unprecedented amounts of extra-vehicular activity. Although the health problems that will occur should not be serious, it will be necessary to compile data on what does happen to the individuals and to verify countermeasures and treatment methods.

The Space Station will be a permanent laboratory where medical and biological studies can last as long as necessary to understand fundamental questions and resolve uncertainties surrounding longer flights. During the 1990s, the Life Sciences program will investigate the physiological and environmental factors that set limits on the ultimate duration of flights with human crews. Also, basic research will be performed to identify specific mechanisms of gravity perception in plants and animals and to show how gravity affects the development of organisms. Technology programs will develop improved countermeasures, methods for definitive care of ill and injured patients, and life support systems that regenerate food as well as air and water for spacecraft crews.

A phased program in biospheric research, planned to begin in the 1980s and to continue through the 1990s, will use Space Station unmanned platforms carrying Earth-looking instruments. Its goal will be to acquire data for a comprehensive model of global biogeochemical processes, which will constitute a key element in understanding Earth as a system. The search for life will continue with expansion of data acquisition and processing capabilities for the Search for Extraterrestrial Intelligence program, and of the use of Space Station payloads to capture extraterrestrial dust and to analyze the organic material content of the dust.

e. Satellite Communications

NASA's role in developing technology for satellites and other components of space communications has been and continues to be one of providing leadership in support of the private sector communication satellite marketplace, flight testing communications satellite advanced technology involving risk beyond that which private companies are able to accept, and supporting government use of space in non-military communications projects.

NASA's Communications program is facing a new challenge in both the private and public sectors. Within only two decades of the launch of the commercial communications satellite, SYCOM II, the orbital arc is approaching saturation, requiring NASA to develop new technologies involving beam-hopping antennas and on-board switching for new satellites that will make more efficient use of the orbital arc. In connection with public sector communications, the Space Station program requires development of technology for satellite-to-satellite links, giant antennas that can be assembled and tested in space, and geostationary platforms.

NASA's current program, developed with industry's help, consists of the following major activities:

- o Basic research and technology development to provide a technology base for all of NASA's communications programs, performed cooperatively by NASA, universities, and U.S. industry
- o Technical consultation and support services to ensure growth of existing satellite services and their incorporation into new satellite applications
- o Advanced technology development to provide new and expanded satellite services and experiment coordination, primarily in the public sector
- o Satellite-aided search and rescue, a cooperative program in which Canada, France, the Soviet Union, and the United States are developing and demonstrating a satellite system for detecting and locating the position of signals transmitted automatically from aircraft, ships, and individuals in distress
- o Development and flight test of the Advanced Communications Technology Satellite to investigate electronically-hopped antenna beam communications, on-board switching, spectrum conservation, and K_a -band circuits
- o Development, in cooperation with U.S. industry and the Federal Communications Commission, of technology and system architecture for a satellite system with large antennas to provide a communications capability to mobile users on Earth; and flight testing of the system in the 1990s

Possible major initiatives for the Communications program include the following:

- o Study and advanced development of communications for the Space Station complex, including tests of 30 GHz, 60 GHz, and optical frequency high and low data rate links (The links also may involve the Advanced Communications Technology Satellite, the Shuttle, and a dedicated Spartan free flyer.)
- o Development of an antenna assembly and test range, collocated with the Space Station, for testing satellites, antennas, and payloads before their commitment to flight or transfer to geostationary orbit
- o Development of giant antennas for use about 1998 by both scientific and commercial platforms assembled at the Space Station and then transferred to geostationary orbit.

f. Microgravity Science and Applications

The strong multidisciplinary base NASA has established in space materials science will be developed further through a vigorous flight program conducted with the cooperation of industry. The goals sought are to investigate the behavior of fluids and the effects on that behavior of

carrying out processes in the microgravity environment of space, to provide a better understanding of the effects and limitations imposed by gravity on processes carried out on Earth, and to evolve processes that exploit the unique character of the microgravity environment of space to produce results that cannot be obtained in unit gravity.

The current program consists of ground-based investigations, experiments in space on the Shuttle's mid-deck, and experiments in the Materials Experiment Assembly. Some of the ground-based investigations that promise valuable results are studies of the effects of convection in the growth of crystals, phase separation mechanisms other than gravity, containerless processing, and bioseparation processes. The two principal Shuttle mid-deck experiments that have yielded interesting results and are expected to be developed further are the Monodisperse Latex Reactor and Continuous Flow Electrophoresis. The Materials Experiment Assembly is a carrier for materials processing experiments that fills the experiments' support needs independent of the Shuttle's systems. Experiments that have been conducted in it include isothermal and gradient processing in general purpose furnaces, processing of monotectic alloys, growth of crystals from vapors, and processing in an acoustic levitator furnace.

The emphasis of the program during the next several years will be on crystal growth of electronic materials, solidification of alloys and composites, containerless melting and solidification, containerless formation of glass, separation processes, fluid and transport phenomena, and combustion processes in microgravity. Another important activity is development of materials research facilities and apparatus. Present emphasis is on Shuttle mid-deck facilities and apparatus that potentially can be upgraded to fly in the cargo bay or Spacelab and, later, on the space station.

Two functions of the Microgravity Science and Applications program will have a substantial effect on the possibilities for the program's commercialization: the use of space to obtain knowledge that can be applied to improve terrestrial processes and the processing of materials in space to take advantage of the weightless conditions there. For the near future, materials processing in space will be restricted to small quantities of high-value, low-volume materials such as pharmaceutical products, electronic materials, optical fibers, highly specialized alloys, and possibly precision latex microspheres. NASA will continue to conduct, with industry participation, a vigorous flight program to foster future ventures by industry that will be of optimum benefit with regard to both the materials produced and the economics of production. NASA sponsors, and encourages others to sponsor, materials processing research, but leaves to industry the task of deciding whether commercial production is feasible.

2. Space Flight

The Space Flight program supports NASA's goals for space transportation and a permanent presence in space. Its early goals are to develop the Space Transportation System further and achieve routine, economical operations with it. Planned programs emphasize development of follow-on systems for space transportation and other large space systems, including the Space Station,

orbital platforms and facilities, and the test, transportation, and servicing systems required to support them.

The program's objectives for the FY 1986 through 1990 period are to:

- o Complete development, acquisition, and upgrading to its full capability of the Space Transportation System, and achieve routine operations with it by 1988
- o Encourage use of the Space Transportation System by domestic and international commercial customers
- o Carry out a total of 30 Shuttle missions in FY 1985 and FY 1986
- o Develop by the second quarter of FY 1986 a cost-effective Centaur upper stage compatible with the Shuttle
- o Support and encourage commercial development of upper stages
- o Develop a tethered satellite system
- o Continue demonstration of the abilities of the Shuttle for servicing satellites
- o Develop by 1990 an Orbital Maneuvering Vehicle for use in conjunction with the Shuttle and, later, the Space Station.

The program's objectives beyond 1990 are to:

- o Maintain a Shuttle launch schedule with reserve capacity, while conducting safe, successful Shuttle missions having progressively lower operational costs and shorter turn-around times
- o Help in meeting NASA's objective of developing and putting into routine operation in low Earth orbit by the early 1990s a manned permanent space station facility
- o Develop an orbital transfer vehicle complementary to the Space Shuttle for transportation of payloads to, between, and beyond Earth orbits
- o Define, design, and provide a second-generation space transportation system, including unmanned cargo vehicles and second-generation orbiters
- o Develop and operate on a routine basis, beginning in the mid 1990s, geosynchronous orbit space platforms that are unmanned, permanent, and multifunction
- o Develop and put into routine operation by the year 2000 geosynchronous orbit facilities that are permanent, multifunction, and able to be periodically manned
- o Develop technology and techniques to construct, deploy, or assemble such facilities in space, and to test and service them in orbit

- o Encourage and support NASA and industry development of technology to improve concepts for space boosters that significantly reduce launch costs.

The objectives associated with bringing the Space Transportation System to full operation will be achieved through completion of the current base-line program. Most Earth-to-orbit and all return-to-Earth transportation needs will be met by the Shuttle, supported by the discrete Shuttle Production and Capability Development program. That program is responsible for Shuttle and propulsion system production and residual development, launch and mission support, and system improvements. Current activities are focused on the Inertial Upper Stage and the Centaur modified for Shuttle use; achieving full flight status for Spacelab; increasing opportunities for Spacelab-based science and applications work; operational support services for the Shuttle and expendable launch vehicles; and procurement of expendable items for both launch systems.

Proposed new initiatives support both the nearer-term objectives of space transportation operations and the longer-term objective to establish a permanent presence in space. During the period of this plan, capabilities for providing orbital services will be demonstrated. System hardware development will follow the demonstrations. The results of those demonstrations and the Tethered Satellite System program will help determine the limits of orbital activities of both the Shuttle and the Space Station.

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

3. Space Station

Establishment of a permanent manned presence in space is one of NASA's current eight goals and is a priority goal of the Administration as a means of maintaining U.S. leadership in space and of exploiting the economic and scientific benefits in that new frontier. Toward that goal, the President has committed to development of a space station by the early 1990s.

The program's near objectives have centered on identifying and synthesizing mission requirements for a civilian space station and reviewing a set of functional capabilities--the station's architecture. In addition, technology and advanced development programs are being initiated. To meet the goal of initial operation in the early 1990s, current plans include a 3-year definition phase and initiation, in FY 1987, of a design and development phase.

Because many aspects of the program will make it unique as compared with past space programs, the following program and management strategies have been established:

- o All major potential users of the Space Station, U.S. and foreign, will be involved from the beginning of planning activities to ensure that their needs are taken into consideration.

- o Thorough project definition will be conducted before system development is undertaken.
- o Involvement in the program will be agency wide and substantive. Overall direction of the program is the responsibility of the recently established Office of Space Station in NASA Headquarters. Johnson Space Center has been designated "lead center," responsible for NASA-wide program management of design, system engineering and integration, advanced development and test, and customer interface. Johnson and other NASA centers are responsible for project management of the development (by contractors) of system elements.
- o The station will be designed to accommodate evolutionary growth through incremental addition, modification, and replication.
- o The station's elements will be maintainable and restorable in space.
- o A rigorous design-to-cost approach will be followed to keep design and development costs within the \$8 billion currently estimated. The program definition phase will fully explore the necessary tradeoffs.
- o International participation in the program will be sought. Participation will be on a government-to-government basis and be designed to prevent unwarranted technology transfer.
- o Although the Department of Defense has not yet identified current military requirements for a space station, NASA will keep the Department fully informed of Space Station activities.
- o The Space Station will be designed to operate as autonomously as possible, except for resupply of materiel and personnel. A major objective of current planning is to define the optimum mix of human and machine functions.

During its existence from 1982 through 1984, the Space Station Task Force focused almost exclusively on mission requirements for the Space Station. Based on the results of contracted studies and workshops with wide participation of potential users, a preliminary set of phased Space Station missions for the period 1991 to 2000 was defined. The initial requirements included a manned element at 28.5° orbital inclination, a platform at low inclination, and a platform in polar orbit. Although no approved configuration exists, the present reference configuration calls for functional capabilities corresponding to two habitat modules, a logistics module, two laboratory modules, an unmanned platform at orbital inclination of 28.5°, an unmanned platform at orbital inclination of 90°, an Orbital Manuevering Vehicle, and a servicing system.

The Space Station program currently is concentrating on selecting contractors for program definition and preliminary design (to extend through 1986) and on advancing critical subsystem technologies; encouraging further international cooperation and planning; completing focused studies on human productivity, automation and robotics, and data management systems; completing development of a separate acquisition plan for a technical and management

information system; and continuing the progressive updating of Space Station functional requirements.

A Space Station advanced development program has been planned to provide advanced technologies needed for an evolutionary station. It will be integrated with system definition activities, with a major milestone and decision point occurring at the end of the definition phase. Both ground-based and space-based test beds are planned and are expected to have a vital role in subsequent definition of evolutionary elements. They are expected to reduce the program's costs and risks.

4. Space Tracking and Data Systems

The Space Tracking and Data Systems program supports the Nation's missions in aeronautics and space by planning for, developing, and operating the space and ground network of tracking and data systems for missions of automated and manned orbital spacecraft, deep space vehicles, sounding rockets, balloons, and research aircraft. The program has four basic elements: space network, ground networks, communications and data systems, and development of advanced systems. Plans for those elements and for supporting mission activities follow.

a. Space Network

By 1986, tracking and data acquisition facilities for spacecraft in near Earth orbit will have evolved from a network of ground tracking stations around the world into a network of two Tracking and Data Relay Satellite System (TDRSS) satellites in geostationary orbit, an in-orbit spare, and a single ground terminal at White Sands, New Mexico, all owned and operated by a contractor. A network control center at Goddard Space Flight Center will control the system and manage network resources. The system will increase coverage of near Earth orbits from 15 percent to 85 percent.

b. Ground Networks

NASA will close nine more ground stations while phasing TDRSS into operation, leaving only six locations fully operational and consolidated under Jet Propulsion Laboratory management. The consolidated ground network will support deep-space missions and missions in high Earth and geostationary orbits. Early improvements planned for the network include arraying antennas to boost the signal received from the Voyager 2 spacecraft when it is close to the planet Uranus and nearly three billion kilometers from Earth in 1986; adding an X-band uplink command system to the ground network about 1987 to reduce the blackout effects of the solar corona on signals from Galileo and later planetary missions, to improve signal stability by a factor of five, and to improve ability to search for gravity waves; developing a capability at Dryden Flight Research Facility for supporting multiple missions; providing tracking and data acquisition support to the National Scientific Balloon Facility at Palestine, Texas; and improving the impact prediction system and fixed radar capabilities at Wallops Flight Facility.

c. Communications and Data Systems

To handle the substantial increase in data transfer and processing that TDRSS services will generate, greater use will be made of electronic data transfer and other automated features to reduce the need for human intervention and tape handling. Aged and obsolete computing systems for mission support will be replaced to increase reliability and reduce maintenance costs; and more use will be made of microprocessors to control dish-antenna operations. By 1986 a program-support communications network will be in operation to provide NASA and its contractors with supplemental communications service for conducting day-to-day business.

d. Research and Development for 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 TDRSS use.

e. Advanced Studies

The TDRSS is expected to meet needs through most of the 1990s, but increases in data volume 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 new technology 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 program will continue to look ahead and make plans to meet such challenges.

5. Space Research and Technology

This program is responsible for conducting space research and technology to support the Nation's civil and defense space programs and overall economic growth. It is concerned with technology with broad applicability rather than that related directly to specific projects; and it concentrates on long-term, high-risk research and technology development to satisfy national space objectives. With commercial and military investments in the use of space growing rapidly, the program is focusing increasingly on national objectives and missions and addressing the technology needs of those other sectors more directly. Much of the work constituting the program is planned in consultation with the other NASA program offices, the Department of Defense, and industry. Much also is conducted jointly with them to facilitate transfer to them of the technology developed.

The following objectives form the basis for the program and related institutional plans:

- o To ensure timely provision of new concepts and advanced technologies
- o To support the development of NASA missions in space and the space activities of industry and other government agencies
- o To utilize the strengths of universities in conducting the NASA Space Research and Technology program
- o To maintain NASA's centers in positions of strength in critical space technology areas.

Those objectives will be realized, as the objectives of the Aeronautics Research and Technology program are, through a program of disciplinary research combined with a program of systems research and technology development; enhancement of the staff, facilities, and computational capabilities of the NASA centers; increased and more productive involvement of the universities; and greater emphasis on favorable transfer of technology. Also, NASA will use and make available for use by others its unique resource of space facilities to conduct research and technology development in the actual space environment.

The disciplinary research and the systems research and technology development both concentrate on maintaining excellence in five priority technical areas: large, flexible structures and their control; space power systems; launch vehicle and space propulsion systems; entry technologies; and space operations. The disciplinary research further concentrates on aerothermodynamics, materials and structures, information sciences, space data and communications, controls and guidance, human factors, space energy conversion, and propulsion. The systems research and technology development further concentrates on space transportation systems, spacecraft systems, and large space systems. The two programs have common technology objectives that provide a basis for decisions on funding, personnel, and facilities. Those objectives are for materials and concepts for thermal protection; longer-life, reusable engines; propulsion and aerobraking for the Orbital Transfer Vehicle; high-capacity electrical power generation, storage, and distribution systems; satellite communications; large antenna systems; space teleoperation, robotics, and autonomous systems; space information management systems; computer science for aerospace applications; computational aerothermodynamic techniques for entry bodies and rocket engines; human capabilities in space; concepts for advanced sensors; and distributed, adaptive controls for large space systems.

Augmentation in FY 1986 is planned for the automation and robotics program, to provide technology to increase the capabilities of systems and the productivity of humans in space; the large space structures program, to provide technology for the control of large flexible structures in space; and the Orbital Transfer Vehicle program, to develop technologies for a space-based, reusable Orbital Transfer Vehicle. Augmentation planned for later years include increases for Orbital Transfer Vehicle technologies, automation and robotics, in-space experiments, enabling technologies, entry research vehicles, a liquid oxygen-hydrocarbon research engine, Mars sample return technologies, and lunar base technologies.

C. A Vision of the Space Era Beyond the Year 2000

Most of the programs described in this report of NASA planning will reach fruition by the end of the 20th century. With the beginning of the next century only 15 years away, it is none too soon to begin preliminary planning of possible systems, programs, and activities for the early years of the 21st century. Detailed planning would be premature, but a range of studies of possible alternative programs must be conducted to help set goals and objectives for that period, to identify programs providing the greatest potential, and to identify technologies that need to be pursued. The results of many such preliminary studies conducted in the past 20 years and others now under way have contributed to the material sketched below.

1. Space Infrastructure by the Year 2000

With the Administration's recent commitment to development of a permanently manned space station to be in orbit in the early 1990s, a significant orbital infrastructure should be in place by the year 2000 to support programs in science and exploration, development of technologies and their application to improve life on Earth, and a wide range of commercial activities. By the end of the present century, the permanently manned Space Station and associated unmanned platforms will have had some years of operation in low Earth orbit conducting many of those activities. Other supporting systems will have been developed, or will be within NASA's capability to provide. They will have the ability to support large, permanent facilities for science, research and development, commerce, and other activities in low Earth orbit and geosynchronous Earth orbit; to provide routine, economical, flexible access to other orbits by manned and robotic systems; to institute routine check-out, refueling, repairing, and upgrading of space facilities, as well as removal of Earth-orbital debris; and to devise and implement uses and missions for the Space Transportation System such as large tethered systems for power generation, nonpropulsive transportation, and satellite constellations.

A cryogenic version of the Orbital Transfer Vehicle evolutionary family, currently in early stages of preliminary design, is expected to provide by the year 2000 reusability for manned sortie flights to at least geosynchronous orbit. It also should be able to provide the basis for transportation for longer flights to establish a lunar base and for planetary missions such as a Mars sample return. Supplemented at times by a remotely controlled Orbital Maneuvering Vehicle with special kits for remote servicing, fueling, and debris capture, it probably should be able to fly with or without crews with minimum change. Because it appears that servicing, maintaining, and refueling those reusable vehicles will be more advantageously accomplished in orbit than on the ground, the Space Station must be equipped with suitable hangar, servicing, and refueling facilities.

A potential need exists for routine flights of unmanned, cargo carrying, Earth to low orbit vehicles that, compared with the Space Shuttle, will have the ability to accept payloads with larger diameters and to lift greater weights. Those Shuttle-derived launch vehicles would be available, of course, for the payloads of other users.

Various advanced systems, tools, and techniques will have to be available by the year 2000 for routine servicing operations in the space regimes

occupied by satellites and other spacecraft. Also, substantial augmentations to crew and life support systems will have to be developed. Those augmentations must provide closed-cycle, regenerative water and air loops for onboard environment control and life support systems; regenerable, space-maintained, life support backpack systems for extravehicular activity; high-productivity mobility systems; Earth-norm food, hygiene, and habitability; and onboard automation that is able to handle tasks that do not necessarily require continuous manned attendance and that is flexible enough to allow easy upgrading as technologies advance rapidly.

2. Space Programs of the Early 21st Century

For the United States to exercise leadership in space and to improve the well-being of humankind on Earth and in space beyond the year 2000, long-range goals will be required for advancing scientific knowledge, space exploration, Earth applications, and commercial uses. Those goals will be set by the Administration and Congress after consideration by many individuals and organizations, the National Commission on Space, NASA, and other groups involved in the U.S. space program. Sustained space research and development also will be necessary to conceive and develop even more advanced innovative systems and techniques than those that have been developed or will be developed by the end of this century. Concepts exist for major manned and automated space missions for achieving those goals and for providing unprecedented scientific and technical benefits. Those missions will use all regimes of space accessible in the early 21st century: low Earth orbit; higher energy Earth orbits, including geostationary orbit; lunar orbit; the lunar surface; and the environs of the inner planets.

Achievements in the early 21st century in science, exploration, Earth applications, and commercial uses will depend on two trends: first, the increasing capabilities of space systems with regard to accessibility, payloads, stay times, and variety and sophistication of operations and, second, the increasing capabilities of instruments with regard to detection, resolution, pointing accuracy, and data collection and management made possible partly by improvement of their power supplies and cooling mechanisms. Those trends and the space infrastructure they produce, such as the Space Station, will support scientific, technical, and commercial activities and systems not now possible, including:

- o Large facility-class observatory instruments in both low Earth orbit and geosynchronous Earth orbit
- o Orbital platforms, both equatorial and polar and both automated and human-tended, carrying instrument payloads that are modular, variable, serviceable, and interchangeable
- o Large facilities such as telescope mirrors and radio antennas assembled in space by humans for both scientific and communications purposes
- o Routine use of the lunar surface for planetary geoscience studies, solar monitoring, astronomical surveys, and possibly extraction of resources

- o Routine materials processing in microgravity, at bench-test through pilot-plant levels, probably with extensive commercial involvement and continual increases in the variety and quantities of materials produced profitably on a commercial basis
 - o Significant increases in the number of humans present in space, in various Earth orbits and possibly on the lunar surface
 - o Large-payload, high-performance planetary exploration missions made possible by clustering launch stages or by using Orbital Transfer Vehicle derivatives
 - o Planetary science networks and other long-term activities on other celestial bodies such as the moon, Mars, and asteroids.
- a. Earth Observations and the Near-Space Environment

NASA's activities in the 21st century will use the Space Station and its platforms to emphasize synoptic, continuous, and long-term observations of Earth and its immediate surroundings from both polar and equatorial low Earth orbits. A wide variety of multispectral, microwave, and other forms of sensors will provide critical global information about Earth's land surfaces, atmosphere, and ocean systems. A complementary system of sensors will collect data on the near-Earth space environment and its dynamic behavior by monitoring the sun, sampling and analyzing the solar wind, detecting solar flare particles, and studying Earth's magnetosphere and its interactions with solar activity.

As space transportation capabilities increase, similar platforms in geostationary orbit will provide continuous monitoring of larger areas of Earth. Also, automated or human-tended instruments located on the lunar surface will begin complementary observations. That location will permit observation of Earth's entire face, with simultaneous investigation of Earth's space environment and magnetotail.

The complexity of the scientific problems involved in studying Earth and its space environment, the variety of observations possible, and the potentially high rates of data collection will require major advances in ground-based data collection, management, and analysis and in modeling and prediction techniques. Also, mechanisms will have been developed for the creation and management of large, integrated, interdisciplinary projects like the current Global Habitability study.

b. Solar System Exploration

Exploration of the solar system will be carried out in several ways, using a variety of space capabilities. Even by the beginning of the 21st century, many relatively small, cost-effective missions contained in the Solar System Exploration Committee's recommended core program will remain to be conducted. They can be carried out with the Shuttle-Centaur combination, an equivalent transportation system as a straightforward continuation of NASA's 1980s and 1990s program, or new transportation systems utilizing the Space Station's facilities. Some more demanding

missions, such as the return to Earth of samples from Mars or a comet, can be carried out in a similar fashion.

Instruments, chiefly telescopes, for planetary studies will be mounted on and supported by the Space Station and its associated platforms. Even more significant, perhaps, the Space Station's fueling and launching capabilities and the availability of launch stages with higher performance will permit automated missions to planetary systems that now are not easily accessible. Examples of those missions are a Mercury orbiter, a Neptune orbiter and probe, intensive study of the Jupiter and Saturn systems, and sample return missions of greater sophistication.

Routine access to the lunar surface will make possible the first intensive, systematic study of another major celestial body. Extensive sample collection and scientific traverses conducted by humans and long-term instrument networks installed and managed by humans will help determine the details of the moon's structure, composition, and history. They also will make accessible the record of solar and cosmic ray particle fluxes preserved in the lunar soil. Similar scientific activities can be carried out on Mars, either by large, automated spacecraft or by a manned mission. Other scientific achievements will include orbital remote sensing of that planet and a rendezvous mission to its moons Phobos and Deimos to emplace instruments on and return samples from them.

c. Astrophysics and Solar Studies

Studies of the universe beyond the solar system will continue to depend on the Shuttle or its equivalent to place into low Earth orbit a mixture of small specialized missions and large observatory-class facilities similar to those studied for the 1990s by the National Research Council's Astronomy Survey Committee. Those missions and facilities will be structured to attack specific problems that remain as the new century begins.

Automated and human-tended platforms in the Space Station system will use a variety of astronomical instruments to conduct a wide assortment of complementary activities. The ability of humans to assemble large structures in space will make possible space-based astronomical instruments not limited by the size and weight constraints of a Shuttle payload; for example, large optical and infrared mirrors and large antennas for radio astronomy. The Space Station also will make possible an exciting program of studies combining observations and spacecraft missions to investigate the sun as a star. The Space Station will support the larger and more sophisticated instruments needed for observing and monitoring the sun; and high-performance launch stages such as clustered Centaurs or Orbital Transfer Vehicle derivatives will make possible solar probes, grazers, and orbiters.

The lunar surface will become available as a platform for astronomical observations. Initial studies will be made with small, prototype, human-tended instruments and will emphasize sky surveys and the detection of unpredictable events like supernovas and gamma-ray bursts.

d. Life Sciences

The first quarter of the 21st century will see a major effort to develop protective systems and physiological countermeasures to qualify humans for space flight missions years in duration. A group of dedicated Space Station modules will provide space laboratory capabilities for this work. Among the most serious problems to be solved are bone demineralization, loss of muscle mass, and radiation protection. Concurrently, operations and life sciences studies in a lunar surface base can develop the information required to plan for human residence on other planets. Around the turn of the century, practical controlled ecological life support systems will enable human habitations to operate with little or no requirement for external supplies of crew support consumables. Therefore, the essential medical and biological requirements for manned missions to destinations far from Earth should be in hand by 2025.

Basic research on gravity effects in living organisms will become an established specialty within medical and biological science, building on the results of the 1990s.

The search for extraterrestrial life will be pursued through the use of large radio telescopes installed in space that will have improved signal analysis capabilities.

e. Materials Processing

Even before the end of this century, materials production in the microgravity of space should have become routine, probably with extensive commercial involvement, for such diverse items as pharmaceuticals, crystals, alloys, and special glasses. Evolution of the Space Station will allow that activity to expand, possibly to the pilot-plant level or beyond, into separate laboratory modules and human-tended laboratories in low Earth orbit.

A variety of space-based power systems, including solar photovoltaic, nuclear, and solar thermal systems, will be essential. They will supply power to the growing industrial complex associated with the Space Station and, perhaps, to facilities in geosynchronous orbit. The program for developing and testing solar power systems also can explore the feasibility of transmitting power to, for example, Earth's surface or the moon.

Access to the lunar surface will make possible the first routine use of extraterrestrial resources. Techniques could be developed to enable a lunar base, even before its permanent occupancy, to mine, extract, and fabricate products from lunar materials. The objectives will be to make the lunar base able to support itself as much as possible from lunar feedstocks and to foster the economic use of lunar resources elsewhere in space (for example, the use of lunar oxygen by space systems in low Earth orbit). Extraterrestrial resources also will be investigated by means of missions, manned or unmanned, to near-Earth asteroids to obtain information on and assess the availability of resources, especially the essential volatile elements carbon, hydrogen, and nitrogen, that are lacking on the moon.

f. Communications

Drastically expanded communications capabilities will be needed in the early 21st century to support both scientific and commercial activities in space. That need will be satisfied mainly by large (10- to 100-meter diameter) antennas--assembled and tended in space by humans at the Space Station and located at geosynchronous orbit. Initiation of long-term human activities on the moon will generate a high demand for communications that will require lunar communications systems consisting both of networks based on the moon's surface and of lunar satellites acting as relays. Satisfying those communications needs will require not only extensive research, but also development of new systems--such as large, space-based antenna arrays--and of space-based storage and assembly techniques. New techniques also will be needed for handling the voluminous communications traffic generated by both scientific and commercial activities.

The space capabilities available after the turn of the century will create a revolution in space research, exploration, and exploitation. The resulting research and operations environment will have a potential that can be imagined only dimly at this time because of the many factors affecting that environment: large payloads; long instrument lifetimes; human-supported space operations; and routine access to low and geosynchronous Earth orbits, the lunar surface, and possibly the Martian surface and, for unmanned missions, the entire solar system. The inevitability of human exploration--and eventually habitation--of the solar system will begin to be apparent, and possibilities for tapping the resources of the moon and the asteroids will become evident. Means developed before the turn of the century for effectively monitoring Earth's environment will help humankind manage that environment wisely for the benefit of all. Use of space for industrial processes and other commercial purposes should be commonplace. Consequently, the early 21st century should be an era of unparalleled achievement for humanity.

D. Aeronautics Program Highlights to Year 2000

Upon completion of the Aeronautics Policy Study in 1982 by the Office of Science and Technology Policy, the Administration declared as a national policy objective the "provision of a proven technology base to support the future development of superior U.S. aircraft." That policy is sustained and, indeed, reinforced by NASA's goal for its Aeronautics program for FY 1986 and beyond: to conduct research and technology development that ensures the enduring preeminence of U.S. aviation. That goal is supported by the following program objectives:

- o Maintain the excellence of the NASA research centers in facilities, computational capability, and technical and professional staff. This objective requires repairing and replacing aging facilities as well as developing additions and improvements, advancing scientific and engineering computational instruments and programs, and enhancing staff competence by selecting personnel with highest abilities and providing them with career incentives.
- o Conduct disciplinary and systems research critical to the continued superiority of U.S. aircraft. Systems integration requires that

technical disciplines, usually treated in isolation at the basic level, be interrelated through systems research.

- o Ensure the timely transition of research results to the U.S. aerospace community. For efficient, timely transfer of technologies to industry, increased attention must be given to active participation of industry in NASA's research and technology development through contractual and joint programs; timely dissemination of results through workshops, conferences, and reports; and dissemination to industry of information on technology advances made outside the United States.
- o Ensure the involvement of universities and industry in NASA's Aeronautics program. NASA grants and contracts are an incentive to academic expertise in the university community and encourage technology development by industry for incorporation into new vehicle designs.
- o Provide development support to the aeronautics activities of other government agencies and U.S. industry. While furnishing that service, NASA gains data and experience of benefit to its primary mission of aeronautical research and technology development.

Decisions on funding, personnel, and facilities for the program must be consistent with the program's long-term technology development objectives, which would:

- o Bring external and internal computational fluid dynamics to a state of practical application for aircraft and engine design
- o Significantly reduce aircraft viscous drag over the full speed range and improve understanding of Reynolds number effects at transonic speeds
- o Through the use of advanced materials, minimize the structural weight of civil and military aircraft engines and airframes
- o Provide advanced control, guidance, and flight management systems to improve performance and operation of future aircraft
- o Increase by 100 percent the productivity and reliability of rotorcraft for military and civil application
- o Ensure the availability of technology for superior military aircraft and missile systems
- o Enhance flight crew effectiveness in advanced cockpit and air traffic environments that include advanced automation, display, and control techniques
- o Exploit modern computers in solving computationally intensive aeronautical problems
- o Exploit the full potential of techniques for enhanced performance through highly integrated propulsion-airframe systems

- o Advance the technology for small gas turbine engines to a level comparable with that for large turbine engines
- o Establish the technical feasibility of high-speed turboprop propulsion
- o Advance enabling technologies for subsonic transport engines to improve their fuel efficiency and durability
- o Increase aviation safety by improving crash and fire worthiness, protection from weather hazards, and aircraft systems.

The program will continue efforts both in basic aeronautical disciplines and in systems research and technology development. The principal areas of technology currently being pursued include: fluid and thermal physics--high Reynolds number cryogenic testing, viscous drag reduction, vortex flows, and computation of the aerodynamics of complex aircraft configurations; materials and structures--light alloy metals, new composite materials, and the crash dynamics of composite structures; controls, guidance, and human factors--aircraft with highly augmented controls, fault-tolerant systems, advanced automation of crew stations, and improved simulation; computer science--concurrent processing architectures, algorithms, and techniques for computational physics research; propulsion--advanced turboprop, small turbine engine, and general aviation and commuter aircraft engine technology; rotorcraft--noise and vibration reduction and unsteady rotor aerodynamics; high-performance aircraft--high angle-of-attack flight, vectored-thrust and short-takeoff-and-vertical-landing aircraft, maneuverable supersonic cruise aircraft, propulsion-airframe integration, increased engine performance and durability through the turbine engine hot section technology program, and hypersonic propulsion, structures, and configuration aerodynamics; and subsonic aircraft--icing and lightning research, natural and controlled laminar flow, and, in coordination with the Federal Aviation Administration, air safety, operations problems, and interfacing with the Air Traffic Control System.

Technical progress during the past year has permitted acceleration of work on advanced turboprops and oblique wings. In an effort to initiate a full-scale flight test of the Advanced Turboprop propulsion concept by 1987, NASA has augmented the Advanced Turboprop work dedicated to the flight test. Work in the oblique wing program now is directed toward flight demonstration and validation tests of the use of oblique wings at transonic and supersonic speeds.

Planned initiatives include development of technology in the following areas to respond to technical opportunities and needs and to satisfy the long-term technology development objectives listed previously:

- o High-speed (hypersonic) flight--to provide a proven technology base for future options in aeronautics and space in the critical areas of air-breathing propulsion, aerothermodynamics, materials, structures, and system analysis, including the development of a recoverable hypersonic research aircraft
- o Supersonic cruise--to obtain long-distance efficiency for future military and civil aircraft

- o Computational fluid dynamics--to facilitate development of focused applications of computational fluid dynamics for important 3-dimensional viscous-dominated flows and development of pathfinding simulations of the fundamental physics of unsteady flows; to initiate development of techniques for performing integrated multidisciplinary analyses; and to apply expert systems to automating development of computational fluid dynamics analyses
- o Rotorcraft systems noise and vibration--to develop design methodology for future helicopters that will be acceptable to the community, have low vibration, and without sacrificing vehicle performance, have low acoustic detectability (for military applications)
- o Advanced fighter aircraft--to accelerate and integrate key enabling technologies, such as those for high thrust-to-weight propulsion, thrust vectoring for control, and high-angle-of-attack flight dynamics, for revolutionary advances in fighter capabilities
- o Transport aircraft laminar flow--to provide flight verification of a hybrid wing concept employing active laminar flow control in leading edges for a new generation of fuel efficient civil and military transports
- o Small-engine components--to provide major improvements in the fuel consumption, weight, reliability, and durability of small turbine engines for a broad range of future military and civil applications
- o Superaugmented rotorcraft--to achieve an all-weather operational capability for a single-pilot helicopter and for operations at remote sites or in emergency medical services
- o Convertible engine propulsion--to provide integrated flight and propulsion control modes for convertible powered rotorcraft and to evaluate advanced convertible engine concepts
- o Composite structures--to achieve effective use of advanced composites in highly loaded airframe structures
- o Advanced transmission systems--to produce more reliable, more efficient, and lighter weight transmissions for advanced turboprop, geared turbofan, and rotorcraft
- o Supersonic STOL/STOVL aircraft--to provide technology for advanced, supersonic, STOL/STOVL fighters able to operate from a variety of surfaces
- o STOVL experimental aircraft--to conduct flight tests of advanced STOVL aircraft concepts.

E. Aeronautics Beyond the Year 2000

At the end of the 20th century, a substantial potential will still exist for major advances in each of the aeronautical disciplines--aerodynamics, structures and materials, propulsion, and controls--and, perhaps of even more

significance, in abilities to combine individual advances into integrated technology for totally new aircraft systems. In addition, continued progress in related areas such as electronics, computer science, artificial intelligence, fiber optics, laser technology, and quite probably some fields not yet identifiable, will increase further the potential for progress in aeronautics over the next century.

Technologies for conventional subsonic transports, general aviation, and helicopters, all of which are major integral components of today's aviation, will continue to be important for many years into the next century. NASA will continue to develop technology for necessary improvements in the safety, productivity, and operational effectiveness of subsonic transports and in the efficiency, safety, and automation of the tasks performed by general aviation pilots. Increases in the all-weather capability and productivity of conventional helicopters and reduction of their noise and vibration will greatly expand their use in civil transportation, as well as in the special-purpose, utility, and military missions they perform today.

But probably of even more significance will be new opportunities and challenges connected with supersonic cruise, high-speed rotorcraft, short-haul subsonic transportation, and hypersonic flight.

1. Supersonic Cruise

Advances in supersonic cruise technology will provide important options for civil transportation, as well as for military aircraft. The next century will be characterized by several trends that are almost certain to alter the outlook for long-range transportation. World population will continue to grow, and the largest component of that growth--over 75 percent--will be in the developing nations. 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 market for over-ocean transportation with stage lengths considerably greater than those over the North Atlantic. Those long stages and the large fraction of travel that will be business oriented, rather than tourist oriented, will increase the value of reducing trip time and increasing productivity, and will precipitate renewed interest in supersonic transportation.

The Concorde already has proven the technical feasibility of supersonic air transportation, but also has proven that a system based on technology of the 1960s cannot be economically viable. Research conducted since termination of the U.S. supersonic transport program has resulted in considerable optimism that a supersonic transport can be economically viable and environmentally acceptable. Design studies conducted by the major aircraft manufacturers indicate that an advanced technology supersonic transport could carry 300 to 400 passengers over intercontinental ranges at more than three times the speed and productivity of today's subsonic transports. Operating cost estimates suggest that little if any surcharges over tourist fares would be required, and some configuration approaches appear to promise sonic boom overpressures that would be sufficiently low that flight over land would be practical.

Supersonic-cruise technology also is important for development of combat aircraft. Recent studies and combat experience indicate that sustained supersonic cruise, coupled with high maneuver capability, would provide a

considerable increase in combat effectiveness and survivability. In addition, the higher engine installed thrust-to-weight ratios associated with supersonic cruise capabilities increase the feasibility of short takeoff and vertical landing capabilities for future fighters.

2. High-Speed Rotorcraft

Although an order of magnitude slower than supersonic aircraft, new rotary-wing vehicles will be much faster than present-day helicopters and, therefore, able to assume a much broader role in both civil and military operations. Tilt-rotor technology developed jointly by NASA and the U.S. Army makes it possible for an aircraft to retain the vertical flight and hover advantages of a helicopter while being capable of efficient, smooth, quiet, forward flight at speeds approaching those of current propeller-driven airplanes. That capability is a first, but important, step toward entirely new generations of high-speed rotary wing aircraft for a variety of military applications and for civil missions including rescue, emergency medical service, and police work.

The tilt-rotor aircraft's increased speed, range, economy, payload, and comfort will provide the basis for large-scale inter-city and inter-region civil transportation. Also, its capability for combined vertical and forward flight will be important in satisfying worldwide needs created by conditions as disparate as urban congestion in highly developed areas and primitive terrain in developing areas. Problems encountered in construction activities at remote sites may focus future attention on another feature of rotary-wing technology--the heavy lift capability of very large helicopters, particularly in the higher-efficiency, reduced-weight versions that current rotorcraft research will make possible.

3. Short-Haul Transports

Although supersonic transports will provide much of future long-range air travel, a large fraction of air transportation in the United States and, even more, in Europe and elsewhere will consist of trips with stage lengths of 160 to 800 kilometers. In the next century, as population grows and shifts away from the older metropolitan areas and as new urban areas and industrial centers develop, the need for efficient, comfortable, short-haul air transportation will increase rapidly. Small commuter aircraft mostly will be replaced by aircraft that have capacities of 50 to 100 passengers or more, that are designed to large-transport standards of air worthiness, operation, safety, and dependability, and that also are designed for maximum efficiency during climb, descent, and short-stage-length flight. The new aircraft also will be able to operate safely and quietly at relatively small airports and on short runways at hub terminals.

Advanced turboprop technology now under development will be an important contributor to that future generation of commuter aircraft by providing important improvements in fuel economy. The new short-haul transports also will benefit from research now under way for long-haul transports in areas such as drag reduction, lightweight structures, active controls, and safety. They also may employ propulsive lift for takeoffs from short runways.

4. Hypersonic Flight

The X-15 research airplane allowed some exploration of the hypersonic regime in the early 1960s and, in fact, helped set the stage for the Shuttle and other space vehicles that must pass through the hypersonic regime on the way to and from orbit. Development of capabilities for sustained hypersonic flight entails technical problems in propulsion and aerodynamic heating that will be more difficult to solve. However, research has indicated that they can be solved, making hypersonic flight operations in the next century practical and perhaps even routine. Long-range cruise missiles with supersonic-combustion ramjet (scramjet) propulsion systems burning high-density hydrocarbon fuels may be the first generation of operational hypersonic vehicles, followed by strategic reconnaissance aircraft able to cruise at Mach 5 to Mach 7 at very high altitudes. There also is renewed interest in a hypersonic maneuvering airplane capable of sustained operation both in the atmosphere and in low orbit. Equipped with a combination of scramjet and rocket propulsion to match the transatmospheric envelope, it probably would be able to take off, as well as land, horizontally. Technology development involving highly coordinated systems research in the propulsion, aerodynamics, materials, structures, and controls disciplines will be required and will have to be conducted on the basis of postulated future vehicle requirements until actual military spaceflight needs can be defined.

5. Research Opportunities

The Aeronautics Research and Technology Base effort, the primary source of the seeds for long-range future growth, well may lead to additional and perhaps even more important next-century developments that now cannot be identified. Two areas of extreme importance to developments in all the types of aeronautical vehicles are the growing dependence of aircraft and engine design on numerical simulation and the use of microelectronics in aircraft controls.

An ability to compute fluid dynamics is essential for enhancing understanding of aeronautical phenomena and for facilitating the aeronautical design process. By the year 2000, solutions to the full Navier-Stokes equations should be possible, providing exact solutions for the real flow of gases, allowing accurate modeling of turbulence and separated flow, and opening the way to a broad range of control mechanisms for improving aerodynamic flows.

Technology advances that should be incorporated into aircraft of the next century will require that systems integration capabilities be developed to a degree more advanced than those reflected in the Space Shuttle, the best current example of a highly integrated aerospace vehicle. Highly reliable flight controls, electric power systems, and electromechanical actuators will allow replacement of mechanical, hydraulic, and pneumatic systems with all-electric systems having higher reliability and lower weight. Fiber optics will make possible fly-by-light systems providing still greater flexibility, weight reduction, and protection from lightning effects. Technology will be available for active controls to alleviate structural loads and suppress flutter, thereby significantly improving ride qualities and reducing pilot workloads and structural fatigue.

Many of the tools and facilities that will be required to support research and technology and vehicle development into the 21st century either already exist or are under development. NASA's impressive capability in low-speed and high-speed wind tunnels recently has been augmented with the National Transonic Facility and will be enhanced further when the 40X80X120-foot wind tunnel at Ames Research Center becomes operational. However, additional capabilities will be needed for large-scale, real-gas, hypersonic engine testing, for icing research, and for large-scale, integrated airframe-propulsion systems research in which altitude, temperature, and speed effects can be studied concurrently.

In addition to those types of ground-based facilities, technology development will continue to require flight research as an essential element. Thus, new experimental vehicles probably will be required in the areas of hypersonics, supersonic short-takeoff and vertical landing, advanced supersonic cruise aircraft, and very high speed rotorcraft.

The future of aeronautics in the next century is replete with technology opportunities for growth and advancement even more impressive and exciting than those witnessed in the present century, but successful realization will require continued effort and commitment. NASA's research is providing, and will continue to provide, a solid foundation from which NASA will proceed effectively in directions it selects on the basis of national needs and priorities.

F. Institution

Two of the eight NASA goals listed in Section A of this chapter, the first and the last, are fundamental to institutional management. As an important step toward meeting the first, creation of a work environment that will enable the Agency to achieve and maintain a work force of highest excellence, NASA has undertaken as a priority activity recruitment of recent graduates of distinction in science and engineering. The current scientist and engineering complement of 10,900 is expected to grow to approximately 11,500 by the end of FY 1989. Of particular significance is that the buildup is occurring within a stable ceiling of about 21,000 for NASA's total permanent work force.

The last of the eight goals calls for developing and applying advanced technology and management techniques and procedures to obtain optimum productivity. Two major activities are being conducted toward meeting that goal. The first is preservation, enhancement, and construction of aeronautical and space facilities, especially facilities essential to support the growing number of Space Shuttle flights and the payloads they carry. The second, computer systems management, has the objectives of ensuring that the best computer tools are available at the right time and at the lowest cost, fostering the use of computer systems to increase management productivity, and advancing computer and computer-related technology for the benefit of NASA and the Nation.

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Space Science and Applications



III. SPACE SCIENCE AND APPLICATIONS

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III. SPACE SCIENCE AND APPLICATIONS

The Space Science and Applications program is responsible for scientific research into the nature and origin of the universe and for applying space systems and techniques to solve everyday problems on Earth. The research includes observation of the distant universe, exploration of the near universe, and characterization of Earth and its environment. The applications work advances the life sciences, improves satellite communications, investigates the behavior of materials during processing in microgravity, and expands knowledge of Earth and its environment.

Observation of the distant universe includes measurement of the radiation and particles reaching Earth from beyond the solar system and study of the sun as the only star that can be observed in detail. Questions under study deal with the origin, evolution, and structure of the universe and the fundamental laws of physics that govern it. Space flight's principal contribution is to provide a view of the universe unobscured by the haze of Earth's atmosphere.

Exploration of the near universe includes visiting and studying objects and environments in or near the solar system to investigate the origin and evolution of the solar system and to compare Earth with the other planets and their satellites. Measurements focus on internal structures, surface features, atmospheres, and plasma environments and, therefore, require remote and in situ observations and sample returns.

Characterizing Earth and its environment involves remote sensing from space and measurement of the particles and electric and magnetic fields of Earth and its surroundings to determine how the solid planet, land surfaces, oceans, atmosphere, and plasmasphere function and interact. Also involved are investigations of how life originated, has evolved, and is maintained on Earth, as well as research on fundamental laws of physics and chemistry and their application. The view from space gives mankind its first truly global perspective on its home in the universe.

The Life Sciences program seeks to ensure the health, safety, well-being, and effective performance of humans in space and to prepare the way for humankind to take a place in the larger environment of the universe. It also uses the space environment to further knowledge in medicine and biology by exposing living organisms to space and noting the effects. If deleterious effects are detected, countermeasures are sought.

The Communications program is designed to develop high-risk electronics technology useful in multiple frequency bands to satisfy the communications needs of NASA, other government agencies, and U.S. industry.

The aim of the Materials Processing program is to improve basic understanding of materials and their behavior in microgravity. Research in the space environment clarifies materials processes and explores feasible and advantageous processing that one day may lead to an industry in space.

A. Program Strategy

Space science and applications programs concentrate on problems whose solution requires placing instruments in space and the upper atmosphere to

provide observations at wavelengths to which Earth's atmosphere is opaque; in situ studies; higher spatial resolutions than can be obtained from Earth's surface; global views of Earth; or the environment of space, especially low gravity. They make use of theoretical studies, data analyses, laboratory measurements and simulations, instrument development, and field measurements. The theoretical studies relate observations to fundamental laws and quantify the understandings gained, while the laboratory investigations provide additional information on observed processes. Field measurements are made from rockets, balloons, aircraft, and ground bases to complement and verify measurements made from space. The ground-based observations provide data needed to interpret the space observations fully. Both the Shuttle and expendable launch vehicles are used to launch the program's payloads. The large amounts of data generated by the programs require constant improvements in data management techniques for efficient data access, storage, and use.

The Space Science and Applications program is conducted in close cooperation with the scientific, engineering, and industrial communities. The Space Science Board and Space Applications Board of the National Research Council provide advice at the program level, while advice at the project level comes both from committees established by those boards and from committees of the NASA Advisory Council. Discipline areas receive outside views in a similar fashion, and the selection of mission payloads and basic research proposals rests in part on evaluations by the outside community.

International cooperation continues to be important. International projects reduce the cost to each of the countries involved and permit more expansive efforts than a single country could afford alone. Each partner gains access to other countries' science and develops technology relevant to its own programs. In addition, international space collaboration serves broader foreign policy goals aimed at retaining positive, productive relationships with the many countries that are benefiting from space activities. The International Ultraviolet Explorer is a good example. Developed jointly by NASA, the European Space Agency, and the Science Research Council of the United Kingdom, it has been operated very effectively by the three partners for the past seven years. The Hubble Space Telescope, Ulysses (formerly the International Solar Polar Mission), and Upper Atmosphere Research Satellite are additional examples. International cooperation is expected to remain a key factor in conducting the Space Science and Applications program, and various opportunities for international cooperation in future programs are being explored.

Continuity is also an important aspect of the program. While answering some questions, scientific research often raises new ones that require capabilities or extensive data not available from current or past projects; the logical outgrowth is a new project. An example of that outgrowth is the proposal for the Advanced X-Ray Astrophysics Facility, which will address questions arising from discoveries made by the High Energy Astronomy Observatories. That new facility will make much more comprehensive investigations of x-ray objects than its predecessors could. Another facet of continuity is the role of enabling technologies; for example, the development of radar altimetry provided the ability to observe the circulation of the oceans. First employed from orbit by Skylab, radar altimetry was improved for use on the third Geostationary Operational Environmental Satellite and further improved for Seasat, which was able to observe regional circulation patterns

in the ocean. Additional improvements will allow the Ocean Topography Experiment to make the first global measurement of the circulation of the oceans. The third element of continuity is sustained commitment to scientific endeavors that require many years of planning and execution. Correspondingly, an appropriate base of research in space sciences and applications contributes to NASA's preparedness for new activities.

B. Study of the Distant Universe

Study of the universe involves questions at the core of human concern. What are the size, scope, and structure of the universe? What is mankind's place in it? How did it begin? Is it unchanging or does it evolve, and will it have an end? What are the laws that govern celestial phenomena?

Answers to such questions are sought by investigating the sun, stars, galaxies, gas, and dust, and the laws of physics governing them. Matter in the universe varies in size, shape, density (by at least 40 orders of magnitude), and temperature (by billions of degrees). Electromagnetic radiation emitted by matter in the universe ranges from highly energetic gamma rays, through x-rays and ultraviolet radiation, further through less energetic infrared and microwave radiations, to the radio regions of the spectrum. Objects in the the universe also radiate particles in the form of stellar winds and cosmic rays, and it is presumed that other objects give off as yet undetected neutrinos and gravitational radiation.

Until the space age, the universe could be observed only through "the dirty basement windows of the atmosphere." Water vapor in the atmosphere blocks much of the infrared spectrum; and radiation in the ultraviolet, x-ray, and gamma ray frequencies does not penetrate the atmosphere at all. Even at the wavelengths of visible light, atmospheric turbulence and scintillation limit the performance of the best ground-based telescopes. However, as a result of the U.S. program in space astronomy and astrophysics during the past two decades, a new view of the universe is emerging. Rocket and satellite observations at ultraviolet wavelengths have shown that many stars eject enormous amounts of material at high velocities. A revolution is occurring in knowledge of the chemical composition and physical state of interstellar gas and dust. Both ultraviolet and x-ray observations have shown that many types of stars possess high-temperature, tenuous outer layers and exhibit solar-like activity. However, the behavior of those stars is not consistent with current understanding of the solar chromosphere and corona. Discovery of celestial x-ray and gamma ray sources has revealed the existence of new types of celestial objects and has shown that explosive events of unimaginable violence occur routinely in the universe.

Evidence accumulated from x-ray measurements suggests that a significant fraction of the matter in the universe may exist as very high temperature gas located between the galaxies. Objects ranging in distance from nearby cool stars to the most distant quasars emit x-rays, and recent observations have shown that some astronomical bodies emit most of their energy as gamma rays. The first survey at infrared wavelengths discovered stars with debris systems that could imply the formation of planets around the stars. Future projects are being designed to sustain the rapid pace of development of observing abilities that will continue this revolution in understanding of the universe.

The sun is the only star that can be studied in detail, and study of it is essential to interpreting the distant universe. Magnetic fields control the solar atmosphere, and the structure of the sun's corona is dominated by magnetic arches and loops. In addition, the corona contains regions called coronal holes from which the magnetic fields extend into interplanetary space, creating the solar wind.

Techniques have been developed recently for measuring the motions of the visible surface of the sun, the photosphere. Observation and analysis of the motions resulting from waves occurring in the sun's convective interior have led to the conclusion that the convective region of the sun extends deeper than previously believed. Observations that are directly related to the sun's interior structure and processes now can be made. The oscillatory motions also may contain information about the change in angular velocity of the convective layer with distance from the sun's center.

1. Strategy

Studies of the universe progress through five stages:

- o Suborbital probes for a "first cut"
- o All-sky surveys
- o Detailed studies of individual sources
- o Flight of full-scale observatories
- o Flight of specialized follow-up and observatory support missions.

The stages of development of the disciplines within astrophysics vary significantly. For example, the first extreme ultraviolet sources have been detected only recently, placing this discipline in the first of the five stages. In contrast, the Hubble Space Telescope will advance ultraviolet and optical astronomy into the fourth stage. Each wavelength and particle-energy range provides specific information about celestial objects and processes. However, full understanding of some objects, such as quasars, requires observations at all wavelengths. In addition, apparently unrelated objects often involve similar phenomena, but on different scales. To obtain a complete picture of the physical universe, all the astrophysics disciplines will have to be advanced.

2. Current Program

The Astrophysics program currently contains ten research projects. Each project is aimed at a particular set of problems but also generally overlaps others to provide a variety of viewpoints and, therefore, a more comprehensive understanding of particular phenomena. An example of a phenomenon subjected to that treatment is flaring of stars. Although only the Solar Maximum Mission is aimed specifically at investigation of flares on the sun, five of the ten projects will contribute to an understanding of how the sun's energy is stored, what triggers its release, and how the sun and its atmosphere respond to the flaring.

a. Solar Maximum Mission

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. The Solar Maximum Mission 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 its in-orbit repair in 1984, it has resumed observations with the goal of discovering how flares are triggered.

Observation of activity on stars thought to be like the sun can tell much about the range of the sun's activity and what it is likely to be in the future. Consequently, in addition to other problems relating to stars and galaxies, the four missions whose descriptions follow will study flares on other stars--hot stars, cool stars, rapidly rotating stars, stars with strong magnetic fields, and stars near the end of their lives.

b. International Ultraviolet Explorer

The International Ultraviolet Explorer is a joint undertaking by NASA, the United Kingdom's Science Research Council, and the European Space Agency. Since its launch in 1978, it has provided ultraviolet spectra for studies of comets, the outer planets and their satellites, the atmospheres of stars, the interstellar medium, and extragalactic objects. It has expanded understanding of stellar winds, gaseous halos around galaxies, and solar-like activity on other stars. It is an important precursor to the Hubble Space Telescope, not only scientifically but also as a facility operated for the benefit of guest investigators.

c. Hubble Space Telescope

The principal element in the astronomy program is the 2.4-meter diameter Hubble Space Telescope to be launched in 1986 by the Space Shuttle. It will be a long-duration orbital facility serviced by the Shuttle and the Space Station, whose crews will replace, as needed or appropriate, science instruments as technological advances and scientific priorities evolve. The Space Station, with its ability to perform extensive and comprehensive servicing, is planned to be able to maintain and update the Telescope entirely in orbit, eliminating the need to return the Telescope to Earth for refurbishment. The solar arrays and one of the science instruments for the Telescope are being provided by the European Space Agency. An international team will staff the Space Telescope Science Institute, which will be responsible for operations and data analysis. The Hubble Space Telescope's ability to cover a wide range of wavelengths from the infrared to the ultraviolet, to provide fine angular resolution, and to detect faint sources will make it the most powerful astronomical telescope ever built. It will be used in extragalactic astronomy and observational cosmology for tasks such as investigation of stars in other galaxies to determine their rotation, age, mass, and chemical composition. It also will be used for observations of our own solar system to aid in understanding the solar system's origin and evolution.

d. Roentgen Satellite

The Roentgen Satellite is a cooperative undertaking with the Federal Republic of Germany. Germany is responsible for developing the spacecraft and telescope, and the United States is responsible for launching the satellite and providing one focal plane instrument. Observation time will be divided equally between the United States and Germany. In addition, the United Kingdom is providing an instrument to observe in the extreme ultraviolet wavelengths and will share in the German observation time. The program's objective is to orbit an x-ray telescope similar to the second High Energy Astronomy Observatory to investigate many phenomena discovered by that observatory, including the high x-ray luminosity of stars that otherwise appear to be identical to the sun.

e. Extreme Ultraviolet Explorer

When stars eventually consume all the nuclear fuel available to them, gravity collapses them and they radiate away their heat. Depending on their mass, their collapse is stopped by the incompressibility of electrons to form white dwarf stars, or of neutrons to form neutron stars, or of nothing at all to form black holes. This program will conduct an initial survey of the sky to detect objects emitting primarily at wavelengths from 10 to 90 nanometers, thereby opening one of the last remaining unexplored spectral regions. Most extreme-ultraviolet objects discovered to date have been stars at advanced stages of evolution, including white dwarf stars. Discovery and study of many such objects are expected to provide new insight into the later stages of stellar evolution and the energetics of the interstellar medium.

f. Gamma Ray Observatory

The Gamma Ray Observatory will observe the universe in the highest energy reaches of the electromagnetic spectrum. It will look at the nuclear processes occurring near neutron stars and black holes and permit investigation of the formation of elements in supernovae, the origin of gamma ray bursts, and details of the gamma ray sources recently discovered in our galaxy. Gamma rays produced by interaction of cosmic rays with the interstellar medium provide direct information about both the interstellar medium and the cosmic rays. Observation of gamma rays from objects such as pulsars--which also emit radio, visible, and x-ray radiation--is essential to understanding those objects.

While the events occurring at the end of a star's life are best observed at wavelengths shorter than visible, such as gamma rays, the events occurring during star formation are best observed at wavelengths longer than visible. The longer wavelengths also are best for observing the radiation from the earliest moments of the Big Bang. Consequently, the two programs described next are investigating longer wavelength regions of the spectrum.

g. Infrared Astronomical Satellite

Launched January 25, 1983, the Infrared Astronomical Satellite has completed the first comprehensive all-sky survey in the 8- to 120-micron

region of the spectrum. The Netherlands provided its spacecraft, the United States provided its telescope, and the United Kingdom provided its ground operations facility. It has located many infrared sources for future investigation and has provided information on the formation of stars in our galaxy, the presence of dust in galaxies, and the number and characteristics of asteroids in the solar system. It has made several notable discoveries, including a debris system around the star Vega, arcs of dust above and below the ecliptic plane, and cirrus-like dust clouds in our galaxy. Cryogen for its telescope has been depleted, but an international team continues to analyze the data it collected. The data will be complemented by an extended-source survey to be carried out with a small telescope on Spacelab 2.

h. Cosmic Background Explorer

The Cosmic Background Explorer will measure precisely the spectral and directional distribution of cosmic microwave background radiation believed to be a remnant of the Big Bang. Measurements from balloons and aircraft have introduced uncertainties and questions that it will be able to resolve, thereby providing definitive fundamental observations in cosmology. Any deviations from uniformity detected will be significant, allowing a look back toward the instant of creation.

i. Heavy Nuclei Collector

Recent developments make it possible to construct a passive cosmic ray telescope with a very large area to detect among the cosmic rays the heavy and extremely rare radioactive nuclei that occupy the top of the periodic table. Those nuclei are especially important because of their origin outside the solar system and because their radioactivity will make possible their direct dating. Acid etches some plastics at a rate proportional to the square of the charge of particles that pass through them. Therefore, by exposing one of those plastics to space, recovering and etching it, and analyzing the etched tracks, scientists can determine the composition of the cosmic rays that have passed through it. Because the plastic is light in weight and no telemetry is involved, the plastic can be placed in trays that will cover almost all of the Long Duration Exposure Facility, providing a total area an order of magnitude larger than that of any other planned investigation of this sort. It therefore will be very valuable for measuring the abundances of rare, heavy nuclei like those of uranium not observed by the cosmic ray telescopes on the third High Energy Astronomy Observatory.

j. Spacelab Investigations

The Shuttle-Spacelab will carry telescopes into space to observe the sun, stars, high-energy sources, and sources of infrared radiation. For Spacelab investigations, NASA is developing instruments of both the facility class and the principal investigator class.

(1) Solar Optical Telescope

The only facility class instrument in the current program is the Solar Optical Telescope, a one-meter Gregorian telescope that will provide

ultra-high resolution observations of the sun in the wavelength band from infrared to ultraviolet. It will have an assortment of focal plane and auxiliary instruments that will be added, refurbished, or replaced between flights. It will study time-related phenomena associated with small solar features such as the fine structures of the chromosphere, magnetic flux ropes, spicules, and flare sites--each of which is believed to measure less than 100 kilometers in any dimension.

(2) Principal Investigator Class Instruments

Spacelab missions will continue to carry principal investigator class instruments. Spacelab 2, like Spacelab 1 before it, will carry U.S. and European instruments that will investigate the sun and the universe.

(a) Spacelab 2

The Solar Ultraviolet Spectral Irradiance Monitor will observe the highly variable ultraviolet output of the sun, and the Solar Magnetic and Velocity Field Measurement System will be able to make measurements undisturbed by the blurring that affects observations made through Earth's atmosphere. The Elemental Composition of Cosmic Ray Nuclei mission will observe cosmic rays with energies greater than those the telescopes on the third High Energy Astronomy Observatory could observe. The composition of those higher energy cosmic rays should be less contaminated by secondary products resulting from the rays' passage through the interstellar medium. The Small Helium-Cooled Infrared Telescope will complement the survey made by the Infrared Astronomical Satellite, whose sensitivity is greatest to point sources, by surveying the sky for extended infrared sources having low surface brightness.

(b) Astro-1

Astro-1 will be a Space Shuttle payload using the Spacelab igloo, the Instrument Pointing System, and two pallets. Its three ultraviolet telescopes will complement the Space Telescope, and each of them will have unique capabilities: Ultraviolet Imaging Telescope--wide field of view; Hopkins Ultraviolet Telescope--short wavelength ultraviolet; and Wisconsin Ultraviolet Spectropolarimeter--polarization. The first flight of Astro-1 will be a special mission in March 1986 to make astronomical observations and observe Comet Halley.

3. Potential New Initiatives, FY 1986 through 1990

a. Advanced X-Ray Astrophysics Facility

The Advanced X-Ray Astrophysics Facility is a potential development start for 1987. It received the highest endorsement from the Astronomy Survey Committee of the National Academy of Sciences. With 4 times the spatial resolution and at least 100 times the sensitivity of the second High Energy Astronomy Observatory, from which it is evolving, it will advance x-ray astronomy into the mature observatory stage and be as significant an advance in x-ray astronomy as the Hubble Space Telescope will be in optical astronomy. It will be launched by the Shuttle and serviced by the Shuttle and the Space Station. The focal plane of its

1.2-meter, grazing-incidence, x-ray telescope will accommodate instruments to collect high-spatial-resolution and spectral data on quasars, galaxies, clusters of galaxies, and the intergalactic medium. An important objective is to image x-rays from iron, since the amount of iron that galaxies produce and expel into the space between themselves tells much about the early history of star formation and destruction in the galaxies. That objective will require that the mirrors on the Advanced X-Ray Astrophysics Facility have the ability to reflect x-rays with energies twice as high as those that the second High Energy Astronomy Observatory reflected. Technology for the mirrors is being developed in the Physics and Astronomy Research and Analysis activity. Technology for x-ray sensors has been developed in part by the Research and Analysis program and in part by the Office of Aeronautics and Space Technology.

b. Space Infrared Telescope Facility

This facility will be a long-lived, meter-class, cryogenically cooled, infrared observatory to study the very cold regions of space. It will be launched by the Shuttle and serviced by the Shuttle and the Space Station. Regions and objects it will study are locations where the cosmic gas and dust condense into stars; cool objects in the solar system--planetary systems, asteroids, and comets; and infrared-emitting extra-galactic objects. It 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. The Astronomy Survey Committee of the National Academy of Sciences has recommended that the Space Infrared Telescope Facility be the first major infrared telescope in space. The Infrared Astronomical Satellite demonstrated technology for long-lived, cryogenic telescopes, and cryogenic servicing by the Shuttle and the Space Station is under study. The Space Infrared Telescope Facility is a candidate for development initiation in the late 1980s.

c. Other Planned Initiatives

Other initiatives planned for the FY 1986 through FY 1990 period are principally investigations into dynamical structures--the structure of space and time and the structure of the sun, collapsed stars, and interstellar space.

(1) Gravity Probe-B

The structure of space and time is investigated through the theory of general relativity. Gravity Probe-B is an orbiting, cryogenic gyroscope experiment 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). That twisting of space acts as a force that is to simple 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. 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 Shuttle

flight planned for 1989. Gravity Probe-B's science mission is planned to follow that test.

(2) Solar Seismology Mission

The objective of the Solar Seismology Mission is to observe the bulk motions of gas at the surface of the sun. Observations lasting several weeks have shown that waves generated in the sun's interior by convection and differential rotation produce global oscillations that are visible at the sun's surface. The internal structure and motions of the sun can be determined by observing those oscillations. However, the observations must be made continuously for months; and that is impossible from Earth, even at the South Pole.

(3) X-Ray Timing Explorer

The X-Ray Timing Explorer will conduct intensive studies of the changing luminosity of x-ray sources over time ranging from milliseconds to years. The 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 100,000 electron volts. Technology is nearly ready, with developments in detector technology under way as part of the mission definition studies.

(4) Far Ultraviolet Spectroscopy Explorer

The Far Ultraviolet Spectroscopy Explorer will be a 1-meter class telescope equipped for very high resolution spectroscopy in the spectral region from 90 to 120 nanometers. 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 the planned x-ray missions. Information on many spectral features that lie in the 90- to 120-nanometer 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. For example, the interstellar medium's structure depends on the medium's temperature, velocity, and location in space. The Far Ultraviolet Spectroscopy Explorer will be sensitive to all phases of the interstellar medium. As all spectrometers, those for this program will rely on gratings to disperse the spectrum. Development of the technology for making gratings and spectrometers for such short wavelengths will be undertaken during mission definition. Also, some mirror coating technology is being investigated.

(5) Solar Corona Diagnostics Mission

Technology is available for this mission, whose objective will be to infer the origins of the inner corona and the solar wind by use of recently developed diagnostic techniques that allow observations from Earth orbit to determine the plasma state.

(6) Spacelab and Space Station

Investigations on Spacelab will become lengthier and will be modified so that they can be conducted on or near the Space Station. They will depend on the Space Station for servicing, assembly, and manned interaction. Current plans include a major facility, two principal investigator class instruments, and an experiment program. The possibility is being studied of making Space Station platforms of the Advanced X-Ray Astrophysics Facility and the Shuttle Infrared Telescope Facility.

(a) Pinhole Occulter Facility

The Pinhole Occulter Facility will be a system for imaging hard x-rays to provide high-resolution studies of x-ray bright points, active regions, solar flares, and the structure and nature of the sun's corona. It will consist of a large, Shuttle-borne, occulting disc with thousands of pinholes and a detector package located 30 meters or more from the disc. Hard x-rays are produced by processes that are in thermodynamic disequilibrium, and the emission regions are expected to carry part of the signature of particle acceleration in their structures. In its occulter mode, the facility will make it possible for optical instruments to look near the base of the corona to obtain diagnostic information on heating and cooling. Technology for deploying and controlling long, weighted booms in space must be developed.

(b) Shuttle High-Energy Astrophysics Laboratory

The Shuttle High-Energy Astrophysics Laboratory program will consist of a series of Shuttle flights of a developing complement of x-ray instruments that will use specialized techniques for investigations in high-energy astrophysics. Its payloads are to be attached to the Shuttle via the Shuttle Payload of Opportunity Carrier.

(c) Cosmic Ray Experiments

The Cosmic Ray Experiments program will use massive instruments, perhaps initially tested and used on Spacelab flights, to make cosmic ray measurements that require observation times longer than those the Shuttle will provide. The measurements can be made as a series of experiments on the Space Station. Emphasis will be on measuring particles of very high energy and low flux; investigating the charge compositions, energy spectra, arrival directions, and isotopic compositions of cosmic ray nuclei; and searching for exotic particles such as super-heavy nuclei, magnetic monopoles, and antinuclei. The technology required is being developed in the Astrophysics Research and Technology program.

4. Possible Initiatives, FY 1991-1995

Two observatories are potential development starts in the FY 1991 through FY 1995 period: the Advanced Solar Observatory for solar physics and the Large Deployable Reflector for submillimeter and far infrared astronomy. The thrust in astronomy following the Hubble Space Telescope and the Advanced X-Ray Astrophysics Facility will be to develop arrays of telescopes for either

very high angular resolution or high sensitivity. Also planned is a mission into the upper atmosphere of the sun.

a. Advanced Solar Observatory

The Advanced Solar Observatory will begin operation when the Solar Optical Telescope and the Pinhole Occulter Facility are put together on the Space Station or another long-duration orbiting platform. It will use high-resolution instruments to study the temporal evolution of solar features and to observe events that are especially revealing. Its coordinated observations of all aspects of the surface of the sun will advance solar physics from an observational science to one capable of prediction. It eventually will include:

- o A high-resolution telescope cluster containing the Solar Optical Telescope, a soft x-ray telescope facility, and an extreme ultra-violet telescope facility
- o Instruments behind the Pinhole Occulter Facility to observe, with very high spatial resolution, the corona close to the sun's surface and energetic phenomena like flares
- o A high-resolution gamma ray spectrometer
- o A low-frequency radio facility.

The technologies for many of those instruments are ready, and others will be developed in the Astrophysics Research and Technology program.

b. Large Deployable Reflector

The processes of birth of celestial bodies are largely unexplored by astronomers. They occur in cold clouds of dust so thick that the light from the bodies as they are forming cannot escape. The light therefore heats the dust, creating infrared radiation that can escape. That radiation is low in temperature and long in wavelength, constituting a weak signal that only a very sensitive telescope will be able to detect. Technology should be sufficiently advanced by the late 1980s to permit development of a telescope as large as 20 meters in diameter for in-orbit spectroscopic and imaging observations at far infrared and submillimeter wavelengths that cannot be observed from Earth. That telescope should be able to collect the weak signals and achieve sufficient resolutions to investigate the formation, transport, and destruction of molecules in the atmospheres of the outer planets, in regions where stars are forming or are shedding their outer layers, and in regions where there are cold clouds of gas and dust but, as yet, no stars. Before the Large Deployable Reflector can be developed, major technological advances must be made in mirror technology, structures, submillimeter and infrared sensors, mirror controls, and assembly in orbit. To provide those advances, the Office of Space Science and Applications and the Office of Aeronautics and Space Technology have in process a system-level study that should lead to initiation of a technology development program in FY 1987. Space Station capabilities could make possible new approaches to implementing and conducting this mission.

c. High Throughput Mission

The High Throughput Mission will have capabilities that complement those of the Advanced X-Ray Astrophysics Facility. It will make a deep-space survey to determine whether active galaxies, quasars, or the million-degree gas filling intergalactic space is the origin of x-rays that appear to come uniformly from all directions in space. It will be an x-ray telescope consisting of many small modules--each with its own mirrors and detector--assembled to form a collector with a very large area. It will have high sensitivity, but its angular resolution will be only about one arc minute. Thus, it will be able to perform studies that do not require precise angular resolution but do require great sensitivity because the x-ray sources either are intrinsically faint or vary rapidly in intensity. Telescope technology will be developed as part of Spacelab activities, and mirror concepts are being investigated as part of the Astrophysics Research and Technology program.

d. Very Long Baseline Radio Interferometry

Very large arrays of telescopes can provide high angular resolution if the radiation they receive can be added coherently, preserving the relative phases of the electromagnetic waves constituting the radiation. That coherent combining of signals is the basis of interferometry currently in use in ground-based radio astronomy networks. Because of the size of those arrays, the technique is called very long baseline interferometry (VLBI). The resolution of a VLBI network can be increased greatly by adding one or more space-based radio telescopes to the network. The addition of a single orbiting antenna 10 to 30 meters in diameter to an existing ground-based network can provide unprecedented angular resolutions of 10^{-3} to 10^{-5} arc seconds. The resulting celestial maps will explain much about the physics of quasars, galactic cores, interstellar masers, and dynamics of star formation. Technology for the space-based antenna is being developed by the Office of Aeronautics and Space Technology, and development of VLBI technology is being supported by that office and the Astrophysics program. The Astrophysics Division and the Office of Space Tracking and Data Systems are studying the possibility of using the Tracking and Data Relay Satellite System to demonstrate two key technical approaches to this mission.

e. Starprobe

This spacecraft will fly to within four radii of the sun's surface to observe the sun's surface, gravitational figure, and upper atmosphere. The Astrophysics program and the Office of Aeronautics and Space Technology have developed radio ranging, thermal protection, and drag-free navigation technology for this mission over the last four years.

5. Summary of Technology Needs

With regard to major observatories, technology will be ready in the next year for the Advanced X-Ray Astrophysics Facility and is ready now for the Advanced Solar Observatory. However, the Large Deployable Reflector needs development of technology for structures, submillimeter and infrared sensors, mirrors, mirror controls, and in-orbit assembly techniques. A systems study

is in process to define a program to develop that technology. Technology for Spacelab and most Explorer missions is sufficiently developed that the last steps can be made ready during mission definition phases. That is true for the X-Ray Timing Explorer, Solar Corona Diagnostics Mission, and Shuttle High-Energy Laboratory; but the Far Ultraviolet Spectroscopy Explorer and the Pinhole Occulter Facility need technological developments in far-ultraviolet spectrometers and long, weighted booms, respectively. For the other astrophysics programs, the status of technology is as follows: Gravity Probe-B--further development is being carried out by the Astrophysics program; Very Long Baseline Interferometry--further development is being carried out by the Astrophysics program and the Office of Aeronautics and Space Technology; Solar Seismology Mission--the technology is ready; Space Infrared Telescope Facility--the Astrophysics program and the Office of Aeronautics and Space Technology are developing technology for infrared sensors. The Astrophysics program and the offices of Aeronautics and Space Technology, Space Flight, and Space Station are planning for development of in-orbit cryogenic servicing, a capability that will benefit the Space Infrared Telescope Facility's mission. Table III-1 summarizes technology needs. An X in a cell of that table indicates that the program shown on the line the cell occupies needs technology of the category shown in the column the cell occupies.

C. Exploration of the Near Universe

To our ancestors, the solar system consisted of a few worlds wandering through a limited region of empty space. To us, it has become a huge sphere containing uncountable bits of solid matter, magnetic fields, and streams of electrically charged atomic particles from the sun. The space program's exploration of that collection of matter and energy is one of the most important scientific activities of this era. The objective of that exploration is to determine the origin, evolution, and present state of the solar system and to compare Earth with the other planets.

United States leadership in the exploration of the solar system has brought new knowledge, prestige, and sense of achievement to the Nation. U.S. spacecraft were the first to visit Mercury, Venus, and Mars; and the highly sophisticated Viking spacecraft landed on Mars. Only U.S. spacecraft have crossed the asteroid belt into the outer solar system, four having encountered Jupiter and three having encountered Saturn. Historic discoveries came from each of those seven encounters. One of the spacecraft, Voyager 2, is on course to an encounter with Uranus in 1986 and Neptune in 1989. Another, Pioneer 10, passed the orbit of Neptune in 1983 on a trajectory to interstellar space. More than two dozen planets and satellites have been explored at close range, and the interplanetary medium has been partially characterized.

The exploration progresses in systematic stages, later stages building on the results of earlier ones and all stages proceeding from a broad overview to increasingly detailed investigations and problem-oriented studies in the following sequence:

- o Reconnaissance--Initial encounter with and observation of a body, usually by a flyby spacecraft
- o Exploration--Characterization of the body by orbiting spacecraft in combination with entry probes and landers

TABLE III-1. TECHNOLOGY NEEDS FOR ASTROPHYSICS PROGRAMS

Major Missions

Advanced X-Ray Astrophysics Facility
 Large Deployable Reflector
 Advanced Solar Observatory
 Starprobe

Moderate Missions

Shuttle Infrared Telescope Facility
 Solar Seismology Mission
 Very Long Baseline Radio Interferometry
 Gravity Probe-B
 High Throughput Mission

Explorers

X-Ray Timing Explorer
 Far Ultraviolet Spectroscopy Explorer
 Solar Corona Diagnostics Mission

Spacelab and Space Station

Shuttle High-Energy Laboratory
 Cosmic Ray Experiments
 Pinhole Occulter Facility

	Maintenance and Repair	Sensors for Detectors	Optical Systems Fabrication and Materials	Controls	Cryogenics	Precise Timing
X	X	X				
X	X	X		X	X	X
X		X		X		
X		X			X	
X						X
X		X				
X					X	
X				X		
X						
X						

- o Intensive Study--Investigation of specific scientific questions stemming from the preceding stage.

Figure III-1 summarizes the status of solar system exploration by the United States. The columns represent the three stages in the exploration sequence, while the rows represent bodies in the solar system. Past and present flight projects occupy cells of that matrix according to the stages and bodies with which they are associated. The figure indicates the emphasis of exploration within each group of bodies and the degree of overall balance in achievements to date.

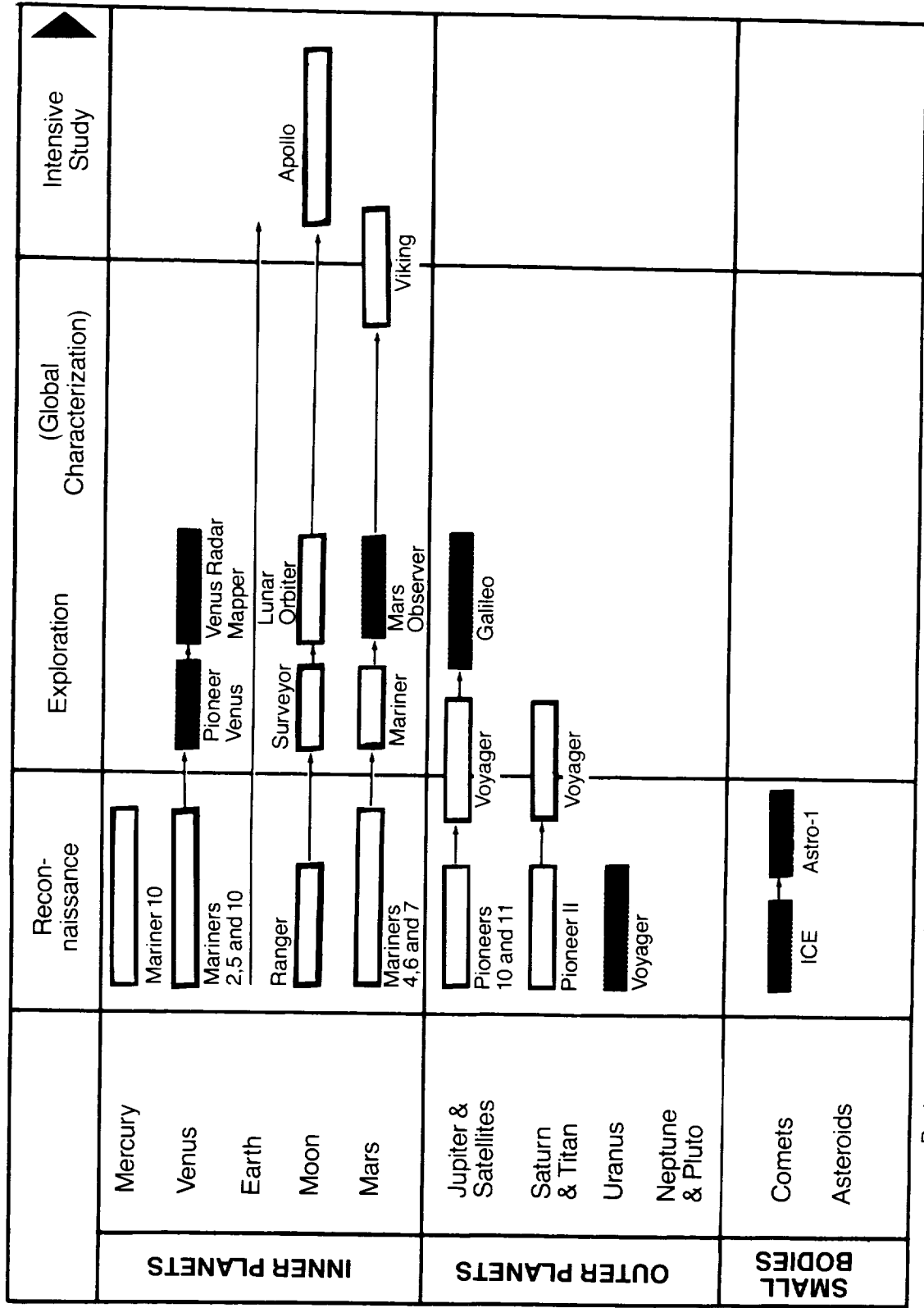
The National Research Council's Space Science Board has recommended a balanced approach to exploration--specifically that exploration "should move forward on a broad front to all the accessible planetary bodies beginning with reconnaissance, into exploration of selected planets, and lastly to intensive study of a limited number of cases." The Board pointed out that "as the reconnaissance phase is nearing completion...for the next decade there should be a shift in emphasis toward systematic exploration with emphasis on selected planets but with some continuing level of reconnaissance to parts of the solar system where ignorance is greatest and the opportunity for new discovery is large."

Since 1974, the Space Science Board's Committee on Planetary and Lunar Exploration has been evolving object and mission priorities for the exploration program and has found it convenient to assign the bodies in the solar system to three groups: the inner planets; the small (primitive) bodies--asteroids, comets, and meteorites; and the outer planets and their satellites. The Committee recommended that the focus for the inner planets for the decade of the 1980s be Venus, Earth, and Mars. Simultaneous and detailed comparative studies in the form of global characterization of and sample returns from those planets, combined with identification of reasons for their differences and similarities, will provide a basis for follow-on scientific investigations. The Committee judged that the moon and Mercury, although also important targets for investigation, are of lower priority and, therefore, should be in a later phase of inner planet exploration.

The motivation for investigating the small bodies is their primitive character. Since detailed study of them will require extended viewing at close range, rendezvous missions have highest priority. However, it is expected that fly-by missions through the comas of comets to study plasmas and gaseous and dusty ejecta will play an important complementary role, as will a combination of fly-by and rendezvous encounters with the main belt asteroids by simple spacecraft. Because samples from both comets and asteroids eventually will be required for answering scientific questions about those kinds of bodies, sample return missions also are an integral part of the exploration strategy.

The outer planets differ significantly from the inner planets, and study of them is fundamental to adequate understanding of the formation and evolution of the solar system. The two Voyager spacecraft have completed reconnaissance of the Jovian and Saturnian systems, and Voyager 2 is en route to fly-bys of Uranus and Neptune. Those fly-bys will complete the initial study of those systems. Jupiter and Saturn have highest priority for follow-

Figure III-1
Planetary Exploration Status: 1984



 Past Projects
 Current Projects
 ICE = International Cometary Explorer

on exploration. Galileo, which will consist of a probe and an orbiter, will explore the Jovian system in the late 1980s. Further exploration of Saturn, its satellites and rings, and the system's magnetosphere will require additional orbiters and probes. The remaining systems--those of Uranus, Neptune, and Pluto--also are of interest but are difficult exploration targets because of the long transit times to them.

Although the United States has dominated the field of solar system exploration, the Soviet Union has begun to increase its studies of the inner solar system and comets. In addition, Europe and Japan recently have joined this endeavor with the Giotto and Planet-A missions, respectively; and foreign scientists have been included on the science teams for U.S. missions such as Pioneer Venus, Viking, and Voyager.

1. Strategy

As planetary flight projects such as Viking and Voyager became more capable and complex during the 1970s, their cost rose. The increase in cost, combined with the fact that innumerable objectives remained to be addressed in solar system exploration, serious concern developed among scientists and program planners over the program's long-term feasibility. To help in reconciling the many continuing challenges of the program with the limited resources foreseeable for it, the NASA Advisory Council formed in 1980 the Solar System Exploration Committee. With the cooperation of the scientific community, that committee took a fresh look at the program, reviewing its goals, identifying the essential attributes that would maintain its viability, and defining new ways to reduce its costs. The Committee's report provided the following guidance:

- o The goals of the solar system exploration program are to:
 - Determine the origin, evolution, and present state of the solar system
 - Understand Earth through comparative planetary studies
 - Understand the relationship between the chemical and physical evolution of the solar system and the appearance of life
 - Survey potential resources in near-Earth space.
- o Mission costs must be reduced without decrement in program performance.
- o A core program of missions must be established to provide a long-term stable base for the planetary sciences.
- o Core program missions must have important scientific objectives, be low in cost, be clearly defined, and employ new technologies only when the technologies' potential for reducing costs can be demonstrated.
- o The core program must be augmented with technologically challenging missions as soon as national priorities permit.

The Committee recommended a core program containing missions to the inner planets, small bodies, and outer planets. Based on current assessments of

technological readiness, launch opportunities, rapidity of data return, balance of disciplines, and other programmatic factors, it identified the sequence of initial core missions and the candidate subsequent missions shown in Table III-2. It concluded that core missions should be designed to use:

- o Spacecraft inheritance--existing hardware spares and duplicates from previous projects such as Viking, Voyager, and Galileo
- o Planetary Observer Class spacecraft--spacecraft derived from "production-line" Earth-orbital systems
- o Mariner Mark II Class spacecraft--spacecraft embodying a new modular design capable of simple reconfiguration.

Planetary Observer Class spacecraft are to be used for flights to the inner planets and for rendezvous missions with Earth-approaching asteroids. Their power and communications limitations will prevent their use beyond the asteroid belt. Mariner Mark II Class spacecraft are to be used for flights to the outer planets and for the remaining small body missions. The Mariner Mark II is a new design using new technology to achieve increased performance within size, mass, and power constraints. It will make possible the use of available launch systems, such as the Shuttle-Centaur combination, for higher energy missions.

The Committee also concluded that at least one augmentation mission should be recommended at this time for each of the three classes of solar system bodies. For the inner planets, it recommended a combined mission, Mars Surface Mobility and Sample Return, that ultimately might become more than one mission. For the small bodies, it selected a Comet Nucleus Sample Return, including the option of a nucleus surface station. It is expected that priorities among the missions in the series will be established as the core program evolves.

2. Current Program

The solar system exploration program is managed in three parts: planetary research and analysis, mission operations and data analysis, and flight project development. The first and second of those parts ensure continuity in the program's pursuit of its goals, while the third part provides the means for making the discoveries and building the information base that permit progress toward the program's goals. Research, analysis, operations, and data analysis have lower visibility than that of flight project development; but they are just as crucial to the continued progress of the program. Research and analysis activities generate ideas for new missions (through advanced planning studies), provide resources for analysis of collected data, and support basic research in the planetary sciences. Mission operations and data analysis activities provide for communications and control during flight, for collection of raw data, and for the processing and distribution of data to investigators for incorporation into their research.

Planetary missions currently in flight include the Voyager 2 extended mission to Uranus and Neptune and the continuing operations of Pioneer Venus, Pioneers 6 through 11, Voyager 1, and International Cometary Explorer en route to a 1985 flyby of Comet Giacobini-Zinner. Approved flight projects in the

TABLE III-2. INITIAL CORE MISSIONS AND CANDIDATE SUBSEQUENT MISSIONS

<u>Initial Core Missions</u>		
<u>Mission</u>	<u>Launch</u>	<u>Data Return</u>
Venus Radar Mapper	1988	1988-1989
Mars Observer	1990	1991-1993
Comet Rendezvous and Asteroid Flyby	1991	1994-1997
Titan Probe and Radar Mapper	1994	1998
 <u>Candidate Subsequent Missions</u> (Order Arbitrary)		
<u>Inner Planets</u>	<u>Small Bodies</u>	<u>Outer Planets</u>
Mars Aeronomy Observer	Comet Atomized Sample Return Observer	Saturn Orbiter
Venus Atmospheric Probe Observer	Multiple Mainbelt Asteroid Orbiter-Flyby	Saturn Flyby and Probe
Mars Surface Network Observer	Near-Earth-Approaching Asteroid Rendezvous Observer	Uranus Flyby and Probe
Lunar Geoscience Observer		

pre-launch development stage include the Astro-1 Spacelab pallet (to provide observations of Comet Halley from the Shuttle), Galileo, Ulysses (formerly International Solar Polar Mission), and two missions from the core program recommended by the Solar System Exploration Committee--the Venus Radar Mapper and the Mars Observer.

a. Pioneers

Pioneer Venus Orbiter and Pioneers 10 and 11 are on extended missions. Pioneer Venus Orbiter has completed a low-resolution (100 kilometers horizontally and 100 meters vertically) map of Venus' surface except for the polar regions. It continues to measure Venus' ultraviolet cloud patterns, from which climate changes can be inferred over a solar cycle, and to acquire data on the interaction of Venus' ionosphere with the solar wind and magnetic field. When the periapse of its orbit precesses farther into Venus' southern hemisphere, it may be able to make altimetry measurements of that planet's south pole. Pioneers 10 and 11 are on escape trajectories, probing the outer limits of the solar system. Pioneer 10, having passed the orbits of Pluto and Neptune, now is seeking the interstellar boundary. Its distance from the sun is greater than that of any of the known planets. Proceeding in the opposite escape direction, Pioneer 11 is beyond the orbit of Uranus and moving toward the expected position of the solar wind's apex. Measurements of the trajectories of Pioneers 10 and 11 are being analyzed for perturbations to determine whether the irregular motions of the outermost planets, Neptune and Pluto, can be accounted for by the existence of another body at the boundary of the solar system.

b. Voyagers 1 and 2

The encounters of Voyagers 1 and 2 with Jupiter and Saturn provided a wealth of data about those planets, their satellites, and the heliospheric environment in the regions they occupy. Since its encounter with Jupiter in March 1979 and Saturn in November 1980, Voyager 1 has followed a trajectory that eventually will allow it to escape from the sun's influence. Voyager 2, after encountering Jupiter in July 1979 and Saturn in August 1981, has been on a trajectory to encounter Uranus in January 1986. It then will continue on to an encounter with Neptune in 1989 and, like Voyager 1, escape the solar system.

c. International Cometary Explorer

In the early summer of 1982, the third International Sun-Earth Explorer spacecraft was diverted from its "halo" orbit around the sun-Earth co-linear libration point to begin a long journey to a September 1985 encounter with the short-period comet Giacobini-Zinner. En route, it made the first ever measurements in Earth's deep geotail region and then was maneuvered to a close swing-by of the moon, on December 22, 1983. Following the lunar swingby, it departed from Earth orbit and was renamed International Cometary Explorer. Its encounter with Giacobini-Zinner will be the first ever of a spacecraft with a comet. Its aim point is behind the comet's nucleus and within the comet's tail, which is expected to be 20 to 50 thousand kilometers wide. As the spacecraft passes through the tail, instruments aboard it will return information on plasma densities,

flow speeds, and the temperatures and character of heavy ions in the plasma. For several months following that encounter, the spacecraft will provide important data on the solar wind for use in studies of Comet Halley. It is expected to be between Halley and the sun, on the same solar radius, on October 31, 1985, and March 28, 1986, and therefore to provide a characterization of the solar wind before the solar wind reaches Halley's coma. This retargeting of a spacecraft is an example of innovative, low-cost approaches to maintaining an active program of solar system exploration.

d. Comet Halley Activities

After a 76-year absence, Comet Halley again will visit sun-Earth space, during 1985 and 1986. The Soviet Union and Japan have launched spacecraft and the European Space Agency is preparing a spacecraft for post-perihelion intercepts with the comet in March 1986. The United States will participate in the European Space Agency and Soviet Union missions, and also in conducting the program of Earth-based observations, the International Halley Watch. For the European Space Agency mission, 32 U.S. scientists have participated in the definition and implementation of 9 of the 10 experiments on the spacecraft and are serving as co-investigators. In addition, a critical component for one of the instruments, the Ion Mass Spectrometer, has been designed and fabricated in the United States. The Soviet Union's Vega missions are dependent on the United States' tracking the comet and determining its orbit to provide information for targeting the two spacecraft, and several U.S. scientists are co-investigators on non-Soviet instruments on the mission.

The International Halley Watch was organized because of strong scientific interest in the comet worldwide. The International Astronomical Union has endorsed the Watch as "the international coordinating agency for Comet Halley observations." Worldwide networks of ground-based observers in seven disciplines will provide daily coverage of the comet with wide-angle imaging, spectroscopy, photometry, and other observations. Each of the seven networks consists of 20 to 40 observatories and is managed by an American specialist and a European counterpart. A steering group has been established, with half its members from other countries, including the Soviet Union and Japan.

To complement the encounters of spacecraft with Halley and the ground-based observations that are planned, Astro-1, an array of ultraviolet telescopes and visible spectrum wide-angle cameras, will be flown on the Shuttle in March 1986 to make post-perihelion observations of Halley near the time the foreign spacecraft encounter the comet.

e. Galileo

The objectives of the Galileo mission are to investigate the chemical composition and structure of Jupiter's atmosphere; the physical state and surface composition of the Galilean satellites; and the structure, composition, and dynamics of the Jovian magnetosphere. Those investigations will fulfill some of the highest priority objectives the Space Science Board established for the 1980s.

Galileo will investigate questions and theories raised by the Voyagers' observations at Jupiter. Features triggering those questions and theories are as follows: the complex Jovian atmosphere, which consists of eastward- and westward-moving belts and zones speeding along at varying rates, some containing convective disturbances such as white ovals and the Great Red Spot; a system of satellites with morphologies determined by volcanism, ice flows, and meteoroid bombardment; an unexpected thin ring, still mostly unexplored; and a magnetosphere that changed greatly in size and pressure between the encounters by Voyagers 1 and 2.

The Galileo spacecraft, consisting of an orbiter and an atmospheric probe, is scheduled for launch in 1986 by the Space Shuttle and a Centaur upper stage on a direct trajectory to Jupiter. It will arrive at Jupiter in the fall of 1988. About 150 days before that arrival, the probe will separate from the orbiter, subsequently entering Jupiter's atmosphere near the equatorial zone to measure the chemical and physical properties of the atmosphere down to a pressure level of at least 10 bars. The orbiter will fly looping orbits around Jupiter and will make multiple encounters with the Galilean satellites during its 11-orbit, 20-month tour. During at least one orbit, Galileo will fly through and map Jupiter's magnetic tail--that portion of Jupiter's magnetic region directly opposite the sun, a region the Pioneers and Voyagers did not visit.

A mission option currently under consideration would add a fly-by, in December 1986, of the asteroid 29 Amphitrite. Inclusion of the option would delay the orbiter's arrival at Jupiter four months. The decision to add the fly-by will be based on an assessment of the health of the orbiter and, therefore, can be made only after launch. However, because of trajectory considerations, the delay in arrival at Jupiter would occur with or without the fly-by.

f. Ulysses (International Solar Polar Mission)

Ulysses, formerly 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. Launch will be in 1986 by the Shuttle and a Centaur upper stage on a trajectory that will use Jupiter's gravity to swing the spacecraft over the sun's polar regions. The spacecraft will be operating through 1989 and 1990.

g. Venus Radar Mapper

Venus Radar Mapper, the first mission in the Solar System Exploration Committee's core program, became an approved flight project in FY 1984. Its only science instrument will be a synthetic aperture radar capable of performing both surface imaging and altitude measurement. The radar will

be able to resolve surface features measuring less than one kilometer in size through the thick cloud layer that always covers Venus. Its altitude measurements will have errors of less than 50 meters. During the mission, Venus' gravity field also will be measured, by tracking the spacecraft's orbit, to provide information about the planet's interior structure. Launch by the Shuttle and a Centaur-G upper stage is scheduled for April 1988, with insertion into orbit around Venus to occur in July 1988. The primary mission of mapping the entire planet will be completed in April 1989.

To help in meeting the mission's low-cost goals, the spacecraft will be based on existing hardware designs and incorporate a considerable amount of spare hardware from earlier projects. Its elliptical orbit around Venus will allow use of a spare 3.7-meter Voyager antenna for both radar mapping and data communications. The primary structure and the small thrusters also will be Voyager spares. Its command data system, attitude control computer, and power-generating units will be spare Galileo components. Its medium-gain antenna will be a Mariner-9 spare, and it will use X-band travelling wave tube assemblies available from the cancelled U.S. International Solar Polar Mission spacecraft. Finally, it will take advantage of existing data systems for processing radar images.

Information that Mariner 9 provided about Mars completely altered understanding of that planet's evolution. Venus Radar Mapper is expected to make an equivalent contribution to an understanding of Venus with regard to the age, history, and characteristics of its surface; the geological processes operating to form and modify the surface; the age of its atmosphere and whether water and oceans were ever present; the presence or absence of plate tectonics; the origin of its highlands; the reasons for the positive correlation between its topography and its gravitational fields; how it dissipates its internally generated heat; and how its evolution relates to Earth's history.

Preliminary review of the radar data acquired by the Soviet Venera 15 and 16 missions has shown the value of radar imaging. It also has shown that the higher resolution imaging Venus Radar Mapper will provide will be very important. Hence, the scientific objectives of the Mapper's mission are, perhaps, even more relevant today than they were when the Mapper first was proposed.

h. Mars Observer

Mars Observer, approved in FY 1985, will seek answers to questions regarding the atmosphere, surface geochemistry, interior, and climate of Mars on a global scale. Geological matters to be investigated include the elemental and mineralogical composition of the surface; the global distribution of different elements and minerals; major minerals present and what they tell about surface processes; nature of major gravity anomalies and how they relate to variations in near-surface composition, topography, internal structure, and magnetic field characteristics; distribution of condensed volatiles (H_2O and CO_2) and their diurnal and seasonal variation; figure of the planet and its internal density distribution; tectonic stresses in the crust, particularly in the Tharsis region; and composition of the volcanoes and the nature of their evolution. Climatology studies

to be performed will lead to an understanding of the global nature of the Martian atmosphere and its seasonal variation; distribution of H₂O, CO₂, and dust in the atmosphere and their seasonal variation; composition of Martian clouds and hazes; history of the Martian atmosphere; nature of the water cycle and the interaction between atmospheric water and the surface regolith; and nature of the upper atmosphere and ionosphere and how they interact with solar radiation and the solar wind. Science instruments needed include a gamma ray spectrometer, a multispectral radiometer, ultraviolet spectrometer-photometer, and spacecraft tracking.

Mars Observer is the first Planetary Observer Class spacecraft. A modified "production-line" Earth-orbital spacecraft will serve as the basic vehicle, and an upper stage will boost the spacecraft from the Shuttle onto its planetary trajectory. Six months after launch in 1990, the spacecraft will be inserted into a non-sun-synchronous polar orbit around Mars. That orbit will be permitted to drift to the desired sun angle and then, to attain solar synchronization, will be lowered to a circular orbit with an altitude of 360 kilometers. The duration planned for the mission is more than two years, with the spacecraft in the sun-synchronous orbit at least one Martian year.

3. Potential New Initiatives, FY 1986-1990

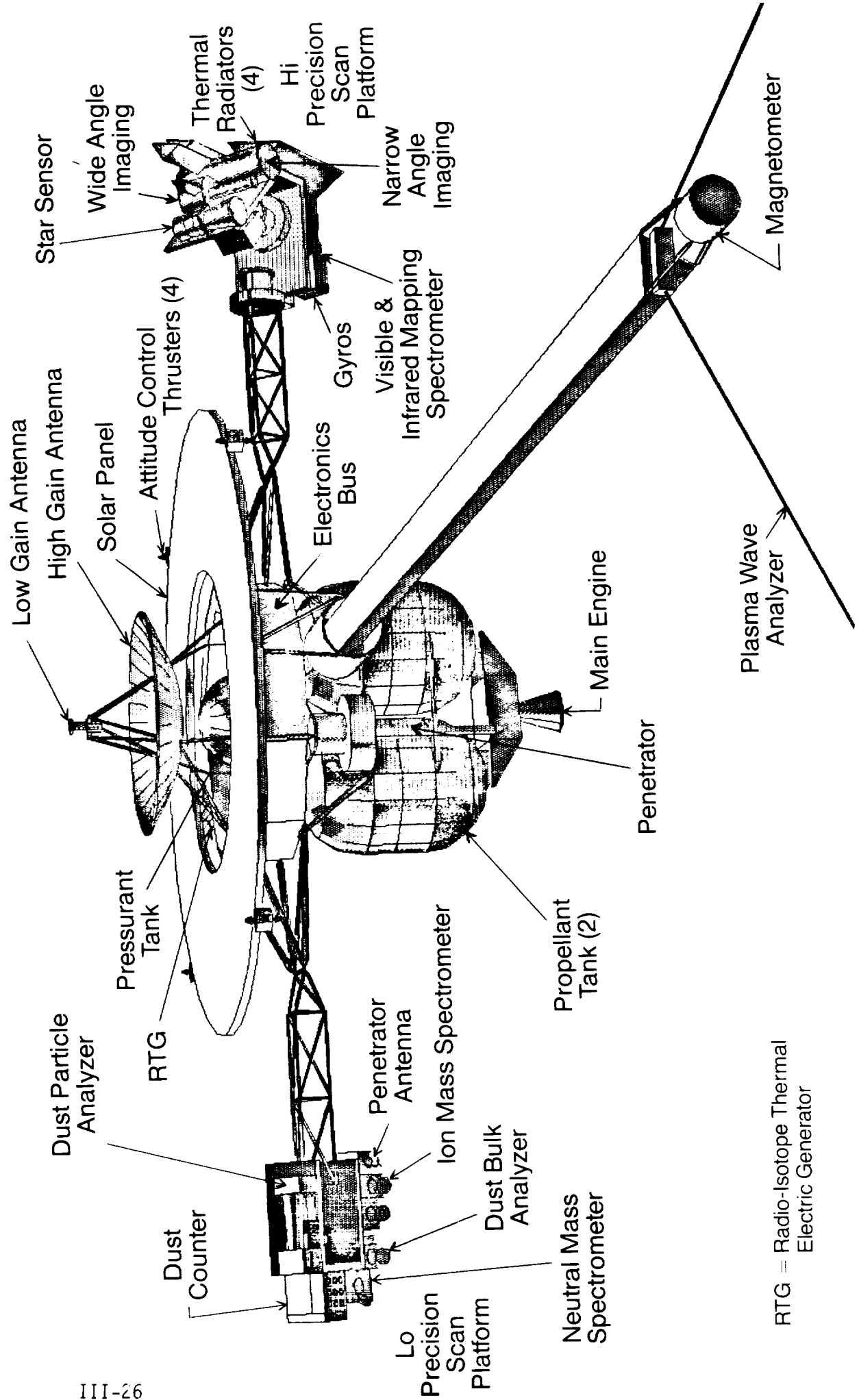
The four new initiatives described below are planned for the next five years in support of the recommended core program.

a. Comet Rendezvous and Asteroid Flyby

The Space Science Board has designated comet rendezvous as one of the highest priority initiatives for exploration of the small bodies. A rendezvous with Comet Wild 2 in 1994 will serve the purpose of investigating the physical and chemical state of comets. It will determine whether a nucleus exists and, if it does, investigate its physical state; analyze in situ the solid grains released from the nucleus during perihelion passage; determine plasma interactions with the solar wind; and make extended observations for more than two and a half years of all the dynamic processes of the comet as it moves from the point of rendezvous approximately 850 days before perihelion (at about four astronomical units) through its closest approach to the sun (about one and a half astronomical units). Typical science activities will include extensive imaging, gamma ray spectroscopy, infrared reflectance spectral mapping, neutral and ion mass spectroscopy, and dust detection, collection, and compositional analysis.

The spacecraft for the Comet Rendezvous and Asteroid Flyby mission will be a Mariner Mark II, which will be launched in 1991 by the Shuttle-Centaur combination. It will use a hybrid Earth-storable propulsion system to provide a direct multi-impulse transfer to the comet and post-rendezvous station keeping with it. Figure III-2 illustrates the first version of the Mariner Mark II core program spacecraft. Since the Comet Rendezvous and Asteroid Flyby spacecraft will traverse the asteroid belt during the cruise phase of its flight, it will be programmed for a flyby encounter with an asteroid. It will rendezvous with the comet before the onset of the well developed coma and ion tail that the comet

Figure III-2
Mariner Mark II—Comet Rendezvous Asteroid Flyby



RTG = Radio-Isotope Thermal Electric Generator

characteristically has exhibited near its perihelion. The viewing geometry from Earth also will be favorable through much of the encounter. After rendezvous, the spacecraft will orbit the comet's nucleus at a distance of 30 kilometers to conduct detailed studies of its surface and will deploy a penetrator that will make physical measurements and conduct gamma ray spectroscopy on the nucleus. About 100 days before perihelion, when the comet becomes increasingly active, the spacecraft will retreat to a safe distance (about 5,000 kilometers). Then, after the dust hazard has subsided, the spacecraft will explore the comet's atmosphere and make passes on the nucleus, progressively closing to a distance of 10 kilometers. Discussions are under way with the Federal Republic of Germany concerning a joint project to meet those objectives.

b. Lunar Geoscience Observer

Like Mars Observer, Lunar Geoscience Observer will use a Planetary Observer Class spacecraft. Its instrument complement also will be similar. Its objectives will involve lunar resources as well as extension to a global scale of the Apollo program's science investigations. The objectives will include global mapping of the elemental and mineralogical composition, surveying for volatile resources in the polar regions, global determination of figure and topography, and refinement of data on the lunar gravity field. Also under investigation will be the compositional heterogeneity of the moon and the time sequence of the differentiation that produced the heterogeneity; relationships between gravity variations, surface composition, and magnetic variations; origin and history of localized magnetization in the surface; nature of the processes that have shaped the surface; nature of volatile materials trapped in the polar regions; and internal density distribution.

Instruments needed for those investigations include a multispectral mapper, a gamma ray and x-ray fluorescence spectrometer, and a radar altimeter. Data also will be derived from tracking the spacecraft's orbit. Other instruments that might be added include a magnetometer, an electron reflectometer, gravity gradiometers, and a charge coupled device camera.

Launch could occur as early as 1992. The orbital portion of the mission will begin in an elliptical orbit, where instrument calibration and orbital tracking will take place. So that the geochemical mapping measurements can be made, the spacecraft then will establish and maintain for at least one year a circular polar orbit with an altitude of 50 to 100 kilometers.

c. Cassini (Saturn Orbiter and Titan Probe)

The Solar System Exploration Committee gave highest priority among new outer planet initiatives to a mission that would provide a preliminary map of Titan's surface and send a probe into its atmosphere. Second priority went to a Saturn orbiter, as a separate mission. However, with the expression of interest by a group of European scientists in a possible joint U.S.-European mission to the Saturn system, the two missions have been combined, with costs to be shared by NASA and the European Space Agency. The joint mission has been named Cassini in commemoration of

Titan's 17th century discoverer. It is being studied by a group of U.S. and European scientists and engineers for possible initiation in FY 1990. The planned 1994 launch and 7.2-year transit time would lead to arrival at Saturn in the year 2002.

Titan, the largest satellite in the Saturnian system, is unique in the solar system in that it has a dense atmosphere. Its atmosphere is predominantly nitrogen, but it contains a few percent of methane and possibly some primordial argon. Of particular interest is the current chemistry. What is the composition of Titan's atmospheric aerosol? Are important biological precursor molecules abundant? Are there hydrocarbon oceans, lakes, or clouds? Do islands or continents exist and, if they do, are they water ice or something else? What is the source of the atmospheric nitrogen? Did meteoroids produce the trace gaseous carbon monoxide or is it primordial?

The other components of the Saturn system are equally interesting. The planet itself has a meteorology, internal structure, and composition that resemble but are distinctly different from those of Jupiter. The system contains more than 17 other known satellites, including Iapetus, which has an inky-black leading hemisphere that presumably is covered with a mixture of organic compounds, and Enceladus, which is the most reflective object in the solar system, has a surface that contains large areas that appear recently melted, and seems to be the source of the particles in the E ring. The magnificent system of rings contains many puzzles still to be sorted out. And all of those components are immersed in a giant magnetosphere that also is similar to, yet different from, that of Jupiter.

Consequently, there is no shortage of tasks for a properly equipped spacecraft. The program's principal objectives include determination of the structure and chemical composition of Titan's atmosphere, investigation of energy exchange and deposition within the atmosphere, and at least local characterization of Titan's surface morphology. Examples of other objectives are to analyze the dark material on Iapetus, search for manifestations on Enceladus of contemporary internal activity, record the F ring with moving pictures for use in watching the configurations of its various strands evolve with time, search for embedded satellites elsewhere in the rings, define the source of the system's kilometer-wave radio emission, and further map Saturn's unusual magnetic field, particularly at high latitudes.

The Cassini mission will fulfill many of those objectives. Its orbiter will be a Mariner Mark II with a scan platform and a spin table. The orbiter will have short- and long-focus cameras with charge coupled device detectors having much greater sensitivity and wavelength range than 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 Titan's surface, and a full complement of fields and particles instruments to map the properties of the magnetosphere in space and time.

The European Space Agency will build the probe, following a new design adapted to the characteristics of Titan's atmosphere and gravity field. The probe will be released after orbit insertion at Saturn so that the probe's entry into Titan's atmosphere will be at low velocity, yielding a descent time to Titan's surface of about four hours and providing repeated measurements of atmospheric composition and structure. An instrument to image Titan's surface and a near-infrared spectrometer are possible additions to provide measurements complementing the radar determination of surface characteristics.

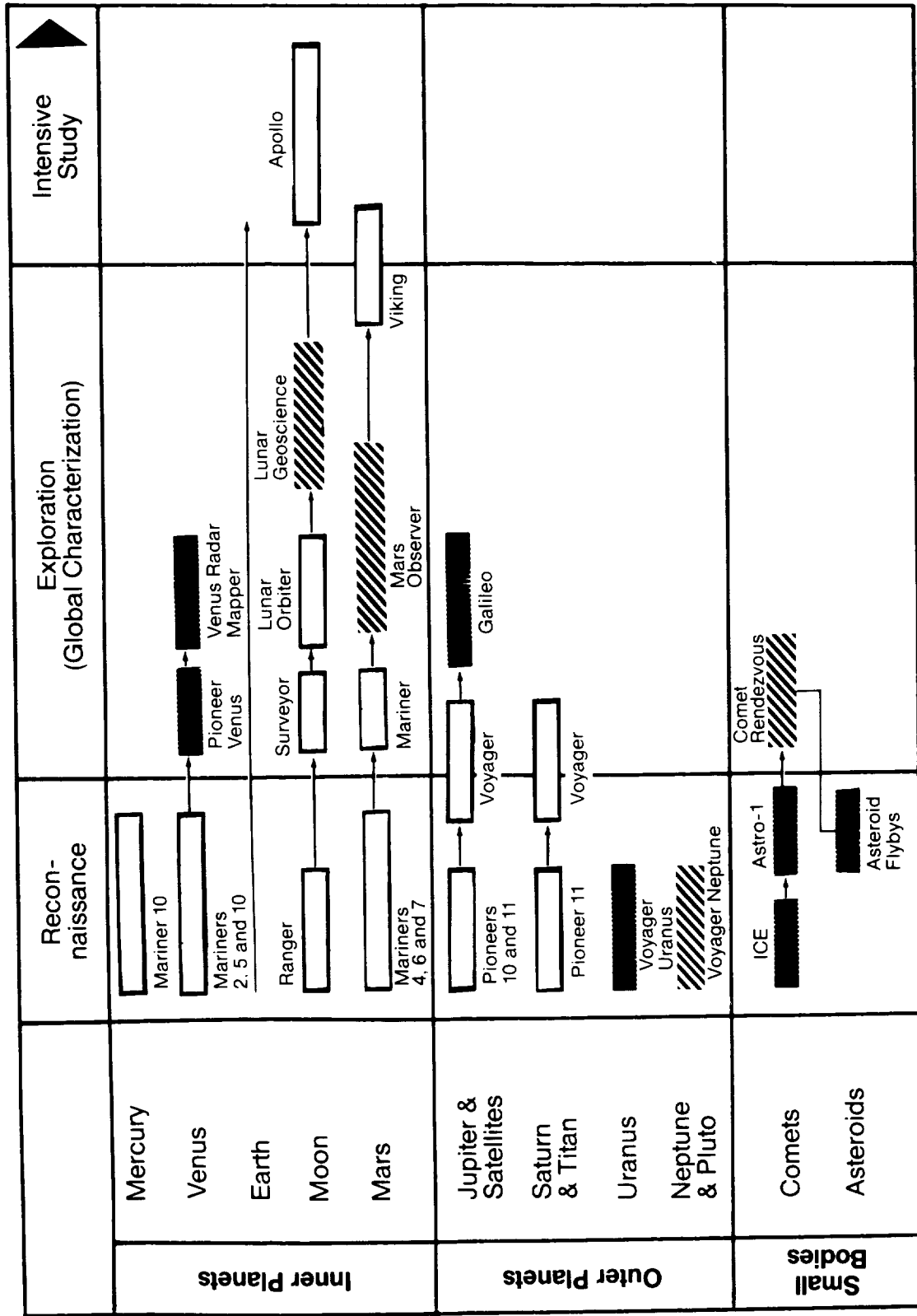
d. Coma Atmospheric & Elemental Sampling and Return




The Coma Atmospheric & Elemental Sampling and Return mission will be a Planetary Observer mission to acquire and return to Earth a sample of a comet's coma. Its principal objective is to return to Earth samples both of intact coma material and of coma material in plasma form collected during its fast fly-by. The concept currently under review for the mission adheres closely to the Solar System Exploration Committee's guidance for core missions, namely that spacecraft inheritance should be relied on heavily for controlling costs. The mission currently is being studied as a potential joint undertaking by NASA and the European Space Agency. The European Space Agency would provide a second Giotto spacecraft and fly-by instruments, while NASA would develop sample-collection devices and provide a reentry vehicle for return of the samples to Earth. With sufficient time for development of devices for collecting and stowing samples, launch could be as early as 1990. A comprehensive analysis of possible trajectories for launches during the period 1988 through 1995 has identified five comets whose comas could be sampled. An encounter with the first, Schwassman-Wachman, could occur in December 1989, with return of samples to Earth one year later, in December 1990. The mission is expected to be the least expensive Planetary Observer mission because of extensive use of existing hardware, minimal requirement for launch energy, short mission time, and joint participation. In contrast, the potential value of returning primordial cometary material to Earth laboratories in the early 1990s is high, making the mission a compelling addition to the Committee's core program.

4. Program Status, FY 1990

The four new initiatives just described will advance solar system exploration as depicted on Figure III-3, which shows how the core program initiatives will reinvigorate the program through exploration missions to all regions of the solar system. Activities related to the inner planets are at the exploration level for both Mars and the moon and are directed at global mapping of both of those bodies. For the outer planets, there is an approved initiative to explore the Saturn system, including to probe Titan's atmosphere. Also, successful continuation of the Voyager 2 mission will provide a fly-by reconnaissance of Neptune. The high-priority comet rendezvous mission will initiate exploration of the small bodies. The coma sample return mission will supplement that mission by providing an opportunity to analyze cometary material in Earth laboratories. Asteroid fly-by reconnaissance also is included as a benefit of the comet rendezvous mission's traversal of the asteroid belt.

Figure III-3
Planetary Exploration Status: 1989



 Past Projects
 Current Projects
 New Projects 1986-1990
 ICE = International Cometary Explorer

5. Possible Initiatives After 1990

The Solar System Exploration Committee recommended initiation of its core program missions by the end of this century. That would require initiation of seven missions in the 1991 to 2000 period. One of those projects, Mars Aeronomy Observer, is similar to the European Space Agency's Kepler mission. The feasibility of its being undertaken as an international contribution to solar system exploration is being discussed with the European Space Agency and its member countries. The remaining six missions and how they might be incorporated into the recommended core program are described below under the three classes of solar system bodies. Also described are augmentations to the core program recommended by the Solar System Exploration Committee. The Committee also recommends that, if resources can be made available, one or more intensive study missions be added to the core program during the decade of the 1990s.

a. Inner Planets

Two additional inner planet missions in the recommended core program are to be undertaken as future initiatives, Venus Atmospheric Probe Observer and Mars Surface Network Observer. The Venus Atmospheric Probe Observer will address questions about the planet's atmosphere raised by previous Pioneer Venus and Venera probe missions. Verification is needed of Pioneer Venus findings of abundant neon and argon and large ratios of argon to krypton, argon to xenon, and deuterium to hydrogen. Also, precise values for the ratios of noble gas isotopes are required so that constraints can be placed on theories of the origin of planetary atmospheres. The oxidation state of Venus' lower atmosphere, hydrogen and water abundances, and density profiles for several sulfur compounds also have been identified as major questions for resolution as a result of Pioneer Venus and Venera measurements. A probe based on the Pioneer Venus design carrying a limited set of instruments and transported to Venus by a modified Earth orbiter could satisfy the mission's objectives at a modest cost. Launch requirements will be comparable to those for inserting communications satellites into geosynchronous orbit.

Mars Surface Network Observer will have two objectives: to measure the bulk chemical composition of the planet's surface material, including key trace elements, and to establish a network of seismic-meteorological stations around the planet. Both objectives can be met by emplacing four to eight penetrators (missile-like projectiles that strike the surface at high velocity and become buried, leaving a small afterbody at the surface to transmit data to Earth). Data transmission will be via the spacecraft, which will be in an elliptical orbit. The geochemical measurements will be made in the first few weeks after probe delivery, while the seismic and meteorological observations will continue for a Mars year. This mission could be a precursor to a global network of perhaps 50 stations if measured seismic and meteorological activity appear to warrant detailed study. Each penetrator will have to be equipped with a small radioisotope thermoelectric generator.

Several Viking-class missions could augment the proposed core program missions to move the strategy for inner planet exploration into the intensive-study phase. Additional Mars exploration is a particularly good

candidate for initiation in the 1990s. Indeed, the Solar System Exploration Committee recently proposed that the primary augmentation candidate be the high-priority Mars Sample Return mission combined with an extensive capability for surface mobility. 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 being 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. To keep payload requirements within the capability of a Shuttle-Centaur, each mission would use aerocapture and orbit rendezvous at Mars. If Shuttle payload limitations are reached, the Centaur could be fueled fully in orbit for additional performance. The Space Station, serving as a transportation node, could provide that service. The Space Station also would be a useful first point of delivery for the returning samples. This and other concepts for Mars sample return missions will continue to be assessed in the coming year for feasibility, exploration value, and technology requirements in preparation for possible augmentation to the core program.

b. Small Bodies

Two additional missions, Near-Earth-Approaching Asteroid Rendezvous Observer and Multiple Mainbelt Asteroid Orbiter-Flyby, are to be undertaken as future initiatives to complete the core program for small bodies.

The Near-Earth-Approaching Asteroid Rendezvous Observer mission will share many measurement techniques with the Multiple Mainbelt Asteroid Orbiter-Flyby and the Lunar Geoscience Observer missions. However, the motivation for undertaking this mission is as much an interest in accessible near-Earth resources as in asteroid exploration. There are believed to be approximately 1,000 near-Earth asteroids greater than a kilometer in size, of which fewer than 10 percent have been discovered. The spacecraft for this mission will be a modified Earth-orbiter of the Planetary Observer Class--perhaps a follow-on to the Lunar Geoscience Observer spacecraft. The propulsion energy required to launch such a spacecraft on rendezvous missions to some near-Earth asteroids will be extremely low, indeed lower than that for a lunar orbiter mission. Thus, the Shuttle and a Transfer Orbit Stage class of upper stage will be able to satisfy launch requirements.

The Multiple Mainbelt Asteroid Orbiter-Flyby mission is a key element of the small body science strategy developed by the Space Science Board's Committee on Planetary and Lunar Exploration. Its objectives are characterization (determining asteroid size, shape, rotation, albedo, mass, and density) and detailed study of asteroid properties, including surface morphology, surface composition, elemental and mineralogical abundances, mass distribution, magnetic field, and solar wind interaction. A Mariner Mark II will be able to satisfy those objectives, but the objectives will press the capabilities of the Shuttle-Centaur combination. Performance in terms of number of accessible asteroids per mission could be improved by using Mars to provide gravity-assisted trajectories, but that improvement would be at the expense of launch opportunity

flexibility. Solar-electric propulsion is needed for the mission to realize its potential of four to six rendezvous targets with four to six additional asteroid fly-bys. NASA is considering international participation for this mission as a means of obtaining the beneficial solar-electric propulsion module.

For augmentation of its small bodies core program, the Solar System Exploration Committee proposed the high-priority Comet Nucleus Sample Return. Because comets are believed to be remnants of the solar system formation process, great importance is assigned to the return of unaltered samples of their nuclei for laboratory analysis of their physical structure, composition, and chemistry. Mission requirements will be comparable to those for the Mars Viking mission. The spacecraft could include an interplanetary, remote-sensing spacecraft bus; one or two lander-samplers, with an option for continued post-sampling surface measurements; and a sample return capsule. Solar-electric propulsion would be an enabling capability to overcome the constraints imposed by a single Shuttle-Centaur launch. Aerocapture at Earth return would increase the mission's attractiveness by reducing the amount of power the solar-electric propulsion system would have to provide.

c. Outer Planets

Two core program missions to the outer planets are to be initiated in the 1991 to 2000 period: the Saturn Flyby and Probe mission and the Uranus Flyby and Probe mission. The probes on those missions will have objectives very similar to those for the Galileo mission's probe; and their design could be the same except for reduction in aeroshell mass, leading to decreased flight time. In addition, those missions would use instruments similar to those used on the Galileo mission. Comparison of the findings of the three missions is one of the important science goals for outer planet exploration. The spacecraft for both missions will be the Mariner Mark II if the total launch mass can be kept within the launch capabilities of the Shuttle-Centaur-Payload Assist Module launching system. Annual launch opportunities exist, with expected trip times of 3.5 and 5.5 years to Saturn and Uranus, respectively.

The Solar System Exploration Committee did not include Neptune and Pluto missions in its core program because it assumed that funding would not be available for them before the year 2000. However, those missions are important to outer planet exploration, and it is expected that they will be started in time for the next series of Jupiter gravity-assisted opportunities around 2005.

6. New Technologies and Space Station Capabilities

The proposed core program for solar system exploration was formulated under the constraint that no new enabling technologies be required. The program does require extensive use of the Shuttle-compatible Centaur upper stage, but development of technology for that stage already is under way. New enhancing technology for spacecraft systems--particularly for telecommunication, data, and power systems--will be incorporated into Mariner Mark II and Planetary Observer spacecraft as they become available and cost effective. Since solar-electric propulsion would provide a significant performance

advantage to the multiple encounter mission to main-belt asteroids, its development will be encouraged, preferably with foreign participation in the development. It also would be an enabling capability for small body and outer planet augmentation initiatives.

In contrast, requirements for new technology for the proposed augmentation initiatives are significant. Every mission will need new enabling or enhancing technologies for delivery and recovery operations, encounter operations, or in situ exploration. Need for new delivery technology arises from a requirement for greater performance. Three enabling capabilities under consideration are electric propulsion, in-orbit fueling of the Shuttle-compatible Centaur, and in-orbit assembly of two or more Centaur-class upper stages. Each offers advantages to different augmentation missions. For example, nuclear electric propulsion would be particularly beneficial to advanced outer planet missions such as a Neptune orbiter or a Saturn ring probe. Since the augmentation initiatives focus on sample return missions, new recovery technologies also would be needed and consideration would have to be given to particular areas such as quarantine and thermal and physical protection of samples during entry or Earth orbit in the recovery process.

Establishment of the permanently manned Space Station will be beneficial to both the launch and recovery phases of the augmentation missions. Modular launch systems could be assembled easily at the station to obtain escape performance substantially greater than that of the Shuttle-Centaur. Space Station recovery of returned samples would provide a means for zero-gravity laboratory studies and would contribute importantly to issues relating to sample quarantine.

Technology needs for encounter operations relate to performance and control. To increase performance and payload, lifting-body aerocapture techniques constitute an attractive alternative to the advances in capabilities of Shuttle upper stages mentioned in the preceding paragraph. In addition to providing performance benefits, aerocapture techniques can compensate for navigation and atmospheric uncertainties that otherwise would prevent landing the heavier payloads in the augmentation missions.

An enhancing technology, especially for the Mars Sample Return mission, would be in situ propellant production. At Mars, for example, it would involve extraction of oxygen from the carbon monoxide atmosphere to produce oxidizer. Other needed technologies for encounter operations include automated rendezvous, docking, and terminal navigation and guidance. Automated rendezvous and docking are under consideration for the Mars Sample Return mission and could become a base-line requirement for the Comet Nucleus Sample Return mission. Automated terminal navigation and guidance would be particularly beneficial to the Mars Sample Return mission because a precise landing ability would directly affect the designs of the lander and the rover.

Technology needs for in situ exploration center on automation and sample control. Expected robotic activities and mobility require advances in automation and artificial intelligence, as do site characterization for, and acquisition of, samples. Control of samples requires technology to allay concerns regarding a priori sterilization, site contamination, and sample protection. Therefore, technology assessment is needed in biology, chemistry, and physics, especially structural and thermal physics. Sampling techniques

also need to be improved because they now lag capabilities for other phases of sample return missions.

D. Earth and Its Environment

Earth's physical characteristics are the result of interactions among many processes. The absorption of solar radiation and subsequent transfer of energy and momentum between Earth's land surface, atmosphere, and oceans produce the terrestrial climate. Convective flow in its interior, manifested by slow but unrelenting motions of large blocks of its surface, reshape it continually. The same fluid motions produce a magnetic field in its metallic core that shields its surface from the solar wind. A delicate balance between the physical and chemical processes on its surface and in the near-space environment provides the conditions on which living organisms on land and in the oceans and the air depend for their continued survival.

The study of Earth sciences began when humans first recorded phenomena they observed around them. Scientific interest in those phenomena arose both from intellectual curiosity and from the effects on daily life of many of the processes studied. Division of Earth sciences into disciplinary areas such as meteorology, atmospheric physics, oceanography, geology, and biology came about because of the necessity to delineate problems that are tractable. However, as the boundaries of each discipline have grown, so has the overlap between disciplines. In recent years, the view of Earth from space has engendered a growing realization that a full understanding of Earth requires global, interdisciplinary research. Study of the processes governing the solid Earth and its oceans, atmosphere, magnetosphere, and life forms requires coordinated global observations and theories to integrate the observations.

NASA's program already has accomplished much, both in basic understanding and in developing techniques that have practical application. Space-acquired data are in regular use and have demonstrated their utility for research in agriculture, land use, hydrology, and geology. Observations from space are used in inventorying land cover; locating, classifying, and measuring major types of forests; identifying shoreline changes, salinity zones, and flood plain boundaries; and identifying water impoundments larger than two acres in area. Knowledge gained has been used in forecasting wheat production and in identifying areas in which crops are under stress. It also can assist in determining global changes in biomass and, in conjunction with a global biology program, can begin to determine the processes involved in those changes.

Perhaps the most dramatic example of the use of space-acquired data has been in the atmospheric sciences. Research instruments and techniques developed by NASA have made global measurements of tropospheric parameters such as temperature, humidity, and winds and therefore have improved knowledge of the troposphere substantially. The National Weather Service has incorporated those techniques into its models to improve the quality of all its forecasts. Also, data from recent NASA satellites are being used to update forecasting techniques so that the goal of a reliable 7-day forecast can be approached. Earth's wobble about its polar axis and its change in rotational rate have been discovered to be caused by the interaction of its atmosphere with the solid Earth. By measuring the distribution of ozone and other important species in the stratosphere, NASA satellites have improved under

standing of the stratosphere and the role that human-made pollutants might have on its ozone content. An experiment carried on the second Shuttle flight, Measurement of Air Pollution from Shuttle, demonstrated a capability for measuring a tropospheric trace species, carbon monoxide, from space.

Equally dramatic prospects are in sight for studying the oceans from space. Seasat measured winds over the oceans and sea-surface height changes, demonstrating that circulation patterns in the oceans can be determined using instrumented satellites. Measurements of the chlorophyll content of the oceans can be made routinely and have been used to determine the probability of fish harvests off the west coast of the United States. Techniques derived from space technology have been used to acquire initial data on the large-scale motion of Earth's crust. Those data eventually will contribute to alleviation of the adverse economic and social effects of crustal hazards and to better understanding of the processes that led to the deposit of mineral and energy resources.

Understanding also has been significantly increased regarding the processes by which energy in diverse forms is generated by the sun, is transported to Earth, and ultimately influences the terrestrial environment. Discovery of Earth's radiation belts in 1958 and of the solar wind in 1960 was but the beginning. Investigation of near-Earth space by several satellites has provided data on Earth's magnetosphere, atmosphere, and ionosphere, leading to better understanding of radio communication, the spacecraft environment, and the possible influence of the sun on Earth's weather. Observations of the output from the sun have shown changes in the solar constant measured in only days. The existence of such rapid change was a major surprise.

1. Strategy

NASA's program to study Earth is global, integrated, and interdisciplinary, with emphasis on understanding processes that affect Earth's habitability, particularly its biological productivity and biogeochemical and hydrologic cycles. The program involves coordinated observational, theoretical, experimental, and modeling investigations, and development of future observing technologies. Those activities are complementary and together form a balanced program of system and process studies. The program emphasizes the physical processes that produce observed phenomena and seeks to determine the underlying cause and effect relationships, thereby making it possible to develop realistic predictive models. The observational investigations usually require use of a variety of instruments making both remote and in situ measurements simultaneously from several locations in the solar-terrestrial system. Some investigations make controlled perturbations of the magnetosphere and the atmosphere, thereby using space as a laboratory. The program uses a broad spectrum of computational resources for modeling and analyses, for archiving data, and for access to multidisciplinary data sets.

2. Current Program

a. Landsat

Landsat-4, launched in July 1982, carried the Thematic Mapper sensor into space for the first time. That sensor's measurement capabilities are

vastly superior to those of the Multispectral Scanner carried by earlier Landsat spacecraft. The Thematic Mapper possesses approximately twice the spectral resolution, three times the spatial resolution, and four times the sensitivity that the Multispectral Scanner possesses. Landsat-4 collected more than 6,000 images before developing technical problems during the spring and summer of 1983 that have seriously curtailed its ability to collect data. Consequently, research now is focused on analysis and interpretation of those images, evaluation of the quality of the imagery, and determination of the types of Earth information that can be extracted from the images. Another spacecraft, Landsat-D', was launched in March 1984. Routine collection of Earth imagery with its Thematic Mapper started in 1984.

b. Shuttle Imaging Radar

A series of radar imaging experiments called Shuttle Imaging Radar A and B (SIR-A and SIR-B) that have been flown on the Space Shuttle will add another major dimension to NASA's program in Earth observations. SIR-A, conducted in November 1981, collected data that provided the first demonstration that radar sensors can penetrate deep into windblown sand deposits in hyper-arid environments. SIR-A imagery of portions of the eastern Sahara Desert revealed the presence of buried drainage channels that provide important clues to the archaeological and geological history of southern Egypt. SIR-A data collected over other areas are still being analyzed using advanced computational facilities developed for radar data.

In December 1982, NASA issued an Announcement of Opportunity soliciting proposals for scientific investigations that SIR-B potentially could conduct. From the more than 180 proposals submitted, 47 investigations tentatively were selected. They will seek to extend the radar penetration studies SIR-A initiated and to conduct studies in geology, oceanography, botany, hydrology, and cartography. Specific investigations are planned of tropical deforestation, ocean waves and currents, forest biomass, crop yields, sea ice, earthquake hazards, and coastal geomorphology. SIR-B, launched in October 1984, is the first spaceborne radar able to image Earth's surface at multiple angles of incidence measured from the local vertical.

Plans are in process for a third experiment, SIR-C, which would be able to obtain radar imagery of Earth's surface at multiple frequencies and polarizations. SIR-C tentatively is scheduled to enter development in 1987.

c. Multispectral Linear Array Sensor

The objective of the Multispectral Linear Array program is to develop an advanced, high-performance, solid-state sensor. Near-term emphasis is on development of a sensor incorporating a new generation of detector materials; a capability for making both visible and shortwave-infrared measurements; use of linear, focal-plane arrays; onboard signal processing; and advanced concepts for data processing on the ground.

d. The Oceans

The analysis of data and the publication of results from Seasat and Nimbus-7 have demonstrated the scientific potential offered by observation of the oceans from space. Joint Oceanographic Institutions Incorporated, representing the greater ocean research community, has published "Oceanography from Space Research Strategy for the Decade: 1985-1995" based on those projects and the scientific requirements for the World Climate Research Program discussed below. That strategy outlines the prospects that satellite techniques complemented by in situ observations provide for determining for the first time the following: wind forcing--via scatterometers; ocean current response--via altimeters; oceanic heat transport--via various radiometric techniques; the associated dependence of biological productivity--via color scanners; and the growth, movement, and decay of sea ice--via passive and active microwave techniques. There is an opportunity not only to understand how the oceans function as a system, but also to assess their influence on the atmosphere, biosphere, and cryosphere.

Under the auspices of the International Council of Scientific Unions, the World Meteorological Organization, and the Intergovernmental Oceanographic Commission, plans are being formulated to conduct a World Climate Research Program in the late 1980s and early 1990s. The role of the oceans has been recognized to be part of the program, and two oceanographic component programs are being defined: the World Ocean Circulation Experiment and the Tropical Oceans/Global Atmosphere Experiment. Satellite altimetry and scatterometry activities, such as those proposed for the Topography Experiment for Ocean Circulation and the NASA Scatterometer described later, will be key components of the two experiments.

e. The Atmosphere

NASA's research program, Global Scale Atmospheric Processes, has developed experience and facilities to deal with the special problems associated with understanding the large-scale motions of Earth's atmosphere. Those problems relate to development of techniques both to observe the atmosphere better and to process and manage the large volumes of data needed in atmospheric studies. Numerical models have been developed to simulate the physical processes that take place in the atmosphere. The models were designed to make the most effective use possible of data from both existing and planned satellite instruments. Such models pave the way for development of satellite instruments by simulating their impact on the accuracy and extent of meteorological predictions. They also guide the development of operational forecasting models. Using the results of its simulation studies, NASA is developing a Doppler Lidar for sensing the wind globally.

Investigation and assessment of data from the Global Weather Experiment are reaching a mature phase. A number of publications that already have appeared show the effectiveness of that data set. The data set contains meteorological parameters not currently available to forecasters, the most notable of which is depiction of global vertical wind profiles.

f. Mesoscale Atmospheric Processes

The Mesoscale Atmospheric Processes Research program is the basic research program at NASA dealing with atmospheric behavior that leads to severe weather. High-altitude and space derived data are analyzed in conjunction with conventional weather observations to obtain new perspectives on and interpretations of atmospheric behavior. In 1984, several studies were conducted of small, high-velocity downdrafts called microbursts, to develop pilots' understanding of them and thereby increase airline safety. Also, a new instrument, the airborne Doppler Lidar, was used to map wind fields in clear air over the Pacific marine boundary layer, air circulation in the California Central Valley, and the flow of air entering storms. The resulting observations were compared with observations made with the new ground-based VHF wind profilers at Pennsylvania State University. Another activity during 1984 was flight over storms by high-altitude aircraft equipped with remote sensors to collect data on temperature, moisture, electric field variations, lightning spectral emissions, and precipitation, for use in numerical studies of the internal processes in storms.

Several additional activities currently in process are seeking to improve mesoscale numerical models to make them able to take into consideration varying input data, land surface effects, improved handling of cumulus cloud effects, and storm triggering factors. Those activities use computer display techniques involving 3- and 4-dimensional presentations that facilitate interpretation of the mechanisms of hurricane evolution and growth, squall line development, and storm initiation.

g. Earth's Radiation Budget

Observations from instruments on Nimbus 6 and 7 and the National Oceanic and Atmospheric Administration's operational satellites are the foundation for a continuing series of data sets on Earth's radiation budget that will serve as a resource for climate research. NASA's Earth Radiation Budget Experiment, launched in 1984, will continue those observations and augment the data sets. Earth's radiation budget also is being addressed in other ways. Evidence from recent Nimbus 7 and Solar Maximum Mission observations confirms that the total output of the sun varies naturally by several tenths of a percent for periods of up to about two weeks. To monitor the long-term trend of the variation and to determine its effect on climate systems, the following instruments have been designed for use on the Shuttle: the Active Cavity Radiometer, the Solar Ultraviolet Spectral Irradiance Monitor, and the Solar Constant Variation instrument. It is expected that such instruments will be flown regularly during the next decade. Research programs have been initiated to develop an understanding of and models for the processes by which clouds are formed and interact with incident or reflected radiation, and to study the sources, compositions, and radiative effects of aerosols that volcanic explosions inject into the stratosphere. In addition, the International Satellite Cloud Climatology Project is expected to develop a global cloud-climatology data set for use in improving climate models.

h. Trace Species

Investigators are developing techniques for measuring major trace species in the troposphere. Field measurements to test the most promising instruments will be followed by a 6-year program of measurements by aircraft to characterize the chemistry of the troposphere on a global scale. Research on the stratosphere and mesosphere also continues and has increasingly used more realistic 2- and 3-dimensional models. The chemical, radiative, and dynamic computer codes used in those models are being improved continually, with the goal of developing fully coupled chemical, radiative, and dynamic 3-dimensional models that simulate the atmosphere very precisely. Also, NASA, in cooperation with European, Canadian, and Japanese investigators, is using a variety of instrument techniques on balloon, rocket, and aircraft flights to obtain measurements of trace species in the stratosphere that will allow accurate comparison of current experimental techniques.

Data from Nimbus 4, Nimbus 6, Nimbus 7, and Stratospheric Aerosol and Gas Experiment have been validated and are becoming available for detailed analysis. Solar Mesosphere Explorer data on ozone, nitric oxide, and water vapor soon will be available for analysis; and two instruments, Imaging Spectrometer Observatory and the Atmospheric Trace Molecule Spectroscopy experiment, have been developed for use on the Shuttle to measure those species in the mesosphere and stratosphere. The Observatory already has flown on Spacelab 1 and the Spectroscopy experiment will fly on Spacelab 3.

i. Geodynamics

Laser ranging and microwave interferometry are being used to measure the motions of Earth's polar axis, variations in the length of day, and the motion and deformation of Earth's crustal layer. A worldwide network of over 20 cooperating space agencies participates in NASA's global geodynamics research. A second Laser Geodynamics Satellite, being built by Italy, is to be launched by the Shuttle in 1987. Data from laser tracking of satellites and altimeter data from Seasat and the third Geodynamic Experimental Ocean Satellite are being used to improve the accuracy of models for global gravity fields used in studies of earth and ocean processes. Similar data acquired by Magnetic Field Satellite are being used in studying secular and temporal variations of Earth's main field and inhomogeneities in Earth's crust.

j. Space Plasma Physics

Space plasma physics has two main thrusts. The first consists of studies of large-scale systems and requires simultaneous measurements by several spacecraft occupying different regions in space. For example, Atmosphere Explorers C, D, and E studied how solar ultraviolet radiation interacts with the upper atmosphere to produce the cool, co-rotating plasma of the ionosphere and helped to explain how those interactions control the thermosphere. International Sun-Earth Explorers 1, 2, and 3 investigated how the incoming solar wind interacts with the outer fringes of Earth's magnetic field to produce the boundaries of the magnetosphere and the hot, convective, magnetospheric plasma. Dynamics Explorers 1 and

2 studied the interactions between the hot, convecting, magnetospheric plasma and the cool, co-rotating, ionospheric plasma and also studied the energizing of particles that produce the aurorae and interact with the atmosphere. International Sun-Earth Explorers 1 and 2 and Dynamics Explorer 1 continue to make measurements in the magnetosphere. Analysis continues of data from all those missions.

The second main thrust is complementary to the first and involves controlled studies of interactive processes. Spacelab provides a unique capability for in situ active experiments involving the injection of particles, the transmission of electromagnetic energy, and the ejection of chemicals into the upper atmosphere so that the effects can be measured and understood. Active experiments of those types have been conducted on OSS-1 and Spacelab 1 and are scheduled for Spacelab 2 in 1985. In addition, Active Magnetospheric Tracer Explorer, which was developed in a cooperative program with the Federal Republic of Germany and the United Kingdom, was launched in August 1984. Its Ion Release Module has released tracer chemicals in front of the magnetosphere, and additional releases will occur in 1985 at the flanks of and in the tail of the magnetosphere. Simultaneously, Charge Composition Explorer will try to detect the tracers inside the magnetosphere so that the entry into and energizing of plasma in the magnetosphere can be studied.

k. Global Biology

An important emerging area is global biology, which deals with the influences of biological processes on global biogeochemical cycles. Because biological processes dominate in the production and removal of many constituents of the biosphere, knowledge about them is critical to understanding the consequences of environmental perturbations. It has become clear that they constitute a key influence on the land, the oceans, and the atmosphere. Factors to be investigated are the areal extent of land use and biomass, rates of change of biomass as determined from remote sensing data, biogenic gas fluxes and the factors that affect them, in situ monitoring of ecological processes, and interpretation of sedimentary fossil records to test hypotheses about modern processes. Although achieving an understanding of Earth as a system is formally part of the Life Sciences program, it will be possible only if study of global biology is a feature of the total Space Science program.

l. Upper Atmosphere Research Satellite

This program's goal is to extend scientific understanding of the chemical and physical processes occurring in Earth's stratosphere, mesosphere, and lower thermosphere. Its primary objective is to understand the mechanisms that control the structure and variability of the upper atmosphere, the response of the upper atmosphere to natural and human-related perturbations, and the role of the upper atmosphere in climate and climate variability. It will use remote sensing instruments currently in development, including two instruments being provided by British and French investigators, to measure trace molecule species, temperature, winds, and radiative energy input from and losses to the upper atmosphere. It also will make in situ measurements to determine magnetospheric energy inputs to the upper atmosphere. Plans include

extensive interaction among experimental and theoretical investigations and an interactive central data facility with direct on-line access via remote terminals to facilitate interaction among investigators.

m. Scatterometer

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, then can 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. Knowledge of wind velocities also will improve forecasts of such factors as wave conditions and the intensity and location of storms. Scatterometer data would provide a unique global perspective of the oceans, significantly improving understanding of how the oceans work; and plans for acquiring the data are being made possible by flight of a scatterometer on the U.S. Navy's Remote Ocean Observing System scheduled for launch in 1989. The scatterometer and the satellite are approved items in the respective budgets of the National Oceanic and Atmospheric Administration and the Navy.

3. Potential New Initiatives, FY 1986-1990

a. Shuttle-Spacelab Payloads

Basic processes in which electromagnetic energy and particle beams interact with plasmas occur in many systems within the universe, but can be studied most easily in the most accessible space plasma--that near Earth. As noted earlier, Spacelab's capabilities are well suited for making those studies. A beginning was made with the flight of the OSS-1 pallet, which used a small electron gun to study vehicle charging and wave generation. Spacelab 1 had a Japanese electron accelerator with pallet-mounted diagnostics, and Spacelab 2 will include an electron gun and a plasma diagnostic package on a subsatellite. In planning is a more ambitious mission called the Space Plasma Laboratory on which those instruments will be joined by other instruments, including a VLF-HF wave injection facility being developed in cooperation with Canada. Because of Spacelab's versatility, the mix of instruments can be changed between flights and the entire payload can be upgraded in an evolutionary fashion. Spacelab laboratory elements can be used later on the Space Station.

Also planned is the assembly into a single payload of several solar radiance instruments (the French-developed Solar Ultraviolet Spectral Irradiance Monitor, the Active Cavity Radiometer, and the Belgian-developed Solar Constant Variation instrument) and two atmospheric instruments (the Atmospheric Trace Molecule Spectroscopy experiment and the Imaging Spectrometer Observatory). That payload will be flown on a regular basis starting in 1985 to provide information on behavior with time of the the solar constant, the solar spectrum, and the upper

atmosphere. In addition, a variety of new instruments for remote sensing of Earth's surface will be flown on Shuttle-Spacelab flights to test their capabilities and to evolve their use from short-duration Shuttle-Spacelab missions to longer missions on the Space Station.

b. Ocean Color Imager

The success of the Coastal Zone Color Scanner, which was launched on Nimbus-7 in 1978 and now is in its sixth year of operation, clearly indicates that a follow-on instrument could determine global primary productivity, which forms the base for the various marine food chains. The synoptic, global measurements of chlorophyll concentration that a satellite color scanner can provide will serve as the primary data base to which complementary data from ships, airplanes, and buoys can be added to yield primary productivity estimates of high accuracy for key oceanic regions.

An improved version of the Coastal Zone Color Scanner, the Ocean Color Imager, has been designed; and plans are being formulated to make possible, for the first time, the relating of wind forcing data acquired by a NASA Scatterometer to data on ocean current response from the planned Topography Experiment for Ocean Circulation mission, to data on the redistribution of oceanic nutrients by the currents, and to data on the resulting changes in primary productivity from the Ocean Color Imager. With appropriate in situ observation, it will be possible to relate biological variability quantitatively to the physical characteristics of the global oceans. Concurrently, studies are under way relating to flight in 1990 of the Ocean Color Imager on either the U.S. NOAA-K or the French SPOT-3 spacecraft.

c. Tethered Satellite System

The Tethered Satellite project is an international cooperative undertaking between the United States and Italy to provide a new facility for conducting Earth Science and Applications experiments (see chapter IV. Space Flight, page 10). The Tethered Satellite will make measurements as far as 100 kilometers from the Space Shuttle. It will make possible long-term scientific experimentation not heretofore feasible, including generation and study of large-amplitude hydromagnetic waves; magnetic field aligned currents; and high-power, very low frequency and extremely low frequency waves in the ionosphere-magnetosphere system. It also will permit studies of magnetospheric-ionospheric-thermospheric coupling and atmospheric processes below 180 kilometers; of high resolution crustal geomagnetic phenomena; and of the generation of power using a conducting tether. Italy has agreed to provide the satellite for the planned atmospheric (tethered downward) and space plasma (tethered upward) missions.

d. Topography Experiment for Ocean Circulation

The large-scale movement of water in the oceans has many direct consequences for life on Earth. For example, climate changes, fish production, commerce, waste disposal, and national security are affected by ocean circulation and, in turn, affect daily life. And many things

about the oceans are poorly understood, largely because the oceans are difficult to observe. The Ocean Topography Experiment is expected to provide significant capabilities for observing the circulation of the oceans on a global basis. Its objectives will be to measure ocean surface topography over entire ocean basins for several years; integrate those measurements with subsurface measurements and use the results in models of the oceans' density fields to determine the oceans' general circulation and variability; and then use the information from all those activities to develop an understanding of the nature of ocean dynamics, calculate the heat transported by the oceans, understand the interaction of currents with waves, and test the capabilities available for predicting ocean circulation.

e. Magnetic Field Explorer

The first Magnetic Field Satellite, Magsat-1, acquired--for the first time--detailed, global data on the scalar and vector magnitudes of Earth's magnetic field. However, that field undergoes major changes over the period of a few years due to variations in the motions of the inner core. The position of the magnetic pole drifts westward, but the rate of drift is not constant. Resulting uncertainties in magnetic maps limit their usefulness to from three to five years. However, those changes provide information on important and enigmatic properties of Earth such as the origin of the main magnetic field and its variations with time; the structure and electrical properties of the mantle; magnetic monopoles; and the relationship among variations in the magnetic field, the mass distribution of the atmosphere, and the rotation rate. The Magnetic Field Explorer will obtain scalar and vector field data that, in conjunction with data from Magsat-1 and the Geopotential Research Mission, will be used to examine magnetic field changes for periods ranging from months to decades. It also will provide an updated data set required for a future magnetic field survey.

f. Geopotential Research Mission

Accurate knowledge of Earth's gravity and magnetic fields is essential to scientific studies of the planet, particularly those involving the solid earth, the oceans, and energy and mineral resources. Earth's gravity field is known to an accuracy of 5 to 8 milligals for resolutions of 500 to 800 kilometers, and the geoid (mean ocean sea level) to an accuracy of about 50 centimeters. Those accuracies are inadequate to resolve key scientific questions relating to the motion of Earth's crust (mantle convection) and the structure and composition of Earth's interior. Magsat-1 provided a map of crustal magnetic anomalies that showed a high degree of correlation with large-scale geological and tectonic features. However, its orbital altitude was too high to yield a map with the accuracy and resolution required for both solid earth science and geological prospecting. Greater accuracy and resolution are needed, and they can be achieved only by a mission at a significantly lower altitude.

The Geopotential Research Mission will provide the most accurate models yet available of the global gravity field, geoid, and crustal magnetic anomalies. It will employ two spacecraft approximately 300 kilometers apart in the same 160-kilometer circular polar orbit. To

determine the gravity field, a drag-free sphere will be positioned at the center of mass of each spacecraft in a cavity that will shield it from all surface forces and therefore permit it to be affected only by gravitational forces. The relative motion of the spheres as they are accelerated and decelerated while passing over a gravity anomaly will be a measure of the size and intensity of the anomaly. The accuracy to which the position of each sphere in the along-track direction can be measured by Doppler tracking will be 1 micrometer per second every 4 seconds. That accuracy in the Doppler data will permit analysis to determine the global gravity field to approximately 1 milligal and the geoid to approximately 5 centimeters, both to a resolution of 100 kilometers. Earth's magnetic field will be surveyed by scalar and vector magnetometers, similar to those flown on Magsat, mounted at the end of a rigid boom extending from the leading spacecraft. The magnetic field data will have an accuracy of 2 nanoteslas and a resolution of 100 kilometers.

g. International Solar Terrestrial Physics Program

This program's purpose is to attempt, for the first time, a quantitative study of the complete solar-geospace system. Geospace comprises the near-Earth environment and contains the near-Earth interplanetary medium and Earth's magnetosphere, ionosphere, and upper atmosphere. Each geospace region has been investigated individually, but it is the collective behavior of the geospace system's highly interactive components that determines the system's overall behavior. In particular, an understanding of the behavior of the entire system will require measurements in the two main energy storage and two main energy deposition regions, as well as knowledge of solar surface and solar wind features. Thus, the mission is envisioned as a multi-instrumented spacecraft mission to be carried out jointly with the Japanese Institute of Space and Astronautical Sciences and the European Space Agency. The elements of the mission may include:

- o The Solar-Pointed Laboratory, stationed at the Earth-sun libration point--to measure solar surface oscillations and deduce solar flare and solar wind processes
- o The Solar Wind Laboratory--to measure the incoming solar wind, magnetic fields, and particles
- o The Polar Laboratory--to measure solar wind entry, ionospheric plasma output, and deposition of energy into the neutral atmosphere at high latitudes
- o The Equatorial Laboratory--to measure solar wind entry at the sunward nose of the magnetosphere and the transport and storage of energetic plasma in the equatorial ring current and near-Earth plasma sheet
- o The Geotail Laboratory--to measure solar wind entry and the acceleration, transport, and storage of plasma in the geomagnetic tail

- o The Multipoint Plasma Laboratory--to study the spatial and temporal behaviors of small-scale plasma processes, including magnetic merging.

4. Future Thrusts, FY 1991-1995

In the decade of the 1990s, the Earth studies program will investigate long-term physical, chemical, and biological trends and changes in Earth's environment, including Earth's lithosphere, atmosphere, magnetosphere, land masses, and oceans. It will study the effects of natural and human activities on Earth's environment by measuring and modeling the chemical cycles of nutrients and will provide improved models for estimating the future effects of humans and other species on Earth's biological productivity and habitability. It will use space and suborbital observations, land- and sea-based measurements, laboratory research, and supporting data management technologies over ten years or more. The space measurements to support the program will require a Space Station polar platform able to support a variety of remote sensing instruments. A concept for such a platform is under study. In addition, platforms for active plasma experiments and free-flyers for in situ measurements will be required.

E. Life Sciences

The Life Sciences program pursues goals in both basic science and applied sciences. Its goals in basic science are to understand how life forms are affected by the conditions found in space and to learn the origins, evolution, and distribution of life in the universe. Its goal in applied science is to ensure the health and well-being of spacecraft crews during prolonged space flights. All three of those goals contribute directly and immediately to meeting two major goals in the national space policy: to establish a permanent human presence in space and to conduct a vigorous program of space exploration and scientific research.

The program's research is performed by laboratories in universities and the Agency's field centers, supported where appropriate by development work performed by private industry. Complementary ground-based research and space experimentation contribute to achievement of the program's goals. Their emphasis is on developing a comprehensive view of life in the universe and on showing how Earth's life forms can live away from the planet where they originated.

1. Objectives

The program's objectives are to:

- o Determine the effects of long-term space flight on humans and understand the basic physiological mechanisms of those effects
- o Develop effective means to maintain spacecraft crews in good health, treat illnesses and injuries that occur in space, and enable crew members to achieve the highest work productivity of which they are capable

- o Learn how non-human organisms sense and react to varied levels of gravitational force
- o Show how life began on Earth and what its distribution throughout the cosmos may be
- o Characterize the role of life in processes that affect the terrestrial environment on a global scale.

2. Strategy

Because it is responsible for medical support to manned space operations, the Life Sciences program is directly concerned with practical biomedical problems in the Space Station and Space Transportation System programs. United States and Soviet space flights have provided a fairly complete picture of the effects of exposure to flight in space lasting up to a few months. Effects that can interfere with operations or that represent potential dangers to crew members are being subjected to intensive research on the ground and selected experiments on Shuttle missions.

The Space Adaptation Syndrome is the least understood of problems that have been identified. It is characterized by anorexia, vomiting, and malaise during the first few days of flight. Because those annoying symptoms appear in approximately half of all persons who fly in space, their elimination would aid operations materially. However, no satisfactory ground-based model or predictive diagnostic method is now available. The current strategy is to improve understanding of the syndrome's mechanisms through research on the fundamentals of balance and motion perception, to obtain data from Shuttle missions, and to conduct controlled tests of the countermeasures derived.

Other physiological effects that occur in space flight include bone and muscle loss, deleterious fluid shifts, bends during extravehicular activity, and similar problems. They can be interpreted in the context of known mechanisms by which the body adapts to changing conditions and can be investigated in controlled, ground-based experiments. It appears, therefore, that satisfactory ways to avoid them will be developed by determining their thresholds and modifying the stimuli that crews will experience.

The fact that the population of spacecraft crew members is becoming much more heterogeneous is increasing the difficulty of combating those effects. To be sure that environmental effects are understood and countermeasures against the effects are adequate for the whole population, it will be necessary to study the reactions of men and women of diverse age groups and with differing medical histories. It also will be necessary to gather data on the people who go to space, both to verify that the effects are understood and to ensure that countermeasures to alleviate them are effective.

On the basis of current knowledge, it is expected that adequate health maintenance measures can be available for Space Station operations when they begin, and that the effectiveness and convenience of the measures will improve steadily as space experience and ground-based research results accumulate. Means to provide medical treatment, a healthful environment, and tolerable living conditions also should be available if adequate definition and development programs are conducted during the 1980s.

More extensive research will be needed to ensure the health and safety of crews that remain in space for a year or more, as would be necessary, for example, on any interplanetary mission. The effectiveness of health maintenance measures developed for the Space Station must be verified for longer duration missions, and questions associated with very long missions must be addressed. The most important of those questions concern exposure to radiation and radioactive particles, particularly high-energy particles, and the psychological effects of prolonged confinement in a remote environment from which there is no escape. Also, substantial developments will be needed in life-support, habitability, and man-machine systems for growth versions of the Space Station, lunar surface operations, and interplanetary missions.

Ground-based research will continue to be important for progress in solving the medical problems associated with long-duration missions and permanent residence in space. However, research on animal models in space will be essential for investigating effects that may become important for stays in space longer than those of Space Station crews. Space experiments also will be needed in developing biologically based life-support subsystems that regenerate food as well as air and water.

The reactions of non-human organisms to space flight have an intrinsic scientific interest in addition to their importance for applied research. Basic research on how plants and animals sense gravity and process the sensed information can throw new light on fundamental physiological questions and strengthen the scientific basis for space medicine. Investigations of how organisms develop in reduced gravity will contribute to understanding how their forms and functions evolved, and also will help NASA to develop biologically based life-support systems and to evaluate the feasibility of living permanently in space.

Ground-based research can point the way to fruitful hypotheses and help identify sensitive systems, but extended space experiments are indispensable for definitive results in gravitational biology. The approach used in the Space Biology program is to maintain a moderate program of ground-based exploratory research and to use available space missions to obtain preliminary data in preparation for full-scale research on the Space Station. Manned laboratories are essential for all parts of the Space Biology program.

Biology and biomedicine will interact closely through shared techniques, equipment, and experimental objectives; and they will involve major payload activities on the Space Station. Both of them must be built up in phases, from a single laboratory module for initial operation of the Space Station to multi-module programs in later years. To deal with the complex relationships involved, the Life Sciences program will conduct its payload planning and development on an integrated basis instead of defining separate activities as individual projects.

Several sources of data are available for developing an understanding of the origin, evolution, and distribution of life in the universe: laboratory experiments, investigation of extraterrestrial materials and environments, studies of how life processes interact with Earth's environment, and direct attempts to detect extraterrestrial life. Laboratory experiments and meteorite analyses have shown that all of the basic materials needed to start life on Earth could have been produced by chemical processes in the primitive

atmosphere and oceans or introduced from extraterrestrial sources. Remaining to be determined are which source was the more important and how the materials of life became organized and self replicating. For the time being, work on the origins of life will continue to rely mostly on biochemical research, supported by studies of terrestrial geology and extraterrestrial environments, that can suggest hypotheses about the conditions in which life actually originated. However, plans are being made to use Space Station facilities for experimental work on the origins of prebiotic materials in space and their possible presence in interplanetary dust grains.

The only currently possible direct method for observing extraterrestrial life is analysis of cosmic radio emissions to determine whether they contain signals emanating from sources controlled by intelligent extraterrestrial beings. Present work is concentrated on analyzing signals received by existing large radio-telescopes. However, studies are being planned to assess the usefulness of supplementing the capabilities of those radio-telescopes with those of specially constructed antennas in orbit.

An understanding of the interactions of life with its planetary environment is important for identifying evidence of primitive life in the geological record, determining whether life exists or has existed on other planets, and resolving current questions about Earth's environment. Resolution of all those issues depends on knowledge of the role of life in large-scale cycling of materials and energy. The approach of the Life Sciences program to acquiring that knowledge is to conduct field studies of biogeochemical processes and to develop remote sensing methods for global observation of those processes from space. The global observations will be obtained using the Space Station system's polar orbiting platform.

3. Current Program

a. Medical Sciences

The Medical Sciences program is responsible for certifying crew members and maintaining their health and career longevity. It includes preflight and postflight medical examinations, inflight health monitoring, training of crews in medical countermeasures and emergency procedures, and research on the likely physiological effects and occupational hazards of future missions.

The program will continue to place major emphasis on problems associated with the Space Adaptation Syndrome until they are understood and successfully treated or prevented. Biofeedback methods and improved pharmacological agents for controlling motion sickness symptoms were tested on Spacelab 3, and the results are being analyzed. Experiments scheduled for the Spacelab 4 and D-1 missions will include several further tests of vestibular function and treatments for the Syndrome.

Extensive research is in process to develop understanding of the physiology of cardiovascular deconditioning, bone demineralization, and other effects of long-term space flight; and countermeasures based on the research are being tested.

Cardiovascular experiments on Spacelab 4 will measure central venous pressure and baroreceptor sensitivity. The relevance to humans of myocardial changes observed in experimental animals will be assessed, and defects in the reflex control of circulation that possibly contribute to deconditioning will be characterized. In addition, countermeasures such as antigravity suits, programmed exercise, and fluid loading with and without medication will continue to be evaluated on Shuttle missions.

For studies of bone demineralization, non-invasive techniques are being developed for measuring the mineral content and elasticity of bone. Experiments are being planned for flight on Spacelab 4 to investigate hormonal control of calcium metabolism and the kinetics of calcium absorption.

The probability of damage to the musculoskeletal system is higher for long-term Space Station missions than for short Shuttle flights. However, since hypercalcemia, kidney stones, and renal damage are possible on missions of any duration, appropriate treatments must be developed. A clearer understanding is needed of the loci of bone loss and whether recovery rates for bone and muscle loss vary with age and sex. Ground-based and flight research is in process to identify the changes space flight causes in red blood cells, body water, electrolytes, hormones, biosynthesis and breakdown of muscle protein, and the immunological capacity of a human body in space to cope with infectious agents.

Greater understanding is needed of respiration in space and its relationship to cardiovascular and other functions. So that better cabin and space suit atmospheres can be provided, understanding also is needed of the effects of changes in both pulmonary function and blood perfusion on crew members' elimination of inert gas from their bodies before decompression for extravehicular activity. Both ground-based and flight analyses of procedures to prevent bends are required.

In process are: studies to improve radiation dosimetry and to characterize the radiation environment in space; radiobiological tests of the effects of high-energy, multicharged particles thought to be components of cosmic rays; and work to determine the shielding requirements of high-inclination and high-altitude flights and to characterize the shielding properties of spacecraft materials.

Research is being conducted in psychology and human performance to explore the effects of nutrition, motivation, personality, and group composition on individual performance and interpersonal interactions. So that more effective countermeasures to stress can be developed, the research will be directed both toward evaluating the efficiency of individuals under the influence of adaptive physiological processes in the space environment and toward studying the overt behavioral responses of those individuals.

Development of technology to support the medical program will address personal hygiene systems, restraints, and equipment for monitoring medical, physiological, and environmental parameters. Means will be sought to improve spacecraft food supply systems, with particular attention to new preparation and preservation techniques. A long-range research and

technology effort is under way to develop practical biological processes for regenerating food, as well as air and water, in life support systems for future programs such as a manned lunar base or mission to Mars.

b. Biological Sciences

The Biological Sciences program comprises three disciplinary programs: Exobiology, Biospheric Research, and Gravitational Biology.

(1) Exobiology

The Exobiology program studies the origin, evolution, and distribution of life and life-related molecules on Earth and elsewhere as part of the evolution of the cosmos. It has six major elements: forms, abundances and reactivities of biogenic elements and their incorporation into simple compounds; chemical evolution of more complex organic compounds; evolution of processes and systems that led to single-celled life; early biological evolution; effects of planetary and astrophysical processes on evolution of complex life; and search for life and life-related molecules in the solar system and beyond.

Research is progressing in all six disciplines, but additional effort is needed to capitalize on the latest scientific thought and progress toward understanding the mechanisms that led to life's origin and evolution. Effort will be increased on development of analytical exobiology instruments suitable for use on the missions recommended by the Solar System Exploration Committee: gas chromatographs, gas chromatograph/mass spectrometers, visible- and infrared-light spectroscopes, and other devices for specific elements and compounds. Instruments for making remote observations must be developed for use with the Earth-orbiting telescopes described in other sections of this chapter, to detect the signatures of life-related chemicals both within and outside the solar system. Those signatures will increase understanding of the nature and extent of chemical evolution beyond Earth.

(2) Biospheric Research

The Biospheric Research program seeks to characterize the effects of biological processes on global dynamics by pursuing three research objectives: characterization of the pathways and rates of exchange for movement of carbon, nitrogen, phosphorous, and sulfur into and out of terrestrial ecosystems and the oceans; development of methods for extrapolating local rates of anaerobic activity to predict global effects; and development of mathematical models to represent the dynamics of global cycles.

Since its initiation three years ago, this program has been strengthened by the addition of tasks to correlate ground-based data with remotely sensed data to determine biomass extent on varying spatial scales, with data from satellite imaging to determine ecosystem extent, and with measurements of atmospheric gases to indicate ecosystem behavior. Stimuli to studies of the biosphere have been provided by satellite observations that have recently become available, computers able to handle large quantities of data, and new analytical instruments for ground-based

research. The thrusts of the program for the near future are to use data collected by Landsat and the Advanced Very High Resolution Radiometer to develop registration techniques for use in producing geographic information systems; to use remotely sensed data in updating existing vegetation and land-use maps, techniques for recognizing ecosystem borders, and methods for determining biomass types and extent; to correlate measured fluxes of ground gases with the type of ecosystem and soil producing the gases; and to develop, for specific types of ecosystems, measurements that are comprehensive and stratified, that incorporate ground truth measurements, aircraft measurements, and satellite observations, and that are all correlated and integrated through multi-dimensional computerized models.

(3) Gravitational Biology

The Gravitational Biology program deals with physiological responses to the full range of gravitational forces, from microgravity to levels greater than that at Earth's surface. It seeks to increase understanding of how gravity affects life on Earth. Its objectives are to understand how organisms perceive gravity and make that perception effective at responsive sites; determine the role of gravity in reproduction, development, and maturation; elucidate the effect of gravity on form, function, and behavior of organisms; and determine how the absence of gravity in space affects living systems. Although limited so far in number and complexity, space experiments have confirmed the sensitivity to gravity of certain biological systems and processes.

Near-term objectives of the program are to identify organs that perceive gravity and to determine how those organs function. Particularly needing characterization are the gravity sensors of plant and animal cells and the role of calcium in gravity perception and mediation. In addition to having fundamental scientific importance, such subjects are relevant to manned space flight and to the use of plants in advanced life support systems. Another objective in the next few years will be to determine the influence of gravity on fertilization, development, and maturation of organisms. Flight experiments will be required for attainment of all three of those objectives, and proposals have been solicited for experiments that can take advantage of the availability of mid-deck space on the Shuttle. Facilities such as centrifuges and containers must be developed for maintaining and manipulating animal and plant species during flight. Plans also are being developed to conduct, on the Space Station, gravitational biology experiments that require much longer durations in weightlessness.

c. Life Sciences Flight Experiment Program

Achievement of the objectives of both the Medical Sciences and Biological Sciences programs depends on the availability of flight opportunities. The flight objectives and instrumentation requirements of the Exobiology and Biospheric Research programs are closely integrated with those of the planetary and Earth observation programs conducted by other divisions in the Office of Space Science and Applications. The principal means for achieving the objectives of the Medical Sciences and Gravitational Biology programs is the Life Sciences Flight Experiment Program, a multimission program encompassing Spacelab flights dedicated to

life science investigations, Spacelab flight shared with partners, experiments on the Shuttle's mid-deck, and investigations on Shuttle-launched, free-flying spacecraft. The Life Sciences Flight Experiment program will provide for investigations of the effects of the space environment on biological systems that cannot be performed on the ground, with emphasis on characterizing and understanding the problems of humans in space flight.

A major feature of the program is development of an inventory of Spacelab equipment that can be flown on many missions, serving the needs of several investigations on each flight. The program's near-term objective is to fly dedicated Spacelab missions at approximately 2-year intervals. Dedicated missions maximize the number of integrated experiments flown, thus permitting extensive, simultaneous measurements on a limited set of specimens. The resulting broad coverage provides opportunities for correlating measurements from diverse experiments to characterize the biological effects of zero gravity.

Life science experiments have flown on the second and third Shuttle flights and on the Spacelab 1, 2, and 3 missions. The first flight dedicated to life science investigations is Spacelab 4; it and subsequent dedicated flights will carry approximately 15 to 20 experiments each.

4. Potential New Initiatives, FY 1986-1990

The need for life sciences initiatives arises from the unprecedented number of crew members required for the Shuttle's operations in space, from NASA's plans to develop the Space Station, and from plans to exploit fully NASA's ability to expand fundamental understanding of major scientific questions about living systems.

a. Medical Care and Health Maintenance in Space

The ability to maintain health and provide adequate medical and surgical care in space will be required if the Nation is to succeed in deploying and utilizing the Space Station. Therefore, expansion is planned of efforts to develop medical measures against the adverse effects of long-term weightlessness, to protect crew members in orbit against radiation damage, and to evacuate injured and sick crew members.

b. Advanced Crew Support

A pre-prototype of a biologically based life support system capable of regenerating food, as well as air and water, will be built and tested on the ground. Tests without human participants will verify the productivity of plants and other organisms raised in the system and provide performance data on the recycling of air, water, and major nutrients. Those data then will be used to design a subsequent preprototype system for manned tests.

c. Human Performance in Space

Enhancement of the productivity of humans participating in future space missions will be achieved not only by improving the habitability of space vehicles, but also by improving the ability of humans to use the

machines at their disposal. Other factors that will be investigated are the psychological compatibility of crew members and the effects of social isolation, sensory deprivation, command and control structures, and motivational factors on human productivity.

d. Mid-Deck Flight Experiments

Action is being taken to make use of Shuttle flights for research and experimentation in both the medical sciences and the biological sciences. Spacelab capabilities will be indispensable, and the Shuttle mid-deck will supplement them by providing frequent flight opportunities. Research equipment based on Spacelab experience and suitable for mid-deck use is being developed. It will make possible a vigorous program of simpler, relatively low cost, medical and biological mid-deck experiments that are expected to total up to ten investigations per year.

e. Space Station Experiment Module, Phase I

The Space Station will provide the first opportunity for work with animals, plants, and experimental equipment in weightlessness for periods of months or more. Plans to take advantage of that opportunity include development of a module to support studies of changes in physiological functions, such as calcium excretion, and in adaptation as a function of increasing length of exposure to weightlessness. The module also will support studies of the use of artificial gravity as an alternative to biomedical countermeasures and of the possible effects of weightlessness on development. This first phase includes development of animal support and data collection systems needed for those studies and of facilities for testing new equipment on the Space Station.

f. Biospheric Research, Phase I

The focus of this phase of the program will be modeling studies that use available data to formulate hypotheses about the behavior of the biosphere as an integrated system. Remote sensing data from NASA satellites will play a key role in tests of the hypotheses and in supporting worldwide field research. Plans include development of models of individual biogeochemical cycles and of analysis techniques in four areas: the areal extent of land use and the rates of change of biomass, as determined from remote sensing data; biogenic gas fluxes and the factors that affect them; in situ monitoring of ecological processes; and interpretation of the sedimentary fossil record to test hypotheses about modern processes.

g. Biospheric Research, Phase II

If Phase I of the Biospheric Research program proceeds as expected and shows promise of success, Phase II will be initiated to formulate a comprehensive model for describing and predicting biogeochemical processes accurately on a global scale. Phase II also will establish in situ devices for monitoring biological and chemical processes; correlate remote sensing data with ground based measurements to monitor the extent, rate, and significance of environmental changes; and establish a biospheric data network for informational, archival, analytical, and general uses. Used

in conjunction with global data on the oceans, atmosphere, and land, the resulting data will be a key element in developing an understanding of Earth as a system.

h. Exobiology Payloads

Any mission outside Earth's immediate environment provides opportunities to gather data important for understanding chemical evolution and the origin of life. Missions that are of particular interest include cometary missions, the Mars Geoscience and Climatology Observer, and the Titan Probe and Radar Mapper. To take advantage of these and other anticipated opportunities, this initiative will develop miniaturized instruments for chemical analysis of extraterrestrial environments. Those instruments will include gas chromatographs, combined gas chromatograph-mass spectrometers, and remote sensors such as microwave spectrometers.

i. Search for Extraterrestrial Intelligence

A low-level, five-year effort was initiated in FY 1983 to define the instruments needed to analyze radio signals in the microwave region of the electromagnetic spectrum. The next phase of the program will consist of active searches with the resulting equipment. Consequently, the bulk of the program's effort will go first into designing and constructing sensitive, multichannel spectrum analyzers and signal processing equipment, and then into carrying out a comprehensive search program with that equipment at existing radio telescope sites.

5. Possible Initiatives, FY 1991-1995

a. Regenerative Life Support Systems

By the end of the 1980s, a breadboard of a closed, food-regenerating, biologically based life support system will have been built and tested. The next step toward a capability for systems that can be used in space will be to develop and test a preprototype system that can sustain a small group of human test subjects in ground-based experiments. It is expected that this project will require approximately five years.

b. Space Station Experiment Module, Phase II

This phase of the program will provide the Life Sciences Space Station Experiment Module, a pressurized laboratory that will be attached to the Space Station. The module will provide long-duration exposure of animals to weightlessness to validate models developed in connection with Spacelab missions. It will use models based on experiments with animals to explore important human problems further, and also will characterize the effects of weightlessness on humans and other biological systems.

c. Biospheric Research, Phase III

The establishment of in situ sensors on Earth and a remote sensing data system in Phase II of the program will be followed in this phase by the use of data relay satellites. Also, special provisions in Earth

looking satellites will optimize their yield of biological information. When comprehensive global data are available, it will be possible to evaluate biological influences on global processes and the sensitivity, rate, extent, and significance of changes in the biota as functions of environmental perturbations.

d. Vestibular and Variable Gravity Research Facility

Definitive data on the ability of living systems to respond to linear and angular accelerations must await experiments that can be done in space using apparatus that can apply force vectors singly and in combination. This program will develop a flight-qualified vestibular and variable gravity research facility incorporating a centrifuge able to subject test subjects at its periphery to gravity fields from zero to one Earth gravity in intensity. The objective is to induce accelerations on the inner ear's otolith and semicircular canals to shed new light on their fundamental reactions to, and requirements for, those stimuli.

F. Satellite Communications

The current era has been characterized as the "Information Age." Information is the foundation for economic growth; and data, news, and other information flow worldwide, both as raw material and as finished product. The coming of the information age was made possible by communications electronics, especially communications satellites, which now constitute a critical and fast-growing segment of the communications industry. The worldwide market for communications satellite hardware alone is expected to total about \$38 billion in 1981 dollars from 1981 to the year 2000.

NASA's Syncom satellite, launched in 1962, was the precursor to Intelsat and the first generation of domestic fixed-satellite services. The Syncom program, undertaken with full knowledge that many respected authorities in the communications industry were opposed to geostationary communications satellites, is a good example of a high-risk program that had large potential benefits, but that industry was not willing to undertake. That crucial step to geostationary orbit led directly to a rapid increase in the use of communications satellites because of their reliability, wide coverage, and low net cost for the communications services they supply.

NASA's Advanced Technology Satellites (ATS) of the 1966-1974 era were precursors to current maritime, land, and aeronautical mobile satellite services. ATS-1, in orbit since the 1960s, has been the backbone of southern Pacific island communications. ATS-6 and the joint Canadian-NASA experimental Communication Technology Satellite (CTS) provided the basis for today's new broadcast satellite service industry. ATS-6 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. CTS opened the door to a whole new generation of fixed-service satellites operating in the 12 GHz band.

Worldwide, about 150 geostationary satellites have been launched. Crowding of the frequency spectrum and the limited geostationary orbit arc already is evident, and positions in the spectrum and arc are a subject of domestic and international competition. Technical innovations in the use of new

frequency bands, frequency re-use, and onboard signal switching and processing will be necessary for additional growth. NASA also will continue to develop high-risk technology that will yield systems to satisfy expanding demands for communications but that industry is unlikely to develop.

1. Objectives

For the next decade, the objectives of NASA's program for communications satellite development and support are to:

- o Develop technology to relieve growing geostationary orbit congestion and frequency allocation shortage
- o Develop communications technology and systems that permit innovative new services in communications, navigation, and search and rescue
- o Develop and support U.S. and NASA interests in international and domestic communications regulations.

Beyond 1994, the program's theme and direction will be interconnectivity; and the mobile satellite will be a component of the program. World communications can progress toward hubs or regions of interconnection using fiber optic cable for trunking and high-density communications. Low-density communications, business communications and data distribution, and the transmission of entertainment programs can be handled by satellites, with access between regions provided by teleports, gateways, and intersatellite links. The region of space between low Earth orbit and geostationary orbit will come into its own for new and innovative communication services through the use, for example, of store and dump techniques.

The Communications program's long-term objectives are based on the interconnectivity theme. They are to:

- o Develop advanced communication technologies for the low Earth orbit to geostationary orbit region
- o Use and develop technology for intersatellite links to cross-link regional satellites with north-south patterns, enabling them to serve international business communities and areas on the coverage fringes of terrestrial cable networks
- o Develop technology for an international commercial tracking and data relay satellite system network to serve private and government requirements
- o Develop technology for second and third generation mobile communications satellites
- o Provide leadership in developing technologies and systems applicable to interconnectivity worldwide.

2. Past and Current Program

Twenty-two years ago, NASA launched a communications satellite into geosynchronous orbit for the first time. Twelve years ago, only two commercial communications satellites, both Canadian, were in geosynchronous orbit serving North America. Today, nearly thirty are in orbit.

Between 1962 and 1985, NASA's program went through three phases and embarked on its current course. In the 1962 to 1973 period, NASA conducted a strong, broad-based program of communications flight experiments, developing six experimental ATS satellites and, with Canada, the experimental CTS satellite. In 1973, after the peak funding for CTS was over, NASA phased down its program in satellite communications technology and, until 1978, concentrated on continuing operations with the ATS-1, -3, -5, and -6 and CTS satellites. Near the end of that period, the idea of a search and rescue program was formulated, and development of the concept started. In 1979, NASA's program was restructured to address the objectives of developing selective high-risk technology for relieving the congestion of the geostationary orbit and the frequency spectrum and of developing new and affordable communications services. The theme for those activities was development of interconnectivity technology and architectures that would permit the current era of "bent pipe" operation to transition to an era in which nodal points in space would be used both for space- and Earth-based information gateways and for interfaces to terrestrial communication systems.

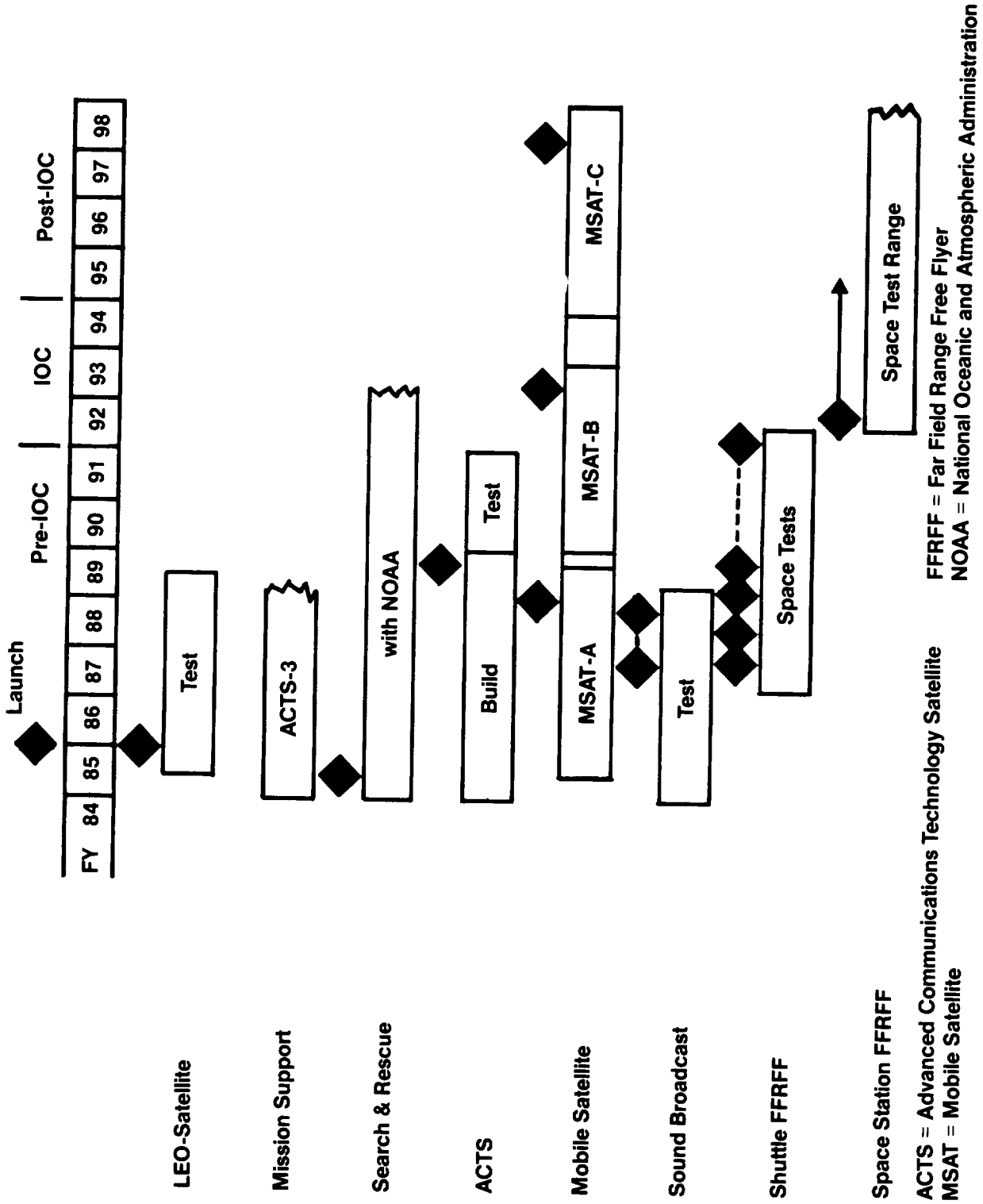
In 1984, the emphasis of the program changed from development of nonflight projects and proof-of-concept technology to development of technology for flight projects needed to support NASA's long-term goals and objectives: the Space Station, the Advanced Communications Technology Satellite, the Mobile Satellite program, and the Geostationary Platform (see Figure III-4). Those projects will meet the challenges posed by the imminent congestion of the frequency spectrum and the geostationary arc, the unfilled demands of the public sector for communications, the eroding U.S. competitive position in satellite communications technology vis-a-vis Europe and Japan, and NASA's long-term requirements for space communications.

a. NASA Communications Support and Service Activity

Since its inception, NASA has provided significant support, service, and consultation on communications matters to both U.S. industry and various government programs. Some of the most important activities are as follows:

- o Technical consultation and support services, including studies of radio interference, propagation, and systems to ensure growth of existing satellite services and incorporation of new satellite applications. Analysis techniques are developed and used to solve problems of interference within and between the signals of satellite and terrestrial communications systems. Those analysis techniques also provide a technical basis for regulatory and policy studies. Orbit and spectrum utilization studies are conducted to aid in developing frequency and orbit sharing techniques and design standards and in determining the effects of propagation phenomena and human-made noise on the performance, design, and efficient use

Figure III-4
Communications Program Outlook



of the geostationary orbit and the radio spectrum. NASA also provides support to the Federal Communications Commission, National Telecommunications Information Administration, Department of State, Federal Emergency Management Agency, and other organizations.

- o Experiment coordination and mission support, including identifying and helping to develop new types of communications services, primarily for the public sector. The principal vehicle for that development has been a series of experiments with the ATS-1 and ATS-3 satellites. Future work will include development of small, low-cost terminals that will work with leased channels on existing communications satellites to provide communications services to remote areas. Use of those terminals with Intelsat in the Pacific Basin has priority.
- o Basic research and technology development, including provision of a technology base for all of NASA's communications programs. The time horizon for the device and component technology pursued is five years or more, and the work is performed cooperatively by NASA, universities, and U.S. industry. This activity has included the Proof-of-Concept Technology Program directed by NASA's Lewis Research Center. That program developed, from 1978 to 1984, the technology for the Advanced Communications Technology Satellite, the innovative switchboard-in-space concept described below.
- o Satellite-aided search and rescue, which is a cooperative program in which Canada, France, the Soviet Union, and the United States are developing and demonstrating a satellite system for detecting and locating the position of signals transmitted automatically from aircraft, marine vessels, and individuals in distress.

b. Advanced Communications Technology Satellite Flight Program

In mid-summer 1984, President Reagan signed into law a bill directing NASA to proceed with a flight experiment with the Advanced Communications Technology Satellite (ACTS). To be built by RCA Corporation teamed with TRW, Inc. and COMSAT Corporation, ACTS is intended to provide advanced technology in support of the commercial satellite communications market. It will include technology development and a ground-based test program to prove the feasibility of advanced communications satellite technologies, including those for multiple fixed-spot-beam and scanning-spot-beam antennas, frequency reuse, beam interconnectivity at both intermediate frequencies and base band, concepts for advanced system networks, and dynamic rain-compensation techniques. Those technologies will be applicable to a wide range of communications systems in the 1990s.

ACTS will be the first satellite to be equipped with scanning beam antennas for domestic satellite communications. The 2.2-meter diameter receiving and 3.3-meter diameter transmitting antennas are larger than previous communications antennas and will provide very high gain, small spot size, and excellent side-lobe performance. High gain is needed to support high burst rates and to overcome fading caused by rain at K_a band. Small spot size and excellent sidelobe performance permit extensive frequency reuse by both fixed- and scanning-beam antennas.

A base-band processor is the heart of the ACTS system. The first processor to be used in domestic satellite communications, it will have the primary functions of demodulating input signals, storing data bits in input memory, routing data bits to output memory, and remodulating. It will route signals between electronically hopped (scanning) uplink and downlink beams and between sectors in synchronism with the processor.

About 1990, ACTS will test a new data communications technology. Data will be transmitted between the Shuttle and ACTS at a rate of about 300 Mbps over a laser link using gallium arsenide diodes operating at 870 nanometers. The test will assess the laser link itself and, in addition, the link's operation between rapidly moving spacecraft simulating the Space Station and the Tracking and Data Relay Satellite System in their advanced stages of development. The principal advantage of a laser system over a K_u-band system as a 300-Mbps link is that the antenna for the laser system will be only 7 inches in size as compared with 12 feet for the K_u system. That smaller size also will provide the additional advantages of reduced beam width and interference.

c. Mobile Satellite

Land mobile communications service within the United States is concentrated in metropolitan areas. The rest of the country, containing about one-third of the total population, has inadequate or no service. Factors contributing to that inadequacy include channel crowding, spotty coverage, and incompatibility between equipments due to different operating frequencies. Although allocation of the 800-MHz band and the recently developed cellular system for mobile communications will help, those improvements are expected to be introduced primarily in densely populated areas and at a rate that will not provide coverage to even those areas until after the year 2000.

After several years of study by NASA of the use of the 860/890 MHz and L bands for mobile satellite communications, the Federal Communications Commission issued in early 1985 a request for applications that led to 12 commercial applications to build a mobile communications satellite. First flight of a commercially designed satellite is expected to occur in the late 1990s, and it is anticipated that a NASA-industry joint endeavor then will produce larger mobile satellites using, successively, 20- and 55-meter antennas.

In 1985, the mobile satellite program became an approved flight program to be conducted by NASA in partnership with U.S. industry. Its objectives are to:

- o Develop high-risk technology to enable commercial mobile satellite service
- o Facilitate development of new markets for satellite and ground terminal hardware
- o Develop terminal hardware that is frequency and power efficient

- o Develop networking techniques for use in experimental government applications
- o Promote growth of commercial services.

The program will be conducted under an agreement between NASA and U.S. industry, with appropriate coordination with Canada. It will facilitate commercial application of this totally new service by reducing the risks the private sector will have to assume. Industry will build, with its own funds, a satellite system able to support first-generation commercialization, including the first and second objectives stated above, and to provide capacity to NASA and other government agencies for two years of experimentation to satisfy the third and fourth objectives. For those two years, approximately 80 percent of the system's capacity will be allocated to commercial use and 20 percent to experimentation. Then the experimental channels will be transferred to commercial service.

To meet the third and fourth objectives, NASA will help other government agencies define their requirements and specialized equipment needs. Those agencies will purchase their own field equipment and, during the two years of experimentation, determine the ability of satellite service to satisfy their needs for mobile communications service. Agencies wishing to continue the service after the experimentation period will enter into a contract for commercial service on the same satellite. NASA thus will help formulate requirements across the government, validate special hardware requirements, and transfer to commercial service technology developed during the two years of experimentation.

3. FY 1986-1990 Program

The Communications program's budget for the FY 1986-1990 period is expected to support continuation of the work described above.

4. Possible Initiatives, FY 1991-1995

a. Direct Satellite Sound Broadcasting

The United States Information Agency's Voice of America has requested NASA to help improve the Government's international sound broadcasts. The agencies' Administrators have signed a memorandum of agreement outlining a study to be undertaken. If it or subsequent studies identify a need for satellites for the broadcast mission, NASA will develop and test the technologies required. Subsystems needing new technology identified so far include space power supplies, such as a nuclear unit providing 100 kilowatts of electricity and a 12.5-kilowatt solar array; high-power, highly efficient transmitters providing, for example, 15 to 30 kilowatts of broadcasting power at 26 MHz; large space antennas, such as 300- to 500-meter diameter reflectors or array antennas; control systems for large space structures; and launch vehicles able to deliver payloads weighing, for example, 10,000 kilograms or more to geostationary orbit.

b. Space Station Communications

With time, the Space Station is expected to become a complex of space systems containing the Station itself in low Earth orbit at an inclination of 28.5° , co-orbiting platforms; tethered platforms or spacecraft, free flyers, an unmanned polar orbiting platform in low Earth orbit, and a staging base in the vicinity of the Station's manned module. That complex will be serviced by systems such as the Shuttle and will be provided with communications by tracking and data relay satellites and a global communication network able to communicate with those satellites, the Shuttle, and the Station's manned modules. The polar platform will be able to view the portions of Earth not visible to manned parts of the complex and will carry scientific instruments, such as side-looking radars and imaging spectrometers, with which to make Earth observations.

The Tracking and Data Relay Satellite System will be the base-line communications system for the Space Station. The Communications program will support the Space Station's needs by verifying experimentally the use of laser and millimeter-wave links to augment that system and by developing technology to provide data rates of as high as gigabits per second. Millimeter-wave communications at 60 gigahertz or higher will compete with laser communications. Both can provide wide-band communications enhanced by the vacuum of space, both require development of new technology, and both are among the most challenging methods for providing high data rate communications between two low Earth orbits, between low Earth orbit and geosynchronous orbit, and between two positions in geosynchronous orbit. The laser experiment between the Shuttle and ACTS mentioned earlier will provide experimental verification that laser intersatellite links can be used to update the Space Station's data handling capability in the post-IOC era.

c. Communications Experiments in Low Earth Orbit: Testing Antennas

The Shuttle and Space Station will make it possible to develop and test, in space, communications systems and technologies that can then be "handed over" to operational systems. For example, the laser communications system could be tested between the Advanced Communications Technology Satellite and the Shuttle or a Spartan type of spacecraft to provide a basis for updating the Tracking and Data Relay Satellite System to make it capable of handling the high (greater than one gigabit) data rates predicted for the late 1990s.

Use is planned of a dedicated Spartan type of maneuverable free flyer that can be instrumented with systems embodying new communications technology and can be maneuvered from the Shuttle or the Space Station. Such a spacecraft will make possible a variety of experimental communication links between the Shuttle, the Space Station, the Advanced Communications Technology Satellite, and the ground. It could be a repeated payload for the Shuttle or it could be stored in the Space Station between uses. It could be used for the following wide range of experimental purposes:

- o To test the Voice-of-America HF beacon

- o To serve as a test vehicle for an Antenna Far Field Test Range by travelling in space to test the side lobes of an antenna attached to the Space Station and to test the operation of related payloads, and by sending the data collected to the Shuttle or Space Station for analysis
- o To conduct at the Space Station the following tests of a mobile-communications satellite with 20-meter diameter antennas: testing and verifying antenna integrity; testing antenna side lobes under multiple-beam conditions; and testing, in the Antenna Far Field Test Range, the beam switching system of the mobile-communications satellite
- o To serve as a vehicle for flight tests of communications at low Earth orbit and between low Earth orbit and the geosynchronous ACTS:
 - To test a 0.8-micrometer gallium arsenide laser transmitter mounted on the free flyer and controlled from the Shuttle or the Space Station with a link to a laser receiver mounted on ACTS, and of a 20-GHz down link between ACTS and its ground station (in association with Lincoln Laboratories)
 - In association with industry, to test laser communications links between the free flyer and ACTS
 - In association with Lincoln Laboratories, to test 0.8-Micron laser links between the free flyer and the Space Station.

Plans for the Antenna Far Field Test Range recognize that optimum use of the geostationary arc will require reuse of positions on the arc and of onboard switching, which will demand, in turn, larger antennas in space than the Shuttle and available expendable launch vehicles can provide. The space assembly capabilities of the Space Station will make possible the needed increase in antenna diameter from 16 feet to 100 meters. Thus, use of large antennas will be possible for the missions of the late 1990s and, in addition, the designers of spacecraft buses no longer will be limited to the "box" or "can" configuration dictated by the accommodations that expendable launch vehicles can provide. Spacecraft of the future are expected to use girders and antennas in such a way that their payloads, including their antenna or antennas, are the principal contributors to spacecraft mass, as compared with the 25-percent payload mass ratio typical of current standard communications satellites.

Large space antennas will require development of technology for distributed space structures; that is, structures whose geometry is maintained by distributed controls rather than by the intrinsic rigidity of the structures. That technology must be developed and tested, in large part, in the space environment. An ability to control the dynamics of large antennas is mandatory because of the extreme pointing accuracy they will be required to have.

Large antenna development currently is being conducted by NASA, with Harris Corporation under contract to Langley Research Center for a

15-meter antenna and Lockheed Missiles and Space Company under contract to the Jet Propulsion Laboratory for a 55-meter antenna.

d. Large Geostationary Communications Platforms

The demand for satellite transponders is expected to grow through the turn of the century, but development of the full potential of the market for them will require resolving two difficulties: saturation of the accessible orbit arc and spectrum and the already evident decrease in cost-effectiveness gains from technology advancements as short term advancements are exhausted. Alleviation of those difficulties will involve increasing the number of orbital positions, use of intersatellite links, expansion into the K_a band, and more effective use of the orbit arc and spectrum. Large geostationary communications platforms are expected to contribute significantly to effective use of the orbit arc and spectrum, but several issues regarding their use will have to be resolved: whether the seeming economy of scale benefits are likely to be realized, the practical limitations on frequency reuse provided by multiple beams, the feasibility of aggregating services, and whether current expectations for system operations and overall cost effectiveness are realistic.

By the year 2000, the Space Station could include, in addition to an expanded complex in low Earth orbit, a geosynchronous platform and orbital transfer vehicles operating in both low Earth orbit and geosynchronous orbit. The geostationary platform would be far advanced from the then innovative orbiting farm concept of 1977. It presents many new challenges with regard to architectural concepts. For example, instead of consisting of a single cluster of antennas, it might consist of multiple clusters of small or giant, or both small and giant, antennas. It might have central or distributed, direct current power systems instead of modular payloads with self-contained power systems. And, instead of consisting of rigid, interconnected structures, it might consist of large, distributed systems held together by cables or even electromagnetic radiation.

NASA started studying space platforms in the mid 1970s and now is studying the feasibility of large geostationary communications platforms, determining what technology must be developed, and defining what the Government's and industry's respective roles and responsibilities should be. An experimental system could be initiated in FY 1994, with launch in FY 1998.

e. Low Earth Orbit Communication Satellite

NASA has a Joint Endeavor Agreement with industry to test a unique, low Earth orbit communications satellite capable of picking up, on command, data from a location on the ground over which it is passing and then transmitting the data, again on command, to another point on the ground. That store and dump satellite will have many applications such as conveying data from buoys to a data processing or collection facility. Its cost will be low, and it can be launched from the Shuttle with the low-cost system used for launching Get-Away Special payloads.

This program represents a thrust toward use of locations not on the geostationary arc for communications, particularly use of low Earth orbit

locations. The Space Station and its free flyers and platforms will stimulate development work on low Earth orbit communication systems in the 1990s.

5. Planned Activities for 1995 and Later Years

About 1995, a new era in the use of space for communications will emerge, due in large part to the availability of the Space Station as a staging base for space assembly and test operations. The Space Station also will make possible a large number of scientific spacecraft that will join the communications satellites in the region between low Earth orbit and geostationary orbit. That proliferation of all kinds of spacecraft will generate many new requirements. For example, Earth observation platforms using side-looking radars will generate hundreds of megabits of data that will have to be returned to Earth; and satellites in geostationary orbit using radiometers to monitor the atmosphere will require very large antennas.

The Space Station will generate many needs for advanced communications technology, but also will provide capabilities that will enable development of the technology. Clusters of science and applications satellites will fly in formation with the Space Station and will require a variety of communications capabilities. As NASA learns how to use the Space Station's capabilities effectively, its fundamental method of doing research and development on antennas will change. Construction, test, and subsequent launching to other orbits of very large antennas will become possible.

NASA is exploring long-term concepts for using laser intersatellite links to provide space communications. One concept is for a commercial data relay satellite using laser links to access satellites in the geostationary arc, satellites between low Earth orbit and geostationary orbit, and even high-flying aircraft. Expected customers for the satellite are sellers of services such as mapping, crop analysis, and exploration for water, oil, and other Earth resources.

Another long-term concept being explored is that of global interconnectivity. This concept calls for a laser intersatellite link from geostationary platform to geostationary platform around the periphery of the geostationary arc, with any point in the peripheral linkage accessible to an Earth station in a north-south corridor and using a microwave or millimeter wave link. By providing interfaces with the proliferating fiber optic terrestrial and submarine cable networks, this laser intersatellite link system can provide the "wiring" or interconnectivity of the entire globe.

G. Microgravity Science and Applications

Earth's gravity influences many processes, often in subtle ways. Small thermal and compositional gradients in fluids cause complicated and sometimes unwanted stirring that is difficult to analyze. Hydrostatic pressure requires confinement of liquids by containers whose walls sometimes produce unwanted effects. Since virtually every process developed by humans evolved in a unit gravity environment, humans have become adept at circumventing some, but not all, of the difficulties imposed by gravity. Now the Space Shuttle provides for extended periods of time a laboratory environment in which the effects of gravity are minute. Thus, new dimensions in process control exist--freedom

from constraints imposed by gravity on Earth-based processes and opportunity to study nongravitational effects that often are masked by gravity-driven flows. NASA encourages the academic and industrial research communities to use the Shuttle's unique environment on a routine basis when it is expedient to suppress various gravitational effects. NASA also works with industry and commercial interests to develop, in space, microgravity processes and products that will help to maintain U.S. technological leadership.

1. Goals

The goals of the Microgravity Science and Applications program are to investigate the behavior of material in a fluid state and the effects on that behavior of carrying out processes in the microgravity environment of space, to provide a better understanding of the effects and limitations imposed by gravity on processes carried out on Earth, and to evolve processes that exploit the unique character of the microgravity environment of space to accomplish results that cannot be obtained in unit gravity. Those goals anticipate that the scientific and industrial communities will find sufficient merit in research carried out in space to justify development, at least partly supported by the user community, of a National Microgravity Laboratory as part of the Space Station. They also anticipate that some of the processes from early research will be sufficiently attractive to industry to form the bases for additional commercial ventures similar to those already undertaken by McDonnell Douglas, Microgravity Research Associates, and the 3M Corporation.

2. Program Scope

The Microgravity Science and Applications program consists of investigations previously sponsored by the Materials Processing in Space Office in the Office of Space Science and Applications and by the Chemistry in Space program in the Office of Aeronautics and Space Technology. It concentrates on the following research discipline areas and does not study the effects of gravity on living organisms:

- o Electronic materials, including crystal growth from the melt, solution, and vapor
- o Metals and alloys, including macro and micro segregation in casting, eutectic formation, and solidification of immiscible metals
- o Glasses and ceramics, including formation of glass compositions and fining (the elimination of gas bubbles from a glass melt)
- o Combustion science, including study of droplet and solid surface combustion
- o Biotechnology, including separation and purification of biomaterials by continuous flow electrophoresis and isoelectric focusing
- o Fluid and transport phenomena, including study of critical point phenomena and wetting behavior.

3. Strategy

Plans for the program include expansion of the research base established during the last several years and the conduct of flight investigations to delineate the potential and limitations of the microgravity environment for scientific and industrial use. Since the merits of that use ultimately will be determined by participating investigators, the following steps are being taken to involve potential users in the program's capability demonstration phase:

- o Establishment of an advisory group consisting of research scientists from universities, government, and industry to provide an external perspective to the program. That group's functions will be to convey to NASA the reactions of the potential user community to various facets of the program, identify the types of research that would be most beneficial to prospective users, and serve as emissaries to the external research community.
- o Establishment of working groups structured along disciplinary lines. The primary functions of the working groups are to identify areas of research relevant to the program and to encourage qualified investigators to become involved in it.
- o Consideration to establishment at various universities of additional centers of excellence to strengthen specific areas of research. Those centers would be similar to the Materials Processing Center at the Massachusetts Institute of Technology and would have the same purpose, the bringing together of the research interests of government, industry, and universities in a setting suitable for innovative activity.
- o In cooperation with NASA's Office of Commercial Programs, encouragement of increased industrial involvement through use of the Technical Exchange Agreement and Joint Endeavor Agreement mechanisms already established and published in the Federal Register and the Commerce Daily. The former mechanism allows an industrial firm to work with NASA in an area of mutual interest with no exchange of funds. The firm conducts experiments in NASA's ground-based facilities--levitation systems, drop tubes, drop towers, and aircraft--to determine whether space experiments are justified. A Joint Endeavor Agreement allows an industrial firm and NASA to share the costs and risks of developing commercial space ventures. Generally, the firm is expected to develop the experimental apparatus; NASA, to provide a specified number of free flights in return for considerations such as data rights and use of the apparatus. If the venture proves to be profitable, the firm reimburses NASA for future flights of the apparatus. Another mechanism in use is an industrial outreach program in which industries with a potential for using microgravity are contacted and supplied with information or invited to visit NASA field centers engaged in microgravity research. NASA also arranges seminars in which researchers involved in the NASA microgravity program describe the program to potential participants and discuss the results they have obtained.
- o Issuance in the near future of an announcement calling attention to the flight opportunities available, now that the Shuttle is operational.

That announcement will emphasize the desirability of starting investigations on apparatus suitable for installation on the Shuttle's mid-deck because that type of apparatus usually can be produced more quickly and is less expensive than apparatus that must be mounted in the cargo bay. Prospective investigators also will be encouraged to use existing cargo bay and Spacelab apparatus, if possible. If existing apparatus cannot be used or readily modified, NASA will determine whether it is more cost effective for NASA to build the needed apparatus or for the investigator to build it. NASA also will determine whether the apparatus can, with minor modifications, accommodate other investigators.

4. Current Program

a. Ground-Based Investigations

With its growing science base and maturing investigations, the ground-based experiment program has begun to make significant contributions to the materials sciences, as indicated by an increase in the number of papers published in refereed journals from a total of a few dozen before 1977 to over 100 in each of the past two years. Some of the areas promising valuable results are described in the paragraphs that follow.

(1) Convection in Crystal Growth

Crystal growers only recently have begun to analyze convective flows and how they affect the growth process. The flows are complicated by the fact that most systems of interest have more than one component, requiring that both thermal and compositional effects be considered. Since thermal diffusivity usually is several orders of magnitude larger than chemical diffusivity, modeling the combined convection is extremely difficult. Solidification in a binary system can be unstable even when the system's concentration is very low. Even a very small convective flow can have a significant effect on the radial distribution of dopants in crystal growth, and it has been found that considerable convection occurs because of radial gradients that are impossible to avoid. Diffusion controlled vapor transport is not possible in a gravity field because viscous interactions between the transporting vapor and the container wall create density gradients that are always convectively destabilizing. Research sponsored by NASA already has contributed significantly to understanding of crystal growth processes, and its results provide a base for the crystal growth experiments in space that NASA plans to sponsor.

(2) Nongravitational Phase Separation Mechanisms

Early attempts to avoid phase separation from density differences in the solidification of certain alloys in microgravity have indicated that phase separation mechanisms other than gravity also are important. Recent work has provided interesting insights into some of those mechanisms, and further understanding of them possibly could allow control of phase separation in such alloys.

(3) Containerless Processing

Containerless processing on and near Earth's surface is possible, but in a limited fashion, using drop facilities, aircraft, and various levitation techniques. A 100-meter drop tube is in operation at Marshall Space Flight Center, and a variety of smaller drop tubes are in operation at the Jet Propulsion Laboratory. Drop towers, which can drop entire experimental packages, are in operation at both Marshall Space Flight Center and Lewis Research Center. General Electric has developed an electromagnetic levitation facility, and other levitator systems are in operation at Marshall Space Flight Center and the Jet Propulsion Laboratory.

In space, liquids--especially high temperature melts--can be contained solely by their surface tension and can be positioned by small noncontacting forces provided by electrostatic, electromagnetic, or acoustic fields. Thus, there are a number of potential applications for containerless processing in space. The Jet Propulsion Laboratory does considerable work on levitation technology. It has developed and tested extensively in KC-135 aircraft, and on flights of Space Processing Applications Rockets, techniques for positioning and rotating samples using acoustic and electrostatic fields, and has developed a 3-axis, acoustic levitator furnace for use on the Space Shuttle. General Electric is modifying a small electromagnetic levitator it developed originally for the Space Processing Applications Rocket program to perform similar experiments on the Space Shuttle.

(4) Bioseparation Processes

Considerable progress has been made in understanding the component flows in continuous flow electrophoresis, the limitations imposed on that process by Earth's gravity, and the possibilities for its use in space. Princeton University has performed analyses; and Marshall Space Flight Center has conducted experiments and developed an electrophoretic separator that eliminates stream distortion by using as walls endless belts that move with the fluid, allowing the stream to occupy the total width of the chamber without loss of resolution from wall effects. The University of Arizona has developed a recirculating isoelectric focusing separator that has major advantages. Both the moving wall electrophoretic separator and the recirculating isoelectric focusing separator have commercial potential and could be the subjects of joint endeavors.

(5) Combustion Science

The fire incidents in the Apollo 1 and Apollo 13 spacecraft made it clear that buoyancy driven flows in a gravity field and the lack of them in space strongly affect the way in which fires propagate. Experiments relating to fire safety technology began in response to those fires. It precipitated an awareness that experiments in low gravity could provide, on a variety of combustion systems, important data unobtainable in unit gravity because the buoyancy driven convective flows that unit gravity creates often mask processes such as conductive and radiative heat transfer and the molecular diffusion of chemical species. In the microgravity of space, relatively simple instruments have provided significant insight into combustion phenomena. It is ironic that that insight applies

principally to ground-based power conversion, propulsion, and fire-safety systems.

b. Space Shuttle Mid-Deck Experiments

Shuttle flights have provided the means for resuming long-duration experiments in a microgravity environment in the Microgravity Science and Applications program. Descriptions of two that have flown on the Shuttle's mid-deck follow.

(1) Monodisperse Latex Reactor

Beginning with the third flight of the Shuttle, Lehigh University has conducted a series of seeded polymerization experiments with the objective of producing precision polystyrene spheres with uniform sizes for use in a variety of applications. Spheres with diameters of 7 to 40 micrometers had been produced on Earth, but they were not available in quantity, were not spherical, and had a size dispersion of about 3 percent. The spheres produced on the Shuttle have size dispersions generally less than 1 percent and are spherical. The National Bureau of Standards has determined that they qualify as standards and has requested additional samples.

(2) Continuous Flow Electrophoresis

The McDonnell Douglas Astronautics Company has developed and built a Continuous Flow Electrophoresis System under the terms of a Joint Endeavor Agreement with NASA. That system has been flown several times on the Shuttle, beginning with that vehicle's fourth flight. The objectives of the experiments conducted with that system are to determine the technical advantages of its operation in microgravity and to assess the commercial viability of its use for separating pharmaceuticals in space. Flight data indicate that operation in space can yield up to 400 times the throughput that can be achieved on the ground in the separation of "proprietary" biomaterial. McDonnell Douglas is proceeding with its flight program, which ultimately may lead to commercial processing in space. Under the provisions of the Joint Endeavor Agreement, NASA-sponsored investigators have had a chance to conduct 8 separation experiments to increase understanding of electrophoretic separations in space. Materials that have been separated are hemoglobin, polysaccharide, and kidney cells. The results of the experiments still are being analyzed.

c. Materials Experiment Assembly Experiments

The Materials Experiment Assembly is a carrier for materials processing experiments. It can accommodate up to four experiment packages of the Space Processing Applications Rocket type, providing them with power, control, data acquisition, thermal control, and heat rejection. Since its provision of those services is independent of the Shuttle's systems, its integration with the orbiter is greatly simplified and it therefore can take advantage of more flight opportunities. It first flew on the seventh Shuttle mission, performing flawlessly. The investigations that have been conducted on it are described below. Their results provide the foundation for microgravity research to be undertaken during the next few years.

(1) Furnace Experiments

Two experiments involving a total of six samples were conducted in two General Purpose Rocket Furnaces. One furnace was configured for isothermal processing and the other for gradient processing. The furnaces functioned to specification and produced the required thermal profiles in the samples.

(a) Monotectic Alloys

Several monotectic alloys were processed in experiments like those flown earlier on sounding rockets except that the crucible materials were chosen to avoid phase separation from critical wetting. One sample was processed in the gradient furnace to examine the effects of thermal migration of droplets of the minority phase driven by thermal capillary flows. Other samples were processed in the isothermal furnace equipped with plungers to eliminate free surfaces and, therefore, possible flows driven by surface tension. Analysis of the samples is in process.

(b) Crystal Growth from Vapor

A Skylab experiment to grow crystals of germanium and selenium from a vapor was repeated on the Space Shuttle except that an inert gas was substituted for the iodine transport gas used previously. The purpose of the experiment was to determine whether previously observed anomalous transport rates were in fact caused by chemical reactions throughout the growth ampoules or by other mechanisms that must be sought. The observed transport rates agree with those predicted from diffusion calculations to within 20 percent. However, one unexpected result has been observed. The crystals grown in space are almost an order of magnitude larger than those grown under identical thermal conditions on the ground. Well-defined platelets, some as large as five by ten millimeters, grow in an open web-like structure in flight ampoules, whereas ground control ampoules contain a crust of very small crystallite or polycrystalline material in the growth region. The effects of small gravity-driven flows in the vicinity of a growing crystal apparently are more pronounced than anyone anticipated.

(2) Levigator Experiments

A single-axis, acoustic levigator furnace with an automatic sample exchange mechanism containing eight samples was flown to test its levitation capability at temperatures up to 1,600^o C and to explore containerless glass formation. Because of a mechanical malfunction, no data were obtained. The equipment has been repaired and will be reflown in 1985.

5. Future Focus

The fact that experiments in a microgravity environment can produce new and unexpected scientific results has been established; for example, the anomalous growth rates and large size crystals mentioned above, which have led to substantial reevaluation of transport theory in growth of crystals from vapor. Other surprises undoubtedly will be encountered as the flight program

accelerates. Such results have intensified interest in the aspects of the program described below, which will be emphasized during the next several years.

a. Crystal Growth of Electronic Materials

Single crystals of various electronic materials are extremely important for continuing progress in the rapidly expanding technology of those materials. In fact, they may have sufficient value per unit mass to be candidates for commercial production in space. As mentioned above, it is becoming increasingly clear that it is virtually impossible to avoid convective effects in crystal growth in unit gravity and that even small flows can result in profound differences in growth morphology, compositional homogeneity, and structural perfection.

b. Crystal Growth of Organic Materials

The academic and industrial research communities are showing considerable interest in the use of microgravity to provide diffusion controlled transport in the crystallization of various complex organic molecules with low symmetry and small bonding energies. The result is expected to be many materials that may have interesting and unique electro-optical properties and that grow into crystals large enough to provide good electro-optical properties.

Results that Spacelab I obtained on the growth of protein crystals have stimulated considerable interest in using microgravity to grow crystals of various proteins whose 3-dimensional structures would be determined by x-ray or neutron diffraction. The techniques for making such determinations have developed rapidly because of advances in interactive computer graphics. Additional impetus has come from the use of knowledge about the 3-dimensional structures of proteins in designing both highly specific pharmaceutical agents and enzymes tailored for specific tasks. That activity has become a major new research area for many chemical and pharmaceutical companies.

Several pharmaceutical companies and cancer research centers at universities have expressed interest in trying to grow protein crystals in space for structural analysis. If their efforts are successful, they could provide commercial as well as societal benefits.

c. Solidification of Alloys and Composites

Low-gravity experiments in the solidification of alloys and composites have revealed some unexpected and interesting effects. As mentioned above, several nongravitational phase separation mechanisms have been discovered in monotectic systems. In addition, rod diameters and spacings found in melts composed of manganese bismuth and bismuth eutectic directionally solidified in space have been much finer than ground control experiments and the theory of convection growth had indicated they would be. Dendrite arms in transparent model systems (such as ammonia hydroxide) and binary metallic alloys (such as lead-tin and copper-aluminum) solidified in space have been observed to have an unexpected difference in spacing from that obtained in control experiments on the

ground. Investigation of such unexpected effects will be the object of future flight experiments designed to reevaluate the role of convection in present theories of solidification.

d. Containerless Melting and Solidification

Drop tube demonstrations have shown that substantial undercooling can be achieved in bulk samples and that unique metastable and amorphous microstructures thus can be produced. To extend that type of research to materials that cannot be solidified in drop tubes, experiments in electromagnetic levitation of nickel alloys will be conducted in space. Also, space experiments involving containerless positioning of high-temperature melts offer unique opportunities to measure high-temperature thermal properties of materials, especially those whose melt phases are highly corrosive.

e. Containerless Formation of Glass

The absence of container walls offers the possibility of avoiding heterogeneous nucleation in glass formation and of extending the range of glass formation to systems that do not readily form glasses. Extreme purity can be obtained by eliminating trace contaminants that a crucible would introduce, especially in gel-derived systems. Also, a degree of manipulation is possible by shaping the noncontacting force fields to form various configurations, such as precision glass shells and optical fibers. The weight of 100 kilometers of 100-micron diameter optical fiber is only a few kilograms. Thus, since there is considerable commercial interest in very low loss optical fibers formed from halide glasses that transmit in the near infrared, production of such fibers in space may become a commercial process.

f. Separation Processes

McDonnell-Douglas' success with continuous flow electrophoresis in space indicates that similar benefits may be possible in other microgravity separation processes such as moving wall electrophoresis, isoelectric focusing, isotachopheresis, photopheresis, thermopheresis, and phase partitioning. Of particular interest are unique separations that can be performed in such processes and the effects that may be caused by the high sample concentrations permitted by microgravity operation. Examples of those effects are particle-particle interactions during separation and electric field distortions caused by electrical conductivity mismatch between sample and buffer.

g. Fluid and Transport Phenomena

Elimination of buoyancy driven convection and sedimentation will permit study of fluid and transport phenomena that are difficult to study in a gravitational field. Examples are 3-dimensional rotating flows, 2-phase flows, thermocapillary flows, drop and bubble dynamics, bubble and droplet migration in thermal and solutal gradients, Soret diffusion, equilibrium configurations in partially filled containers, critical wetting and spreading, nucleation and growth, Oswald ripening, foam stability, rheology, and critical phase transitions.

h. Cloud Microphysics and Aerosol Science

Microscale processes in the atmosphere--aerosol formation resulting from gas to particle conversion and its mechanisms, cloud droplet and ice crystal nucleation and growth, riming, collision-coalescence, charge separation, precipitation formation, droplet breakup, aerosol scavenging, etc.--are among the most difficult physical processes to study experimentally because of the small energies involved and the care that must be taken to prevent foreign influences from altering the results obtained. Elimination of convective motions and artificially supported large hydro-meters can improve experiment performance greatly by isolating the gas being studied from the disturbing influences of chamber walls and other surfaces. The absence of convection also implies that temperatures and vapor fields within the gas are controlled only by conduction and diffusion mechanisms that can be accurately modeled and, therefore, that unpredictable experimental variations caused by eddy motions can be eliminated. Encouragement will be given to the undertaking of fundamental microgravity experiments that could lead to greater or more precise understanding of the important processes in atmospheric cloud microphysics.

i. Combustion Science

The absence of a significant gravity field facilitates observation of fundamental combustion mechanisms that buoyancy driven convection would mask under unit gravity. Such observations increase understanding of combustion processes in traditional terrestrial systems by permitting comparison of the data obtained with predictions from models with gravity controlled terms removed. Those observations also can lead to direct application, in both space-based and ground-based systems, of the technology developed. Experimentation will continue in droplet burning, particle cloud combustion, solid-surface flame spreading, smoldering combustion, pool burning, gas-jet diffusion flames, and premixed gas flame propagation. Experimentation will be started in buoyancy effects in turbulent combustion; and several directed studies will be conducted on such aspects of the fire safety of spacecraft as radiative ignition of solids in the absence of buoyancy.

6. Facilities and Apparatus

NASA has conducted, since 1968, a program of research into phenomena associated with the processing of materials in low gravity provided by drop tubes, aircraft, and rockets. That research and other laboratory investigations are continuing but have the limitation that they can provide only seconds to minutes of low gravity. The Space Shuttle makes frequent and long-term microgravity investigations possible. Table III-3 lists the Nation's low-gravity research facilities, Table III-4 the processing equipment currently available and planned, and Table III-5 the apparatus being used on the Shuttle's mid-deck and being used or planned for use in the Shuttle's cargo bay. Other systems and apparatus will be defined and developed as required for support of experiments that will be proposed in response to a solicitation that soon will be issued. Small systems will be developed that can be accommodated on a space available basis and, therefore, may have frequent opportunities to fly. Spacelab will provide support for advanced, sophisticated processing systems.

TABLE III-3. U.S. LOW-GRAVITY RESEARCH FACILITIES

<u>Facility</u>	<u>Mode of Accommodation</u>	<u>Low-Gravity Time</u>	<u>Typical Sample Size*</u>
Drop Tube	Sample Dropped in Evacuated Tube and/or Backfilled to Provide for Supercooling	Up to 4.5 Seconds	1 mm to 5 mm Diameter
Drop Tower	Processing System Dropped in Tower	Up to 4.5 Seconds	5 mm Diameter X 8mm Long
KC-135 and Learjet Aircraft	Parabolic Trajectory Flown with Processing System Aboard	15 to 25 Seconds (Repeats per Flight)	20 mm Diameter X 8 mm Long
F-104 Aircraft	Parabolic Trajectory Flown with Processing System Aboard	30 to 60 Seconds (Repeats per Flight)	20 mm Diameter X 8 mm Long
Rockets	Parabolic Trajectory Flight with Processing System Aboard	4 to 6 Minutes	20 mm Diameter X 8 mm Long
Shuttle Mid-Deck	Demonstration Processor (1 Kilowatt Typical)	1 to 7 Days (Through 1987)	1 cm Diameter X 5 cm Long
Shuttle Cargo Bay	Demonstration and Production Prototype Processing System (1360 Watts Typical)	1 to 7 Days (Through 1987)	As Required
Free Flying Experiments Carrier (Under Study)	Production Processing System (12 Kilowatts Typical)	As Required	As Required

* Specific sample size dependent on experiment apparatus size, weight, heat flow conditions, and low-gravity time

TABLE III-4. AVAILABILITY OF U.S. MATERIALS PROCESSING SYSTEMS

<u>Processing System</u>	<u>For Rockets and Aircraft</u>	<u>For Shuttle and SpaceLab</u>	<u>For Free Flyers</u>
Fluids Experiment System	Ready Now	In Development (1984)	
Vapor Crystal Growth System		In Development (1984)	
Float Zone Experiment System	Planned	Planned	Planned (1988)
High-Gradient Furnace System	Ready Now	In Development	Planned (1988)
Acoustic Containerless Experiment System	Ready Now	Planned (1987) In Development (1985)	Planned (1988)
Electromagnetic Containerless Processing System	Ready Now		Planned (1986)
Bioprocessing Experiment System		Planned (1985)	Planned (1989)



TABLE III-5. U.S. MATERIALS PROCESSING INSTRUMENTS

<u>Apparatus</u>	<u>Shuttle Location/Carrier</u>	<u>Availability</u>
Directional Solidification Furnace	Mid-Deck	Ready Now
Isoelectric Focusing Experiment	Mid-Deck	Ready Now
Acoustic Containerless Experiment System	Mid-Deck	Ready Now
Electrophoresis Equipment Verification Test	Mid-Deck	Ready Now
Continuous Flow Electrophoresis System	Mid-Deck	Ready Now
Monodisperse Latex Reactor	Mid-Deck	Ready Now
Droplet Combustion Experiment	Mid-Deck	Planned (1986)
Particle Cloud Combustion Experiment	Mid-Deck	Planned (1986)
Solid Surface Combustion Experiment	Mid-Deck	Planned (1987)
Single Axis Acoustic Levitator	Orbiter/Materials Experiment Assembly	Ready Now
General Purpose Furnace #1 (Isothermal)	Orbiter/Materials Experiment Assembly	Ready Now
General Purpose Furnace #2 (Gradient)	Orbiter/Materials Experiment Assembly	Ready Now
General Purpose Furnace #3 (Gradient)	Orbiter/Materials Experiment Assembly	Ready Now
General Purpose Furnace #4 (Gradient)	Orbiter/Materials Experiment Assembly	Ready Now
Single Axis Acoustic Levitator-II	Orbiter/Materials Science Laboratory	Planned (1984)
Three-Axis Acoustic Levitator	Orbiter/Materials Science Laboratory	Planned (1985)
Directional Solidification Furnace-II	Orbiter/Materials Science Laboratory	Planned (1984)
Advanced Directional Solidification Furnace	Orbiter/Materials Science Laboratory	Planned (1986)
Isoelectric Focusing Experiment	Orbiter/Materials Science Laboratory	Planned (1985)
Electromagnetic Levitator	Orbiter/Materials Science Laboratory	Planned (1984)
Acoustic Containerless Experiment System-II	Orbiter/Materials Science Laboratory	Planned (1986)
Fluids Experiment System	Orbiter/Spacelab 3	Ready Now
Vapor Crystal Growth System	Orbiter/Spacelab 3	Ready Now

Present emphasis is on apparatus and experiments, for installation on the Shuttle's mid-deck, that potentially can be upgraded to fly in the cargo bay or Spacelab. Need for longer experiment times and higher power levels is expected to develop, requiring a carrier such as the Space Station system or Leasecraft. Those systems will provide a low-gravity environment that is continuous and free of the constraints that flight on the Shuttle places on mission duration, power availability, and freedom from minor disturbances.

Lewis Research Center has established the Microgravity Materials Science Laboratory to provide easy access and assistance to researchers in industry, universities, and government wishing to conduct materials research with experimental equipment designed for use on the Shuttle. That laboratory will allow researchers to precede establishment of a formal project with brief exploration of microgravity science concepts and examination of ideas aimed at potential flight experiments.

7. Prospects for Commercialization

Two functions of the Microgravity Science and Applications program will have a substantial effect on the possibilities for the program's commercialization: the use of space to obtain knowledge that can be applied to improve terrestrial processes and the processing of materials in space to take advantage of the weightless conditions there. The first of those functions anticipates the routine use of microgravity experimentation as an accepted method for solving problems related to the processing of materials on the ground, with industry paying at least a portion of the cost of the experimentation. A number of companies recently have indicated an interest in using space for such problem solving. Now that use of finite element analysis techniques to model industrial processes is spreading, the need for more accurate knowledge of the thermophysical properties of materials is becoming acute. The companies also have expressed interest in testing their models of various processes by determining whether the results from carrying out the processes in the absence of gravity verify that the models correctly predict the essential nature of the processes before the complicating effects of gravity enter in. Other matters attracting industrial attention are the role of convection in crystal growth processes and the growing of various crystals in microgravity to try to discover why they are difficult or impossible to grow on Earth. Another activity that could be useful to a number of industries is preparation in space of small quantities of unique materials to determine their characteristics or to use them as paradigms.

The processing of samples in space will be restricted, at least for the near future, to small quantities of high-value, low-volume materials such as pharmaceutical products, electronic materials, optical fibers, highly specialized alloys, and possibly precision latex microspheres. However, other applications can be expected to emerge as experience with the flight program increases and unforeseen results are obtained. To form the basis for and foster future ventures by industry, NASA will continue to conduct its flight program with inputs from and participation by industry. NASA sponsors, and encourages others to sponsor, materials processing research on materials and processes known to be of technological interest so that sufficient information will be available for industries interested in commercialization to determine whether the technology is advanced enough to warrant commercialization. The Office of Space Science and Applications works in cooperation with the Office

of Commercial Programs to foster commercial endeavors. The task of deciding whether a material can be produced in space on a commercial basis is left to industry, since industry is best qualified to make such decisions.

H. Institution

The Office of Space Science and Applications has responsibility for institutional management of Goddard Space Flight Center and the Jet Propulsion Laboratory. It also will continue to use the capabilities and facilities of the other NASA centers to achieve its science and applications goals.

1. Goddard Space Flight Center

Goddard Space Flight Center will be strengthened and sustained as a center of excellence to provide expertise in the scientific disciplines related to NASA's space science and applications programs with emphasis on unmanned satellite systems, satellite tracking networks, and broad-based scientific research. Its specific functions are to:

- o Plan and develop Earth orbiting science and applications spacecraft and plan and execute associated operations and data analyses
- o Provide for acquisition and dissemination of data from science and applications missions
- o Develop science and applications instruments to be flown or placed in Earth orbit by the Shuttle
- o Plan and develop designs for platforms, accommodations for attached payloads, servicing and assembly equipment, and user characteristics of the data system for the Space Station during the Station's definition phase
- o Conduct balloon and sounding rocket programs for science and applications research
- o Maintain the large-scale computer resources needed to support the research and data analysis programs, including the long-term archiving of space data, of the Office of Space Science and Applications
- o Sustain excellence in development and operation of Earth orbital spacecraft
- o Enhance tracking and data acquisition systems and support operations as the primary mode is changed from a ground-based system to a satellite system
- o Maintain itself as the NASA center of excellence for overall space science and applications disciplines
- o Sustain its excellence in the development, launch activities, and operation of the sounding rocket program at Wallops Flight Facility

- o Enhance its excellence in management of special Shuttle payloads and analysis of resulting data.

2. Jet Propulsion Laboratory

The Jet Propulsion Laboratory will be strengthened and sustained as the center of excellence for development and operations of planetary missions. Its specific functions are to:

- o Plan and execute scientific research involving unmanned automated space systems
- o Develop science instruments to be flown or placed in Earth orbit by the Shuttle
- o Serve as lead center for solar system exploration, including operation of the Deep Space Network
- o Undertake work for other U.S. government agencies
- o Sustain its excellence in applying advanced information systems technologies to support the programs of the Office of Space Science and Applications
- o Maintain its excellence in advanced guidance and propulsion systems
- o Sustain its excellence in acquisition and analysis of planetary data.

3. Other NASA Centers

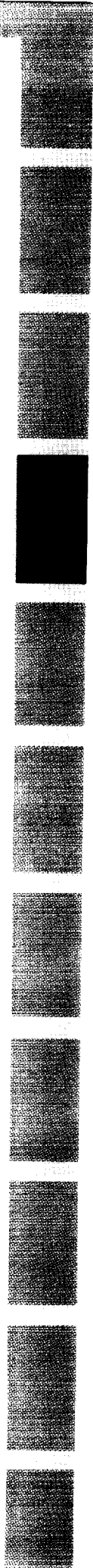
Capabilities of other NASA centers will be used and reinforced in the following areas:

- o Ames Research Center
 - Life sciences flight experiments
 - Mission operations for Pioneer spacecraft
 - Management of the Office of Space Science and Applications' aircraft programs
- o Johnson Space Center
 - Life sciences flight experiments
 - Lunar and planetary geosciences disciplines
 - Development of space-based sensors for Earth observations
- o Kennedy Space Center
 - Life sciences flight experiments

- Spacelab payload processing operations
- o Langley Research Center
 - Atmospheric sciences technology
 - Development of space instruments for atmospheric sensing
- o Lewis Research Center
 - Advanced communications systems technology, including management of the Advanced Communications Technology Satellite project
- o Marshall Space Flight Center
 - Development and mission management of Spacelab payloads
 - Specialized automated spacecraft activities, including management of the Space Telescope project and conduct of studies for advanced missions.

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IV. SPACE FLIGHT

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IV. Space Flight

In calendar year 1984 the Space Transportation System (STS) made five operational flights, including the first two flights of Discovery, the third Shuttle orbiter. Those flights also included the first use of the Manned Maneuvering Unit, the first 7-member crew, the first in-space repair of a satellite, the first flight of a "commercial" payload specialist, the first landing at Kennedy Space Center, the first demonstration of refueling in orbit, and the first retrieval and return of satellites.

The STS has begun to change the traditional view that space activities are merely idiosyncratic activities of and for a limited few to the more forward looking view that they are an integral part of human activity and of great benefit to all of society. The STS will provide, into the 1990s, reliable, low-cost transportation from Earth's surface to low Earth orbit and return. However, as currently defined and approved, it will not meet requirements for the more distant future. As space becomes more and more a part of daily life, new space transportation capabilities will be required. The plan described in this chapter is designed to meet the goals and objectives for U.S. space transportation systems through at least the end of the century. It describes current programs and programs planned to be started by FY 1995.

The program of the Office of Space Flight has four components:

- o Development of space transportation capabilities--acquisition, testing, production, and continuing improvement of space vehicles and the services they provide
- o Space flight operations--prelaunch, launch, flight, landing, and post-landing activities and the concomitant customer services
- o Active support of the commercial use of space and of privatizing space transportation systems such as expendable launch vehicles and upper stages for the Shuttle
- o Advanced programs--planning and evolutionary development of follow-on programs to exploit the STS, define a second-generation system, provide an infrastructure for permanent presence of humans in space, and increase space flight capabilities through development of advanced transportation, satellite services, advanced crew and life support, and tethered systems.

A. Goals

The President's space policy commits NASA to maintain world leadership in space flight by developing and employing space transportation systems able to meet appropriate national needs. Four of the Agency's primary goals are relevant to that commitment, namely:

- o Make the STS fully operational and cost effective in providing routine access to space for domestic and foreign, commercial, and governmental users

- o Develop within a decade a permanently manned Space Station
- o Expand opportunities for U.S. private sector investment and involvement in civil space and space-related activities
- o Establish NASA as a leader in the development and application of advanced technology and management practices which contribute to significant increases in both Agency and national productivity.

Progress in meeting those goals requires that the Space Flight program have as a goal maintenance of a strong, responsive, reliable, and cost-effective space transportation system. That goal calls for NASA to prepare for the anticipated demand on the STS from U.S. and foreign users and to focus its activities in the immediate future commensurately on completing development of the STS, making each mission safe and successful, maintaining an operational launch schedule, reducing operational costs, and exploiting the STS' inherent abilities. Development of new customer markets will require that the STS evolve to meet advanced requirements for more economical support of payloads, manned space operations beyond those the STS now can provide, reduced costs for communications satellite activities, increased use of the orbiter fleet, larger and heavier payloads, extension to geostationary orbit of the reusability of spacecraft, and provision of orbital research and development facilities.

The Space Transportation System will be considered fully operational when it is ready and available for routine use in its intended operational environment to achieve its committed operational objectives. Required, therefore, is that its flight and ground system design and performance be verified by test or analysis, including flight demonstration of critical capabilities; that adequate logistic support for it be in place; that its flight rate capability be adequate to support its committed flight schedule; and that appropriate operational management capabilities be in place.

The Agency's second major goal related to space transportation systems is to establish a more permanent presence in space. Permanent human occupancy of space is necessary for undertaking larger-scale scientific, exploratory, and industrial space activities to fulfill economically and effectively the transportation, facility, and operations needs of exploration, science, and applications space missions, as well as many transportation needs of national security space missions. It is the logical next step in evolution of capabilities provided by the STS and in the further development of space flight. The means for achieving this goal is development of a manned, permanent Space Station in accordance with the President's directive to NASA in his January 1984 State of the Union address. Because of the large scope of that development, NASA established in 1984 the Office of Space Station to manage the development. That office's program plan is described in chapter V of this report.

Exploitation of the STS's unique abilities to further the permanent occupancy goal requires objectives extending into the 1990s that can serve as a basis for initiatives to be undertaken in the near term. The objectives that have been established are described in subsections 1 and 2 below.

1. Objectives for FY 1986 through 1990

- o Completing development, acquisition, and upgrading of the STS to its full capability, and achieving routine operations with it by 1988
 - Maintaining the production schedule
 - Bringing Spacelab to operational status
- o Encouraging use of the STS by both domestic and international commercial customers on a reimbursable basis by implementing the strategies of the STS marketing plan
 - Improving support to current commercial communications satellite missions
 - Identifying new areas of commercial activity that would benefit from STS launch support to create new STS launch markets
- o Successfully carrying out a total of 14 STS missions in FY 1986
- o Developing by the second quarter of FY 1986 a Centaur upper stage compatible with the Shuttle to provide cost-effective transportation to higher energy orbits
- o Supporting and encouraging commercial development of upper stages to ensure a reliable and effective upper stage capability
- o Establishing an institutional framework for space flight activities that meets civil and defense needs, appropriately utilizes industry capabilities, and facilitates international cooperation
- o Stabilizing and expanding the STS market by establishing and implementing a business plan that includes both identification of constraints and a financial management program with an adequate commercial pricing policy, a customer service organization, and an aggressive marketing program
- o Developing a tethered satellite system for the controlled deployment, orbit stabilization, and retrieval of science and applications satellites above and below the orbiter
- o Continuing demonstration of the abilities of the STS in servicing satellites in order to emphasize this new operational capability and thereby influence systems designs and operations adopted by users
- o Developing by 1990 an orbital maneuvering vehicle to meet the needs of planned and prospective spacecraft, platforms, and facilities for maneuvering in and between Earth orbits.

2. Objectives Beyond FY 1990

- o Maintaining an operational launch schedule with reserve capacity, while conducting safe, successful STS missions having progressively lower operational costs and shorter turn-around times
- o Helping the Office of Space Station to meet its objective of developing and putting into routine operation by the early 1990s a manned permanent facility (the Space Station) in low Earth orbit for operations, construction, and research in space
- o Developing an orbital transfer vehicle complementary to the Space Shuttle to meet the needs of planned and prospective spacecraft, platforms, and facilities for transportation to, between, and beyond Earth orbits
- o Defining, designing, and providing a second-generation STS, including unmanned cargo vehicles and second-generation orbiters
- o Developing and operating on a routine basis, beginning in the mid 1990s, space platforms that are unmanned, permanent, and multifunction; are in geosynchronous orbit; and meet advanced telecommunications, science, environmental and resource observation, and other needs
- o Developing and putting into routine operation by the year 2000 permanent, multifunction facilities in geosynchronous orbit that are capable of being manned periodically and that meet communications, observation, science, and national security needs
- o Developing technology and techniques to construct, deploy, or assemble each of the above systems in space, and achieving an ability to test and service the systems in orbit
- o Encouraging and supporting NASA and industry development of technology to improve concepts for space boosters that will reduce launch costs significantly
- o Continuing to develop goals and planning information for expanding manned programs in space beyond the period covered by this plan.

B. Planned Programs

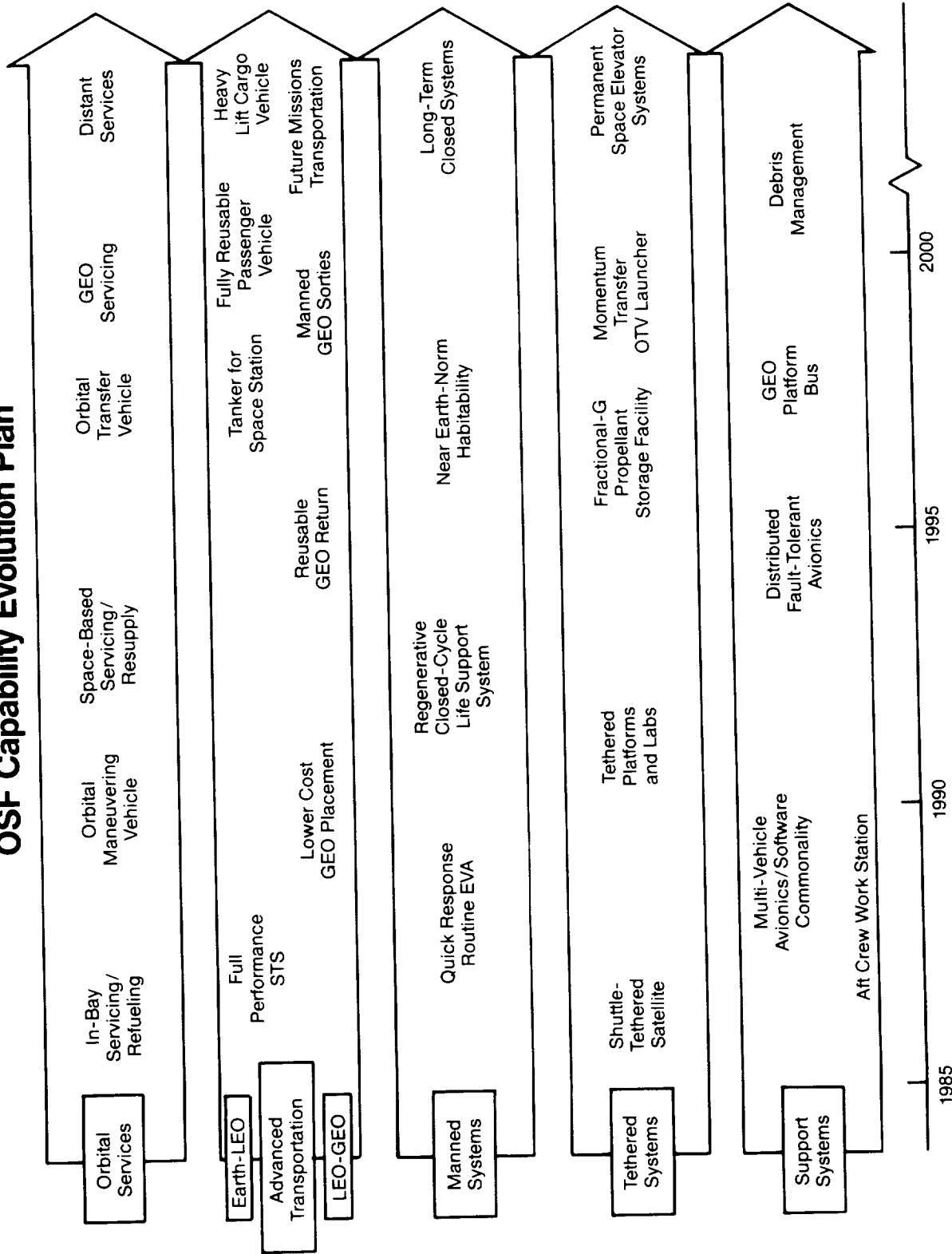
The evolutionary objectives discussed above have functional implications that give rise to the technological requirements shown in Table IV-1. Those requirements are basic to the Space Flight program's ability to exploit fully the unique characteristics of the STS. Technological solutions to them will implement the evolutionary plan for the program depicted on Figure IV-1 and discussed in greater detail in the later sections of this chapter entitled New Initiatives and Advanced Studies. Relationships among the elements shown on Figure IV-1 are described further in Figure IV-3 in the later section entitled Technical Relationships Between Program Elements.

TABLE IV-1. EVOLUTION IMPLICATIONS

<u>OBJECTIVE</u>	<u>IMPLICATION</u>	<u>TECHNOLOGICAL REQUIREMENT</u>
<p>Establish permanent facilities to Provide Science, Research and Development, Commercial, and Operations Support Manned and Unmanned Low Earth Orbit and Geostationary Orbit</p>	<p>More Power and Time in Orbit Manned Operations</p>	<p>Crew Systems Permanent Free-Flying and Tethered Platforms</p>
<p>Provide Routine, Economical, and Flexible Access to All Orbits for Manned and Cargo Payloads</p>	<p>Remote Exchange of Payloads and Modules</p>	<p>Module Exchange Mechanisms Reusable High-Energy Upper Stage Satellite Services Use of Space Station and External Tank Propellants Maneuvering Vehicle</p>
<p>Institute Routine Manned and Remotely Controlled Checkout, Refueling, Repairing, and Upgrading of Spacecraft in Orbit</p>	<p>Aggregation of Payloads Man-Tending Assembly in Orbit Manned and Remote Exchange of Payloads and Modules</p>	<p>Permanent Free-Flying and Tethered Platforms Satellite Services Module Exchange Mechanisms Maneuvering Vehicle In-Orbit Assembly and Storage</p>
<p>Capitalize on the STS as a Test Bed for Space Research and Development</p>	<p>Shuttle-Based Research, Testing, and Demonstration Using Spacelab Elements as Appropriate</p>	<p>Flight Experiments and Demonstrations Payload-of-Opportunity Standby (Hitchhiker) Carriers Generic Tool Kits and Training for Extravehicular Activity</p>
<p>Devise Innovative STS Uses and Missions</p>	<p>Greater Power and Time in Orbit Manned Operations Access to Other Orbits</p>	<p>Permanent Space Station Maneuvering Vehicle Flight Experiments Advanced Transportation</p>



**Figure IV-1
OSF Capability Evolution Plan**



Note: For definitions of acronyms, see Chapter X.

1. Baseline

The STS provides efficient, economical access to space, as well as capabilities (summarized in Table IV-2) that today's expendable launch vehicles cannot supply. It constitutes almost the whole of the NASA space-flight baseline program. In FY 1984 the third orbiter, Discovery, joined the orbiters Columbia and Challenger; and the three conducted a total of four operational flights. The orbiter, payloads, ground control, flight control, and processing teams have been proven; and the STS now is ready to grow and mature, over the next few years, into a system that will use the assets developed by NASA and the Air Force to meet the space transportation needs of our nation's and the free world's governmental, scientific, commercial, and national security payloads.

The key element of the STS, the reusable Space Shuttle, has reintroduced flight crews into spaceflight operations. The Shuttle's major advantage is its ability to service, maintain, repair, retrieve, and reuse payloads. Its most important characteristic is its versatility, which will make using it most effectively a distinct challenge. It has demonstrated some of its advantages and versatility by launching commercial communications satellites and the first Tracking and Data Relay Satellite; by retrieving satellites for repair in orbit or return to Earth; by supporting the first extravehicular activity (space walk) astronauts had conducted in nine years; and by carrying Spacelab into space.

a. Shuttle Production and Capability Development

The objective of NASA's Shuttle production and capability development activity is to provide a national fleet of Space Shuttle orbiters that will meet the needs of NASA, the Department of Defense, and other domestic and international users. Included are launch site facilities, initial spares, production tooling, and related support activities. This development activity provides spares for the orbiter and develops structural spares.

(1) Orbiters

The third orbiter, Discovery, was first flown in FY 1984; and the planned delivery date for the fourth, Atlantis, is FY 1985. Current plans also provide for completing production of structural spares, with delivery of the last component in FY 1987; changeover of the orbiter Columbia into its operational configuration; and performance of residual development tasks.

The need for additional orbiters is under assessment. Although the approved 4-orbiter fleet will satisfy the current mission manifest, projected increases in launch demand and mission duration would require the addition of one or more orbiters. Also, an additional orbiter would be needed if an orbiter were removed from service by an accident or for an extensive overhaul.

TABLE IV-2. STS CAPABILITIES

SHUTTLE

Delivery of Tended and Untended Satellites and Other Payloads to Low Earth Orbit
Repair and Retrieval of Spacecraft
Delivery of Propulsive Stages and Satellites to Low Earth Orbit for transfer to High-Energy Orbits
Delivery of 29,500 kg (65,000 lbs) of Payload to 250-km (150-nmi) Circular Orbit (Due East)
Delivery of 14,500 kg (32,000 lbs) of Payload to Polar (98°) 250-km (150-nmi) Circular Orbit
Return of 11,340 kg (25,000 lbs) of Payload from Space

SPACELAB

Payload Capability: 4,800 to 8,800 kg (10,600₃ to 19,400 lbs)
Pressurized Volume: 8 to 22 m³ (280 to 775 ft³)
Average Electrical Power: 3 to 5 kW
Payload Specialists: 1 to 4
Nominal Mission Duration: 7 days

INERTIAL UPPER STAGE (2-STAGE)

Delivery of up to 2,270 kg (5,000 lbs) to Geosynchronous Orbit

PAYLOAD ASSIST MODULES (PAMs)

Delivery of 1,270 kg (2,800 lbs) to Geosynchronous Transfer Orbit (PAM-D)
Delivery of 1,995 kg (4,400 lbs) to Geosynchronous Transfer Orbit (PAM-A)

CENTAUR-G PRIME

Delivery of 5,895 kg (13,000 lbs) to Geosynchronous Orbit (Centaur-G: 4,535 kg (10,000 lbs))
Delivery of 2,360 kg (5,200 lbs) to Outer Planets ($C^3 = 85 \text{ km}^2/\text{sec}^2$)

(2) Propulsion System

The Shuttle's propulsion system consists of three main engines, two solid rocket boosters, and an external tank. Residual development tasks and production of flight hardware constitute the main focus of the plans for the system.

(a) Space Shuttle Main Engine

In March 1983 the basic full-power-level configuration of the Space Shuttle main engine (SSME) was certified for service on the orbiter fleet. After that configuration's first flight, the emphasis of the SSME test program shifted to flight confidence testing to prove that flight engine components have sufficient mean-time-before-replacement margins to provide an extended life capability. One engine will be subjected to the equivalent of about 80 missions and two more engines will be tested to approximately 40 mission equivalents to prove their durability and reliability. The tests will be scheduled so that any problems relating to engine life will be found on the ground well before they can occur in flight.

Under consideration are ground tests in which the SSME would be operated at a higher thrust level to accelerate the occurrence of any fatigue problems. The tests could reveal problems early and provide a time margin for developing fixes and applying them to flight engines. In addition, the higher-thrust operation could provide a basis for increasing the SSME's thrust performance if operational demands requiring greater payload capacity should develop.

Because electronic components in the engine controller are obsolescent, development of a new controller is in process. To increase the reliability and reduce the maintenance costs for other critical components of the SSME, a product improvement program has been initiated.

(b) Solid Rocket Boosters

Lightweight steel cases for the solid rocket boosters, used for the first time on the Shuttle's April 1983 flight, increased the Shuttle's payload capacity by about 260 kilograms. A configuration provided by reshaping the thrust-time curve, increasing the nozzle expansion ratio, and decreasing the throat diameter, first flown on the Shuttle's eighth flight, provided a payload improvement of 1,360 kilograms. A filament-wound composite motor case planned for development for use in high-performance launches will provide a payload capacity about 2,275 kilograms greater than that provided by the current steel case. It will require minimal or no reconfiguration of the external tank and the orbiter. The plan for its development is designed to provide the shortest development schedule, the least cost, the least technical risk, and the least effect on the external tank's current design. Its first developmental firing is planned for July 1984, and its first flight use for October 1985.

Plans for the solid rocket boosters emphasize greater reusability of parts and the reduction of flight damage, particularly damage to the hydraulic power unit.

(c) External Tank

The first lightweight external tank was flown in April 1983, providing a weight saving of more than 4,545 kilograms. Development is continuing, with emphasis on cost reduction, producibility, and production readiness as the tank's production rate increases and anticipated production-flow and processing improvements are identified and implemented. Tooling for both the external tank and the solid rocket boosters currently is based on a flight rate of 24 per year rather than the higher flight rates anticipated.

(3) Launch and Mission Support

Current facilities at Kennedy Space Center can support simultaneous launch processing of two Space Shuttles through assembly and checkout. However, the single launch pad available allows the launch of only one Shuttle at a time. A second launch pad will become operational January 1, 1986. At Johnson Space Center, support facilities are being improved to upgrade techniques related to flight design, flight analysis, and software development.

(4) Changes and Systems Upgrading

Changes and systems upgrading activities pertain to potential changes, system modifications, and developments that are not included in the current program. They result from development testing, which will continue during early operational flights, ground testing, and experience. They consist of programmatic and technical changes to improve operational effectiveness. The resulting modifications and improvements are essential to ensure that development objectives are met and turn-around times are reduced as flight rates increase. System studies and cost-benefit analyses are integral to the process of establishing priorities for proposed changes and system upgrades.

Proposals currently under consideration include development of an advanced (8-psi) extravehicular mobility unit and pressure suit to reduce or eliminate pre-breathe time before extravehicular activity; modification of the orbiter reaction control system to eliminate single-point failures, reduce propellant usage, and reduce life-cycle costs; redesign of the orbiter landing gear to make it capable of accommodating heavier landing weights, to reduce tire loads, and to extend brake life; and modification of the orbiter auxiliary power unit to reduce turn-around time and weight.

(5) Tethered Satellite System

The Tethered Satellite System will consist 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 200 to 500 kilograms and may be deployed upward or downward to distances of as much as 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, 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. Some of its planned uses are described in Chapter III of this report.

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, overall program management, and integration of the system with the orbiter. Work to prepare the system for its first flight was a FY 1984 new initiative. It will yield an initial operational capability in FY 1988. The Italian government has appropriated all the funds necessary for its activities associated with the development and first flight of the satellite.

b. 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 a high-energy Centaur stage modified for use with the Shuttle. 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.

(1) Inertial Upper Stage

The U.S. Air Force is developing the IUS, a two-stage, solid-propellant vehicle capable of boosting 2,270 kilograms into geosynchronous orbit from the Shuttle and the Titan 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. That IUS experienced anomalies that prompted deferral of the second use of the IUS on the Shuttle to 1984. 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.

(2) Centaur Upper Stages

The Department of Defense and NASA have agreed to develop jointly the Centaur-G, an adaptation of the Centaur stage of the Atlas-Centaur expendable launch vehicle. Centaur-G will be able to boost 4,535 kilograms from the Shuttle to geosynchronous orbit and will become operational in 1987.

NASA is developing a longer version of the Centaur-G, the Centaur-G Prime, for use in planetary missions. It will be able to deliver about 5,900 kilograms to geosynchronous orbit and is planned for use in 1986 to place the Galileo and Ulysses (formerly International Solar Polar Mission) spacecraft on their interplanetary trajectories.

(3) Payload Assist Module

The McDonnell Douglas Corporation has undertaken development of payload assist modules for use on missions requiring less propulsive energy than that provided by the IUS. The Payload Assist Module (Delta Class), called the PAM-D, has been used to launch several missions on both Delta expendable launch vehicles and the Shuttle. An improved performance version of the PAM-D, designated PAM-DII, is currently under development. The Payload Assist Module (Atlas Class), PAM-A, has completed development.

(4) Other Stages

In January 1984, the Orbital Sciences Corporation contracted to develop the Transfer Orbit Stage for use in missions requiring propulsion capabilities between those of the IUS and the Centaur-G Prime. The Transfer Orbit Stage will be able to place payloads weighing 2,725 to 5,910 kilograms (6,000 to 13,000 pounds) into geosynchronous orbit. Its planned availability is mid 1986.

Several other private firms are considering commercial development of upper stages to provide propulsion from the Shuttle's orbit for payloads with various propulsion requirements.

c. 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.

(1) Spacelab Operations

Two Spacelab pallets carrying scientific instruments were flown during the Shuttle 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 of two communications satellites. A second dedicated verification flight, involving an all-pallet configuration and an instrument pointing system, is scheduled for flight in mid 1985. Figure IV-2 shows Spacelab related missions planned through FY 1989.

(2) Spacelab Capability Development

The Spacelab program offers a wide range of capabilities to users, as shown in Figure IV-3. 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 and a new payload operating control center at Marshall Space Flight Center to complement the existing one at Johnson Space 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, a Spacelab pallet system configuration called the Spacelab Igloo Pallet System is under development. It is to be used for the first time in early 1986 to carry the Instrument Pointing System and a major science payload associated with Halley's Comet. For mixed cargo payloads that are substantial but do not require so much data management support, another version of the Spacelab pallet system called the Multiplexer, Demultiplexer Pallet has been used successfully. To reduce payload integration costs, that pallet is being modified to be independent of the orbiter's General Purpose Computer system.

A novel concept, designated Hitchhiker, is under development to provide a simple interface with small experiments and with the Shuttle, thus making integration for flight easier and less costly. Two versions are being developed, and both will add to Spacelab's capability and flexibility. Flight of an experiment using Hitchhiker will be possible only six months after the experiment's selection. Hitchhiker is designed to reduce experimenters' costs and to optimize Shuttle load factors. Its first application is planned for 1985.

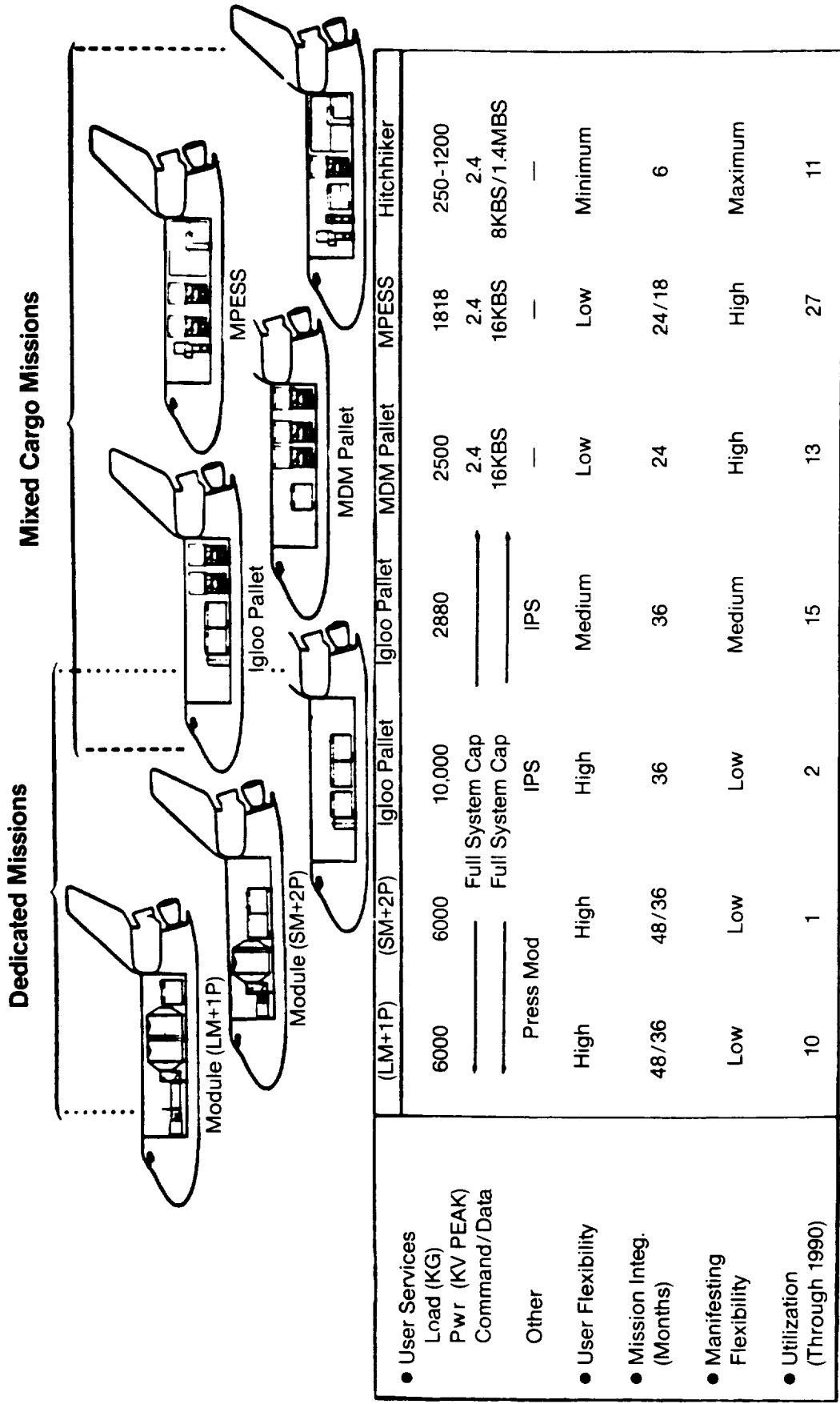
(3) Spacelab Pricing Policy

The successful completion of the first Spacelab mission has drawn the interest of potential commercial users. To establish a consistent basis for cost reimbursement and make public the cost of using Spacelab, a pricing policy for Spacelab is being developed. Planned for publication this year, it will provide pricing principles for standard Spacelab services by configuration.

d. Spaceflight Operations

Spaceflight operations consist of all the essentials for planning, scheduling, and conducting space missions, including people, facilities and ground equipment, supporting computers and communications links, ancillary flight hardware, flight planning and scheduling, operating procedures, mission control, logistics support, user interfaces, and overall program management of all those elements. Plans include continuing provision of standard operational support services to expendable launch vehicles, as well as to the Shuttle.

Figure IV-3
Spacelab Flight Services



Note: For definitions of abbreviations and acronyms, see Chapter X.

(1) Space Shuttle Operations

The Space Shuttle operations program provides for launching missions for NASA, the Department of Defense, other U.S. government agencies, domestic commercial organizations, and international organizations. Four flights took place in FY 1984. Ten flights are planned for FY 1985, 14 for FY 1986 (including the first West Coast launch, set for October 1985), 16 for FY 1987, 23 for FY 1988, and 24 for FY 1989 and each year beyond. Operational support provided 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.

The price to non-NASA customers for the Shuttle's launch services depends on the size of the customer's payload and the services required. For standard launch services, the price in FY 1982 dollars is \$36 million per flight through FY 1985 and \$71 million per flight for FY 1986 through FY 1988. The charge to the Department of Defense in FY 1975 dollars is \$16 million for flights in FY 1984 and FY 1985 and \$29.8 million for FY 1986 through FY 1988. A post-1988 price is being developed and may be announced officially before the end of the year.

Space Shuttle operations are being streamlined by consolidating related program functions under single management contractors. A Base Operations Contract has been in force since December 1982 at Kennedy Space Center for all Shuttle, cargo, and institutional support. It replaces 14 contracts and 7 subcontracts. A Shuttle Processing Contract in effect at Kennedy since September 1983 for handling all of the launch and landing operations at both Kennedy and Vandenberg Air Force Base supplants 12 contracts, and a Facility Maintenance Contract has been in effect at Michoud Assembly Facility since January 1983. Johnson Space Center has planning in process for an STS Operations Contract that will become effective in early 1986, replacing approximately 12 contracts.

(2) Expendable Launch Vehicles

NASA has managed a stable of expendable launch vehicles for 25 years. It currently consists of the Scout, Delta, and Atlas-Centaur vehicles.

The "small" vehicle in the present stable is the 4-stage solid-fuel Scout. The project office for the Scout program is at Langley Research Center; the launch contractor is LTV-Aerospace, Dallas, TX; and launch facilities are at Wallops Flight Facility, VA, Western Space and Missile Center at Vandenberg AFB, CA, and the Italian San Marco platform off the coast of Kenya, Africa. Scout can launch payloads weighing as much as approximately 225 kilograms (500 pounds) into circular low Earth orbit. Its manifest through 1987 contains 13 Department of Defense missions and 1 NASA mission. NASA's announcement in 1983 of its willingness to foster the taking over by commercial operators of full operation of its expendable launch vehicles evoked no response concerning Scout. During recent months, however, interest has been expressed; and NASA is drafting a request for proposals to elicit proposals from those who are interested. Since NASA currently is operating the Scout program for the Department of

Defense, it will have to coordinate with that agency any arrangement for commercial operation of the Scout program.

The "medium" vehicle in the stable is the 3-stage liquid-fuel Delta. The project office is at Goddard Space Flight Center, with launch activity management provided by Kennedy Space Center. The launch contractor is McDonnell Douglas, Huntington Beach, CA; and launch facilities are at Cape Canaveral, FL, and Vandenberg AFB, CA. Delta can launch payloads weighing as much as 3,050 kilograms (6,700 pounds) into circular low Earth orbit and, with the PAM-D as a third stage, 1,300 kilograms (2,850 pounds) into synchronous transfer orbit. Its manifest contains only two missions, GOES-G AND -H, to be launched for the National Oceanic and Atmospheric Administration in late 1985 and early 1986, respectively. NASA signed an exclusive interim agreement under which Transpace Carriers, Inc. is trying to establish a viable technical and business plan for operating Delta and to develop a market for Delta launches.

The "large" vehicle in the stable is the 2-stage liquid-fuel Atlas-Centaur. The project office is at Lewis Research Center, with launch activity management provided by Kennedy Space Center. The launch contractor is General Dynamics Corporation, San Diego, CA; and launch facilities are at Cape Canaveral. Atlas-Centaur can launch payloads weighing as much as 5,910 kilograms (13,000 pounds) into circular low Earth orbit and 2,275 kilograms (5,000 pounds) into synchronous transfer orbit. Its manifest through mid 1987 contains seven missions, four for Intelsat and three for the Navy's FLTSATCOM program. Negotiations between NASA and General Dynamics Corporation are in process for that corporation to operate the Atlas-Centaur program commercially after completion of the NASA program.

In addition, NASA acts as agent for the National Oceanic and Atmospheric Administration in arranging for the Air Force to launch that agency's low-altitude weather satellites. The vehicles for those launches are refurbished Atlas-E/F ICBMs, and the launch site is Vandenberg AFB, CA.

2. New Initiatives

In consonance with the President's January 1984 State-of-the-Union address, NASA's next major goal is to establish a permanent manned space station in low Earth orbit. The Office of Space Flight has focused its advanced programs on that goal, identifying potential space programs and systems that will support it and developing technical, programmatic, and cost data for evaluating those programs and systems. Included also are advanced development activities to improve performance and reliability and to reduce program costs and risk. The major goals of the advanced programs, therefore, are to help define the infrastructure and systems elements needed for achieving a permanent manned presence in space and for conducting space operations over the next 20 years.

The Office of Space Flight's advanced programs fall naturally into six major categories: crew systems, such as life support systems, to support the Space Station; spacecraft systems such as geosynchronous platforms and tether applications; satellite services; advanced transportation; generic systems (definition for flight demonstrations, multi-vehicle avionics and software

commonality, orbital debris management, and the like); and long-range (post-Space Station) studies. Planned work is in consonance with those categories. Descriptions of proposed new initiatives follow, and section E of this chapter describes advanced studies to identify future systems and operations.

a. Orbital Maneuvering Vehicle

The Orbital Maneuvering Vehicle (OMV), a reusable extension of the STS formerly called the Teleoperator Maneuvering System, will fill a need for conducting orbital operations with spacecraft and payloads beyond the practical operational limits of the base-line STS. It will be a free-flying, remotely piloted vehicle for use with the STS, and later with the Space Station, to perform satellite services. Controlled primarily from the ground, and later from the Space Station, the OMV in its initial configuration will provide spacecraft viewing, deliver and retrieve payloads and satellites under both planned and contingency conditions, reboost satellites to their original operational altitudes or higher, de-orbit satellites that have completed their useful lives and space debris that may be a hazard to operations, and provide science support as a free-flying subsatellite operating in the vicinity of the orbiter. The OMV can be evolved with the addition of advanced mission kits to provide more advanced servicing capabilities in remote orbits.

Studies are in process to define the OMV system and its supporting elements and to establish detailed schedule and funding requirements. System definition was begun in FY 1984. Related supporting development work includes evaluation of display and control station requirements; definition of rendezvous and docking system requirements and sensor needs; development and test of a payload docking mechanism; enhancement of simulation facilities and associated software; development of a full-scale mock-up for fit, form, and systems integration and packaging analyses; advanced development of a rendezvous and docking radar; test and evaluation of cameras, lighting, and radio-frequency control systems; and development of payload servicing controls and interface mechanisms.

System definition studies will be terminated in FY 1985. Initiation of system development will require proposals that identify new start candidates. The proposal process is planned to be completed in FY 1986, leading to the availability in 1990 of an OMV able to perform payload delivery and retrieval from the orbiter. A second OMV flight unit, acquired with Space Station funds, will be orbit based. Advanced mission kits providing a capability for refueling and servicing spacecraft in remote orbits could be added one to two years later.

b. Flight Demonstrations and Satellite Services

One of the major objectives of the Office of Space Flight's program is to capitalize on the STS as a test bed for experiments and demonstrations in flight. Shuttle operations and satellite servicing activities of the orbiter and the Space Station will create a great need for orbital tests and demonstrations of advanced payload operations and of some systems between the development phases of systems definition and systems design. To meet that need, flight experiments are continually being defined to demonstrate Shuttle capabilities and develop user confidence in satellite

services and orbital operations with large space structures. Particularly with respect to Shuttle capabilities, the focus is on definition of tools, techniques, and standard flight-developed equipment for servicing, placement, and repair of satellites in low orbit and on other equipment, systems, and demonstrations such as an orbital refueling system, extra-vehicular activity (EVA) tools, the companion demonstrations EASE and ACCESS (Experimental Assembly of Structures in EVA and Assembly Concept for Construction of Erectable Space Structures), tethered platforms, systems for transferring cryogenics and for voice control, a set of standard spacecraft fluid connectors, and an in-bay tanker. The in-bay tanker would store the propellant for refueling satellites and would be carried like any other payload in the orbiter's cargo bay. Standard spacecraft quick-disconnect fluid connectors will be equipment common to all satellites requiring in-orbit resupply. Flight development of a quick-disconnect fluid transfer device will start in FY 1985, and one of the two sets to be developed will be delivered to the Gamma Ray Observatory for a refueling mission. New and improved EVA tools will increase the efficiency of crews working in space suits outside the orbiter, enabling them to operate servicing equipment efficiently and service satellites effectively.

When possible, flight demonstration objectives will be satisfied using either low-cost, experimental, and prototype equipment or equipment acquired for other purposes. In 1984, for example, the Shuttle's 41-C mission demonstrated satellite retrieval and repair on the incapacitated Solar Maximum Mission observatory. On the Shuttle's 41-G flight, satellite propulsion tanks were refueled with hydrazine in the orbiter's cargo bay. During that demonstration, an EVA astronaut manually connected a refueling valve to the propulsion system and conducted several cycles of refueling to investigate fluid flow and adiabatic concerns. That orbital refueling demonstration is the foundation for a series of demonstrations to be conducted of satellite servicing systems such as the in-bay tanker mentioned above. Before demonstration of that system in the orbiter's cargo bay, engineering understanding of fluid transfer behavior will be acquired through demonstrations conducted in the orbiter's mid-deck with plastic tanks, passive fluid management devices, and a reference fluid. Other flight demonstrations that may be included in the orbital refueling program would involve alternate tankage configurations, fluids, and new quick-disconnect valving systems designed to provide ease of servicing and known, proven interfaces for both NASA and the users.

Other flight demonstrations under development are as follows:

- o The companion demonstrations EASE and ACCESS mentioned above, to obtain basic data for evaluating construction capabilities provided by the astronaut-Shuttle team
- o Use of voice commands to augment manual control of closed circuit television cameras
- o Use of a force-feedback end effector to improve the dexterity of the Remote Manipulator System

- o Use of a secure, infrared communications system to improve the STS' voice and data systems.

Flight demonstrations tentatively selected for development are as follows:

- o In-orbit transfer of superfluid helium
- o Proof of function of a plasma motor and generator
- o Use of a kinetic isolation tether.

c. Advanced Crew Support

A need is anticipated for quick-response satellite servicing systems for use by both the Shuttle and the Space Station and for providing the high rate of daily EVA expected in Space Station operations. To meet that need, a study is in process on a totally new EVA system, the Extravehicular Mobility Unit, and on the improvement it would make in human productivity. The study currently is concentrating on projected mission requirements and preliminary system concepts. Its results will be incorporated into the work package for Space Station definition and subsequent system acquisition. The initial Space Station will be provided with six flight units. A preliminary set of requirements for the Extravehicular Mobility Unit includes daily use in EVA; high mobility; in-orbit maintainability; long life; non-venting operation; automated check-out; heads-up display capability; regenerable, portable, life support subsystems; and automated control of visor density. The work on advanced crew support systems also is supporting advanced developments to provide mature engineering options for EVA systems beyond the Extravehicular Mobility Unit.

C. Institutional Management

The Office of Space Flight has responsibility for institutional management of four NASA field installations: Johnson Space Center, Marshall Space Flight Center, Kennedy Space Center, and National Space Technology Laboratories.

1. Marshall Space Flight Center

Established in 1960 for the purpose of developing launch vehicles for the Apollo and subsequent programs, Marshall Space Flight Center today designs and develops space transportation systems, orbital systems, science and applications payloads, and other systems for space exploration. It has the principal role within NASA for development of rocket propulsion systems. It also has assembly facilities and provides centralized computer services for other NASA centers and their contractors and for other government agencies. It has the following areas of technical expertise:

- o Propulsion systems design analysis
- o Materials science and engineering

- o Structural design and analysis
- o Test design and engineering
- o System dynamics analysis
- o Large systems engineering, analysis, and management
- o Heat transfer analysis
- o Data systems design and analysis.

2. Johnson Space Center

Johnson Space Center was established in November 1961 to satisfy NASA's need for a center with primary responsibility for managing the design, development, and manufacture of manned spacecraft; selecting and training astronaut crews; and conducting manned spaceflight missions. The need for those functions has continued as the Nation has progressed through ambitious undertakings such as the Apollo and Skylab programs, Apollo-Soyuz Test Project, and Space Shuttle program. Johnson now is the "lead center" for the Space Station, with responsibility for NASA-wide program management of design, system engineering and integration, advanced development and test, and customer interface. Johnson also conceives, plans, and develops advanced missions; conducts research in the life sciences; and performs Earth resources surveys. Its areas of technical expertise are as follows:

- o Space flight mechanics of manned vehicles
- o Data systems and analysis
- o Space flight systems for manned vehicles
- o Flight crew training and mission simulation
- o Mission operations for manned vehicles
- o Earth resources surveys
- o Environmental control and life support systems
- o Management of large-scale systems and programs
- o Remote sensing systems.

3. Kennedy Space Center

Kennedy Space Center was established in July 1962 to serve as the primary NASA center for test, checkout, and launch of space vehicles. It has since grown to become the major Free World launch site, with a civil service staff possessing unparalleled skills in testing, checking out, and launching space vehicles and in designing associated ground support equipment. Space Shuttle flights began at Kennedy in 1981 and will begin at the Western Space and Missile Center at Vandenberg Air Force Base in 1986. Expendable launch

vehicle operations are conducted at both Vandenberg and the Eastern Space and Missile Center at Cape Canaveral Air Force Station. Kennedy's areas of technical expertise include:

- o Flight systems testing
- o Facility and equipment development and operations
- o Launch operations
- o Cargo processing
- o Technical project management.

4. National Space Technology Laboratories

Constructed and operated during the 1960s under the name Mississippi Test Facility, National Space Technology Laboratories conducted acceptance testing of the booster stages of the Saturn rocket systems. Today, it is NASA's principal static test facility for large liquid-propellant rocket engines and propulsion systems. Its change in name was made in June 1974 to emphasize its emerging role in space and environmental technology. Its areas of technical expertise are as follows:

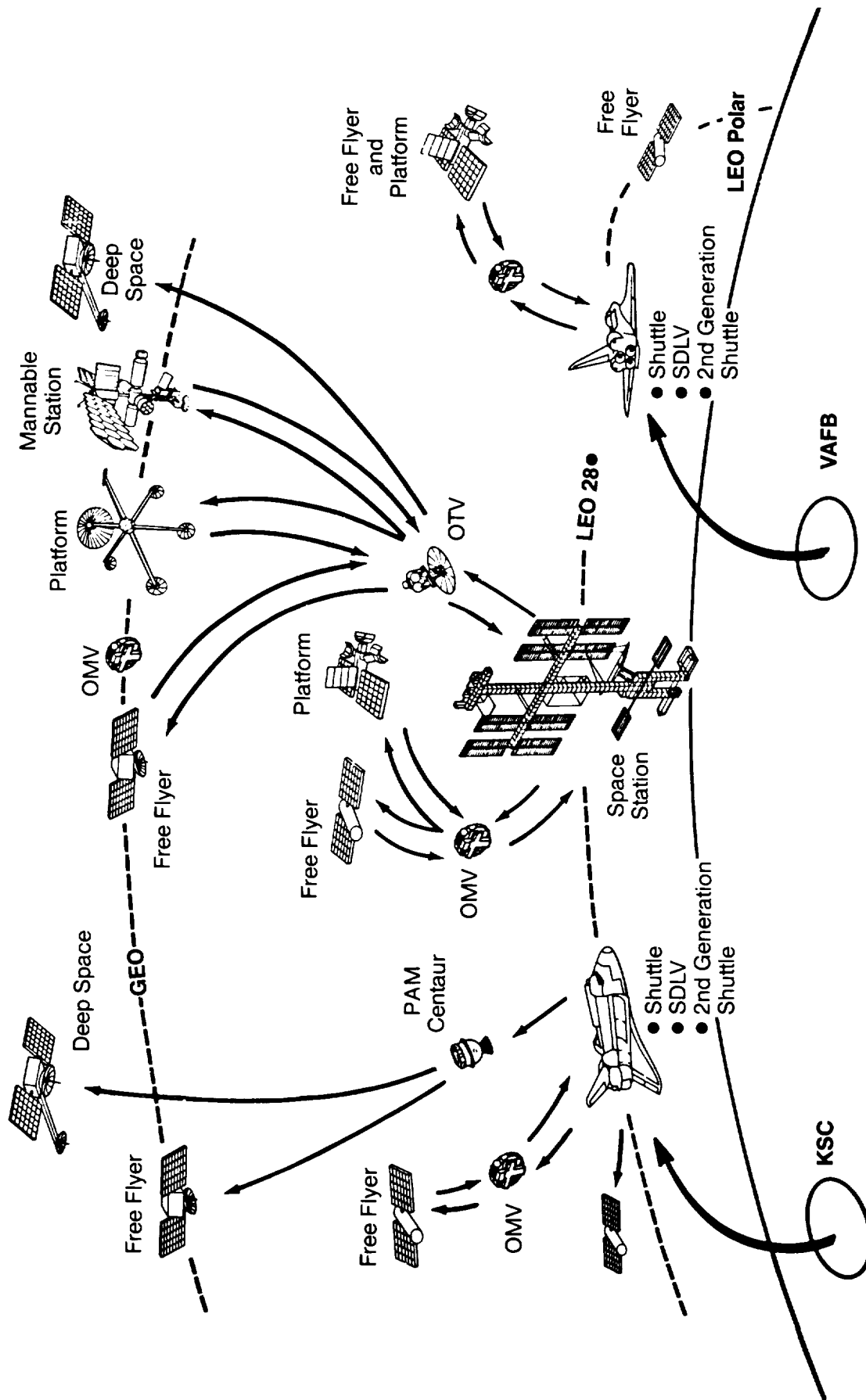
- o Testing of large liquid-propellant rocket engines
- o Earth resources observation.

D. Technical Relationships Between Program Elements

The goal of a permanent U.S. manned presence in space requires development of a multi-equipment infrastructure of ground- and space-based technical systems, as well as smooth interplay and efficient complementarity between those systems to provide the greatest possible economy and effectiveness of operation. The central space-based element is the Space Station. In essence, what the Space Shuttle is in importance to transportation from Earth to low Earth orbit, the Space Station is to operations in space. It will transcend traditional scientific roles and become both an orbital service center and an indispensable transportation node to higher orbits--a "beachhead" in space. As focal point and "mother ship," it will enable efficient use of the Shuttle fleet while ensuring economical and efficient access to all other space-based elements of the infrastructure. Vastly superior to the Shuttle as an orbital operations base because of its greater onboard resources and permanent duration, it will serve as a facility for servicing free-flying spacecraft, for storage and assembly operations, and as a communications and data processing node.

The Space Station cannot be expected to create by itself a permanent presence in space. That goal will require associated elements such as those shown on Figure IV-4, which illustrates the necessary infrastructure and the relationships between its elements. The major elements and relationships are described in section E of this chapter.

**Figure IV-4
Elements of Space Infrastructure**



Note: For definitions of acronyms, see Chapter X.

In considering the technical relationships between current and future program elements, it is clear that the Shuttle is the primary means of access to low orbits, including that of the Space Station, and that the Space Station will be the primary means of access to geosynchronous and other orbits. To be most useful, the Shuttle and the Space Station will have to operate in conjunction with unmanned platforms and free flyers in various orbits, and with auxiliary transportation and maneuvering vehicles. Orbital transfer vehicles may be either expendable or reusable. If reusable, they either may be brought back to Earth by the Shuttle after their return from high orbit or, as space-based vehicles, be serviced and refueled at the Space Station. Free flyers and platforms the orbiter cannot reach will require the services of a close-in maneuvering system such as the Orbital Maneuvering Vehicle described earlier under New Initiatives. Pairing that vehicle with an orbital transfer vehicle will permit it to service unmanned platforms and free flyers in geosynchronous orbit.

E. Advanced Studies

The Office of Space Flight's advanced studies serve the six major program categories mentioned earlier, in subsection B.2. of this chapter: crew systems, spacecraft systems, satellite services, advanced transportation, generic systems, and advanced (long-range) studies.

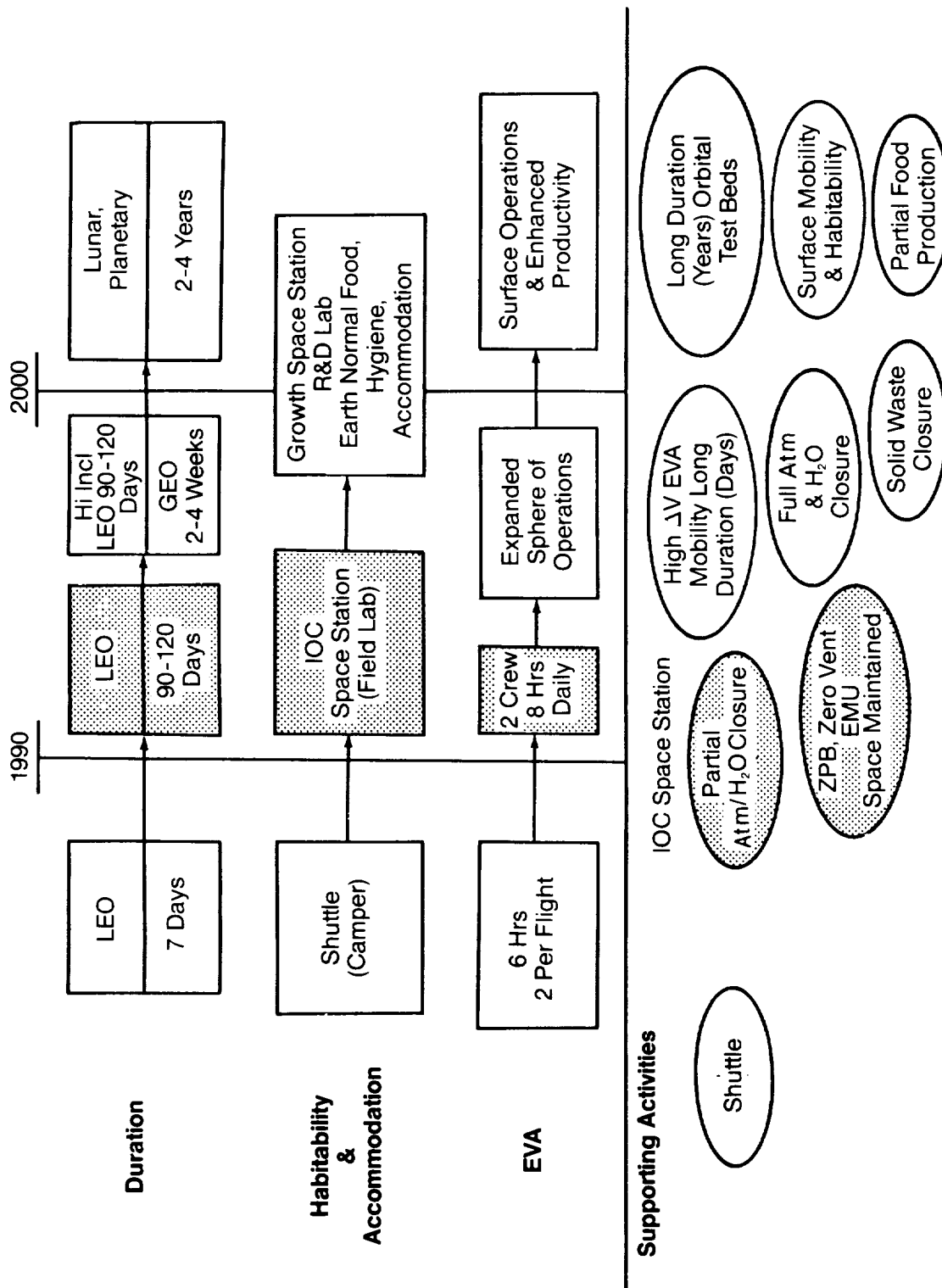
1. Crew Systems

Crew and life support systems are central to the support of manned operations in space. Their anticipated development in the three major areas of life support, habitability provisions, and EVA systems is shown on Figure IV-5. For the onboard life support systems, experiments using the Shuttle and, later, the Space Station as a test bed will be targeted at successive closure of the water and air loops to provide the closed cycle life support system shown schematically on Figure IV-6. Permanent manned presence in space also will require improvements in habitability that ultimately will provide Earth norms in space food and hygiene systems, as well as enhancement of man-machine interactions to achieve higher human productivity. That higher productivity will be sought aggressively, using both the Shuttle and the Space Station in the development of superior EVA systems such as the higher-pressure space suit currently under development to eliminate the need for prebreathing; a regenerable EVA mobility unit and backpack maintained in orbit; an advanced manned maneuvering unit; and a crew capsule for manned access to higher orbits.

2. Spacecraft Systems

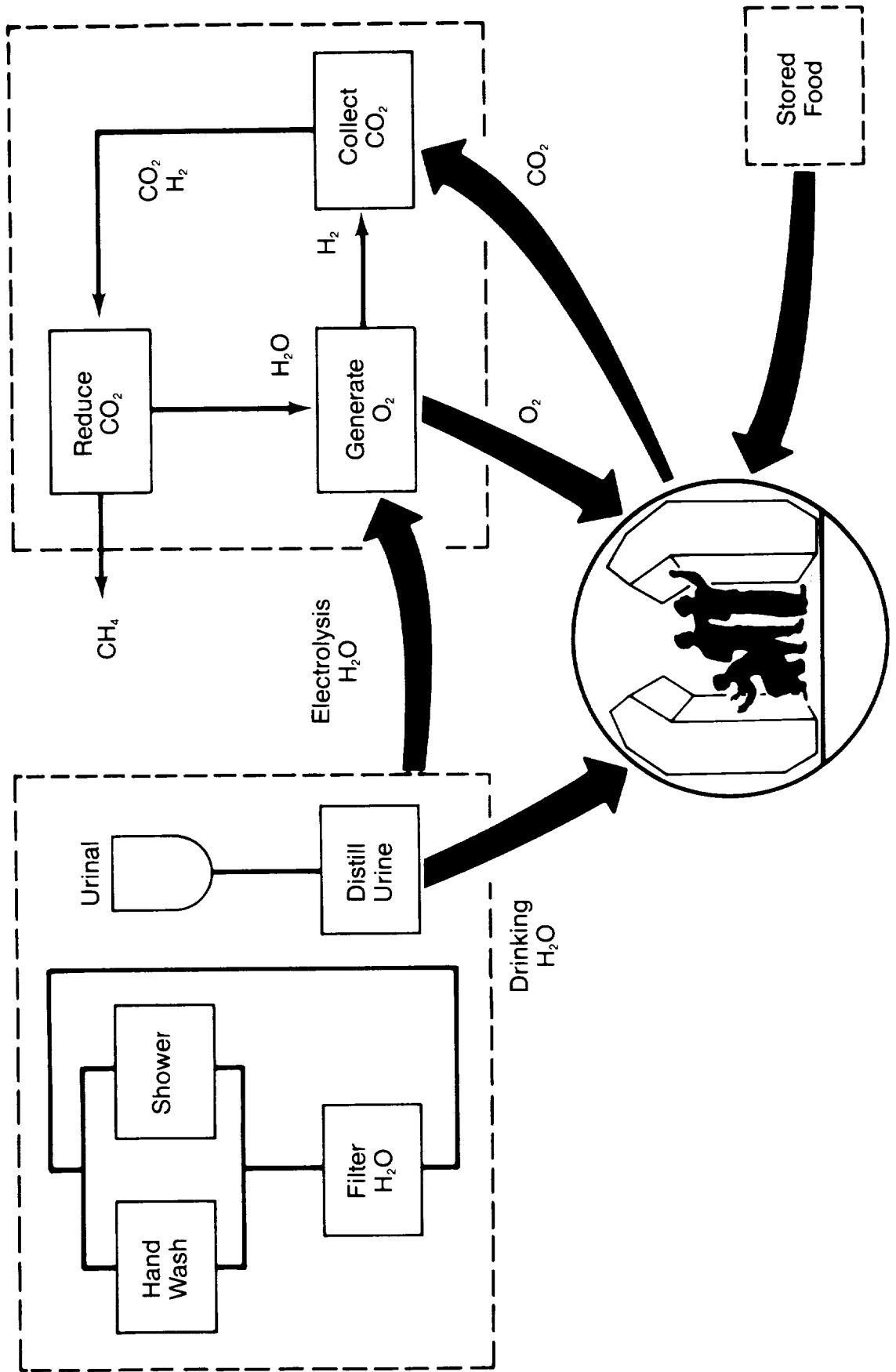
The Agency's objective of economical support of payloads requires payload aggregation, standardized orbits, and human-tending (see Table IV-1). The first step in meeting those requirements will involve the use of platform-like instrument carriers called quick-reaction opportunity carriers, such as the Hitchhiker mentioned earlier. Then, permanent free-flying or tethered platforms and facilities based at the Space Station or remotely tended from it will be needed. The remotely tended platforms and facilities will include ones in geosynchronous orbit. As indicated in Table IV-1 and Figure IV-4, economical transportation and support also will be required.

Figure IV-5
Advanced Manned Systems



Note: For definitions of acronyms, see Chapter X.

Figure IV-6
Closed Cycle Life Support



a. Geostationary Platforms

Studies have shown that the technical and economic benefits are potentially greater from the use of large platforms in geosynchronous orbit than from the use of smaller, single-purpose satellites. Both economy of scale and conservation of the geostationary arc favor large multipurpose systems. The best methods for developing the potential of those systems are the subject of a joint study program between the Office of Space Flight and the Office of Space Science and Applications. The Office of Space Science and Applications is sponsoring studies at Lewis Research Center to define possibilities for aggregation of communications payloads; and the Office of Space Flight is sponsoring studies at Marshall Space Flight Center to develop configurations for the spacecraft and to develop an understanding of the possible evolutionary paths. These studies will provide background data NASA needs to address questions regarding the utility, systems, and institutional implications of large operational geostationary platforms. The answers derived will determine what further efforts NASA will apply to development of technologies for large geostationary platforms.

b. Advanced Tether Applications

The Tethered Satellite System described previously is in development. Approved as a new initiative in FY 1984, it is an innovative concept that will provide an important new platform facility for conducting aggregated space experiments at a distance from the Shuttle orbiter and the Space Station. More advanced applications of tethers, such as those shown on Figure IV-7, are under investigation. Tethers are expected to be valuable for positioning space structures and for use in power generation, gravity control, transportation, cryogenic propellant storage and transfer in space, attitude control of space stations, and many other applications that could revolutionize space operations. Figure IV-8 shows the likely evolution of space tethers toward highly advanced applications during the next 20 years. Tethering and its possible applications, such as use of the electrodynamic interactions the tether causes, are understood far less than are other elements of the Shuttle and Space Station infrastructure. However, they appear extremely promising and will be investigated carefully.

3. Satellite Services

The manned Space Station and planned unmanned low-altitude and geosynchronous platforms clearly will create a need for new and unique systems and equipment, such as satellite servicing systems, large structures, handling aids, and teleoperators--all with greater capabilities than those the current basic STS systems possess. As mentioned earlier, those advanced systems and equipment will require development testing in orbit. Consequently, NASA's satellite services advanced studies are focused on flight demonstration, as well as on development of the systems and equipment.

Industry is hesitant to incorporate satellite maintenance and servicing provisions into spacecraft design. At a satellite-services workshop held June 22-24, 1982, potential users of satellite servicing concluded that to change

Figure IV-7
Tether Applications in Space

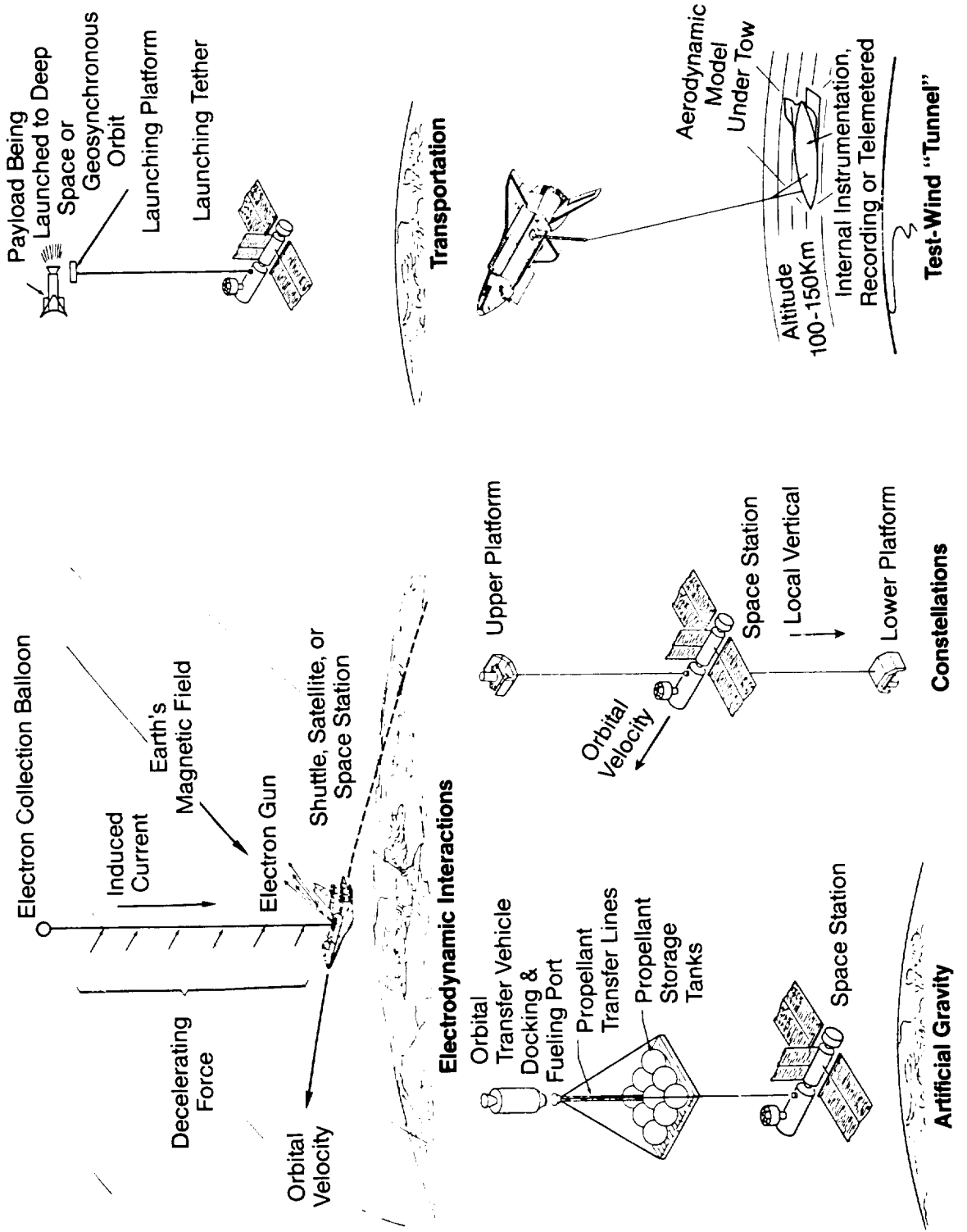
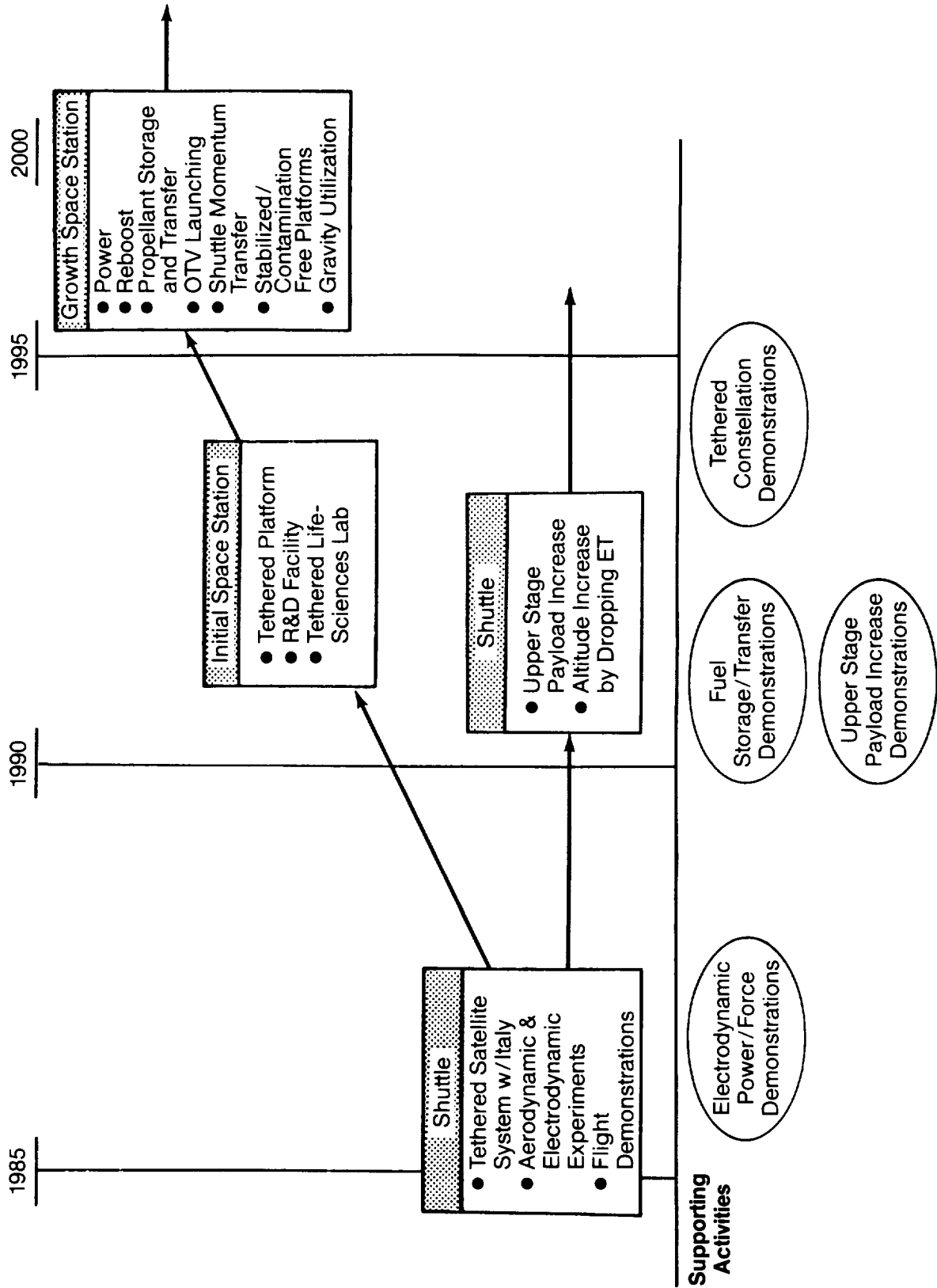


Figure IV-8
Tethered Systems



the attitude of users toward satellite servicing, NASA must demonstrate that needed capabilities exist. They stated that they look to NASA not only to demonstrate basic servicing capabilities, but also to define and develop requirements, standards, interface specifications, operational procedures, baseline servicing equipment and costs, and policy guidance on routine EVA. Therefore, NASA must institute a series of demonstrations with the Shuttle that will be highly visible and technically meaningful to STS users.

The flight experiments program described earlier (in subsection B.2.b.) has been established to meet that need. Satellite servicing has been demonstrated already in the Solar Maximum Mission repair and the orbital refueling demonstration described in that subsection. Figure IV-9 shows an example of an evolutionary line of future flight experiments dedicated to development of satellite services capabilities.

a. Satellite Services at the Orbiter

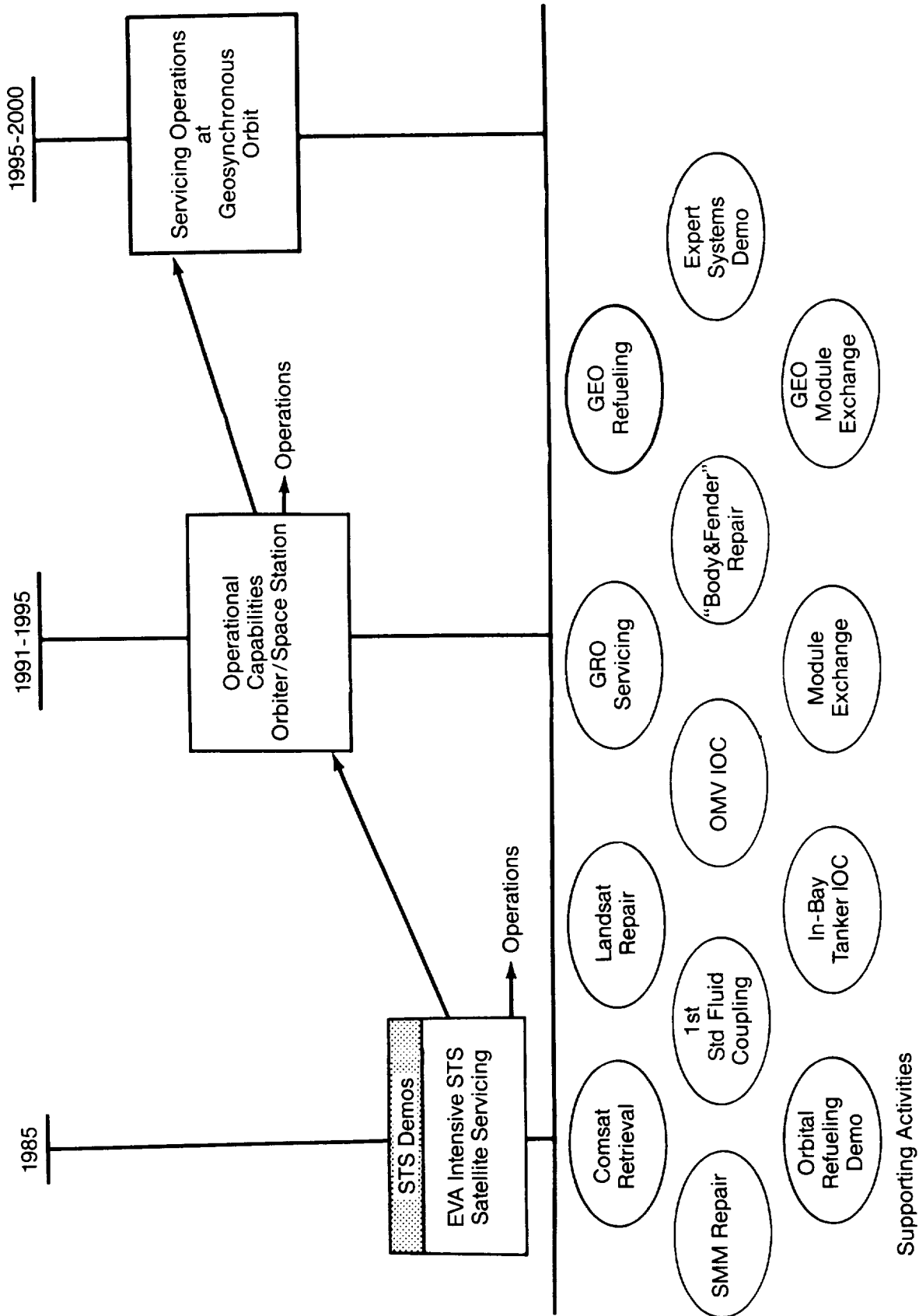
The objective of this portion of the satellite services program is to define, develop, and demonstrate capabilities for placing, retrieving, maintaining, repairing, and replenishing the consumables of satellites in orbit; retrieving nonstabilized satellites; and deorbiting space debris--all in the vicinity of the orbiter.

An initial capability for placement and limited retrieval of satellites is provided by the orbiter-mounted Remote Manipulator System, Manned Maneuvering Unit, integrated space suit and backpack called the Extravehicular Mobility Unit, and early tools for EVA. The Remote Manipulator System already has proven its ability to perform those functions by placing and retrieving the SPAS-01 platform during the Shuttle's STS-7 flight; and all those systems were used during the Shuttle's 41-C flight to perform the Solar Maximum Mission repair mentioned earlier. However, improved and new services will be needed by systems such as the Long Duration Exposure Facility, Multi-Mission Spacecraft, Space Telescope, Advanced X-Ray Astrophysics Facility, Space Station, and space platforms. Required will be equipment such as holding and positioning aids, maintenance and repair tools, servicing tools, berthing platforms, refueling tools and techniques, end effectors for the Remote Manipulator System, versatile television systems, and equipment for assembling and supporting large structures.

By the early 1990s, retrieval of nonstabilized satellites and debris near the orbiter should be possible with the use described earlier of the Orbital Maneuvering Vehicle (OMV) equipped with special front-end kits. Deorbiting of space debris by the OMV would free vital "space lanes" of hazardous debris.

Advanced development will provide other needed capabilities. Currently in development are proximity sensors and force-torque systems for "smart," highly capable end effectors for the Remote Manipulator System and of orbital refueling systems providing standard quick-disconnect mechanisms.

**Figure IV-9
Orbital Services**



Note: For definitions of abbreviations and acronyms, see Chapter X.

b. Satellite Services Remote from the Orbiter

Providing satellite services in locations remote from the orbiter will require communications and control capabilities much greater than those for services at the orbiter. Those greater capabilities also will be essential to the ability of the Space Station to function as an operational center for satellite servicing. The spacecraft that will provide those greater capabilities is the OMV. Its development will benefit considerably from experience gained a few years ago from development work on the Teleoperator Retrieval System, which was to be used to boost Skylab to a higher orbit. Contingent only on the availability of a suitable upper stage such as the Transfer Orbital Stage, Centaur, or reusable orbital transfer vehicle, demonstration is expected in the late 1990s of the use of an OMV service module teamed with an upper stage to service a satellite or platform in geosynchronous orbit.

Figure IV-10 shows the evolution of capabilities for providing satellite services remote from the orbiter and Space Station.

4. Advanced Transportation

Payload sizes and functions are expected to increase, since the increases will improve the performance and effectiveness of users' missions. For example, as discussed in subsection E.2.a. above, large communications satellites and platforms permit aggregation of functions, decrease service costs, and relieve the current trend toward overcrowding of the geostationary orbit arc. They may require remote or manned in-orbit services and maintenance, creating a need for further augmentation of STS and upper stage capabilities. Also, demands on the STS for transporting greater volumes and weights from Earth to low orbit can be expected to create further need for reducing costs and establishing more flexible manifesting.

a. Earth to Low Orbit Transportation

Figure IV-11 shows the expected evolutionary trend of transportation from Earth to low Earth orbit to satisfy the requirements mentioned in the preceding paragraph.

(1) Aft Cargo Carrier

Studies are under way of a possible near-term modification of the Shuttle, called the Aft Cargo Carrier, to provide more volume for payloads on flights that otherwise would be volume limited. That modification would provide a payload container projecting behind the Shuttle's external tank, which would be modified appropriately. It would take advantage of a currently unused location, doubling the Shuttle's payload volume while leaving the orbiter's cargo bay free for other payloads and placing virtually no penalty on payload weight. It also could take advantage of the expected increases to 32,000 to 36,000 kilograms in the STS' lift capability without requiring redesign of the orbiter's structure and landing gear.

Figure IV-10
Flight Experiments and Demonstrations—Satellite Services

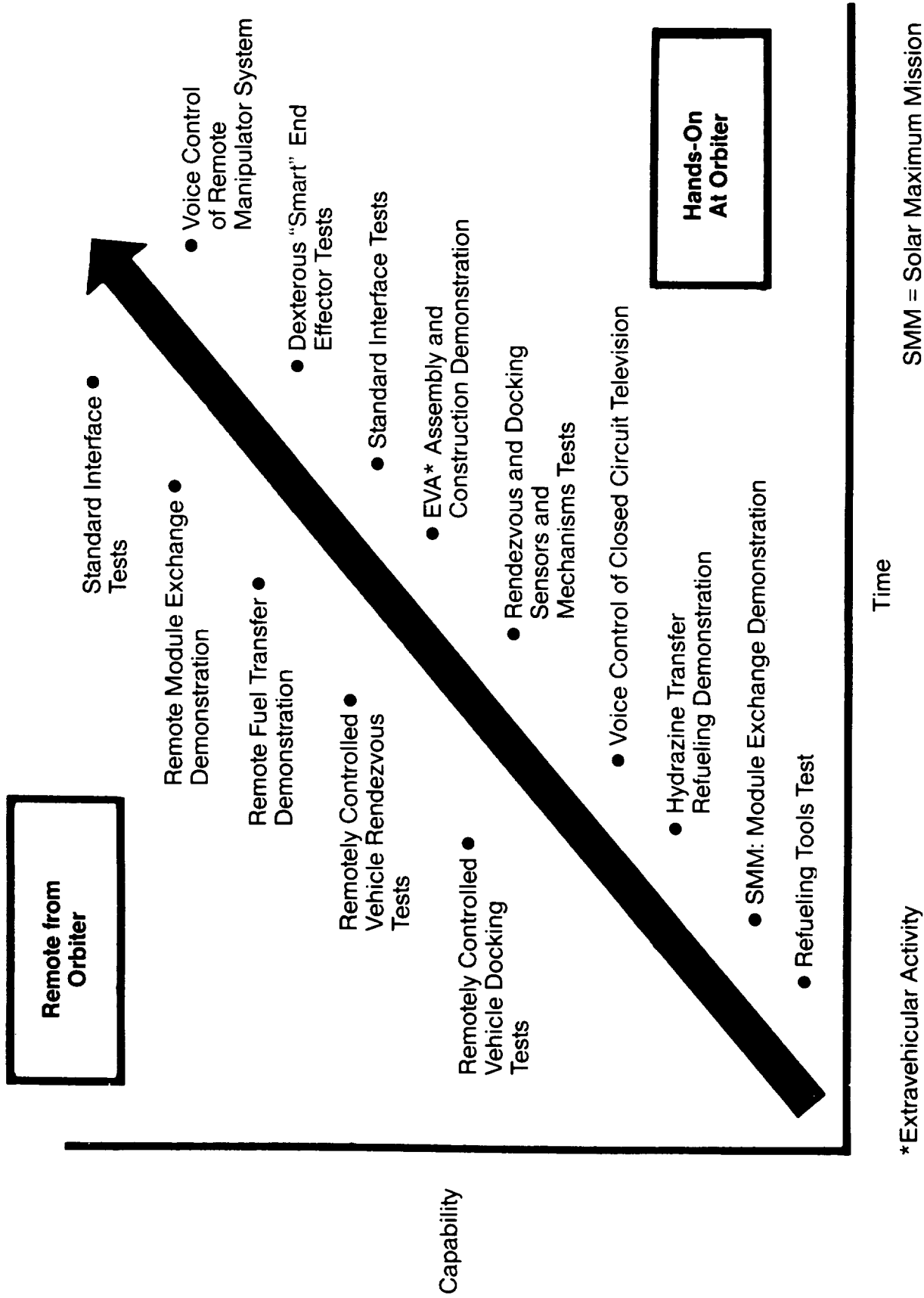
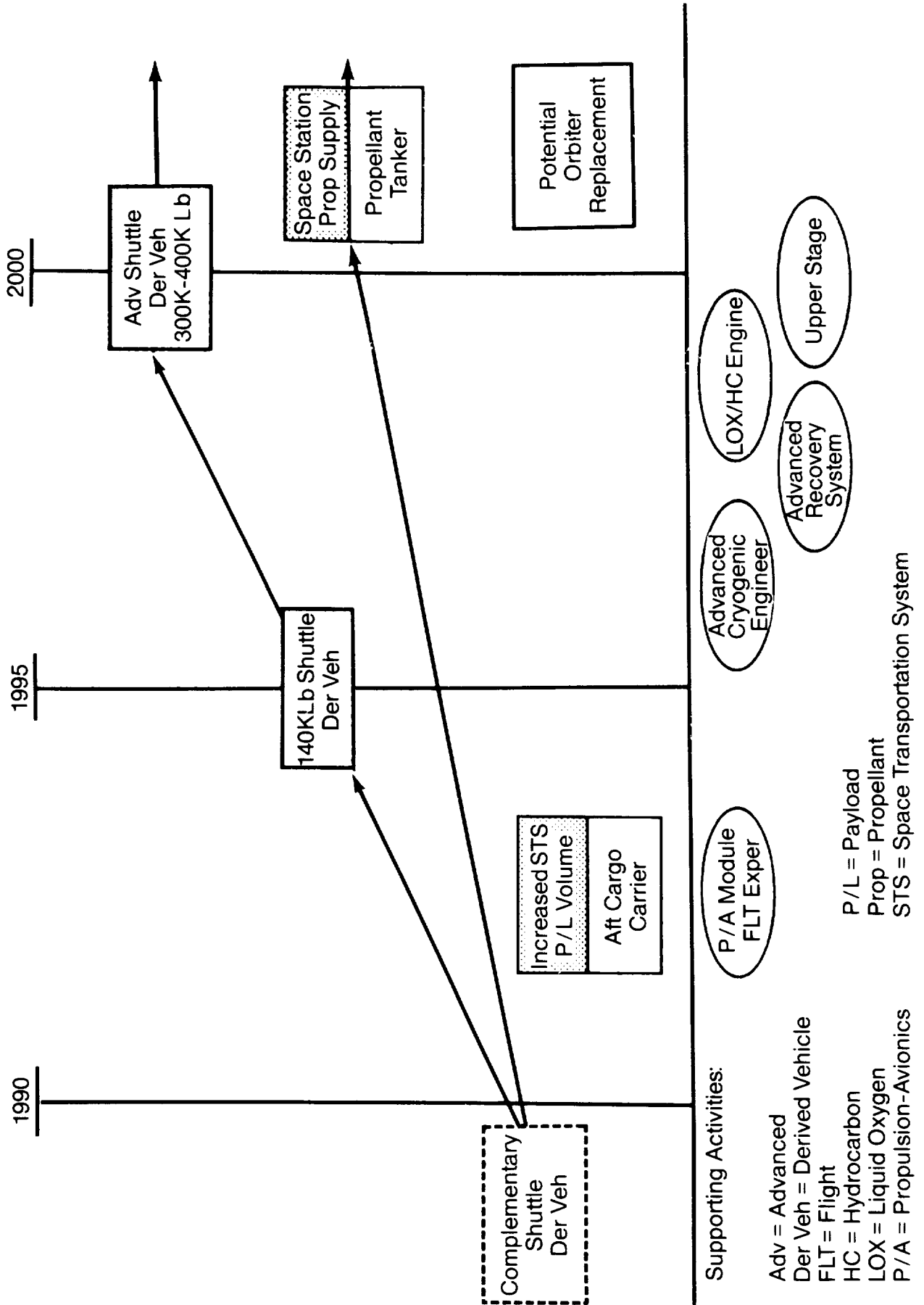


Figure IV-11
Advanced Launch Vehicles



(2) Shuttle-Derived Launch Vehicle

A variety of studies have been conducted in recent years in a search for a practical means to carry large, heavy payloads from Earth to low Earth orbit using a vehicle that would borrow extensively from STS hardware and facilities but would be unmanned and, therefore, not need to incorporate the orbiter itself. Most candidate configurations use the solid rocket boosters, the external tank or a shortened version of it, and one to three Shuttle main engines. Some configurations show considerable promise and will be pursued further as requirements emerge.

Figure IV-12 lists advanced missions "driving" the definition and possible development of transportation systems more advanced than the Shuttle. One anticipated requirement is for a "tanker" to transport propellants to the Space Station for the Orbital Transfer Vehicle. Such a tanker might be configured to transport approximately 63,600 kilograms (140,000 pounds) of cryogenic propellant in a single launch from existing STS facilities.

A major factor in establishing other uses for Shuttle-derived launch vehicles will be needs related to Department of Defense activities such as the new Strategic Defense Initiative. NASA is discussing with the Department of Defense and the Air Force potential joint definition and evaluation of candidate vehicles for such activities.

Development is anticipated of an economical vehicle to launch approximately 68,200 kilograms (150,000 pounds) to low Earth orbit to support the Space Station and possibly large unmanned platforms, as well.

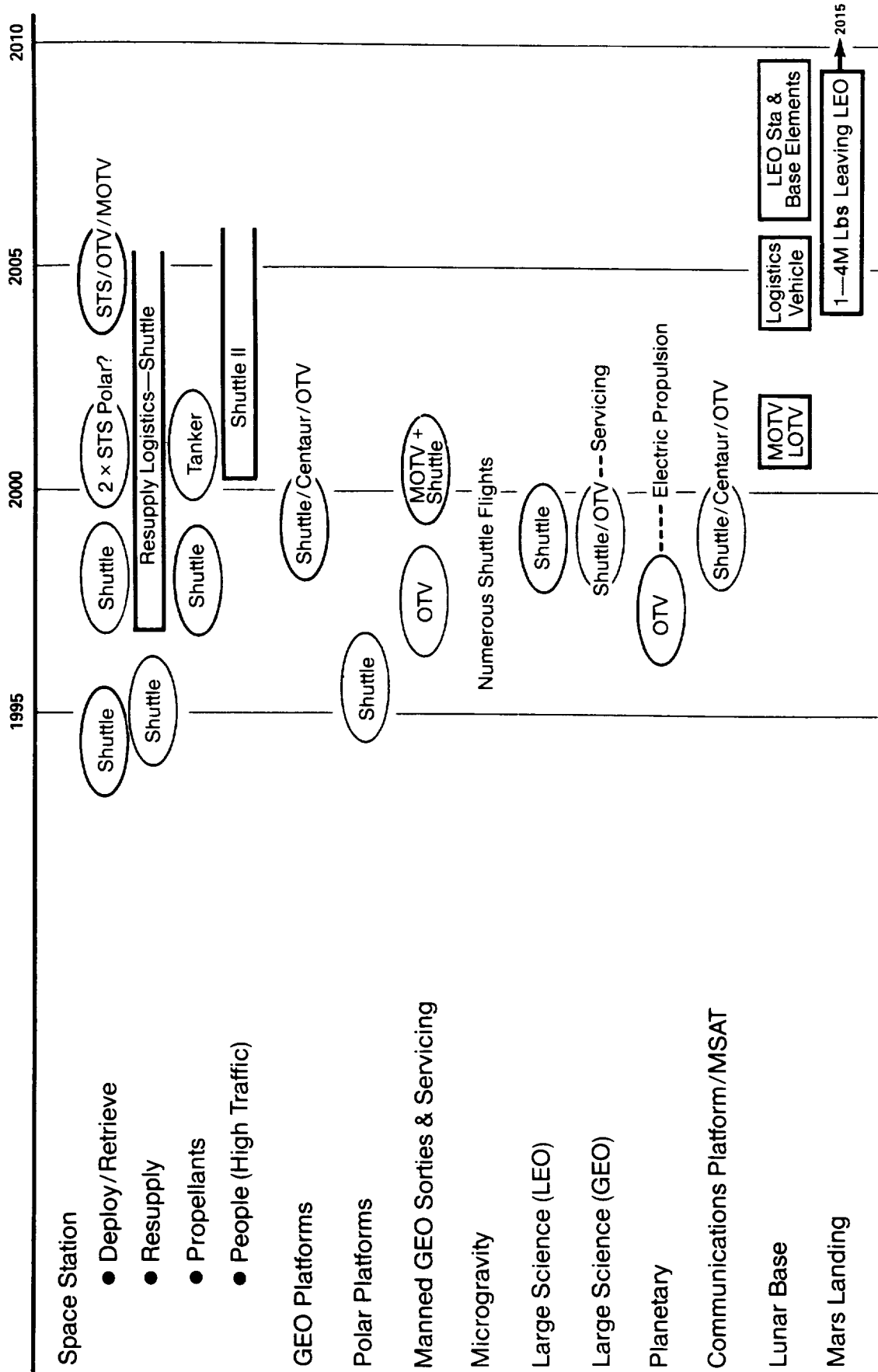
About the end of the century, the Shuttle orbiters may start to wear out, requiring replacement. A concurrent need is expected to develop for transporting increasingly larger numbers of persons to the Space Station or other low Earth orbit destinations. In addition to the rotation of crews, scientists, and technicians to the Space Station, there will be a need for transporting workers to assemble large structures at or near the Station. Farther into the future, the number of paying passengers is expected to grow. Consideration of all those factors has led to initiation of studies relating to a second-generation Shuttle that would emphasize transportation of personnel, with a secondary objective of transporting small, high-priority cargo. That vehicle would complement, and operate in conjunction with, the unmanned Shuttle-Derived Launch Vehicle.

(3) Heavy-Lift Vehicle

The Department of Defense's Strategic Defense Initiative possibly could involve payloads so large, heavy, and numerous that a major departure from STS technology would be warranted. NASA expects to participate in the Department of Defense's studies and tradeoff decisions as the Strategic Defense Initiative's requirements are defined, and to have a significant part in developing any new heavy-lift vehicle required.



Figure IV-12
NASA “Driver” Missions



Note: For definitions of acronyms, see the glossary.

b. Low Orbit to Geostationary and Other High-Energy Orbits

The evolution of advanced transportation from low Earth orbit to geosynchronous and other high-energy orbits is illustrated schematically in Figure IV-13. The Transfer Orbital Stage and the STS Centaur upper stage will satisfy the requirements of many geostationary and Earth-escape missions in the late 1980s, but an orbital transfer vehicle (OTV) will become necessary to facilitate use of the Space Station as a major transportation node in the 1990s.

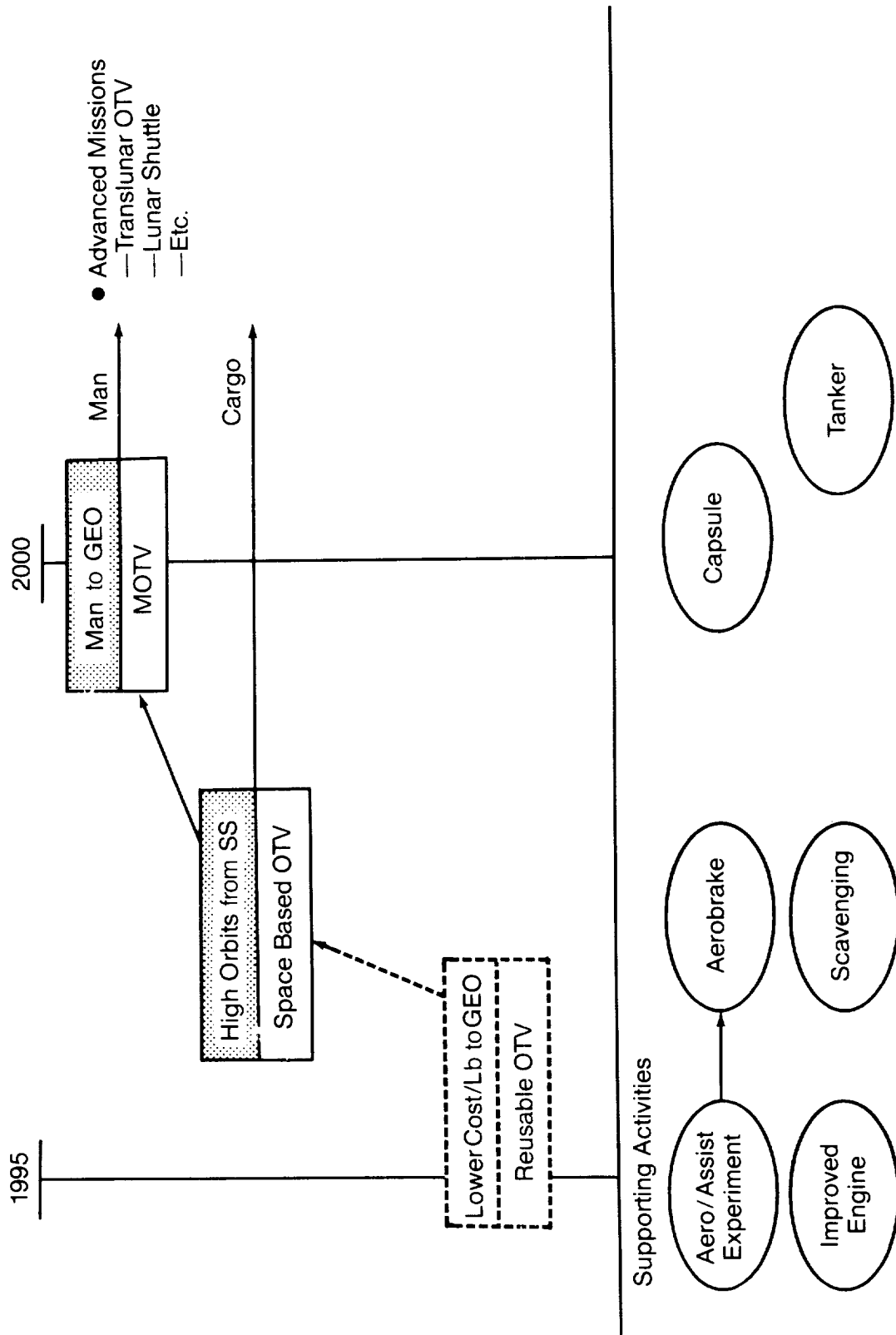
The OTV will be a reusable, high-performance upper stage mainly intended to be based at and launched from the Space Station. Although most of its destinations are expected to be at geosynchronous orbit, some of its civil payloads will be Earth-escape spacecraft. Concept studies for the OTV are in process, and preliminary results indicate that space-based OTVs may provide significantly lower costs than the STS Centaur will be able to provide for transportation to geosynchronous and other high-energy orbits. Large, reusable, cryogenic OTVs will be needed to place into geosynchronous orbit in the next 20 years heavy payloads such as large communications platforms. A low-thrust OTV will be needed to reduce accelerations imposed on large structures during deployment. Toward the end of the century, manned sorties to geosynchronous orbit and return will be the most demanding task for OTVs.

Current studies are examining configurations of OTVs that would be transported to orbit in the Aft Cargo Carrier described earlier, others that would be transported intact in the Shuttle's cargo bay, and still others that would be assembled at the Space Station. The studies also cover alternative propellants and tradeoffs among engine concepts.

Use of aerodynamic forces to brake OTVs returning to Earth orbit is being contemplated. Upon return to Earth orbit, a reusable orbital transfer vehicle must lose 2,400 meters per second of speed to achieve orbit circularization. If the OTV can make that reduction by deploying an aerodynamic drag device (aerobrake) at high altitude to interact with the upper atmosphere, it can carry nearly two times as much payload for the same propellant load.

To achieve maximum economy and minimum risk in development of the advanced transportation systems discussed in the paragraphs above, use of the Shuttle and, later the Space Station as test beds for flight experiments and demonstrations appears to be highly desirable. Experiments and demonstrations related to transportation from Earth to low Earth orbit are expected to address the Aft Cargo Carrier, the use of the Shuttle's solid rocket boosters to carry Hitchhiker payloads to conduct high-altitude soundings during the boosters' reentry, and an understanding of propellant transfer that could make possible the scavenging of fuel from the external tank. Experiments and demonstrations related to transfer from orbit to orbit are expected to focus on such suggested developments as long-duration storage of cryogenics in space, aerobraking technology using tethers to "troll" braking devices through the atmosphere, other uses of space tethers, and advanced EVA maintenance of propulsion systems.

Figure IV-13
Orbital Transfer Vehicle



Note: For definitions of acronyms, see Chapter X

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Space Station





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V. SPACE STATION

A. Goals

One of NASA's eight current goals is to develop, within a decade, a permanently manned Space Station. That goal reflects the President's directive to NASA in his January 1984 State of the Union address. Also, the Space Station is essential to the national policies of maintaining U.S. leadership in space activities and exploiting the economic and scientific opportunities offered by space. The Space Station has been a focus of NASA planning activities since May of 1982.

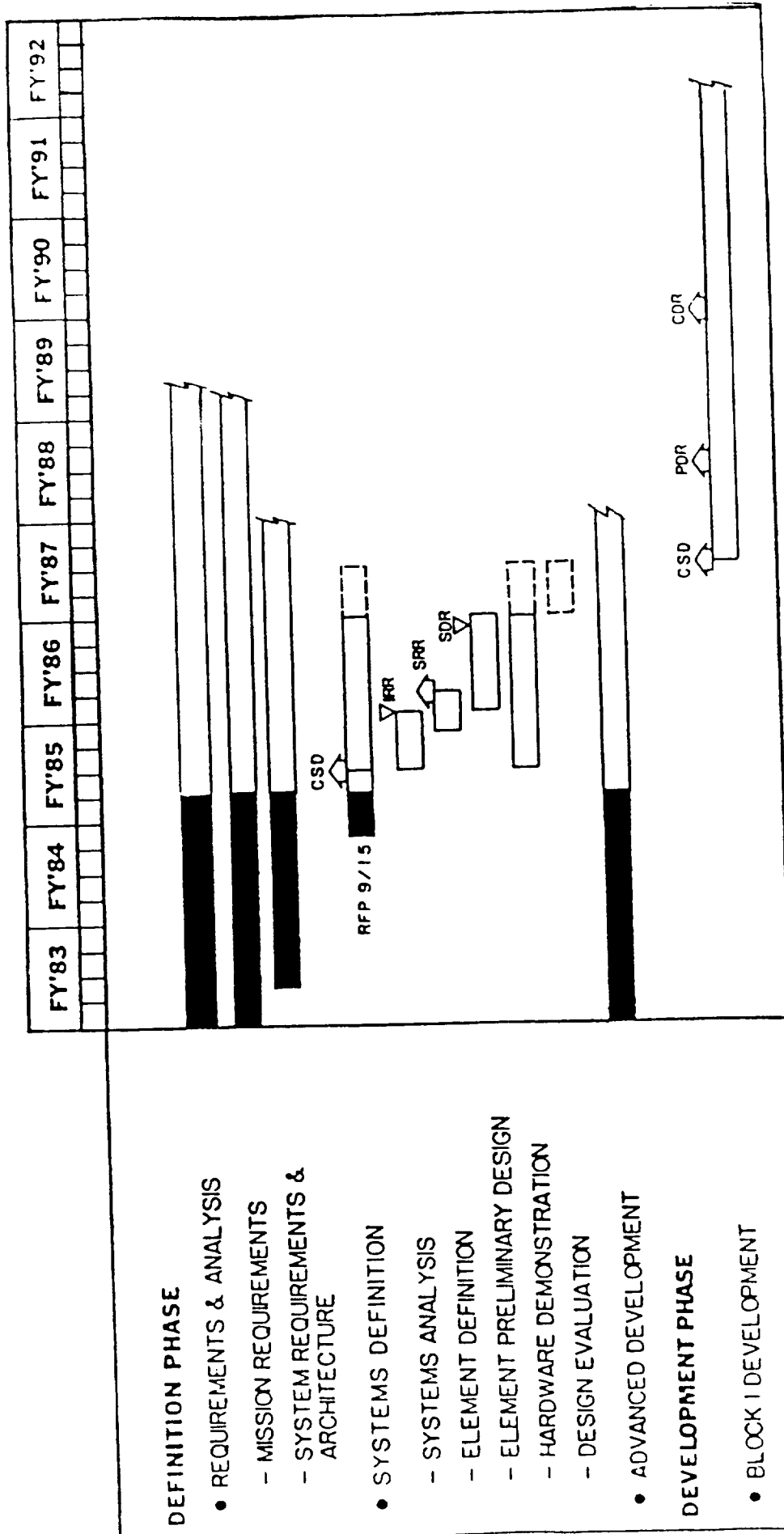
The goals of the Space Station program are to:

- o Establish means for a permanent and productive presence of people in space
- o Establish routine, continuous, and efficient use of space for science, applications, technology development, and operations
- o Develop further the commercial use of space
- o Develop and exploit the synergistic effects of the man-machine combination in space
- o Provide essential system elements and operations practices for an integrated, continuing national space capability
- o Stimulate the mutual benefits traditionally derived from cooperation in space with allies and friends
- o Reduce the cost and complexity of living in and using space
- o Be a major contributor to U.S. leadership in space in the 1990s and beyond
- o Ensure that the elements of the Space Station are compatible with and can interface with space elements of the operational Space Transportation System
- o Motivate future scientists and technologists and provide leadership in furthering their education.

B. Objectives

The near-term objectives of the Space Station program center on refining mission requirements for the Station; initiating technology and advanced development programs to ensure the availability of options for key technologies; and initiating systems definition studies to be performed by industry. Current plans call for a 3-year definition phase leading to initiation of a design and development phase in FY 1987 and an initial operational capability in the early 1990s (see Figure V-1).

FIGURE V-1
SPACE STATION PROGRAM SCHEDULE



DEFINITION PHASE

- REQUIREMENTS & ANALYSIS
 - MISSION REQUIREMENTS
 - SYSTEM REQUIREMENTS & ARCHITECTURE
- SYSTEMS DEFINITION
 - SYSTEMS ANALYSIS
 - ELEMENT DEFINITION
 - ELEMENT PRELIMINARY DESIGN
 - HARDWARE DEMONSTRATION
 - DESIGN EVALUATION

DEVELOPMENT PHASE

- BLOCK I DEVELOPMENT

CSD - CONTRACT START DATE
 CDR - CRITICAL DESIGN REVIEW
 IRR - INTERFACE REQUIREMENTS REVIEW
 PDR - PRELIMINARY DESIGN REVIEW

SDR - SYSTEM DESIGN REVIEW
 SRR - SYSTEM REQUIREMENTS REVIEW
 ◊ - LEVEL A CONTROLLED MILESTONE

The program's long-term objective is to provide the main elements of the system, key organizational structures, and expert operational procedures that, together, will constitute the principal in-orbit infrastructure needed to support national goals for the U.S. civil space program in the 1990s and beyond. This objective includes participation by international partners in the design, development, construction, use, and operation of Space Station elements; enhancement of The Station's capacity and technical capability by both the addition of elements and the incorporation of new subsystem technologies; advancement of the technologies of automation and robotics; and assurance of high productivity from humans in the space environment.

Due to the Space Station program's requirements for long-lifetime, evolutionary growth, in-orbit integration, and international cooperation, NASA plans to perform system engineering and integration itself. All of the NASA centers have participated in the planning for the system. The Space Station Office at Johnson Space Center will manage the overall integration of the program, with assistance from the other centers. During the definition and preliminary design phase, which will begin April 1, 1985, system alternatives will be identified and evaluated as a basis for selection of a base-line configuration that best satisfies program requirements. NASA will use the data and analyses developed by its own personnel, study contractors, and potential international participants in selecting the initial and subsequent designs.

One of the challenges of the Space Station program is to determine as optimum a mix as possible of humans and machines in order to achieve the best of manned, man-tended, and automated systems. Space Station systems that will advance automation and robotic technologies will be identified and analyzed with a view toward maturing the technologies as a part of the definition and preliminary design phase. The Station that evolves will include both manned space flight elements and unmanned spacecraft in such a way that humans will perform activities requiring their presence, while activities more suitable for automated systems will be accomplished in a man-tended mode.

C. Planning Strategy

Many significant aspects of the Space Station program make it unique compared with major programs of the past and, taken together, dictate a set of strategic planning guidelines that govern program activities. The principal planning guidelines follow.

1. User Community Involvement

To meet the goals of the program and maintain consistency with national space policy, NASA has made a concerted effort to involve all potential U.S. users in planning for the Space Station: the science and applications communities, aerospace industry, commercial organizations, and technology development organizations, in the United States and abroad. Users will develop a continuously changing and growing spectrum of requirements that must be refined, updated, and accommodated in a manner that achieves the best balance among resources, capabilities, and technological readiness.

2. Extensive Definition Before Program Initiation

One of the major conclusions of NASA's Project Management Study (the Hearth Report) in 1981 was that thorough project definition should precede system development. In agreement with that conclusion, the Space Station program is conducting an extensive definition and preliminary design phase that includes an already completed period of inhouse concept definition that will be followed by an 18- to 24-month contracted definition effort to begin in early CY 1985. The inhouse definition work has improved the Agency's ability to be a capable buyer and has laid a foundation for systems engineering and integration activities.

3. Agencywide Participation

Planning for the Space Station program has involved all NASA installations, first through their representation on the Space Station Task Force and then through their participation in preparation of the request for proposals for definition and preliminary design. The breadth of the program calls for their continued involvement. The program's success depends on both the contributions of the Agency's science and applications experts and the technologies developed at the research centers.

4. Evolution

Except for the Space Transportation System, NASA's past programs have provided hardware with limited evolutionary capability. A "permanently manned Space Station" inherently must span decades and be designed to accommodate evolutionary growth through incremental addition, modification, and replication. To ensure that its useful life is not short, the Station must be able to evolve in capacity, capability, and technology. A properly designed station will provide a foundation for succeeding major space activities, be they manned operations at geosynchronous orbit or missions beyond Earth orbit, such as establishment of a lunar base, the mining of precious resources from the moon or asteroids, or a sample return or manned mission to Mars.

5. Maintainability

The Space Station must be designed for in-orbit maintenance to retain its equipment in, or restore it to, a fully operational condition. Cost-effective operations will depend on integration of maintainability considerations and requirements with other closely related functions such as reliability, safety, quality assurance, verification testing, and logistics.

6. Operational Autonomy

From the outset, the Space Station must be able to operate as independent of the ground as possible. Ideally, it would be totally autonomous except for resupply of materiel and personnel. In particular, there should be no need for full-time monitoring of subsystem status, detailed crew work scheduling, or crew health assessments by teams of engineers, scientists, and mission controllers on Earth. Almost all of the Station's routine monitoring tasks should be automated.

NASA plans to retain overall operational control of the Station, but expects participation in the operation by personnel of other user organizations, which also will employ Station payloads autonomously in making scientific observations and performing manufacturing tasks.

7. International Participation

In his January 1984 State of the Union message, the President invited friends and allies of the United States to participate in development and use of the Space Station. NASA's long-standing partners have expressed interest in participating in the planning, development, operation, and use of the Station. The European Space Agency, Canada, France, Germany, Italy, and Japan have conducted, at their own initiative and expense, mission analysis studies paralleling NASA's. In addition, they and the United Kingdom are examining what future part they potentially could play in the program.

To coordinate Space Station planning activities and exchange information, NASA held in 1984 a series of workshops attended by all potential international partners. Negotiations were initiated with the European Space Agency, Canada, and Japan for cooperative agreements on the definition activities each country will undertake. A near-term goal is agreement by the mid-term of the definition studies on what elements each partner will carry into development. A long-term goal is a capable initial Space Station enhanced by the participation of international partners.

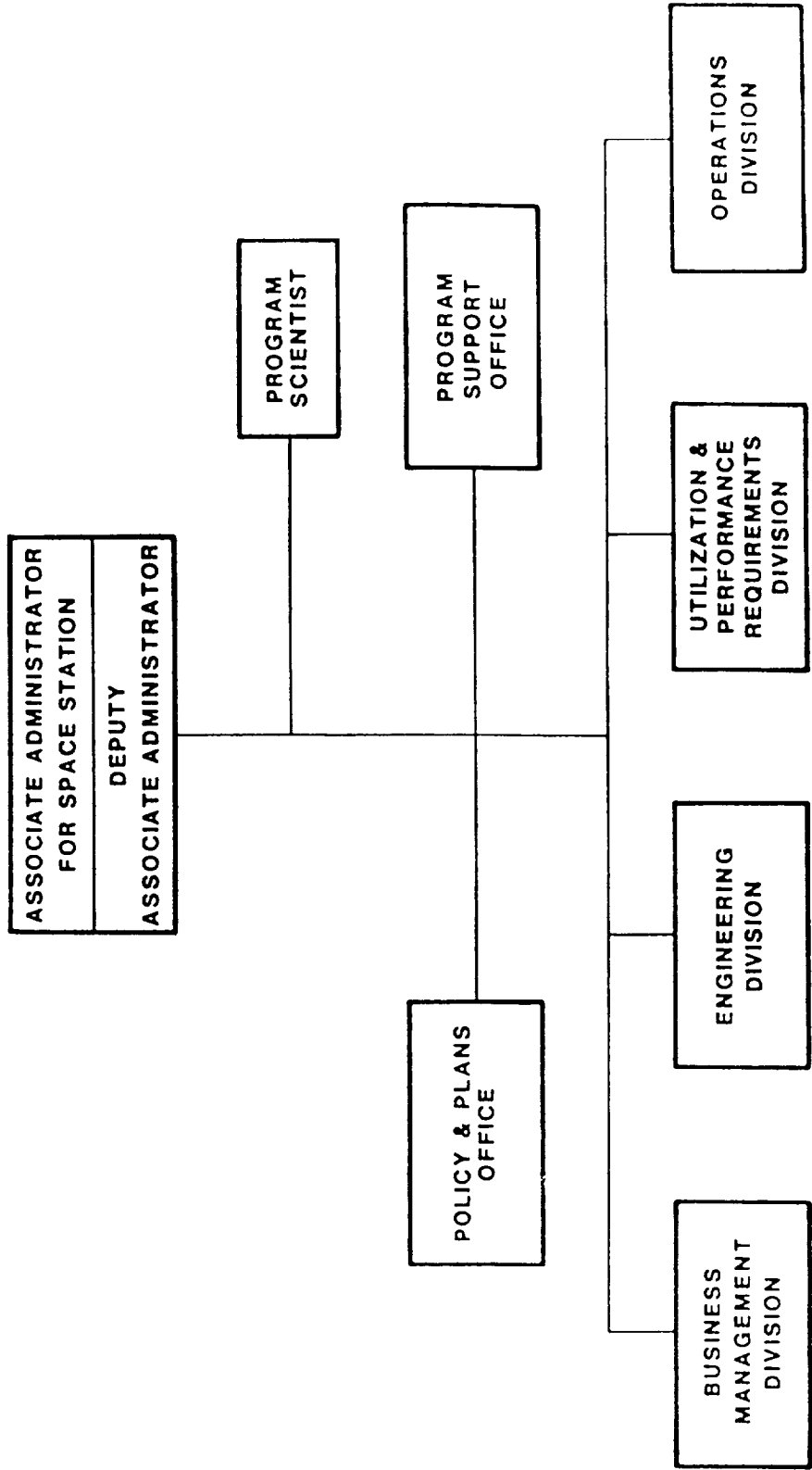
D. Key Features of Program

1. Management Approach

At the time the President directed NASA to develop a permanently manned space station, NASA was in the final months of Space Station concept definition. Conducted over a 2-year period, concept definition was completed in April 1984 under the aegis of the Space Station Task Force, an amalgam of engineering, scientific, financial, and administrative experts from every part of the Agency, with augmentation and advisory support from academia and the aerospace industry.

Concern for the development of technical concepts and operational requirements is equaled by concern for the management approach to Station development. In May 1984, the Space Station Task Force was replaced at NASA Headquarters by the Interim Program Office. Concurrently, Johnson Space Center was designated "lead center" and assigned responsibility for NASA-wide program management of design, system engineering and integration, advanced development and test, and customer interface. Overall direction of the program was the responsibility of the Interim Program Office and now rests with the Office of Space Station, which was created at NASA Headquarters in September 1984 following approval of funding in the FY 1985 budget for advanced development, program definition, and preliminary system design. That office's organization is pictured in Figure V-2. Responsibilities remaining with NASA Headquarters are for overall policy and program direction, establishment of requirements, schedule and budget guidelines, and related actions involving commercial and international users, Congress, the Office of Management and Budget, the Office of Science and Technology Policy, and other government departments.

FIGURE V-2
OFFICE OF SPACE STATION



The Agency's research and development centers have been assigned responsibility for project management of system definition, design and development of major elements of the Station, participation in the system engineering and integration program, and specific advanced development projects. Proposals for the definition phase have been received. Concurrent with its planning for the definition phase, NASA has appraised extensively the need for advanced technology projects that will minimize the risk associated with the development phase. A substantial advanced development program will be initiated in FY 1985 to advance, during the next several years, key technologies that will allow final design choices to be made with higher confidence. The development phase will begin in FY 1987.

Continuing emphasis has been given to involving the scientific and technical communities in every step of program planning and implementation to the maximum degree possible. Key to the management approach, this early and continued involvement of potential users has included extensive use of NASA's external advisory structure to supplement the Agency's internal expertise. For example, the NASA Advisory Council's Task Force on the Scientific Uses of the Space Station advised NASA on how best to ensure and enhance the Station's scientific capabilities. Continuing managerial attention also has been given to development of policies and plans for international participation.

A final major management challenge has been to continue the iterative process of developing requirements, analyzing configurations, and estimating costs to ensure achievement of the program's technical and schedule goals within the estimated total cost of \$8 billion (FY 1984 dollars). The advanced development program in key technology areas mentioned earlier will broaden the subsystem options for the final design and reduce the technical risks in critical areas. During development, to begin in FY 1987, all major contracts for hardware will include a formal performance measurement system to allow contractor and NASA managers to assess progress, identify problems, and take timely corrective action to ensure integrity of program content, schedules, and budgets.

2. Space Station Operations

The Space Transportation System will deliver the elements of the Space Station system to orbit; and initial assembly, activation, checkout, and operational verification will be achieved in a Shuttle-tended mode by the Space Station flight crew assisted by ground control. The Shuttle will transport expendables and spares to the Station in a resupply module every 90 days. Crew occupation will occur after the manned system is verified. Initially, the crew will number 6 to 8 and will be rotated totally or partially by the Shuttle every 90 days. Later, long-term operations will include larger flight crews including payload specialists and scientists.

The Space Station system is expected to evolve through in-orbit integration of additional hardware, including more habitat and laboratory modules, attached payloads, additional equipment for servicing and repairing spacecraft, facilities for mating spacecraft to upper stages, protective storage facilities with environmental conditioning equipment for spacecraft awaiting deployment and for storing orbital replacement units, and facilities and equipment for basing, servicing, and maintaining upper stages.

Propulsive stages will be based at the Station to bring to the proximity of the Station, for servicing, satellites and platforms that do not have their own propulsion. The Orbital Transfer Vehicle, based at the Station, will move payloads to and from different orbits. Manned Maneuvering Units at the Station will provide mobility during extravehicular activity within the immediate vicinity of the Station.

The Space Station will have significant and growing functions involving logistics, information control and processing, and proximity traffic control. Because the Station will operate for years with minimal ground support, a major challenge for the program is to incorporate operability, reliability, maintainability, and provisions for logistics support into the Station.

3. Design to Cost

As mentioned previously, the total cost of the Space Station program has been estimated to be approximately \$8 billion in FY 1984 dollars. That cost includes all the work performed by the NASA centers, program support, integration, and deployment of the initial Station. Satisfaction of program requirements within that cost constraint requires a rigorous design-to-cost approach to all definition and development activities. Full exploration is planned of design-to-cost tradeoff studies during the program definition phase.

4. Technology Transfer

As stated earlier, the President invited other countries to participate in the Space Station program. Participation will be achieved on a government-to-government basis in such a way as to prevent unwarranted transfer of technology while creating meaningful international cooperation. This aim is in keeping with NASA's policy of encouraging the domestic dissemination of technology to enhance the competitive posture of U.S. industry while preventing the loss of sensitive technology to international adversaries and competitors. All cooperative agreements will be structured to provide clean technical interfaces between the participants and NASA and to ensure that all participants assume full responsibility for developing their projects.

5. Department of Defense Participation

The Space Station is a civil endeavor, based on civil requirements. Although the Department of Defense is studying what uses it might have for a permanently manned space station, it has not identified current military requirements for a station. However, NASA believes that in the future the Department might use the Station's laboratory facilities for research purposes. In any event, NASA will continue to keep the Department fully informed on Space Station activities.

6. Modularity, Commonality, and Evolutionary Nature

Several new approaches will be used in the program to reduce costs and to impose on the Station fewer weight and configuration constraints than those imposed on past space systems. Many Station elements will have common subsystems and components. That commonality and modularity are expected to lower total costs. Further, the Station's evolutionary nature should allow new

systems and components to be developed, tested, and upgraded in an operational setting, eliminating the need for some of the currently necessary qualification testing on the ground.

7. Proper Mix of Humans and Machines

Many studies and experience in the Skylab and Shuttle-Spacelab programs have indicated the utility that humans will have in the Space Station system. However, many potential missions will be performed best by automated, free-flying spacecraft, with only periodic human intervention through remote "telepresence." A major objective of current planning is to define the proper mix of human and machine functions in the Space Station setting so that tasks can be distributed properly and machines and humans will enhance each others' abilities. To increase understanding of advantageous uses for automated and robotic systems aboard the Space Station, NASA--at the direction of Congress--established the Advanced Technology Advisory Committee. The Committee's report is expected in the Spring of 1985 and will be made use of in Space Station preliminary design activities.

8. Functional Requirements

A Space Station Mission Synthesis Workshop was held in May 1983, with participants from NASA, the National Oceanic and Atmospheric Administration, the U.S. Air Force, and U.S. industry. It examined the findings of previous mission analyses, inhouse studies, and reports from advisory committees. The Workshop produced a preliminary set of more than 100 phased activities for the Space Station during the period from initial operation to the year 2000, and base-line requirements for the initial configuration. The base-line requirements included a manned element at an orbit inclination of 28.5° and two platforms, one at low inclination and one in polar orbit.

Two subsequent workshops were held during 1984, the first in March and the second in September. The first included NASA science and technology users and users from the National Oceanic and Atmospheric Administration and from industry. The second added users from the European Space Agency, Canada, France, Germany, and Japan. In both workshops, all potential users of the Station were invited to present the requirements that their activities would place on the Station for the period from initial Station operation to the year 2000. The potential uses that resulted range from mounting single instruments on a Station element to programs requiring a complete manned module for their fulfillment. The users identified a major emerging need for the manned element to serve as a base for modification, repair, and servicing of free-flyers.

The consolidated data base now reflects the funding priorities of the sponsoring user organizations and will provide requirements information to the Space Station contractors at the start of their program definition and preliminary design work. The data base contains more than 300 entries covering scientific, technological, and commercial activities, both domestic and foreign.

Organizations reporting directly to program management have been established at both the Headquarters and the lead center to represent and interact with the users. Those organizations are responsible for maintaining a current

set of user requirements, translating the requirements into performance requirements for the Station, and ensuring that those requirements are reflected in the Station's design and operational procedures to the satisfaction of the users.

E. Current Program

For CY 1985, the Space Station program is concentrating on the following principal tasks:

- o Evaluation of proposals and selection of sources for contractors for the program definition and preliminary design phase, which is planned to extend to the end of FY 1986 and has the following objectives:
 - To define innovative concepts that will increase productivity and provide cost-effective means for conducting all phases of the program
 - To define and conduct system engineering and integration activities associated with the work package described in Table V-1
 - To define the initial and growth Space Station program and determine the optimum scenario for assembly of the Station, including the option of a man-tended version
 - To define the benefits of automation and robotics technology and incorporate it, as appropriate, into the design of the Station
 - To create preliminary designs of the initial manned and man-tended elements of the Station and conceptual designs of growth elements
 - To understand and develop required advanced technology
 - To understand operations planning for the elements of the Station
 - To plan means for accommodating the use of Station elements by customers
 - To develop plans for implementing the design and development phase and to understand the scope, schedule, and cost of the program
- o Advancement of subsystem technologies critical to selection of the design to be developed during the design and development phase of the program. Advanced developments in process involve studies, prototype devices, and flight-experiment planning for attitude control and stabilization, data management, auxiliary propulsion, environmental control and life support, space operations mechanisms, thermal controls, and electric power generation, storage, and distribution. Activity on all those advanced developments will continue beyond FY 1987 and will play a major role in reducing the technical risk in selecting the initial and growth designs for the Station.
- o Encouragement of international cooperation and planning, which has proceeded actively since the London Economic Summit in June 1984, at

TABLE V-1

WORK PACKAGE SUMMARY DEFINITION

WP-01-MSFC

SE&I SUPPORT

- ECLS ANALYSIS
- LOGISTICS ANALYSIS
- OMV/OTV INTERFACE ANALYSIS
- COMMON MODULE COMMONALITY ANALYSIS
- PROPULSION ANALYSIS
- REBOOST ANALYSIS
- LABORATORY ANALYSIS

WP-02-JSC

SE&I SUPPORT

- GROWTH ANALYSIS
- DMS ANALYSIS
- COMM/TRACKING ANALYSIS
- LOADS ANALYSIS
- THERMAL ANALYSIS
- CONTROL ANALYSIS
- ASSEMBLY SEQUENCE DEFINITION
- STS PROXIMITY OPERATIONAL BERTHING ANALYSIS
- CREW INTERFACE ANALYSIS
- RESOURCE INTEGRATION ANALYSIS

WP-03-GSFC

SE&I SUPPORT

- PLATFORM CONFIGURATION AND COMMONALITY ANALYSIS
- PLATFORMS/SATELLITES SERVICING ANALYSIS
- ATTACHED PAYLOADS ANALYSIS
- LABORATORY ANALYSIS
- STATION/PLATFORM INTERFACE ANALYSIS

WP-04-LeRC

SE&I SUPPORT

- POWER SYSTEM ANALYSIS

HARDWARE/SOFTWARE

- COMMON MODULE
- STRUCTURE
- DISTRIBUTION FOR:
 - DMS
 - POWER
 - ECLS
 - THERMAL
 - COMMUNICATIONS
- ECLS SYSTEM
- PROPULSION SYSTEM
- LABORATORY MODULE OUTFITTING (1)
- LOGISTICS MODULE OUTFITTING (2 of 3)
- OMV/OTV ACCOMMODATIONS
- APPLICATIONS SOFTWARE

HARDWARE/SOFTWARE

- ASSEMBLY STRUCTURE
- TRUSS
- MODULE INTERCONNECT
- AIRLOCK
- STS BERTHING
- PWR, THERM., GIMBALS
- MANIPULATORS
- RESOURCES INTEGRATION
- THERMAL CONTROL SYSTEM OUTFITTING
- EVA SYSTEM AND AIRLOCK OUTFITTING
- GUIDANCE, NAVIGATION AND CONTROL SYSTEM
- COMM/TRACKING SYSTEM
- DMS
- HABITAT MODULE OUTFITTING
- STS INTERFACE
- APPLICATIONS SOFTWARE

HARDWARE/SOFTWARE

- PLATFORMS
- ATTACHED PAYLOAD ACCOMMODATIONS
- PLATFORM AND FREE FLYER SERVICING ACCOMMODATIONS
- LABORATORY MODULE OUTFITTING (1)
- APPLICATIONS SOFTWARE

HARDWARE/SOFTWARE

- POWER SYSTEM
- GENERATION
- CONDITIONING
- STORAGE
- APPLICATIONS SOFTWARE

which the President explained and extended again his invitation for other nations to participate in the program. The general procedure to be followed is that each foreign government participating in the program will conduct independent, but parallel, program definition studies through early CY 1987, with an interface requirements review attended by all participants to be held at the end of CY 1985. That schedule will allow all participants to proceed with their own development of hardware concurrent with preliminary design development planning by the United States in the Spring of 1987.

- o Completion of focused studies on human productivity, automation and robotics, and Space Station data management systems to provide essential information for use in the preliminary design contracts to be let in 1985.
- o Completion of development of the separate acquisition plan begun in late 1984 for the Station's Technical and Management Information System. That system should provide the hardware, software, and operation and service support required by all technical and programmatic elements of NASA and the associated contractors. Plans are for the system to be operational in the summer of 1986 to be proved and ready for use when development of Station hardware begins.
- o Continuation through early 1985 of the progressive updating of functional requirements by means of a series of activities involving U.S. government, foreign government, and selected U.S. commercial participants. The purpose is to develop a complete, coordinated set of formal requirements for use from the beginning of the program definition and preliminary design contracts in 1985. Definition of requirements will continue, at least for the next several years, as definitions of attached payloads and orbiting platforms mature and their needs for in-orbit control, data processing, servicing, and maintenance become better understood.

F. Space Station Configuration

In April 1983, the Space Station Task Force managed and coordinated trade-off studies, conducted preliminary cost analyses, and integrated the results of mission requirements studies into a set of functional capabilities, or "architecture." The first architecture was completed in May 1983 in conjunction with a study conducted by the Senior Interagency Group (Space) at the request of the President. An iteration was completed in July 1983 for use in preparing NASA's FY 1985 budget submission. A second iteration was completed in December 1983, and a third, at Johnson Space Center, for use as a reference configuration in preparation for procurement of system definition. This iterative process will continue and should provide a thorough system definition based on the most current mission sets, functional capabilities, and budget plans.

An approved configuration for the Space Station does not yet exist. Although the reference configuration for the Station specified in the request for proposals for systems definition calls for functional capabilities represented by the following elements, some of the elements could change: two habitat modules, a logistics module, two laboratory modules, an unmanned

platform at an orbital inclination of 28.5⁰, an unmanned platform at an orbital inclination of about 90⁰, an orbital maneuvering vehicle, and a servicing system.

G. Underlying Technology

In 1981, NASA formed the Space Station Technology Steering Committee to assess technologies expected to be needed for a 1990s space station. The Committee concluded that a station using state-of-the-art technology would not meet the goals for the program because it would not have affordable growth potential and because providing it with an indefinite life through in-orbit maintenance would not be cost effective. The Committee also identified technology advances that would be necessary for the station to meet program goals. To help guide technology development for the station, a workshop was convened in FY 1983 to review the technologies relevant to a space station, both those now available and those in process in NASA and industry research and development programs.

1. Advanced Development Program

To provide advanced technologies needed for an evolutionary space station, the Office of Space Station has initiated an advanced development program and, to coordinate the program, has worked out agreements with relevant program offices. The program will use test beds in key technology areas--such as power, life support, and data management--in the research and testing conducted to develop technology options for use in developing the station.

Integration of the advanced development program with system definition activities will be important. Plans are to involve the definition contractors in the program through both their contracts and the NASA test beds. To encourage the contractors to develop advanced technologies they believe the station will need to meet its goals, the requests for proposals for system definition will call for them to propose selection criteria, tasks, and funding for development of advanced technology. They may propose that as much of their funding as they deem necessary be spent for that purpose. In addition, NASA will make its test beds and the Space Transportation System available to the contractors for testing advanced technology ideas. A schedule exists for announcing these plans to industry, working out agreements for use of the test beds, informing contractors of the status of development of the test beds, and reviewing the contractors' progress in advanced technologies.

Major decisions will occur near the end of the definition phase when NASA reviews the progress made in developing advanced technologies and selects those that will be used in the development phase.

2. Definition Program

The definition program has four major components: supporting studies and analyses covering functional and system requirements, system definition, advanced development, and technology. It will evolve into the system development phase, scheduled to begin in FY 1987.

The principal emphasis of the supporting studies component is early and continuous involvement of users in derivation of all the program's activities. System definition must focus on development of a concept for growth of the total system through the year 2000 that will be reflected in the detailed definition of the system's initial elements. Subsequent definition will begin as the initial elements enter development.

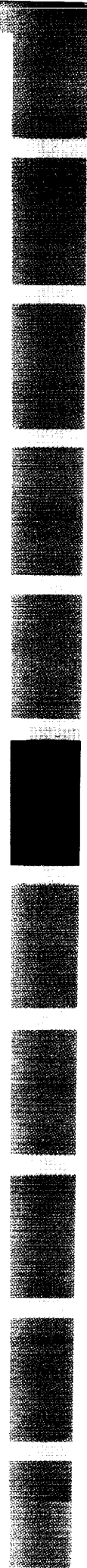
As stated in Section 1 immediately above, success for the definition program is highly dependent on its efficient interaction with the advanced development program. Both ground-based test beds and flight experiments are planned and are expected to play a vital role in definition of evolutionary elements. The test beds will serve as a conduit through which NASA's technology will be channeled, and incentives for their use will be included in the definition contracts. Valuable results are expected to be reduction in program cost and risk through an increase in insight into design details and through demonstration of hardware.

H. Technological Relationships with Other Program Areas

The Space Station program has close relationships with the Office of Space Science and Applications in developing mission requirements and in planning accommodations for science and applications payloads in the design and operation of Station elements. The Office of Aeronautics and Space Technology is helping to implement the Station's advanced technology program, and the Office of Space Tracking and Data Systems is assisting in the planning for processing data generated by the Station and the systems and activities it supports. The activities those program offices will conduct in support of the Station are described in chapters III, VI, and VII of this report.



Space Tracking and Data Systems





VI. SPACE TRACKING AND DATA SYSTEMS

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VI. SPACE TRACKING AND DATA SYSTEMS

A. Function

The primary function of the Space Tracking and Data Systems (STDS) program is to provide tracking and data support to the Nation's space missions. The program plans for, develops, and operates the space and ground network of tracking and data systems required to support the inflight missions of automated and manned orbital spacecraft, deep space vehicles, sounding rockets, balloons, and research aircraft. For operational support, the STDS program provides three basic elements: a space network, a ground network, and the related communications, control, and data systems. In addition to those three operational elements, the program includes studies and development of advanced systems, which provide the technology base from which future operational elements are derived. The STDS program also must provide responsive management of NASA's program support communications and of its activities related to allocation of the radio frequency spectrum.

B. Major Objectives

1. Space Network

The program's most important objective is that of getting the Tracking and Data Relay Satellite System (TDRSS) ready for full operation. To handle the combined support workload created by low Earth orbit systems anticipated for the last decade of the century, at least three satellites must be maintained in operation.

2. Ground Network

After phasing out ground stations in the Space Tracking and Data Network that TDRSS makes unnecessary and after consolidating the remaining stations with those of the Deep Space Network, NASA will operate a single ground network under the management of the Jet Propulsion Laboratory. 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 back-up support for certain missions in low Earth orbit, such as those of the Space Shuttle.

3. Other

Other important objectives for the STDS are to:

- o Improve efficiency and economy in processing large volumes of data
- o Upgrade the communications support provided by NASCOM (the NASA network of leased communications services for operational data flow among stations, control facilities, and users) to meet the demands of NASA missions with high data rates
- o Develop technology to facilitate use of the TDRSS space network
- o Improve current capabilities for receiving telemetry from Voyager's encounters with Uranus and Neptune

- o Continue support to the aeronautics, sounding rocket, balloon, and geodynamics programs and increase the support capacity of the aerodynamics test range
- o Provide support for the processing of Spacelab data and for controlling the Space Telescope mission
- o Improve and increase the efficiency of NASA's program-support communications
- o Plan for a follow-on system for the TDRSS
- o Participate in the definition of space station requirements and prepare for its support.

C. Plans for Program Elements and Mission Support

1. Space Network

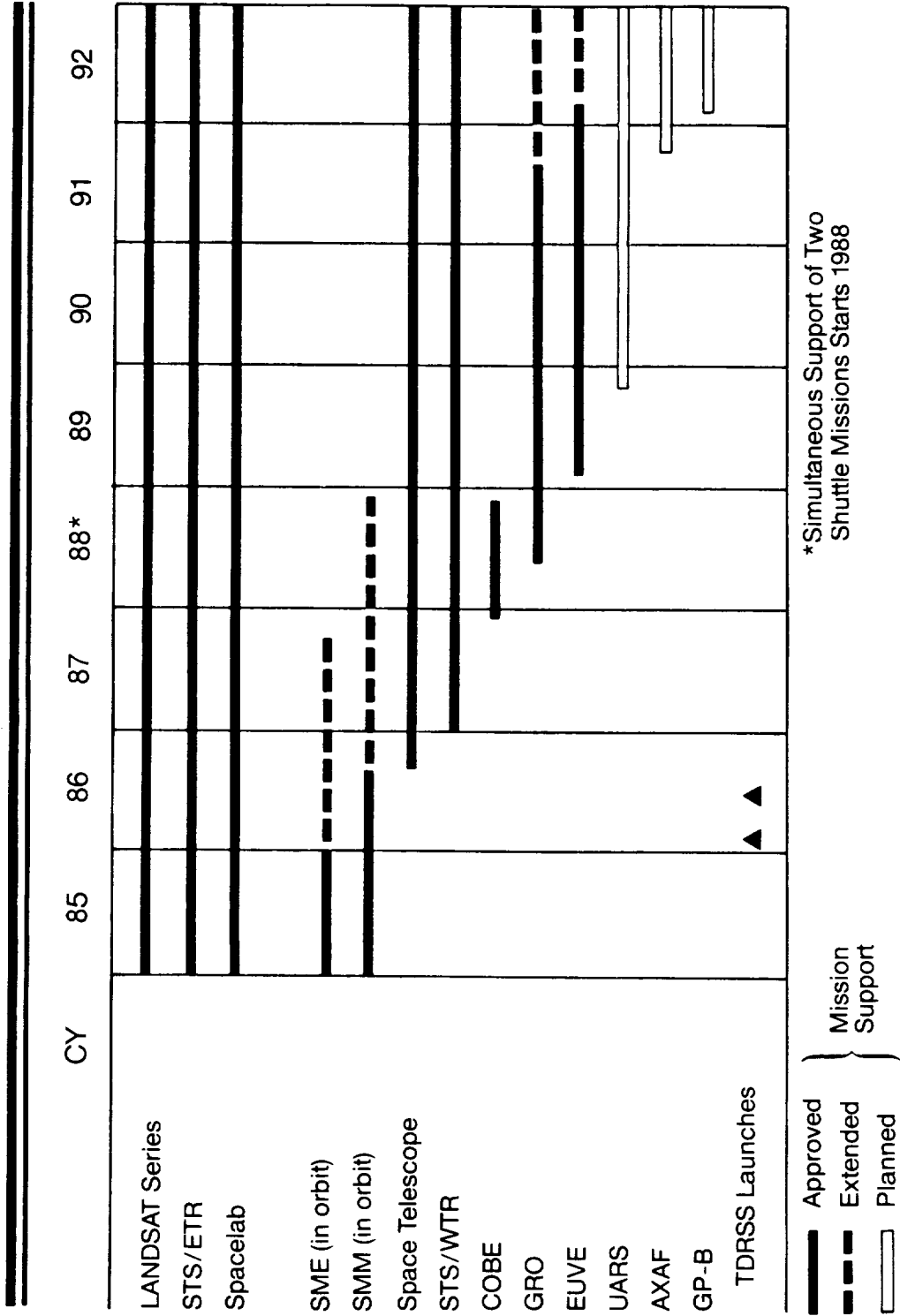
From a network of ground tracking stations located around the world, NASA's tracking and data acquisition facilities related to spacecraft in near Earth orbit will evolve into a network of two TDRSS satellites in geostationary orbit, an in-orbit spare, and a single ground terminal at White Sands, New Mexico. A single satellite currently is operating in Earth orbit, and the system is expected to be fully operational in 1986. The contractor, Spacecom, owns and operates the system and will provide NASA with leased support services for ten years of system operation. NASA has collocated a communications terminal to interface with the TDRSS ground terminal at White Sands and is operating its own network control center at Goddard Space Flight Center to control the system and manage network resources. The system achieves extensive coverage of near Earth orbits, 85 percent compared with the 15 percent provided by a network of 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 contact the mission control center, and vice versa, almost continuously, if necessary. Missions planned for support by TDRSS are shown in Figure VI-1.

The capabilities of the Space Network will be augmented in the early 1990s. Support of current missions must continue, of course; and expected increases in the number of spacecraft transmitting wide-band data will require more capability than the present four single-access relay links can provide. The Office of Space Tracking and Data Systems therefore plans to replace the Tracking and Data Relay Satellites at the end of their useful lives, increase the number of operating orbital spacecraft, and increase 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.

2. Ground Networks

After full operation of the TDRSS is achieved, nine more ground stations will be closed, leaving fully operational in the ground network only the three Deep Space Network stations and the three Space Tracking and Data Network locations shown in Figure VI-2. Collocated facilities of the satellite

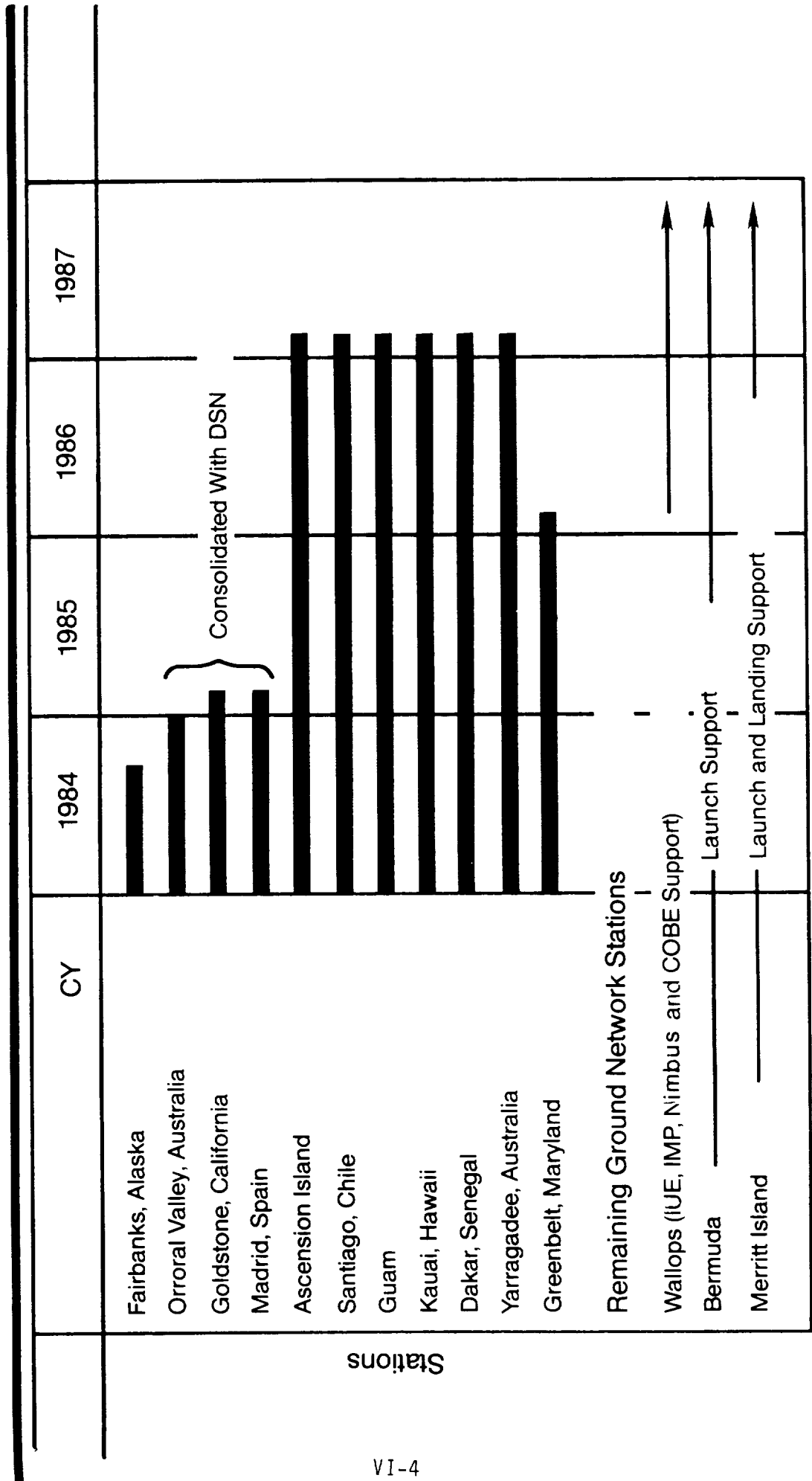
Figure VI-1
Major Mission Support Plans of the Space Network



Note: For definitions of acronyms, see Chapter X



Figure VI-2
Ground Network Phase Down Plans



Note: For definitions of acronyms, see Chapter X.

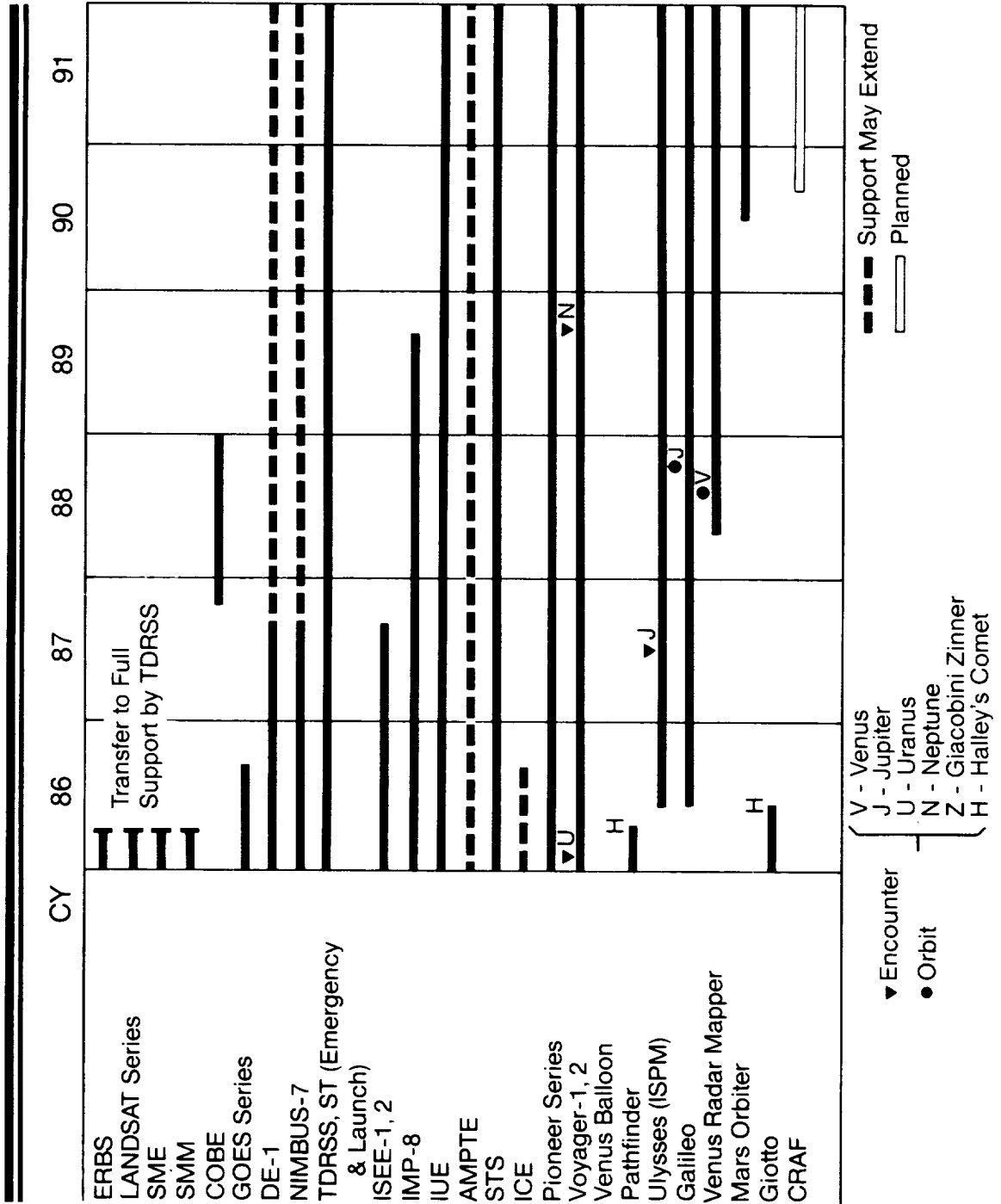
network and the deep-space network at Canberra (Australia), Goldstone (California), and Madrid (Spain) have been consolidated under Jet Propulsion Laboratory management to gain technical and economic advantages. A central signal-processing center has been established at each of those sites. Those sites can array their large antennas into various combinations and thereby have flexibility to tailor the support they give individual satellite missions and to increase their performance for planetary missions. With the transition to TDRSS for support of satellites in near Earth orbit and the consolidation of the Deep Space Network and the Space Tracking and Data Network into a single ground network, NASA began a new era of STDS support. Mating network activities to the needs of NASA's space programs remains a continuous coordination process that provides current plans, such as those shown in Figure VI-3, for mission support by the ground network. The consolidated ground network will support several Earth satellite missions with orbits that would not be compatible with TDRSS. The principal early improvements planned for the network are described in the paragraphs that follow.

In 1986, the Voyager 2 spacecraft will be nearly three billion kilometers from Earth, close to the planet Uranus, and the signal a single station will receive from it will not be strong enough to generate the images needed. The ground network will increase signal strength by combining the signal received by the 64-meter radiotelescope near Parkes, Australia, with that received by the NASA ground network array at Canberra. For Voyager 2's encounter with Neptune in 1989, plans are to add two more non-NASA antennas to the array: a 64-meter antenna in Japan and the Very Large Array in New Mexico. Also, a program is under way to increase to 70 meters, before 1989, the size of the 64-meter antennas at each of the three sites mentioned in the preceding paragraph.

An X-band command system scheduled to be operational at two 34-meter antenna sites in 1987 will provide several advantages to Galileo and later planetary missions. Because of the perturbing effects of the solar corona on communications with spacecraft, the current S-band command system cannot ensure that spacecraft at Jovian distances will receive commands over transmission paths within 15 degrees of the sun. The X-band system will reduce the blackout, which otherwise could last up to 30 days. It also will provide two additional full-time benefits: an improvement by a factor of 5 in signal stability, as it affects navigation, and a better ability to search for gravity waves. By 1991 the third 34-meter antenna site will have an X-band uplink, and by 1992 all the 70-meter antenna sites will have X-band uplinks.

To sustain NASA's flight tests aboard sounding rockets, research aircraft, and balloons, the STDS program includes a phased activity to upgrade and replace equipment for the domestic, foreign, and mobile tracking and data acquisition facilities operated by NASA's Wallops Flight Facility and Dryden Flight Facility. The program includes development of a capability at Dryden for supporting multiple missions; providing tracking and data acquisition support to the National Scientific Balloon Facility at Palestine, Texas; and improving the impact prediction system and fixed radar capabilities at Wallops. Consolidation of Dryden, Moffett Field, and Crows Landing facilities under Ames Research Center management was completed in 1984.

Figure VI-3
Mission Support Plans of the Ground Network



Note: For definitions of acronyms, see Chapter X

3. Communications and Data Systems

The maturing of TDRSS services will be accompanied by a substantial increase in the volumes of data to be transferred and processed. Economies and improvements will be obtained through more transfer of data electronically to reduce the need for human intervention and tape handling; automated alerts, alarms, and control of data quality; and standard data labeling among data bases. Aged and obsolete computing systems for mission support will continue to be replaced to reduce downtime and maintenance costs; and more use will be made of microprocessors.

In mid 1986, mission control systems will be ready to support launch of the highly interactive Hubble Space Telescope. In addition, programs now under way will provide mission control systems for new spacecraft such as the Upper Atmosphere Research Satellite, International Solar Terrestrial Physics program satellites, Gamma Ray Observatory, and Cosmic Background Explorer. 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.

Currently, NASCOM can accommodate data rates as high as 56 kilobits per second on most of its circuits. To meet future requirements for even higher data rates, plans for NASCOM include digital voice circuits, data rates up to 224 kilobits per second from overseas stations, greater use of fiber optics for local links between NASCOM and satellite ground terminals, and possibly direct Intelsat hop from network stations to the Jet Propulsion Laboratory. Also, NASA will introduce into NASCOM during the next two to three years the use of time division multiple access, a capability for dynamically assigning bandwidth among remote locations as a function of their changing demands.

In 1986, NASA will complete a program-support communications network that will provide the Headquarters, field centers, and major contractors with supplemental communications services for conducting day-to-day business. Those services will include a data transfer rate of 56 kilobits per second or greater and limited video conferencing.

4. Research and Development for Advanced Systems

The Advanced Systems program, a relatively small but vital portion of the total program, consists of studies and developments in advanced technology. It provides a base for future planning and for development of cost-effective support capabilities. It 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 for future missions. The following are examples of its objectives and programs:

- o Increase 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
- o Improve navigation capability, using the Global Positioning System to track Earth-orbiting missions with decimeter precision and developing techniques for using ground-based navigation systems to measure the

angular directions of deep-space missions to an accuracy of 5 nano-radians

- o Improve ground-station and data handling and processing operations, using new technology such as custom VLSI (Very Large Scale Integration) and automation
- o To facilitate TDRSS use, develop technology such as that for on-board recorders with data rates of 20 megabits per second and higher and that for steerable beam antennas.

5. Advanced Studies

a. 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. The planned next-generation system, the Tracking and Data Acquisition System, will provide 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.

b. Orbiting Deep Space Relay Station

Rapid advances being made 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 Tracking and Data Systems program will continue to examine the feasibility of promising concepts and will study technologies and tradeoffs for such a relay satellite.

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Space Research and Technology



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VII. SPACE RESEARCH AND TECHNOLOGY

Consistent with NASA's resources, the Space Research and Technology (R&T) program addresses the future mission needs of the other NASA program offices, the U.S. government, and U.S. industry. Its domain is technology with broad applicability to missions in space. While it devotes some of its effort directly to current missions, it concentrates on long-term, high-payoff research and technology development to provide the knowledge, opportunities, alternatives, and capabilities needed to satisfy future national space objectives and support the Nation's economic growth and defense. Its formulation requires extensive consultation with the other NASA program offices, the Department of Defense, and the aerospace industry to ensure that their needs are identified. Many of its projects are conducted jointly with other program offices and the Department of Defense to facilitate transfer of the technology developed.

A. Mission

The mission of the Space R&T program is to conduct effective, productive research and technology programs that contribute materially to continued U.S. leadership and security in space. Success depends on commitment to advancing the technology base and to maintaining technical strengths in the scientific and engineering disciplines required for future national programs in the exploration and exploitation of space. Advances in the technology base are essential for conceiving and designing advanced spacecraft for scientific and applications missions, providing low-cost access to space through Shuttle enhancements and orbital transfer concepts, supporting a permanent human presence in space through evolutionary growth of the Space Station, and serving projected long-term needs in military and commercial uses of space.

B. Mission Objectives

To accomplish its mission, the Space R&T program emphasizes the maintenance of a technically disciplined base of expertise, facilities, and knowledge and on generating advanced technology options. The program's mission objectives are to:

- o Support the development of NASA missions in space and the space activities of industry and of other government agencies
- o Maintain NASA centers in positions of strength in critical space technology areas
- o Ensure timely provision of new concepts and advanced technologies
- o Utilize the strengths of universities in conducting the NASA Space R&T program.

1. Support for Development of Missions

The Space R&T program involves technical staff and facilities that are national resources valuable not only in the performance of NASA missions, but also to other government agencies and U.S. industry. It supports the space user community in areas in which it possesses recognized technical excellence,

particularly those in which maintenance of the technology base is its unique or principal responsibility. In supporting users, it augments the existing store of experience and data to the benefit of subsequent research and development programs. This involvement with the user community will be continued.

The planning of space R&T will take into consideration the needs of both current and planned space programs. For example:

- o Space Station--technology programs focused on and supportive of the initial configuration will be completed, and activities to provide the technology base for evolutionary concepts will be expanded.
- o Launch vehicles--a technology base in propulsion, aerothermodynamics, and structural concepts and materials will be provided for heavy-lift cargo vehicles and advanced Earth-to-orbit vehicles.
- o Orbital transfer vehicle--a joint program with the Office of Space Flight will supply demonstrated technology for an aero-assisted orbital transfer vehicle.
- o Space exploration and exploitation--joint programs with the Office of Space Science and Applications will continue to address the technology needs.

Effective support to the Department of Defense (DOD) in satisfying its needs for space systems requires understanding of its requirements and coordination of plans with it. Consequently, steps will be taken to reestablish effective interactions via the DOD-NASA Aeronautics and Astronautics Coordinating Board (Space Research and Technology Panel) and the Air Force-NASA Space Technology Interdependency Group. Also, NASA plans to formulate with DOD joint R&T programs relating to that agency's Strategic Defense Initiative, including programs to provide advanced space transportation and an entry research vehicle.

The needs of industry in space technology will require several forms of response: the seeking of means to conduct joint NASA-industry projects; development of technologies that may be needed for commercial uses of space, a new initiative of the Administration; and encouragement of industry to use NASA ground and space facilities in areas of mutual interest. To gain the best use of both government and industry resources, information will be exchanged and mutual support will be achieved through bilateral and multi-lateral reviews of NASA's programs and industry's Independent Research and Development plans, performance, and results.

The concluding step in the advanced research and technology development process is the transfer of technology to users. To facilitate that transfer, the Space R&T program will expand its reporting, using existing reporting mechanisms such as technical publications and presentations at technical symposia and conferences; increase its use of conferences sponsored by the Headquarters and the field centers in both broad and specific technical areas; and expand its cooperative and co-sponsorship arrangements with other NASA program offices, other civil government agencies that encourage industrial participation, and the Department of Defense. Through visits and other means,

personnel in Headquarters and the field centers will exchange regularly with industry reports on program progress and accomplishments.

2. Maintenance of NASA Centers' Strengths

The strength of NASA's field centers in critical areas of space technology is an essential element in the Agency's ability to satisfy the Nation's needs for advanced space systems. The institutional base provided by the centers has been a national resource since NASA was established. To maintain and strengthen the centers' technical capabilities requires continuous assessment of their personnel, facilities, and programs.

The most important factor in the strength of the field centers is the competence of their technical staffs, maintained by ensuring that each center's mix and balance of skills match its assigned programmatic responsibilities and that its work environment will attract and hold the best of newly graduated scientists and engineers. Dual career ladders are maintained to provide promotions for members of the technical staff who prefer to remain researchers rather than to become managers. To stimulate creativity further, the regular professional staff is augmented through grants to visiting scientists and with researchers on temporary appointments and postdoctoral fellowships.

Production of technical results of the highest quality also requires acquisition and maintenance of state-of-the-art facilities and laboratory equipment. The Space R&T program's facilities and equipment, now mostly ground based, are becoming increasingly space based or transportable to space for experiments and tests in the space environment. The in-space facilities and equipment constitute a unique resource available for government and industry use, just as NASA's wind tunnels serve aeronautics needs.

Because available resources are limited, planning the maintenance of the field centers' strengths involves major choices and compromises. NASA cannot and should not expect to establish and maintain a center of strength or excellence in every area of space R&T. However, NASA cannot afford to eschew knowledge in any discipline vital to missions in space and, therefore, must choose in which areas it wishes each of its centers to be a "center of excellence," a "center of technical competence," or merely a provider of "technical cognizance." Preliminary views on technology areas in which the research centers should have excellence or competence are given in subsection a. below. Those views are derived from the results of advisory committee reviews, knowledge of the capabilities of the individual field centers, and recognition of which technologies will require emphasis during the next decade. Technologies that will receive priority include those for:

- o Large, flexible structures and their control
- o Space power systems
- o Launch vehicle and space propulsion systems
- o Entry technologies
- o Space operations.

The Office of Aeronautics and Space Technology has institutional responsibility for the three research centers and supports the space flight centers in areas essential to the Space R&T program. It distributes the work of the Space R&T program according to the capabilities for specialized research established at each field center. Allocating the work in that manner permits assignment of the most qualified researchers to each project, optimal use of research facilities and equipment, and avoidance of duplication of effort. The field centers reinforce their expertise by collaborating with industry and university researchers. The priority research areas listed for the centers in subsections a. and b. below represent current emphases and possible future directions.

a. Research Centers

The research centers will continue to be sustained and strengthened as centers of excellence or competence in fundamental space disciplines as indicated below.

(1) Ames Research Center

- o Maintain excellence in entry aerothermodynamics, thermal protection system materials, computational physics, and large scientific computational facilities
- o Maintain competence in life sciences and infrared detection systems
- o Strengthen capabilities in artificial intelligence and computer science and application

(2) Langley Research Center

- o Maintain excellence in spacecraft materials, structures and their dynamics, and atmospheric sciences
- o Maintain competence in space electronics, including electronics for remote sensing, control systems, and data systems
- o Strengthen technical competence in concepts and system analysis for space vehicles, teleoperation, robotics, and large space structures for antenna systems

(3) Lewis Research Center

- o Maintain excellence in space power systems, including photovoltaics, fuel cells, and energy storage devices
- o Maintain competence in electric propulsion and communications systems, components, and devices
- o Strengthen competence in liquid rocket systems.

b. Space Flight Centers

To support flight development programs and operations, the space flight centers have developed various levels of expertise in the technology areas listed below.

(1) Goddard Space Flight Center

- o Information systems
- o Data handling and sensors
- o Laser communications
- o Thermal management

(2) Jet Propulsion Laboratory

- o Guidance, control, and navigation
- o Sensors and instruments for space observation
- o Photovoltaics, energy storage, and thermal-to-electric conversion
- o Teleoperator and autonomous systems
- o End-to-end information systems

(3) Johnson Space Center

- o Thermal management
- o Human factors and life support
- o Fuel cells
- o Flight controls
- o Software development
- o Data management systems

(4) Marshall Space Flight Center

- o Structures, materials, and dynamics
- o Chemical propulsion systems
- o Electric power systems.

3. Provision of New Concepts and Advanced Technologies

In helping to ensure the continuing preeminence of the United States in space, the Space R&T program must, in addition to supporting current and

planned missions, ensure timely provision of technology to enable the orderly development of new space concepts and mission capabilities. With primary responsibility for maintaining and expanding space research and technology, the Space R&T program is the sole or principal sponsor in some discipline areas. In those areas particularly, the Space R&T program plans to identify and support research on innovative concepts and on subjects that provide opportunities for high payoffs. An objective is to allocate 30 percent of the program's available resources to technologies for missions with launch dates more than 15 years in the future. Another objective is to establish strong capabilities to perform systems analysis of space missions in order to provide systems concepts and perspectives to guide the Space R&T program. In identifying needs and opportunities at the systems level, the program will address, for planning purposes, growth capabilities for permanent human presence in space, lunar bases, space transportation systems, advanced space energy systems, planetary missions, commercial space activities, in-space capabilities to conduct engineering research, and, in conjunction with DOD, the Strategic Defense Initiative.

4. Utilization of Strengths of Universities in NASA Research

The Nation's universities are an important source of technical understanding, new concepts, and trained technical personnel for space research and technology. Currently, 12 percent of the space R&T budget goes to the universities. The research centers will be encouraged to increase their cooperation with universities and university consortia, thereby creating "national centers of excellence." Also, special equipment grants will be made to upgrade university equipment, and the universities will be given access to NASA's specialized equipment and facilities.

The Space R&T program is planning to engage several universities in year-round programs of classroom study, systems analysis, colloquia, and interaction with NASA centers focused on concepts and technologies for advanced missions and systems.

C. Program Planning and Direction

To provide the technologies that are critical to or strongly affect mission capability, cost, and productivity, the Space R&T program uses a variety of mechanisms for ensuring that its activities are comprehensive and that priorities are established. Those mechanisms ensure a match between the program's technology thrusts and the capability needs of users.

1. NASA 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 program managers 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.

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, is also available in a limited number of copies to serve the needs of space technologists in industry, the universities, and other U.S. 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.

Although the data base currently is directed primarily at NASA systems and programs, expansion to include other civil and commercial systems is planned. Even now, trends and forecasts 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.

2. System-Level Planning

To focus its systems research and technology development, the Space R&T program divides systems into three classes: space transportation systems, spacecraft systems, and large space systems. That categorization has the additional advantage of providing a systems perspective for coordination and integration of development efforts in the various technology disciplines. In the system-level activities, technology requirements and opportunities for planned and potential missions are identified, system-level analyses are conducted to identify high-leverage disciplinary technologies and quantify their impact, and disciplinary technology programs are developed.

a. Space Transportation Systems

Future transportation missions and vehicles fall into two broad categories: Earth to orbit and orbital transfer. Vehicles in both categories must be provided new capabilities by about the end of the century so that they can supply routine, flexible, and low-cost delivery and return of cargo and personnel to destinations such as the Space Station, platforms in geosynchronous orbit, the lunar surface, and deep space. Because of the planned permanent presence of humans in space and the expected increase in space activity, systems that are reliable, reusable, and economical to operate will be needed. Consequently,

technology programs related to space transportation are focused on increasing system performance and improving reliability, thus reducing costs and increasing service life. The key technology areas are advanced concepts, materials, and fabrication methods for structures; high-performance propulsion systems; techniques for predicting aerodynamic and aerothermodynamic design and performance; and autonomous systems required for guidance and navigation.

b. Spacecraft Systems

New technology will be required for spacecraft to perform both civil and national security missions. The civil missions will include all the areas of space science and applications, such as planetary exploration, astrophysics, the Earth sciences, and communications. The missions and systems expected to be the principal drivers of technology include planetary and comet sample returns, mobile communications satellites, Earth observing systems, large infrared observatories, and space-based radar systems. To provide the technology required for such diverse spacecraft in an affordable manner will be a real challenge.

Spacecraft will continue to grow much more complex physically and functionally. They will require advanced detectors across the full range of the electromagnetic spectrum, and many of them will require improvement in the precision of their pointing to optimize the outputs of their sensors. Substantial augmentations will be needed in their capabilities for communications and on-board data processing and storage. Many of them will have to have utilities that function autonomously. Systems analyses of spacecraft have indicated that potential advances in technologies such as those for spacecraft power and propulsion could double spacecraft payload fractions by the mid 1990s. That gain could provide a very beneficial increase in science return and spacecraft profitability; and it could even be essential to the ability of the United States to remain competitive with foreign countries conducting space programs.

c. Large Space Systems

In recent years, the development of technology for space platforms has been concentrated on technology to permit efficient development and productive use of the Space Station in its initial configuration. Now that those planning and definition activities are approaching the point of providing the baseline technology for the system, attention will be turned to the requirements for evolving the Space Station and developing any unmanned platforms that may appear to be needed by the turn of the century. New technologies are expected to be needed in the following key areas:

- o Automation--artificial intelligence, human-machine interaction, teleoperation, and robotics. A primary objective is to reduce operating costs through automated control of key system functions.
- o Information--advanced data systems, including data processing networks and data storage devices. The principal aim is to incorporate VHSIC (very high speed integrated circuit) technology into data processing systems to ensure that the systems are compatible with projected

advances in space platform systems and will permit their evolution as technology advances.

- o Energy management--photovoltaic generation systems and high-voltage distribution and management systems. A program is being started in FY 1985 to develop technology for solar dynamic power generation to support the Space Station program's needs, which are evolving toward dynamic systems.
- o Human capabilities--a broad discipline front including human factors; extravehicular activity systems such as space suits, robotics, mobility aids and devices, and work stations; crew facilities such as environmental control and life support, personal hygiene, and waste management; intravehicular activity systems such as work stations, communications, and special facilities; and space operations. The main objective is to develop system technologies that will increase human productivity in functional areas where human involvement has the greatest potential payoff.
- o Many space systems will be much larger than their predecessors and therefore will require an increase in fundamental understanding of large space structures, especially of how to design, fabricate, and deploy them. The Space Station, for example, will start as a structure of modest size, but will grow through the addition of modules and appendages through the 1990s. Specific technical challenges include adaptive control, precision control of the shape of large structures in space, and long-term stability of the systems in space. Because there is a limit to the validity of ground-based experiments in development of the technology in this area, a necessary part of the research will be experimentation in space.

In addition to developing generic R&T, as discussed in the preceding subsections, the Office of Aeronautics and Space Technology develops focused technology for selected programs. In 1985, it is conducting the focused technology part of the advanced development program for the Space Station. In doing so, it ensures both that the focus of its generic R&T program is proper and that needed continuity is maintained from the technology development phase through the demonstration phase. This cooperation between the two program offices is expected to continue through the evolutionary phases of the Space Station program.

3. Internal and External Coordination and Review

The Space R&T program plans, develops, and reviews its activities in coordination with the other program offices, other government agencies, advisory committees, and industry and university organizations. It has formal agreements with the Office of Space Flight and the Office of Space Science and Applications to promote coordination in specific areas such as spacecraft technology experiments in space and life support systems. Several ad hoc technical groups have been formed under those agreements for the purpose of coordinating specific technology needs, programs, and results.

The formal agreement with the Office of Space Science and Applications, the OAST/OSSA Coordination Memorandum of Understanding, was established to

improve the coordination that existed between the two offices and to provide a framework for joint planning and program oversight. Improved coordination has been sought in three ways: closer coordination of long-range planning to anticipate technology needs and emerging options, more joint attention during the annual Research and Technology Objectives and Plans (RTOP) cycle to ensure a focus on high-priority programmatic needs, and more joint participation in oversight and evaluation of the technology development efforts of both offices. The agreement calls for the creation of six joint technology plans--in communications, sensors, planetary, astrophysics, life sciences, and Shuttle payload experiments. The plans compare the Office of Space Science and Applications' mission requirements with the Office of Aeronautics and Space Technology's technology programs. Following discussions between the two offices, the Office of Space Science and Applications will provide a prioritized list of technology requirements, and then the Office of Aeronautics and Space Technology will respond by describing how it will support the items on the list in its technology plan.

The Space R&T program conducts similar coordination activities with the Air Force and other defense agencies in technology areas important to their missions. Two formal mechanisms have been established for both information exchange and decision making. One mechanism operates through delegates of NASA's Associate Administrator for Aeronautics and Space Technology and the Under Secretary of Defense for Research and Engineering. The other operates through the Space Research and Technology Panel of the Aeronautics and Astronautics Coordinating Board. In addition, the Space Technology Interdependency Group provides a forum for identifying candidate interdependent programs as a means for encouraging cooperative space technology programs between the Department of Defense and NASA.

Advisory groups provide additional external coordination and review. The two groups with the most interest in the Space R&T program are the Aeronautics and Space Engineering Board of the National Academy of Engineering and the Space Systems and Technology Advisory Committee of the NASA Advisory Council. Both groups, and their subgroups, review the program and its plans and provide recommendations on direction and content. To obtain further review and coordination, the Office of Aeronautics and Space Technology periodically sponsors technology workshops involving representatives from industry and universities. Also, through membership on the Advisory Group on Electron Devices, it coordinates with the Department of Defense spacecraft technologies involving sensors, electro-optics, solid state electronics, and communications.

Universities have an additional involvement in the planning of the program through the Summer Faculty Fellowship Program, which the Office of Aeronautics and Space Technology, in conjunction with the American Society for Engineering Education, conducts at the NASA field centers. Those summer sessions, usually ten weeks long, permit the fellows to conduct research, systems design, concept development, and feasibility assessment for selected disciplinary topics. The program's purposes are to give college and university faculty members an opportunity to deepen or broaden their research and teaching interests, learn about NASA's space research and technology development program, gain insight into the management of federal research and development, and contribute their expertise to space research and technology problems of interest to NASA.

4. Assessment

The Office of Aeronautics and Space Technology regularly conducts formal assessments of its Space R&T program to ensure that it responds to the needs of the space user community. The groups conducting the assessments are composed of persons from both within and outside the Agency. The scope of the assessments ranges from specific technology development programs to an individual discipline or topic. Such assessments will be continued, and their results will be used to modify the program and justify program augmentations.

D. Technology Objectives

The Space R&T program has a broad range of technical thrusts. The principal ones are embodied in the technical objectives described below, which support the program's goal and objectives and provide a basis for decisions on funding, personnel, and facilities. The order in which they are presented does not imply priority, and the listing is not all-inclusive. Many activities not listed continue as valuable elements of the program.

1. Materials and Concepts For Thermal Protection

Concepts for thermal protection materials and structures will continue to be crucial for advances in space transportation systems. A broad range of future vehicles, each with its own unique aerothermal environment, is being studied.

Several types of materials will be available for protection of vehicles against temperatures of 2300⁰ F and above. Ablating materials are the least desirable because they cannot be reused. However, they have been characterized very adequately and do offer the advantage of protection against extremely high temperatures. Advanced carbon-carbon composites that protect against temperatures up to 3000⁰ F will be used in advanced vehicles, especially on their leading edges, in their nose region, and on their control surfaces. Advanced ceramics, similar to those used on the Shuttle orbiter but more durable and resistant to higher temperatures, are attractive alternatives for protection against higher temperatures.

Heat pipes will provide active thermal control in high-temperature stagnation regions, especially on small manned vehicles with extremely sharp leading edges and noses.

Aeroassist concepts under consideration for use in advanced orbital transfer vehicles vary considerably in the rate of heat transfer they must accommodate. The rate for the aerobrake concept and the ballute concept is relatively low, but the aerobrake requires a durable, reusable thermal protection material while the ballute material must be flexible. Aerocapture vehicles will have high heat transfer rates and therefore may be protected with high-temperature ceramics and metals, advanced carbon-carbon composites, and ablating materials. Planned system studies of advanced vehicle requirements and expected aerothermal environments will provide a clearer understanding and permit thermal protection and aeroheating R&T to be concentrated in areas promising the greatest payoff potential.

2. Longer Life, Reusable Engines

High-efficiency, reusable rocket engines are a necessity for routine access to space. They must operate reliably for many missions with minimal maintenance and lowest reasonable cost. Therefore, technology must be developed for critical concepts, components, procedures, and materials. Advanced analytical methods must be established for explaining and quantifying engine phenomena. The result should be viable options for development programs to improve engine performance, life, reliability, and maintainability.

Attention is being given to extending the life and performance of the Shuttle's main engines. Increasing the number of missions the engines are able to fly requires improvements in engine components and in analytical techniques for predicting their aerodynamic, aerothermodynamic, and material performance. Under development are diagnostic instrumentation and an ability to identify incipient failures and to schedule engine maintenance so as to cause minimum disruption to mission schedules. A heavily instrumented main engine will be used in system-level testing to ensure that hardware embodying advanced technology performs as intended and is ready for further development, on a flight engine. The testing also will validate instrumentation and provide data for use in checking analytical models. Other activities planned for the near future are to finish modeling the fluid flow and rotor dynamics of the engine; test improved rotary bearings, including those that operate in oxygen; and evaluate heat resistant coatings for turbine blades and methods of applying the coatings.

The technology of large, high-pressure, hydrocarbon-fueled booster engines is being improved. Those engines can provide high system efficiency in high-thrust booster stages because the high density of their fuel makes possible the use of lighter weight tankage. Being investigated as a means for improving the efficiency of boosters are dual-nozzle engines having a low expansion ratio during flight in the atmosphere and a high expansion ratio for operation in near vacuum.

3. Orbital Transfer Vehicle Propulsion and Aerobraking

A versatile, cost-effective, orbital transportation vehicle is essential for exploitation of space orbits beyond those the Shuttle, advanced Earth-to-orbit vehicles, and the Space Station will be able to reach. The planned Orbital Transfer Vehicle will be reusable, space-based, and able to deliver 6,800 kilograms (15,000 pounds) to geosynchronous orbit. It will have growth potential to permit delivery of large deployable structures and manned systems to geosynchronous orbit. It will have a high-performance, variable thrust propulsion system; cryogenic tanks capable of being refilled totally with little loss of fuel; and aero-assisted braking for return to low Earth orbit from higher orbits.

The propulsion system will include an engine that has a high chamber pressure and burns liquid hydrogen and liquid oxygen, and will have a nozzle with a large expansion ratio. Technology development is required for concepts, component designs, and analytical techniques. Also required are high efficiency pumps, improved nozzles with large uncooled skirts, and development of diagnostic instrumentation and analytical techniques that will

detect incipient failures and allow timely scheduling of corrective action. Three companies have been granted contracts for design studies of propulsion systems for orbital transfer vehicles. By 1986, they will have completed the concept definition phase and will have started to test critical subcomponents. Then, each will design a test-bed engine and order components for testing in subsequent years.

The use of aero-assisted braking instead of propulsion braking to recover reusable orbital transfer vehicles at low Earth orbit offers a potential for increasing significantly the payload that those vehicles can deliver to geosynchronous orbit. Technology development is needed for vehicle navigation and control in an aerodynamically unpredictable environment; a low-weight aerobrake, including a thermal protection system and control of backface heating; and a system design that will permit servicing of the vehicle in low Earth orbit and recovery of both the vehicle and a manned capsule from geosynchronous orbit.

Technology development essential for low-loss refilling of cryogenic tanks in zero gravity includes that for techniques to prechill the tanks, to introduce fluids in such a way that the system being filled is vapor-free, and to fill the tanks with a predetermined amount of fuel. Under development is an experiment to be conducted in the Shuttle's cargo bay to investigate the storage, acquisition, and transfer of cryogenic fluids under zero-gravity conditions. The first flight is planned for the late 1980s.

4. High-Capacity Electrical Power Generation, Storage, and Distribution Systems

The maximum electrical power available in spacecraft has been tens of kilowatts, with power-to-weight ratios as low as 5 watts per kilogram and costs as high as \$1,500 per watt. However, research on photovoltaic cells and arrays should provide by the late 1980s substantially greater power levels and, at the same time, lower system costs and weights. The development of arrays for solar electric propulsion systems is expected to demonstrate a power-to-weight ratio of 66 watts per kilogram. Further development will provide array outputs of 100 or more kilowatts, with a power-to-weight ratio for high-performance silicon arrays of 300 watts per kilogram and with costs reduced by a factor of 5 or more. Under study are improved photovoltaic materials and better designs to provide cells and arrays with high concentration efficiency, lightweight structures, and the ability to maintain high performance for long periods in the space environment.

For Space Station applications, solar dynamic power systems offer potential advantages over other solar conversion systems, particularly for power levels greater than 300 KW, because of their substantially smaller areas and, therefore, their lesser need for station-keeping propulsion. Assessment has been initiated of the possible use of such a system in the initial Space Station. The critical technology areas are those for the receiver-storage and concentrator subsystems, and those areas will be addressed in conjunction with the system integration studies for the Station.

High-power systems generate substantial amounts of waste heat that must be removed and radiated to space. They therefore require efficient thermal management systems possessing high capacities and low vulnerability to

meteoroid damage. For managing the heat inside spacecraft, cold plates will be integrated into thermal, power, and data handling subsystems. Also, removal of waste energy by use of heat pipes and by forced-convection (pumped) two-phase fluid systems is being investigated. To be investigated for radiating heat to space are liquid droplet and liquid metal belt radiators and possibly additional concepts. For energy storage, both single-phase and two-phase materials will be assessed.

In February 1983, the Department of Defense, the Department of Energy, and NASA created the Tri-Agency Space Nuclear Reactor Power System Technology Program to advance technologies suitable for a space power system capable of producing 100 kilowatts or more of power and of operating 7 years at full power. Approximately 200 civil and military mission concepts were identified in the initial mission definition phase of the program, and current studies of civil and military mission needs and requirements are defining the desired characteristics for the system from the user viewpoint. Three concepts for the system are being investigated: an in-core thermionic system, a lithium-cooled reactor (thermoelectrical energy conversion system), and a low-temperature reactor using existing liquid-metal, fast-reactor technology coupled with a dynamic (free-piston Stirling cycle) energy conversion system. Special emphasis is being placed on nuclear safety in flight. The technology assessment and advancement phase currently in process is expected to end in 1985 with the selection of a single system concept for investigation in the ground test phase. The objective of that phase, which will last 3 to 4 years, is to complete all activities needed before prototype flight units can be assembled and qualified for flight testing.

Future large space systems will require power management and distribution at high voltages and possibly at high alternating current frequencies. They also will need advances in materials resistant to elevated temperatures and radiation, circuits, transmission lines, electronic components, switching networks, high-speed switches, short-term energy storage, state-of-charge indicators for batteries, autonomous operation, and control of interactions between high voltages and the space environment.

Energy storage systems are a dominant factor in the weight, reliability, and length of life of high-capacity space power systems. Technology is being developed for systems based on nickel and hydrogen electrochemistry and for regenerative electrolyzer systems for fuel cells. The objective is reliable orbital systems able to store hundreds of kilowatts of energy at high voltage levels for use in the Space Station. Compared with a battery system, a regenerative fuel cell system offers lighter weight and considerably more operational flexibility. Acid and alkaline technologies are under investigation for their performance and endurance characteristics in connection with both the fuel cell and the electrolyzer elements of fuel cell systems. Breadboard testing is leading to prototype development that is expected to result in application in the 1990s.

5. Satellite Communications

Research and development for communications systems are centered on components and technology to ensure U.S. preeminence in satellite communications and data transfer. The purpose of work currently in process is to improve electron beam amplifiers, solid-state devices, and antennas. The

results will be applied to communications satellites, intersatellite links, deep-space exploration systems, and terrestrial terminals.

The work on electron beam amplifiers seeks to reduce the weight and cost of microwave power amplifiers and to increase their operating lifetime, efficiency, and linearity through research on multistage depressed collectors, the surface physics of cathodes, and novel slow-wave circuits such as those known as the tunneladder traveling wave tube. Scheduled for completion in 1986 is an experimental, 60-gigahertz, coupled-cavity traveling wave tube for use as a spaceborne amplifier for intersatellite communications.

Research in solid state devices is concentrated on development of monolithic microwave integrated circuits, gallium arsenide field effect transistors, IMPATT (impact avalanche transit time) diodes, semiconductor lasers, receivers with high signal to noise ratios, and passive devices. Developments expected are an X-band solid-state transponder for use in deep space by 1986, a 20-gigahertz monolithic microwave integrated circuit amplifier, and a solid state laser with a power output of more than 200 megawatts by the late 1980s.

Antenna research will be directed toward development of antennas employing multiple scanned beams to transfer data between orbiting vehicles and to relay point-to-point communications; multiple-use antennas for spacecraft; large antennas for terrestrial and airborne mobile communications; computer modeling techniques for antenna structures; and antenna testing facilities. Important milestones in this program will be the testing of a 15-meter diameter antenna, completion of a study of multiple-use antennas, and, in the late 1980s, start of operations of the Antenna Technology Laboratory.

6. Large Antenna Systems

Research is needed in the packaging of antenna structures, minimum sizes for structural members, and methods for deploying and assembling large antennas. The large antennas will need to be light in weight and compact when stored, but be able to maintain very stringent surface tolerances when deployed. A 15-meter diameter, ground-based prototype of a hoop-column antenna, a key element of structural research, is under construction. During 1985, it will be prepared for deployment and dynamic testing, which will be followed in 1986 by electromagnetic characterization of the antenna surface. Technology gained from the testing will be used to guide flight experiments planned for initiation by 1989 to develop methods for controlling the configuration of large flexible space structures and for investigating their dynamics.

7. Space Teleoperation, Robotics, and Autonomous Systems

Autonomous space systems will increase current capabilities for conducting unmanned science experiments in space, provide for automated operation of systems and devices on the Space Shuttle and Space Station, and reduce the overall dependence of space systems on ground-based operations personnel. The approach to be followed in developing autonomous systems is to develop and apply artificial intelligence to planning, monitoring, controlling, and diagnosing subsystem operations. In 1986, a rudimentary, closed-loop, autonomous system is to demonstrate in the laboratory, in connection with the

Voyager spacecraft, the capabilities listed above. Also scheduled for 1986 is a major demonstration of an experimental automated controller for an advanced life support system.

Research on teleoperations and robotics is focused on remote servicing, assembly, and related manipulative tasks for maintaining and operating space systems. The major activity planned for 1986 is to develop the final technology elements needed for conducting two major technology demonstrations in 1987. The technology element for the first demonstration is an interactive, sensor-referenced, teleoperator control system using distributed computing. The second is a machine vision and robot control system capable of automatic acquisition and tracking of target bodies, integrated real-time control of robot arms, and control of mobile platforms. The technology base will be validated through a series of pilot experiments currently in process to demonstrate progressively increasing levels of automation and autonomy of remote systems. Those technology elements will free personnel to concentrate increasingly on supervisory and other intellectual tasks and, therefore, will increase the capability, efficiency, and economy of space-based human-machine systems.

8. Space Information Management Systems

The purposes of this objective are to develop and apply technologies to reduce the cost of deriving information from manned and unmanned space missions and to increase the capabilities of space-based and ground-based data systems. The resulting space information systems will provide more efficient and effective transfer of data from sensors to users via intelligent, autonomous systems. The approach to this objective includes development of high-speed, wide-band optical networks; adaptive network nodes; radiation hardened, very high speed integrated circuit processors; and optical mass storage systems for spaceborne applications. Related technology must be developed for optical information processors, image-based data and symbolic processors for spaceborne systems, and data-base management systems.

9. Computer Science for Aerospace Applications

This technical objective seeks to understand the principles underlying aerospace computing and the relationships and tradeoffs between algorithms and computing architectures. It strives to apply the understanding gained to development of computational concepts and system architectures with improved reliability and performance for application to space operations. It is focused on concurrent processing algorithms, software management, and information management. Its results will be applied in computational physics, image processing, flight systems, and ground-based, large-scale information systems.

Concurrent processing research includes analysis of highly parallel, single-instruction, and multiple-data stream computer architectures for problems that can be vectorized. It also includes analysis of the more complex, but potentially more promising, multiple-instruction and multiple-data stream architectures. Parallel research on algorithms is developing robust, numerically stable algorithms for solving sets of thousands of simultaneous linear and nonlinear equations. A long-term goal of software research is to develop by 1989 a support environment for software management

that will engender automatic extraction of measures of software reliability and quality during software development and modification. In 1986, the focus of the research will be on development and validation of a dynamic cost model for the life cycle of software. Research in management of space information will result in completion in 1986 of the design phase for a prototype set of methods for gaining data-independent access to high-volume, distributed, heterogeneous data bases.

10. Computational Aerothermodynamic Techniques for Entry Bodies and Rocket Engines

Development of design optimization concepts for aerospace vehicle systems requires an understanding of fluid flow and thermal physics. The following major capabilities will be sought: techniques for predicting the radiative and convective heating rates of orbital transfer vehicles using aero-assisted braking and of other flight vehicles during flight in the atmosphere; methods for estimating aerodynamic forces acting on bodies with a variety of shapes and control surfaces during entry into the atmospheres of Earth, other planets, and the satellites of planets; improved facilities for verifying computational methods; and a complete and verified theory for flow conditions in the rarefied atmosphere at low orbit altitudes and in spacecraft jet plumes. Development and validation of computational fluid dynamics techniques will provide more accurate predictions of flow phenomena and vehicle responses too complex to be simulated in wind tunnels and other ground facilities. Conditions encountered during ascent to orbit, in low Earth orbit, and during reentry will receive special attention. Validation will be accomplished in existing and new test and simulation facilities on the ground and, increasingly, in flight research vehicles and with research-quality instrumentation in the Space Shuttle.

11. Human Capabilities in Space

The Space Shuttle provides frequent opportunities for flying experiments in space, and the Space Station will add a capability for extended duration missions. Together, they will require a wide variety of intravehicular and extravehicular activities for deployment, construction, assembly, maintenance, satellite and vehicle servicing, and other tasks. Automation of operations and system autonomy will need to increase continuously to reduce the costs and complexity of ground support, lengthen system lifetimes, and enhance system versatility. Also, technologies related to human-machine interactions and to life support for long-duration operations will have to be advanced to support and exploit fully the capabilities of humans in space.

An understanding of human capabilities and technology to enhance them is needed in four areas: supervision and management of automated subsystems to ensure optimal performance of the total system, including optimal division of functions between humans and machines; teleoperation of remote systems from spacecraft and Earth-based work stations, evolving toward telepresence (remote operations with perception and dexterity); extravehicular activity during construction and other long-duration operations, including trade-offs between extravehicular activity and teleoperations; and performance and physical and psychological well-being of humans performing repetitive tasks in confined spaces in a hostile environment.

The aims of human factors research are design criteria for allocating functions between humans and automated systems; electronic displays and input devices in crew stations--to increase reliability and operational capability, decrease cost and weight, and provide interfaces for automated and autonomous systems; work stations--to provide ground control of autonomous manned and unmanned spacecraft; human-teleoperator interfaces--to increase operational capabilities and reduce the cost of in-orbit assembly, maintenance, and repair; tools and devices--to increase the operational capability of astronauts working in space suits; and habitability--to improve vibroacoustics, food technology, and crew quarters. Flight experiments will be conducted to help establish those design criteria.

12. Advanced Sensor Concepts

The sensor program provides technology in lasers, microwave tubes, and infrared detectors for passive and active sensing of terrestrial, planetary, and galactic environments. The research involved has general applicability in sensing technology and is used in NASA's space science and applications programs and in programs conducted by the Department of Defense and commercial satellite operators.

Technology is under development for linear, infrared, and x-ray detectors; large arrays of silicon, charge-coupled devices; broad-band radiometers; synthetic aperture radars; solid state lasers; infrared and ultraviolet light detection and ranging systems; and cryogenic coolers. Infrared detectors and cryogenic coolers will be used in the Shuttle Infrared Telescope Facility and the Large Deployable Reflector. Synthetic aperture radar technology will be incorporated into the Shuttle Imaging Radar-D, and solid state lasers will serve as sensors for Space Station light detection and ranging measurements. The solid state laser and synthetic aperture radar programs are conducted in cooperation with the Department of Defense.

13. Distributed, Adaptive Controls for Large Space Systems

As space structures become larger and more flexible, they will have to be equipped with distributed, adaptive controls to maintain the structures' desired configuration and stability. Modular structures incorporating decentralized control may be used to permit adaptation during operation and incremental modification as the structures grow.

Algorithms will be required for analyzing distributed controls for active vibration damping, control during deployment, and attitude control. Various types of adaptive controls will be evaluated for their ability to compensate for large changes in the inertia of structures during deployment in space and for mode and frequency changes caused by structural interactions. On-board, real time, adaptive controls will require numerical procedures, compatible with the structures' adaptive control algorithms, for analyzing memory, size, and timing. The data base for the technology of distributed, adaptive controls must provide high tolerance to uncertainties and to failures of the many components distributed throughout large space systems.

E. Current Program, New Directions, and Program Emphasis

The R&T program to satisfy the 13 technology objectives discussed in section D. above has two parts. The first is discipline research in 8 advanced technology areas to provide the data base and understanding necessary for creating new space concepts and for extending mission capabilities. The second is systems-level analysis and research to identify high-leverage technologies and to generate data critical to validation of advanced technology for space applications.

1. Discipline Research

a. Aerothermodynamics

The objective of the research in this technology area is to develop analytical and predictive techniques for the continuum, transitional, and rarefied flow regimes, with emphasis on transatmospheric flight. Included are bluff-body highly nonequilibrium-radiative flows that are altered by catalytic wall phenomena and transition into highly expanding after-body flows with turbulent separation; flows around complex, 3-dimensional vehicles that react chemically and interact viscously; and free-molecular flows that, diffusing forward over spacecraft from rocket plumes located and directed astern, could contaminate payloads.

b. Materials and Structures

This technology area includes structures with large areas, the effects of the space environment on materials, thermal protection materials, hot structures, thermal-structural analysis, technology for generic mechanisms, and the combined effects of structural dynamics and controls.

c. Information Sciences

Included in this technology area are concurrent processing, optics, tolerance to faults and radiation, electronics, sensing, computer science, and automation to make space systems more autonomous and capable.

d. Space Data and Communications

Included are advanced techniques for processing information; high-capacity, high-data-rate storage systems to increase the capabilities of space and ground data systems; and advanced microwave and optical communications.

e. Controls and Guidance

Included are large, flexible, precisely controlled structures; integration of attitude control and energy storage functions in flywheels; and precise pointing of large spacecraft.

f. Human Factors

Included are enhancement of astronaut productivity by improving techniques for managing information and by providing extravehicular work stations and telepresence.

g. Space Energy Conversion

Included are high-capacity power and thermal systems for the Space Station, systems with high specific power and low weight for geosynchronous-orbit and planetary missions, and thermal-to-electric energy conversion for power systems incorporating 100-kilowatt class nuclear reactors.

h. Propulsion

Included are the life and performance of advanced, high-pressure, cryogenic engine systems, with emphasis on component and integrated diagnostic instrumentation techniques; space-based, throttleable, and reusable orbital transfer engines; gaseous oxygen-hydrogen propellant systems for use in the evolutionary Space Station and as auxiliary propulsion for orbital transfer vehicles; and electric propulsion for Earth-orbital and planetary missions.

2. Systems-Level Research

a. Space Systems Analysis and Studies

The objective of the space systems analysis and studies activity is to quantify the key technologies required for space missions that will provide direction and scope to the Space R&T program. The systems on which the activity is focused and the key technology areas for each system are as follows: transportation systems--aeroassisted braking and maneuvering, thermal protection systems, and advanced cryogenic engines; spacecraft systems--autonomous systems, sensors, and precisely controlled structures; and large space systems--assembly, deployment and control of large space structures and evolutionary growth potential of the initial Space Station, including architectures for distributed data systems, automated and teleoperated systems, advanced life support systems, and operational extravehicular activities. In addition, identification will begin of technology development activities that can benefit from use of the operational Space Station as a research facility.

b. Chemical Propulsion Systems

A heavily instrumented Space Shuttle main engine will be used as a testbed to acquire systems-level data for use in evaluating advanced technology components derived from the discipline research program on propulsion. The systems-level data also will be used to validate instrumentation and modeling techniques to be employed in predicting the performance and life of propulsion systems. This program is being conducted jointly with the Office of Space Flight, which will provide and operate a nonflight Space Shuttle main engine as the testbed. The

advanced technology components to be tested will be available in 1986, and testing will start in 1987.

c. Space Flight Systems

This activity encompasses the design, development, and flight testing of experiments and the development of special purpose, reusable, flight research facilities for use in space. Current flight experiments support a broad, ground-based program of discipline research in the following areas: structures and controls--to validate technologies critical to the design, analysis, test, and operation of large space structures (see newly initiated program 3.b., Control of Flexible Structures, below); management of cryogenic fluids--to enable in-orbit supply and resupply of cryogenics to spacecraft and space platforms and in-orbit refueling of space-based orbital transfer vehicles; and high-capacity heat rejection systems--to verify the technology for 2-phase heat-pipe radiator elements for use on the Space Station. The Orbiter Experiments program will continue to use the orbiter as a test-bed in developing technology for advanced transportation systems.

F. Planned FY 1986 Augmentations

Augmentation in FY 1986 is planned for the Space R&T programs described below.

1. Automation and Robotics Technology

The objective of this program is to provide technology to increase, through automation, the capabilities of systems and the productivity of humans in space. The continually increasing scope and complexity of NASA's missions rapidly are making the satisfaction of requirements with conventional technology and approaches unaffordable and, in some cases, unachievable. This deficiency becomes particularly evident when the mission objectives for space platforms are considered. The ability to meet the long-term challenges of space missions requires a coherent approach to the automation of space systems, using emerging and evolving technologies.

The degree of autonomy of space operations can be increased substantially by systems able to perform remote manipulation and intelligent control in space. Automation of space systems reduces mission costs, enhances scientific and engineering mission capabilities and provides new ones not otherwise attainable, and makes possible the evolution and optimization of the human-machine role in space.

The major elements of technology involved in this program are sensing, planning, decision making, and in-space operations with human-supervised and autonomous systems. The program will integrate those basic technologies to provide a basis for evaluating and understanding the tactical situation and for exercising supervisory control over the remote manipulation and mobility required. Major activities that will benefit from automation of operations include maintenance and operations of ground-based systems and space platforms, in-situ operation of experiments, satellite servicing, assembly of large space structures, repair and maintenance of space-based systems, and remote operation of scientific payloads.

Congress has displayed substantial interest in accelerating the dissemination of advanced automation technology to and in U.S. industry. The result of its concern over international competitiveness was a search for a national high-technology program that not only would serve as a highly visible demonstration of advanced automation, but also would spur the dissemination of that technology in the private sector. The program selected by Congress for those purposes is the Space Station program, and this newly initiated automation technology program is the principal R&T program contributing to the satisfaction of those purposes.

2. Control of Flexible Structures

Successful operation of large space structures, such as large-area space platforms and antennas, is dependent, to a large extent, on an ability to control the static configurations and dynamic responses of the structures. Large space structures have a high degree of flexibility and are subjected to varied sources of loading, including non-uniform temperatures, docking, deployment, pointing adjustments, and static and dynamic loads imposed by normal operations aboard the structures. Consequently, the structures must be equipped with active, positive controls that will prevent excessive static deformation and will damp dynamic motions.

The objective of this program, therefore, is to develop in a timely manner, consistent with NASA's overall space objectives, technology for controlling the static configurations and dynamic responses of large space structures. The program will consider a variety of structures, including multibodied flexible arrays, supported mesh antennas, and joint-dominated, deployable beams of a generic nature. It will concentrate initially on a joint-dominated, slender, flexible beam. Beginning in 1985, it will develop analytical methods and conduct ground-based experiments to characterize and synthesize accurately the dynamic behavior of that type of structure and to develop the control laws and methods required for controlling its configuration and motion. Starting in 1989, three flight experiments will be conducted on the Space Shuttle to validate ground-based testing and analysis methods and to demonstrate damping, tip stabilization, and adaptive control methods. Concurrently, other analyses and ground-based experiments will focus on expanding newly developed technology for application to more complex structures, such as multibody and 3-dimensional structures.

3. Orbital Transfer Vehicle Technologies

The objective of this program is to provide the technologies that are key to the development of the space-based, reusable, Orbital Transfer Vehicle, which is planned for use in the late 1990s. Those key technologies are for advanced propulsion and aerobraking.

The objective of the program in propulsion is to develop technology for an advanced space-based engine. The current program is analyzing and designing components and instrumentation for technology development of components. To provide for integration and system testing of technology concepts and components developed under the base program, development of a full-scale research engine is being planned.

The objective for aerobraking is to develop technology to satisfy needs in the key technical areas related to development of an aerobrake for the Orbital Transfer Vehicle; namely, aerodynamic and aerothermodynamic environments, brake structures, thermal protection material, and adaptive navigation and guidance. To support the technology development program, the Office of Aeronautics and Space Technology and the Office of Space Flight are jointly planning to develop and fly an aerobrake test vehicle. The test vehicle will be deployed from and recovered by the Shuttle, and its entry trajectory will create an entry environment similar to that the full-scale Orbital Transfer Vehicle will experience. The test vehicle will be instrumented to provide data that are essential to development of the Orbital Transfer Vehicle, but cannot be obtained with ground-test facilities.

G. Proposed FY 1987 through FY 1991 Augmentations

The Following Space R&T programs are being considered for augmentation in the FY 1987 through FY 1991 period.

1. FY 1987

a. Orbital Transfer Vehicle Technologies

The orbital transfer vehicle technologies program will be augmented in FY 1987 to add an aeroassist flight experiment and advanced engine research. Those augmentations will provide the technology base needed to establish design, performance, and operational specifications for development of a space-based, aeroassisted orbital transfer vehicle currently planned for operation in the late 1990s. The Aeroassist Flight Experiment will be conducted jointly with the Office of Space Flight and will result in flight testing of an aerobrake concept in late FY 1991. It will provide data on the aerobraking entry environment that heretofore have been unobtainable and that are critical to development and validation of aerothermodynamic prediction techniques and to verification of thermal protection materials. The result from the advanced engine research augmentation will be design and fabrication of engine-level components that then will be evaluated in full-scale testbed engines.

b. Automation and Robotics

Augmentation of the automation and robotics program will increase activity in the development of core technology (sensing and perception, task planning and reasoning, operator interface, control execution, and system architecture) and expand ground-based demonstrations and in-space experiments. The program addresses both system automation of routine housekeeping tasks and robotic technologies to extend the in-space capabilities of humans. It proceeds through increasingly complex demonstrations as new technology products become available.

Selected in-space experiments will be conducted as necessary either to explore phenomena that cannot be addressed suitably on the ground or to validate ground-developed technology for applicability in space. Joint programs with the mission program offices will be sought for ground demonstrations as well as in-space experiments.

c. In-Space Experiments

Two augmentations to the in-space experiments program are planned. The first is to develop understanding of and technology to characterize and accommodate the effects of the space environment on structural materials, sensors, optical surfaces, protective coatings, and structural dynamics. Environmental factors to be considered include plume impingement, atomic oxygen, and plasma ram and wake. The objectives of this first augmentation are to characterize space environmental factors that could damage long-term space systems, to develop and verify analytical models for environmental interactions, and to validate technologies for limiting the environmental effects. The second augmentation is to determine the structural dynamic performance of large space systems by using the Space Station as a testbed during its assembly and operation. Objectives are to update predictive, ground-based, structural dynamics models and techniques; flight test instrumentation needed for determining the dynamic performance of space systems; provide guidelines for instrumenting the Space Station's structure; verify structural dynamic interactions during Space Station assembly; and identify the performance of operational systems.

d. Enabling Technologies

This augmentation will provide enabling technologies for science and applications systems and missions in the 1990s, including the Earth Observing System, the Large Deployable Reflector, communications platforms, and sample return missions to the planets. It will develop components for use in the submillimeter spectrum, including detectors, mixers, oscillators, and tunable solid-state laser components. It also will include laser materials research programs to develop material alternatives and control technologies for large multifaceted surfaces.

2. FY 1988 through FY 1991

a. Entry Research Vehicle

Development of entry vehicles that make effective use of aerodynamic forces to maneuver at high altitudes and Mach numbers will require major advances in technology. Also, since those environmental conditions cannot be simulated in ground facilities and are outside the flight envelope of all existing vehicles, analytical prediction methods currently cannot be validated. An entry flight research vehicle is being proposed as a joint Department of Defense-NASA program. The entry vehicle would provide means for assessing advanced thermal protection materials, advanced structural concepts, aerodynamic and aeroheating prediction techniques, and the feasibility of using advanced adaptive navigation and guidance systems to accommodate atmospheric uncertainties. Validation of trajectory analyses that optimize various entry maneuvers will identify prediction and performance deficiencies, providing insight into potential design solutions for future vehicles.

b. Liquid Oxygen-Hydrocarbon Research Engine

A high-pressure liquid oxygen-hydrocarbon engine offers significant advantages over a liquid oxygen-hydrogen engine for the boost phase of heavy-lift and advanced Earth-to-orbit vehicles. The high-density propellant and the greater compactness of the liquid oxygen-hydrocarbon engine permits reduced engine weight and vehicle base area. A reusable engine with chamber pressures greater than 2,000 pounds per square inch will require development of a new class of engine.

This planned augmentation will provide for engine-level testing of component advances from the on-going technology activity. Engine-level testing is required to validate advanced component and engine system designs and unique reusability features associated with a liquid oxygen-hydrocarbon engine. An engine research capability should make possible the attainment of technology readiness for this class of engine by the mid 1990s.

c. Mars Sample Return Technologies

The currently envisioned mission strategy for a Mars sample return mission will require acquisition of a significant number of critical mission-enabling technologies. The mission strategy includes deployment of payload elements by the Space Shuttle; in-orbit assembly of the full system; in-orbit fueling and injection into a Mars transfer trajectory; lander aerocapture and orbiter deployment; sample collection, launch, and orbital rendezvous and docking; return-to-Earth transfer, aerobraking, and Space Station rendezvous and docking; and Shuttle transfer of samples to Earth's surface.

This augmentation will include development of required technologies in automated rendezvous and docking; aerocapture and aeromaneuver; highly autonomous telerobotics; surface mobility and manipulator dexterity; and adaptive guidance, control, and route planning.

d. Lunar Base Technologies

A lunar outpost or lunar base program will require scientific and technological research, including initiation of pilot plants to exploit lunar materials. It is expected to depend initially on systems derived from the Space Station and adapted to survive on the lunar surface. It also is expected to evolve from being intermittently manned toward supporting the permanent presence of humans. The range of technologies and the scale of research activities that will be involved include closed-loop life support, transportation infrastructure (cislunar transfer systems and surface mobility systems), extraction of oxygen and hydrogen, production and management of energy, and extraction and fabrication of construction materials.



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VIII. AERONAUTICAL RESEARCH AND TECHNOLOGY

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VIII. AERONAUTICAL RESEARCH AND TECHNOLOGY

This long-range plan for aeronautical research and technology development describes work to be conducted by NASA personnel and their academic and industrial associates. Their combined expertise is critical to NASA's ability to satisfy the Nation's needs for aeronautical research and technology development. Also critical is NASA's unique aeronautical test facility capability. This plan emphasizes the preservation of and continuing development in both of those critical areas as much as it stresses the elements that constitute the plan itself.

During 1984, the Aeronautics and Space Engineering Board of the National Research Council conducted, at NASA's request, a workshop to identify technology advances that might be possible by the year 2000, assuming that adequate resources are available. Participants in the workshop included representatives from industry, academe, and government. A Vehicle Applications Panel conducted a follow-on study to evaluate more fully the combined effects of the predicted technology advances and to project advanced vehicles that might result from them. The results from the workshop and the study are providing the basis for a longer range, more visionary approach for NASA's research program and facilities planning in aeronautics.

This plan addresses three principal subjects: governmental policies that establish NASA's role in aeronautics, the goal and objectives that guide NASA's actions in accordance with that role, and the elements of NASA's planned aeronautical research and technology development program.

A. Governmental Policies Establishing NASA's Role

NASA's role in aeronautics is broadly described in the National Aeronautics and Space Act of 1958, as amended. However, interpretations of the Act's meaning have ranged from limiting the Agency to conducting basic inhouse research, following the NACA tradition, to working more closely with industry, including more extensive funding of technology demonstrations. In 1982 the Office of Science and Technology Policy convened a group of senior representatives from all government agencies with responsibilities in aeronautics to examine the Nation's aeronautical research and technology development policy and related matters. That examination clarified the policy, delineated more clearly the roles of the participating agencies in the process of technology development and application, and asserted again the importance of aeronautics to the defense and economic well-being of the United States. The group recommended:

- o National goals that would ensure timely provision of a proven technology base to support development of superior U.S. aircraft and of a safe, efficient, and environmentally compatible air transportation system
- o Government support, consistent with overall national priorities and the availability of funds, for aeronautical research and technology development and for demonstration of technology for military aircraft
- o Continued maintenance of present organizational relationships, in which:

- The Department of Defense (DOD) funds, directs, and implements aeronautical technology development and demonstration programs for military applications
- NASA funds, directs, and implements aeronautical research and technology development and supports military aeronautical technology demonstrations
- NASA and DOD encourage transfer of aeronautical research results to and within U.S. industry
- Both NASA and DOD manage, maintain, and operate aeronautical research, development, test, and evaluation facilities
- The Federal Aviation Administration, with NASA and DOD support, is responsible for air traffic control and safety-related aeronautical research and technology.

With the President's acceptance of those recommendations as U.S. aeronautical policy in November 1982, they became a base for NASA's long range plan for aeronautics.

B. Goal, Strategy, and Objectives

1. Goal

The goal of the Aeronautics program is to conduct effective and productive research and technology programs that contribute materially to the enduring preeminence of U.S. civil and military aviation. That goal will require maintenance of the capabilities of the NASA research centers, bold and imaginative program management, and greater involvement of NASA with others in the research and development community.

2. Strategy

The principles underlying the aeronautics program plan are emphasis on the initial steps in the research and development process, recognition of the common civil and military utility of aeronautical technology, and capitalization on the synergism between aeronautical and space technologies and capabilities. To avoid the confusion that often accompanies the somewhat arbitrary partitioning of the research and development process, the following definitions apply to the three activities that are the principal elements of NASA's aeronautical research and development:

- o Disciplinary Research--research to increase knowledge of fundamental physical phenomena and generate new concepts in primary aeronautical technical disciplines
- o Systems Research--research in individual technical disciplines and in technologies uniquely related to various general classes of aircraft to increase knowledge of interactions among system components

- o Proof of Concept--investigations to determine the feasibility of promising technical advances.

Two subsequent steps in the research and development process will be given secondary but important emphasis: technology demonstration and product development. Technology demonstration is concerned with advanced technologies for which confidence must be established through demonstration of their technical value. NASA's technology demonstration activities will be restricted generally to technology with potential military applications and will be coordinated or conducted with DOD.

NASA engages in product development only in connection with military systems, to provide technical and test support to DOD and industry.

Most technology development is independent of potential applications. However, when a particular type of aircraft tends to place greater demands on technology than do others, development work is planned and, at times, conducted jointly with potential users of the technology for that type of aircraft. In fact, technical laboratories operated by DOD, the Federal Aviation Administration, and private industry constitute important components of the NASA research community, as do universities engaged in basic aeronautical research.

Devoted largely to technology development, NASA's research facilities also are used in development testing when they possess needed unique capabilities. Data from development testing enhance the research data base and thus contribute to the primary research and technology program. Aeronautical research facilities are used in tests on various space, launch, and entry vehicles. In addition, the needs in a number of aeronautics and space technology areas are closely related; for example, high-temperature materials, aerodynamic heating, secondary power, control, and guidance. Aeronautical research and space research are synergistic.

3. Objectives

The Aeronautics program plan has the following five key objectives:

- o Maintain the excellence of the NASA research centers in facilities, computational capability, and technical staff
- o Achieve appropriate levels of disciplinary and systems research at the leading edge of technology in those areas critical to the continued superiority of U.S. aircraft
- o Assure the timely transition of research results to the U.S. aerospace community
- o Assure the appropriate involvement of universities and industry in NASA's Aeronautics program
- o Provide development support to the aeronautics activities of other government agencies and U.S. industry.

The significance of those objectives and NASA's approach to achieving them are described below.

a. Maintain Research Center Capabilities

A primary strength of NASA and its predecessor, NACA, in aeronautics has been the institutional excellence of the Ames, Langley, and Lewis Research Centers. Those centers possess most of the key aeronautical research and development facilities in the United States. In addition, their technical staffs comprise an unmatched pool of experts. The centers not only conduct research themselves, but also coordinate the efforts of peers elsewhere in government, industry, and academe. Their aeronautical facilities, which have a replacement value of over \$4 billion, are in most instances unique special purpose research and test facilities essential to the development of both commercial and military aircraft. An important new facility, the National Transonic Facility, is becoming operational at Langley; but many wind tunnels and engine test cells and their auxiliary equipment are aging and in need of extensive rehabilitation. Consequently, the Facility Integrity Program has been initiated to provide rehabilitation through a multi-year repair and replacement activity. Existing facilities also are being enhanced through the Facility Productivity Improvement Program, which is designed to provide a more efficient test capability.

As computational methods have matured, they have become a powerful, complementary partner to NASA's experimental facilities and have extended NASA's basic ability to conduct research in a broad range of disciplines. However, as computational codes have been developed to address increasingly more complex physical phenomena, they have pushed the current state-of-the-art of computational capabilities. To ensure the continued rapid advancement of computational methods, the research centers are enhancing their computational capabilities by acquiring the world's most advanced supercomputers. In the longer term, major advances in computational methods will require an evolutionary approach. The Numerical Aerodynamic Simulation program will address those needs.

Full-scale implementation of the Numerical Aerodynamic Simulation program was initiated in 1984. When operational, in 1986, the system will feature high-speed processing networks with work stations, graphics capabilities, and long-haul, wide-band satellite communications links between the research centers. The heart of the system, the world's most powerful prototype high-speed processor, will perform up to 250 million floating point operations per second (MFLOPS), approximately four times the sustained operating speed of current computers. As the system evolves to an extended operational capability, in early 1989, a newer, more powerful processor will provide up to 1,000 MFLOPS to a wider community of users, as remote access is provided to industry, university, and other government research laboratories. This national resource will be upgraded continually to ensure that it will provide the computational capability required to maintain U.S. leadership in this area.

The staffing of the research centers is being improved by adjusting their mix of skills to maintain consistency with their defined areas of research and by creating an environment designed to attract the best and

brightest of newly graduated scientists and engineers. Opportunities for advanced education and training are provided, as are dual career ladders that allow advancement through either management or research. Staffs are augmented in critical areas with temporary personnel obtained through postdoctoral fellowships, grants to visiting scientists, cooperative work-study programs with universities, and intercenter personnel exchanges.

Because of limitations on both staff size and budget, the Aeronautics program will distribute its resources to the research centers in accordance with the priorities this plan establishes for each of them. Since each research center's capabilities usually are supplemented by supporting or related capabilities at the other research centers, the centers' areas of excellence are closely interrelated. For example, when the newly modified 40x80x120-foot wind tunnel at Ames Research Center becomes operational, it will provide a unique capability for noise research that will complement the current noise prediction and analysis capabilities at Langley Research Center. Similarly, the experimental and computational capabilities being advanced in Lewis Research Center's turbine and compressor research will be supported by the development of the computational system and algorithms at Ames. All of the research centers are national laboratories responsible for advancing fundamental aeronautical disciplines. In addition, each has the following special responsibilities:

- o Ames Research Center--flight research and technologies for commercial and military rotorcraft, powered-lift aircraft, and high-performance aircraft
- o Langley Research Center--airframe technologies for commercial and military transports, general aviation aircraft, and military high-performance aircraft
- o Lewis Research Center--technologies of aeronautical propulsion and power.

b. Achieve Appropriate Levels of Disciplinary and Systems Research

Increased emphasis will be placed on systems integration. To achieve technological improvement, interactions among the individual components of a vehicle, its subsystems, the flight crew, and its operating environment must be understood. Technical disciplines must be interrelated in systems research. For instance, aerodynamics sets the basic shape of an airplane, while materials and structures technologies maintain the integrity of that shape and minimize the airplane's weight. Similarly, propulsion systems involve both fluid mechanics and structures. Flight controls interact with the airplane's aerodynamic shape and structural response modes to determine its flight performance, handling qualities, and maneuverability. Vehicle dynamics and integration of the airframe with the propulsion system and weapons further control the design. Because all of those elements interact and cannot be separated, all must be addressed when seeking improved performance, increased durability, and reduced acquisition and operating costs for a total system.

Systems research investigates those complex interrelationships to provide understanding of the overall behavior of a system--be it an engine, a complete aircraft, or a structural component such as a large composite wing span--and an understanding of the interaction of the system or subsystems with the environment, natural and man-made.

Technology goals and current program plans, including future initiatives, are described in sections C, D, and E of this chapter.

c. Ensure Timely Transfer of Research Results to U.S. Aerospace Industry

Rapid and unconstrained dissemination of research and technology results that, though unclassified, are economically or militarily sensitive can allow exploitation by potential competitors or adversaries before use by the United States. NASA endeavors to prevent such exploitation of its results. At the same time, because the results are essential to the productivity of the U.S. aerospace community, NASA maintains their free flow to the extent that commercial competitiveness and national security permit.

A second concern is that U.S. industry may not be aware of all technical advances, even unclassified ones, made outside the United States. Therefore, the NASA centers have accepted responsibility for acquiring, assimilating, and disseminating to U.S. industry information on relevant technology advances made outside the United States.

To ensure rapid transfer of NASA generated technologies to industrial application, emphasis is being increased on two important mechanisms: active participation of industry in the Agency's research and technology activities through contracted and joint programs, and timely dissemination of results through workshops, conferences, and reports.

d. Ensure Appropriate Involvement of Universities and Industry

The universities participate in NASA's aeronautics research and technology in several ways. Faculty members serve on advisory committees that help formulate and critique NASA programs. With their students, they participate in basic research programs, generally in close collaboration with personnel at the research centers. The resulting contacts give visibility to NASA and its programs in the universities and direction to academic research activities. They also stimulate the transfer of ideas and talent between the universities and the research centers.

The principal mechanisms for university participation are NASA grants and contracts that foster collaboration between personnel at the research centers and faculty and graduate students at the universities. Increased use of those mechanisms is planned. Another kind of arrangement to enlarge NASA's academic interface will include formation near Ames Research Center of the Research Institute for Advanced Computer Science, which will be an analog of the Institute for Computer Applications in Science and Engineering at Langley Research Center. Similarly, two or more centers of excellence in computer science and its aerospace applications will be established. The purposes of the Institute and the two centers of excellence will be to focus academic expertise in computer science and

applications critical to aerospace and to develop a group of young aerospace engineers highly proficient in computer technology.

With regard to industry participation, the principal purpose of NASA's Aeronautics program is to develop technology that can be incorporated expeditiously and economically into new vehicle designs. For that purpose and to ensure that the program's projects include consideration of both technology needs and technology opportunities, program planning and execution are undertaken in close coordination with senior management, program and project leaders, and technical specialists in U.S. industry and the Department of Defense.

Aeronautical systems research must be a cooperative endeavor between NASA personnel and their counterparts in industry, since much of the understanding of system requirements and integration problems resides in the latter. Thus, an important feature of the Aeronautical program is research performed by industry with NASA funding and technical collaboration.

e. Provide Development Support to Other Government Agencies and to U.S. Industry

Although devoted primarily to the conduct of research and technology development, NASA's technical staff and facilities also aid government and industry in the development of new aircraft. In providing support, NASA augments its own store of experience and data to the benefit of its subsequent research and technology development activities.

C. Technology Objectives

Technology objectives, established to provide a framework for decisions on funding, personnel, and facilities, represent areas for long-term emphasis. The level of emphasis may differ from center to center, and the total amount of effort will depend on the funding and manpower available. The order in which the objectives are presented does not imply priorities, and it should not be assumed that activities not included will be abandoned. The objectives are as follows:

- o Bring external and internal computational fluid dynamics to a state of practical application for aircraft and engine design
- o Significantly reduce aircraft viscous drag over the full speed range and improve understanding of Reynolds number effects at transonic speeds
- o Minimize structural weight through use of advanced materials for civil and military aircraft engines and airframes
- o Provide advanced control, guidance, and flight management technologies to improve performance and operation of future aircraft
- o Improve by 100 percent the productivity and reliability of rotorcraft for military and civil application

- o Ensure availability of technology for superior military aircraft and missile systems
- o Enhance flight crew effectiveness in advanced cockpit and air traffic environments that include advanced automation, display, and control techniques
- o Exploit modern computers in solving computationally intensive aeronautical problems
- o Exploit the full potential of techniques for enhancing performance through highly integrated propulsion-airframe systems
- o Advance the technology for small gas turbine engines to a level comparable with that for large turbine engines
- o Establish the technical feasibility of high-speed turboprop propulsion
- o Advance design technologies for subsonic transport engines to improve their fuel efficiency and durability
- o Increase aviation safety through improvement of crash- and fire-worthiness, protection from meteorological hazards, and aircraft systems.

NASA's approach to those objectives follows.

1. Computational Fluid Dynamics

Computational Fluid Dynamics has been identified as one of the major tools required for addressing a wide range of aeronautical analysis and design problems. It enables analyses, both to expand understanding of fundamental flow physics and to provide easy-to-use methods for creating synergistic designs and conducting performance analyses of increasing complexity and completeness. Major gains in computational aerodynamics during the next decade are expected to result from increased emphasis on fundamentals such as advanced algorithm development, computer-aided geometric modeling, generation of 3-dimensional adaptive grids, turbulence simulation, and modelling of 3-dimensional flow for complex configurations. The rapid progress being made is expected to provide advanced design tools that will yield, for aircraft and engines, preliminary designs that are much closer to final configurations than current preliminary designs can be. The result will be greater economy in wind tunnel and test rig activities and, at the same time, superior products. The Numerical Aerodynamic Simulation system will support directly the objectives of computational aerodynamics and will provide pathfinding capabilities to advance understanding of aerodynamics.

2. Aircraft Viscous Drag and Reynolds Number Effects

Reduction of aircraft drag is a major factor in progress toward aircraft design goals such as increased range and speed, decreased fuel consumption, and decreased weight and volume. As other sources of drag are being reduced, viscous drag is becoming an ever increasing fraction of total drag. One technique for reducing wing-skin friction drag is laminar flow control. That

technique may provide a reduction of 80 percent; however, it has not yet been proven feasible for day-to-day aircraft operations. Maintaining laminar flow at supersonic speeds also is plausible. It could reduce total aircraft drag by as much as 30 percent and, at the same time, reduce surface temperatures. Research areas that should prove fruitful in reducing viscous drag include maintenance and reliability of laminar flow control systems; active control of laminar instabilities; and optimization of passive techniques (such as use of pressure gradients and passive bleed) for maintaining laminar flow.

Concerted effort also is under way to reduce drag due to turbulent skin friction. This work, which consists primarily of modifying the geometry of aircraft surfaces, is applicable to fuselages as well as to wings. Some of the more promising techniques being developed are passive ones such as large-eddy breakup devices and longitudinal surface striations (riblets) that manipulate and control the turbulence to reduce its scrubbing action on aircraft surfaces. Reductions projected for fuselage skin friction are up to 30 percent for subsonic speeds and up to 15 percent for supersonic speeds. A pacing item in developing concepts for reducing drag caused by skin friction is lack of understanding of turbulence physics. Further understanding of the complexities involved will be provided by advances in computational fluid dynamics and test techniques.

Differences in the Reynolds numbers from full-scale and wind tunnel tests often introduce inaccuracies that seriously compromise aircraft design. The new National Transonic Facility provides a full-scale Reynolds number testing capability, effectively eliminating the potentially costly errors arising from extrapolation from data obtained in tests that previously could be conducted only in low Reynolds number tunnels. The National Transonic Facility and the Numerical Aerodynamic Simulation system will form a powerful combination providing a synergistic analysis and design capability heretofore not available for synthesis of advanced aircraft configurations. A result will be increased emphasis on the complementary interaction of experimental testing and computational simulation.

3. Use of Advanced Materials to Minimize Structural Weight

Advanced materials that reduce the structural weight of aircraft contribute significantly to increases in the overall performance and efficiency of the aircraft. Consequently, NASA's materials and structures program addresses structural concepts and analysis methods to exploit the increases in strength and stiffness and the reductions in density that advanced materials can provide. The program also addresses material constituents and processes that can improve durability by increasing fatigue resistance and tolerance to damage and high temperatures.

Research to improve the structural performance of aluminum will continue. Rapid solidification and improvements in basic metallurgy processes for aluminum powders are under investigation, and superplastic forming techniques will be developed for fabricating geometrically complex structural components.

Materials with higher strengths and stiffnesses and lower densities will be provided by development of lithium-aluminum alloys, strengthening with dispersed silicon carbide particles, and reinforcement with whiskers. The primary objectives of NASA's composites activities are to improve the

toughness of the composites, to develop structural concepts that exploit the advantages of composites, and to understand failure mechanisms that limit structural performance. Increases in their tolerance to flaws and damage will improve their durability and impact resistance and, therefore, increase their safety.

NASA's approach to improving aircraft engine structures is to increase the durability of hot-section superalloy components and to continue research on hot-section ceramic components. The ceramics research will focus on identifying critical processing variables that affect reliability, developing methods to measure variables that affect reliability, developing methods to measure the growth of cracks that occur, and nondestructive evaluation methods for monitoring the population and the propagation of small cracks. The superalloy research will use a newly developed, high-temperature structures laboratory to study the behavior of turbine blade material and burner liner hardware under realistic aerothermomechanical loading conditions. That research will be supported by research on thermal barrier coatings that are non-corroding, and will be paralleled by continual development of specialized structural analysis techniques designed to predict the detailed history of the stress-strain deformation of engine components over an entire mission cycle.

4. Advanced Control, Guidance, and Flight Management

Advanced concepts applied to flight management, control, display, and crew station interfaces can provide designs for aircraft systems able simultaneously to follow planned flight paths more accurately and to perform functions that are crucial to the safety of flight. As dependence on digital fly-by-wire control systems increases, system reliability requirements drive the applicable technology toward a high degree of fault tolerance. Improvement in operational efficiency requires better techniques for flight path management in conjunction with improved air traffic control. The approach that will be followed is to develop methods for fully integrating flight-crucial controls and guidance functions; identify alternative system architectural concepts; establish emulation-simulation and physical testing techniques for advanced digital systems; and develop advanced concepts for display, information, and flight path guidance systems. Strong emphasis will be placed on advancing the technology for management of dynamic, fault-tolerant systems and for highly reliable computer systems able to support complex interacting functions.

In close cooperation with the Federal Aviation Administration, NASA will conduct research to improve capabilities for defining and executing efficient and safe flight paths in the congested terminal area under adverse weather conditions and to ensure that advanced aircraft features can be accommodated by the evolving national airspace system. Other research will exploit the synergistic benefits from integrating advances in aerodynamics, structures, propulsion, and digital electronics to obtain revolutionary changes in configuration concepts and thereby provide major gains in fuel savings and reductions in direct operating costs and weight.

5. Improvement in Rotorcraft Productivity and Reliability

Rotorcraft technology is relatively immature and therefore presents a broad range of disciplinary, component, and systems research challenges. Because of the complexity of rotor aerodynamics and dynamics and the resulting

vehicle aeroelastic, stability, and control problems, there are opportunities for major gains in performance, flying qualities, and all-weather operating capabilities, and in reducing vibration and noise. The program's focus will be on system improvements such as a 100-percent increase in speed and range, world-wide self-deployment capability, 50-percent decrease in noise and vibration, 25-percent reduction in mission fuel requirements, and 100-percent increase in payload capacity. Those advances will increase significantly the operational capabilities of both civil and military rotorcraft. Key factors for both civil and military rotorcraft are low vibration and noise, high payload capacity, productivity, economy, speed, agility, self-deployability, and adverse weather capability--with the last four factors being particularly important for military applications.

The planned program will concentrate on critical technologies, with special emphasis on improving fundamental understanding and analytical prediction methodologies. The research approach will use ground-based experimentation, simulation, verification through flight tests, and development of certification criteria for advanced rotorcraft concepts with regard to performance, controls, propulsion, structures, guidance, and navigation. Technology development tasks for the next generation of rotorcraft will include establishment of a data base for large transport and heavy-lift rotorcraft; evaluation of circulation-control rotor concepts, such as the X-wing for high-speed rotorcraft; and refinement of tilt-rotor technology for civil and military applications.

The program also will investigate aero-acoustics to provide design tools, methodology, and substantiation of the data base in order to achieve improvements in rotorcraft designs that will reduce external noise by 5 to 10 decibels, increase hover efficiency by 10 percent, and increase cruise efficiency by 20 percent. Analytical prediction methods and a comprehensive data base on rotor parameters affecting performance and noise will be important factors, as will the establishment of criteria for structuring small-scale aero-acoustic model tests and the accurate projection of results to full-scale designs.

6. Technology for Superior Military Aircraft and Missile Systems

Evolution and development of advanced concepts for high-performance military aircraft and missiles provide the technology foundation upon which the Department of Defense and industry develop better weapon systems. The High Performance Aircraft program is aimed at generating technology advances for high-speed aircraft and missiles, including powered-lift aircraft with vertical or short takeoff and landing capabilities, supersonic cruise and maneuver aircraft with conventional or short takeoff and landing characteristics, and hypersonic cruise aircraft. Emphasis will continue on improvement of analytical and experimental techniques to acquire the data base necessary for developing high-performance vertical or short takeoff and landing aircraft capable of operating from a variety of bases.

Analysis, simulation, wind tunnel tests, and tests using remotely controlled, free-flight models will be continued on fighter aircraft embodying new concepts to improve their controllability at high angles of attack, during stall departure, and in spins. Analyses and simulations will be emphasized over the next several years to improve high-altitude, low-speed combat

maneuverability. A cooperative analytical and experimental program with industry is in process on concepts for high-performance supersonic aircraft and missiles. Methods for analyzing the aerodynamics of supersonic vehicles will be refined and applied to promising unconventional configurations. Research on hypersonic air-breathing vehicles will continue to evaluate concepts for integration of turbojets and ramjets. Wind tunnel tests of advanced concepts will parallel the development of aerodynamic prediction and performance codes. In addition to those research and technology base activities, flight test programs are under way in cooperation with the Air Force, Navy, and Defense Advanced Research Projects Agency on a variety of concepts for advanced high-performance aircraft.

7. Technology to Enhance Flight Crew Effectiveness

Cockpit automation is being increased through more use of electronic displays and information input devices. Consequently, the crew's role is becoming more one of management and less one of attitude control. Automation promises increased economy, safety, and capacity for aerospace systems. However, a new body of technology is needed for system interface designs to enhance the overall capability and reliability of the crew-cockpit system. Lack of that technology has forced designers to be very conservative in their use of automation and advanced cockpit systems with capabilities far beyond those of conventional electromechanical devices. NASA's human factors program plans to develop guidelines for the use of automated cockpit systems, electronic displays, and information input and output devices. The Federal Aviation Administration is especially interested in such activity, since it needs the results for use in developing methods for certifying advanced electronic cockpit systems.

For that research, NASA has installed at the Ames and Langley Research Centers full-mission, transport-aircraft simulators based on advanced technology. Research in process includes a study of the effects of increased automation on crew performance and an evaluation of cockpit display of traffic information. Plans include studies of crew interactions with computers and intelligent systems and allocation of functions between crews and automation.

8. Exploitation of Modern Computers for Aeronautics Research

The long-term computing requirements for aeronautics research require a thousand times the capability that current commercial computers can provide. Consequently, the Office of Aeronautics and Space Technology's computer science program is striving to provide a technical foundation for developing, understanding, and exploiting advanced computing architectures and methodologies. The key to achieving the required performance is successful exploitation of high degrees of parallelism in computation and effective use of knowledge-based techniques for specifying problems and analyzing results. Little is known about the technologies involved, but their importance is being increasingly recognized throughout the high-performance computing community. Parallel hardware architectures, distributed operating systems, and concurrent algorithms and software are all vital elements of this effort. An important aim is to understand the interplay between advanced architectural concepts and the performance properties of algorithms. Algorithmic complexity, time-space tradeoffs, convergence properties, numerical accuracy, and human productivity are the major performance metrics. The principal objective is to provide

sufficient computational capability by the year 2000 that routine design procedures will include detailed 3-dimensional analysis of aeronautical vehicles and their performance, and will provide detailed understanding of internal and external flow phenomena.

The airborne environment is sufficiently unique that it calls for specific consideration. Computational systems for use in it in the future will depend on high-integrity, distributed systems whose critical characteristics will include extraordinarily high reliability, integrated systems consisting of processing sites with widely varying capabilities, and real-time distributed processing. The Office of Aeronautics and Space Technology's research is addressing software reliability through empirical studies, and is focused on developing a coherent, integrated operating system for airborne distributed processing systems.

9. Highly Integrated Propulsion-Airframe Systems for Enhanced Performance

Favorable integration of aircraft propulsion and airframe systems provides important savings in fuel and direct operating costs by reducing interference drag. The reduction potentially can produce a value as low as three percent of total drag. Drag reduction is particularly important for military aircraft because it has a direct influence on range, payload, and other performance characteristics that determine combat capability. Therefore, the Aeronautics research and technology program has under way the Propulsion-Airframe Integration program to improve performance and reduce losses associated with integration of advanced propulsion systems with airframes. The approach will be to develop technology, analytical codes, and design methodologies and to extend the experimental data base for inlets, nozzles, and propellers. Experimental and theoretical studies will develop an understanding of the complex flow phenomena associated with propulsion systems in advanced configuration aircraft.

Concepts are under study to reduce drag, enhance wing lift, and incorporate thrust vectoring and reversing to reduce landing and takeoff distances. Proper contouring of nacelle pylons and cleaner nacelle installations can reduce interference drag significantly. Use of advanced, unconventional configurations integrating nacelles, pylons, and wings is expected to reduce skin friction drag enough to lower total drag an additional one to three percent. Analytical techniques are being developed for predicting the interactions of nozzles and afterbodies; nacelles, pylons, and wings; turboprop propulsion systems, nacelles, and wings; and inlets and forebodies. Generic 2-dimension and 3-dimension viscous codes will be developed for analyzing and optimizing the integration of both turboprop and turbofan engines with airframes.

10. Technology for Small Gas Turbine Engines

The quality of small turbine engines is very important to many types of aircraft, including general aviation aircraft, commuter aircraft, helicopters, cruise missiles, and military trainers, as well as to many related ground applications. Projections indicate that advances in small gas turbine engines will reduce the fuel consumption of small fixed-wing aircraft and helicopters by 40 percent and increase the range of cruise missiles substantially. Improvement of component efficiencies is expected to provide a gain of 15 to

20 percent and regeneration an additional 10 to 15 percent, with ceramics and intercooling providing a final 10 to 15 percent. The efficiencies of small engine components currently are 8 to 10 percent less than those of large transport engine components because of scale and Reynolds number effects and manufacturing limitations associated with factors such as relative surface finish, fillet size, and minimum thickness. Also, design techniques for large components are inadequate for predicting accurately the performance of small components; and manufacturing cost constraints prevent some aerodynamics and turbine cooling techniques used in large engines from being applied to smaller engines. Therefore, a new technology base specially adapted to the requirements of small gas turbine engines will be developed for use in improving small engine performance to levels similar to those of large subsonic transport engines.

11. High-Speed Turboprop Propulsion

Technological advances in turboprop propulsion can provide large gains in fuel efficiency and operating economy for civil and military transport aircraft. Compared to turbofans of the same technological level, turboprops have the potential to reduce fuel use by 15 to 30 percent. Realization of that potential will require establishment of several interrelated technologies involving design of single- and counter-rotation propellers, reduction of cabin noise, integration of propulsion and airframe, and integrity of mechanical systems.

Small-scale research spanning five years has produced a good understanding of advanced propellers (propfans) suitable for use at cruise speeds as high as those of modern turbofan transports. The research also has produced a good understanding of the efficiency of, and the noise created by, multibladed propellers with thin, swept blades operating at high power and high tip Mach numbers. The next task is to build large-scale propellers and test them in laboratories, wind tunnels, and, ultimately, at cruise flight conditions for the purpose of investigating their structural, dynamic, and acoustic characteristics that cannot be resolved in subscale tests.

The objective is to create both an experimental data base and analytical methodology to advance all the technologies critical to application of high-speed turboprops. The program encompasses both single- and counter-rotation propellers and their drive systems, wing and aft-fuselage mounted engines, tractor and pusher thrust orientations, and a range of other parameters such as cruise Mach number, power loading, and tip speed. The resulting array of technology options will allow the U.S. aerospace industry to produce fuel-efficient, high-speed turboprop aircraft for both civil and military applications.

12. Advanced Turbofan Research

Because fuel cost has become the major portion of the direct operating cost for subsonic transport aircraft, fuel efficiency is the principal design criterion for advanced subsonic turbofan engines. The Energy Efficient Engine program has demonstrated a 15-percent improvement in fuel efficiency through advances in technologies for turbofan components and systems. Some of those advances currently are being incorporated into development programs for new

and derivative engines. For even greater gains in fuel economy, a new technology base will be required. Advanced concepts for engines incorporating improvements in both component and thermodynamic efficiency offer an additional 15-percent reduction in fuel consumption.

Fundamental discipline research will provide basic information and understanding needed for developing high bypass ratio turbofans with high efficiency components and high overall engine pressure ratios. It will be focused on improvement of lightweight and high-temperature materials; improvement of structural design techniques; computational fluid dynamics to describe 3-dimensional viscous flow fields in turbomachinery, including heat transfer and turbine cooling; and fiber optics for use in transferring information.

Improvements in techniques for predicting flow fields and in methods for analyzing advanced materials and structures will provide turbomachinery having higher speed, greater efficiency, and less weight. Analytical predictions that are more accurate will reduce the time and cost of development testing, and better understanding of system dynamics and control will allow each engine to provide maximum performance without exceeding its limits or encountering nonrecoverable stall. The net result will be engines with higher performance, lighter weight, and lower development and operating costs.

13. Aviation Safety

The objective of the Office of Aeronautics and Space Technology's aviation safety and operating systems research program is to increase the safety of flight for all types of aircraft. Research related to meteorological hazards is one major activity under that program. It is focused on the detection and avoidance of severe storm hazards such as lightning strikes, wind shear, turbulence, and icing, as well as on the effect of those hazards on aircraft encountering them. Emphasis is on airborne detection of those hazards and on incorporating their characteristics into pilot-training and engineering simulators. Also to be pursued more vigorously is development of analysis techniques for determining the effects of weather on aircraft performance and the degradation that weather hazards such as lightning can inflict on advanced technology flight systems and materials. The resulting knowledge will permit the design of aircraft better able to withstand many of the hazards of encounters with severe weather.

Research is under way to develop aircraft with greater crash-worthiness in order to reduce fatalities and trauma injuries from crashes. Data from a full-scale crash test conducted in 1984 is providing information needed to analyze the failure mode of many aircraft cabin components affecting human survivability. The results will allow the design and development of cabin structures having greater crash-worthiness and fire resistance.

Past research on aircraft stall and spin concentrated on using models and full-scale aircraft to develop an experimental data base. Emphasis now is on development of analytical techniques for predicting aircraft stall and spin characteristics and on establishing reliable design methods. Future research will focus on designs for twin-engine aircraft and extension of single-engine prediction methods and modifications to the twin configuration. It also will include development of methods to analyze separated flow on 3-dimensional

wings, automatic spin prevention systems, and the effects of advanced airfoil designs on resistance to stall and spin.

Flight management and human engineering research will exploit advances in electronic technology to establish new concepts in flight station design that will provide safer and more efficient system operation. Because the flight station is the place where the pilot must interface with virtually all aircraft systems and the air traffic control system, development of the flight station should precede design of the rest of the aircraft. Of primary concern is how much automation is needed and how much is optimum. Alternative control and display devices, formats, procedures, and mode switching to optimize flight station design will be assessed for their effect on crew performance.

D. Current Program--New Directions and Emphasis

The elements constituting the current program reflect the need to continue work in the basic aeronautical disciplines and in systems research, maintain specialized facilities essential to aeronautical research, and develop technology of high potential payoff to the Nation.

The emphasis of fluid and thermal physics research will continue to be on cryogenic testing at high Reynolds numbers and reduction of turbulent drag. Additional emphasis will be given to advanced applications of computational aerodynamics to investigate vortex flows and to model geometrically, and generate grids for, complex aircraft configurations. The Numerical Aerodynamic Simulation system will make possible the solution of heretofore intractable problems in computational fluid dynamics and other areas of computational physics.

Materials and structures activities will be concentrated on light alloy metals, new composite materials, and the crash dynamics of composite structures. Improved and new manufacturing and forming processes will permit the production of structures that have very high strength, are light in weight, and are smooth and without waviness, thereby enhancing the possibility of achieving high-aspect-ratio lifting surfaces having natural laminar flow.

Research in controls, guidance, and human factors will focus on the flying qualities of aircraft with highly augmented controls; methods for validating fault-tolerant systems; human factors connected with automation of crew stations, including crew information generated by computers and displayed on electronic displays; development of technology to improve the fidelity of simulations; and improvement of aircraft capabilities to define and execute efficient and safe flight paths under adverse weather conditions in congested terminal areas.

The major areas of emphasis in computer science will be concurrent processing architectures, algorithms, and techniques to support the Agency's computational physics research. The research base for this critical area will be provided by the universities and the two computer science research institutes mentioned earlier, the Institute for Computer Applications in Science and Engineering at Langley Research Center and the Research Institute for Advanced Computer Science near Ames Research Center.

In propulsion, emphasis will be on advanced turboprop systems, technology for small turbine engines, and technology for engines for general aviation and commuter aircraft.

Rotorcraft research will stress the reduction of noise and vibration, the unsteady aerodynamics of rotors, and flight research to investigate the X-wing rotorcraft.

High-performance aircraft research will concentrate on flight at high angles of attack; vectored thrust aircraft; maneuverable, supersonic cruise, short takeoff and vertical landing aircraft; hypersonic propulsion; structures and configuration aerodynamics; and propulsion-airframe integration. Effort also will be made to increase the performance and durability of turbine engine hot sections. NASA and the military will flight test the Advanced Concepts X-29 Forward Swept Wing demonstrator aircraft in the 1985 through 1987 period to determine the value of advanced technologies for use in designing the next-generation tactical fighter.

The emphasis of subsonic aircraft research will be on significant reductions in viscous drag; advanced composites and metallics for lightweight primary structures; flight management and active control systems; optimization of interactions between aerodynamics, structures, propulsion, and controls; and improvement of the interaction between the aircraft and its environment, natural and manmade.

Technological progress during the past year has permitted work to accelerate on two programs that were new initiatives in last year's Aeronautics plan. Those programs and how they relate to the technology objectives described in Section C of this chapter are described below.

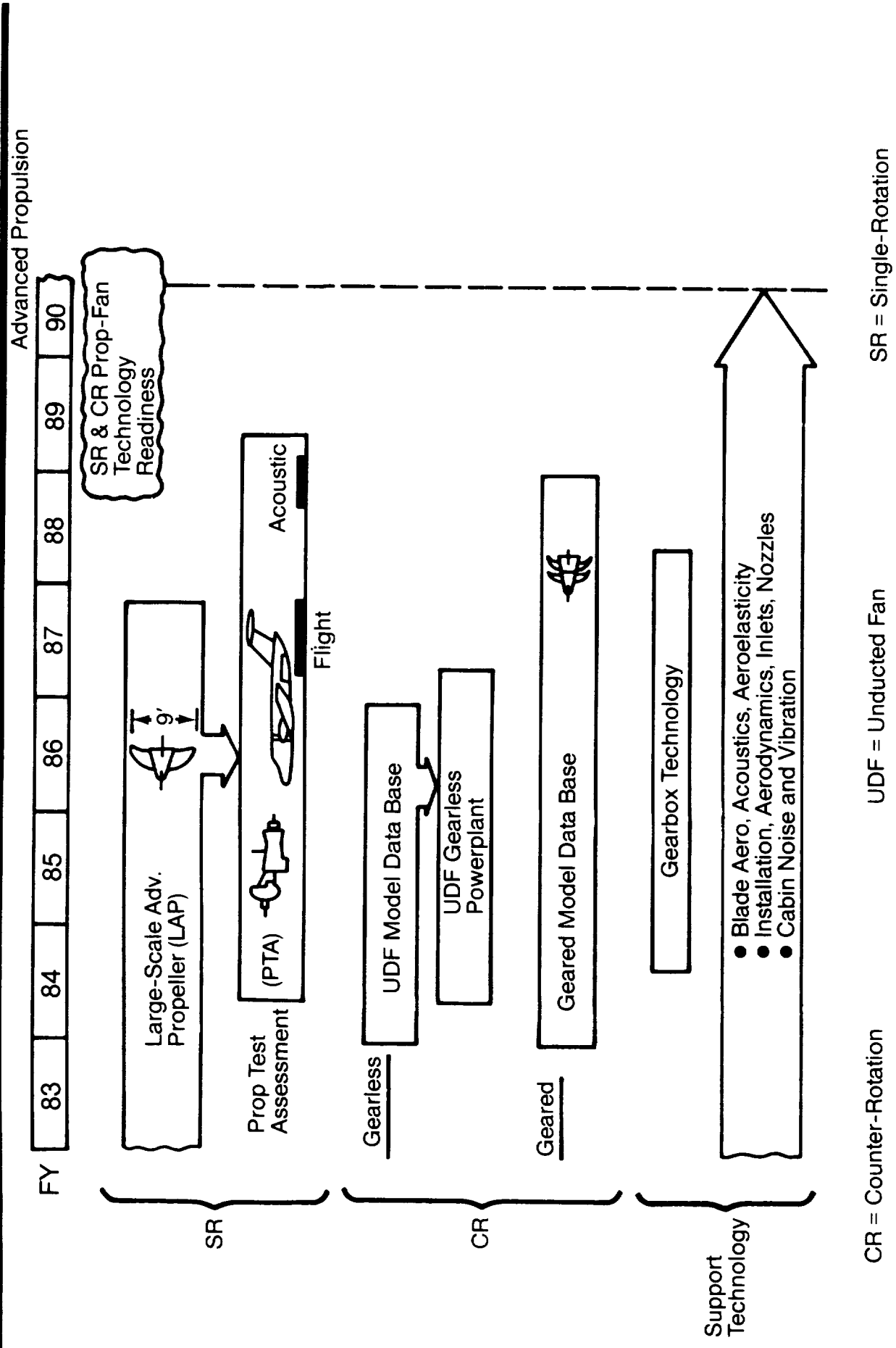
1. Advanced Turboprop Large-Scale Systems Research

As shown in Figure VIII-1, this program will provide for flight testing, by as early as 1987, of a large-scale advanced propeller to evaluate and correlate its structural integrity and acoustic characteristics. Neither factor can be addressed adequately in the small-scale model tests that have laid the foundation for this flight testing. A second major activity will be the large-scale, proof-of-concept testing of a unique, counter-rotating, unducted-fan propulsion system that will provide an additional 5- to 8-percent increase in fuel savings while eliminating the need for a high-power gearbox. A 9-foot diameter advanced propeller integrated with a flight-worthy nacelle and semispan wing will be tested in the 40x80-foot leg of the 40x80x120-foot low-speed wind tunnel at Ames Research Center, and then will be mounted on the wing of a modified Gulfstream II testbed aircraft and flown over a wide range of flight conditions up to and beyond the propeller's high-speed design point. Subsequent flight tests will evaluate aircraft system modifications to achieve cabin noise and vibration levels equivalent to those of modern turbofan-powered aircraft. In addition, the unducted-fan propulsion system will be ground tested, using a modified R404 engine as a research testbed.

2. Oblique Wing Technology

The objective of this program is to extend the data base for oblique wing technology through flight demonstration and validation at transonic and

Figure VIII-1
Advanced Turboprop Program Plan



supersonic speeds. NASA's investigation of the oblique wing configuration has covered many years, starting with concept development and continuing with a technology program that has included wind tunnel tests; simulations; light-weight, low-speed flight tests; and aircraft design studies. The results show that, for missions requiring a long-endurance or long-range flight segment in combination with a supersonic flight segment, the oblique wing configuration has lower overall drag and structural weight than either a conventional variable-sweep wing or a fixed wing.

For the flight demonstration and validation tests, NASA's existing F-8 digital fly-by-wire test aircraft will be modified to include an oblique wing and its associated systems. As shown in Figure VIII-2, the program will be carried out in three phases. Phase I will be a competitive preliminary design phase to determine the general size and configuration for an aeroelastically tailored composite oblique wing and its pivot assembly. It also will provide the details and tradeoff information needed for completion of the "design to" specifications. Phase II will include detailed design, fabrication, aircraft modification, and flight qualification testing. Phase III will be the flight tests. The results of this program will provide a design option for future civil and military applications.

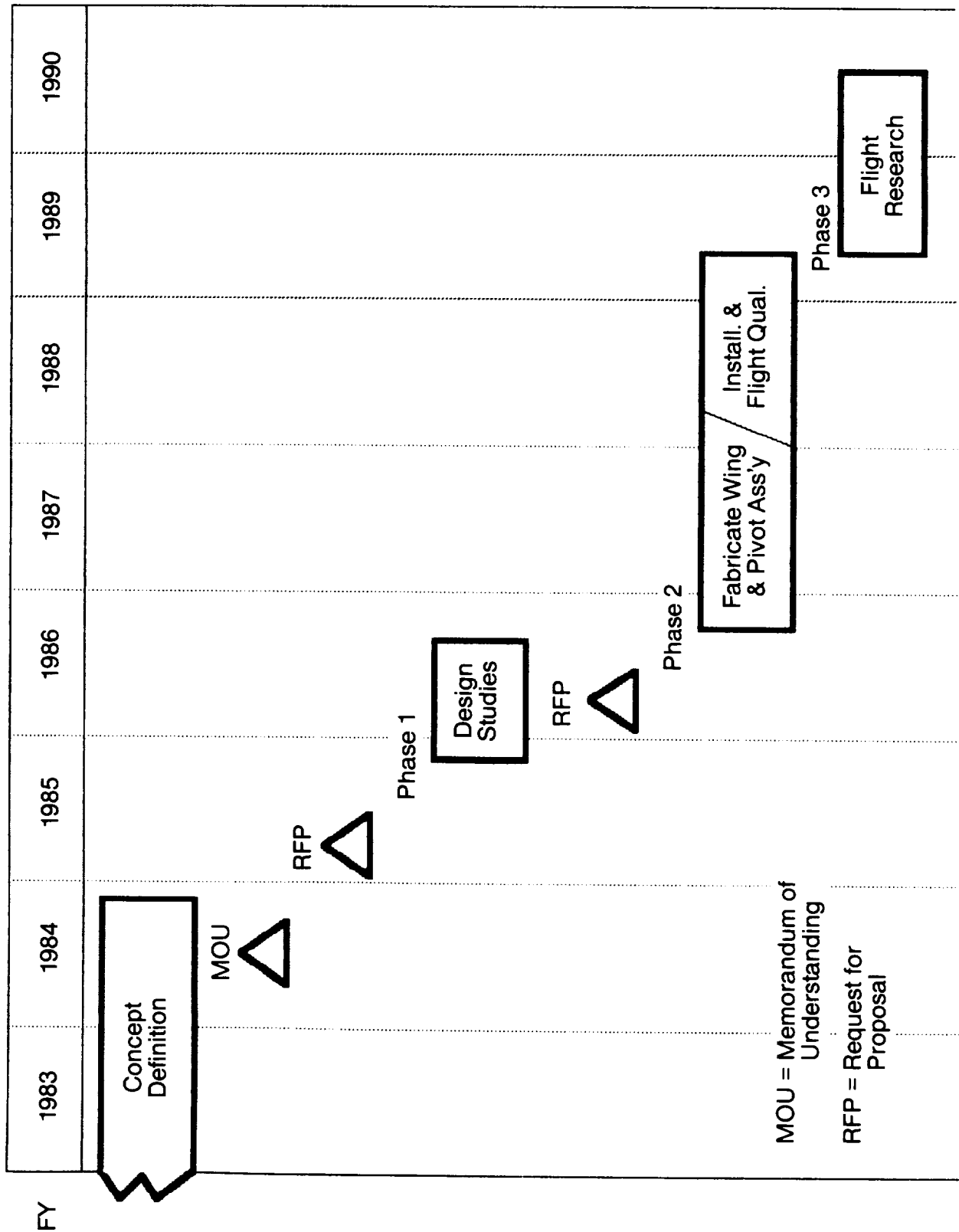
E. Future Initiatives

The initiatives described below are planned augmentations to the current aeronautics research and technology development program that will facilitate realization of the technology objectives listed earlier. They update and, in some cases, replace the initiatives in last year's plan. Some of them will be proposed as adjustments to current programs described in Section D of this chapter, some are proposed as new program elements, and others will be conducted within the Research and Technology Base funding line of the budget. Initiation of these proposed activities will depend on future budget levels and program priorities.

1. High-Speed Technology (Hypersonics)

Augmentation of this technology area will place primary emphasis on advanced air-breathing propulsion systems; but significant efforts in aerodynamics, aerothermodynamics, materials, and structures also will be included. The research program will be a long-range one to develop a broad technology base applicable to hypersonic cruise and accelerator vehicles and ultimately to develop a recoverable hypersonic research airplane. Studies of engine and aircraft systems will be conducted to define the needs and requirements for flight demonstrations. Because the technological status is quite different for various speed regimes, distinct efforts will be devoted to each of the Mach 0 to 6, Mach 6 to 12, and greater than Mach 12 regimes. Research in the Mach 0 to 6 regime will set the stage for a research aircraft in the Mach-6 class. For Mach numbers up to 12, emphasis will be on propulsion; demonstration is anticipated of missile-size propulsion at Mach 7 and, later, at Mach 12. Research for Mach numbers greater than 12 will address key questions about the maximum practical speed for air-breathing propulsion and the difficult task of achieving high performance in propulsion systems and vehicles operating in the extremely difficult conditions involved.

**Figure VIII-2
Oblique Wing Research Aircraft Program**



2. Supersonic Cruise Technology

As a focused program in NASA, development of supersonic cruise technology has been dormant since FY 1982. This new initiative will place primary emphasis on establishing multidisciplinary research programs to develop critical technologies and on starting a companion program dedicated to technology integration. Critical technologies are those for advanced propulsion systems, the aerodynamics of laminar flow, aerodynamic configurations, high-temperature materials and structures, and the technology of advanced controls. Work related to advanced propulsion systems will include determining the feasibility of the supersonic fan concept and assessing the turbine bypass-engine concept for supersonic cruise applications. Special emphasis will be placed on technology for high-temperature materials; and research will be initiated on components for variable geometry propulsion systems, including inlets, nozzles, and noise control devices. In structures and materials, a broad-based program will investigate lightweight, temperature-resistant materials for airframes and, for new materials, efficient structural designs. Aerodynamic efficiency will be increased by fuselage shaping, wing-body blending, planform designs that minimize drag due to lift, and favorable integration of the propulsion package. Systems integration studies will focus on interdisciplinary methods for integrating technologies to ensure that the full synergistic benefits of each technology advance are realized in the aircraft design process.

3. Computational Fluid Dynamics

The planned augmentation in this technology area will further the development of the methodology and applications for computational fluid dynamics, expanding the solid foundation now in place within NASA and the aeronautics community. It will ensure that applications of computational fluid dynamics to important problems are at a level commensurate with the high level of the computational capabilities that are emerging. The Numerical Aerodynamic Simulation system, scheduled to become fully operational in late 1987, will bring to the Nation the most advanced computational capabilities available.

Augmentation of the computational fluid dynamics area has the objective of ensuring that the Numerical Aerodynamic Simulation system's capabilities are used fully to maintain U.S. preeminence in aeronautics. The principal objectives of the augmentation are to tap more completely the knowledge and expertise that exist throughout the U.S. computational fluid dynamics community, and to ensure the increasing involvement of the computational fluid dynamics user community. The augmentation will facilitate the development of applications of computational fluid dynamics focused on important 3-dimensional flows dominated by viscous flow; aid in developing pathfinding simulations of the fundamental physics of unsteady flows; initiate development of techniques for performing integrated multidisciplinary analyses; and apply the concept of expert systems to automating the development of computational fluid dynamics analyses. The principal focus will be development of a capability for calculating the steady and unsteady viscous flows around complete aircraft with complex configurations--including the flows around engine inlets, exhaust plumes, and attached and separating stores for both cruise and maneuvering flight.

4. Rotorcraft Systems Noise and Vibration

This augmentation will support cooperative work by three NASA centers to develop methodology for creating low noise, low vibration designs for helicopters that will be acceptable to the community, have low vibration, and have low detectability (in military applications) without significantly sacrificing performance. It will make use of NASA's unique facilities in carrying out four principal tasks: fundamental aeromechanical experiments on 4-bladed rotors to provide empirical and theoretical predictions; investigations of innovative concepts, including tilt-rotor concepts; development of an extensive data base on rotor aeromechanics and aeroacoustics for use in predictions and in validation of theory; and exploration of the high-speed flight limitations of rotors.

5. Advanced Fighter Aircraft Technology

Evolving technologies, most notably those for high thrust-to-weight engines and thrust-vectoring controls, provide a potential for a revolutionary increase in the capabilities of advanced fighters. Achievement of that increase in a timely fashion will require a focused program of technology development to accelerate development and integration of the key enabling technologies. That program will have to build on and expand NASA's current program to develop technology for flight at high angles of attack. It also will have to capitalize on opportunities for configuration integration, which promises unprecedented levels of sustained supersonic performance and vehicle maneuverability and agility throughout the envisioned air-combat flight envelope. Its major elements will be development and validation of technologies related to: the design, control, and integration of propulsion systems, including studies of engine cycles, design of multi-axis vectoring nozzles, and investigation of performance, stability, and control of integrated inlets, engines, and nozzles; flight dynamics and control, including high-angle-of-attack technology development and in-flight evaluation using the F-18 High Alpha Research Vehicle, of airplane configurations, including in-house and contracted technology-integration studies to determine the performance, sizing, and sensitivities of candidate configuration concepts; and experimental and analytical methods for configuration integration, including tests in wind tunnels and ground facilities, development and application of new analytical integrity methods, and development of design methods and concepts for integrated flight control systems.

6. Transport Aircraft Laminar Flow Technology

The objective of this initiative is to develop concepts for achieving laminar flow over the wing and tail surfaces of transport aircraft and for validating those concepts sufficiently that U.S. aircraft manufacturers will consider their use in future production aircraft. Laminar flow potentially can reduce fuel consumption by 20 percent. The proposed approach is to design, build, and test a hybrid laminar flow control system. The concept for the hybrid system is to employ active suction over the leading edge portion of the wing to initiate laminar flow that then is maintained by favorable pressure gradients over the wing box structure, resulting in laminar flow over a substantial portion--up to 80 percent--of the wing's surface area. Initial concepts for a test aircraft will be evaluated and the most desirable concept will be selected. Manufacturers of transport aircraft are expected to play a

major role in the program, including commitment of significant resources to support technology development. Their anticipated activities are aircraft design and modification, flight hardware design and fabrication, and flight test support.

7. Small Engine Technology

This initiative has the objective of providing the technology base needed to secure for U.S. manufacturers preeminence in small engines by giving them a technical advantage in the market for future civil and military small engines. Its focus will be structural ceramics for turbine engines and technology for small turbine engine components and for multi-fuel rotary engines to be used in the 1990s in business, commuter, helicopter, and general aviation aircraft and in auxiliary power units. Technology to be developed includes that for reliable ceramic components such as turbine blades, abradable seals, vanes, combustor liners, and coatings made of silicon carbide, silicon nitride, and zirconia. Technology areas that are key to success in developing a highly advanced, ceramic, adiabatic, rotary engine are stratified-charge combustion; heat-resistant materials for use in components having low ability to reject heat; tribology for seals, bearings, and lubricants; and turbocharging and turbocompounding.

In the development of core components, emphasis will be on defining, quantifying, and developing design methodologies to minimize adverse size-related effects and on developing unique concepts for using advanced materials to overcome those size-related limitations on system performance. Verification testing will be conducted on annular, reverse flow combustors and dual and centrifugal compressors and turbines.

8. Superaugmented Rotorcraft Technology

This augmentation will address two related needs: that of the civil sector for a helicopter able to operate at remote sites and to provide emergency medical services, and that of the Department of Defense for a single-pilot light helicopter. The planned approach is to achieve an all-weather operational capability by developing and evaluating technology for integrating flight controls, propulsion controls, and guidance systems. The project will take advantage of and be complementary to the Army's Advanced Rotorcraft Technology Integration program; make use of analyses, simulation, and flight tests in a modern Army test helicopter; and exploit existing microelectronics technology. It will seek concepts for integrating flight propulsion controls; apply active controls; develop and evaluate multispectral imaging concepts to provide a zero-visibility approach, landing, and taxi capability; and develop design criteria for integrating control, guidance, and navigation systems, with emphasis on the interface between the pilot and the integrated system.

9. Convertible Engine Propulsion Technology

This augmentation's objectives are to develop and evaluate technology for integrated flight- and propulsion-control systems for rotorcraft with convertible engines and to experimentally evaluate maturing concepts for advanced convertible engines. Planned work has for its foundation the results of the Convertible Engine Systems Technology program conducted by NASA and the

Defense Advanced Research Projects Agency. That program explored the concept of engines able to operate in both the turbofan mode and the turboshaft mode, and the applicability of such engines to rotary wing and vertical-takeoff-and-landing aircraft such as the Folding-Tilt Rotor, X-Wing, and Tilt-Fan aircraft.

This augmentation will fund research on integration of controls in the engine test facility at Lewis Research Center that was used in the Convertible Engine Systems Technology program. Later, the Defense Advanced Research Projects Agency will furnish an advanced convertible engine to which the controls technology that has been developed will be applied. The success of the integration of flight and propulsion controls will be evaluated by correlating engine test data with flight simulator data. Studies in process to define concepts for advanced convertible engines will be coordinated with related Department of Defense and industry programs.

The tasks included in this augmentation are expansion of the control methodology for conventional helicopters so that the methodology is also applicable to rotorcraft powered by convertible engines; contracting for definition of integrated-control modes and for development of flight simulations; testing the integration of control systems with an advanced convertible engine at Lewis Research Center and with flight simulations at Ames Research Center; and testing promising concepts such as those for a torque converter and cross shafted, shared power systems.

10. Supersonic Short Takeoff and Vertical Landing Technology

This initiative's primary objective is to develop, in a broad ground-based program, supersonic short takeoff and vertical landing (STOVL) technology for use in selecting the most promising concepts for development of 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. The research will emphasize development, fabrication, and test of small- and large-scale models and propulsion components; development and test on a large-scale aircraft model of a nearly full scale, flight-like, ejector-augmentor propulsion system with vectored core thrust; modification of an existing engine for use in demonstrating on the ground a concept for an advanced STOVL propulsion system; development of methodology for evaluating leading supersonic STOVL concepts and propulsion systems; and computational analyses of the cruise performance of propulsive-lift configured aircraft.

11. Composite Structures Technology

The focus of this augmentation will be the key technologies needed for effective use of composites in highly loaded airframe structures. Special attention will be given to concepts that exploit the high structural efficiency of composites, are amenable to cost-effective fabrication, and can tolerate damage. Examples of approaches to achieving more effective composite structures are wound structures and pultruded sections (sections formed by pulling composite matrix through shaping dies). So that a broad range of structural concepts can be explored and unique fabrication capabilities will be applied, industry participation will be sought. The work under this augmentation will provide a focus for the tough resins, processing science,

and structural mechanics research being conducted in the composite materials community. It is expected to provide a technology base that will lead in the early 1990s to a new thrust in large composite primary structures.





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IX. INSTITUTION

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IX. INSTITUTION

A. Goals and Objectives

The Office of Management plays a leading role in the formulation of goals and objectives for the Agency. The eight goals listed in Chapter II, "Summary and Perspective," and subsidiary objectives for each of them were originally adopted in 1983 after a series of discussions with Headquarters office heads and the directors of the NASA field centers. Those goals and objectives were distributed to all employees to provide a focus for planning and concentrating effort. They are to be updated periodically. The first review, in 1984, resulted in updating the Space Station goal, restating the work-force goal, and revising the objectives extensively.

Two of the goals, the first and eighth, are particularly applicable to management of the NASA institution. The first seeks to create an environment and provide the tools that will encourage and enable NASA's high-quality, integrated work force to achieve and maintain excellence.

The eighth goal recognizes the need within NASA for management and employees to participate in improving quality and enhancing productivity, thus reducing costs. Development and application of advanced technology and management practices help to increase significantly both NASA and national productivity. This goal also encompasses management practices that provide incentives for contractor productivity and quality, with emphasis both inside and outside NASA on a team approach and modernization.

NASA's plans for people, facilities, and computers and other equipment are aimed at meeting those two goals.

B. Manpower

In FY 1983, NASA started augmenting its scientist and engineer work force with an infusion of recent graduates. The objective is to staff the Agency with sufficient scientists and engineers possessing the latest skills and knowledge in areas essential for conducting the Agency's current and emerging programs, including advanced data processing and computation.

Although ceiling constraints inhibited progress on that objective during FY 1984, the scientist and engineer complement continued to increase as a percentage of the total work force from 51.6 percent to 51.7 percent. The current scientist and engineer population of 10,900 (down from last year's 11,000) is expected to grow to approximately 11,500 by the end of FY 1989. That build-up is within a stable ceiling of roughly 21,000 for NASA's total permanent work force. Table IX-1 shows the hiring dynamics underlying that projection, including the emphasis on recruiting recent graduates and the part to be played by graduates from the cooperative education (co-op) work-study program. Figure IX-1 shows the expected effect on the age distribution of the scientist and engineer complement.

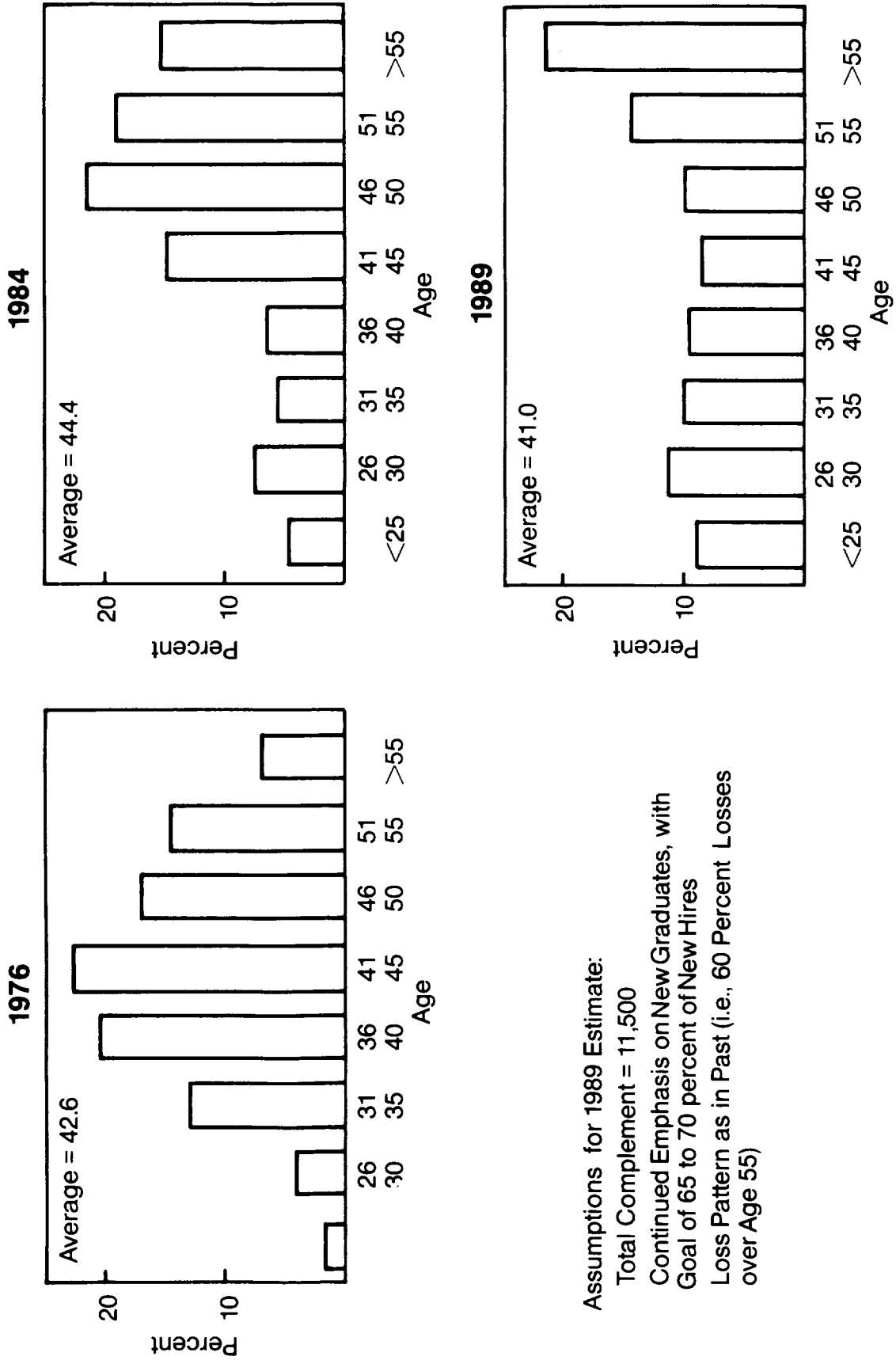
Continued success in increasing the scientist and engineer base will depend on factors such as budget and manpower authorizations; the levels of federal pay and benefits; and the state of the economy, especially in the aerospace sector. To meet the challenges of the 1980s, as the Nation pursues

TABLE IX-1. SCIENTIST AND ENGINEER HIRES

	<u>NUMBER HIRED</u>	<u>PERCENT FRESH OUTS</u>	<u>PERCENT CO-OPS</u>
FY 1978-1981	1,800	55	25
FY 1982-1983	1,050	77	20
FY 1984-1985	900*	65-70	20*
FY 1986-1989	4,000-4,500*	65*	25*

* Estimate

Figure IX-1
Age Distribution of Scientists and Engineers



Assumptions for 1989 Estimate:
 Total Complement = 11,500
 Continued Emphasis on New Graduates, with
 Goal of 65 to 70 percent of New Hires
 Loss Pattern as in Past (i.e., 60 Percent Losses
 over Age 55)



its declared policy of continued leadership in space and aeronautics, NASA must maintain a stable technical work force with up-to-date skills.

C. Facilities

New priority was assigned in FY 1983 to improvement and construction of facilities as a means to enhance the NASA institution. Emphasis is being placed on the following:

- o Current activities
 - Provision of manufacturing, testing, launching, and landing facilities to support 24 flights per year of the Space Shuttle
 - Activation and repair of large aeronautical facilities
 - Construction and upgrading of the antenna systems of the Deep Space Network
 - Preservation and enhancement of aeronautics and space technology facilities
- o Planned activities
 - Expansion of the capabilities of payload processing facilities
 - Continued improvement of aeronautics and space technology facilities
 - Improvement in the efficiency of Space Transportation System production.

After FY 1989, the program is expected to emphasize facilities to support 24 flights per year of the Space Shuttle, additional payload processing facilities, unique large aeronautics facilities, and augmentation of facilities to permit them to support the Space Station.

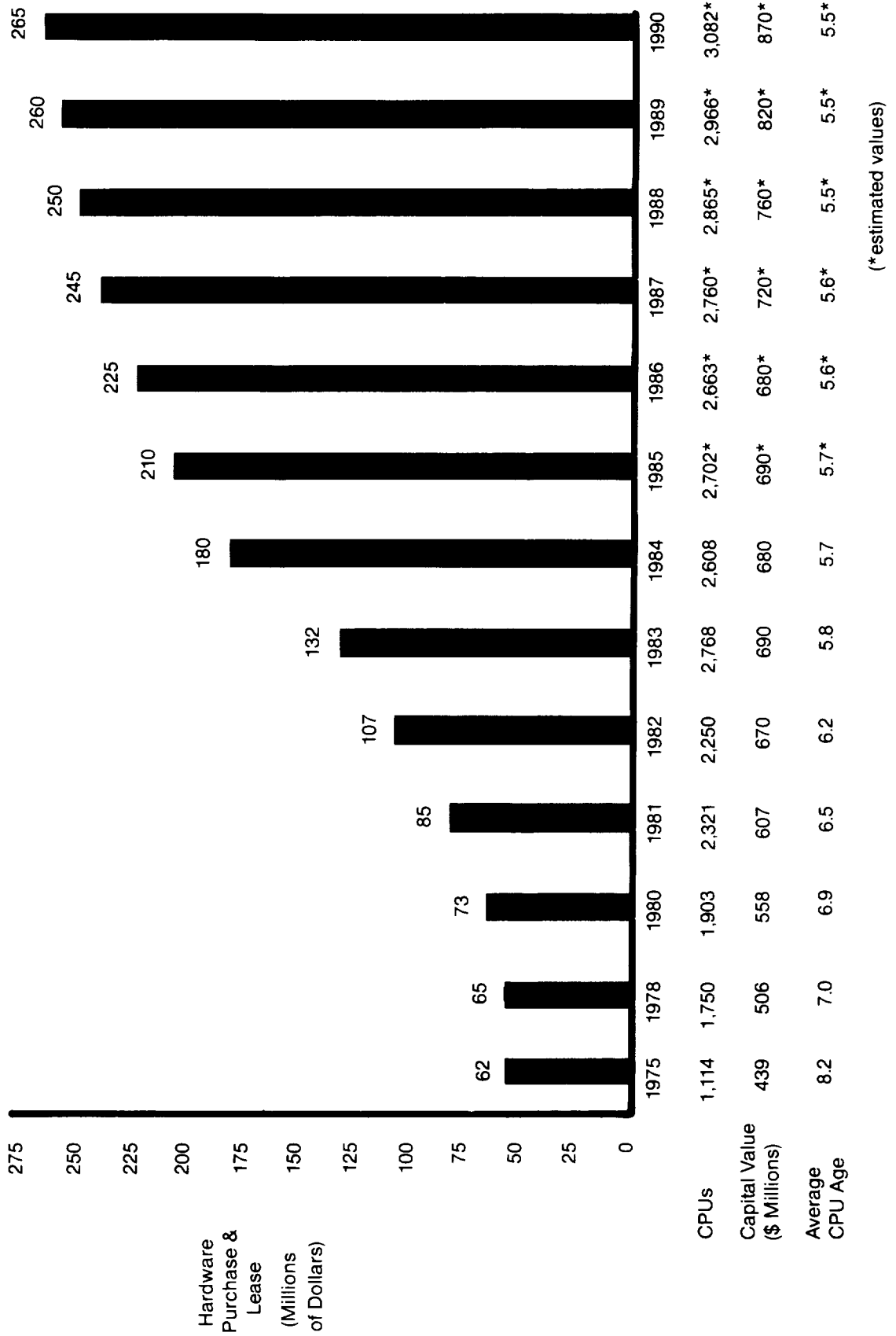
D. Automatic Data Processing

The objectives of NASA's computer systems management are to:

- o Ensure that the best computer tools for NASA's use in carrying out its missions are available at the right time and at the lowest cost
- o Foster the use of computer systems to increase management productivity
- o Advance computer and computer-related technology for the benefit of NASA and the Nation.

The program offices and the Office of Management jointly develop an annual plan for acquisition of automatic data processing equipment. Figure IX-2 displays the annual value of acquisitions from FY 1980 projected through FY 1989. The largest planned acquisition is a powerful computer facility, Numerical Aerodynamic Simulation, to be installed at Ames Research Center (see chapter III. Aeronautical Research and Technology).

Figure IX-2
NASA Annual ADPE Acquisitions
1975-1990
(3 Year Moving Averages)



A significant indication of the Agency's effort to meet research and development needs by exploiting advancing technology is its plan for expanding and upgrading its base of Class VI computers (supercomputers). Figure IX-3 shows that plan through FY 1989.

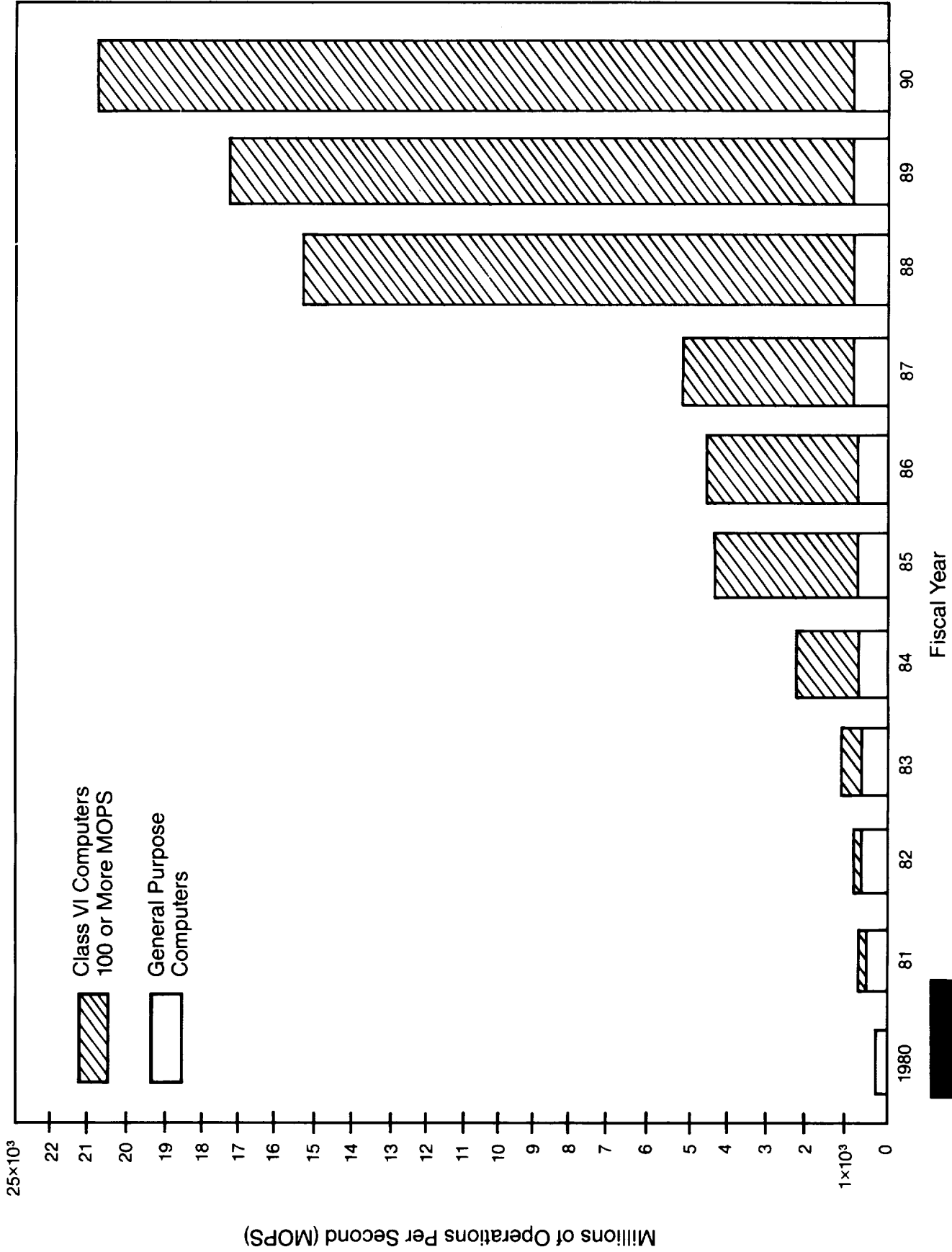
NASA will upgrade its computational capability continually and is arranging a program with the National Science Foundation under which it will transfer to the Foundation, for distribution to universities, serviceable Class VI computers that are being replaced with computers having greater capabilities. The Agency thereby will serve as a permanent source of high-speed computers for the academic community. Currently, in response to a request from Congress, Lewis Research Center is preparing for such a transfer.

An initiative in the President's Reform 88 program established the Automated Information Management program. That program combines administrative data processing, telecommunications, and office automation into a comprehensive system of computer-based tools to handle a variety of tasks. It ensures not only maximum information exchange, but also great flexibility for accommodating growth and changes in needs. In developing its strategic plan for automated information management, NASA established in 1984 a council to provide program direction and policy. The council includes representatives from each Headquarters program office, the Office of the Comptroller, and each field center.

NASA also has developed an Agency-wide equipment management system. The system was installed at two field centers during 1984 and will be placed in operation at the remaining field centers during 1985.

A study expected to lead to an Agency-wide payroll-personnel system was initiated in 1984. Its results, including the recommendations it develops, will be presented to NASA management about June 1985.

**Figure IX-3
Computational Capability Plan**



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Abbreviations and Acronyms



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X. ABBREVIATIONS AND ACRONYMS

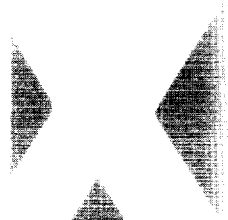
ACCESS	Assembly Concept for Construction of Erectable Space Structures
ACTS	Advanced Communications Technology Satellite
ADPE	Automatic Data Processing Equipment
Adv	Advanced
AMPTE	Active Magnetospheric Tracer Explorer
ASTRO	Space Shuttle payload using the Spacelab igloo
Atm	Atmosphere
ATS	Advanced Technology Satellite
AXAF	Advanced X-Ray Astrophysics Facility
CDR	Critical Design Review
COBE	Cosmic Background Explorer
CPU	Central Processing Unit
CR	Counter-Rotation
CRAF	Comet Rendezvous and Asteroid Flyby
CSD	Contract Start Date
CTS	Communications Technology Satellite
CY	Calendar Year
DE	Dynamics Explorer
Der Veh	Derived Vehicle
DMS	Data Management System
DOD	Department of Defense
DSN	Deep Space Network
EASE	Experimental Assembly of Structures in EVA
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Mobility Unit
EOM	Environmental Observation Mission
ERBS	Earth Radiation Budget Satellite
ET	External Tank
ETR	Eastern Test Range
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
FFRFF	Far Field Range Free Flyer
Flt	Flight
FLTSATCOM	Fleet Satellite Communications
FY	Fiscal Year
GEO	Geosynchronous Orbit, Geostationary Orbit
Giotto	European Space Agency comet mission
GOES	Geostationary Operational Environmental Satellite
GP-B	Gravity Probe-B
GRO	Gamma Ray Observatory
HC	Hydrocarbon
HF	High Frequency
ICBM	Intercontinental Ballistic Missile
ICE	International Cometary Explorer
IML	International Microgravity Laboratory

IMP	Interplanetary Monitoring Platform
IMPATT	Impact Avalanche Transmit Time
Incl	Inclination
IOC	Initial Operational Capability
IPS	Instrument Pointing System
IRR	Interface Requirements Review
ISEE	International Sun-Earth Explorer
ISPM	International Solar Polar Mission
IUE	International Ultraviolet Explorer
IUS	Inertial Upper Stage
KSC	Kennedy Space Center
LAP	Large-scale Advanced Propeller
LEO	Low Earth Orbit
LFC	Laminar Flow Control
LM	Long Module
LOTV	Lunar Orbit Transfer Vehicle
LOX	Liquid Oxygen
MDM	Multiplexer Demultiplexer
MFLOPS	Million Floating Point Operations Per Second
MOPS	Millions of Operations Per Second
MOTV	Manned Orbital Transfer Vehicle
MOU	Memorandum of Understanding
MPESS	Mission Peculiar Experiment Support Structure
MSAT	Mobile (communications) Satellite
MSL	Material Science Laboratory
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications (Network of Leased Communications Services for Operational Data Flow)
NOAA	National Oceanic and Atmospheric Administration
OAST	Office of Aeronautics and Space Technology
OMV	Orbital Maneuvering Vehicle
OSS-1	Space Shuttle pallet carrying Office of Space Science experiments
OSSA	Office of Space Science and Applications
OSTA	Office of Space and Terrestrial Applications (combined in 1982 with Office of Space Science to form Office of Space Science and Applications)
OTV	Orbital Transfer Vehicle
P	Pallet
P/A	Propulsion Avionics
PAM	Payload Assist Module
PAM-A	Payload Assist Module (Atlas Class)
PAM-D	Payload Assist Module (Delta Class)
PDR	Preliminary Design Review
P/L	Payload
Prop	Propeller, Propellant
PTA	Propeller Test Assessment

R&D	Research and Development
R&T	Research and Technology
RFP	Request for Proposal
RTOP	Research and Technology Objectives and Plans
SDLV	Shuttle Derived Launch Vehicle
SDR	System Design Review
SE&I	System Engineering and Integration
SIR	Shuttle Imaging Radar
SL	Spacelab
SLS	Spacelab Life Sciences
SM	Short Module
SME	Solar Mesosphere Explorer
SMM	Solar Maximum Mission
SR	Single-Rotation
SRB	Solid Rocket Booster
SRL	Shuttle Radar Laboratory
SRR	System Requirements Review
SS	Space Station
SSME	Space Shuttle Main Engine
ST	Space Telescope
Sta	Station
Std	Standard
STDN	Spaceflight Tracking and Data Network
STDS	Space Tracking and Data System
STOL/STOVL	Short Takeoff and Landing/Short Takeoff and Vertical Landing
STOVL	Short Takeoff and Vertical Landing
STS	Space Transportation System
Sunlab	Igloo-pallet Spacelab for study of the sun
Syncom	A commercial communications satellite
TDRSS	Tracking and Data Relay Satellite System
TOPEX	Topography Experiment for Ocean Circulation
UARS	Upper Atmosphere Research Satellite
UDF	Unducted Fan
VAFB	Vandenberg Air Force Base
VHF	Very High Frequency
VHSIC	Very High Speed Integrated Circuit
VLF	Very Low Frequency
VLSI	Very Large Scale Integration
WTR	Western Test Range
XTE	X-Ray Timing Explorer
ZPB	Zero Pre-Breathe (suit)



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