National
Aeronautics and
Space
Administration

1985 Long-Range Program Plan

CONTENTS

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 1985 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 1985 budget the President submitted to Congress in January 1984. That budget proposes the Nation's first new major manned space flight initiative in recent years: the development of a space station to establish a permanent U.S. manned presence in space. That initiative, to be undertaken at the President's direction on an international, cooperative basis, if at all possible, is an important step toward ensuring NASA's and the Nation's continued primacy in the exploration and use of space.

For the years beyond FY 1985, 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.

Section II of this report summarizes the major features of the programs described in greater detail in Sections III through IX. Section X lists the abbreviations and acronyms that appear in this report; and Section 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 1984. Comments and suggestions are welcome and will receive careful consideration.

For detailed information on a planned program, contact the responsible program office. The plans continually evolve. Consequently, f you are working in areas related to NASA's programs and knowledge of the latest status of NASA's plans is important to your 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.

In January 1984, NASA's Office of Aeronautics and Space Technology updated the NASA Space Systems Technology Model. 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 only to those who can demonstrate a need for them.

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. That commitment was reaffirmed by the President 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." The last of those goals is, the President said, "our greatest aspiration."

Accomplishment of the second goal, development of the space frontier, will affect, and contribute to achievement of, the other three. Toward its accomplishment, the President directed NASA "to develop a permanent manned space station--and to do it within a decade." The permanent U.S. presence in space it will provide will enable the Nation, he said, "to follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain."

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 payloads for space. As it evolves, it ultimately will serve as a base for new operations and initiatives in space and, most important, it 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 1992, 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.

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 NASA personnel a creative environment with the best facilities, support services, and management support so that the conduct of their research, development, mission, and operational responsibilities will be of the highest excellence
- o Develop a fully operational and cost effective Space Transportation System to provide routine access to space for domestic and foreign commercial and governmental users
- o Establish a permanent manned presence in space to expand exploration and use of space for activities which enhance the security and welfare of humanity
- o Conduct an aeronautics research and development program which contributes substantially to advanced technology and to the maintenance of U.S. leadership in civil and military aviation
- o Conduct research and development in the space sciences to expand knowledge of Earth, its environment, the solar system, and the universe
- o Maintain space applications and technology programs to advance U.S. leadership and security
- o Expand opportunities for investment and participation in civil space and space-related activities by the U.S. private sector
- o Establish NASA as a leader in the development and application of advanced technology and management to improve and increase Agency and national productivity.

The Administration's proposed budget for NASA for FY 1985 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 seven to eight Shuttle missions in FY 1984, 11 in FY 1985, 16 in FY 1986, and continued increases through the end of the 1980s.

The principal activities provided for are as follows:

- 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

- Space Science and Applications--Continued progress on approved projects, initiation of such programs as Upper Atmosphere Research Satellite and Mars Geoscience and Climatology Observer and further technology development and a ground test program for the Advanced Communications Technology Satellite

- 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

- 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

- 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 (New Starts for Next 10 Years; Program Activities to Year 2000)

The subsections of this chapter that follow present the highlights of the programs NASA plans for FY 1985 and beyond, including the programs' goals, objectives, and major new initiatives. Each program is described in greater detail in the remaining chapters of this report, Chapters III through IX.

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, 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. <u>Study of the Distant Universe</u>

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 often may 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 and is an important precursor to the Space Telescope. The Space Telescope, scheduled for launch in 1986 as a cooperative project with the European Space Agency, will serve for the next two decades as a major astronomy facility covering a range of ultraviolet and visible wavelengths. The Infrared Astronomy Satellite was launched in 1983 in cooperaton with the Netherlands and the United Kingdom. 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 1989 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 1985 through FY 1989 period are principally investigations of the structure of space and time and the structure of the sun, collapsed stars, and interstellar space. They include Gravity Probe-B, Shuttle Infrared Telescope Facility, Solar Seismology Mission, Fxtreme Untraviolet Explorer, X-Ray Timing Explorer, Far Ultraviolet

Spectroscopy Explorer, Solar Corona Diagnostics Mission, and several Spacelab investigations.

In the period between FY 1990 and FY 1994, 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.

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; and only U.S. spacecraft have crossed the asteroid belt into the outer 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 retargeted International Sun Earth Explorer-3 spacecraft, which is on its way to an encounter with the comet Giacobini-Zinner. Approved flight projects in the pre-launch development stage include reflight of the OSS-3 Spacelab to observe Halley's Comet during its 1985 and 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; and Venus Radar Mapper, the first of the moderate-cost missions recommended by the NASA Advisory Council's Solar System Exploration Committee.

The Solar System Exploration Committee has recommended a core program containing 13 exploration missions 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 Mars Geoscience and Climatology Observer, which is to be launched in 1990 to investigate that planet's atmosphere, surface geochemistry, interior, and climate on a global scale. The second is the Comet Rendezvous and Asteroid Flyby, which also is scheduled for launch in 1990. Its purpose will be to investigate the physical and chemical state of comets. The third 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 fourth is the Titan Probe and Radar Mapper, to be launched in 1993 to investigate the largest of Saturn's satellites, especially its unique, dense atmosphere.

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 and its 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 flight of an improved imaging radar system on the Shuttle in 1984 and later years.

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 use sounding rockets; balloons; aircraft; free-flying satellites, such as the Earth Radiation Budget Experiment to be flown in 1984; and Shuttle-borne instruments. Programs are in process to study global biology, Earth's plasma envelope and its interaction with the sun, and oceanography.

Atmospheric science programs planned for initiation by FY 1989 include the following: Upper Atmosphere Research Satellite--to extend understanding of the chemical and physical processes occurring in Earth's stratosphere, mesosphere, and lower thermosphere; 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; Scatterometer--to measure upper-ocean currents, surface waves, and small-scale roughness of sea surfaces to advance understanding of the momentum coupling of the atmosphere and oceans; 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 is responsible for ensuring the health and well-being of spaceflight crews and for advancing knowledge of fundamental biological processes at the cosmic, global, and organismic levels. It is multidisciplinary and concentrates on two interrelated disciplines, medical science and biological science. The former is concerned with problems experienced by human spaceflight passengers that must be addressed immediately, using whatever instruments, technology, and facilities are available. The latter relates to problems anticipated in future missions that can be approached in a more fundamental and ordered manner. Ground-based research and technology development constitute the program's primary approach, but use of flights to verify hypotheses and results is extensive.

Among the medical science problems that need immediate attention are the space adaptation syndrome (space sickness), cardiovascular changes, and dysbarism (bends). Problems related to future missions include the effects of radiation, loss in flight of bone and muscle, differences between the physiological systems of men and women and the response of those systems to spaceflight, spacecraft habitability and life support systems, and the interaction between humans and the machines at their disposal.

In the biological sciences, research objectives are met through three disciplinary elements: exobiology, biospheric research, and gravitational biology. The exobiology program studies the origin, evolution, and distribution of life and life-related molecules on Earth and throughout the universe. The biospheric research (global biology) program seeks to determine the effect of biological processes on global dynamics. Gravitational biology, formerly called space biology, studies physiological response to variations in gravitational forces ranging from microgravity to more than unit gravity in order to understand more completely how gravity affects life on Earth.

The need for new initiatives in the Life Sciences arises from plans to fly unprecedented numbers of astronauts, scientists, and, ultimately, citizen passengers on Shuttle missions; to develop the space station; and to exploit fully NASA's ability to increase fundamental understanding of major scientific questions about living systems. Initiatives are planned to find solutions for the space adaptation syndrome, improve medical care and health maintenance of humans in space, advance controlled ecological life support and extravehicular activity systems, and enhance human performance and productivity in space by improving the habitability of space vehicles and by investigating crew compatability and various social and motivational factors relevant to human productivity. A phased program in biospheric research constitutes another planned initiative. It is expected to result in a comprehensive model to describe and predict biogeochemical processes on a global scale and to provide a data base that will be a key element in understanding Earth as a system. Other initiatives in the 1980s include gravitational biology payloads, exobiology payloads, and the search for extraterrestrial life.

Looking ahead to the first half of the 1990s, research is expected to expand in all those areas, particularly as laboratory facilities are developed and attached to the space station. Development also is planned of a flight-qualified vestibular and variable gravity research facility to determine the response of living systems to linear and angular accelerations in space.

e. Satellite Communications

NASA's role in developing technology for communications satellites has been and continues to be one of leadership beneficial to the U.S. communications industry and to the consumer worldwide. Government has moved ahead of industry in this important field because the cost and economic risk have been too high for private investment. NASA's current program plan, developed with industry's help, consists of the following major components:

- 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

- Advanced technology development to provide new and expanded satellite services

- Technical consultation and support services to ensure growth of existing satellite services and incorporation into them of new satellite applications

- Satellite aided search and rescue, an international system to detect and locate automatic signals from aircraft, ships, and individuals in distress

- Experiment coordination and mission support, a program to identify and aid development of new types of communications services, primarily in the public sector

- Advanced Communications Technology Satellite to investigate multibeam communications, spectrum conservation, and K_a-band circuits.

In the FY 1985 through 1989 period, initiation is planned of a mobile satellite commercialization program to be accomplished jointly by NASA and U.S. industry, in cooperation with Canada, to provide commercial land mobile communications services to remote areas and to solve problems such as poor quality caused by channel crowding. Possible initiatives for the early 1990s are large geostationary communications platforms to help alleviate the growing saturation of the electromagnetic spectrum and the accessible orbit arc and direct satellite sound broadcasting to improve the Government's international sound broadcasts.

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, cloud microphysics and aerosol science, 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. N A sponsors, and encourages others to sponsor, materials processing research, but leaves to industry the task of deciding whether commercial production is feasible.

2. <u>Space Flight</u>

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 1985 through 1989 period are to:

- Complete development, acquisition, and upgrading to full capability of the Space Transportation System (Shuttle, Spacelab, Inertial and Spinning Solid Upper Stages, Shuttle-compatible Centaur, and ground facilities)

- Establish routine operation of the Space Transportation System

- Conduct a total of 27 Shuttle missions in FY 1985 and FY 1986

- Use expendable launch vehicles for schedule assurance and special needs

- o Develop a Centaur upper stage compatible with the Shuttle to provide transportation to higher energy orbits
- o Establish a business organization to increase the number of Shuttle customers
- o Develop and install a tether system for applications such as the deployment, stabilization, and retrieval of satellites
- o Demonstrate the ability of the Shuttle to service satellites in orbit so that Shuttle customers can adopt suitable systems designs and operational procedures.

The program's objectives beyond 1989 are to:

- o Maintain a Shuttle launch schedule with reserve capacity
- o Reduce the operational costs of the Space Transportation System
- o Shorten Shuttle turn-around time
- o Develop an orbital transfer vehicle
- o Develop technology and techniques to construct, deploy, test, and service systems in space.

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

3. <u>Space Station</u>

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 three-year definition phase beginning in FY 1985 and initiation of a design and development phase in FY 1987.

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

- All major potential users of the station, U.S. and foreign, will be involved from the beginning of planning activities to ensure that their needs are taken into consideration.
- Thorough project definition will be conducted before system development is undertaken.
- Involvement in the program will be agency wide and substantive.
- The station will be designed to accommodate evolutionary growth through incremental addition, modification, and replication.
- The station's elements will be maintainable and restorable in space.
- The station will be designed to operate as autonomously as possible, except for resupply of materiel and personnel.
- International participation in the program will be sought.
- The Department of Defense will be kept informed.
- New approaches will be taken toward reducing costs.
- The station's mix of humans and machines will ensure proper distribution of tasks so that the humans and machines will enhance each other's capabilities.

Mission requirements for the space station have been virtually the exclusive focus of the Space Station Task Force since its establishment in 1982. Eight studies to define those requirements were contracted to major aerospace corporations, which were encouraged to explore imaginatively all aspects of potential uses for a space station. Their principal recommendations were for an initial station consisting of a manned base, an unmanned platform at an orbital inclination of 28.5^{o}, an Orbital Manuevering Vehicle, and an unmanned platform derived from the space station design and operating at a polar or near-polar inclination.

A Space Station Mission Synthesis Workshop held in May 1983 defined a preliminary set of 107 types of phased space station missions for the period 1991 to 2000. The initial requirements it established included a manned element at 28.5° orbital inclination, a platform at low inclination, and a platform in polar orbit. A Concept Development Group formed as part of the Space Station Task Force integrated the mission requirements in May 1983 into a set of functional capabilities. The set has been revised twice since then and will be revised yet another time just before system definition. Although an approved configuration for the space station does not exist, the concept currently under consideration includes a living quarters module, berthing and assembly module, logistics module, resources module, laboratory module, unmanned platform at orbital inclination of 28.5°, unmanned platform at orbital inclination of 90°, Orbital Manuevering Vehicle, and servicing system.

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 tests 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. The goal for having the first structure in space remains 1992.

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 early 1985, tracking and data acquisition facilities for spacecraft in near Earth orbit will evolve 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 to 85 percent from 15 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 consolidatd ground network will support deep-space missions and missions in high Earth and geostationary orbits. Early improvements planned for the network include providing to 64-meter antenna sites the ability to receive L-band signals; 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

TDRSS is expected to meet needs through the 1980s, but increases in data volume for missions planned for 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 economic growth, defense, and space exploration. 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:

- To excel in critical space technology areas, facilities, technical staff, and computational capability
- To provide concepts and advanced technology for U.S. civil and military space activities
- To involve universities and industry in the Space Research and Technology program
- To transition research results to the U.S. aerospace industry
- To support the spaceflight projects and other space activities of NASA, other government agencies, and U.S. industry.

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 program concentrates on the following areas: fluid and thermal physics, materials and structures, computer science and electronics, space energy conversion, controls and human factors, space data and communications, and chemical propulsion. The systems research and technology development program focuses on space transportation systems, spacecraft systems, and space station systems. The two programs have common technical 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.

Newly initiated programs include the Spaceflight Experiments program, the Space Shuttle Main Engine Test-Bed Engine program, a program to develop technology for the space station, and a program to strengthen the Agency in computer science and to infuse state-of-the-art computer science and technology into aerospace applications. Planned initiatives will develop technology for the Orbital Transfer Vehicle, vehicles with high lift to drag, space nuclear power, power and propulsion for the Spacecraft Bus, system response of large structures, additional flight experiments in space, autonomous systems, liquid oxygen-hydrocarbon propulsion, scientific payloads, large deployable reflectors, and the Free-Flying Experiments Carrier.

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 16 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 as early as 1992, 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 and industrial activities. By the end of the present century, one or more permanently manned space stations 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 all orbits by manned and robotic systems; to institute routine check-out, refueling, repairing, and upgrading of space facilities, as well as debris removal at geosynchronous Earth orbit; and to devise and implement innovative Space Transportation System uses and missions 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 Earth 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 mission. 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 space leadership and pursue the long-term purpose of improving the well-being of humankind in the Earth and space environments beyond the year 2000, long-range goals will be required for advancing scientific knowledge, space exploration, Earth applications, and commercial uses. 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 and 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 will support scientific, technical, and commercial activities and systems not now possible, including:

- Large facility-class observatory instruments in both low Earth orbit and geosynchronous Earth orbit

- Orbital platforms, both equatorial and polar and both automated and human-tended, carrying instrument payloads that are modular, variable, and interchangeable

- Large facilities such as telescope mirrors and radio antennas assembled in space by humans for both scientific and communications purposes

- Large-payload, high-performance planetary exploration missions made possible by clustering launch stages or by using Orbital Transfer Vehicle derivatives

- Planetary science networks and other long-term activities on other celestial bodies such as the moon, Mars, and asteroids

- Routine use of the lunar surface for planetary geoscience studies, solar monitoring, astronomical surveys, and possibly extraction of resources

- 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.

a. Earth Observations and the Near-Space Environment

NASA's activities in the 21st century will emphasize synoptic, continuous, and long-term observations of Earth and its immediate surroundings from platforms in 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 modelling 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 or an equivalent transportation system as a straightforward continuation of NASA's 1980s and 1990s program. 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

A major goal of the Life Sciences program will continue to be to carry out studies and experiments to support permanent human activity in space. Essential ingredients will be continuing ground-based research, as well as space facilities in the form of dedicated research and laboratory modules attached to human habitats in low Earth orbit, in geosynchronous Earth orbit, and on the moon. Those modules will permit studies of several critical matters related to long-term human occupancy of space: long-term physical and psychological effects of the space environment on humans; techniques for low-gravity surgery and related medical care; environmental support systems increasingly independent of outside sources and using animals and plants, as appropriate, to increase that independence; and quarantine and materials handling techniques that possibly will allow space habitats to be used for potentially hazardous studies or for preliminary examination of samples returned from other planets.

Another Life Sciences goal, to study the origin of life in the universe, will continue to be pursued through an active and diverse ground-based research program. In addition, large radio telescopes installed in space will provide the means for a major effort in the Search for Extraterrestrial Intelligence program by providing improved listening capabilities.

e. Materials Processing (Use of Microgravity)

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 will be developed to enable a lunar base, even before its permanent occupancy, to mine, extract, and fabricate products from lunar materials. The goals 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 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. Large payloads, long instrument lifetimes, human-supported space operations, and routine access to low and geosynchronous Earth orbits, the lunar surface, possibly the Martian surface, and, for unmanned missions, the entire solar system will create a research and operations environment whose potential now can be imagined only dimly. 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 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 Study last year 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 1985 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.

- 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.

- 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.

- 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 in new vehicle designs.

- 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, namely:

- Advance computational fluid dynamics to a level of practical application for aircraft and engine design

- Reduce aircraft viscous drag and improve understanding of Reynolds number effects at transonic speeds

- Develop advanced materials to minimize structural weight of aircraft engines and airframes

- Provide advanced control, guidance, and flight management systems to improve performance and operation of future aircraft

- Double rotorcraft productivity

- Ensure availability of technology for superior military aircraft and missile systems

- Enhance flight crew effectiveness through development of advanced automation, display, and control techniques

- Exploit computer systems to solve aeronautical problems

- o Reduce the drag of 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 Provide turbofan components to improve the fuel efficiency of subsonic transport engines
- 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, turbulent 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--general aviation and commuter aircraft engine technology, engine dynamics, and stall recovery; 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--advanced composite structures technology, icing and lightning research, natural and controlled laminar flow, and, in coordination with the Federal Aviation Administration, air safety and operations problems.

In FY 1984 three new initiatives focused on the long-term technology development objectives listed previously got under way. Those programs are Numerical Aerodynamic Simulation, which will help solve some heretofore intractable problems in computational fluid dynamics; Advanced Composite Structures, which will extend the technology of composite structures to allow their use in segments of the wings and fuselages of large transport aircraft; and Next Generation Rotorcraft, which will demonstrate technology for the X-wing rotor.

Initiatives planned for FY 1985 and later years to respond to technical opportunities and needs and to satisfy the long-term technology development objectives listed previously include development of technology for:

- o Advanced turboprop systems integration, which will evaluate large-scale advanced propfan systems through flight tests on a modified test-bed aircraft at cruise flight conditions, and proof-of-concept testing of unique counter-rotation concepts

- o Oblique wings, to make posssible their use at transonic and supersonic speeds
- o A comprehensive data base for demonstrating the feasibility of integrating changes in rotorcraft to decrease the noise they generate
- o Fault-tolerant active controls for civil and military aircraft
- o Ceramic components for gas turbine engines which will provide technology for ceramic components with consistent properties and reliability for use in gas turbine hot sections
- o All-weather capability for helicopters able to satisfy the civil sector need for operating at remote sites and providing emergency medical services and the military need for a single-pilot light helicopter
- o Laminar flow systems for transport aircraft
- o Small-engine components, which will improve the performance of small turbine engines for use in rotorcraft, commuter and general aviation aircraft, cruise missiles, and auxiliary power units
- o Electric secondary power systems and fault-tolerant flight controls, with emphasis on samarium-cobalt motors, induction motors, and electromechanical actuators
- o Advanced supersonic short takeoff and vertical landing fighters
- o Improved controllability, handling qualities, and safety of high-performance aircraft operating at the extremes of their flight envelopes
- o A data base covering the full range of flight conditions and speeds for an integrated, dual-mode, supersonic combustion ramjet engine
- o Techniques for predicting the vibration that coupled airframes and rotors will experience and advanced technology for reducing rotorcraft vibration
- o Dynamic three-dimensional finite-element computations to optimize aircraft designs.

E. Aeronautics Beyond the Year 2000

At the end of the 20th century, aeronautics will still offer a substantial potential 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 both civil transportation and 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 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 presently 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 intercity 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 transporation 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, aerodynamic, 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 even 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. During the past year, the science and engineering complement increased by nearly 350, to 11,094, and 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 activit 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 many of the programs require regular improvements in the efficiency of data management.

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 effort than a single country could afford alone. Each partner gains access to other countries' science and 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 four years. The Space Telescope, 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.

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 a much more comprehensive survey 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.

B. Study of the Distant Universe

Study of the universe involves questions at the core of human concern. What is 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, 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 those particles 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 this country'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 Preliminary surveys to detect gross features
- o Initial all-sky surveys to start defining source characteristics, approximate source locations, and collect other useful information
- o High-sensitivity surveys or 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 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 nine 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, four of the nine 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. Despite the limited time its primary sensors were operational, 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. After its planned in-orbit repair in 1984, it will resume 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 three missions whose descriptions follow will study flares on other stars--hot stars, cool stars, rapidly rotating stars, and stars with strong magnetic fields.

b. International Ultraviolet Explorer

The International Ultraviolet Explorer was 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 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, whose crew will change and update the Telescope's focal plane instruments as scientific priorities and instrument capabilities evolve. One of the focal plane instruments and the solar arrays 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 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. The effect of chemical composition on stellar activity can best be studied in other galaxies, and stars closer to the center of a galaxy generally have richer compositions than those farther out.

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, amd 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. 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.

f. 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 already 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. An international team continues to analyze the data it collected. It will be complemented by an extended-source survey to be carried out with a small telescope on Spacelab 2.

g. 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 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.

h. Heavy Nuclei Collector

Recent developments make it possible to construct a passive cosmic ray telescope with a very large area to detect charged particles. Acid etches the plastic CR-39 at a rate proportional to the square of the charge of particles that pass through it. Consequently, by exposing CR-39 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, it 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.

i. 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 instruments that will be 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 currently scheduled to carry principal investigator class instruments are described below. In addition to U.S. instruments, Spacelabs 1 and 2 will carry European instruments that will investigate the sun and the universe.

(a) Spacelab 1

The Far Ultraviolet Telescope, developed jointly with the French, will observe aging stars in our galaxy, and the Active Cavity Radiometer will measure precisely the variations in the total luminosity of the sun.

(b) 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 and Energy Spectra of Cosmic Ray Nuclei instrument 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.

(c) Astro-1

Astro-1 will be a Space Shuttle pallet with three ultraviolet telescopes that will complement the Space Telescope. Each of the telescopes will have unique capabilities: Ultraviolet Imaging Telescope--wide field of view; Hopkins Ultraviolet Telescope--short wavelength ultraviolet; and Wisconsin Ultraviolet Spectropolarimeter--polarization. Astro's first flight will be a special mission to observe Comet Halley.

3. Potential New Initiatives, FY 1985-1989

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 Space Telescope will be in optical astronomy. It will be launched and serviced by the Space Shuttle. The focal plane of its 1.2-meter, grazing-incidence, x-ray telescope will accommodate instruments to collect data with 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 was developed in part by the Research and Analysis program and in part by the Office of Aeronautics and Space Technology.

b. Other Planned Initiatives

Other initiatives planned for the FY 1985 through FY 1989 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.

(2) Shuttle Infrared Telescope Facility

This program will provide a meter class, cryogenically cooled, infrared telescope designed to study the very cold regions of space, where cosmic dust and gas condense into stars; cool objects in the solar system --planets, asteroids, and comets; and infrared-emitting extragalactic objects. One major application will be to obtain detailed infrared spectrometry of the faint infrared sources that the Infrared Astronomical Satellite has discovered but cannot observe in detail. Technology is ready for cryogenic telescope systems, but their performance will depend on the performance of their infrared sensors. The sensitivity of sensors in the current generation is much higher than that of the sensors on the Infrared Astronomical Satellite but is still an order of magnitude above the limitations placed by natural cosmic background. The Shuttle Infrared Telescope Facility will benefit from sensor technology that will be developed in this decade.

(3) 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.

(4) 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 and the one that follows will be concerned in part with determining the structure of the three kinds of collapsed stars.

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. With all relevant technologies developed, this program is ready to begin.

(5) 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- to 100-thousand electron volts. Technology is nearly ready, with developments in detector technology under way as part of the mission definition studies.

(6) Far Ultraviolet Spectroscopy Explorer

The Far Ultraviolet Spectroscopy Explorer will be a one-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 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 must be developed.

(7) 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 obervations from Earth orbit to be used for that purpose.

(8) Spacelab and Space Station

Investigations on Spacelab will evolve into longer ones on or near the space station that will depend on the space station for servicing, assembly, and manned interaction. Current plans include two major facilities and two principal investigator class instruments.

(a) Starlab

This cooperative venture among the United States, Australia, and another partner would use a one-meter class telescope to conduct, at high angular resolution in the visible and ultraviolet bands, imaging investigations of sources too large to be observed efficiently with the Space Telescope. Those sources will include globular clusters, gas clouds, nearby galaxies, and large clusters of galaxies. The technology for the required large-format, high-resolution, photon-counting detectors is being developed in the Physics and Astronomy Research and Analysis program.

(b) 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.

(c) Shuttle High-Energy Laboratory

The Shuttle High-Energy Laboratory will consist of a pallet carrying three x-ray telescopes that will use specialized techniques for investigations in high-energy astrophysics. The technology for those investigations is being developed as part of the preliminary design of the system.

(d) 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 Spacelab 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 composition, energy spectra, arrival direction, and isotopic composition 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 1990-1994

Two observatories are potential development starts in the FY 1990 through FY 1994 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 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 a 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:

- A high-resolution telescope cluster containing the Solar Optical Telescope, a soft x-ray telescope facility, and an extreme ultraviolet telescope facility
- 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
- A high-resolution gamma ray spectrometer
- 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 angular 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, and mirror controls. 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 1986.

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 greatly increased 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 jointly by that office and the Astrophysics program.

e. Starprobe

This mission 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 more technology for structures, submillimeter and infrared sensors, mirrors, and mirror controls. A systems study is in process to define a program to develop that technology. Technology for Spacelab, space station, 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, Shuttle High-Energy Laboratory, and Starlab; 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; Shuttle Infrared Telescope Facility--the Astrophysics program and the Office of Aeronautics and Space Technology are developing technology for infrared sensors. Table III-1 summarizes technology needs. An X in a cell of that table indicates that the program shown on that line needs technology of the category shown in that column.

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

	Maintenance and Repair	Sensors for Detectors	Optical Systems Fabrication and Materials	Controls	Cryogenics	Precise Timing
Major Missions						
Advanced X-Ray Astrophysics Facility	X	X	X			
Large Deployable Reflector	X	X	X	X	X	X
Advanced Solar Observatory	X			X		
Starprobe		X	X	X		
Moderate Missions						
Shuttle Infrared Telescope Facility	X	X			X	
Solar Seismology Mission	X					
Very Long Baseline Radio Interferometry	X					X
Gravity Probe-B					X	
High Throughput Mission	X	X	X			
Explorers						
X-Ray Timing Explorer	X					
Far Ultraviolet Spectroscopy Explorer	X		X			
Solar Corona Diagnostics Mission	X					
Spacelab and Space Station						
Shuttle High-Energy Laboratory			X			
Starlab		X				
Cosmic Ray Experiments	X					
Pinhole Occulter Facility				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."

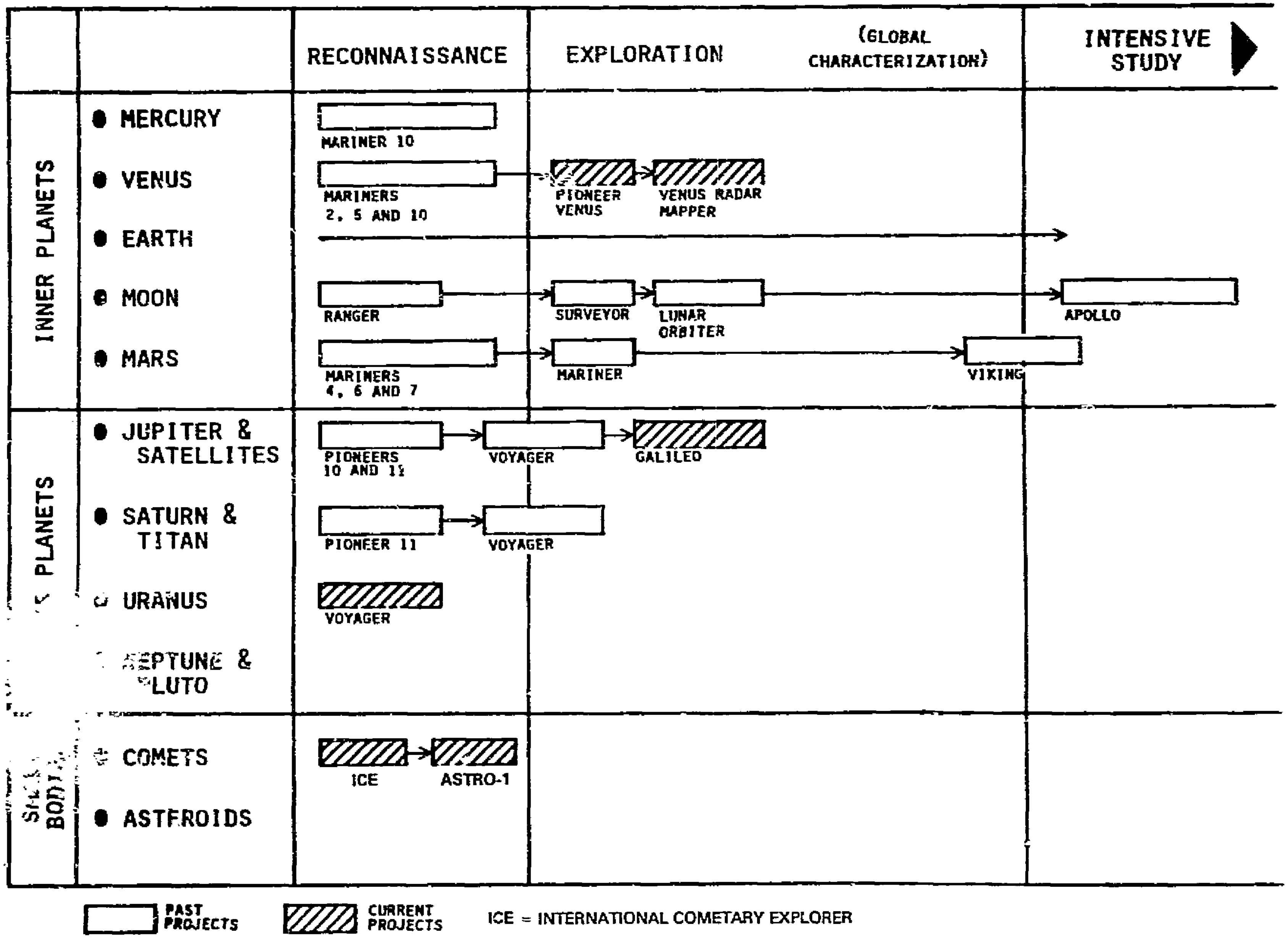
Since 1974 the Space Science Board's Committee on Planetary and Lunar Exploration has been evolving object and mission priorities for the exploration program and has found it convenient to assign the bodies in the solar system to three groups: the inner planets; the small (primitive) bodies--asteroids, comets, and meteorites; and the outer planets and their satellites. The Committee recommended that the focus for the inner planets 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 the next 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 flyby 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 flyby 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 flybys of Uranus and Neptune. Those flybys will complete the initial study of those systems. Jupiter and Saturn have highest priority for follow-on exploration. Galileo, which will consist of a probe and an orbiter, will

FIGURE III-1

PLANETARY EXPLORATION STATUS: 1984



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, Europe and Japan recently have joined this endeavor with the Giotto and Planet-A missions, respectively. In addition, foreign scientists have been included on the science teams for predominently U.S. missions such as Pioneer Venus, Viking, and Voyager.

1. Current Program

The solar system exploration program is managed in three parts: planetary research and analysis, development flight projects, and mission operations and data analysis. The first and third of those three parts ensure continuity in the program's pursuit of its goals, while development flight projects are undertaken to obtain specific pieces of information needed for understanding better the origin and evolution of the solar system. The first and third parts generally have lower visibility, but they are just as crucial to the continuing progress of the program. Research and analysis activities generate ideas for exploration missions (through advanced planning studies), analysis of collected data, and basic research in the planetary sciences. Mission operations and data analysis activities provide for mission operations and control during flight, return to Earth of collected data, and processing and distribution of data to investigators for incorporation into their research.

Planetary missions currently under way include the Voyager 2 extended mission to Uranus and Neptune and the continued operation of Pioneer Venus, Pioneers 6 through 11, Voyager 1, and the International Cometary Explorer (the retargeted third International Sun-Earth Explorer) spacecraft, which is on its way to an encounter with Comet Giacobini-Zinner. Approved flight projects in the pre-launch development stage include reflight of the Astro-1 Spacelab pallet to observe Comet Halley, Galileo, the International Solar Polar Mission, and the Venus Radar Mapper.

a. Pioneers

The Pioneer Venus Orbiter and Pioneers 10 and 11 are on extended missions. The 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. Giacobini-Zinner Encounter

In the fall of 1983, the third International Sun-Earth Explorer spacecraft was diverted from its "halo" orbit around the sun-Earth colinear libration point to begin a long journey to a September 1985 encounter with the short-period comet Giacobini-Zinner. That encounter will be the first ever of a spacecraft with a comet. The spacecraft's aim point is behind the comet's nucleus and within the comet's tail, which is expected to be several 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 the 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 therefore to provide a characterization of the solar wind before it strikes the comet'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, from November 1985 to April 1986. The European Space Agency, the Soviet Union, and Japan are preparing spacecraft missions to intercept the comet in March 1986. The United States will participate in the European Space Agency and Soviet Union missions, and also is conducting the program of Earth-based observations, the International Halley Watch, described in the next paragraph. For the European Space Agency mission, 32 U.S. scientists are participating in the definition of 9 of the 10 experiments on the spacecraft and serving as principal or co-investigators. In addition, a critical component for one of the instruments, the Ion Mass Spectrometer, is being designed and fabricated in the United States. The Soviet Union mission is dependent on the United States' tracking the comet and determining its orbit to provide information for targeting the spacecraft.

The International Halley Watch originated during the period of increased scientific interest generated by the comet's reacquisition in October 1982. 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 are providing around-the-clock 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 both the spacecraft encounters and the ground-based observations, Astro-1 will be reflown on the Shuttle in March 1986 for post-perihelion observations of Halley when the comet is closest to Earth.

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 100 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.

f. International Solar Polar Mission

The International Solar Polar Mission is a cooperative undertaking by the European Space Agency and NASA to reconnoiter the solar wind and other interplanetary phenomena perpendicular to the sun's equatorial plane. It will consist of a single spacecraft provided by the European Space Agency and instruments supplied by both participants. U.S. scientists are principal investigators for five of the nine experiments to be conducted and are serving as co-investigators for some of the European Space Agency experiments. The United States will provide the radioisotope thermoelectric generator, launch services, and tracking and data acquisition services. 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 in place in 1989 and 1990.

g. Venus Radar Mapper

The Venus Radar Mapper mission is a flight project approved for initiation in 1984. Its primary instrument will be a synthetic aperture radar able to resolve surface features measuring one kilometer or less in all dimensions through the thick cloud layer that always covers Venus. Launch by the Shuttle and a Centaur upper stage is scheduled for 1988, with insertion into orbit around Venus in mid 1988. The radar mapping mission will be completed in early 1989. The planet's gravity field also will be mapped, by tracking the spacecraft's orbit, to provide information about Venus' interior structure.

To meet its low-cost goals, the project will use existing designs and subsystem hardware in the spacecraft. The spacecraft's elliptical orbit will allow it to use a 3.7-meter Voyager antenna for both radar mapping and data transmission. It also will use other hardware and software from the Voyager, Galileo, and International Solar Polar Mission projects.

Information that Mariner 9 provided about Mars completely altered understanding of that planet's evolution. The 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 what knowledge it can provide about Earth's history.

2. Strategy

Concern about the viability of the solar system exploration program as operated led to the formation in 1980 of the Solar System Exploration Committee under the NASA Advisory Council. 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:

- 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 enable available launch systems such as the Shuttle-Centaur combination to launch higher energy missions.

The Committee also concluded that one augmentation should be recommended 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. Because of the large number of viable competing concepts, an augmentation for the outer planets has yet to be selected. Selection is expected to occur in the spring of 1984.

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

Initial Core Missions

Mission	Launch	Data Return
Venus Radar Mapper	1988	1988-1989
Mars Geoscience and Climatology Observer	1990	1991-1993
Comet Rendezvous and Asteroid Flyby	1990	1994-1997
Titan Probe and Radar Mapper	1993	1997

Candidate Subsequent Missions
(Order Arbitrary)

Inner Planets	Small Bodies	Outer Planets
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 Asteroid Rendezvous Observer	Uranus Flyby and Probe
Lunar Geoscience Observer		

3. Potential New Initiatives, FY 1985-1989

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

a. Mars Geoscience and Climatology Observer

The Mars Geoscience and Climatology Observer, included as a new start in the President's budget request for 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 minerological 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 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 diurnal and seasonal variation; distribution of H_2O, CO_2, and dust in the atmosphere and their diurnal and 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 mapper, a radar altimeter, a magnetometer, and a thermal-infrared spectral radiometer.

This will be the first Planetary Observer Class mission. A modified "production-line" Earth-orbital spacecraft will serve as the basic bus. A Transfer Orbit Stage upper stage will boost the spacecraft from the Shuttle onto its planetary trajectory. Six months after its 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 will be lowered to a 350-kilometer altitude, circular orbit to attain solar synchronization. The mission duration planned is two years, with the spacecraft in the sun-synchronous orbit at least one year.

b. 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 Kopff 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 (about four A.U.) through its closest approach to the sun (about one and a half A.U.). Typical science activities that will be involved include extensive imaging; x-ray and gamma ray spectroscopy; infrared reflectance spectral mapping; neutral and ion mass spectroscopy; and dust detection, collection, and compositional analysis.

The spacecraft for this mission will be a Mariner Mark II, which will be launched in 1990 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. Since the spacecraft will traverse the asteroid belt during that cruise phase of its flight, it will be programmed for one or two flyby encounters with asteroids. Its rendezvous with the comet will occur before the onset of the well developed coma and ion tail that the comet 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 to conduct detailed studies of its surface. At about 100 days before perihelion, when the comet becomes increasingly active, the spacecraft will retreat to a safe distance (about 5,000 kilometers). 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.

c. Lunar Geoscience Observer

Like the Mars Geoscience and Climatology Observer, the 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. They will include global mapping of the elemental and minerological 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 consideration are investigation of the compositional heterogeneity of the moon and the time sequence of the differentiation that produced the heterogeneity; global variation of the surface elemental and mineralogic phase composition; detailed figure of the moon, detailed lunar gravity field, and 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 spectrometer, and a radar altimeter. Data also will be derived from tracking of the spacecraft's orbit. Other instruments that might be added include a magnetometer, an x-ray fluorescence spectrometer, an electron reflectometer, and gravity gradiometers.

Launch is scheduled for 1991. 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.

d. Titan Probe and Radar Mapper

The Solar System Exploration Committee gave this program the highest priority for new outer planet initiatives. Titan, the largest satellite in the Saturnian system, is unique in that it has a dense atmosphere. The atmosphere is dominantly nitrogen, but it contains a small amount of methane and possibly some argon; and it completely obscures Titan's surface. The organic processes taking place on Titan provide the only planetary scale laboratory for studies of a pre-life terrestrial atmosphere.

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.

Many of Titan's features are unknown. For example, is argon really abundant? What is the composition of the aerosol in its atmosphere? 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? Was the trace gaseous carbon monoxide produced by meteroids or was it primordial? What is the nature of and what governs the temperature profile above the 200-kilometer altitude level? Are the predicted strong zonal winds really present? What energy source in addition to incident solar radiation causes its excess ultraviolet day-glow, and why is it confined to the day side? Is there an internal magnetic field and, if there is, how does it affect the interaction between the co-rotating plasma and the atmosphere?

The Titan Probe and Radar Mapper will be designed to answer many of those questions. It will consist of a Mariner Mark II spacecraft equipped with a radar mapper and an atmospheric probe. It will be launched in 1992 or 1993 by the Shuttle-Centaur combination and will take 3.5 years to reach Titan. The mapper will map up to 20 percent of the part of Titan's surface facing Earth. The probe will be of a new lightweight design, partly made possible by the relatively benign entry conditions, which may allow the use of a fabric decelerator. The probe's light weight will produce a lower ballistic coefficient, permitting important measurements of atmospheric composition to be made at the beginning of descent into the atmospheric haze layer that lies above the 200-kilometer altitude level.

An alternative plan also is being considered. It would combine the Titan probe with a Saturn orbiter, with Titan mapping postponed until another opportunity becomes available. This alternative would be a cost-sharing venture with the European Space Agency, which favors the Saturn orbiter. It is expected that project initiation would be in 1989 and launch in 1992 or 1993. Launch to an Earth orbit would be by the Shuttle-Centaur combination. After launch from orbit by the Centaur stage, a deep-space spacecraft maneuver and a subsequent Earth-gravity assist would be used to accelerate the spacecraft probe onto a trajectory toward Saturn. Its flight time to Saturn would be approximately seven years.

4. Program Status, FY 1989

The four new initiatives just described will advance solar system exploration as depicted on Figure III-2, 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 is at the exploration level for both Mars and the moon and is directed at global mapping of both of those bodies. For the outer planets, there is an approved exploration initiative to probe Titan's atmosphere. Also, successful continuation of the Voyager 2 mission will provide a flyby reconnaissance of Neptune. The high-priority comet rendezvous mission will initiate exploration of the small bodies. Asteroid flyby reconnaissance also is included as a benefit of the comet rendezvous mission's traversal of the asteroid belt.

5. Possible Initiatives After 1989

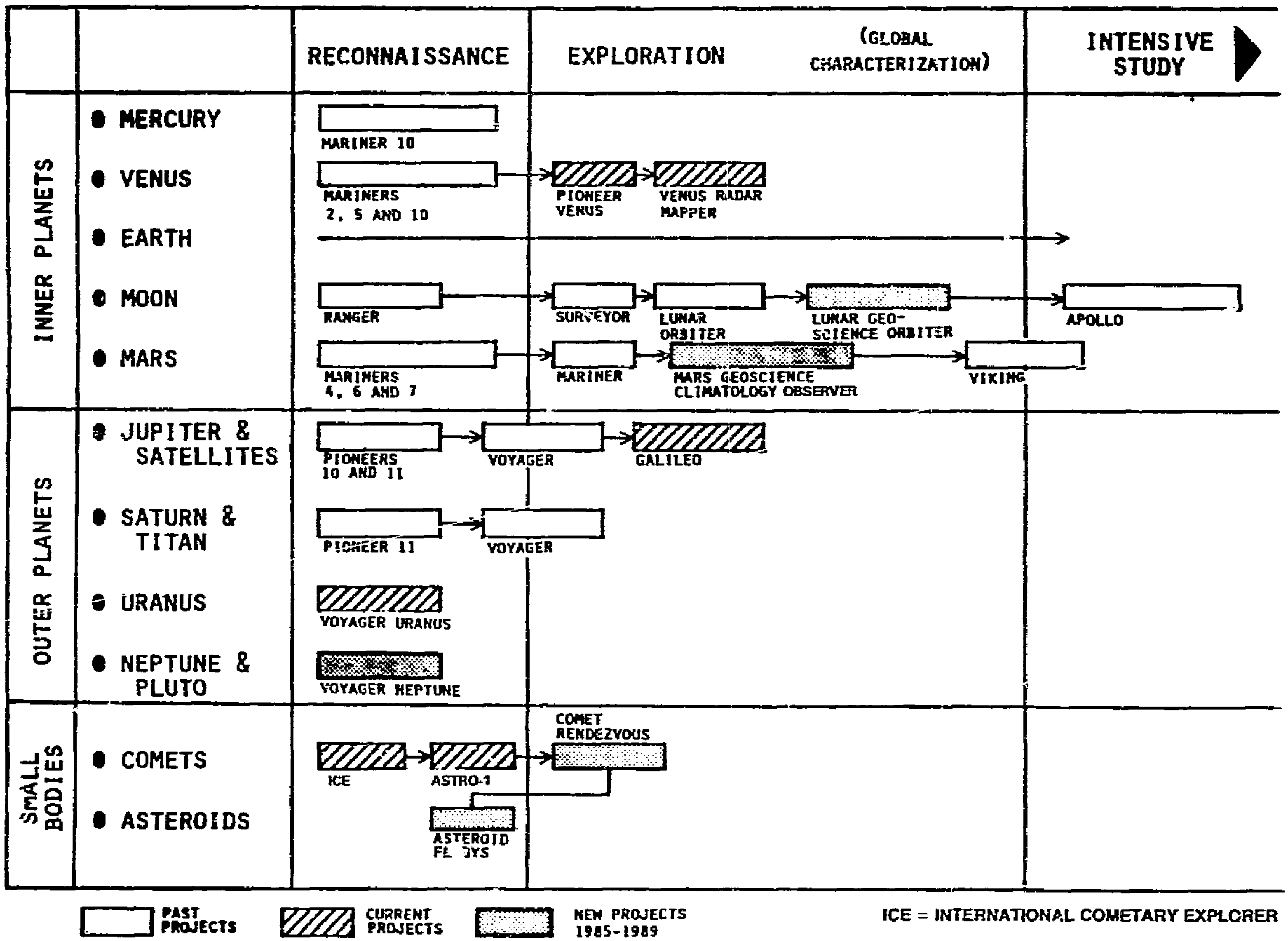
The Solar System Exploration Committee recommended initiation of its core program missions by the end of this century. That would require initiation of nine missions in the 1990 to 2000 period. Two of those projects, the Comet Atomized Sample Return and the Mars Aeronomy Observer, have been identified as potential foreign initiatives. The feasibility of their being undertaken as international contributions to solar system exploration is being discussed with the European Space Agency and its member countries. The remaining seven 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's recommendation is 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, a Venus Atmospheric Probe Observer and a 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.

The 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

FIGURE III-2
PLANETARY EXPLORATION STATUS: 1989



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 precurser 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, in particular, is a good candidate for initiation in the 1990s. Indeed, the Solar System Exploration Committee recently proposed that the prime 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 fully-loaded Centaur stage, each mission would use aerocapture at Mars and perhaps for recovery at Earth. Because of Shuttle payload limitations, the Centaur would have to be fueled in orbit. 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 be assessed in the coming year for feasibility, exploration value, and technology requirements in preparation for possible augmentation to the core program.

b. <u>Small Bodies</u>

Two additional missions, the Multiple Mainbelt Asteroid Orbiter-Flyby and the Near Earth-Approaching Asteroid Rendezvous Observer, are to be undertaken as future initiatives to complete the core program for small bodies. 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 spacecraft 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 flybys. NASA is considering international participation for this mission as a means of obtaining the beneficial solar-electric propulsion module.

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. 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 can be a modified Earth-orbiter of the Planetary Observer Class of spacecraft--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 the Inertial Upper Stage II or Transfer Orbit Stage upper stages will be able to satisfy launch requirements.

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

Three core program missions to the outer planets are to be initiated in the 1990 to 2000 period: a Saturn Orbiter, a Saturn Flyby and Probe, and a Uranus Flyby and Probe. The Saturn Orbiter mission is a part of the outer planet exploration strategy recommended by the Committee on Planetary and Lunar Exploration. It will be similar to the Galileo mission, but without a probe. Its objectives will include global study of Saturn's atmospheric structure, physical properties, and dynamics; continued mapping of icy satellite surfaces; mapping of Titan's surface with radar; investigation of Saturn's ring structure; and time-dependent mapping of Saturn's magnetosphere. The Solar System Exploration Committee recommended that a Mariner Mark II spacecraft be used for this mission. Launched by the Shuttle-Centaur combination on an Earth gravity-assisted trajectory, the spacecraft would require 7.5 years to reach Saturn orbit. Jupiter gravity-assisted trajectories could be used, reducing flight time to less than five years. However, whereas Earth gravity-assisted trajectories are possible every year, launch opportunities for a Jupiter gravity-assisted flight will occur only in 1997 and 1998. Orbit duration of at least 18 months is needed to conduct this mission properly.

Addition to this mission of either the Titan Probe described previously or the Saturn Probe mentioned above is under consideration. That change would reduce by one flight the number of missions in the core program and, with the participation of an international partner, the combined mission could be more cost effective. The Saturn Orbiter and Titan Probe combination, in particular, is being studied as a possible joint effort with the European Space Agency.

The probes of the Saturn Flyby and Probe and Uranus Flyby and Probe missions will have objectives very similar to those for the Galileo mission's probe. Their design could be the same as that of the Galileo probe except for reduction in their aeroshell mass, leading to decreased flight time. Also, those missions could use many of the instruments the Galileo mission will use. 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 between 2000 and 2005. The Committee identified several missions as possible augmentations to the core program before 2000, but has yet to choose a prime candidate. Both the Committee and the Committee on Planetary and Lunar Exploration are continuing to [illegible] possible augmentations, and a choice is expected to be made [illegible]4. Those possible augmentations include a range of Galilean satellite missions, a Titan buoyant station or survivable lander, a Saturn ring mission, and a Neptune orbiter provided with nuclear electric propulsion

6. New Technologies and 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. As indicated in the next paragraph, 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 particular 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 a permanent space station would 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 landings of 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 currently are expected to form 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 subsquent transfer of energy and momentum within Earth's 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, and that field shields its surface from the solar wind. The remaining physical and chemical processes on its surface and in the near-space environment provide 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 seven-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 understanding 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.

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. Studies also have been conducted of the interactions of solar ultraviolet radiation with the upper atmosphere and of the incoming solar wind with the outer fringes of Earth's magnetic field.

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 air and water quality. 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.

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 6000 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 the Thematic Mapper will resume during the spring of 1984.

b. Shuttle Imaging Radar

A series of radar imaging experiments called SIR-B currently being planned for flight on the Space Shuttle will add another major dimension to NASA's program in Earth observations. An earlier experiment, the Shuttle Imaging Radar-A (SIR-A), was conducted in November 1981. The data it collected 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. SIR-B is a follow-on experiment scheduled for launch in 1984. It will be the first spaceborne radar able to image Earth's surface at multiple angles of incidence measured from the local vertical.

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. 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. An instrument to fly on the Shuttle entered development in 1981 and is expected to fly during 1987 and 1988.

d. The Oceans

Viewing the oceans from space can contribute to scientific knowledge in three general areas: the circulation, both geostrophic and wind-driven, and the heat content of the oceans, and how they are influenced by the atmosphere; the primary productivity of the oceans, how it is influenced by the physical and chemical environment, and how it in turn influences the higher elements in the marine food chain; and the growth and movement of sea ice and how they are affected by the atmosphere and oceans. Techniques are in development for removing the directional ambiguity associated with scatterometer measurements of winds and surface stress, and the Global Scale Atmospheric Program is making quantitative studies to assess how scatterometer-measured winds can be used to improve atmospheric forecasts. In situ ocean-current sensors are being developed for evaluating the potential utility of spaceborne sensors in determining surface currents and complementary subsurface currents. Investigations are in process to determine the capabilities and limitations that spaceborne observations of chlorophyll concentration have for providing estimates of phytoplankton productivity and to look at in situ techniques for measuring phytoplankton patchiness. Initial results have been obtained using successive images from synthetic aperture radars to quantify the movement and deformation of fields of sea ice.

Plans are being formulated, under the auspices of the International Council of Scientific Unions and the World Meteorological Organization, 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 in the Topography Experiment for Ocean Circulation and the NASA Scatterometer described later will be key components of the two experiments.

e. The Atmosphere

NASA has both the experience and the facilities to deal with the special problems involved in understanding the circulation of the atmosphere; namely, the processing of voluminous data, interpretation of results in meteorological terms, and application of the results to meteorological issues. Investigation and assessment of data from the First Global Atmosphere Research Program Experiment are proceeding. A substantial part of NASA's work is devoted to development of new techniques. For example, an effort is under way to develop and fly an advanced temperature and moisture sounder whose expected performance could approach that of radiosondes, but with far more complete spatial coverage.

f. Mesoscale Processes

The emphases of research on severe storms and local weather are meteorological observations from space or high-flying aircraft and high-technology interactive computer techniques to assimilate and analyze data from multiple sources. One aspect of developing new measurement techniques is use of aircraft flights for field tests; for example, flights of the CV-990 aircraft for testing the new Doppler Lidar Wind Velocimeter. Also being emphasized are development of research applications of the Visible-Infrared Spin-Scan Radiometer Atmospheric Sounder on Geostationary Operational Environmental Satellites and development of new algorithms for determining temperature, moisture, and winds at different heights in the atmosphere for use in numerical models. Flow scales in the atmosphere must be understood if progress is to be made in relating large-scale weather to local weather.

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, scheduled for launch in 1984, will continue 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.

h. Trace Species

Investigations are developing techniques for measuring major trace species in the troposphere. Field measurements to test the most promising instruments will be followed by a six-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 two- and three-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 three-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 the 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, the 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 the 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 energization 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 Astro-1 and Spacelab 1 and are scheduled for Spacelab 2. In addition, the Active Magnetospheric Tracer Explorer, which is being developed in a cooperative program with the Federal Republic of Germany and the United Kingdom, is scheduled for launch in August 1984. Its Ion Release Module will release tracer chemicals in front of, at the flanks of, and in the tail of the magnetosphere. Simultaneously, a Charge Composition Explorer will try to detect the tracers inside the magnetosphere so that the entry into and energization 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.

3. Potential New Initiatives, FY 1985-1989

a. 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 that interaction among investigators.

b. 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.

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 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, such as the Multispectral Linear Array, 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.

c. 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 ship, airplane, and buoy data 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, the redistribution of oceanic nutrients by the currents, and 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.

d. 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. 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.

e. 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.

f. 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. Other possibilities include flight of a scatterometer in conjunction with the Topography Experiment for Ocean Circulation and with satellite instruments to be flown by other agencies such as the National Oceanic and Atmospheric Administration and the Navy.

g. Magnetic Field Satellite

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.

h. 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 or 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 nanotesla and a resolution of 100 kilometers.

i. 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 with the following functions:

- The Solar-Pointed Laboratory, stationed at the Earth-sun libration point--to measure solar surface oscillations and deduce solar flare and solar wind processes

- The Solar Wind Laboratory--to measure the incoming solar wind, magnetic fields, and particles

- The Polar Laboratory--to measure solar wind entry, ionospheric plasma output, and deposition of energy into the neutral atmosphere at high latitudes

- 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

- The Geotail Laboratory--to measure solar wind entry and the acceleration, transport, and storage of plasma in the geomagnetic tail

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

4. Future Thrusts, FY 1990-1994

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 aim of the Life Sciences program is to achieve two of the major goals of the national space policy: to establish a more permanent human presence in space, utilizing the space station, and to conduct a vigorous program of scientific research in space. Inhouse laboratories and university scientists implement those goals by conducting both ground-based research and space-based research using manned and unmanned vehicles. Since its inception, the program has had primary responsibility for ensuring the health and well-being of spaceflight crews. In addition, it selectively advances knowledge of fundamental biological processes at the cosmic, global, and organismic levels.

1. Objectives

In pursuit of the two goals mentioned above, the program has adopted the following objectives:

- To provide medical care and fill requirements for life support to spacecraft crews in the Space Shuttle and space station

- To devise preventive and therapeutic measures to counteract untoward effects of spaceflight that might affect the health and performance of crew members in the Space Shuttle and space station

- To determine how life began on Earth and what its distribution throughout the cosmos may be

- o To characterize the role of life in processes that affect the terrestrial environment on a global scale
- o To determine and characterize the effects of gravity variations on organisms.

2. Strategy

The Life Sciences program concentrates its research on two interrelated disciplines, medical science and biological science. The medical sciences must address promptly any problems that arise in Shuttle operations and those anticipated to arise in space station missions. Because these problems can be studied most effectively through inflight experimentation, progress in the life sciences depends to a considerable extent on the availability of flight opportunities.

Foremost among immediate problems in medical science are the anorexia, vomiting, and malaise that characterize the space adaptation syndrome. Additional problems involve spatio-temporal illusions and cardiovascular changes that sometimes affect crew members during their return to Earth and problems associated with denitrogenizing crew members before they engage in extravehicular activity. Denitrogenation must be made more convenient and less likely to cause subsequent dysbarism (bends).

With regard to problems related to future missions, including those on the space station, means must be found to protect crew members from the effects of exposure to radiation, particularly high-energy, multicharged, heavy ions. Measures must be developed to mitigate the loss in flight of bone and muscle. And, because the presence of female astronauts on crews is becoming routine, differences in their endocrinological, musculoskeletal, cardiovascular, and urogenital systems and in their responses to dysbarism and radiation must be understood and accommodated.

Enhancing the in-orbit capabilities of Shuttle and space station crews requires improvement in spacecraft habitability and optimization of the interaction between humans and machines. Also, physicochemical or biological regeneration of oxygen, water, and ultimately food aboard spacecraft is essential to the creation of microenvironments able to sustain humans efficiently for long periods of time.

The biological sciences seek understanding of the nature of life--its past, present, and future--and of life's relationship with its environment. Since life is a product of a series of physical and chemical processes that started with the beginning of the universe, research on a cosmic scale is focused on life's relationship with the universe. On a global scale, life is viewed as a modulating force governing the complex cycling of materials and energy throughout the biosphere. On an organismic scale, emphasis is placed on understanding how living systems have adapted to various evolutionary forces, especially gravity.

Understanding the origin, evolution, and distribution of life and life-related molecules, on Earth and throughout the universe, requires correlation of ground-based simulations of prebiotic environments with observations of extraterrestrial matter such as planetary surfaces and atmospheres, interstellar molecules, meteorites, comets, and cosmic dust. The role of Earth's biota in cycling materials through the biosphere is investigated by measuring biogeochemical cycle parameters in the field and then developing sensing techniques for making similar measurements on a global scale remotely from space. Determining the physiological effects of gravity, or lack of gravity, on organisms requires spaceflight verification of hypotheses developed using Earth-based zero-gravity simulation models.

Ground-based research and technology development constitute the initial approach in each program element, with all elements using space flights to verify hypotheses and results.

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 examination, inflight health monitoring, and preflight training of crews in onboard emergency medical procedures. In preparing for the space station it must assess occupational hazards associated with space-based industry and devise preventive and therapeutic measures for coping with them. It also must improve ground- and space-based clinical operations, developing procedures suitable for persons working in space.

Development of effective countermeasures to cardiovascular deconditioning depends on understanding the underlying physiology. To extend that understanding, experiments on Spacelab 4 will measure central venous pressure and baroreceptor sensitivity. Existing countermeasure devices, such as antigravity suits, programmed exercises, and fluid loading with and without medication, will continue to be evaluated on Shuttle missions to determine the limits of their effectiveness. 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 cardiovascular deconditioning will be characterized.

Better ways are being sought to measure the acute physiological and psychological phenomena that appear during the first two to three days of weightlessness. Several tests of vestibular function will be conducted on Spacelabs D-1 and 4; and both biofeedback methods and improved pharmacological agents for controlling motion sickness symptoms will be tested on Spacelab 3. The problems associated with motion sickness will continue to receive major emphasis until they are understood and successfully treated or prevented.

The physiology of bone demineralization is under study. Work is in process to develop non-invasive techniques for measuring mineral content and bone elasticity. Experiments are being planned for flight on Spacelabs 2 and 4 to investigate hormonal control of calcium metabolism and the kinetics of calcium absorption. The probability of musculoskeletal system damage is higher on long-term space station missions than on short-term Shuttle missions. Moreover, since hypercalcemia, kidney stones, and renal damage are possible on missions of any duration, appropriate treatment regimes must be developed. A clearer understanding is needed of whether the bone loss experienced by humans during space flight is cortical or trabecular or both, and whether bone and muscle loss and recovery rates vary with age and sex. Ground-based and inflight 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 of respiration in space and its relationship to cardiovascular and other functions is needed. So that better cabin and spacesuit 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 inflight analyses of procedures to prevent bends are required.

Studies to improve radiation dosimetry and to characterize the radiation environment in space are under way, as are radiobiological tests of the effects of high-energy, multicharged particles thought to be components of cosmic rays. Work also is under way to determine shielding requirements and the shielding characteristics of spacecraft materials. High-inclination and polar orbit flights involve greater exposure to solar particles, galactic cosmic rays, and, in particular, the high-energy, multicharged, heavy ions called HZE particles. High-altitude flights in elliptical and geosynchronous orbits have substantially increased exposure to the geomagnetically trapped radiation belts and to solar particles that also produce HZE particles. Understanding of the effects of HZE particles must be improved.

Research in psychology and human performance explores the effects of nutrition, motivation, personality, and group composition on individual performance and on small-group interactions. Assessment is needed of the effects of combined stresses and altered physiological state on performance, information processing, decision making, motor control, and interactions with spacecraft systems. So that more effective countermeasures to stress can be developed, the research will be directed toward evaluation of the efficiency of individuals under the influence of adaptive physiological processes in the space environment and of the individuals' overt behavioral responses.

The ability of astronauts to work in space suits and use remote manipulators will be expanded by development of additional hardware; and better personal hygiene systems, sleep stations, and equipment for monitoring medical, physiological, and environmental safety will be developed. Means will be sought to improve spacecraft food supply systems, with particular attention to new preparation and preservation techniques; and research on the use of biological processes to regenerate food and to control environmental conditions aboard spacecraft will continue.

b. Biological Sciences

The Biological Sciences program meets its objectives through 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 in process in all six elements, but additional effort is essential for capitalizing on the latest scientific thought and for progressing toward understanding the mechanisms that led to life's origin and evolution. In addition, more effort will be applied to developing exobiological analytical instrumentation suitable for the missions recommended by the Solar System Exploration Committee: gas chromatographs, gas chromatograph/mass spectrometers, light (visible, near-infrared, and far-infrared) spectroscopes, and other devices for specific elements and compounds. Instrumentation for remote observations must be developed for use with Earth-orbiting telescopes, described in earlier 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, formerly the Global Biology 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 representing the dynamics of global cycles.

This program was initiated two years ago. Subsequently, it was strengthened by the addition of tasks to correlate ground-based data with remotely sensed data to determine biomass extent on varying spatial scales, with satellite imaging to determine ecosystem extent, and with measurement of atmospheric gases to indicate ecosystem behavior. Recently availabile satellite observations, computers able to handle large quantities of data, and new analytical instrumentation for ground-based research have acted as stimuli to studies of the biosphere. The thrusts of the program for the near future include development of registration techniques using data collected by Landsat and the Advanced Very High Resolution Radiometer to produce geographic information systems; use of remote sensing to update existing vegetation and land-use maps, techniques for recognizing ecosystem borders, and methods for determining biomass types and extent; correlation of measured fluxes of ground gases with the type of ecosystem and soil producing the gases; and development, for specific types of ecosystems, of comprehensive stratified measurements that incorporate ground truth measurements, aircraft measurements, and satellite observations, all correlated and integrated through multidimensional computerized models.

(3) Gravitational Biology

Gravitational Biology, formerly Space Biology, deals with physiological response to the full range of gravitational forces, from microgravity to gravities greater than one. The program seeks to increase understanding of how gravity affects life on Earth. It has the following objectives: to understand how organisms perceive gravity and transmit that understanding to responsive sites; to determine the role of gravity in reproduction, development, and maturation; to elucidate the effect of gravity on form, function, and behavior of organisms; and to determine how the absence of gravity in space affects living systems. Although limited so far in numbers and complexity, space experiments have confirmed the sensitivity to gravity of certain biological systems and processes.

A near-term objective of the program is to identify the organs for perceiving gravity and 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 spaceflight 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 the attainment of all 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 for animal and plant species must be developed to provide for maintaining and manipulating the test organisms 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 principle 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 flights shared with partners, experiments on the Shuttle's mid-deck, and investigations on Shuttle-launched, free-flying spacecraft. That program will provide for investigations of the effect 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 spaceflight. 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 mission. The program's near-term objective is to fly dedicated Spacelab missions at approximately two-year intervals. Dedicated missions maximize the number of integrated experiments flown, thus permitting extensive, simultaneous measurements on a limited set of specimens. That broad coverage provides opportunities for correlating measurements from diverse experiments to characterize the biological effects of zero gravity.

Life science experiments flew on the second and third Shuttle flights and on Spacelab 1, and will fly on Spacelab 2 and Spacelab 3. The first flight dedicated to life science investigations, Spacelab 4, is scheduled for launch in late 1985. It and subsequent dedicated flights will carry approximately 15 to 20 experiments each. Efforts also are under way to arrange for the flight of three racks of life sciences investigations on Spacelab 3.

4. Potential New Initiatives, FY 1985-1989

The need for new life sciences initiatives arises from the fact that Shuttle operations will require the presence in space of unprecedented numbers of humans, from plans to develop a 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 will be required if the Nation is to succeed in deploying and using the space station. Expansion therefore 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

Technology will be developed for the life-support and extravehicular activity systems of the space station, and human-system design research will be expanded to develop objective methods for determining the most effective ways for humans to function in space. Construction and inflight evaluation will be undertaken of prototype modular subsystems for the Controlled Ecological Life Support System.

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

Activity is in process to take advantage of Shuttle flights for research and experimentation in both the Medical Sciences and the Biological Sciences. Spacelab capabilities will be indispensible, and the Shuttle mid-deck will provide 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 starting in FY 1985.

e. Space Station 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 base 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. So that those and other anticipated opportunities can be taken advantage of, 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 instrumentation needed for analyzing 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 first will go 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 radiotelescope sites.

5. Possible Initiatives, FY 1990-1994

a. Regenerative Life Support Systems

By the end of the 1980s, a breadboard Controlled Ecological Life Support System will be available for ground-based testing. It will use "conventional" advanced life support technology and also biological subsystems. It will allow development of an operational system for use on longer missions during the early 1990s.

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 a function 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 canal 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 ATS 1, 3, and 6 experimental communications satellites were precursors to current maritime, land, and aeronautical mobile satellite services. ATS-6 and the joint Canadian-NASA CTS Experimental Satellite provided the basis for today's new broadcast satellite service industry. CTS also opened the door to a whole new generation of fixed service satellites operating in the 12 GHz band. 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 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.

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 intends to continue to develop high-risk technology that will yield systems to satisfy expanding demands for communications but that industry is unlikely to develop. Industry can be expected to make use of the resulting technology to offer new and expanded services.

1. Current Program

NASA launched its last experimental communications satellite in 1973 and then, for the next several years, maintained only a minimum involvement in advanced technology, initiating no new flight programs. Subsequently, awareness grew of the imminent congestion of the spectrum and geostationary arc, the unfilled demands of the public sector for communications, and the eroding U.S. competitive position in satellite communications technology vis-a-vis Europe and Japan. In 1979, urged by several independent organizations and committees to resume its leadership role in the development of advanced technology for satellite communications, NASA--with U.S. industry's help--developed a program plan consisting of the activities listed below. The first of those activities is conducted by the Office of Aeronautics and Space Technology, the remainder by the Office of Space Science and Applications.

- Basic research and technology development, which provide 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.

- Advanced technology development, which develops technology for the Advanced Communications Technology Satellite, opening new bands in a fashion that will conserve the spectrum and be economically competitive, and providing new and expanded satellite services.

- Technical consultation and support services, which conduct 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 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.

- 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.

- Experiment coordination and mission support, which identifies and aids development of 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.

- Advanced Communications Technology Satellite, which will be a technology development and ground test program to prove the feasibility of certain advanced communications satellite technologies. Technologies to be validated include use of multiple fixed and scanning spot-antenna beams, frequency reuse, beam interconnectivity at both intermediate frequencies and baseband, advanced system network concepts, and dynamic rain-compensation techniques. Those technologies will be applicable to a wide range of communications systems in the 1990s.

2. Potential Initiative, FY 1985-1989: Mobile Satellite Program

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, they 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.

Satellite communications service can solve those problems related to land mobile communications by relaying voice, message, and data communications between mobile terminals and fixed base stations. It can meet a wide range of commercial and public safety communications needs such as for mobile telephone, dispatch, law enforcement, emergency communications, and paging. Consequently, initiation is planned of a mobile satellite commercialization program with the objectives of:

- Developing technology to enable commercial mobile satellite service
- Facilitating development of new markets for satellite and ground terminal hardware
- Developing terminal hardware that is frequency and power efficient
- Developing networking techniques for use in experimental government applications
- Promoting growth of commercial services.

The program will be conducted under an agreement between NASA and U.S. industry, with appropriate coordination with Canada, to facilitate commercial application of this totally new service by reducing the risks the private sector would have to assume. Industry would 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 would be transferred to commercial service.

To meet the third and fourth objectives, NASA would help other government agencies define their requirements and specialized equipment needs. Those agencies would 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 would enter into a contract for commercial service on the same satellite. NASA thus would help formulate requirements across the government, validate special hardware requirements, and transfer to commercial service technology developed during the two years of experimentation. Critical technology items for the space segment of a first-generation system would include linear, high-power amplifiers and high-gain, pointing antennas. For later systems, large multibeam antennas to provide frequency reuse probably would be required.

In brief, most of the funding for the mobile satellite program would come from the private sector. The program would fill the needs for experimentation and, at the same time, make possible the earliest possible introduction and future growth of commercial service.

3. Possible Initiatives, FY 1990-1994

a. 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 increases in the number of orbital positions, use of inter-satellite 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. The Office of Space Science and Applications, Office of Space Flight, Lewis Research Center, and Marshall Space Flight Center are cooperating in a study to examine those issues, determine the feasibility of large, geostationary communications platforms, determine what technology must be developed, and define what the government's and industry's respective roles and responsibilities should be. An experimental system could be initiated in FY 1989, with launch in FY 1993 or 1994.

b. 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.

G. Microgravity Science and Applications

Although Earth's gravity is weak compared to other physical forces, it 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 and Microgravity Research Associates.

2. Program Scope

The program concentrates on the following physical sciences and does not study the effects of gravity on living organisms:

- Materials sciences, including crystal growth, solidification of alloys and composites, and containerless processing
- Physics and chemistry, including fluid mechanics, transport phenomena, combustion science, cloud physics, and critical phenomena
- Biotechnology, including separation processes, suspension culturing, and blood rheology.

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:

- Establishment of an advisory group consisting of research scientists from academia, 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.
- 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. The disciplines for which groups will be established are electronic materials, metals and alloys, glass and ceramics, biotechnology, fluids and transport, and combustion science.
- 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 academia in a setting suitable for innovative activity.
- 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--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 the past year. 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. Solification 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 operational at Marshall Space Flight Center, and a variety of smaller drop tubes are in operation at the Jet Propulsion Laboratory. General Electric has developed an electromagnetic levitation facility, and air-jet levitators are in operation at Marshall Space Flight Center.

In space, liquids--especially high temperature melts--can be contained solely by their surface tension and 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 now is developing a three-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.

b. Space Shuttle Mid-Deck Experiments

Shuttle flights have provided the means for resuming long-duration experiments in a microgravity environment in the Materials Processing Science program. Descriptions of two that are suitable for flight 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 and up to 5 times the purity that operation on the ground can yield 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 elecrophoretic 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 it provides those services 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. That result is not yet available, but 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) Levitator Experiments

A single-axis, acoustic levitator furnace with an automatic sample exchange mechanism containing eight samples was flown to test its levitation capability at temperatures up to 1,600° C and to explore containerless glass formation. Because of a mechanical malfunction, no data were obtained. The equipment is being repaired and will be reflown in 1984.

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 electronic 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. 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.

c. 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. Space experiments to extend that type of research to materials that cannot be solidified in drop tubes can be expected. Also, containerless positioning of high-temperature melts offers unique opportunities to measure high-temperature thermal properties of materials, especially those whose melt phases are highly corrosive.

d. 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.

e. 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, isotachophoresis, photophoresis, thermophoresis, 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, such as particle-particle interactions during separation and electric field distortions caused by electrical conductivity mismatch between sample and buffer.

f. 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 three-dimensional rotating flows, two phase flows, thermocapillary flows, drop 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 studies, Oswald ripening, foam stability, rheological studies, and critical phase transitions.

g. 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 processs to study experimentally because of the small energies involved and the care that must by taken to prevent foreign influences from altering the results obtained. Elimination of convective motions and artificially supported large hydrometers 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.

h. Microgravity Combustion Science

The absence of a significant gravity field facilitates observation of fundamental combustion mechanisms that buoyancy driven convection might obscure under normal gravity conditions. Such observations can increase understanding of combustion processes in traditional terrestrial systems by permitting comparison of the data obtained with predictions from use of models with gravity controlled terms removed. Available microgravity experimental techniques include uniform distribution of particulate fuels free from gravity induced settling and the burning of fuel masses that are both motionless and mechanically and thermally isolated. Programs under development will investigate droplet combustion, particulate cloud combustion, premixed gas flammability limits and flame propagation, and large solid surface combustion. Programs to investigate gas-jet diffusion flames, liquid pool burning, and smoldering are undergoing feasibility studies.

6. Materials Research 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 materials processing activities 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 processing systems and apparatus will be defined and developed as they are 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.

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 processing times and higher power levels is expected to develop, requiring a carrier such 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.

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 speci-

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

Facility	Mode of Accommodation	Low-Gravity Time	Typical Sample Size*
Drop Tube	Sample Dropped in Evacuated Tube and/or Backfilled to Provide for Supercooling	4.5 Seconds	1 mm to 5 mm Diameter
Drop Tower	Processing System Dropped in Tower	4.5 Seconds	5 mm Diameter X 8mm Long
KC-135 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

Processing System	For Rockets and Aircraft	For Shuttle and Spacelab	For Free Flyers
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)	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

Apparatus	Shuttle Location/Carrier	Availability
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)
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

alized 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 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' responsibilities include institutional management of Goddard Space Flight Center and the Jet Propulsion Laboratory, and 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:

- Plan and develop Earth orbiting science and applications spacecraft and plan and execute associated operations and data analyses
- Provide for acquisition and dissemination of data from science and applications missions
- Develop science and applications instruments to be flown or placed in Earth orbit by the Shuttle
- Conduct balloon and sounding rocket programs for science and applications research
- Sustain excellence in development and operation of Earth orbital spacecraft
- Enhance tracking and data acquisition systems and support operations as the primary mode is changed from a ground-based system to a satellite system
- Maintain itself as the NASA center of excellence for overall space science and applications disciplines
- 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 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.

Space Flight

IV. SPACE FLIGHT

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IV. SPACE FLIGHT

A. Goals and Objectives

The President's space policy commits NASA to maintain the Nation's leadership in space flight. To meet that commitment and the goals NASA has set for itself, the Space Flight program consists of three major kinds of activities:

- 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 Advanced programs--planning and evolutionary development of follow-on programs to increase space flight capabilities with advanced transportation, satellite services, and advanced crew and life support.

The primary NASA goals of direct relevance to the Space Flight program are to:

- o Make the STS fully operational and cost effective in providing routine access to space for domestic and foreign, commercial and governmental users
- o Establish a permanent manned presence in space to expand the exploration and use of space for activities that will enhance the security and welfare of mankind
- o Expand opportunities for U.S. private sector investments 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 that contribute to significant increases in both Agency and national productivity.

In consonance with those NASA goals, the Space Flight program has adopted two major goals. The first is to provide to the Nation, as rapidly as possible and on schedule, the ability to operate the Space Transportation System (STS) as an efficient, effective business enterprise that will arrest the loss of space transportation customers in the near term and develop new customer markets in the long term. Achieving that goal will require STS operations that are responsive, safe, reliable, and cost effective, as well as adequate preparedness for the anticipated increase in demand on the STS from U.S. and foreign users. The STS will be considered operational when its operational costs are well understood and controlled and its flight schedules can be met. Meeting that goal also will require that the program currently focus on completing the development of the STS, making each STS mission safe and successful, maintaining an operational launch schedule, reducing operational costs, and exploiting the inherent capabilities of the STS.

Development of new customer markets will require evolution of the capabilities of the STS to meet requirements for more economical support of payloads, manned space operations beyond those provided by the Shuttle, reductions in costs for communications satellite activities, increased utilization of the Shuttle fleet, larger and heavier payloads, reusability of geostationary spacecraft, and provision of an orbital research and development facility.

The Space Flight program's second major goal 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 represents the logical next step in evolution of capabilities provided by the STS and in the further development of space flight.

To make the best possible use of the unique capabilities of the STS and to serve as a basis for new initiatives to be undertaken in the next few years, the Space Flight program has established objectives extending into the 1990s. Those objectives support, in general, capitalizing on the STS as a space test bed for research and development activities; devising innovative uses for the STS; providing routine, flexible, economical access to all orbits for both cargo and manned payloads; increasing the time in space and economical operation of payloads by establishing permanent space facilities to support science, research and development, commercial, and operations activities, both manned and unmanned and in both low and geostationary Earth orbits; and instituting routine checkout, refueling, repair, and upgrading of spacecraft in orbit through manned and remotely controlled servicing.

The specific objectives, divided into those for the near term and those to be pursued later, follow.

1. <u>Objectives for FY 1985 through FY 1989</u>

   o Completing development, acquisition, and upgrading of the STS to its full capability, and achieving routine operations with it by the mid 1980s

     - Maintaining the production schedule

     - Bringing Spacelab to operational status

   o Encourage 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 27 STS missions in FY 1985 and FY 1986

- Continuing the use of expendable launch vehicles for schedule assurance and special needs

- 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

- Establishing an institutional framework that meets civil and defense needs, appropriately utilizes industry capabilities, and facilitates international cooperation

- 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

- Developing a tether system for the controlled deployment, orbit stabilization, and retrieval of science and applications satellites above and below the orbiter

- Demonstrating early the ability of the STS to service satellites in order to verify this new operational capability and thereby influence systems designs and operations adopted by users.

2. Objectives Beyond FY 1989

- Maintaining an operational launch schedule with reserve capacity, while conducting safe, successful STS missions having progressively lower operational costs and shorter turn-around times

- Developing advanced transportation systems that are complementary to the Space Shuttle and meet the needs of planned and prospective spacecraft, platforms, and facilities for maneuvering in and transportation to, between, and beyond Earth orbits

- 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

- Developing and putting into routine operation by the year 2000 permanent, multifunction space facilities that are capable of being manned periodically and that meet communications, observation, science, and national security needs

- Developing technology and techniques to construct, deploy, or assemble each of the above systems in space, and achieving an ability to test and service them in orbit

- 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 report 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.

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 1983 the second orbiter, Challenger, joined the orbiter Columbia, and the two conducted a total of four operational flights. The orbiter, payloads, ground control, flight control, and processing teams have been proven in flight several times; 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 five commercial communications satellites and the first Tracking and Data Relay Satellite; by deploying and retrieving a West German satellite platform; and the first extravehicular activity (space walk) astronauts have conducted in nine years.

a. Shuttle Production and Capability Development

The objective of NASA's Shuttle production and capability development activity continues to be 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 uses strategically the providing of spares for the orbiter and the development of structural spares.

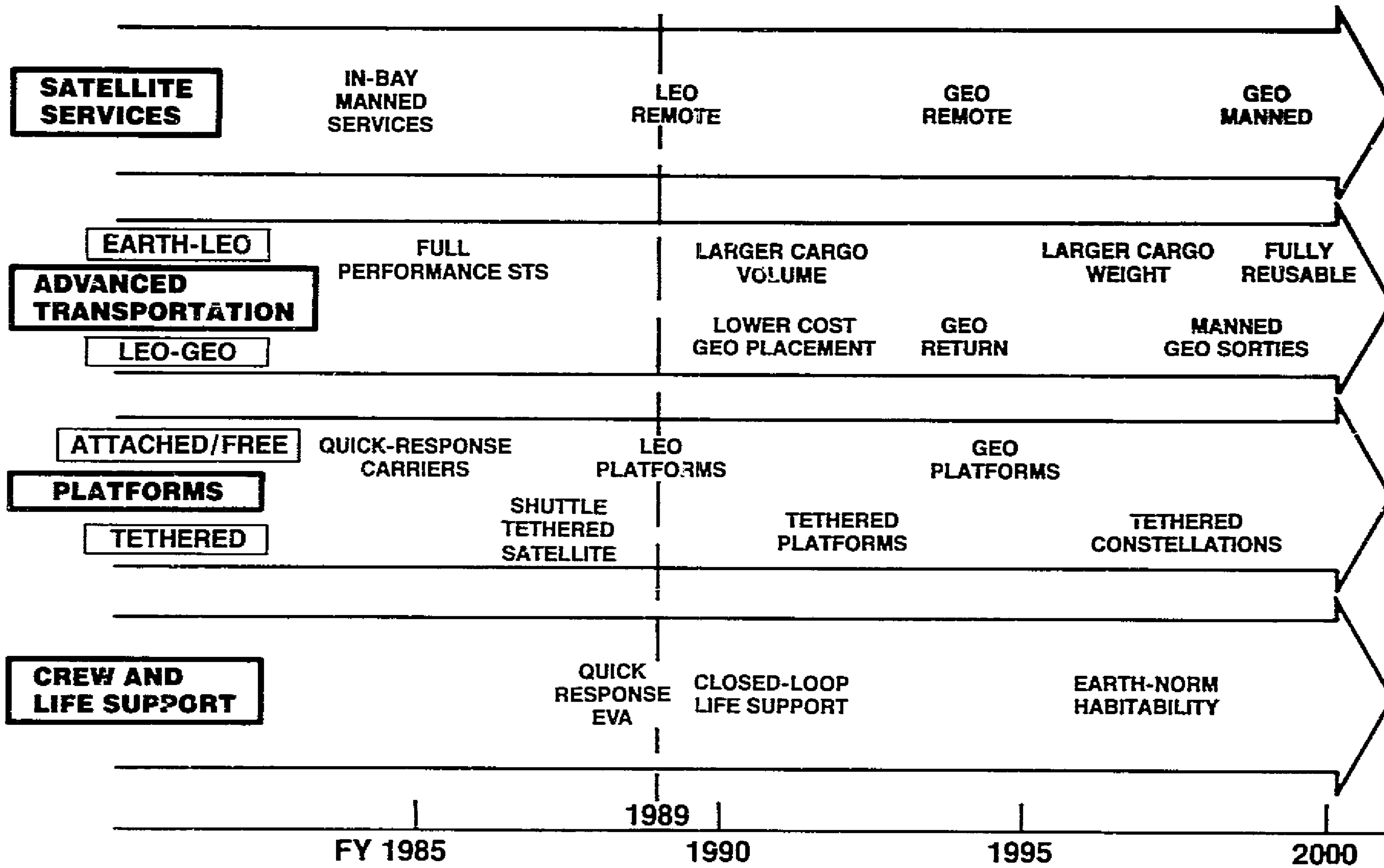
(1) Orbiters

The third orbiter, Discovery, was delivered to NASA in October 1983; 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.

TABLE IV-1. EVOLUTION IMPLICATIONS

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

FIGURE IV-1
CAPABILITY EVOLUTION PLAN



LEO = LOW EARTH ORBIT   GEO = GEOSYNCHRONOUS ORBIT   EVA = EXTRAVEHICULAR ACTIVITY

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^{o}) 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 (10,600 to 19,400 lbs)
Pressurized Volume: 8 to 22 m^3 (280 to 775 ft^3)
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 km^2/sec^2)

The need for additional orbiters is under assessment. Although the approved four-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 because of the need for an extensive overhaul.

(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, 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 SRB 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 deployer 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 kil· ·ters 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-km 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 IV 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, o··all program management, and integration of the system with the orbiter. Work to prepare the system for its first flight is a FY 1984 new initiative. It will yield an initial operational capability in CY 1987. The Italian government already 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 three versions of a spinning, solid-propellant upper stage and another solid upper stage called the Transfer Orbital Stage.

(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 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 5,895 kilograms to geosynchronous orbit and is planned for use in 1986 on both Galileo and the International Solar Polar Mission.

(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.

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; an Instrument Pointing System; and ground support, including hardware integration and payload operations control facilities. It is a 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 as the OSTA-1 payload in November 1981 and one as the OSS-1 payload in March 1982. The verification flight of the Spacelab module configuration was conducted during a dedicated Shuttle flight launched November 28, 1983. A second dedicated verification flight, involving an all-pallet configuration and an Instrument Pointing System, is scheduled for flight in mid FY 1985. The STS manifest also includes a number of Spacelab Operational Missions. 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 cost effectively the many needs of users are currently being either evaluated or developed. Examples are development of the mixed cargo mode and the streamlining of ground techniques to allow the flying of payloads within six months or less.

FIGURE IV-2
SPACELAB OPERATIONAL PLANNING

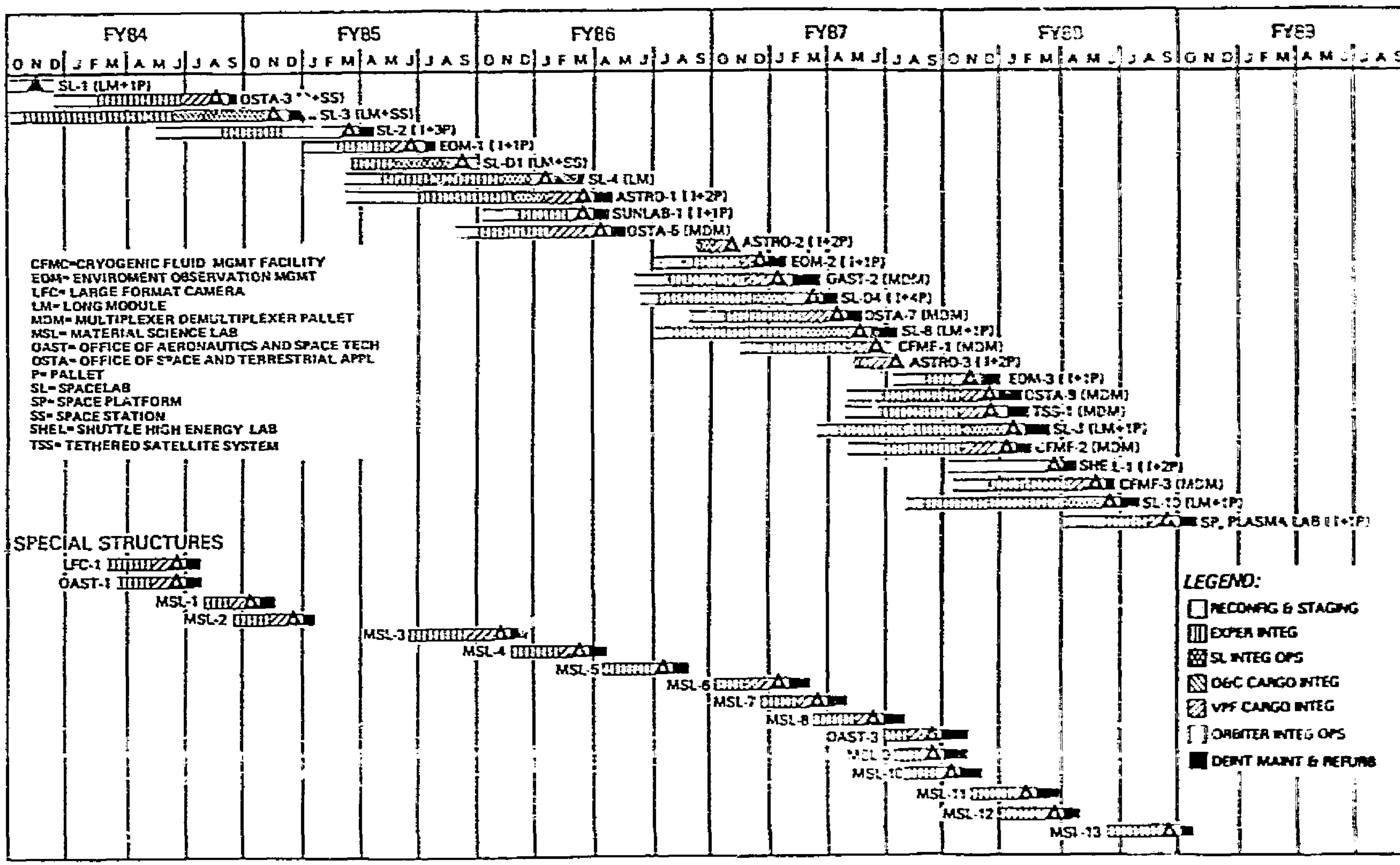
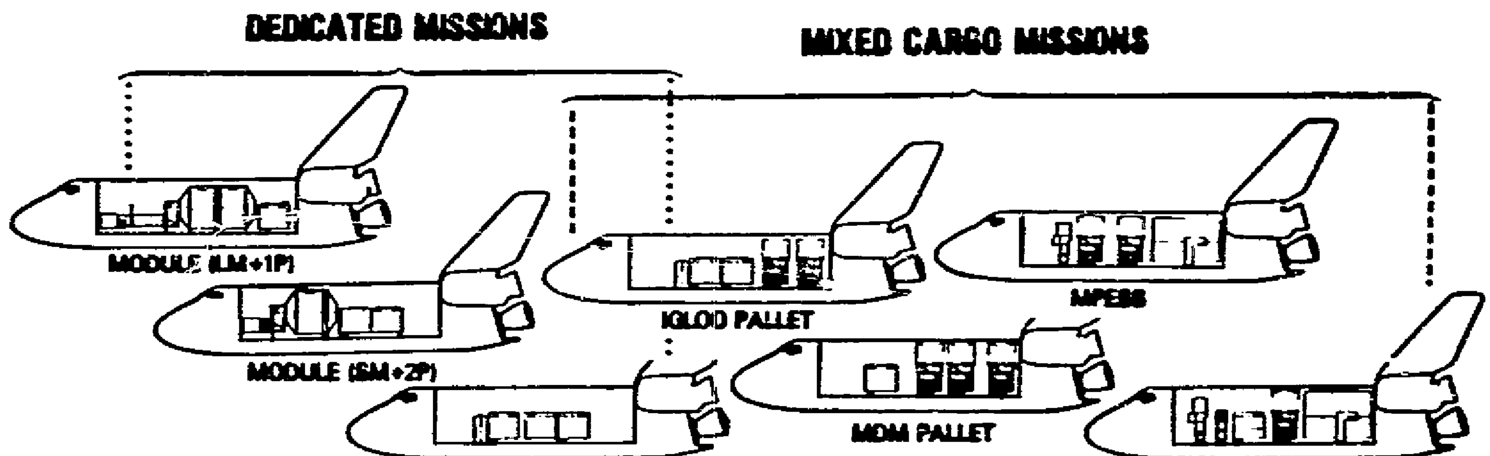


FIGURE IV-3

SPACELAB FLIGHT SERVICES



	(LM+1P)	(SM+2P)	IGLOO PALLET	IGLOO PALLET	MDM PALLET	MPESS	HITCHHIKER
• USER SERVICES							
LOAD (KG)	6000	6000	10,000	2880	2600	1818	1600
PWR (KV PEAK)	FULL SYSTEM CAP				2.4	2.4	2.4
COMMAND/DATA	FULL SYSTEM CAP				16KBS	16KBS	16KBS
OTHER	PRESS MOD		IPS	IPS	—	—	—
• USER FLEXIBILITY	HIGH	HIGH	HIGH	MEDIUM	LOW	LOW	MINIMUM
• MISSION INTEG. (MONTHS)	48/36	48/36	36	36	24	24/18	6
• MANIFESTING FLEXIBILITY	LOW	LOW	LOW	MEDIUM	HIGH	HIGH	MAXIMUM
• UTILIZATION (THROUGH 1990)	9	3	2	17	11	14	11

NOTE: FOR DEFINITIONS OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X

Many flight opportunities for Spacelab payloads will be available on Shuttle flights whose primary purpose is to deploy satellites and upper stages. Multiplexer-demultiplexer pallets currently provide limited subsystem support for such payloads. For mixed-cargo missions requiring Spacelab's full data-management capability, a modified system called the Spacelab Pallet System is under development. It is to be used for the first time in late 1985 to carry the science payload associated with the arrival of Halley's Comet.

A novel Shuttle manifesting concept, designated Hitchhiker, that also will add to Spacelab's capability is under development. It will provide a simple interface with experiments, as well as with the Shuttle, thus making integration for flight easier and less costly. 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.

(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 1983. Six flights are scheduled for FY 1984, twelve for FY 1985, 15 for FY 1986 (including the first West Coast launch, set for October 1985), 21 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 1975 dollars is $18 million per flight through FY 1985 and $38 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.

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 a Mission Operations Contract That will become effective in early 1986, replacing approximately 12 contracts.

(2) Expendable Launch Vehicles (ELVs)

The ELV program provides for procuring ELVs and supplying launch-support services not only to meet the needs of NASA's automated spacecraft, but also the needs of other agencies and organizations using the ELVs and services on a reimbursable basis. The current family of ELVs consists of the Scout, Delta, Atlas, and Atlas-Centaur systems.

Expectations are that about 42 ELV launches will be required during the 1983 through 1987 transition of payloads to the Shuttle. ELVs will launch spacecraft that the Shuttle schedule is unable to accommodate and will provide launch assurance in case of slips in the Shuttle schedule. They will be phased out as the Shuttle's operational capability increases to meet all demands for launch services.

Transpace Carriers Inc. and General Dynamics Corporation have been selected to be the commercial operators of the Delta and Atlas Centaur programs. Agreements are being negotiated outlining details of the transition of production and marketing responsibilities to them.

2. New Initiatives

In consonance with National Space Policy, NASA's next major goal is to establish a permanent manned presence in space. The Space Flight program has focused much of its advanced programs on that goal, identifying potential space programs and systems that will support it. The program also includes advanced development activities to improve performance and reliability and to reduce program costs and risk. Therefore, the program's major objectives are to define the systems elements and systems architecture needed to achieve a permanent manned presence in space and to conduct space operations over the next 20 years.

Systems options depend on the availability of the space station that the President's State of the Union address established as NASA's next major initiative (see Chapter V). Including it, the Space Flight program's future activities fall naturally into four major categories: manned facilities (crew- and life-support systems), unmanned platforms, satellite services, and advanced transportation. Planned work is in consonance with those categories. Descriptions of proposed new initiatives follow, and Section E describes advanced studies planned to identify future systems and operations.

a. Orbital Maneuvering Vehicle (OMV)

The OMV, formerly the Teleoperator Maneuvering System, will be a reusable extension of the STS to fill the need for conducting operations with spacecraft and payloads in orbits beyond the orbiter's practical operational limits. 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 initially will provide spacecraft placement, planned and contingency payload retrieval, spacecraft viewing, science support as a free-flying subsatellite operating in the vicinity of the orbiter, and satellite and payload services. Later, advanced mission kits can be added to the OMV to give it more advanced servicing capabilities such as assembly and servicing of large space systems, dexterous manipulation in planned and contingency servicing of satellites, remote refueling of satellites and platforms, and the retrieval and deorbit of disabled satellites, space debris, and other objects. Still later, the OMV could be boosted from the Shuttle or space station by the Transfer Orbital Stage, a Centaur upper stage, or an advanced orbital transfer vehicle to provide those services 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 is scheduled to begin in late 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; development 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. Advanced mission kits to provide remote refueling and servicing could be added one to two years later. Extension of OMV capabilities to include operation from the space station may be required in the early 1990s.

b. Satellite Services Flight Experiments and Demonstrations

One of the major objectives of the Space Flight program is to capitalize on the STS as a test bed for flight experiments and demonstrations. Shuttle operations and satellite servicing activities of the Shuttle and the space station will create a great need for orbital tests and demonstrations of some systems and of advanced payload operations between the development phases of systems definition and systems design. To meet that need, flight experiments are 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 and techniques for the placement, servicing, and repair of satellites in low orbit and on initial studies of replenishment for satellites in geostationary orbit. The low orbit developments are aimed at an In-Bay Tanker pallet, a set of standard spacecraft fluid connectors, and extravehicular activity tools. The In-Bay Tanker pallet will be carried like any other payload in the orbiter's cargo bay to store the propellant for refueling satellites. Standard spacecraft fluid connectors will be equipment common to all satellites requiring in-orbit fueling. New and improved extravehicular activity tools will increase the efficiency of crews working in space suits outside the orbiter, enabling them to operate the servicing equipment efficiently.

Plans are to use low-cost, experimental, and prototype equipment or equipment acquired for other purposes to satisfy the objectives of flight demonstrations. For example, the Shuttle's eleventh flight, in 1984, will demonstrate satellite retrieval and repair on the currently incapacitated Solar Maximum Mission observatory. In a subsequent flight demonstration, fluid behavior first will be studied using plastic tanks and a reference fluid in the orbiter mid-deck to establish engineering understanding of fluid transfer. Then, an Orbital Refueling Demonstration is planned during which an astronaut performing extravehicular activity will connect a refueling valve manually to the fill valve of actual satellite propulsion tanks mounted in the orbiter's cargo bay and conduct several cycles of refueling with hydrazine to study flow and the attendant adiabatic conditions. That demonstration is a keystone to a series of demonstrations of the potential of satellite servicing equipment and facilities such as the In-Bay Tanker pallet mentioned in the preceding paragraph. The orbital refueling program possibly also will include flight demonstrations with alternate tankage configurations, fluids, and new quick-disconnect valving systems designed to provide ease of servicing and known, proven interfaces.

Another example is a current experiment that is using data from operations with the Shuttle's Remote Manipulator System to develop and evaluate models for large, flexible structures. Also, in two planned experiments, the Experimental Assembly of Structures in Extravehicular Activity and the Assembly Concept for Construction of Erectable Space Structures, crew members on the Shuttle's twenty-fifth flight will provide data for use in calibrating the Neutral Buoyancy Simulator at Marshall Space Flight Center by assembling and deploying structures in flight with the same tools and techniques they had used in the simulator.

The program of satellite services flight experiments and demonstrations will continue to address matters such as module exchange; proximity operation techniques; smart, dexterous end effectors; voice-controlled television; infrared intercoms; laser docking; and large-scale storage of cryogenics. It will develop further capability thereby and is expected to generate new evolutionary programs and establish their feasibility, merits, and relative priorities.

c. Advanced Crew Support

To equip the Shuttle and the space station for quick-response servicing of satellites and the space station for meeting the expected high daily rate of extravehicular activity, the Space Flight program has under study a totally new extravehicular activity system and interfacing elements that will foster human productivity. The study initially will concentrate on projecting mission requirements and developing preliminary system concepts. Its results will be incorporated into an acquisition plan that will provide six flight units to the initial space station and two flight certification units for use in demonstrating the system on the Shuttle before final decisions are made on the requirements for the system to be used on later space stations. A pr liminary set of requirements includes daily usage, in-orbit maintainability, high mobility, long life, non-venting operation, automated check out, heads-up display, automated visor density control, and regenerable, portable life support subsystems.

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 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:

- Propulsion Systems Design Analysis
- Materials Science and Engineering
- Structural Design and Analysis
- Test Design and Engineering
- System Dynamics Analysis
- Large Systems Engineering, Analysis, and Management
- Heat Transfer Analysis
- 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. In addition, Johnson 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 1985. 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:

- Testing of Large Liquid-Propellant Rocket Engines

- 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 element in the space-based part of the infrastructure is the space station. In essence, the importance of the space station to operations in space is equivalent to the importance of the Space Shuttle to transportation from Earth to low Earth orbit. In addition to providing laboratory facilities for science, applications and technology experiments, the space station will become an indispensable node in transportation to higher orbits as well as an orbital service center. As focal point and "mother ship" of the entire space infrastructure, it will allow the limited Shuttle fleet to be used efficiently while ensuring economical and efficient access to all other elements of the infrastructure. Because it will be vastly superior to the Shuttle as an orbital operations base by virtue of its greater onboard resources and permanent duration, it will serve the infrastructure as a facility for servicing free-flying spacecraft, for storage and assembly operations, and as a communications and data processing node.

The space station alone cannot create 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 the infrastucture's elements. The major elements and the rationale underlying and linking them are described in Section E of this chapter.

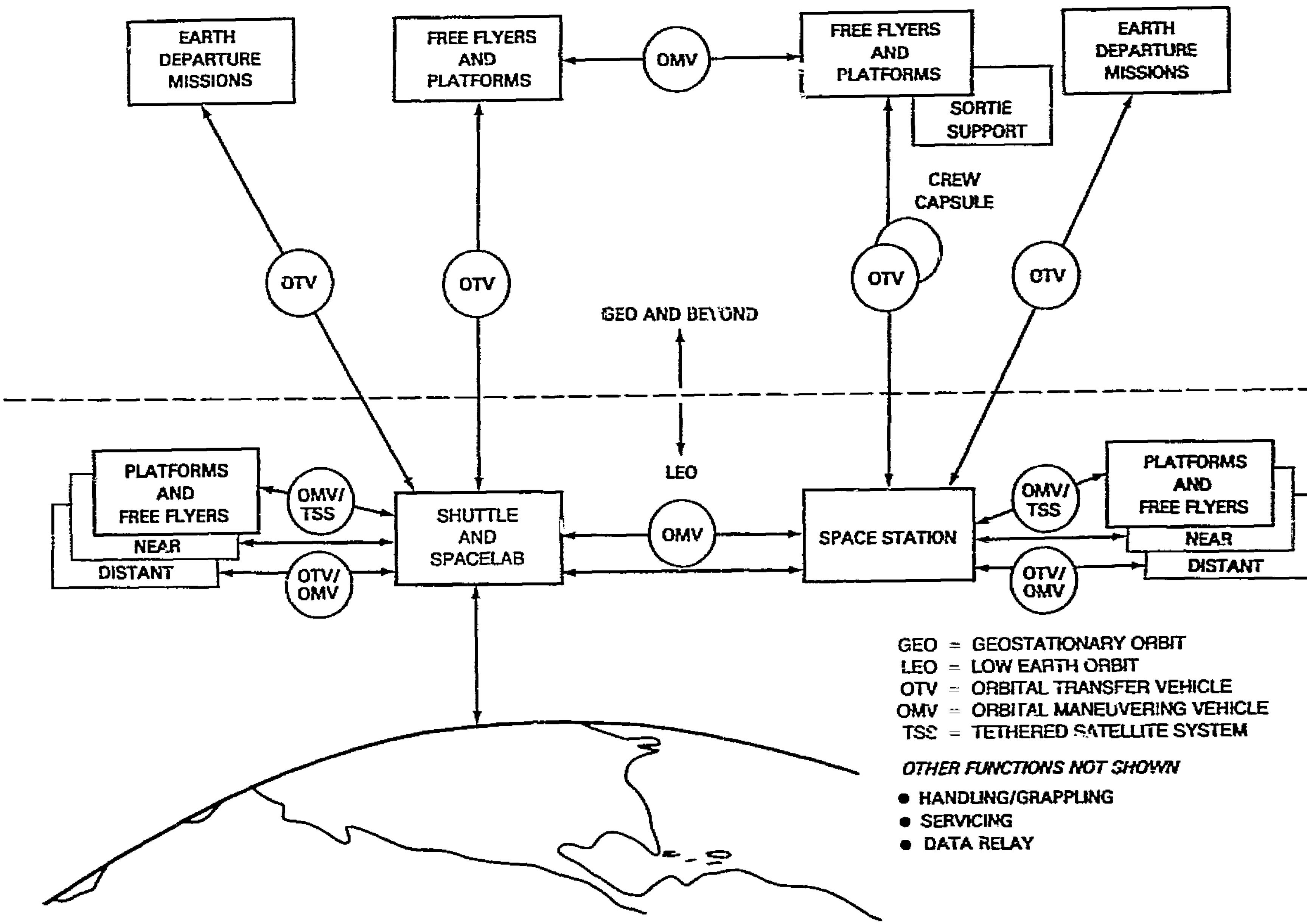
Figure IV-4 shows clearly that the Shuttle is the primary means of access to low orbits and to the space station, which then is the primary means of access to geosynchronous and other orbits. To be most useful, both the Shuttle and the space station will have to operate in conjunction with other systems, such as permanent 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 higher orbits or be serviced and refueled at the space station. Free flyers and platforms in orbits the orbiter cannot reach will require the services of a 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 Space Flight program's advanced studies serve the same four major program categories that its new initiatives serve: manned space facilities, unmanned platforms, satellite services, and advanced transportation.

FIGURE IV-4

ELEMENTS OF SPACE INFRASTRUCTURE



GEO = GEOSTATIONARY ORBIT
LEO = LOW EARTH ORBIT
OTV = ORBITAL TRANSFER VEHICLE
OMV = ORBITAL MANEUVERING VEHICLE
TSS = TETHERED SATELLITE SYSTEM

OTHER FUNCTIONS NOT SHOWN

- HANDLING/GRAPPLING
- SERVICING
- DATA RELAY

1. Manned Facilities

Crew and life support systems are central to the support of manned operations in space. Their expected evolution in the three major areas of life support, habitability provisions, and extravehicular activity systems is shown on Figure IV-5. For the life support systems of the space station and later manned facilities, the target of experiments using the Shuttle and, later, the space station as a test bed will be successive closure of the water loop and air loop to provide the closed cycle life support system shown schematically on Figure IV-6. Some early suggestions for flight experiments and demonstrations and possible development steps to evolve crew and life support systems are displayed on Figure IV-7. Improvements in habitability also will be required for permanent manned presence in space. Those improvements ultimately must provide norms in space food and hygiene systems that approach those on Earth, as well as enhancement of man-machine interactions to achieve higher human productivity in space. That higher productivity will be sought agressively, using both the Shuttle and the space station in the development of superior extravehicular activity systems such as a higher-pressure space suit currently under development to eliminate the need for prebreathing; a regenerable extravehicular mobility unit and backpack that can be maintained in orbit; an advanced manned maneuvering unit; and a crew capsule for manned access to higher orbits.

2. Unmanned Platforms

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 that are based at the space station or are remotely tended 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.

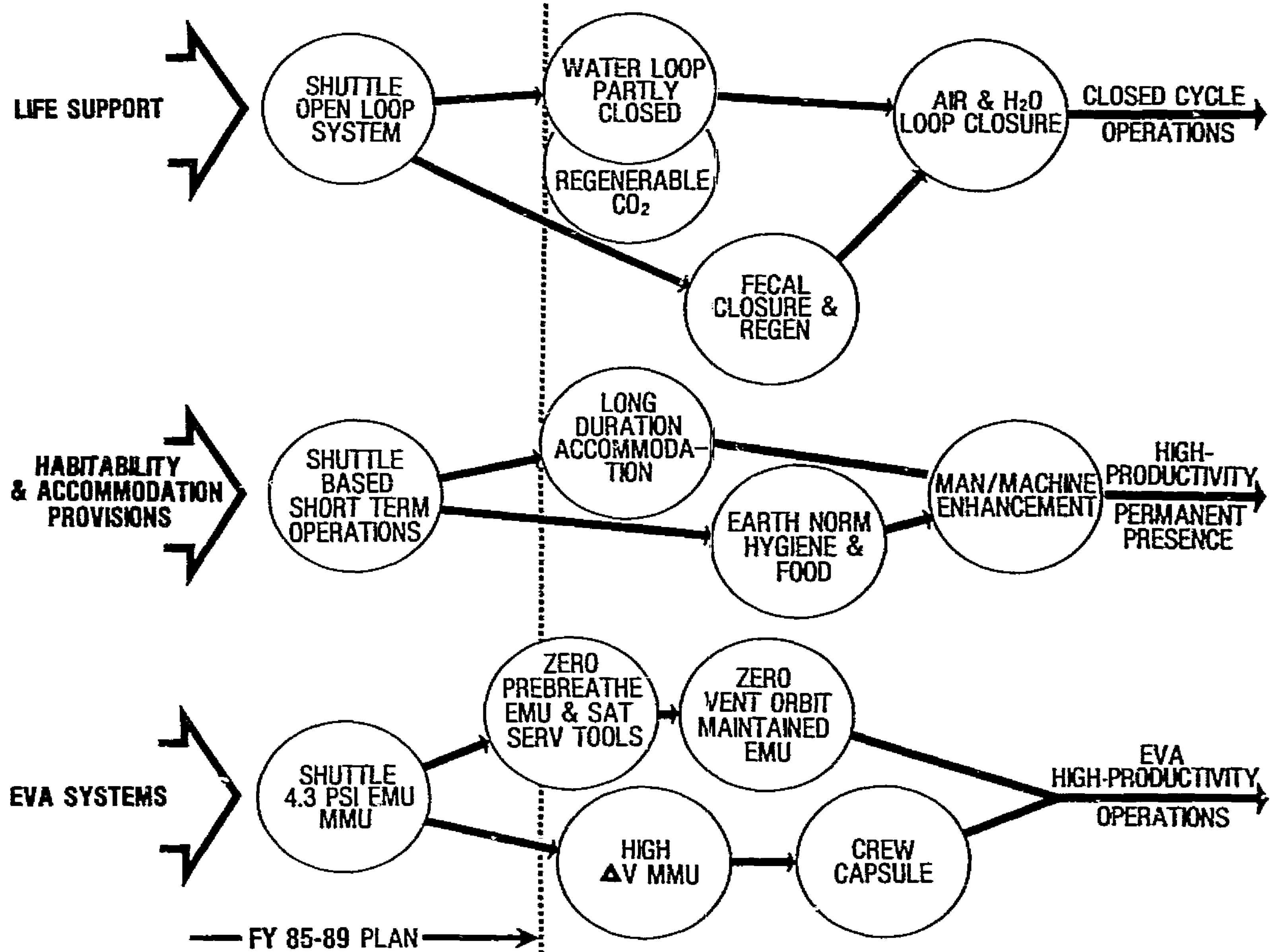
The planned evolution of unmanned platforms is depicted on Figure IV-8.

a. Low Earth Orbit Free-Flying Space Platforms

Orbital durations and power levels provided by the orbiter and the orbiter-Spacelab combination are limited to nine days and seven kilowatts, respectively. Some payloads require longer times in orbit. Indeed, aggregation of payloads, which can provide great economies, may require months or years in orbit. Consequently, a need exists for free-flying platform systems operating from and supported by the space station and able to operate for very long periods (see Figure IV-4).

Studies have determined the sizes and capabilities the platforms must have to accommodate a limited number of pallets carrying science and applications payloads. The platforms are expected to operate in various combinations near the space station. They will provide electrical power, communications, and attitude and thermal control. A variety of payloads will share each platform, benefiting from the resulting lower support costs. The payloads will remain attached for long periods and will be

FIGURE IV-5
CREW AND LIFE SUPPORT EVOLUTION



NOTE: FOR DEFINITION OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X

FIGURE IV-6
CLOSED CYCLE LIFE SUPPORT

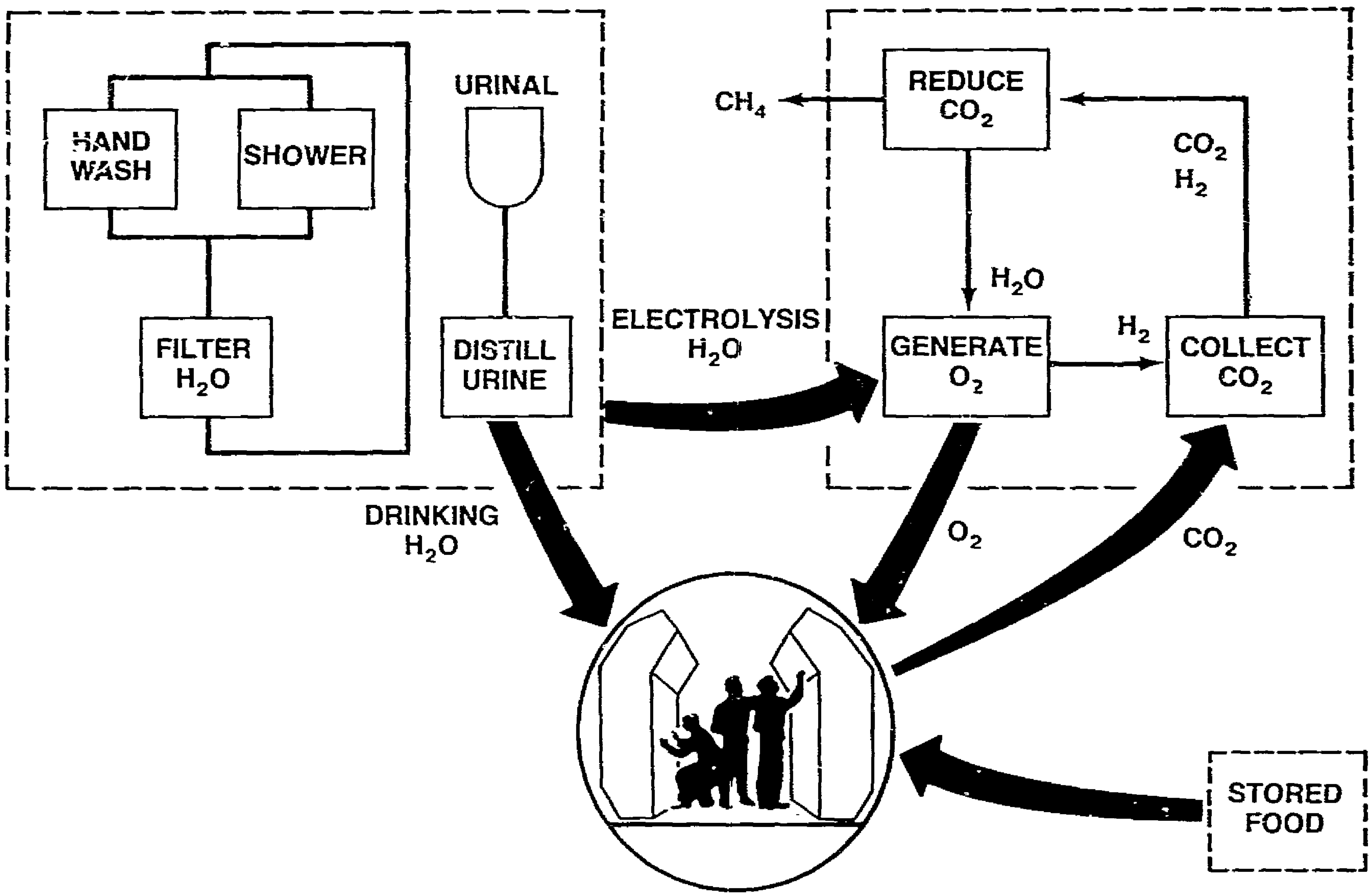


FIGURE IV-7

FLIGHT EXPERIMENTS AND DEMONSTRATIONS — CREW AND LIFE SUPPORT

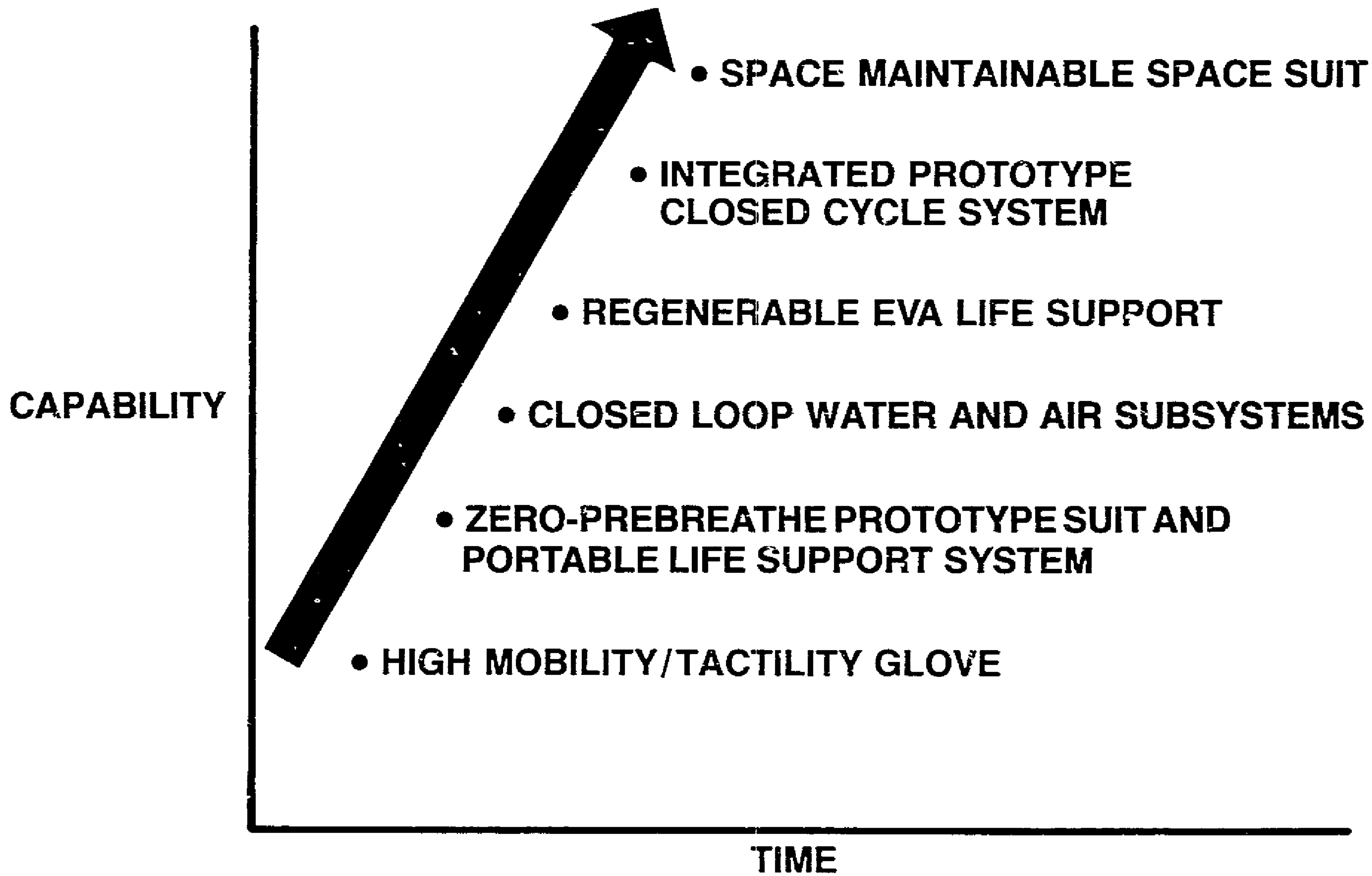
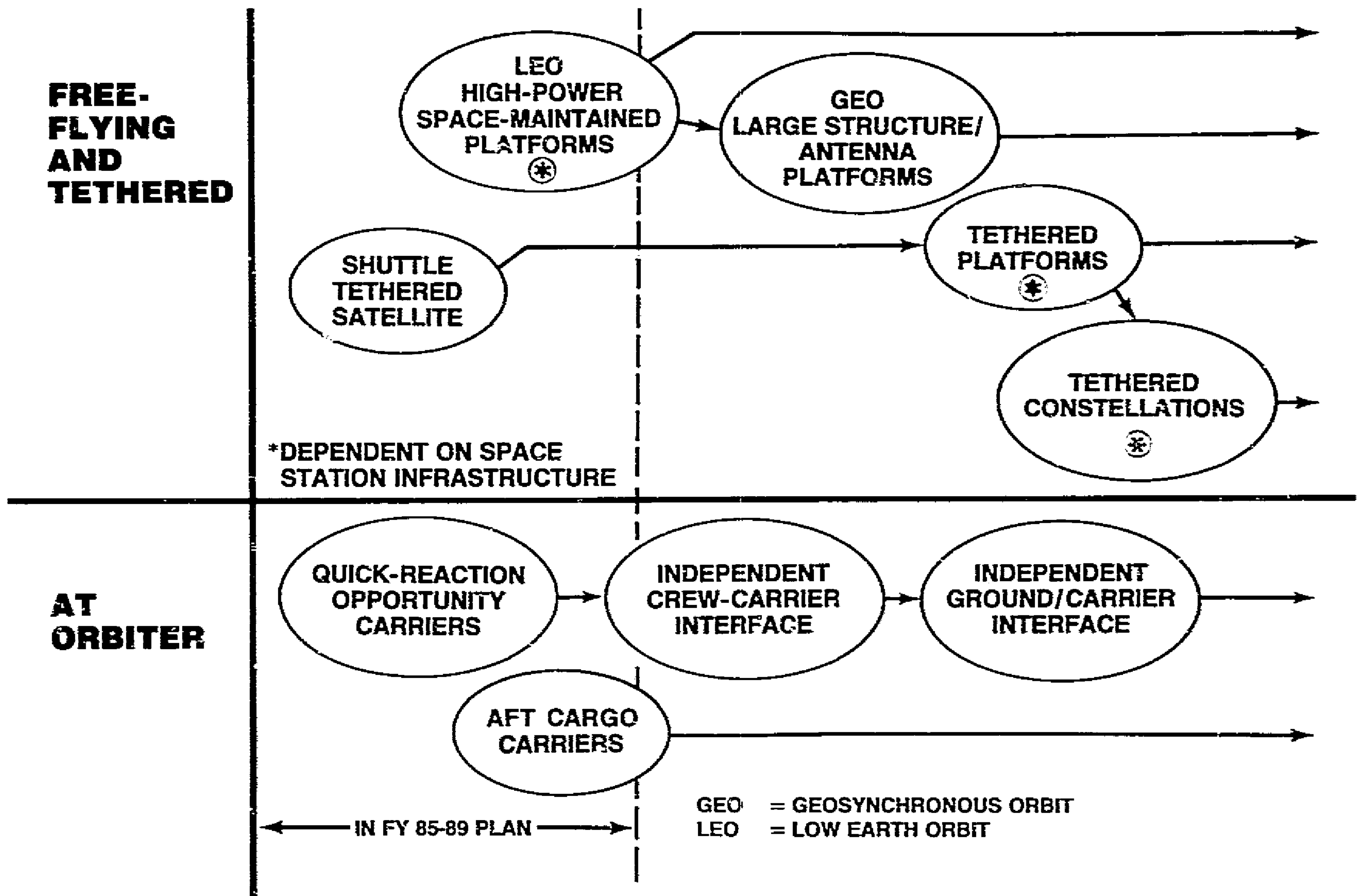


FIGURE IV-8

PLATFORM EVOLUTION



serviced from time to time by the space station or the Shuttle. Periodic exchanges of individual payloads or entire pallets of payloads will be possible.

One of the most promising uses for the platforms is systematic, sustained research on the processing of materials in space. Skylab results showed that longer time in orbit and more electrical power can reduce significantly the unit cost of such research. Therefore, an automated materials processing pallet attached to the space platform could make extended periods of research efficient and practical. It also would free the research from human-induced disturbances.

Another promising use is for research in the life sciences. A platform equipped with a controlled environment habitat and tended as needed by the space station or the Shuttle could conduct life sciences research of extended duration.

The Space Station program continually evaluates uses such as those described above, including growth options involving the addition of habitation modules to the platforms, as part of the evolutionary approach to space station architecture. Pending completion of those evaluations and selection of a preferred concept, space platform development will initiated with the objective of launching the first platform in time it to interface effectively with the space station and the Shuttle.

b. <u>Advanced Tether Applications</u>

Tethered systems attached to the space station also could provide the required longer times in space. The Tethered Satellite System mentioned previously is in process. Approved as a new initiative for FY 1984, it is innovative and will provide important new capabilities 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-9, 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-10 shows the evolution toward highly advanced applications that space tethers are likely to undergo during the next 20 years. Although tethering and its possibilities, such as exploitation of the electrodynamic interactions the use of a tether creates, are understood far less than other elements of the Shuttle and space station infrastructure, they appear extremely promising and should be investigated carefully.

c. <u>Geostationary Platforms</u>

Studies are in process on the utility and the technical and economic benefits of multifunction, geostationary orbit platforms on which space-communications, science, applications, and certain military functions could be aggregated. Economy of scale promises to favor aggregated, high-power platforms over separate, dedicated satellites. In addition, large telecommunications platforms bearing a number of large antennas, beam switching systems, and common support systems appear to be a means

FIGURE IV-9

TETHER APPLICATIONS IN SPACE

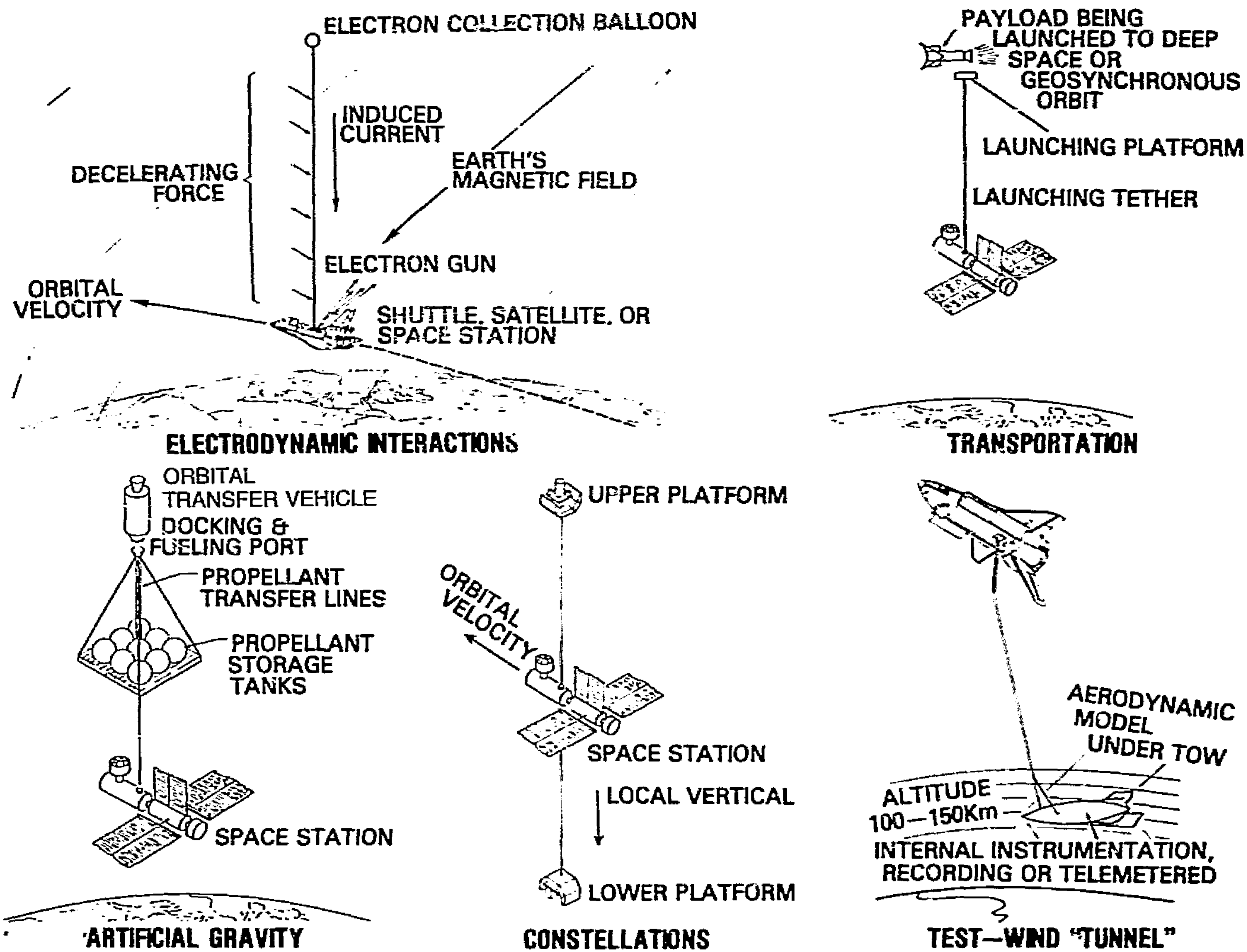
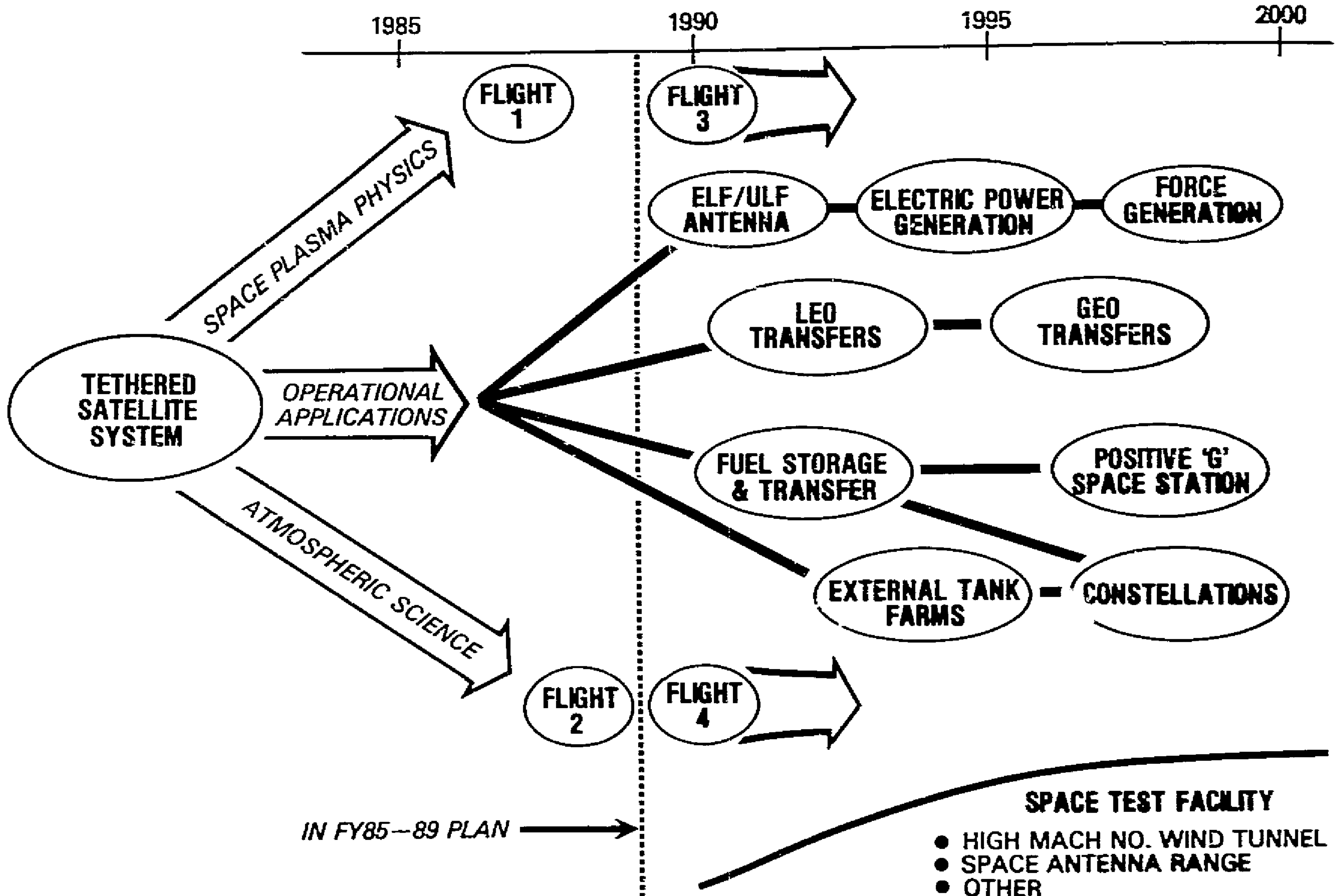


FIGURE IV-10

EVOLUTION OF TETHERS IN SPACE



GEO = GEOSYNCHROUS ORBIT LEO = LOW EARTH ORBIT for alleviating the rapidly developing saturation of geosynchronous orbit positions and the electromagnetic frequency spectrum.

The studies are focused on development of concepts for a platform able to support a variety of users, with initial concept-definition studies concentrating on early uses, primarily for communications. With initiation in FY 1988, a system could be available for first flight in the early 1990s.

As already indicated in the subsection of this chapter entitled New Initiatives, the conduct of flight experiments and demonstrations on Shuttle flights and later on the space station is very important to the economical, efficient development of elements of the orbital infrastructure, including unmanned platforms. Some suggested flight initiatives for both free-flying and tethered platforms are shown on Figure IV-11.

3. Satellite Services

The manned space station and the planned unmanned low-altitude and geosynchronous platforms clearly will create a need for new and unique satellite service systems, large structures, handling aids, and teleoperators, all with greater capabilities than those the STS system possesses. As mentioned earlier, development of those advanced capabilities will require testing in orbit based on flight demonstrations.

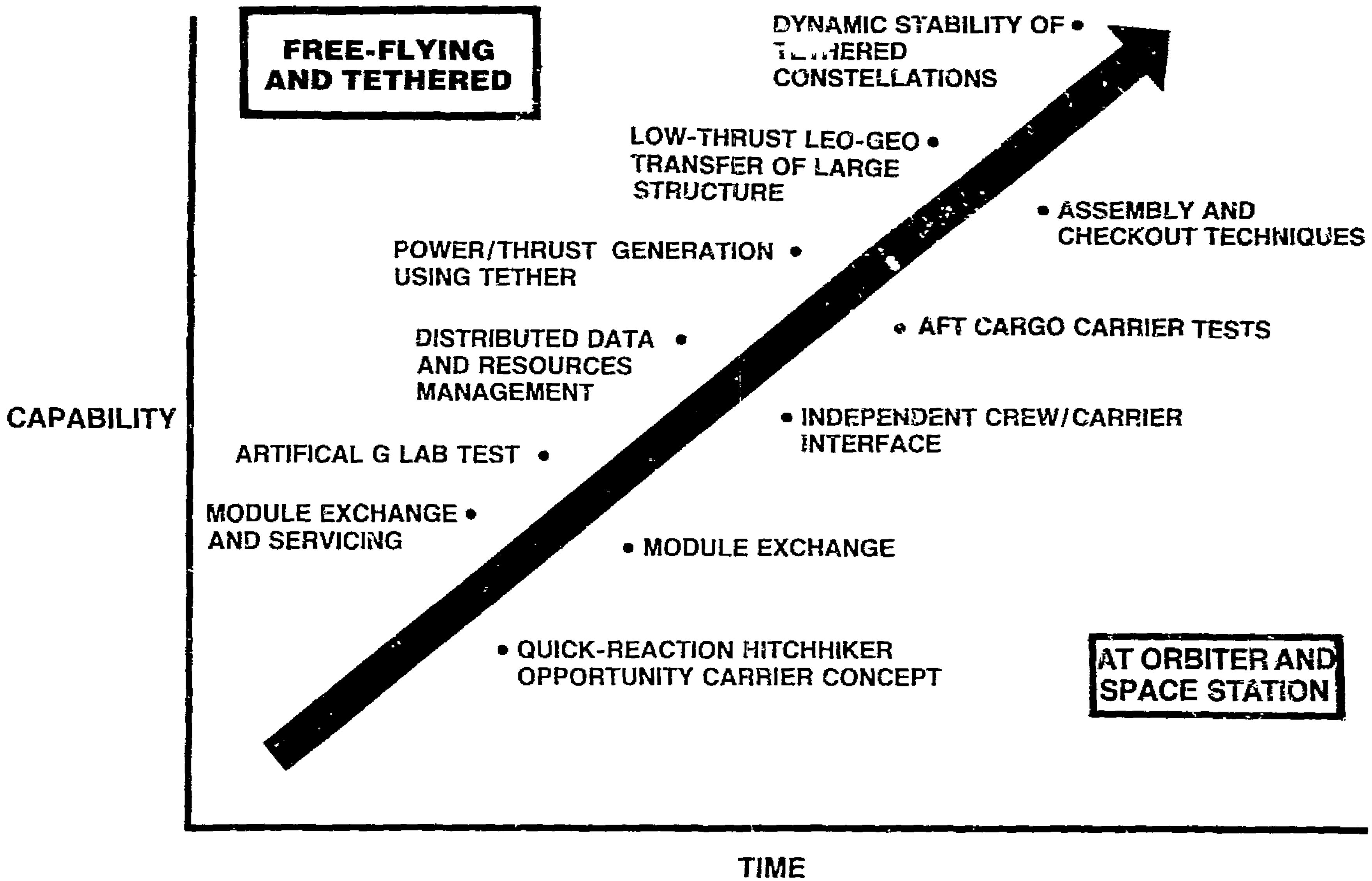
a. Satellite Services at the Orbiter

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. The planned evolution of those capabilities is illustrated in Figure IV-12.

The orbiter-mounted Remote Manipulator System (RMS), Manned Maneuvering Unit, integrated space suit and backpack called the Extravehicular Mobility Unit, and early tools for extravehicular activities provide an initial capability for placement and limited retrieval of satellites. The RMS already has proven its ability to perform those functions successfully by placing and retrieving the SPAS-01 platform during the Shuttle's seventh flight. All those systems are to be used during the Shuttle's eleventh flight to conduct the Solar Maximum Mission repair mentioned earlier under Satellite Services Flight Experiments and Demonstrations. 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 (mechanical hands) for the RMS, a remote work station called the Manipulator Foot Restraint mounted to the free end of the RMS arm, television systems, and equipment for assembling and providing support to large structures.

FIGURE IV-11

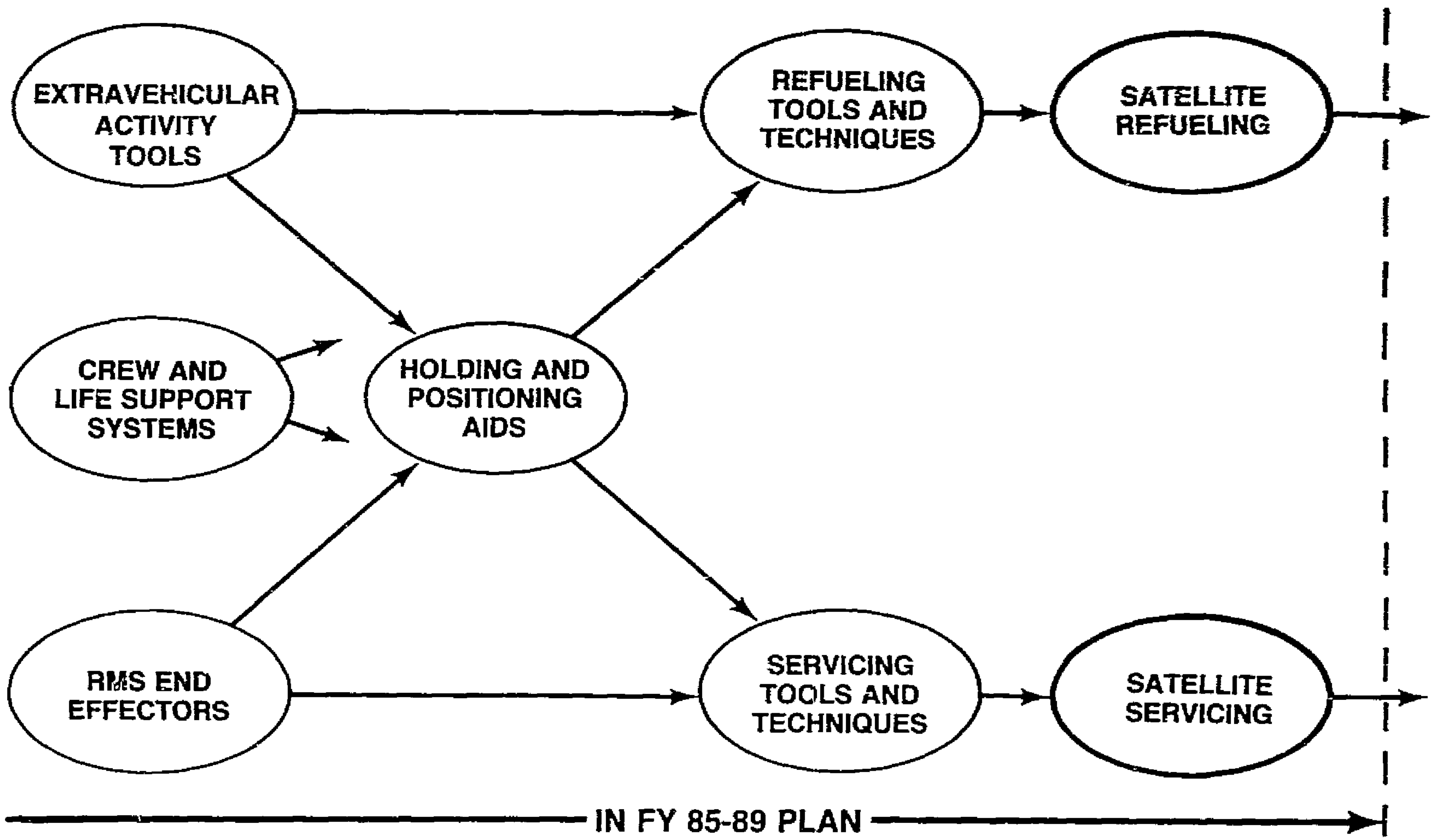
FLIGHT EXPERIMENTS AND DEMONSTRATIONS — PLATFORMS AND CARRIERS



GEO = GEOSYNCHRONOUS ORBIT
LEO = LOW EARTH ORBIT

FIGURE IV-12

SATELLITE SERVICES EVOLUTION AT THE ORBITER



By the early 1990s, the Orbital Maneuvering Vehicle equipped with special front-end kits should be able to retrieve nonstabilized satellites and debris near the orbiter. Selective deorbiting of space debris by the Orbital Maneuvering Vehicle would free vital "space lanes" of unwanted and dangerous debris.

Other needed capabilities will be provided by advanced development, currently in process, of proximity sensors and force-torque systems for "smart," highly capable end effectors for the RMS and of orbital refueling systems with standardized quick-disconnect valves.

b. Satellite Services Remote From 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. The space station also will require those greater capabilities to function as an operational center for satellite servicing. The principal element in plans for providing those greater capabilities is development of the Orbital Maneuvering Vehicle. That development will benefit considerably from experience gained a few years ago in connection with 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 mid 1990s of the use of an Orbital Maneuvering Vehicle service module teamed with an upper stage to service a satellite or platform in geosynchronous orbit.

Figure IV-13 shows the evolution of capabilities for providing satellite services remote from the orbiter and space station.

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 that attitude, 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 extravehicular activity. Therefore, NASA must institute a series of demonstrations with the Shuttle that will be highly visible and technically meaningful to STS users.

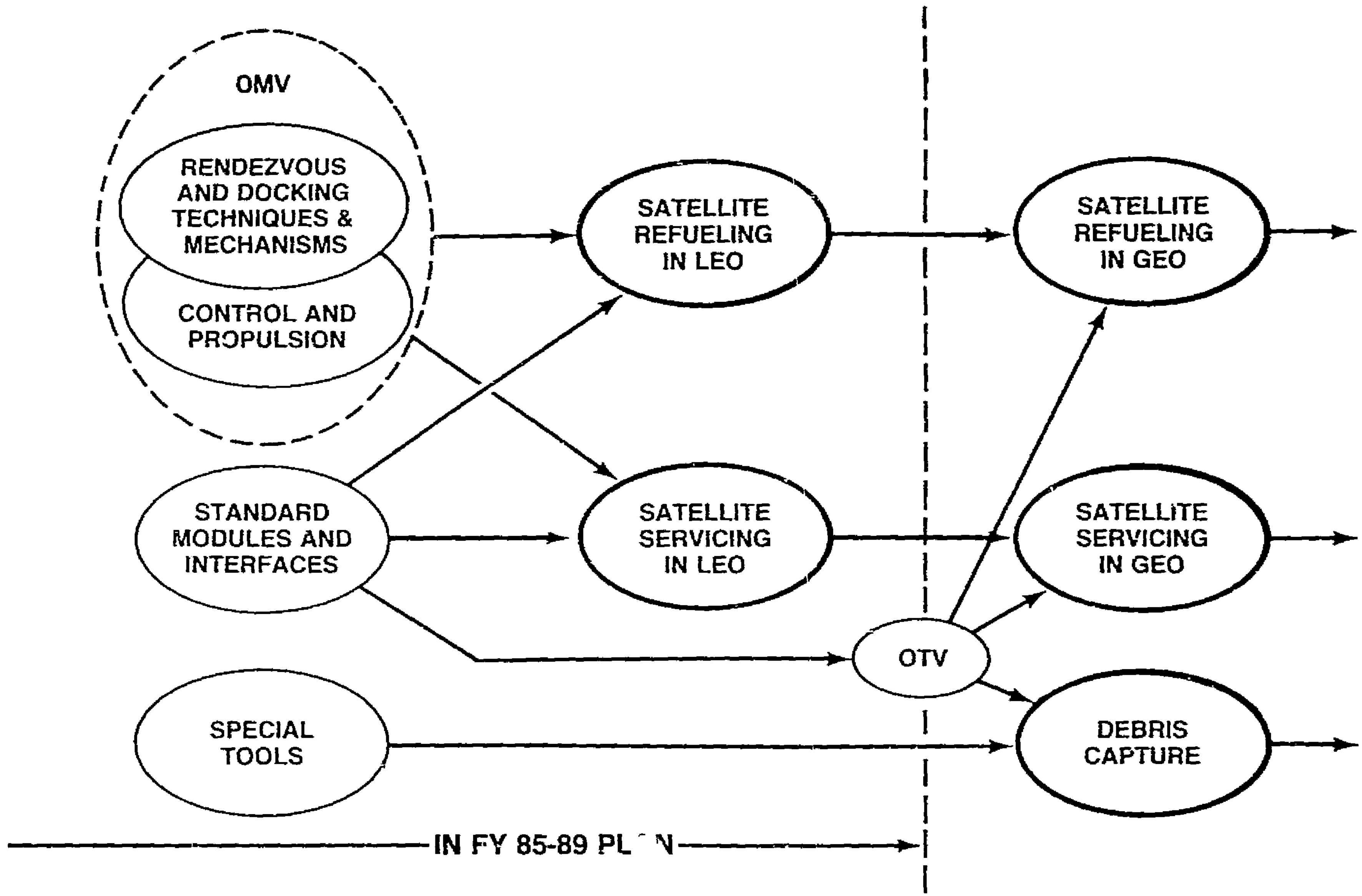
The flight experiments program described earlier under New Initiatives will meet that need. Satellite servicing demonstrations currently approved for flight are the Solar Maximum Mission repair and the Orbital Refueling Demonstration. Figure IV-14 shows an example of an evolutionary line of flight experiments dedicated to development of satellite services capabilities.

4. Advanced Transportation

Payload sizes and functions are expected to increase to improve the performance and effectiveness of users' missions. For example, as discussed

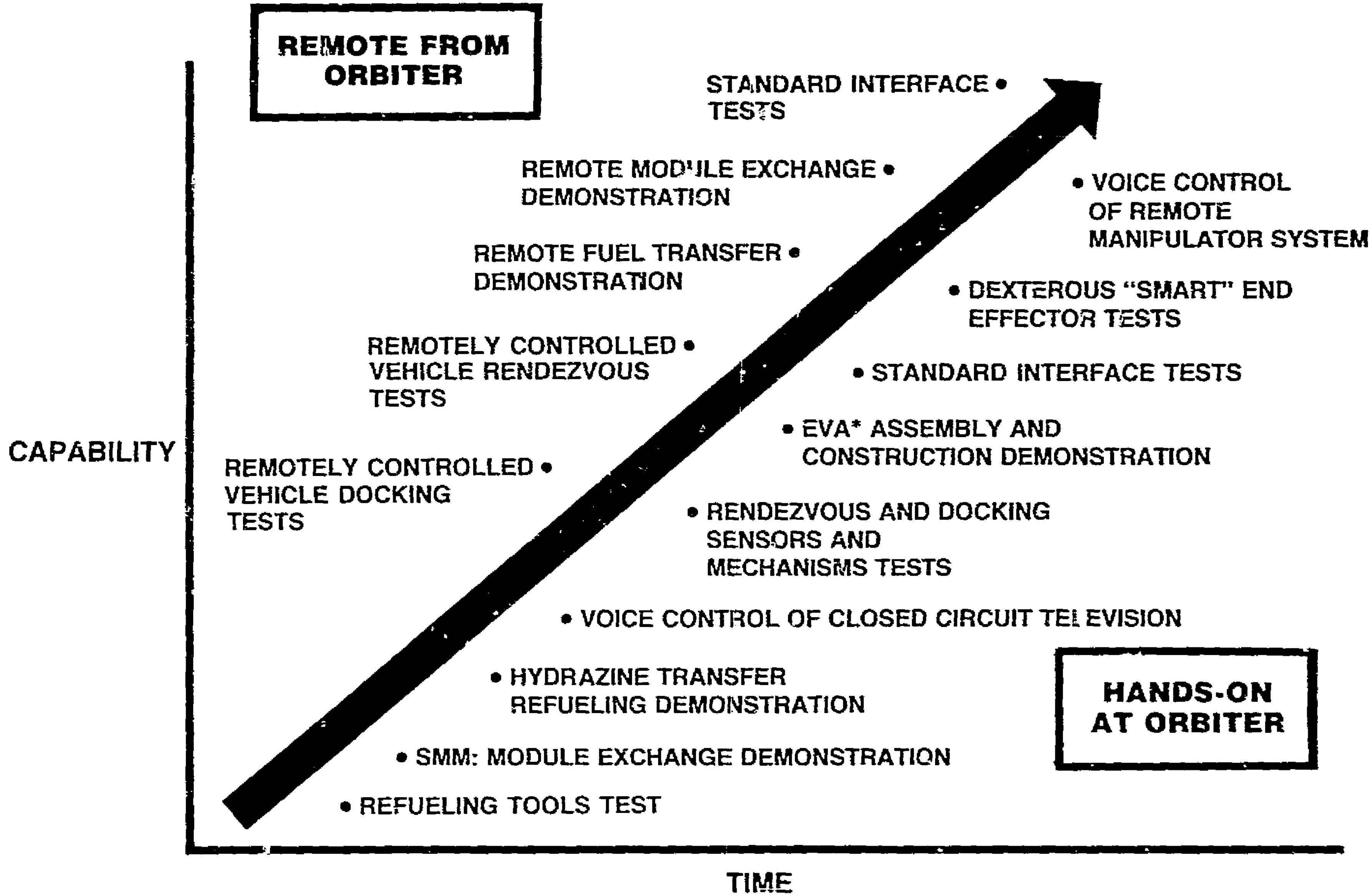
FIGURE IV-13

SATELLITE SERVICES EVOLUTION REMOTE FROM THE ORBITER



GEO = GEOSYNCHRONOUS ORBIT LEO = LOW EARTH ORBIT OTV = ORBITAL TRANSFER VEHICLE

FIGURE IV-14
FLIGHT EXPERIMENTS AND DEMONSTRATIONS — SATELLITE SERVICES



* EXTRAVEHICULAR ACTIVITY

earlier under Geostationary Platform, large communications satellites and platforms will permit aggregation of functions, thereby decreasing service costs and relieving the current trend toward overcrowding of the geostationary orbit arc. Those satellites and platforms can be expected to 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

The expected evolutionary trend of transportation from Earth to low Earth orbit is displayed on Figure IV-15.

(1) Aft Cargo Carrier

Studies are under way of a possible near-term modification called the Aft Cargo Carrier to provide the Shuttle with more volume to carry 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 to carry payloads or propulsion stages. It would double the payload volume while leaving the orbiter cargo bay free for other payloads and would place virtually no penalty on payload weight. It also could take advantage of expected increases in the STS' lift capability to 32,000 to 36,000 kilograms without requiring redesign of the orbiter's structure and landing gear.

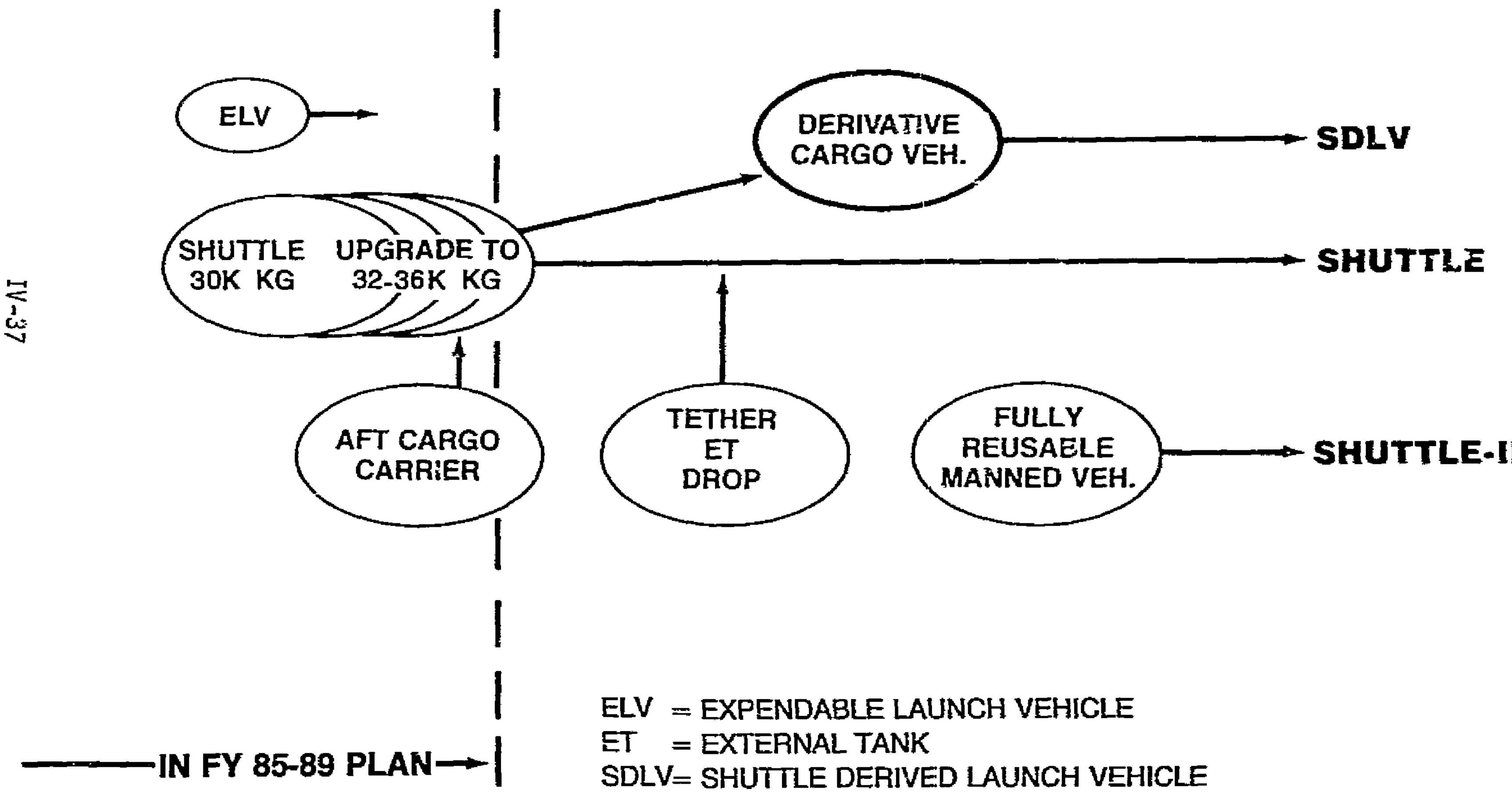
(2) Shuttle-Derived Launch Vehicle

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 use STS hardware and facilities to the extent possible but would be unmanned and, therefore, would not need to incorporate the orbiter itself. Most of the configurations that have been considered 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, the degree of promise depending very strongly on the requirements and uses assumed.

Studies of two of the most promising configurations are in process, with emphasis on identifying supportable applications. One of the configurations uses three Shuttle main engines and has a payload canister alongside the external tank in the position normally occupied by the orbiter. The Shuttle main engines would be recovered in a reentry pod with parachutes. The other configuration has one to three Shuttle main engines in a recoverable pod behind the external tank, and positions the payload ahead of and in line with the tank. A variant of one of these configurations will be studied for its potential use as a tanker to refuel the space-based Orbital Transfer Vehicle described below with cryogenic fuel.

FIGURE IV-15

ADVANCED TRANSPORTATION EVOLUTION — EARTH TO LOW ORBIT



Major studies planned for the near future will expand understanding of the potential requirements for and the capabilities of those launch vehicles and of ones able to deliver even larger and heavier cargoes. Further activity then will depend on the outcome of those studies.

b. Low Orbit to Geostationary and Other High-Energy Orbits: Orbital Transfer Vehicle

The evolution of advanced transportation from low Earth orbit to geosynchronous and other high-energy orbits is shown schematically in Figure IV-16. 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 will become necessary to facilitate use of the space station as a major transportation node in the 1990s.

The Orbital Transfer Vehicle will be a reusable, high-performance upper stage intended to be based mainly at and launched from the space station. Most of its civil payloads are expected to have destinations at geosynchronous orbit, but some will be Earth-escape spacecraft. Department of Defense payloads generally will be targeted to geosynchronous and other high-energy orbits. Preliminary studies have indicated that space-based orbital transfer vehicles may provide drastically lower costs than the STS Centaur will be able to provide for transportation to geosynchronous and other high-energy orbits. Large, reusable, cryogenic orbital transfer vehicles will be needed in the next 20 years to place heavy payloads such as large communications platforms into geosynchronous orbit; and a low-thrust version will be needed to reduce deployment accelerations imposed on large structures.

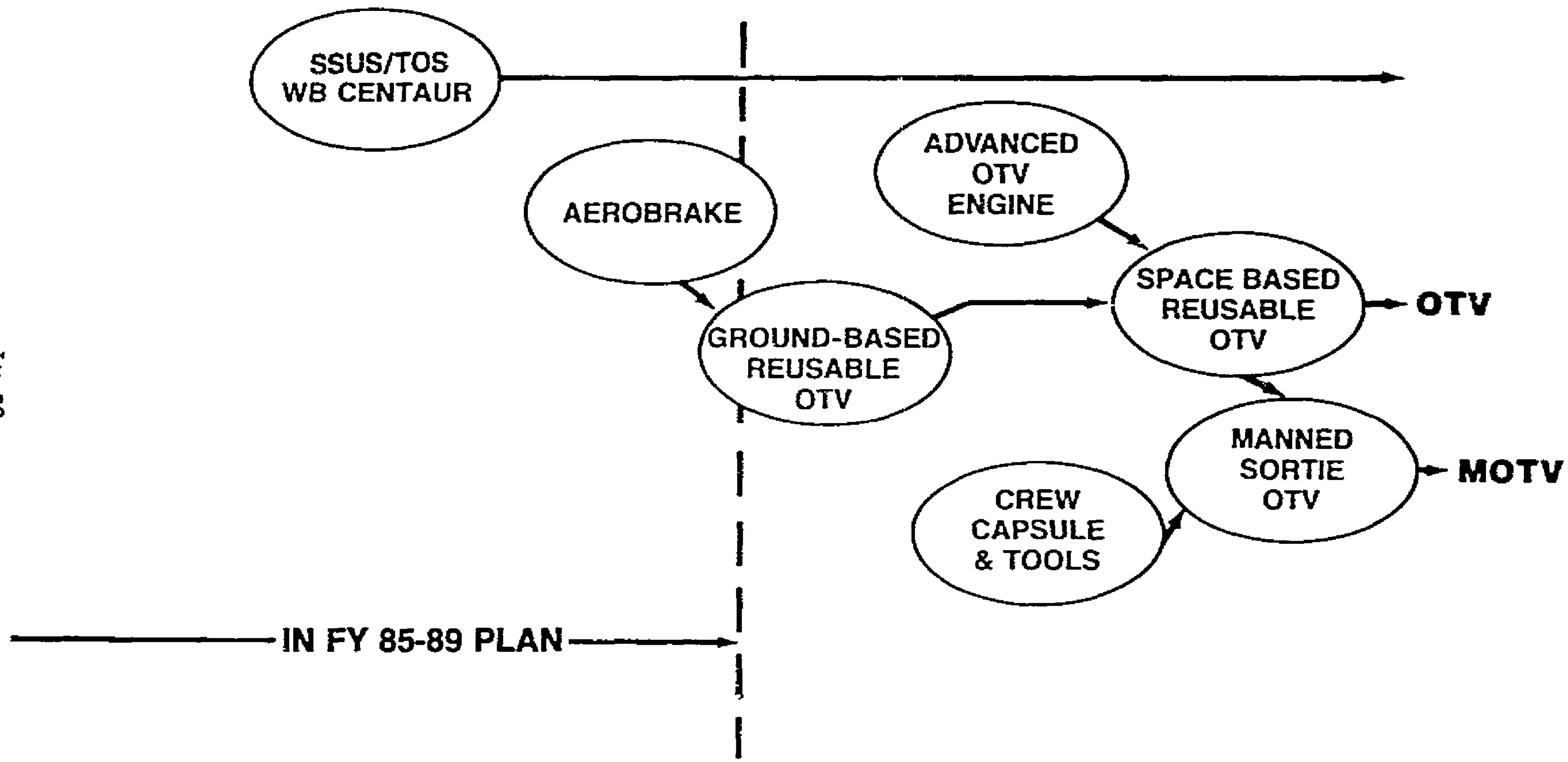
Upcoming studies will examine a new concept called the ACC-OTV that calls for the Orbital Transfer Vehicle to be transported to space in the Aft Cargo Carrier described above. The concept appears readily adaptable to yield a space-based vehicle with a capacity for as much as 34,000 kilograms of propellant, which would be adequate for boosting manned spacecraft to geosynchronous orbit. Studies also are planned of new configurations for orbital transfer vehicles specifically designed to be based in space.

Upon return to Earth orbit, a reusable orbital transfer vehicle must decelerate 2,400 meters per second to achieve orbit circularization. Consequently, use of aerodynamic forces for braking is being contemplated. The vehicle can halve its propellant use on its return trip by deploying an aerodynamic drag device (aerobrake) at high altitude.

The preceding discussions indicate that the use of the Shuttle and the space station as test beds would be highly desirable for reducing the costs and risks of flight experiments and demonstrations in developing advanced transportation capabilities. Some tentative, higher-priority technology milestones for such flight experiments and demonstrations are shown on Figure IV-17. For transportation from Earth to low Earth orbit, those experiments would be concerned with the Aft Cargo Carrier concept, the use of Shuttle solid rocket boosters for carrying Hitchhiker payloads to make high-altitude soundings during the boosters' reentry and return, and an understanding of

FIGURE IV-16

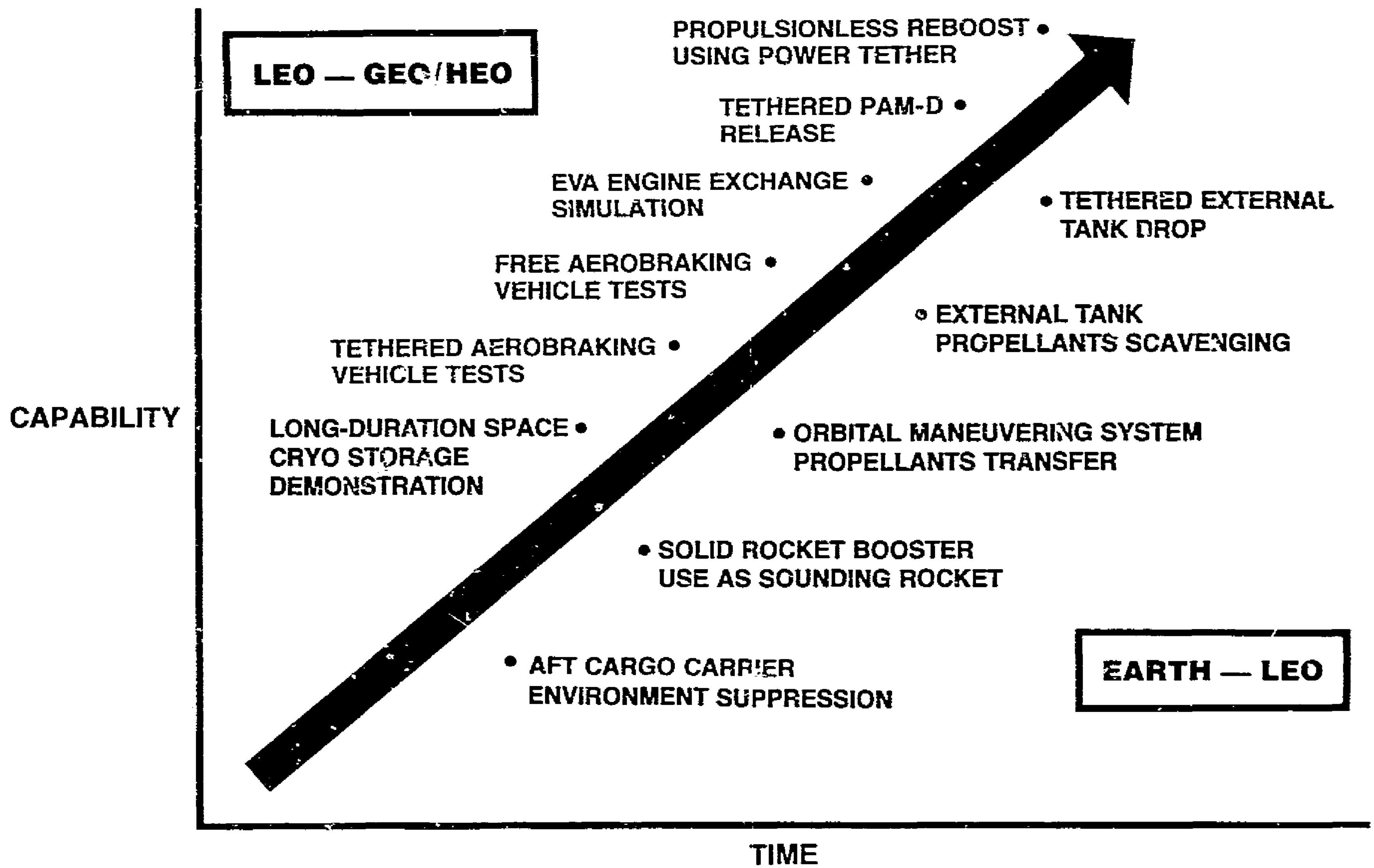
ADVANCED TRANSPORTATION EVOLUTION — LOW ORBIT TO GEOSTATIONARY AND OTHER HIGH ENERGY ORBITS



MOTV= MANNED ORBITAL TRANSFER VEHICLE
OTV = ORBITAL TRANSFER VEHICLE
SSUS= SPINNING SOLID UPPER STAGE
TOS = TRANSFER ORBITAL STAGE
WB = WIDE BODY

FIGURE IV-17

FLIGHT EXPERIMENTS AND DEMONSTRATIONS — ADVANCED TRANSPORTATON



EVA = EXTRAVEHICULAR ACTIVITY
GEO = GEOSYNCHRONOUS ORBIT
HEO = HIGH-EARTH ORBIT
LEO = LOW EARTH ORBIT
PAM-D = PAYLOAD ASSIST MODULE, DELTA CLASS

propellant transfer that eventually could lead to scavenging fuel from the external tank. For transfer from orbit to orbit, demonstrations may 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 advanced uses of space tethers, and extravehicular activity maintenance of propulsion systems.

Space Station

V. SPACE STATION

CONTENTS

FIGURES

V. SPACE STATION

A. Goals and Objectives

One of the Agency's eight current goals is to "establish a permanent manned presence in space to expand the exploration and use of space for activities which enhance the security and welfare of mankind." That goal flows from the national policy for space, which calls for maintaining U.S. leadership in space and exploiting the economic and scientific benefits of space. Since May of 1982, the focus of planning activities to achieve that goal has been the Space Station program.

The goals of the Space Station program are to:

- Establish means for the permanent presence of people in space
- Provide space-based facilities that will enable routine, continuous use of space for activities related to science, applications, technology development, commercial exploitation, national security, and space operations
- Develop and exploit the synergistic effects of the human-machine combination in space
- Provide system elements and operational practices essential for achieving an integrated national space capability
- Reduce the cost and complexity of living in and using space.

The program's near-term objectives are centered on identifying and synthesizing mission requirements for a civilian space station and on iterating a set of functional capabilities for the station (see Figure V-1). In addition, technology and advanced development programs are being initiated to ensure the readiness of options for key technologies. Current plans call for a two- to three-year definition phase beginning in FY 1985, leading to initiation of a design and development phase in FY 1987 and an initial operational capability in the early 1990s.

B. Planning Guidelines

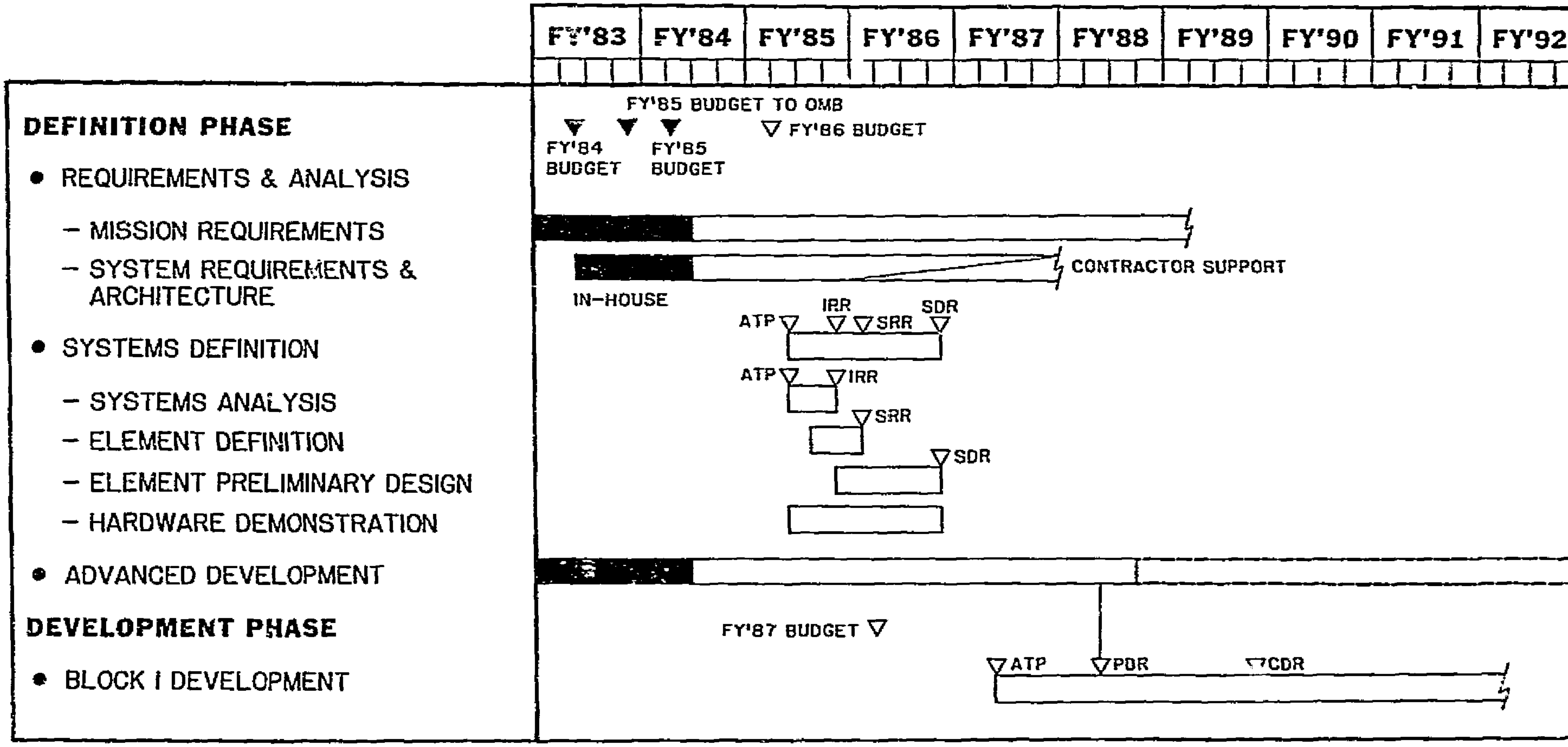
Many significant aspects of the Space Station program make it unique compared with major programs of the past and, taken together, have dictated a set of planning guidelines (boundary conditions) that have governed the program activities. The principal ones follow.

1. User Community Involvement

To meet the program's goals and maintain consistency with national space policy, NASA has made a concerted effort to involve all the space station's potential users in the planning for the station. Potential users include the science and applications communities, aerospace industry, a broad spectrum of commercial organizations, and technology development and international organizations. User needs will constitute a continuously changing and growing spectrum of requirements that must be refined, updated, and accommodated

FIGURE V-1

SPACE STATION PLANNING SCHEDULE



ATP – AUTHORITY TO PROCEED
CDR – CRITICAL DESIGN REVIEW
IRR – INTERFACE REQUIREMENTS REVIEW
PDR – PRELIMINARY DESIGN REVIEW
SDR – SYSTEM DESIGN REVIEW
SRR – SYSTEM REQUIREMENTS REVIEW

continuously and in a phased manner to achieve the best balance among resources, capabilities, and technology readiness.

2. Extensive Definition Before Program Initiation

One of the major conclusions of NASA's 1981 Project Management Study (the Hearth Report) was that a thorough project definition should be conducted before system development is undertaken. The space station program plan calls for an extensive two- to three-year definition phase including intensive inhouse concept development followed by an extended contract definition activity. The inhouse definition work will improve the Agency's ability to be a capable buyer and lay a foundation for its systems engineering and integration activities.

3. Agencywide Participation

The Space Station program is to be more than an extension of previous spaceflight programs. Its planning has involved all NASA installations through their representation on the Space Station Task Force and its working groups, and the breadth of the program provides the potential for the substantive involvement of all installations in subsequent phases. The success of the program will depend critically on both the contributions of the science and applications communities in NASA and the technologies developed by the NASA research centers.

4. Evolution

Before development of the Space Transportation System, NASA's programs provided systems with limited evolutionary capability. "Permanent presence," however, inherently calls for a program spanning decades that must be designed to accommodate evolutionary growth through incremental addition, modification, and replication. To ensure that a space station's useful life is not short, the station must be able to evolve not only in size, but also in technology. Planning also must consider manned operations above low Earth orbit. A properly planned station will serve as the foundation for the succeeding major step, be it manned operations at geosynchronous orbit, a lunar base, a sample return or manned mission to Mars, or some other mission beyond Earth orbit such as the mining of precious resources from asteroids.

5. Maintainability and Restorability

For the space station to have a true operational capability, its elements must be maintainable and, in event of failure, restorable to operational effectiveness in orbit. Cost-effective operation by a system with so long a lifetime will depend on replacement of single mission, multiple redundancy design by a system providing subsystems that can be maintained routinely and are inherently restorable in space.

6. Operational Autonomy

Even the initial configuration of the space station should be able to operate as independently as possible. A station ideally would operate autonomously except for resupply of materiel and personnel. NASA would retain operational control, but nongovernment personnel would be expected to use the station to perform scientific observation and manufacturing tasks.

7. International Participation

In his 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. Many of NASA's long-standing cooperative partners have expressed interest in participating in space station planning, development, and use. The European Space Agency, Canada, Japan, France, Germany, and Italy have conducted, at their own initiative and expense, mission analysis studies paralleling NASA's. In addition, they are examining what part they potentially could play in the program. The scope and complexity of a space station is great, and the international community's early involvement has provided a good basis for developing a successful cooperative program.

8. Department of Defense (DOD) Cooperation

NASA has kept DOD fully informed of its activities. Also, DOD has participated, with limited funding, in mission requirements studies. However, it has not as yet identified any requirements for a manned space station.

9. Modularity, Commonality, and Evolutionary Nature

Several unique aspects of the space station program promise new approaches that will reduce costs and impose few weight and configuration constraints on the station compared with those on past space systems. Many space station elements will have subsystems in common with other elements. Modularity and the use of common hardware promise to lower overall costs. Further, the Space Station program's evolutionary nature should allow development, testing, and upgrading of new systems and components in an operational setting, eliminating the need for some of the ground qualification testing currently necessary.

10. Proper Mix of Humans and Machines

Experience in the Skylab program and many studies have demonstrated the utility that human capabilities will have in a space station system. However, many potential missions could be performed best by automated, free-flying spacecraft, with only periodic human intervention by means of remote "telepresence." A major objective of current planning activities is to define the proper mix of humans and machines in a space station setting so that necessary tasks will be distributed properly and machines and humans will enhance each others' capabilities.

C. Mission Requirements

During its first year, the Space Station Task Force applied its activities almost exclusively to identifying potential mission requirements rather than to the configuration of, or the elements that would constitute, a space station. The initial main focus of the mission requirements phase of the program was eight studies contracted to major aerospace corporations in August 1982. The study contractors were given little specific direction. Instead, they were encouraged to explore imaginatively all aspects of potential uses for a space station. Their final reports, received in April 1983, were generally consistent in their conclusions and recommendations. The principal recommendations were for an initial station consisting of a manned base and an unmanned platform at an orbital inclination of 28.5°; an Orbital Maneuvering Vehicle operating in conjunction with the station; and an unmanned platform that would be derived from the space station design, operate at a polar or near-polar orbit inclination, and be serviced by the Shuttle.

A Space Station Mission Synthesis Workshop held in May 1983, with participation by NASA, the National Oceanic and Atmospheric Administration, the U.S. Air Force, and industry, examined the findings of the mission requirements studies, the results of inhouse studies, and reports from advisory committees. The Workshop established a computerized data base and defined a preliminary set of 107 types of phased space station missions for the period 1991 to 2000 in the fields of science and applications, technology development, and commercial applications. The baseline requirements established for the initial mission set included a manned element at an orbit inclination of 28.5° and two platforms, one at low inclination and one in polar orbit, as recommended by the mission requirements studies. The power required by users of the station appeared to be the most stringent resource requirement.

D. Concept Development

In April 1983, the Concept Development Group was formed as an arm of the Space Station Task Force to orchestrate tradeoff studies and integrate the results of the 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 on 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 the final iteration is planned for completion just before initiation of system definition. This iterative process will provide a thorough and extensive system definition based on the most current mission sets, functional capabilities, and budget plans.

An approved configuration for the space station does not exist. The concept currently under consideration for the station will provide functional capabilities represented by the following elements, although some of them could change:

- Living quarters module
- Berthing and assembly module
- Logistics module
- Resources module
- Laboratory module
- Unmanned platform at orbital inclination of 28.5°
- Unmanned platform at orbital inclination of 90°

- Orbital Maneuvering Vehicle

- Servicing System.

E. Advanced Development Program

Before creating the Space Station Task Force, NASA formed the Space Station Technology Steering Committee to assess technologies relevant to a space station for the 1990s. The Steering Committee concluded that a station using state-of-the-art technology would not meet program goals because it would not have affordable growth potential and because an indefinite life for it through in-orbit maintenance would not be cost effective. The Steering Committee also identified technology advances that would be necessary for the station to meet its goals. In FY 1983 a major workshop reviewed the technologies available and in process in NASA'S program and in industry research and development programs relevant to a space station.

On the basis of those activities, a space station advanced development program has been planned to provide the advanced technologies needed for an evolutionary station. Test beds will be used in key technology areas such as power, life support, and data management to support the research and testing required to develop the options identified for potential use in development of the space station.

To coordinate the advanced development program, the Space Station Task Force is working out agreements with the relevant program offices. The nature of the relationships between the Task Force and the program offices for this advanced development program is illustrated in Figure V-2.

An important part of the advanced development program is its integration with system definition activities. Definition contractors will be involved in the advanced development program through both their definition contracts and the NASA test beds. The proposed approach is to include selection criteria, tasks, and funding in the requests for proposals for the system definition contracts to encourage contractors to develop advanced technologies they believe are needed for the space station to meet its goals. As much as 30 percent of system definition phase funding may be allocated for that purpose. In addition, NASA's test beds will be available to the contractors for testing advanced technology ideas. A schedule has been developed for announcing these plans to industry, working out agreements for use of NASA's test beds, informing contractors of the status of development of the test beds, and reviewing contractors' progress in advanced technologies.

A major milestone and decision point will occur at the end of the definition phase when NASA reviews the progress of the advanced technology development and selects the technologies for the development phase.

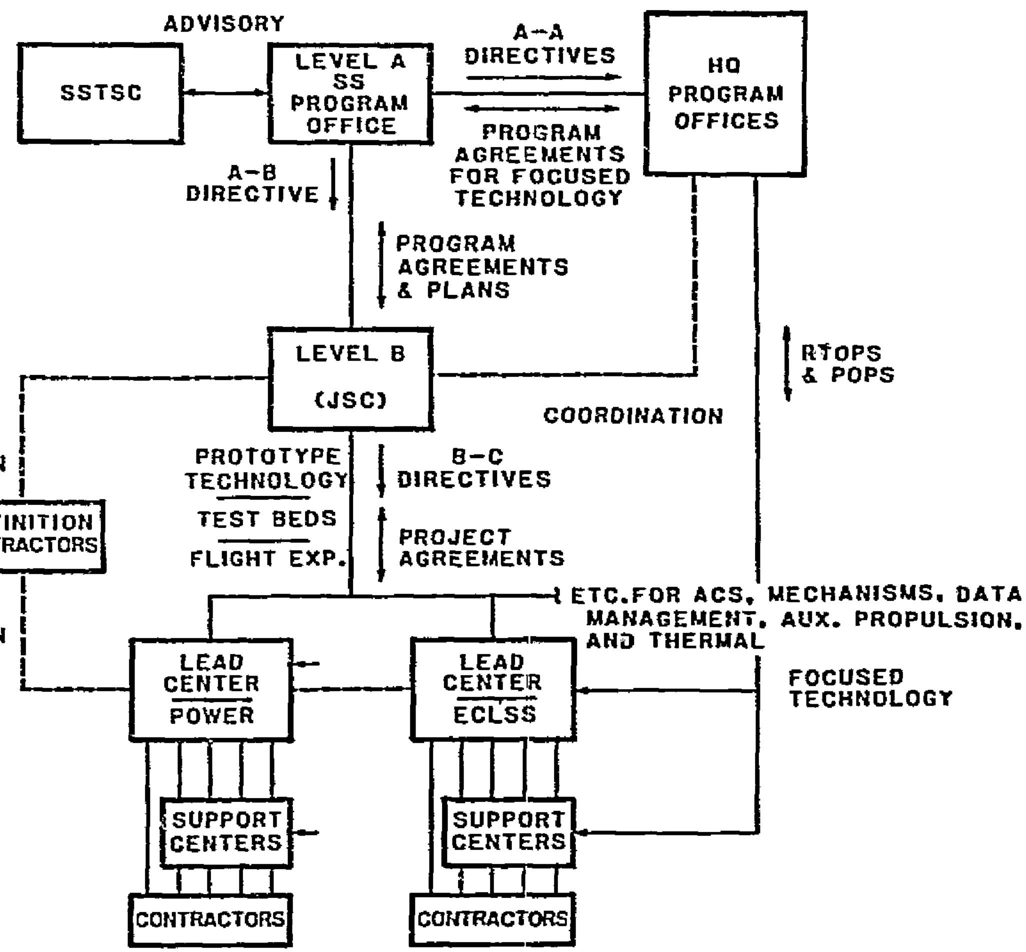
F. Definition Program Logic

The definition program has four major components: supporting studies, systems definition, advanced development program, and technology. Those four components evolve into the system development phase.

FIGURE V-2

SPACE STATION ADVANCED DEVELOPMENT PROGRAM

MANAGEMENT RELATIONSHIPS



NOTE: FOR DEFINITIONS OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X.

The principal emphasis of the supporting studies component is early and continuous involvement of users in the derivation of all program activities. Work under the definition contract must focus initially on a concept for the total system through the year 2000 before progressing to detailed definition of elements of the system. Subsequent definition efforts will begin as initial elements of the station enter the development phase.

As indicated in the preceding section of this chapter, success for the definition program is highly dependent on efficient interaction between it and the advanced development program for the station. Both ground-based and space-based test beds are planned and are expected to play a vital role in subsequent definition of evolutionary elements. The test beds will serve as a conduit through which NASA's technology will be channeled into the definition efforts, and incentives for their use will be included in the definition contracts. A valuable result is expected to be reduction in program cost and risk through increased insight into design details through demonstration of hardware.

Space Tracking and Data Systems

VI. SPACE TRACKING AND DATA SYSTEMS

CONTENTS

FIGURES

VI. SPACE TRACKING AND DATA SYSTEMS

A. Function

The primary function of the Space Tracking and Data Systems 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. It includes three basic elements: a space network, ground networks, and communications and data systems. The fourth basic element of the program is development of advanced systems. The program also must provide responsive management of NASA's operational and program support communications and of its radio frequency spectrum allocation activities.

B. Major Objectives

The program's most important objective concerns the space network. It is to complete, and have ready for operation in 1985, the Tracking and Data Relay Satellite System (TDRSS), including the spacecraft, the ground systems at White Sands, and the ground system at Goddard Space Flight Center. The program then must operate and maintain the TDRSS throughout its useful lifetime.

The major objective of the ground network portion of the program, which currently consists of the Deep Space Network and the Satellite Tracking and Data Network, is to provide tracking of and data support for all current and approved missions until the support of missions in low Earth orbit becomes the function of the TDRSS. Within the following year, NASA will phase out operation of unneeded stations and consolidate the remaining stations into one ground network under Jet Propulsion Laboratory management to support deep-space missions and missions in high Earth and geostationary orbits, as well as certain missions currently in low Earth orbit.

Other important objectives 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 Continue support for Spacelab data processing and Space Telescope mission control

- o Improve and increase the efficiency of NASA's program-support communications
- o Plan for a follow-on system for the TDRSS.

C. Plans for Program Elements and Mission Support

1. Space Network

NASA's tracking and data acquisition facilities related to spacecraft in near Earth orbit will evolve in the mid 1980s from a network of ground tracking stations located around the world into a network of two TDRSS satellites in geostationary orbit, an in-orbit spare, and a single ground terminal at White Sands, New Mexico. The contractor, Spacecom, owns and operates the system and, in accordance with the TDRSS contract, will provide NASA with leased support services for 10 years of system operation. NASA has collocated a ground terminal to interface with the TDRSS ground terminal at White Sands and has constructed a network control center at Goddard Space Flight Center to control the system and manage network resources. The system will achieve extensive coverage of near Earth orbits, 85 percent compared with the present 15 percent. Therefore, a majority of ground stations can be phased out and user space systems, including the Space Shuttle, Spacelab, and 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.

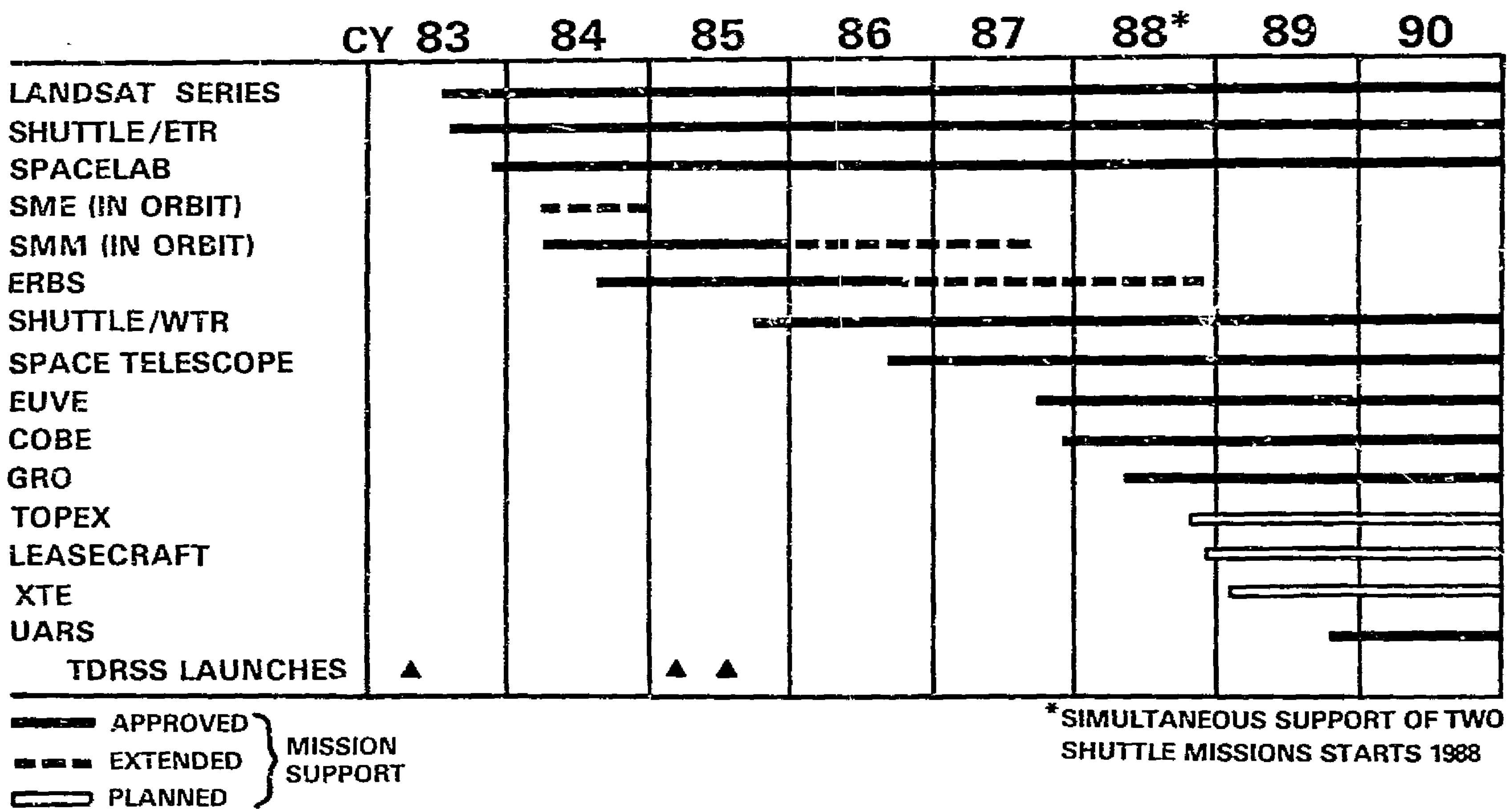
2. Ground Networks

While phasing TDRSS into operation, NASA will close nine more ground stations, leaving only the six locations shown in Figure VI-2 fully operational. Collocated facilities of the satellite network and the deep-space network at Canberra (Australia), Goldstone (California), and Madrid (Spain) will be consolidated under Jet Propulsion Laboratory management to gain the resulting technical and economic advantages. A central signal-processing center will be established at each of those sites. Those centers will be able to array their large antennas into various combinations, thereby improving the flexibility with which satellite missions can be supported and increasing performance for planetary missions. Both the transition to TDRSS of support for satellites in near Earth orbit and the consolidation of the two ground networks will cause the level of activity for the Space Tracking and Data Systems program to increase through 1985. Mating network activities to the needs of NASA's programs is 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 that would not be compatible with TDRSS. The principal early improvements planned for the network are described in the paragraphs that follow.

For the telecommunications needs of the Venus Balloon Experiment and the Pathfinder missions, the 64-meter antenna sites of the ground network will be provided a capability for receiving L-band signals.

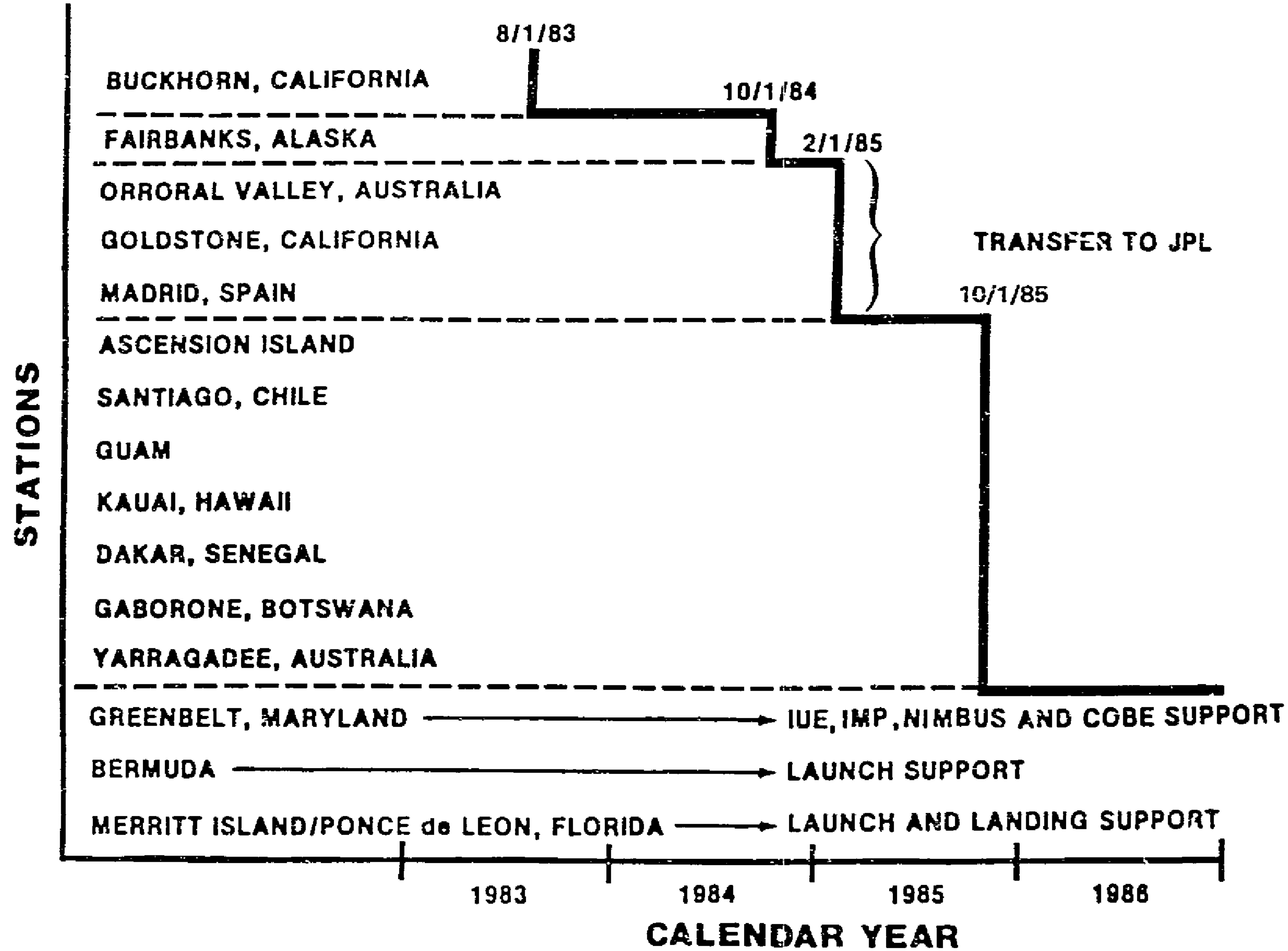
FIGURE VI-1

SPACE NETWORK — MAJOR MISSION SUPPORT PLAN



NOTE: FOR DEFINITIONS OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X

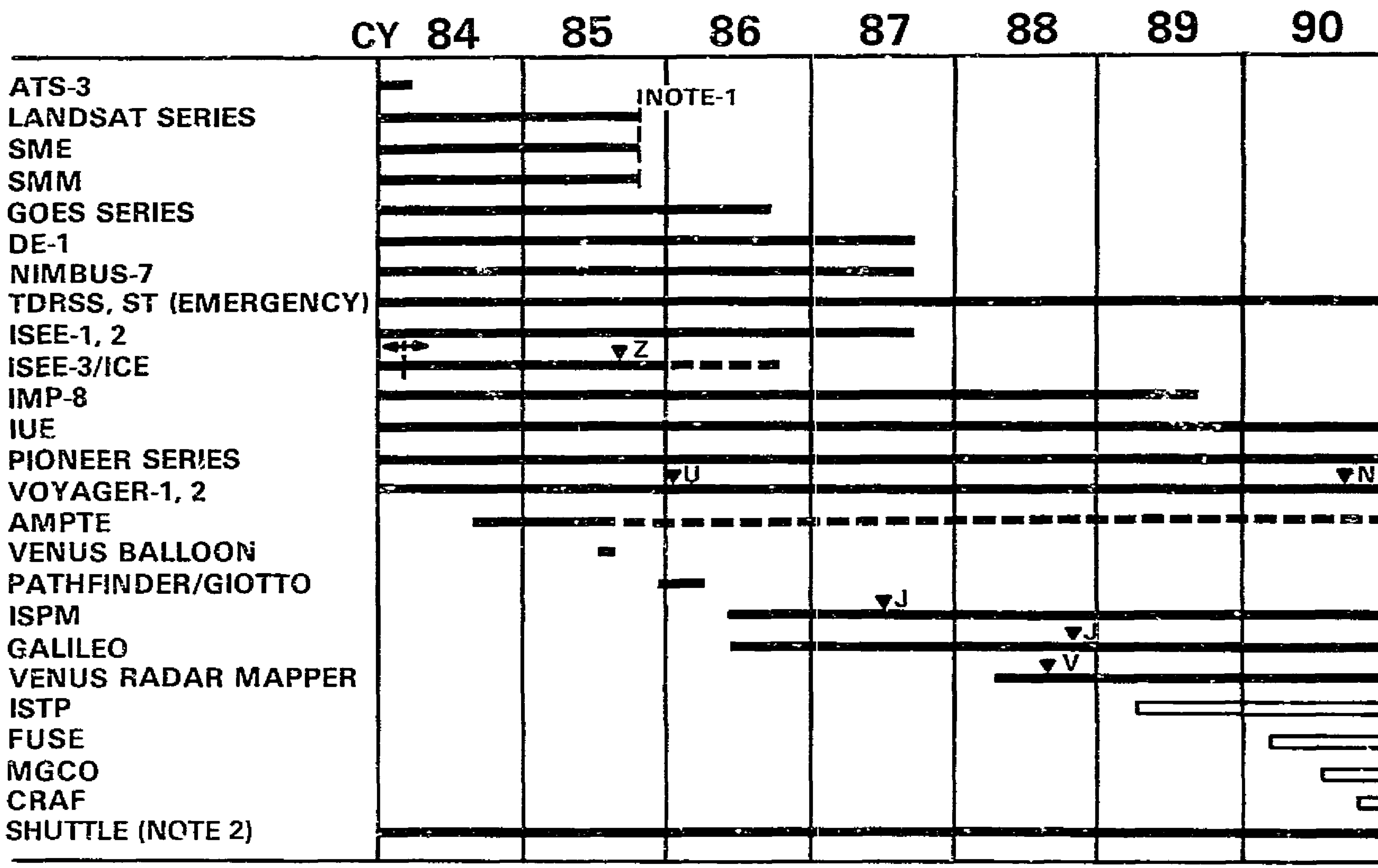
FIGURE VI-2
GROUND NETWORK STATION OPERATIONS TERMINATION PLAN



NOTE: FOR DEFINITIONS OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X

FIGURE VI-3

GROUND NETWORK — MAJOR MISSION SUPPORT PLANS



NOTES:

1. BEGIN FULL SUPPORT BY TDRSS.
2. TRANSFER TO SUPPORT BY CONSOLIDATED NETWORK
   STDN STATION CLOSURES: GOLDSTONE, MADRID, AUSTRALIA

LEGEND:

PLANNED

SUPPORT MAY EXTEND

▼ ENCOUNTER (J — JUPITER,
V — VENUS, U — URANUS,
Z — GIACOBINA ZINNER
N — NEPTUNE)

NOTE: FOR DEFINITIONS OF ABBREVIATIONS AND ACRONYMS, SEE CHAPTER X

In 1986, when the Voyager 2 spacecraft will be nearly three billion kilometers from Earth, close to the planet Uranus, its received signal will be below the required threshold. The ground network will boost the signal by adding the signal received by the Australian 64-meter Parke radiotelescope to that received by the NASA ground network array at Canberra.

An X-band uplink command system to be added to the ground network about 1987 will provide several advantages to Galileo and later planetary missions. Because of the blackout effects of the solar corona, the current S-band system does not ensure that spacecraft at Jovian distances can receive commands over transmission paths within 15 degrees of the sun. The X-band system will reduce the blackout, which could last up to 30 days, to 3 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.

To sustain NASA's flight tests aboard sounding rockets, research aircraft, and balloons, the Space Tracking and Data Systems 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 Research Facility. The program includes developing a capability at Dryden for supporting multiple missions; providing tracking and data acquisition support to the National Scientific Balloon Facility at Palestine, Texas; consolidating Dryden, Moffett Field, and Crows Landing facilities under Dryden management; and improving the impact prediction system and fixed radar capabilities at Wallops.

3. Communications and Data Systems

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 be replaced to reduce downtime and maintenance costs; and more use will be made of microprocessors.

Within the next few years, mission control systems will be ready to control the operations of the highly interactive Space Telescope. In addition, the Space Tracking and Data Systems program will develop mission control systems for new spacecraft such as the Earth Radiation Budget Satellite, Upper Atmosphere Research Satellite, International Solar Terresterial Physics Program satellites, Gamma Ray Observatory, and Cosmic Background Explorer. The program also will increase automation of its control facilities and will support studies of the architecture of the space station's data system. By 1986, it will have completed a program-support communications network to provide NASA's 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 (kbps) or greater and limited video conferencing.

NASCOM already has incorporated a 56-kbps capacity into most of its circuits. To accommodate expected future requirements for even wider bandwidths, plans include digital voice circuits, bandwidths up to 224 kbps from overseas stations, greater use of fiber optics for local links to satellite ground terminals, and possibly direct Intelsat hop from network stations to the Jet Propulsion Laboratory.

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 development of 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 the state of its technology:

- o Increase in ability to communicate with spacecraft
  - K-band antenna with 34-meter diameter for deep space missions
  - Use of millimeter waves and optics for telecommunications
- o Greater navigation capability
  - Tracking of Earth-orbiting missions with decimeter precision
  - Measurement accuracy of 5 nano-radians for ground-based navigation
- o Operational improvements for ground stations and data handling and processing
  - More use of digital receiver design and custom VLSI (Very Large Scale Integration)
  - Unattended station operations and distributed command management
  - Autonomous spacecraft data handling, including a numerically controlled oscillator and onboard merging of sensor data with attitude, orbit, and time
- o Technology to facilitate TDRSS use by providing for user spacecraft:
  - Recorders with 20- and 150-Mbps capability
  - Second-generation transponder
  - Directive antennas.

5. Advanced Studies

a. Tracking and Data Acquisition System for the 1990s

The TDRSS is expected to meet the needs of the space program through the 1980s, but increases in data volume for missions planned for the 1990s will produce a need for new relay capabilities. The follow-on Tracking and Data Acquisition System being planned for the 1990s must provide more links; greater (gigabits) capacity; a relay-to-relay link, and direct, relay-to-ground, links. Studies already have examined the support needs of remote spacecraft, concepts for and the form of relays, and the role of new technology such as that for optical and millimeter-wave telecommunications.

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.

Space Research and Technology

VII. SPACE RESEARCH AND TECHNOLOGY

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TABLE

VII. SPACE RESEARCH AND TECHNOLOGY

The Space Research and Technology program is designed to satisfy the needs for space technology of the U.S. Government and U.S. industry consistent with NASA's resources and the long-range plans of the other NASA program offices. Its domain is technology with broad applicability not related directly to specific projects. It concentrates on long-term, high-risk research and technology development to provide the knowledge, opportunities, alternatives, and capabilities needed to satisfy 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. Goal

The program's goal is to conduct effective, productive, long-term research programs that contribute materially to continued U.S. leadership and security in space. That goal requires a commitment to advance the technology base supporting future national programs to conceive and design advanced spacecraft, continue building the technology foundation for improving low-cost access to space through Shuttle enhancements and orbital transfer concepts, support a permanent human presence in space by focusing technology that can make evolutionary growth of a space station possible, and support projected, long-term needs related to military and commercial use of space.

B. Objectives

The program is structured to support that goal with emphasis on maintaining a technically disciplined base of expertise, facilities, and knowledge and on generating advanced technology options. Its objectives are to:

- o Maintain NASA centers in positions of excellence in critical space technology areas, facilities, technical staff, and computational capability
- o Ensure timely provision of new concepts and advanced technology for U.S. civil and military space activities
- o Assure the appropriate involvement in the Space Research and Technology program by universities and industry
- o Assure the transition of timely research results to the U.S. aerospace industry
- o Provide development support to NASA's space flight projects and to space activities of other government agencies and U.S. industry.

1. Maintain Excellence in NASA Center Capabilities

The excellence of NASA's field centers in critical areas of space technology is an essential element in NASA'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 the Agency was established. To maintain and strengthen their technical capabilities requires continuous assessment of their personnel, facilities, and programs.

The most important factor in the excellence of the field centers is the competence of their technical staffs, maintained by ensuring that the mix and balance of skills match the center's assigned programmatic responsibilities and that the 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 creative production 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 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.

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 Technology program. It distributes the work of the Space Technology 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 university researchers. The priority research areas at the centers representing current emphases and possible future directions are listed below.

a. Research Centers

The research centers will continue to be sustained and strengthened as centers of excellence in fundamental space disciplines, with the emphases of each as indicated by the following objectives:

(1) Ames Research Center

- Maintain excellence in entry aerothermodynamics, thermal protection system materials, life sciences, and infrared detection systems

- Establish excellence in artificial intelligence, computer science and applications, and use of large scientific computers as research tools.

(2) Langley Research Center

- Maintain excellence in aerothermodynamics, materials, structures and their dynamics, remote sensing technology, atmospheric sciences, space electronics, control systems, data systems, and concepts and system analysis for space vehicles

- o Enhance excellence in teleoperation, robotics, and large space structures for antenna systems.

(3) Lewis Research Center

- o Maintain excellence in liquid-chemical and electric propulsion; communications systems, components, and devices; and space power systems, including photovoltaics, fuel cells, and energy storage devices

- o Enhance excellence in materials and structures for liquid rocket systems.

b. Space Flight Centers

To support flight development programs and operations, the space flight centers have developed expertise in the technology areas listed below. That expertise will be used and continually reinforced.

(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

- Software development
- Data management systems

(4) Marshall Space Flight Center

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

2. Ensure Timely Provision of New Concepts and Advanced Technology

A strong technology base is essential to the preeminence of the United States in space, and timely provision of technology is critical to the orderly development of new space concepts and mission capabilities. With primary responsibility for maintaining and expanding space research and technology, the Space Technology program is the sole or principal sponsor in some discipline areas. To provide a technology base for the space activities of NASA, industry, and the Department of Defense, it will continue to identify technology needs and to coordinate, review, and assess space technology work within and external to NASA. It will provide advanced technology for routine access to space, commercialization, and permanent space facilities. It also will provide a technology base for the project-related technology development conducted by the Space Science and Applications program.

3. Ensure Appropriate Involvement of Universities and Industry

To ensure the maximum rate of technology advancement and the widest use of the resulting products, participation by the most capable government, university, and industrial organizations is essential. An increase in that participation will be encouraged, and additional funding for that purpose is planned.

The Nation's universities are an important source of technical understanding, new concepts, and trained technical personnel for space research and technology. Currently 11 percent of the space research and technology budget goes to the universities, and an increase in that fraction is planned. For its centers-of-excellence objective, the Space Technology program will encourage the research centers to increase their cooperation with universities and university consortia, thereby creating "National Centers of Excellence." The program also will make special equipment grants to upgrade university equipment and will provide to the universities access to NASA's specialized equipment and facilities.

NASA's intent to increase university participation complements similar recent activities of other federal agencies. An ad hoc working group on scientific instrumentation convened by the National Research Council, a study by the National Science Foundation, and the Interagency Working Group on Scientific Instrumentation have concluded individually that modernization of instruments and equipment in university research laboratories is essential to the future research capability of the United States. They recommended that the federal government work with the research universities, industry, and other institutions to replace obsolescent and worn out instruments and equipment in university laboratories. In support, NASA is strengthening the university component of the Space Technology program, with emphasis on upgrading university research instruments and equipment that support NASA's technology objectives.

Increased participation of industry in space research and technology will be sought. The Space Technology program, with the assistance of private organizations on contract, will concentrate its inhouse resources on long-range, high-risk research and development; industry will be encouraged to take the lead in more mature technologies and to develop operating devices and systems. Those complementary activities will be coordinated, information will be exchanged, and mutual support will be achieved through bilateral and multilateral reviews of plans, industry Independent Research and Development, performance, and results. The outcome should be the best use of both government and industry resources.

4. Ensure Timely Transfer of Results to U.S. Aerospace Industry

Transfer of technology to users is the final step in the advanced research and technology development process. It requires proper reporting of research results and maturity of technology development. The Space Technology program will expand its reporting through use of existing reporting mechanisms such as program reports to Congress and the Office of Management and Budget, technical publications, and presentations at technical symposia and conferences. Use also will increase of conferences sponsored by the Headquarters and the field centers in both broad and specific technical areas, as well as of cooperation and co-sponsorship with other NASA program offices, other civil government agencies that encourage industrial participation, and the Department of Defense. Interested segments of the aerospace community will be given early notification of the conferences, and broad national participation will be encouraged. Personnel in Headquarters and the field centers will exchange reports on program progress and accomplishments regularly with industry through visits and other means.

A technology's maturity is important with respect to its selection for inclusion in flight programs. The Space Technology program will ensure maturity by validating research and technology results through experiments and tests on the ground and in space. The program element, Additional Flight Experiments in Space described in Paragraph F, Planned Initiatives, will support that activity.

5. Provide Development Support to NASA, Other Government Agencies, and Industry

The Space Technology program's technical staff and facilities are national resources valuable not only to the other NASA program offices, but also to other government agencies and U.S. industry. The program supports the space user community in the 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 the users, it also makes use of the opportunity to augment its own store of experience and data, to the benefit of its subsequent research and development programs. This involvement with the user community will be continued.

C. Program Planning and Direction

The Space Technology program uses a variety of mechanisms to ensure that its activities are comprehensive and are prioritized so as to provide the technologies that are critical to or strongly affect mission capability, cost, and productivity. 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. Its use ensures that current space research and technology development activities support NASA's overall goals and objectives. 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. It consists of three volumes of information assembled from a variety of sources, notably the Headquarters program offices.

Volume I provides plans for and forecasts of systems, programs, and payloads for both near-term and far-term missions. The systems, programs, and payloads range from those approved, planned, or candidates for initiation within the next ten years to more speculative "opportunity" missions for later years. Volume II contains the Space Technology program's assessment of trends and forecasts of space technology and provides figure-of-merit data characterizing research and technology development plans and opportunities. Volume III is an analysis of stated and implied technology requirements and opportunities derived principally from the data base of Volumes I and II. It identifies a set of "landmark" NASA missions--missions that, of all the Agency's missions, have the most ambitious objectives and employ the most advanced technology.

Derivation of the trend and forecast portions of the Model did not take into consideration the identity of the ultimate user, whether NASA, the Department of Defense, or industry. However, the missions and systems of Volume I and the landmark missions of Volume III are limited to NASA missions. The Department of the Air Force has developed a technology model to provide comparable information for its missions. The Space Technology program uses that model in its planning and, better to satisfy its responsibility for providing technology for space missions in general, will broaden its technology model to cover the needs of missions planned by other government agencies and industry.

2. System-Level Planning

To focus its systems research and technology development, the Space Technology program divides systems into three classes: Space Transportation Systems, Spacecraft Systems, and Space Station 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-priority disciplinary technologies and quantify their impact, and disciplinary technology programs are developed.

a. Space Transportation Systems

Needed space transportation capabilities fall into three categories: Earth-to-orbit vehicles, including the existing Space Transportation System, a cargo vehicle more advanced than the Space Shuttle, and an orbit-on-demand vehicle; orbital transfer vehicles; and in-space service vehicles. Each category has technology needs generated by its mission objectives and service environment. Needs for the advanced cargo vehicle are reduced payload delivery costs and an ability to carry heavier and more varied payloads. The orbit-on-demand vehicle must be able to respond rapidly, with high reliability and maneuverability.

Orbital transfer vehicle requirements are reusability; space-basing capability; ability to return to low Earth orbit, probably through use of aerodynamic braking; and ultimately man-rating. The propulsion system most likely will use liquid oxygen and liquid hydrogen, but use of hydrocarbon and other storable fuels for special missions is possible.

With regard to in-space service, the space station will provide a capability for assemblying, servicing, maintaining, and repairing spacecraft, launch vehicles, and other hardware in orbit. Some servicing tasks will require service vehicles able to move about independently in space. The service vehicles must be equipped with autonomous navigation, guidance, and rendezvous and docking systems; propulsion systems requiring little maintenance; and reliable, fault-tolerant avionics systems.

b. Spacecraft Systems

Research and technology development for spacecraft systems must satisfy the needs of free-flying spacecraft and of large space structures such as large optical systems and large radio-frequency antennas. Free-flying spacecraft, both Earth-orbiting and planetary, require advances in computer hardware and software that will permit a high degree of spacecraft automation and autonomy and will reduce mission costs. In addition, advances in energy conversion technology can reduce the weight of spacecraft. Large optical systems and radio-frequency antennas are needed for science, applications, and communications missions. Technology needs for them center on means to achieve shape control and stability of large space structures.

c. Space Station Systems

As part of the national commitment to establish a permanent human presence in space, NASA plans to begin development of a space station capability. Critical capabilities for efficient development and productive use of the planned initial and evolutionary systems will require advances in almost every technology discipline and spacecraft system. Early emphasis will be on the following:

- Automation--to reduce the costs of operations and increase the productivity of the human-machine system through automated control of space station functions, particularly housekeeping, thereby making those functions autonomous

- Information--to permit onboard processing, distribution, and storage of information for controlling space station functions and managing scientific and operations information

- Human Capabilities--to foster efficient performance of humans in the intra- and extra-vehicular activities necessary for operation of the space station

- Attitude Control and Stabilization--to provide adaptive, distributed controls that can maintain the integrity and effective operation of a flexible structure

- Energy Management--to provide power generation systems, high-voltage distribution networks, high-capacity storage devices, and efficient thermal management systems

- Integrated Hydrogen-Oxygen Systems--to develop a capability for scavenging hydrogen and oxygen from the Shuttle's external tank for use in environmental control, life support, onboard propulsion, energy production and storage, and fueling transport vehicles serviced by the station.

3. <u>Internal and External Coordination and Review</u>

The Space Technology 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. An example is the Space Station Technology Steering Committee, which was established to provide guidance throughout the Agency on technology development programs to support the space station program. That committee has the following objectives:

- To determine the technology needed for initial design and operation and subsequent evolution of the space station (Initial technology needs to be available by approximately 1987 to support launch as early as 1991.)

- To assess technology applicable to the space station that the base research and technology development program is expected to produce

- To plan, recommend, and monitor a program to advance current technology to the level required for space station development

- To identify, evaluate, and recommend opportunities for using the space station as a research and technology development facility.

To meet its objectives, the Committee formed ten discipline-area working groups composed of Headquarters program personnel and center project personnel. NASA's Space Station Task Force submits to the Committee statements of mission requirements from which the Committee and the working groups formulate and recommend technology programs. The Committee and working groups then advise the Space Technology program on the conduct of those programs.

The Space Technology program carries out similar coordination activities with the Air Force and other defense agencies in technology areas important to their missions. Also, technology workshops involving representatives from industry and universities are sponsored periodically to obtain further review and coordination.

Advisory groups provide additional external coordination and review. The two groups with the most interest in the Space Technology 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 their direction and content.

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 discipline 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. For example, in the summer of 1983 Ames Research Center and Stanford University managed a study, "Autonomy and the Human Element in Space," in which an interdisciplinary team of 20 fellows examined interactions that could be expected to occur between autonomous machines and humans in a space station and provided recommendations on the symbiotic use of humans and machines.

4. <u>Assessment</u>

The Office of Aeronautics and Space Technology regularly conducts formal assessments of its Space Technology 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 the entire NASA space research and technology development program down 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. <u>Technology Objectives</u>

The Space Technology program has a broad range of technical thrusts. The principal ones are embodied in the technical objectives described below. Those objectives 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

Exploration and use of space will continue to grow only if reductions in system and mission costs are achieved. Better materials and concepts for the Shuttle's thermal protection system are expected to be a key element in reducing cost and increasing the Shuttle's payload and mission capabilities. Ceramic, metallic, and advanced carbon-carbon materials and composite systems will be developed for use in lighter and more durable heat shields. Improvements to be sought for space transportation systems are higher strength, higher temperature resistance, longer operating life, and lower maintenance requirements. For multi-use orbital transfer vehicles using aero-assisted braking for return to low Earth orbit, research will be conducted on lightweight radiative and reflective heat shields. Research on ablative heat shields will provide improved systems for planetary and solar probes.

2. Longer-Life, Reusable Engines

Large, reusable rocket engines for space transportation vehicles, necessary for routine access to space, must be able to operate reliably at high performance levels for many missions with minimal maintenance. Therefore, technology must be developed for critical components, concepts, procedures, and materials; and advanced analytical methods must be established for explaining and quantifying engine phenomena The result will be proven options for development programs to meet engine performance, life, reliability, and maintainability requirements. Attention will be given first to the Shuttle's main engines. Increasing to the planned level the number of missions those engines are able to fly will require improvements in engine components and in analytical techniques for predicting their aerodynamic, aerothermodynamic, and material performance. To maintain their mission-life capability while increasing their performance and thrust level will require a continuing effort. The resulting technologies then will be extended to the large, high-pressure hydrocarbon engine and the dual nozzle engine, one or both of which will be needed for Earth-to-orbit vehicles more advanced than the Shuttle. This objective also includes development of diagnostic instrumentation and an ability to identify incipient failures and schedule engine maintenance on a mission compatible basis.

3. Orbital Transfer Vehicle Propulsion and Aerobraking

A versatile, cost-effective, orbital transportation vehicle is essential for exploiting 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 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 low Earth orbit recovery and rendezvous.

The high-performance, variable-thrust propulsion system will use an expander cycle, high chamber pressure engine burning liquid hydrogen and liquid oxygen fuel and will have a nozzle with a large expansion ratio. Technology development is required for concepts, component designs, and analytical techniques to permit more effective extraction of energy from the combustion process so that the increased pump performance necessary for high chamber pressures can be obtained. Also required are design of nozzles with large expansion ratios and development of diagnostic instrumentation and analytical techniques for detecting incipient failures and scheduling corrective action.

The use of aero-assisted braking instead of propulsion braking to recover reusable orbital transfer vehicles at low Earth orbit may offer a potential for doubling 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 concept, 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 pre-chill 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.

By the late 1990s, the largest use of Earth-to-orbit transportation services will be to provide fuel for orbit transfers. Reducing or eliminating that use would reduce the cost of space operations significantly. Therefore, a propulsion system will be sought that uses an external, renewable energy source instead of chemical reactions. Such a system would use solar energy either directly or to produce electricity to drive a moderate thrust propulsion system. Technology is needed for propulsion system concepts and the energy source.

4. <u>High-Capacity Electrical Power Generation, Storage, and Distribution Systems</u>

Current power systems for spacecraft have power-to-mass ratios of about 5 watts per kilogram and cost about $1,500 per watt. However, a potential exists for increasing power production while reducing system cost and weight by the late 1980s. Research on photovoltaic solar cells emphasizes those improvements, and the solar cell array in development for use in a solar electric propulsion system is expected to demonstrate a power-to-mass ratio of 66 watts per kilogram. The goal for that ratio by the end of the decade is 300 watts per kilogram for a high-performance silicon array. Techniques will be explored for reducing costs and deployed array area by improving concentrator efficiency. Fundamental research into thermal-to-electric conversion in nuclear reactor systems and solar thermal concentrators is focused on development of thermoelectric materials having higher conversion efficiencies and able to operate at higher temperatures. The Department of Defense, the Department of Energy, and NASA are conducting a joint program to develop technologies needed for demonstrating in the 1990s a nuclear reactor power subsystem in the 100-kilowatt class and for providing insights into the technologies necessary for larger nuclear power systems.

Energy storage systems often are a dominant factor in the weight, reliability, and length of life of high-capacity space power systems. Technology should be developed for systems based on nickel and hydrogen electrochemistry and for fuel cell electrolyzer systems so that orbital systems able to store hundreds of kilowatts of energy can be developed by the late 1980s.

Also essential is a capability for controlling the generation and distribution of energy to achieve efficient, environmentally compatible operation of high-power, high-voltage space systems. Technology advances will be needed in electronic components, heat pipes, radiators, rotary joints, transmission lines, and controls.

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 under way 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 and the dynamic velocity taper. An engineering model of a tunneladder traveling wave tube is to be completed in 1985, and an experimental 60-GHz coupled-cavity traveling wave tube for use as a spaceborne amplifier for intersatellite communications is scheduled for completion in 1986.

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. The result expected is development by 1985 of an X-band solid-state transponder for use in deep space, a 20-GHz monolithic microwave integrated circuit amplifier by 1987, and a solid state laser with a power output of more than 200 megawatts by 1988.

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 in 1984, completion of a study of multiple use antennas in 1987, and start of operations of the Antenna Technology Laboratory in 1988.

6. Large Antenna Systems

This objective is concerned with developing a comprehensive ability to analyze antennas and with developing and testing large-aperture mesh reflectors and array assemblies having multiple-beam feeds that could provide contiguous spot coverage of large geographical areas. A large antenna system in geostationary orbit would provide mobile communications service for a very large area on Earth's surface, such as that of the continental United States. It would provide transmission and reception service for rural and remote regions and thus complement the terrestrial communication networks serving metropolitan centers.

Research is needed in antenna structures packaging, minimum sizes for structural members, and methods for deploying and assembling large antennas. Experimental identification in orbit of the dynamic parameters of large antenna structures and correlation of the resulting experimental data with analytical predictions will be required so that a capability can be developed for controlling the geometry of the antenna's surface and feed. A structures and controls experiment will be conducted in space in 1989 to verify technology developed for application to large antenna systems.

7. Space Teleoperation, Robotics, and Autonomous Systems

Teleoperator and autonomous space systems will increase current capabilities for conducting unmanned science experiments in space, providing autonomous operation of systems and devices on the Space Shuttle and space station, and reducing dependence on ground-based operations personnel. Thus, the purpose of the Space Technology program's work on autonomous systems is to develop and apply artificial intelligence to the planning, monitoring, controlling, and diagnosing of subsystem operations; and the purpose of its teleoperation and robotics work is to provide technology for remote servicing, assembly, and related manipulative tasks for maintaining and operating space systems. The technology data base will be validated through pilot experiments demonstrating progressively increasing levels of automation and autonomy of remote systems. Success will free personnel to concentrate increasingly on supervisory and other intellectual tasks to increase the capability, efficiency, and economy of the total human-machine system.

8. Space Information Management Systems

The purposes of this objective are to develop 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; optical mass storage systems; and nonvolatile memory systems for spaceborne applications. Related technology needs to be developed for optical information processors, image-based symbolic processors for spaceborne systems, data base management systems, and architectures for processing 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 also seeks to apply that understanding to improve computational concepts and system architectures. It supports systems reliability and performance, software development, and information management. Its results will be applied to computational modeling of physical processes, flight systems that are crucial to mission safety, and autonomous systems. Research is in process on highly reliable, cost-effective computing that will make possible the construction of advanced systems for man-rated flight vehicles and long-duration, unattended space missions. The research also includes investigation of fault tolerant hardware architectures and cost-effective tools and techniques for developing verifiably correct software.

NASA currently is receiving from space approximately ten billion words of scientific data per day, with expectations of a hundred-fold increase over the next decade. The ability to manage and distribute such large volumes of data to the scientific community must be developed. A technique that may help provide that ability is concurrent processing. Research on it is in process to develop system architectures and algorithms for computationally intensive problems in aerospace research such as those in computational fluid dynamics and image processing. The research includes analysis of highly parallel, single instruction, multiple data stream, computer architectures for problems that can be vectored and analysis of more complex, but more promising, multiple instruction, multiple data, and data flow architectures.

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 and other 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 and 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 are 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 Earth and planetary 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 silicon charge coupled device arrays; 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. Onboard, real time, adaptive controls will require numerical procedures, compatible with the structure's 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 research and technology development program to satisfy those 13 technology objectives consists of work in 7 discipline and 3 system areas. In addition, there is a spacecraft systems technology element that includes space flight experiments. The program's structure is shown in Table VII-1.

1. Discipline Areas

- Fluid and thermal physics--analytical and predictive techniques for the continuum and rarefied flow regimes, with emphasis on transatmospheric flight
- Materials and structures--concepts for large-area structures, 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
- Computer science and electronics--concurrent processing and optics research
- Space energy conversion--high-capacity power and thermal systems for the space station, systems with high specific power and low weight for geosynchronous orbit and planetary missions, electric propulsion for auxiliary propulsion applications, and thermal-to-electric energy conversion for the 100-kilowatt class nuclear reactor power subsystem program mentioned in paragraph D.4 above
- Controls and human factors:
  - Controls--large, precisely controlled structures; integration of attitude control and energy storage functions in flywheels; and precise pointing of large spacecraft
  - Human factors--enhancement of astronaut productivity through improved information management techniques, extravehicular work stations, and telepresence capability

TABLE VII-1. WORK BREAKDOWN STRUCTURE OF SPACE RESEARCH AND TECHNOLOGY DEVELOPMENT PROGRAMS

<u>Fluid and Thermal Physics R&T</u>

Aerothermodynamics
Aerothermal Loads
Thermo-Gasdynamic Facility Operations

<u>Materials and Structures R&T</u>

Propulsion
Materials Science
Space-Durable Materials
Propulsion
Advanced Thermal Protection Systems
Advanced Space Structures
Analysis and Synthesis

<u>Computer Science and Electronics R&T</u>

Electronics
Sensor Systems
Computer Science
Automation

<u>Space Energy Conversion R&T</u>

Electric Propulsion Technology
Photovoltaic Energy Conversion
Chemical Energy Conversion and Storage
Thermal-to-Electric Conversion
Power Systems Management and Distribution
Thermal Management

<u>Controls and Human Factors R&T</u>

Control Theory and Analysis
Human Factors
Advanced Controls and Guidance Concepts

<u>Space Data and Communications R&T</u>

Data Systems
Communications Systems

<u>Chemical Propulsion R&T</u>

Advanced Earth-to Orbit

Advanced Onboard Propulsion
Advanced Orbital Transfer

<u>Spacecraft Systems R&T</u>

Systems Analysis
Spacecraft Technology Experiments

<u>Transportation Systems R&T</u>

Systems Analysis
Orbiter Experiments Program

<u>Platform Systems R&T</u>

Systems Analysis
Operations
Crew and Life Support

<u>Spacecraft Systems Technology</u>

Space Flight Experiments
Long-Duration Exposure Facility
Ion Auxiliary Propulsion Systems

- o Space data and communications--space information systems, automation, robotics, and optical data systems

- o Chemical propulsion--life and performance of the Space Shuttle's main engine and other high-pressure engine systems; space-based, throttleable, and reusable orbital transfer engines; and gaseous oxygen-hydrogen auxiliary propulsion systems.

2. Systems Areas

- o Spacecraft systems--Earth orbiting and planetary spacecraft, communications technology, and sensor systems. Satellite communications research and technology development is in the K_a band through the 100-GHz range. Sensor technology work focuses on laser, electro-optic, and microwave devices and techniques.

- o Transportation systems--Earth-to-orbit transportation systems, including orbital transfer systems and improvement of the Space Shuttle. For orbital transfer systems, consideration is being given to aeromaneuvering, space-basing, maintainability, operational flexibility, and man-rating.

- o Platform systems--architectures for distributed data systems, automated and teleoperated systems, life support systems, and operational extravehicular activities.

3. Newly Initiated Programs

Since publication of NASA's FY 1984 through FY 1988 program plan, the Space Technology program has initiated the programs described in the paragraphs that follow.

a. Space Flight Experiments

The objective of space flight experiments is to provide the Nation with the ability to conduct in space research that either cannot be conducted adequately on Earth or can be conducted more effectively in space. The Shuttle system, including Spacelab, is a cost-effective laboratory for research and technology experimentation that extends the Nation's laboratory base from ground to space. The space station will add a capability for conducting long-duration experiments. Shuttle experiments already have demonstrated the advantages of research in space to verify and augment results from tests and analyses conducted on the ground. The results of the Shuttle experiments also will benefit future space missions by reducing the uncertainties and risks of activity in the space environment. The space flight experiments have been limited to discipline technology experiments and the Orbiter Experiments program. However, three major research areas will be added in FY 1985: large structures and their controls, management of cryogenic fluids, and power and thermal systems.

Experiments in the structures-control area will validate critical technologies for the design, analysis, test, and functional operation of large space structures requiring distributed controls. First flight of an experiment is planned for 1988 to identify the structural dynamics of a large, flexible structure. Cryogenic fluid management experiments will provide enabling technology for in-orbit supply and resupply of cryogenics to spacecraft and space platforms and for in-orbit refueling of orbital transfer vehicles. A multiple flight program is planned, with the first flight in 1988. A power and thermal system experiment will develop space power systems that generate several hundreds of kilowatts. Small-scale experiments to verify the technology and provide understanding of the physical phenomena involved are planned to start in 1985, and full-scale flight experiments are planned to start in 1987.

b. Space Shuttle Main Engine Test-Bed Engine

The Space Shuttle main engine technology program is part of the advanced Earth-to-orbit propulsion system program. Its objective is to provide a technology base for longer life, higher performance, reusable rocket engines and to improve the performance and extend the operational life of the Space Shuttle main engine. Its aims are to develop analytical models that define the dynamic environment of the engine and predict the engine's operating lifetime; to develop and test concepts for hardware; and to develop instruments to measure the engine's environment, validate models for simulating that environment, and diagnose the performance of the engine during operation.

The Space Shuttle main engine test-bed engine will provide the means for system-level testing to ensure that advanced technology hardware for the Space Shuttle main engine performs as intended and is ready for transfer to a development program. It also will validate instrumentation and provide data for use in validating analytical models. It will be assembled and operated by the Office of Space Flight. As concepts mature under the Space Shuttle main engine technology program, they will be tested in the test-bed engine, ensuring evolution of the Space Shuttle main engine and, later, development of advanced reusable engines.

c. Space Station

This program's objective is to provide technology at both the system level and the subsystem level for development and evolutionary growth of the space station. The configuration of the station must be such that the station will satisfy its immediate mission and operational requirements, but it also must provide a foundation for continual increases in the station's capabilities. The following are examples of program content:

- o Advanced data systems--to provide onboard processing that will increase automation and autonomy
- o Long-life, low-cost photovoltaics--to provide power systems with greater capacity
- o Control systems--to maintain the shape and stability of flexible space structures and, later, to provide controls for composite vehicles

- o Auxiliary propulsion systems that have high specific impulse and are maintainable and noncontaminating--for attitude control and orbit maintenance

- o Fuel cell improvement--for more efficient power storage

- o Storage and transfer of cryogens--to support orbital transfer vehicle operation from the space station

- o Life support--to maintain humans in space, permit daily extravehicular activity and in-orbit servicing and maintenance operations, and enhance human capabilities in space

- o Thermal management--to develop concepts for heat acquisition, transfer, and rejection in two-phase, very high capacity thermal systems.

d. <u>Computer Science and Technology</u>

The objective is to strengthen the Agency in computer science through research and experimentation and to infuse state-of-the-art computer science and technology into aerospace applications. The program will provide theory, concepts, techniques, and capabilities for use and management of aerospace information. The following are examples of program content:

- o Multiple processor computing--to develop computing architectures, operating systems, programming languages, and algorithms for addressing tightly-coupled multiprocessors through distributed computing systems

- o Architectural concepts for computers--to improve reliability and fault tolerance

- o Life cycle software--to provide engineering tools, techniques, and models for aerospace-related applications

- o Automated planning, decision making, problem solving, knowledge-based systems, teleoperation, and robotics--to expand the functional range and cost effectiveness of operations in space, leading ultimately to autonomous operations

- o Spaceborne symbolic computer--for implementation of autonomous systems.

F. <u>Planned Initiatives</u>

Space research and technology development programs and systems being considered for initiation in the FY 1986-FY 1988 period are listed below. The list is not in priority order.

- o FY 1986:

  - Orbital Transfer Vehicle Technologies

  - High-Lift-to-Drag Vehicle Technologies

- Space Nuclear Power
- Power and Propulsion for the Spacecraft Bus
- Control of Flexible Structures
- In-Space Experiments

o FY 1987:

- Research for Autonomous Systems
- Liquid Oxygen-Hydrocarbon Propulsion Technologies
- Scientific Payload Technologies

o FY 1988:

- Large Deployable Reflector Technologies
- Free-Flying Experiments Carrier.

1. FY 1986 Initiatives

The orbital transfer vehicle initiative will focus on a liquid oxygen and hydrogen propulsion system that can be maintained in space; aerobraking systems' aerodynamics, aerothermodynamics, brake structure, and thermal protection systems; adaptive navigation and control; a flight experiment to obtain critical data on aerobraking system capabilities; and fuel tanks capable of being based in space and of minimizing fuel losses.

The high lift-to-drag vehicle initiative will study the aerodynamics, aerothermodynamics, thermal structure, and controls of such vehicles. It also will provide the foundation for a future initiative to develop and test an entry research vehicle to be launched by the Shuttle to validate entry models and the data they generate.

The space nuclear power initiative will extend the existing 100-kilowatt class nuclear power system program, which is focused on technology verification, to develop ground demonstration units for verifying system designs and for qualifying long-life components and subsystems.

Technologies needed for the next generation of spacecraft will be developed in the spacecraft bus program, with emphasis on an integral power and propulsion system.

The subject of the control of flexible structures initiative will be technologies to permit accurate pointing, alignment, and shape control of large, non-rigid, space structures.

The in-space experiments program will augment the FY 1985 initiated space flight experiments in structures and their controls, power and thermal systems, and cryogenic fluid transfer to provide earlier development of those technologies than would be possible under the current funding level. This initiative also will permit flight research to be conducted in additional discipline and system technology areas requiring the space environment. Proposed flight experiments include the dynamics of a flexible robotic arm, propulsion contamination, and reflight of the multidiscipline experiment carrier, the Long Duration Exposure Facility.

2. FY 1987 Initiatives

Space systems must become increasingly autonomous because they are becoming increasingly complex and because their cost effectiveness needs to improve. The autonomous systems initiative will seek to develop technology to provide the needed increases in autonomy.

A high-density propulsion system with a chamber pressure greater than 2,000 pounds per square inch will be essential for many space transportation vehicles. Technologies unique to such a system will be investigated in the liquid oxygen-hydrocarbon propulsion initiative.

Spacecraft must become more capable of carrying large, heavy, complex payloads. Technology to provide the needed increases in capability will be the subject of the scientific payloads initiative, with special attention to sensors, optics, and data systems.

3. FY 1988 Initiatives

The large deployable reflector initiative will seek advances in technologies, figure control, wave-front correction techniques, pointing, and vibration control for segmented mirrors.

The free-flying experiments carrier initiative will provide a capability for obtaining data on the performance of materials, components, and subsystems in orbit for extended periods.

Aeronautical Research and Technology

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VIII. AERONAUTICAL RESEARCH AND TECHNOLOGY

CONTENTS

FIGURES

* Rotor Systems Research Aircraft

VIII. AERONAUTICAL RESEARCH AND TECHNOLOGY

This long-range plan for aeronautics 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. The plan emphasizes the preservation of and continuing development in both areas as much as it stresses the elements that constitute the plan itself. It 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 reasserted the importance of aeronautics to the defense and economic well-being of the United States. The group recommended:

- 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
- 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
- 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 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:

- Disciplinary Research--research to increase knowledge of fundamental physical phenomena and generate new concepts in primary aeronautical technical disciplines

- 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

- 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:

- Maintain the excellence of the NASA research centers in facilities, computational capability, and technical staff
- 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
- Assure the timely transition of research results to the U.S. aerospace community
- Assure the appropriate involvement of universities and industry in NASA's Aeronautics program
- 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, a Facility Integrity Program has been initiated to provide rehabilitation through a multi-year repair and replacement activity. Existing facilities also are being enhanced through a Facility Productivity Improvement Program designed to provide a more efficient test capability.

Enhancement of computational capabilities at all three of the centers is increasingly important. The centers will use the most advanced supercomputers to push the state-of-the-art in network and software systems that increase computational power but remain user friendly. The Agency's new Numerical Aerodynamic Simulation system will play a lead role. It will feature prototype high-speed processors surrounded by work stations, graphics stations, mass storage, and a long-haul, wide-band satellite communications link between the centers. By early 1986 its initial high-speed processor will be operational and able to perform 250 million floating point operations per second (MFLOPS). In 1987 a follow-on processor will increase that capability to more that 1,000 MFLOPS.

The Numerical Aerodynamic Simulation system exemplifies the overall direction all the NASA centers are taking to use and advance scientific and engineering computing. Communications will be employed to increase usable computational power even further. Key to that use will be a satellite link that, starting in 1986, will allow a user at one research center to run systems at the other research centers. To ensure access to the latest developments in computer technology, OAST has initiated a computer science program that involves all three of the research centers, the universities, and industry.

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 (currently projected for December 1985), 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. <u>Achieve Appropriate Levels of Disciplinary and Systems Research</u>

Increased emphasis will be placed on systems integration. To achieve technological improvement, interactions among the individual components of a vehicle, its subsystems, 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.

Technology goals and current program plans, including future initiatives, are described in sections C, D, and E of this chapter.

c. <u>Ensure Timely Transfer of Research Results to U.S. Aerospace Industry</u>

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 will endeavor 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 will maintain 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 will be 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. 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. <u>Provide Development Support to Other Government Agencies and to U.S. Industry</u>

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 Provide technology to 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 Provide technology advances for a 100-percent improvement in productivity of rotorcraft for military and civil application
- o Provide technology to ensure development of superior military aircraft and missile systems
- o Provide technology to enhance flight crew effectiveness in advanced cockpit and air traffic environments that include advanced automation, display, and control techniques
- o Provide a technology base for exploiting modern computers in solving computationally intensive aeronautical problems
- o Exploit the full potential for reducing the drag of 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 Provide turbofan component advances that improve the fuel efficiency of subsonic transport engines 15 percent beyond the level possible from application of energy efficient engine technology
- o Provide technology to increase aviation safety through improved crash and fire worthiness, protection from meteorological hazards, and aircraft systems.

NASA's approach to those objectives follows.

1. Computational Fluid Dynamics

Development of computational fluid dynamics and accuracy in predicting external and internal flow are progressing rapidly. Major gains foreseen for the next decade in computational aerodynamics will result in preliminary designs for aircraft and engines much closer to final configurations than is currently possible, permitting greater economy in wind tunnel and test rig activities. The Numerical Aerodynamic Simulation system mentioned previously is in direct support of this objective. Started in FY 1984, that system will provide and maintain the world's most advanced scientific computation system.

2. Aircraft Viscous Drag and Reynolds Number Effects

The ability to achieve very low form drag is quite advanced. Consequently, drag due to skin friction remains the major problem in reduction of total drag. Since prevention of turbulent flow at surface boundaries can provide large reductions in aircraft drag, various means for stabilizing boundary layer flows are being pursued. In addition, attempts are being made to reduce the friction drag of established turbulent flows by geometric modification of vehicle surfaces. 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 mentioned previously will provide a full-scale Reynolds number test capability, effectively eliminating the potentially costly errors arising from extrapolation from data obtained in tests that can be conducted only in currently available tunnels.

3. Use of Advanced Materials to Minimize Structural Weight

Emerging concepts in advanced materials have high potential for improving the performance and durability of aircraft. NASA's development of resin-matrix composites for empennage structures is nearly complete. Full-scale ground and flight tests of stabilizers will conclude NASA's technology development of moderately loaded, stiffness-critical structures. Technology development now is in process on safety-of-flight critical structures such as wings and fuselages for transport aircraft, including development of a complete data base and the design criteria necessary for commitment to production. Also under development are tougher, more processible resin systems to provide greater resistance to impact damage and, through powder metallurgy techniques, advanced metal alloys that will increase allowable design strength with no loss in durability or fracture toughness.

Development of technology is in process to improve the performance and durability of turbine engines. Included are studies to improve the definition and quantification of factors that affect engine durability such as the aerothermal environment, dynamic thermomechanical loading effects on materials, and initiation and propagation of cracks. New analytical methods to account for complex loading and realistic geometries are being developed and verified through laboratory tests. Fundamental studies on the strengthening of superalloys for engine applications are continuing, with emphasis on innovative alloying concepts using melt spinning. Thermal barrier coatings with improved resistance to foreign object damage and greater durability will be developed.

An intensive effort has been initiated to develop the technology needed to produce reliable ceramic components for engines. Research in materials and processes will investigate fundamental relationships among starting powders, processing variables, and resultant microstructures and properties. Improved design methodology will provide the analytical tools needed for designing parts made with brittle materials. Advancement in techniques for predicting and evaluating nondestructively the life of ceramic materials will improve capabilities for addressing accurately the service life of components made from them and, therefore, increase confidence for their use.

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 improve flight path guidance and perform functions that are crucial to the safety of flight. As dependence on 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 guidance in conjunction with improved air traffic control. The approach that will be followed is to develop methods for integrating fully the 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 dynamic, fault-tolerant system management and highly reliable computer systems able to support complex interacting functions.

Research will be conducted to optimize air traffic flow strategies, integrate air traffic control and flight path management displays and controls, develop air traffic control automation concepts and operating procedures, evaluate performance, and reduce workloads. Other research will exploit synergistic benefits from integrating electric secondary power systems, electromechanical actuators, active controls, and digital electronics to obtain major gains in efficiency, economy, and performance.

5. Improvement in Rotorcraft Productivity

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, vibration and noise reduction, flying qualities, and all-weather operating capabilities. 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 will provide the technology foundation upon which the Department of Defense and industry can develop better weapon systems. The High Performance Aircraft program is aimed at generating technology advances needed 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 free flight models will be continued on fighter aircraft embodying new concepts to improve their behavior characteristics at high angles of attack, during stall departure, and in spins. Also, 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 airbreathing 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 is installing full-mission, advanced technology, transport aircraft simulators at the Ames and Langley Research Centers. Research under way 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

Commercially available computer systems do not satisfy the needs of long-range aeronautics research. To provide the needed accuracy, reliability, and durability, OAST has established a computer science program to provide a foundation for developing computer science and computing methodologies for use in aeronautics and other NASA research and technology activities. An important objective is to understand the interplay between advanced architectural concepts and the performance properties of algorithms, including algorithmic complexity, time and space tradeoffs, convergence properties, and accuracy. The program also will investigate the theoretical basis for high reliability and fault tolerance in order to provide insight into promising new architectural concepts. Analytic techniques, simulation, and modeling for analyzing and evaluating systems performance will be improved, as will capabilities for communicating information between humans and computers, particularly through computer graphics.

9. Drag Reduction for Highly Integrated Propulsion-Airframe Systems

Favorable integration of aircraft propulsion and airframe systems can provide significant savings in fuel and direct operating costs by reducing interference drag to three percent of total airplane drag. That reduction is particularly important for military aircraft because it will increase their range, payload, and other performance. Therefore, the Aeronautics Research and Technology program has under way the Propulsion-Airframe Integration program to improve stability and performance and reduce the 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 flow phenomena associated with propulsion systems incorporated 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 should 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 by mid 1985. Analytical techniques will be 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, commuters, 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 that 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 20 percent. Realization of that potential will require establishment of several interrelated technologies involving propeller design, cabin noise reduction, propulsion-airframe integration, and mechanical system integrity.

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 thick, 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 more thoroughly their structural, dynamic, and acoustic characteristics that cannot be resolved fully in subscale tests.

The long-term 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 will encompass both single and counter-rotating propellers, wing and aft-fuselage mounted engines, tractor and pusher thrust orientations, and an adequate 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. Turbofan Components for Fuel-Efficient Subsonic Transport Engines

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 initiating programs to develop technology for advanced components. It will be focused on improvement of lightweight and high-temperature materials; improvement of structural design techniques; computational fluid dynamics to describe three-dimensional viscous flow fields in turbomachinery, including heat transfer and turbine cooling; and fiber optics for use in transferring information. It also will address system dynamics related to optimum engine control and recovery from engine stall.

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. More accurate analytical predictions 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 OAST'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. Future emphasis will be placed on airborne detection of those hazards and on detection of wake vortices. 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 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 cabin materials with greater fire resistance, aircraft with greater crash worthiness, and safer fuels in order to reduce fatalities and trauma injuries from crashes and fires. Data from full-scale crash tests will provide 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 three-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.

Materials and structures activities will be concentrated on light alloy metals, new composite materials, and the crash dynamics of composite structures.

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 cathode ray tubes; and development of technology to improve the fidelity of simulations.

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, engine technology for general aviation and commuter aircraft, engine dynamics, and stall recovery.

In advanced turboprop systems, NASA is conducting a broad-based research and technology development program for single- and counter-rotating propellers, drive systems, and aircraft for a new generation of advanced, high-speed, fuel-efficient aircraft. The program emphasizes design, fabrication, and ground tests in preparation for flight research to evaluate and correlate the structural integrity and acoustic characteristics of a single-rotating, large-scale (nine-foot diameter), highly swept propeller. Preliminary investigations also will be conducted of unique configurations of gearless, counter-rotating propfans. Supporting technology is being developed both inhouse and in industry in propfan aerodynamics, acoustics, and structures; aircraft cabin environment; and aerodynamic integration and innovative installation arrangements.

Rotorcraft research will stress the reduction of noise and vibration and the unsteady aerodynamics of rotors.

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.

The emphasis of subsonic aircraft research will be on technology for advanced composite structures, research on icing and lightning strikes, natural and controlled laminar flow, and, in coordination with the Federal Aviation Administration, improvement of air operations and air safety.

Technological progress during the past year has permitted work to begin on three of the new initiatives proposed in last year's Aeronautics plan. Those initiatives and how they relate to the technology objectives described in Section C are described below.

1. <u>Numerical Aerodynamic Simulation</u>

The Numerical Aerodynamic Simulation (NAS) system will make possible the solution of heretofore intractable problems in computational fluid dynamics and other areas of computational physics. It will be assembled from commercially available equipment and designed to be user friendly. It eventually will contain at least two high-speed scientific processors. The first processor will be procured in FY 1985, and follow-on processors will be acquired as the state of the art advances. As shown by Figure VIII-1, NAS is expected to be in partial operation in late FY 1985 and fully operational in FY 1987. It will be located at Ames Research Center and will be available to researchers from industry, the universities, and other government agencies, as well as from NASA. Its features will include graphics stations where users can visualize quickly the physical processes they simulate, work stations designed to optimize the human-computer interface, telecommunications with satellite relays to link it to remote users, a large data-base mass storage, and a fast network linking its elements.

NAS will play an important role in all phases of aeronautical research and development. In basic research, it will make possible solutions of the full Navier-Stokes equations and thereby reveal underlying mechanisms of turbulence, flow separation and reattachment, and aerodynamic noise. It will permit deeper examination of many more preliminary design alternatives than currently is possible, leading to greater refinement of initial designs before the start of costly and time-consuming wind tunnel tests. Then, after validation of designs by wind tunnel tests, it will be able to handle techniques for optimizing the configurations that show promise, accounting simultaneously for all components of a design in combination. It also will allow similar advances in other computationally intensive disciplines.

2. <u>Advanced Composite Structures Technology</u>

This program's objective is to extend the technology for composite structures by developing data and generic approaches to design that will make possible the use of composite structures as segments of the wings and fuselages of large transport aircraft. Concentrated loads, impact damage, and the performance of thick laminated joints will be special areas for emphasis. Also to be included are development and determination of the characteristics of tough composites that can withstand high working strains and that have good resistance to impact damage.

As shown by Figure VIII-2, attention first will be given to the design, development, and testing of small critical components. Development of detailed designs by 1987 and then fabrication of full-size sections of aircraft structures by 1988 will follow. To be completed in 1989 are ground tests of moderately large sections of wing and fuselage panels to verify the designs of those sections and the analysis procedures used in their design. Also in 1989, the performance of composite structures under very high and repeated loads will be evaluated.

FIGURE VIII-1
NUMERICAL AERODYNAMIC SIMULATION

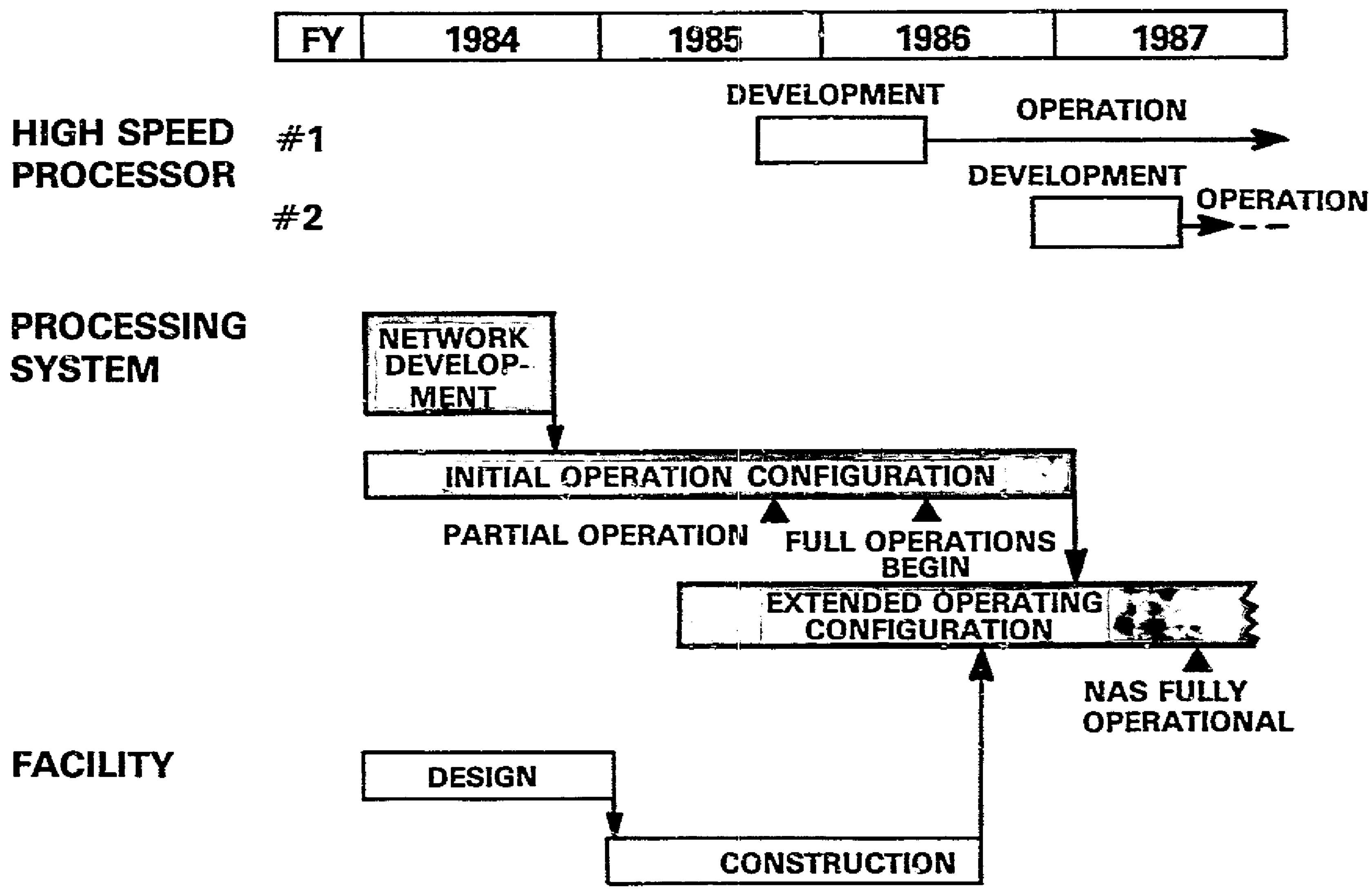
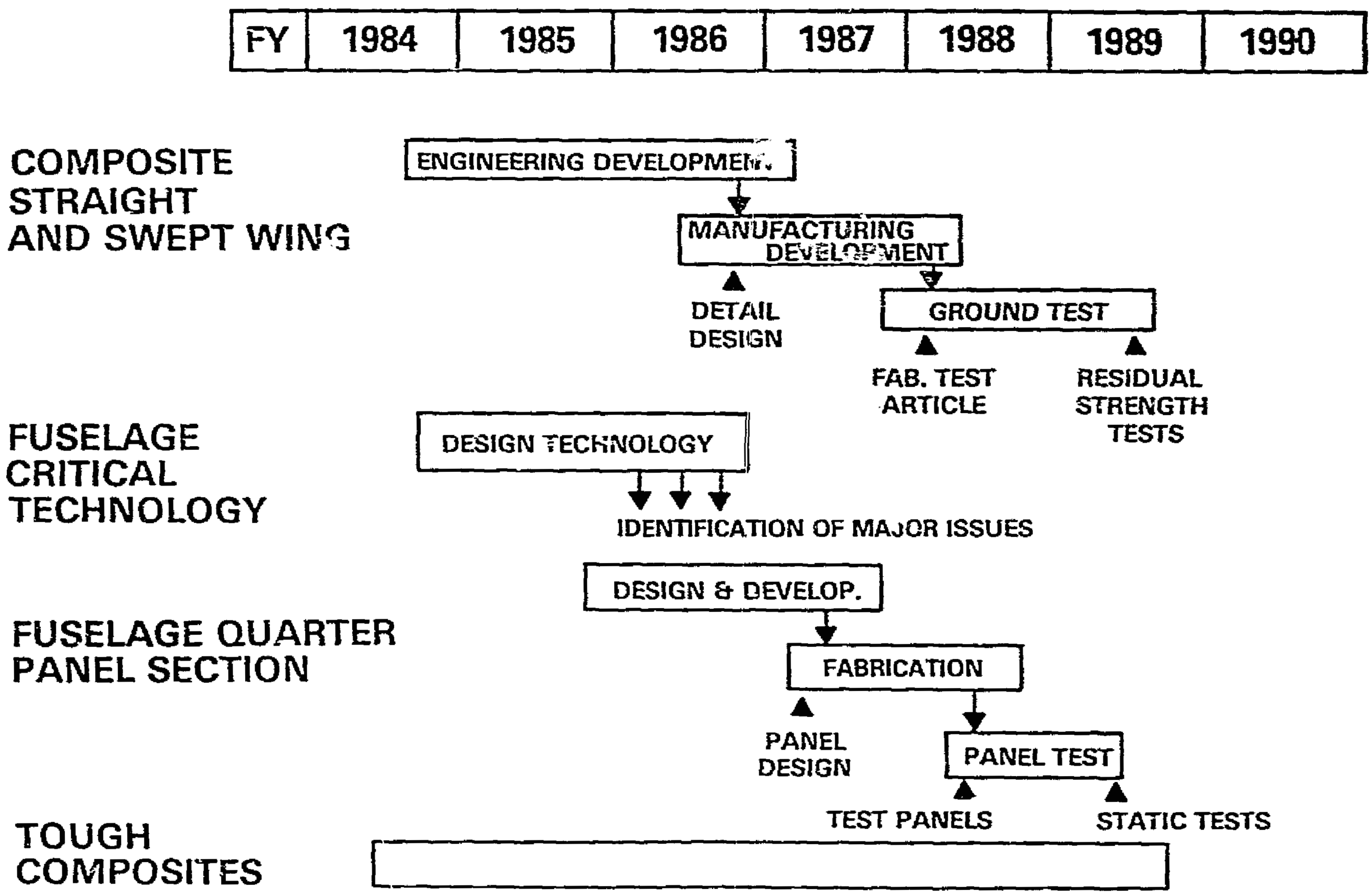


FIGURE VIII-2
ADVANCED COMPOSITE STRUCTURES TECHNOLOGY



3. Next Generation Rotorcraft

The objective of this program is to demonstrate technology for the X-wing rotor through proof-of-concept flights with the Rotor Systems Research Aircraft (RSRA). The X-wing rotor is a four-bladed, extremely stiff rotor whose lift and rotor control are produced by circulation control aerodynamics. It is stoppable in flight to become two forward swept and two aft swept fixed wings in an X configuration. The RSRA will be configured as a compound helicopter with an X-wing rotor system powered by two General Electric T-58 engines and thrust provided by two TF-34 turbofans in the stopped rotor mode. Control of the rotor will be by a digital fly-by-wire system using higher harmonic control and hub moment feedback.

As Figure VIII-3 shows, the program consists of design, fabrication, installation, ground tests, and flight tests of an X-wing rotor system followed by modification of the RSRA and renewed basic research. That complete sequence of activities will be supported by analysis, wind tunnel tests, and simulation. The results from this program, together with those from the DOD-NASA Convertible Engine program and the DOD No Tail Rotor program, will provide the technology base for a future X-wing aircraft.

E. Future Initiatives

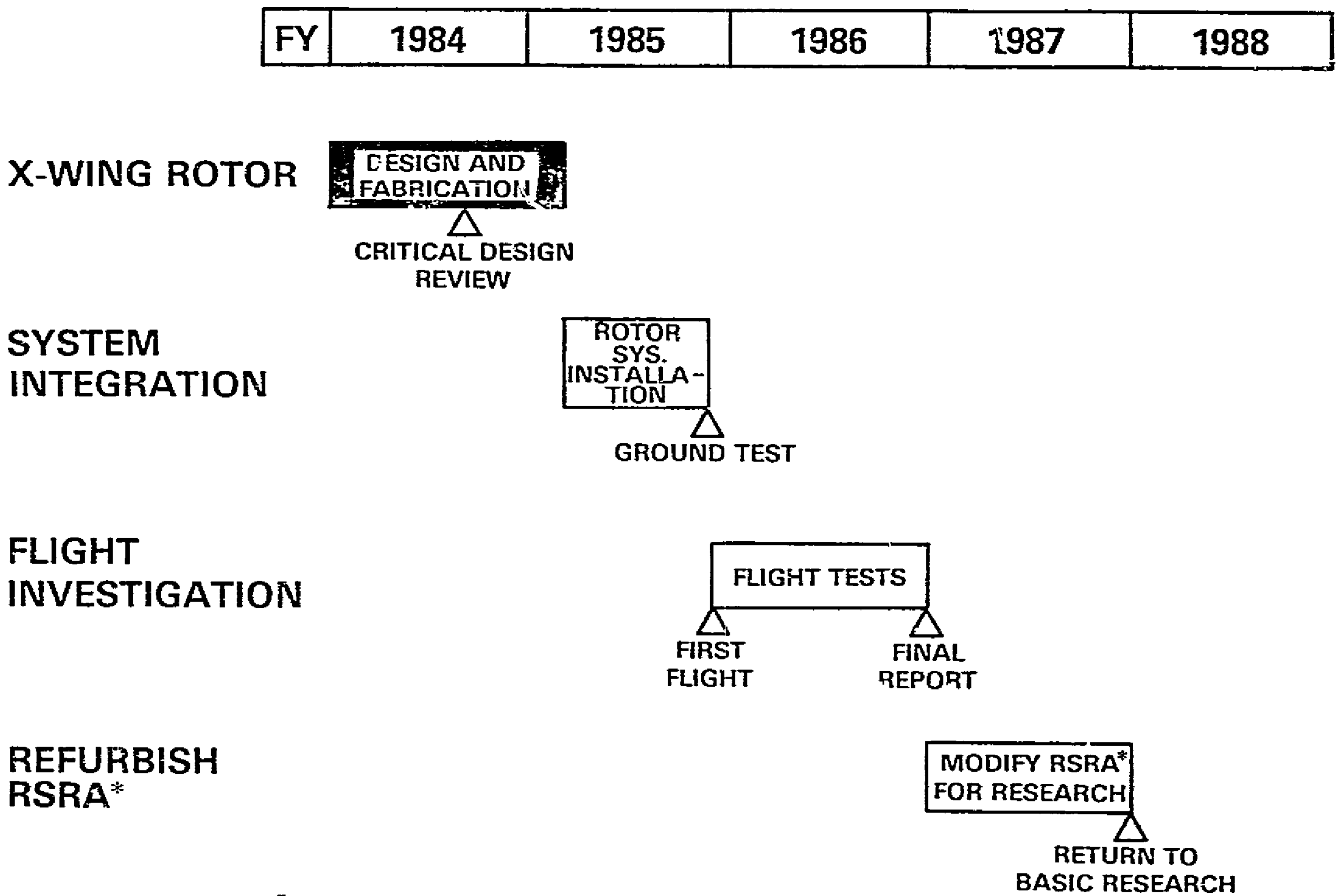
The initiatives described below are planned as augmentations to the current aeronautics research and technology development program to facilitate realization of the technology objectives listed earlier. They update and, in some cases, replace the initiatives in last year's plan. Some of them will be proposed as adjustments to current programs described in Section D of this chapter, some are proposed as new program elements, and others would 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. Advanced Turboprop Large-Scale Systems Research

This augmentation will provide for flight testing, by as early as 1987, a large-scale advanced propeller (propfan) 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, which will provide the additional 5- to 8-percent increase in fuel savings of counter-rotation while eliminating the need for a high-power gearbox. A 9-foot diameter advanced propeller integrated with a flightworthy 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 F404 engine as a research testbed.

FIGURE VIII-3

RSRA*/X-WING ROTOR FLIGHT INVESTIGATION



*ROTOR SYSTEMS RESEARCH AIRCRAFT

2. Transonic-Supersonic Oblique Wing Technology

The objective of this initiative is to extend the technology for oblique wings to include transonic and supersonic speeds. Subsonic, transonic, and supersonic wind-tunnel tests on models and flight tests of a subsonic oblique wing aircraft, the AD-1, have established a firm data base for the aerodynamic, structural and flight control, and handling characteristics of oblique wings. However, additional flight research is needed in the transonic speed regime because it is there that the oblique wing promises the greatest benefits for DOD missions. To meet that need, a high-performance military aircraft will be modified by incorporating a new, composite, aeroelastic oblique wing and related actuation, control, and other systems for use in flight research at speeds up to at least Mach 1.2. That research will yield aerodynamic performance and stability and control data to determine whether the concept of a transonic-supersonic wing is valid.

3. Rotorcraft Systems Noise

Emerging developments in acoustic research for rotorcraft require a reliable, comprehensive data base for demonstrating the feasibility of integrating expected changes in rotorcraft to decrease the noise they generate. To acquire that data base, three NASA centers will cooperate to measure completely the noise levels inside and outside a modern, four-bladed helicopter, as well as those generated by its transmission. The work will be coordinated with DOD and the Federal Aviation Administration and will exploit results the Army obtains in its Integrated Technology Rotor program. The data on noise levels outside the aircraft must be of precise quality, must be measured over the full hemisphere beneath the aircraft, and must be coordinated with full data on blade loads and from monitoring within the cockpit. Wind tunnel tests of full- and small-scale models will demonstrate whether the results from such tests can be used for certification purposes. Then tests to assess the decrease in noise levels produced by integrating various noise-reduction design features will be conducted with a new research rotor the Army is developing.

4. Critical Active Flight Controls

This multicenter initiative to develop technology for fault-tolerant active controls for civil and military aircraft will focus on further development of active control algorithms, design of architectures for fault-tolerant electronic systems, and verification and validation of the integrated aircraft and fault-tolerant active control system. Requirements will be formulated and algorithms and design tools will be developed for active control systems for both civil and high-performance military aircraft. The accuracy of current control laws will be verified through simulation, wind tunnel testing, and flight testing. Architectures for electronic systems that are crucial to safety of flight will be formulated and validated by analyses, simulation-emulation, and flight testing to determine their ability to implement the control laws reliably.

5. Structural Ceramics for Turbine Engines

The performance, durability, and replacement costs of gas turbine engines depend largely on the materials used in hot-section components and the processes by which those components are fabricated. Ceramic materials have the potential to provide greater high-temperature strength, lower density, lower cost, and greater corrosion resistance than do current materials; and they have the added advantage that they contain no strategic materials. Consequently, this initiative will seek to develop the technology needed for reliable ceramic components such as turbine blades, abradable seals, vanes, combustor liners, and coatings made of silicon carbide, silicon nitride, and zirconia. The emphasis of this initiative will be on removing the principal impediments to expanded use of ceramics: poor reproducibility and poor reliability.

6. Superaugmented Rotorcraft

This initiative 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 DOD 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 and 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.

7. Laminar Flow Wing Flight Research

This initiative will try to develop technology that will lead to laminar flow systems for transport aircraft. New materials, fabrication methods, analysis techniques, and design concepts provide convincing evidence that such systems are practicable. If positive results are obtained from wing leading edge and variable sweep transition flight tests now under way and planned, the practicality of achieving more extensive laminarization in flight can be explored. Selection of concepts for full-chord flight research will be based on the results of the variable sweep transition flight tests and on aerodynamic design studies of laminar flow wings. A DC-9 class of transport with gloves to produce laminar flow currently is expected to serve as a test bed. Gloves to produce natural laminar flow, laminar flow control, and hybrid laminar flow control could be included to permit flight research in crucial problem areas, evaluate reliability and maintainability, and gain experience with actual flight operations.

8. Small-Engine Component Technology

The Small Engine Component Technology program will be a focus for technology development for small-engine components throughout DOD and industry. It will provide fundamental understanding of and an analytical data base for flow phenomena and heat transfer in small compressors, combustors, and turbines. It also will develop analytical techniques for use in designing advanced components to decrease the weight and increase the thermal efficiency, reliability, and durability of small turbine engines suitable for use in rotorcraft, commuter and general aviation aircraft, cruise missiles, and auxiliary power units. Its emphasis will be on defining, developing, and quantifying design techniques to minimize the adverse effects of small size.

9. Aircraft Electric Power Systems Technology

This initiative will be a multicenter one to develop a technology foundation for aircraft with electric secondary power systems and fault-tolerant flight controls. Emphasis will be on fault-tolerant systems, samarium-cobalt motors, power conditioning, and electromechanical actuators with high-frequency response. It will span the research spectrum from laboratory investigations through flight research.

10. Supersonic Short Takeoff and Vertical Landing Technology

This initiative's objective is to develop a technology base for advanced, supersonic, short takeoff and vertical landing fighters. That technology base is needed for a new generation of high-performance fighters capable of operating from a variety of surfaces, including damaged runways and the decks of small ships. Such fighters also could be used to increase sortie rates from large aircraft carriers and to enhance inflight maneuverability. The activities under this initiative will be in four phases: preliminary design studies on several concepts, testing of models and components to validate the critical elements of the concepts selected, designing and building an experimental aircraft for conducting proof-of-concept and flight tests, and use of the aircraft in a flight-research and experiments program.

11. High-Performance Aircraft

Research will be conducted on the controllability, handling qualities, and safety of high-performance aircraft operating at the extremes of their flight envelopes. Operation at high angles of attack and with vortex lift will be investigated. Theoretical analysis will use nonlinear mathematical models to predict the forces and moments on maneuvering vehicles. Wind tunnel tests will be followed by flight tests to validate the ground-based research and assess controllability, handling qualities, and human factors. Control laws and sensors will be developed to improve the flying qualities, safety, and operation at high angles of attack of aircraft controlled by full-authority digital flight control systems.

12. Hypersonic Engine Technology

This initiative will conduct ground tests and supersonic flight evaluations to develop and extend a data base to cover the full range of flight conditions and speeds for an integrated, dual-mode, supersonic combustion ramjet (scramjet) engine. The specific tasks planned are to design, fabricate, and build two engines; conduct a series of ground-based tests of the engines in NASA's 8-foot High Temperature Structures Tunnel; acquire a supersonic aircraft and modify it for captive flight testing of the engines; conduct supersonic flight tests across the test aircraft's entire speed, altitude, angle-of-attack, and turbulence range; and study options for free flight tests of the engines.

13. Rotorcraft Vibration Research

This initiative will focus on techniques for predicting the vibration that coupled airframes and rotors will experience and on advanced technology for reducing the vibration. The first focus will be to exploit the potential of modern analytical techniques such as finite-element analysis to predict the vibration spectrum of new rotorcraft during their design. The second focus will be on advanced technology to reduce vibration levels through integration of such advanced systems concepts as higher-harmonic control and aeroelastically conformable rotor blades. Research will center on analyses, verification through small-scale tests, and, eventually, tests using the Rotor Systems Research Aircraft equipped with the Integrated Technology Flight Research Rotor or a similar rotor. Industry is expected to conduct complementary work that will bring about the transfer of NASA's generic results into applications for each rotor configuration--single, tandem, hingeless, teetering, etc.

14. Parallel Processing for Structural Analysis

Dynamic three-dimensional finite-element computations can improve aircraft construction significantly and thereby reduce fabrication and operating costs. Development of an experimental large-scale computer system for finite-element calculations will give aircraft designers a means for optimizing their designs. Research using the present 16-element finite-element research computer will provide the algorithms needed for designing and fabricating an experimental computer system with 200 to 400 times the capability of any existing class VI computer system.

Institution

IX. INSTITUTION

CONTENTS

TABLE

FIGURES

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 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 for concentration of effort. Provisions were included for updating the goals and objectives to keep them on a multiyear basis.

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 the work force to achieve and maintain excellence. The eighth calls for applying the latest in technological developments and management thought to make the NASA institution as productive as possible.

NASA's plans for people, facilities, and computers and other equipment are aimed at meeting those two goals.

B. Manpower

In FY 1983, NASA began a modest augmentation of its scientist and engineer work force with a significant infusion of recent graduates. The objective is to staff the Agency with sufficient scientists and engineers possessing the latest skills and knowledge in areas, including advanced data processing and computation, essential for conducting the Agency's current and emerging programs.

The scientist and engineer complement increased by nearly 350--to 11,094--during the year and 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.

The FY 1983 increase in scientists and engineers was the result of a vigorous college recruitment program spearheaded by top management. Continued success 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 its declared policy of continued leadership in space and aeronautics, NASA must maintain a work force stable in size and containing a technical component that possesses up-to-date skills.

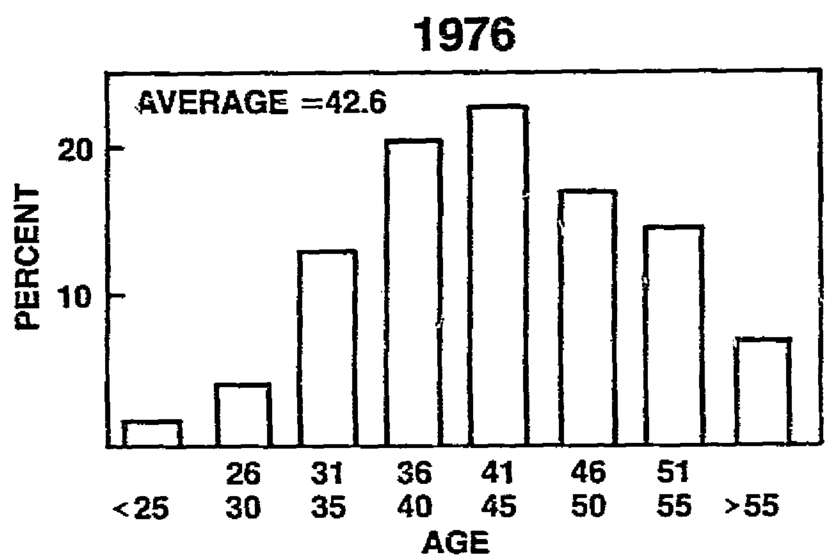
TABLE IX-1. SCIENTIST AND ENGINEER HIRES

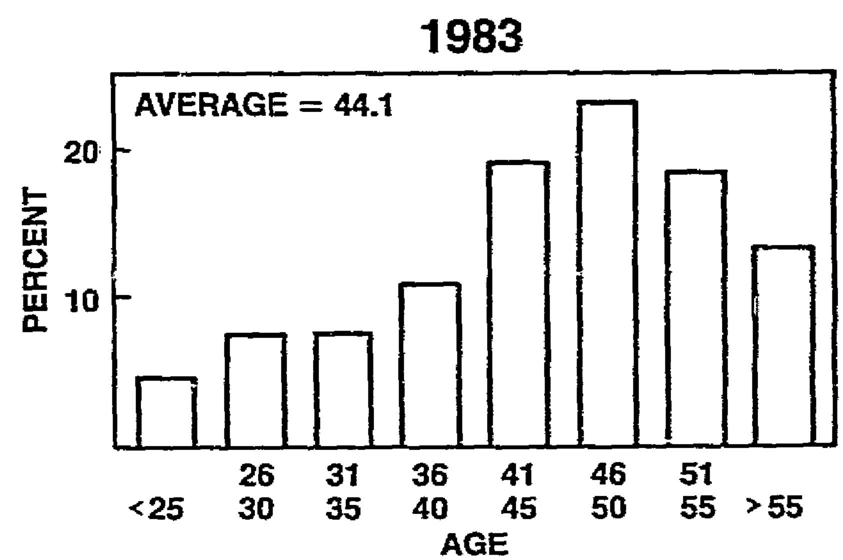
	NUMBER HIRED	PERCENT FRESH OUTS	PERCENT CO-OPS
FY 1978-1981	1,800	55	25
FY 1982-1983	1,050	77	20
FY 1984-1985	1,100*	65-70*	20*
FY 1986-1989	4,000-4,500*	65*	25*

* Estimate

FIGURE IX-1

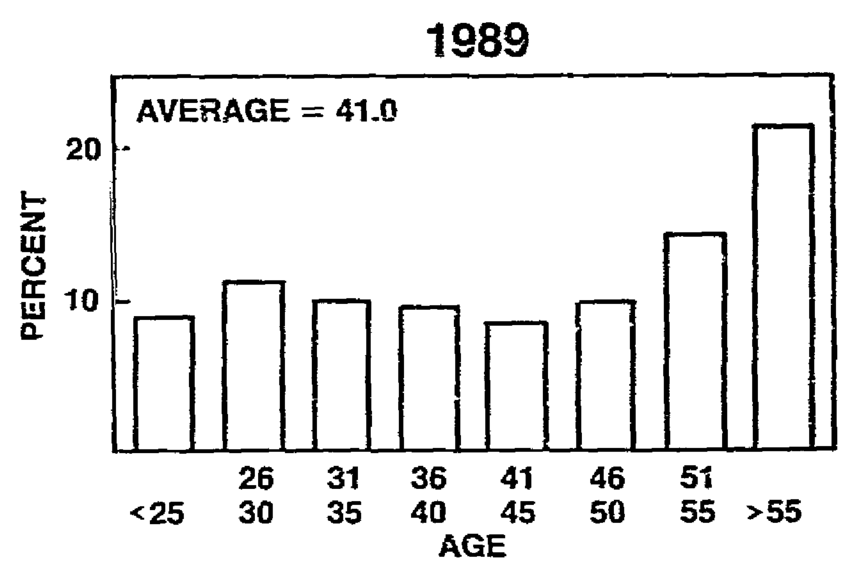
AGE DISTRIBUTION OF SCIENTISTS AND ENGINEERS





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)



C. Facilities

New priority was assigned in FY 1983 to improvement and construction of facilities as a means to enhance the NASA institution. The program's emphasis is 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 Programmed 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 30 to 40 flights per year of the Space Shuttle, additional payload processing facilities, unique large aeronautics facilities, and augmentation of facilities to make them able to support a space station.

D. Automatic Data Processing

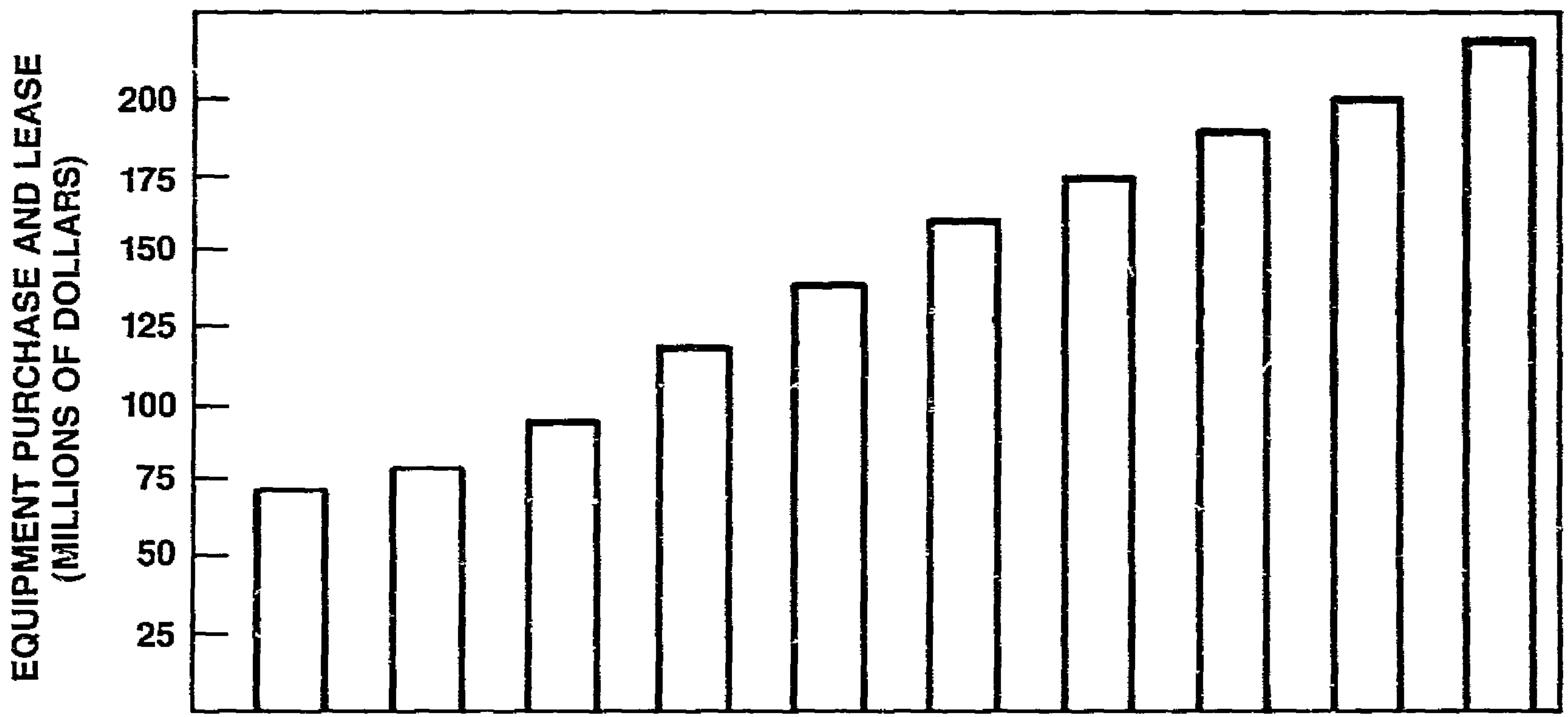
The objectives of NASA's computer systems management are to:

- 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 Aerodynamics Simulation, to be installed at Ames Research Center (see Chapter III. Aeronautical Research and Technology).

FIGURE IX-2

AUTOMATIC DATA PROCESSING ACQUISITION PLAN

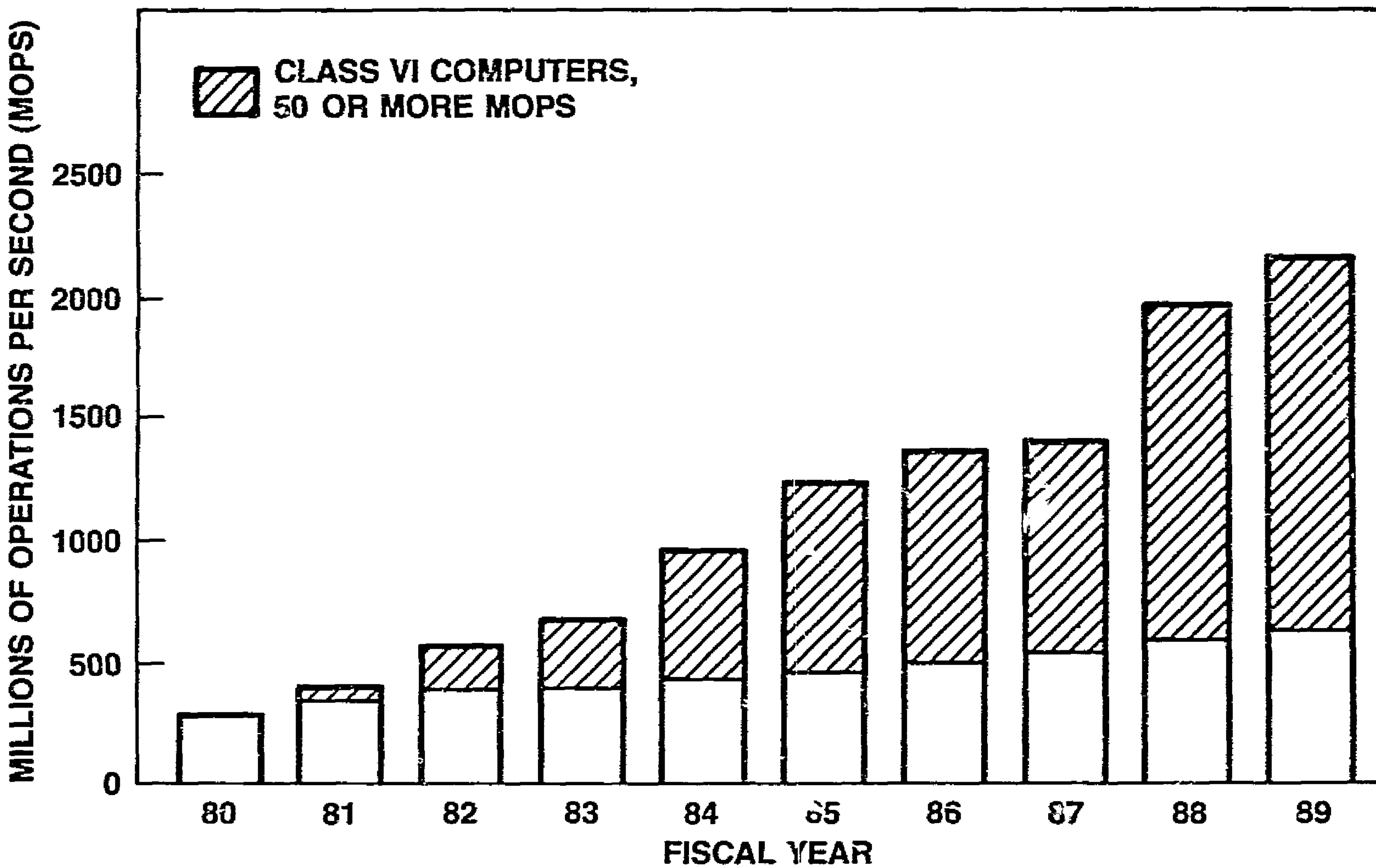


	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
AVAILABLE CPU CAPACITY	1,903	2,321	2,550	2,564*	2,491*	2,550*	2,700*	2,850*	3,000*	3,200*
AVERAGE CPU AGE	6.9	6.5	6.2	6.0*	5.9*	5.8*	5.8*	5.7*	5.7*	5.6*

* PROJECTED

A significant indication of the Agency's effort to meet research and development needs by exploiting advancing technology is its plan for acquiring class VI computers, able to perform 50 million or more operations per second. Figure IX-3 shows that plan through FY 1989.

FIGURE IX-3
COMPUTATIONAL CAPABILITY PLAN



Abbreviations and Acronyms

X. ABBREVIATIONS AND ACRONYMS

ACC	Aft Cargo Carrier
ACS	Attitude Control System
AMPTE	Active Magnetospheric Tracer Explorer
ATP	Authority to Proceed
ATS	Advanced Technology Satellite
CDR	Critical Design Review
CFMC	Cryogenic Fluid Management Facility
COBE	Cosmic Background Explorer
CRAF	Comet Rendezvous and Asteroid Flyby
CTS	Communications Technology Satellite
CY	Calendar Year
DE	Dynamics Explorer
DOD	Department of Defense
ECLSS	Environmental Control and Life Support Systems
ELF	Extreme Low Frequency
ELV	Expendable Launch Vehicle
EMU	Extravehicular Mobility Unit
ERBS	Earth Radiation Budget Satellite
ET	External Tank
ETR	Eastern Test Range
EUVE	Extreme Ultraviolet Explorer
EVA	Extravehicular Activity
FUSE	Far Ultraviolet Spectroscopy Explorer
FY	Fiscal Year
GEO	Geosynchronous Orbit, Geostationary Orbit
GOES	Geostationary Operational Environmental Satellite
GRO	Gamma Ray Observatory
HEO	High Earth Orbit
ICE	International Cometary Explorer
IMP	Interplanetary Monitoring Platform
IMPATT	Impact Avalanche Transmit Time
IPS	Instrument Pointing System
IRR	Interface Requirements Review
ISEE	International Sun-Earth Explorer
ISPM	International Solar Polar Mission
ISTP	International Solar Terrestrial Physics
IUE	International Ultraviolet Explorer
IUS	Inertial Upper Stage
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LEO	Low Earth Orbit
LFC	Laminar Flow Control, Large Format Camera
LM	Long Module

MDM	Multiplexer Demultiplexer Pallet
MFLOPS	Million Floating Point Operations per Second
MGCO	Mars Geoscience and Climatology Orbiter
MMU	Manned Maneuvering Unit
MOTV	Manned Orbital Transfer Vehicle
MPESS	Mission Peculiar Experiment Support Structure
MSL	Material Science Lab
NACA	National Advisory Committee for Aeronautics
NAS	Numerical Aerodynamic Simulation
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications (Network of Leased Communications Services for Operational Data Flow)
OAST	Office of Aeronautics and Space Technology
OMV	Orbital Maneuvering Unit
OSS	Office of Space Science (combined in 1982 with Office of Space and Terrestrial Applications to form 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
PAM-A	Payload Assist Module (Atlas Class)
PAM-D	Payload Assist Module (Delta Class)
PDR	Preliminary Design Review
POP	Program Operating Plan
R&T	Research and Technology
RMS	Remote Manipulator System
RSRA	Rotor Systems Research Aircraft
RTOP	Research and Technology Objectives and Plans
SCRAMJET	Supersonic-Combustion Ramjet
SDLV	Shuttle Derived Launch Vehicle
SDR	System Design Review
SHEL	Shuttle High Energy Lab
SIR	Shuttle Imaging Radar
SL	Spacelab
SM	Short Module
SME	Solar Mesophere Explorer
SMM	Solar Maximum Mission
SP	Space Platform
SRB	Solid Rocket Booster
SRR	System Requirements Review
SS	Space Station
SSME	Space Shuttle Main Engine
SSTSC	Space Station Technology Steering Committee
SSUS	Spinning Solid Upper Stage
STDN	Spaceflight Tracking and Data Network
STS	Space Transportation System

TDRS(S)	Tracking and Data Relay Satellite (System)
TOPEX	Topography Experiment for Ocean Circulation
TOS	Transfer Orbital Stage
TSS	Tethered Satellite System
UARS	Upper Atmosphere Research Satellite
ULF	Ultra Low Frequency
VLBI	Very Long Baseline Interferometry
VLSI	Very Large Scale Integration
WB	Wide Body
WTR	Western Test Range
XTE	X-Ray Timing Explorer

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OF POOR QUALITY

Index

XI. INDEX

NASA-Langley, 1984