

**Aeronautics
and
Space Report
of the
President**



1988 Activities

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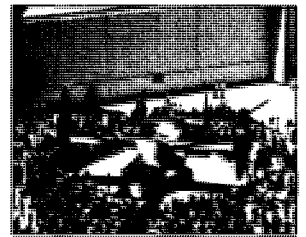
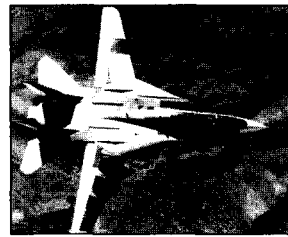
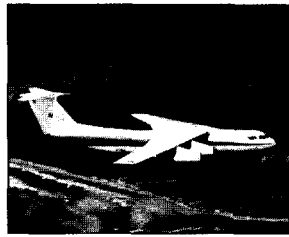
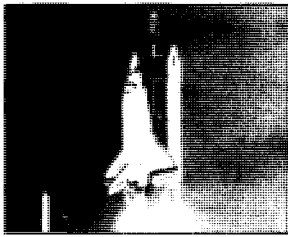
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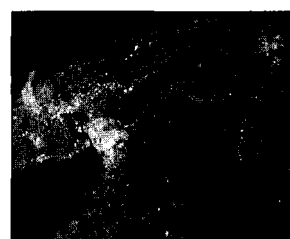
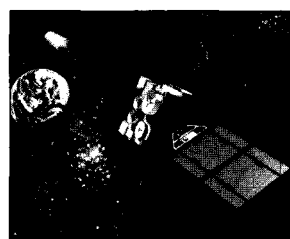
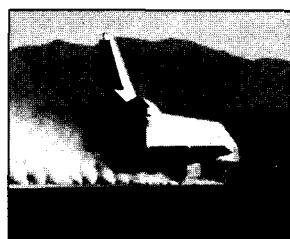
National Aeronautics
and Space Administration
Washington, DC 20546

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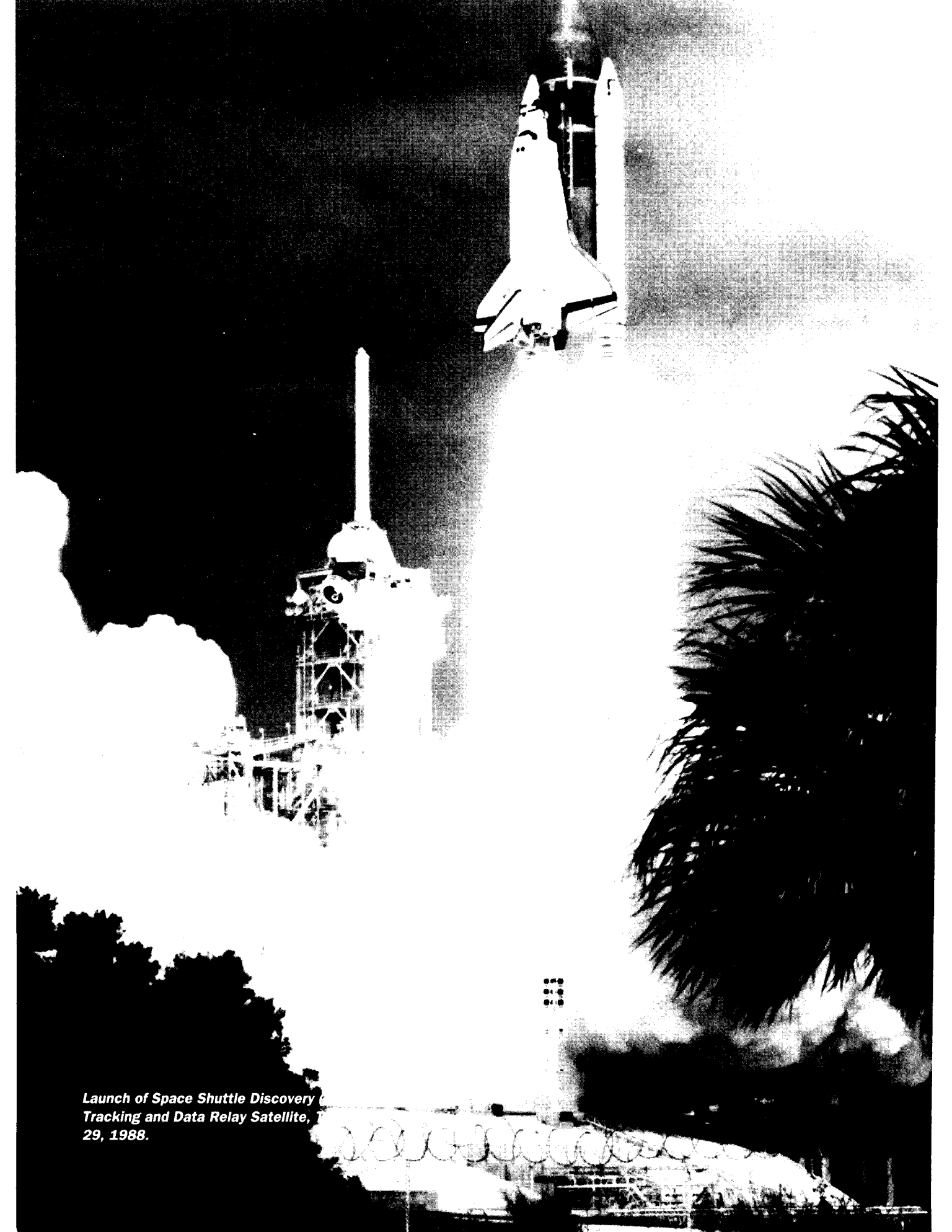
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Launch of Space Shuttle Discovery (with Tracking and Data Relay Satellite, TDRS) on 29, 1988.

Summary

Nineteen eighty-eight marked the United States' return to space flight with two successful space shuttle launches in September and December, as well as six successful expendable rocket launches. Meanwhile, many other less spectacular but important contributions were made in aeronautics and space by the 14 participating government organizations. This chapter summarizes the accomplishments of each of these participating organizations. The remaining chapters of this report provide more detail on each organization's aeronautics and/or space activities for the year.

National Aeronautics and Space Administration

Space Science and Applications

The NASA space science and applications program uses space-based technology 1) to study the universe including Earth, the sun, and the planets; 2) to solve practical problems on Earth; and 3) to provide the scientific research foundation for expanding human presence beyond Earth into the solar system. Scientific disciplines include the following: astrophysics, solar system exploration, space physics, Earth science and applications, life sciences, microgravity science and applications, and communications and information systems.

Astrophysics

The NASA astrophysics program studies the origin and evolution of the universe, the fundamental laws of nature, and the birth of stars, planets, galaxies, and ultimately, life. The program research uses space observatories, supported by a ground research base of instrument developments, suborbital research activities, data analysis, and theoretical studies.

Supernova 1987a. NASA and its international partners continued to study Supernova 1987a in 1988 using spacecraft and radio observatories, as well as rocket, balloon, and airborne campaigns from the Southern Hemisphere. The observations enabled

researchers to determine the composition, average expansion velocity, and other important characteristics of this body.

Hubble Space Telescope. Assembly and retesting of the Hubble Space Telescope (HST), the first of the four Great Observatories, was scheduled for completion in early 1989, with launch expected in 1990. HST is an optical telescope that will enable astronomers to see distant objects about ten times more clearly than can be seen from even the best Earth-based observatories.

Gamma Ray Observatory. Construction of the Gamma Ray Observatory (GRO) continued in 1988, with three of its four scientific instruments being installed on the spacecraft. Like the Hubble Telescope, the GRO is scheduled for launch in 1990. GRO will be used to study extraterrestrial gamma rays, the highest energy radiation in the electromagnetic spectrum.

Advanced X-Ray Astrophysics Facility. In 1988, NASA selected TRW, Inc. to be the prime contractor for the development and integration of the Advanced X-Ray Astrophysics Facility (AXAF). TRW immediately began work on the facility's High Resolution Mirror assembly. The AXAF is designed to observe celestial sources of x-rays, key to answering many of astronomy and astrophysics' most important questions.

Space Infrared Telescope Facility. Detailed studies of the Space Infrared Telescope Facility (SIRTF) were made in 1988. These studies included analyses of the spacecraft and telescope systems. Expected to be the fourth of the Great Observatories, the SIRTF will be used for astrophysical studies in the scientifically critical infrared spectral region. A major focus will be the study of cosmic birth, including that of our solar system.

Solar System Exploration

NASA's solar system exploration program studies the evolution and nature of the planets and other bodies, and why the "terrestrial" planets are so different from one another.

Pioneer Venus. In December 1988, the Pioneer Venus Orbiter completed 10 years of successful observation and data gathering at Venus.

The Interplanetary and Interstellar Medium. The Pioneer 10 and 11 spacecraft are still providing valuable science data on the interstellar medium. Following its encounters with Jupiter, Saturn, and Uranus, Voyager 2 continued its journey toward Neptune. Voyager 1 has left the solar system.

Mars Observer. During 1988, the Mars Observer was descoped to bring the estimated cost of the mission within budget. The Mars Observer will obtain images of the surface and atmosphere of Mars during the four seasons of one Martian year.

Magellan. The Magellan spacecraft completed development and was shipped to the Kennedy Space Center for pre-launch processing in 1988. Launch of the spacecraft was planned for 1989. Magellan will provide global maps of the geological features of cloud-shrouded Venus.

Galileo. Development of the Galileo spacecraft continued toward a planned launch in October 1989. A combined orbiter and atmospheric probe, Galileo will make a detailed exploration of Jupiter and its moons.

Ulysses. During 1988, development of the Ulysses continued, aiming at an October 1990 launch date. Ulysses is a joint NASA/European Space Agency program designed to observe the sun's corona, the solar wind, and other solar events.

Space Physics

The NASA space physics program investigates the origin, evolution, and interactions of particulate matter and electromagnetic fields in a wide variety of space plasmas. Its studies focus on the upper atmospheres, ionospheres, and magnetospheres of the Earth and other planets, the sun, and plasmas throughout the solar system and galaxy.

International Solar Terrestrial Physics Program. Implementation of this program continued with the participation of Japan and the European

Space Agency. This umbrella program will include extensive studies of the sun and its plasma and interaction with that of Earth. The major U.S. contribution will be the Global Geospace Science program, which will study the transfer of energy in the interactive geospace system.

Explorer Missions. In 1988, the International Cometary Explorer (ICE) continued its operations, making solar wind measurements and collecting other data. The Dynamics Explorer conducted two tests to collect data about the Earth's magnetic field. The Charge Composition Explorer collected samples of solar magnesium and sulfur for the first time, leading to new clues about how the solar wind is produced.

Astromag. Further work to define and design the Astromag facility for the space station occurred in 1988. Astromag will be a superconducting magnet attached to the space station to analyze the highest energy cosmic rays from our galaxy and beyond.

Earth Science and Applications

The purpose of NASA's Earth science and applications program is to develop a scientific understanding of how Earth and its environment work as a system.

Upper Atmosphere Research Satellite System. The Upper Atmosphere Research Satellite (UARS) critical design review was completed in early 1988. The spacecraft was undergoing construction and the instruments were being assembled and tested. The UARS will provide a data base necessary to understand the dynamics and chemistry of the Earth's upper atmosphere, the effects of solar activity, and the impact of changes in key constituents such as ozone.

Operational Satellites. NASA continued to support the National Oceanic and Atmospheric Administration's (NOAA) operational weather satellite program in 1988. The program includes both geostationary and polar-orbiting spacecraft.

Atmospheric, Oceanic, and Geological Research. NASA continued a number of atmospheric, oceanic, and geological studies in 1988. These studies

included work to assess the status of the ozone hole over the Antarctic, other studies of stratospheric and tropospheric chemistry, assessment of land processes using Landsat Thematic Mapper data, terrestrial ecosystems research, and crustal dynamics research.

Earth Observing System. During 1988, the Earth Observing System (EOS) progressed to the definition and preliminary design phase of activity. Over 450 instrument and research proposals were received and evaluated. EOS is an interdisciplinary Earth system science mission that will enable a better understanding of the interactions of the atmosphere, oceans, cryosphere, biosphere, and solid Earth. The mission will include a series of orbiting satellites and ground-based research. An international program, EOS involves participants from the United States, Japan, the European Space Agency, Canada, and other nations.

Life Sciences

The NASA life sciences program pursues two goals: 1) understanding of the origin, evolution, and distribution of life in the universe; and 2) development of countermeasures and life support systems that will enable humans to live and work productively in space. Research in these areas is conducted on the space shuttle, on other space-based facilities, and in ground-based facilities.

Space Medicine. During 1988, several drugs were tested for their effectiveness in combatting space motion sickness. Work continued on the development of exercise and other countermeasures to the physiological deconditioning that occurs in space. Other research focused on crew nutrition and environmental health factors such as air and water quality. Planning for the Life Sciences Extended Duration Orbiter Medical Program began in order to support crew stays in space of up to 16 days beginning in 1992. NASA also continued planning for the space station crew-related systems.

Spacelab Life Sciences. In 1988, NASA confirmed the payloads that would be flown on the Spacelab Life

Sciences (SLS) module in mid-1990. SLS-1 will be the first space shuttle mission dedicated to life sciences investigations; experiments will focus on cardiovascular, musculoskeletal, and neurovestibular adaptation to space.

Microgravity Science and Applications

The goals of the NASA microgravity science and applications program is to use the unique environment of space to: 1) advance the understanding of fundamental processes on Earth; 2) understand the influence of gravity on Earth-based processes; 3) pursue limited in-space production of materials with enhanced properties; 4) encourage commercial production of materials in space; and 5) explore the possibility of processing extraterrestrial materials. Related scientific disciplines include the fundamental sciences, materials science, and biotechnology. During 1988, microgravity experiments were flown on the STS-26 shuttle mission. These investigations involved protein crystal growth and other materials science activities.

Space Flight

Throughout 1988, NASA focused on returning the space shuttle to flight, which it accomplished in September with the successful Discovery mission (STS-26). Moreover, the agency moved vigorously to establish a mixed fleet capability which assures access to space using both the shuttle and expendable (unmanned) launch vehicles (ELVs). Another major activity has been NASA's efforts to assist in the commercialization of space use and to encourage private sector investment in space transportation systems as called for by the President's National Space Policy of January 1988. Finally, the agency continued its ongoing studies of an advanced space transportation infrastructure to support future national requirements, including manned and unmanned exploration of the solar system and the permanent presence of human beings in space. In sum, NASA continued the process of maintaining and improving a strong, safe and reliable U.S. space transportation capability.

Orbiter. An extensive review and analysis process undertaken following the Challenger accident identified 226 changes for the orbiter alone. Of these, 107 were considered mandatory for the September Discovery mission. Two hundred sixty-one alterations to Discovery had been completed in total by July.

Solid Rocket Booster. A flawed joint in the solid rocket motor (SRM) was directly responsible for the explosion that caused the Challenger accident, so it was carefully and extensively redesigned. The redesigned SRM received intense scrutiny during 1988 and was subjected to a thorough certification process to verify that it works properly and to qualify the motor for manned flight.

Space Shuttle Main Engine. Although the space shuttle main engines have never experienced a problem during a shuttle flight, NASA used the flight downtime to undertake an intensive reexamination and safety margin improvement program for the main engines. As with the solid rocket booster, the focus was on testing the main engines to insure their readiness for the return to flight.

1988 ELV Launches. The expendable launch vehicle (ELV) program also had a perfect launch record in 1988—six for six: one Delta, four Scouts, and one Atlas-E expendable launch vehicles.

The Mixed Fleet Strategy. NASA's mixed fleet strategy, codified by the President's January 1988 National Space Policy, calls for manifesting civilian missions on ELVs whenever the unique capabilities of the shuttle are not required.

Phase I of the strategy covers launches in the 1988-92 time-frame and allows for the acquisition of launch services either through DOD or commercially. Specifically, four near-term payloads previously intended to fly on the shuttle (ROSAT, EUVE, CRRES, and Mars Observer) have been designated to launch on ELVs during Phase I.

In addition to arranging for the purchase of launch services from the commercial sector, NASA also

followed the President's space policy by taking steps to divest itself of an adjunct ELV capability and by making NASA-owned ELV property and services available to the private sector. During 1988, NASA finalized a barter agreement with General Dynamics—negotiated over 15 months—that gives the company ownership of NASA's Atlas/Centaur flight and non-flight assets. In exchange General Dynamics will provide the agency with two Atlas/Centaur launches in the future at no charge.

Furthermore, in May 1988, the agency transferred accountability for Delta Launch Complex 17 at Cape Canaveral to the USAF. Finally, NASA signed enabling agreements with McDonnell Douglas, Martin Marietta, and LTV to allow those companies to negotiate directly with NASA centers for access to NASA ELV property and services.

Orbital Maneuvering Vehicle. The development of the unmanned, free-flying orbital maneuvering vehicle (OMV) continued in 1988, and a preliminary design review was completed in October. Additionally, NASA's Office of Space Flight undertook in 1988 a joint study with NASA's Space Station Office to determine the feasibility of resupplying the station using ELVs and the OMV. Also, a study on man-rating the OMV was completed.

Spacelab. During 1988, replacement of Spacelab's on-board computers with units similar to the updated orbiter computers continued. Also, the changes recommended by the Spacelab recertification board continued to be carried out.

Additionally, management of the Hitchhiker program was consolidated to reduce costs under the responsibility of the Goddard Space Flight Center. The Hitchhiker system creates a simple interface between small experiments and the shuttle thereby making integration for flight easier and less costly. Finally, the development of the Spacelab enhanced pallet was near completion at the end of 1988.

Next Manned Launch Vehicle. Attention was devoted in 1988 to examining various next-generation

manned launch vehicle concepts. Three possible directions were under consideration: shuttle evolution, a personnel launch system, and an advanced manned launch system. Preliminary studies, conducted primarily in-house, on all three possibilities proceeded in 1988.

Assured Crew Return Capability. NASA continued assessing the need and concepts for a capability to transport space station crew back to Earth in case of an emergency. During 1988, NASA completed an in-house Phase A (conceptual) study to explore various possibilities.

Shuttle-C. Studies continued in 1988, and included a definition (Phase B) study.

Space Station

Development of a permanently manned space station was mandated by President Reagan in 1984. He reaffirmed the national commitment to the station in 1988 in his National Space Policy, and in July christened the station "Freedom." Space Station Freedom will be a versatile facility to support research in a broad spectrum of technical disciplines, and may evolve to support other potential roles, such as manned missions to the moon and Mars.

The program at NASA moved from the definition phase into the design and development phase in 1988, making schedule adjustments where necessitated by revised funding profiles. Hardware design and development contracts were signed for the four work packages and the Intergovernmental Agreement (IGA) was signed by representatives of the United States, Canada, Japan, and the participating European countries. Memoranda of Understanding (MOU) were also signed by NASA with its counterpart agencies in Canada and Europe, establishing cooperative arrangements for station design, development, operation and utilization work. A similar MOU will be signed with Japan after ratification of the IGA by the Japanese Diet.

By the end of 1988, program requirements had been verified and agreements between the work package

contractors had been implemented to simplify program integration and management.

Utilization and operations planning proceeded steadily, and NASA revised its commercial guidelines and implemented procedures to accommodate proposals.

Commercial Programs

America's space program has embarked on a new beginning. Beyond the efforts leading to the space shuttle's return to flight, there is a strong emphasis on the commercial development of space as a national economic asset.

NASA has established Centers for the Commercial Development of Space (CCDS), which are a nationwide network of unique research organizations which combine industrial interest, university talent, and government sponsorship to investigate and develop areas of commercial potential. Participation and interest has steadily risen since 1985, with the number of CCDS industrial affiliates now totaling well over 100.

Capitalizing on New Ideas from Small Businesses. A growing number of small business concerns are initiating new commercial products in many fields as a result of R&D funding through NASA's continuing Small Business Innovation Research (SBIR) Program. Many of the results and products are being utilized in NASA programs and several have been successfully commercialized.

Expendable Launch Vehicle Commercialization. Assuring a highway to space by fostering growth of a U.S. commercial launch industry is another key initiative of the President's new National Space Policy. NASA's efforts to advocate and encourage development of an expendable launch vehicle (ELV) industrial base have helped make commercial space transportation services a reality.

In addition to procuring commercial launch services on ELVs, NASA moved toward the commercialization of space use in 1988 by playing an integral role in the initiation of two new cooperative ventures with the

private sector: the Commercially Developed Space Facility and Spacehab.

The Administration initiated the Commercially Developed Space Facility program in February 1988 as part of the Commercial Space Initiative. This program would involve the private sector developing an orbital facility for both government and commercial users.

Spacehab, another venture focused upon in the February 1988 Commercial Space Initiative, is a pressurized module for the space shuttle payload bay that is being developed and financed by a private company (SPACEHAB, Inc.). The module will increase the amount of pressurized volume available in the middeck, and thus allow for more commercial ventures and research activities requiring man-tending.

Further Efforts. NASA is also working closely with industry to explore the potential commercial uses associated with the Space Station Freedom. In November 1987 and in October 1988, workshops were held where NASA officials met with more than 200 corporate executives, representing diverse industries, to discuss how the Space Station Freedom can best meet future industry needs.

Technology Utilization. In 1988, the economic impact of some of the NASA-derived spinoffs or applications reported in the *NASA Spinoff* publication were assessed. These NASA spinoffs have resulted in economic benefits from contributions to sales or savings approximately \$27 billion since 1978.

Getting U.S. industry into space with the best prospects for long-term commercial success requires laying a sound foundation on the ground. NASA's efforts in 1988 were focused to support private sector commercial space division and contribute to the overall economic strength of the country.

Space Operations

A vital element of the infrastructure needed to conduct research and science in aeronautics and space is the capacity to communicate with and receive,

distribute, and process information from space vehicles and aircraft.

The NASA Space Operations program provides planning, development, acquisition, and operations of worldwide tracking, data acquisition, data processing and communications systems facilities, and operational support to meet NASA flight-program requirements. A portion of Space Operations' on-going operational communications support was reactivated to meet the needs of our return to shuttle flight. The Tracking and Data Relay Satellite-3 (TDRS-3) was deployed in September 1988 to join TDRS-1 in providing low-Earth orbit operational support to space missions. TDRS-4 will be added to the geosynchronous satellite network in March 1989 (STS-29), bringing to fruition NASA's goal of a space-based tracking capability for low-Earth-orbiting missions, as well as to space missions government-wide. During the past year, the Tracking and Data Relay Satellite in space continued its excellent support of the Landsat, Solar Mesospheric Explorer, Earth Radiation Budget Satellite, and Space Shuttle missions. The TDRS replacement spacecraft program, to replace the satellite lost in 1986, has continued and will ensure continuity of service in the mid-1990s.

The Deep Space Network is preparing for a major challenge when the Voyager 2 spacecraft encounters Neptune in August 1989. During 1988, a number of modifications to the Deep Space Network were under way to improve its sensitivity to prepare for the Neptune encounter and support of several new spacecraft launches. These launches include the Galileo mission to Jupiter and its moons, the Magellan Venus mapping mission planned for 1989, and the Mars Observer mapping mission planned for 1992.

Basic elements of the Communications and Data Systems program form the vital link between the data acquisition stations and the users, and include communications, mission control, and data capture and processing. Communication services were fully activated and all systems supported the shuttle return-to-flight launch in September 1988.

Aeronautics Research and Technology

NASA conducts fundamental disciplinary and vehicle-specific research and technology programs to improve the nation's economic competitiveness, to help ensure a safe and productive national aviation transportation infrastructure, and to contribute to our national defense. To accomplish these goals, NASA works closely with industry, the Department of Defense, and the Federal Aviation Administration to conduct research and develop technology for subsonic aircraft, rotocraft, high performance military aircraft, supersonic cruise aircraft, and hypersonic vehicles.

Disciplinary research is characterized by investigations of basic engineering sciences applicable to a broad spectrum of vehicle classes. Research efforts include conducting computational and wind tunnel aeronautical experiments and flight tests; determining the physical phenomena of turbomachinery operation; developing the material and structural technologies for advanced, cost-effective airframes; exploring emerging technologies to improve cockpit management, crew coordination and decision-making processes; and addressing issues of flight safety arising from natural phenomena and flight operations.

Vehicle-specific research is focused on those emerging technologies which have the potential to enhance the performance and capabilities of specific aircraft classes. Research in the transport category includes both subsonic and supersonic cruise vehicles and is focused on development of those technologies that will provide efficient, safe, and affordable operation within the National Airspace System and will maintain U.S. leadership in the highly competitive world aviation marketplace. To recognize a major contribution in this important area the NASA/Industry Turboprop Team was presented the 1987 Robert J. Collier Award for the conception, development, and flight verification of advanced turboprop propulsion systems.

Research activities in rotocraft address those technical issues, such as structural dynamics, acoustics, and

propulsion, that will expand the utility and community acceptance of this vehicle class. NASA's high performance aircraft research develops high-risk technologies to enhance the agility, performance, and reliability of military aircraft. The hypersonics research program focuses on the enabling technologies, such as propulsion and materials and structures, that will potentially result in the development of a hypersonic flight research vehicle.

In addition to its aeronautical research, NASA operates a unique set of experimental and analytical research facilities. The health and productivity of these national aeronautical research facilities are crucial to the continued success of civil and military aeronautics research and development programs. In 1988, NASA initiated a major five-year revitalization program to ensure that these critical national facilities will continue to be able to meet the needs of the Nation's aviation community.

Space Research and Technology

Through the space research and technology program, the Office of Aeronautics and Space Technology (OAST) is developing a wide range of advanced capabilities that will enable future space missions and ensure continued U.S. leadership in space. To achieve this goal, NASA is committed to providing a technology base that effectively supports future needs for human and robotic exploration of the solar system, for Earth and space science, for space stations, and for transportation systems. NASA's technology efforts range from feasibility research to technology validation, and include flight experiments to demonstrate proof of concept. OAST is also committed to developing technical strengths in the engineering disciplines within industry and academia while maintaining a strong in-house capability at the NASA research centers.

The space research and technology program consists of two complementary program areas, the research and technology base and focused programs.

The research and technology base (R&T base) program conducts fundamental research in promising and innovative advanced technologies in 10 technical disciplines: aerothermodynamics, space energy conversion, propulsion, materials and structures, space data and communications, information sciences, controls and guidance, human factors, space flight, and systems analysis. The R&T base provides expertise and facilities to ensure that NASA has cutting-edge capability to meet future technology requirements over a range of timeframes. The R&T base also supports university engineering research programs to expand and enhance the capabilities of the Nation's engineering community to participate more effectively in the U.S. civil space program. Through the R&T base, and usually in the environment of the laboratory, scientists and engineers evaluate the potential applicability, usefulness, and overall benefit associated with the new technologies. Once the usefulness of the new knowledge is documented, decisions are made to carry selective discoveries into the next stage of technology development—which is called focused technology.

Two focused programs have recently been initiated, the Civil Space Technology Initiative (CSTI) whose goal is to restore technical strength and provide options for future Earth orbit high-priority civil space missions, and the Pathfinder Program, which will develop critical capabilities to enable future human and robotic missions that will expand human presence and activities beyond Earth orbit into the solar system. The CSTI program will address high-priority national and agency needs of the 1990s. The program includes research in technologies to enable efficient, reliable access to, and operations in Earth orbit and to support science missions. The program's technology thrusts are divided into three categories: Transportation, Science, and Operations.

The Pathfinder Program, begun in 1988, implements the new national space policy directing that we start planning for potential exploration missions beyond the

turn of the century. Pathfinder is conceived as a partnership between NASA, industry, and academia and will add to our Nation's ability to maintain leadership in space. The Pathfinder Program will develop a broad set of technologies in five major areas: surface exploration, in-space operations, humans in space, space transfer vehicles, and mission studies.

In 1988, increased planning efforts were directed in two new areas of future activity. The first is aimed at expanding the in-space experiments program to take full advantage of the opportunities that will be provided with the deployment of the Space Station Freedom. The second area of emphasis will increase research and technology activity in support of future programs associated with monitoring Earth's global climate change.

Exploration

Since its establishment in June 1987, the Office of Exploration has led NASA-wide studies to analyze how to expand human presence into the solar system. The intent of this effort is to develop a better understanding of opportunities and options and identify appropriate investments in both near- and long-term NASA programs.

To organize and examine a full spectrum of options for study of the moon and Mars, the office identified three potential strategies for study in 1988. The first strategy, expeditionary trips to the Mars system, emphasized a visible effort to establish the first human presence on another planetary body. The second strategy emphasized advancing scientific knowledge by establishing a science outpost on the moon. The third strategy, evolutionary expansion, would sustain a methodical, step-by-step program to open the inner solar system for exploration, space science research, extraterrestrial resource development and ultimately, permanent human presence. Key factors in the development of case studies to analyze these strategies included the results of trade studies and other assessments, opportunities to advance science and scientific

applications and both near-term and long-term programs, plans, and budgets.

The four case studies evaluated in 1988 were: Human Expeditions to Phobos, Human Expeditions to Mars, Lunar Observatory, and Lunar Outpost to Early Mars Evolution. The two expeditionary studies focused on sending humans to the Mars system as soon as it was feasible. The Lunar Observatory case study was analyzed to evaluate the scientific benefit of establishing astronomical facilities on the lunar surface. The fourth 1988 case study, Lunar Outpost to Early Mars Evolution, examined an evolutionary strategy establishing a lunar base that would become a staging base for a journey to Mars.

Department of Defense

Nineteen eighty-eight could be signified as the year of recovery for the Department of Defense (DOD) in the space area. Notable space achievements included the successful launch of Atlantis with a DOD mission in December 1988 and the first launch of the Titan II in September. Also 1988 saw the initiation of a joint DOD/NASA space booster technology effort known as the Advanced Launch System.

The DOD continued to place high priority on maintaining a robust military satellite communications systems through a combination of government-owned and contractor-leased satellites. The DOD initiated concept work on the Defense Satellite Communications System (DSCS) follow-on, while paying increased attention to the development of common, interoperable, anti-jam, super high-frequency modem for DSCS terminals. The Strategic Defense Initiative (SDI) made tremendous strides during 1988, especially in the program's organizational maturity and in the number of technology options, culminating in a successful Defense Acquisition Board (DAB) review of the Phase I systems.

In the aeronautics area, the DOD completed delivery of all 100 B-1Bs, saw the roll-out of the first B-2 in November, continued development efforts associated

with the Advanced Tactical Fighter program, and completed airframe and electronic flight critical design reviews for the C-17. Assembly of the first C-17 started in August.

In the advanced technology areas, the initial flight of the F-15 Short Takeoff and Landing/Maneuver Technology Demonstrator occurred in September, Phase II of the Advanced Flight Technology Integration F-16, which will demonstrate a two-ship internetted attack and manual night attack capability, began in December. Nineteen eighty-eight saw the start of a follow-on program for the highly successful X-29 (forward swept-wing) program, which will evaluate X-29 agility at high angles of attack. The National Aero-Space Plane Program continued to make major advances in the areas of material characterization, computerized fluid dynamics calculations, critical engine and airframe component fabrication and testing, and development of engine test facilities up to Mach 8.

Department of Commerce

Throughout 1988, NOAA, of the Department of Commerce, was responsible for both polar orbiting and geostationary operational satellites. Also, NOAA provided the government management of the Nation's land remote sensing program—Landsat, conducted by the Earth Observation Satellite Company. The principal users of the operational data are the Nation's weather and climate services—for routine weather forecasting, in climatic evaluation models, and in studies of severe storms and hurricanes. Improvements in accuracy of temperature and moisture soundings were made during this ninth year of operation. Other elements from remote sensors were applied to global and regional studies of vegetation, and to severe weather research for aviation. Major efforts continued in studies of ozone and accurate calibration of its observation because of the importance for climate change studies.

NOAA developed techniques for accurately positioning instrument platforms and set up a global

positioning system network. For fisheries applications, satellite observations provided synoptic information for studying the effects of ocean environments on tracking, distribution, and location of fish populations.

Commerce's National Telecommunications and Information Administration participated in the World Administrative Radio Conference on the use of the geostationary satellite orbit and planning of space services using it. The PEACESAT—designed to provide two-way voice, data, and slow-scan video services in the Pacific—was being reestablished.

Commerce's National Institute of Standards and Technology had projects for studying a special lamp used in the space telescope and evaluating special materials to be used in spacecraft. In space and atmospheric research, there were ongoing studies in water vapor amounts and in measuring atmospheric and electromagnetic parameters around stars.

Department of Energy

The U.S. Department of Energy (DOE) provides nuclear power sources for National Aeronautics and Space Administration (NASA) space missions. These have included the Voyager and Pioneer missions to the outer planets and the Apollo lunar landings. Program descriptions and 1988 progress summaries are described below.

The Radioisotope Thermoelectric Generator (RTG) Program produces power sources that directly convert heat from the decay of Plutonium-238 to electricity. Under this program, 34 units were used in 19 spacecraft launches from the 1960s through 1988. Progress in 1988 saw issuance of the Final Safety Analysis Report for the October 1989 Galileo mission, completion of over 35,000 hours of heat source testing, and over 6,000 hours of life testing of a more efficient power unit. A contractor was selected to develop a rotating turbine/alternator system that would produce energy efficiencies of 18-25 percent in the Turbine Energy Conversion System Program, and the Closed

Brayton energy conversion system was selected as the conversion medium.

The SP-100 Space Reactor Program is intended to develop and demonstrate technology for space power in the 10s and 100s of kilowatts electric power range. Progress highlights in 1988 include fabrication of almost half of the fuel for the ground unit test and achievement of about 85 percent burnup in a fuel test.

The Multimegawatt Space Reactor Program is intended to provide power in the 10s and 100s of megawatts electric range for DOD and NASA. Progress in 1988 saw selection of six contractors and definition of concepts.

The Thermionic Fuel Element Verification Program, which like thermoelectrics converts heat directly to electricity without moving parts, has the potential of higher energy conversion efficiencies with smaller radiators. Progress in this program included component testing.

An additional DOE responsibility is providing satellite equipment for continuous monitoring for nuclear detonations anywhere within the Earth's atmosphere or in neighboring interplanetary space. This program supports treaty verification, intelligence gathering, and military goals.

Department of the Interior

The Department of the Interior (DOI) uses data acquired by satellite and aircraft sensors to inventory natural resources and monitor changes on lands under its management, and maintains an active program of research and technique development in remote sensing. In 1988, the DOI continued to archive, process, and distribute Landsat and Advanced Very High Resolution Radiometer satellite data. The National Aerial Photography and Side-Looking Airborne Radar Programs acquired data over priority U.S. areas. Major land-management applications of remote sensing included wildlife habitat mapping, land-use/land-cover mapping (especially in Alaska), wildfire damage assessment, and irrigated lands inventory. Hydrologic

applications included near realtime snow mapping to support operational snow cover area monitoring, and mapping of reservoir surface water parameters. Oceanographic applications included studies of major ocean circulation patterns and the forms, seasonal distribution, and movement of sea ice. Geologic applications included detecting and identifying mineral deposits with airborne imaging spectrometers; determining the relationship between geological lineaments interpreted from Landsat data and ground hazards in underground mines; designing, monitoring, and reclaiming surface coal mines; and radon hazard assessment. Cartographic applications included satellite image mapping and digital image processing research. Planetary studies were conducted to support the Magellan Mission to Venus (1989) and the Mars Observer Mission (1992). Global change research was conducted in several areas, including global ice monitoring; studies of coastal erosion processes and sea-level change; and regional vegetation condition monitoring. International programs were carried out in Africa, the Middle East, Latin America, the People's Republic of China, and Iceland.

Department of Agriculture

Airborne and space-based remote sensing systems provided vital information to agencies of the U.S. Department of Agriculture (USDA) for agricultural assessment and resource management. Significant achievements during 1988, in addition to ongoing applications research, included use of satellite data for drought and flood impact analysis, testing and development of satellite electronic positioning equipment for forest management, and implementation of geographic information systems which use digitized remotely sensed data as a primary component.

Federal Communications Commission

Pan American Satellite Corporation's (PanAmSat) "Simon Bolivar" (PAS-1) satellite provides services to Europe, the Caribbean, and Latin America. It was

launched aboard an Ariane IV rocket and placed in orbit at 45 degrees West Longitude on June 15, 1988. The Commission granted authority to the Communications Satellite Corporation (Comsat) to participate in the launch of the International Telecommunications Satellite Organization (INTELSAT) V-B (F-13) satellite which was on May 17, 1988. By the end of 1988, INTELSAT maintained 13 satellites in geosynchronous orbit. The Commission also authorized the construction and launch of nine new and 10 replacement domestic fixed-satellites, increasing the total number of authorized in orbit domestic satellites to 42. Twenty-nine domestic satellites were in orbit and located between 69 degrees West Longitude and 143 degrees West Longitude on the geostationary orbital arc. Three domestic satellites were launched in 1988, one of which was not in its proper orbit.

INMARSAT operated the MARECS B-2 in the Atlantic Ocean region, and the Maritime Communications Subsystem (MCS) satellite packages on the INTELSAT V (F-8) in the Pacific Ocean region, and the INTELSAT V (F-5) in the Indian Ocean region, all under lease agreements. Second-generation satellites were being built and would have a capacity about triple that of the already leased satellites. INMARSAT's four second-generation spacecraft were being constructed with 3 megahertz of bi-directional bandwidth in the Aeronautical Mobile-Satellite Service (R) band. Aeronautical Radio, Inc. is pursuing international aeronautical services via INMARSAT. In addition, a consortium of eight qualified applicants for domestic mobile-satellite service, the American Mobile Satellite Consortium, submitted a technical proposal and joint operating agreement. The AMSC also proposed to provide aeronautical service on its system.

Six additional applications for new Direct Broadcast Satellite (DBS) authorizations were filed in 1988, and the Geostar Positioning Corporation began to provide start-up radiodetermination satellite service.

The concluding Second Session of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of the Space Services Utilizing It (WARC-ORB[2]-88) was concluded in 1988. Also, the international procedures used to provide orderly access to the geostationary-satellite orbit in other frequency bands were improved.

Department of Transportation

Federal Aviation Administration

During 1988, the Department of Transportation's Federal Aviation Administration (FAA) engaged a wide range of research and development activities designed to promote civil aviation and enhance its safety and security. The agency made progress under its National Airspace System Plan, an evolving strategy for modernizing air navigation and air traffic control. In June 1988, for example, the last of 20 Host Computer Systems began operation, upgrading the efficiency of en route air traffic control while providing the computer capacity for further improvements. In another major step, the FAA awarded an acquisition contract for an Advanced Automation System to equip controllers with wholly new workstations and automated capabilities. In addition to such measures to enhance the ground-based air traffic control system, the agency continued to develop the airborne Traffic Alert and Collision Avoidance System.

Continuing its drive to improve airport capacity, the FAA engaged in multiple activities that included an operational demonstration of a prototype Precision Runway Monitor to facilitate simultaneous approaches to parallel runways. The FAA also used a variety of approaches to reduce the aviation problems caused by adverse weather. Examples included the commissioning of the first two expanded-network Low Level Wind Shear Alert Systems, an operational evaluation of a Terminal Doppler Weather Radar, and continued development of an airborne windshear detection system.

Many other safety research projects addressed such diverse issues as aircraft crashworthiness, toxicity from burning materials, new detection systems for airport security checkpoints, and the role of human factors in preventing accidents. Efforts to foster aviation included programs to improve runway design and to promote rotocraft and power lift vehicles.

Commercial Space Transportation

The Department of Transportation's Office of Commercial Space Transportation (OCST) during 1988 adapted its programs to prepare for the commercial launch operations that were to begin in 1989. To support this, OCST continued to enter new areas and break new ground to create the foundations for guiding privately conducted U.S. launch activities.

In 1988, OCST issued two launch licenses: one to Conatec, Inc., covering two sub-orbital microgravity payloads to be launched from the White Sands Missile Range in New Mexico; and one to McDonnell Douglas Corp. for the launch of a telecommunications satellite (INSAT 1-D) from Cape Canaveral, FL.

OCST also established insurance requirements for four companies. The office issued both third-party liability and government property insurance requirements to Conatec, Inc. The office also completed the analytical work upon which to base government property insurance requirements for the three major launch firms—Martin Marietta, McDonnell Douglas, and General Dynamics.

In June 1988, OCST and NASA jointly sponsored a highly successful symposium, "Future of the U.S. Space Transportation Industry," and in October 1988, OCST, NASA, and the Air Force jointly sponsored the "Commercial Space Risk and Insurance Symposium." This symposium was targeted to the insurance community for the purpose of describing OCST's technical approach to the risks associated with space transportation.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), through its Environmental Monitoring Systems Laboratory in Las Vegas, NV, routinely conducts research and technical support using both satellite and aircraft-based remote sensing as part of an overall environmental monitoring program. Large-scale aerial photography is collected and interpreted to support the provisions of the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act; medium-scale photography is collected and interpreted to support non-point pollution studies, wetlands protection, coastal zone studies, and forest ecosystem decline due to acid deposition; and high altitude photography is interpreted for broad area studies in the coastal zone and to contribute land-use/land-cover information in risk assessment studies. Airborne and satellite multispectral scanner data are collected and interpreted to support water quality, non-point pollution, hazardous waste, and acid deposition investigations. Airborne laser systems are developed which contribute to air and water monitoring, and a geographic information system is used to integrate multiple data sets in support of environmental risk assessment and the development of alternative actions for remediation and pollution prevention.

National Science Foundation

The National Science Foundation is the principal supporter of academic research in atmospheric sciences and ground-based astronomy. Major 1988 activities in atmospheric sciences included the development of the world's most powerful sodium resonance lidar system at the University of Illinois, Urbana; verification of a new meteorological phenomenon—the “downburst”—as a serious hazard to aircraft; and installation of a network of stations for monitoring ultraviolet radiation at the Earth's surface under the Antarctic “ozone hole.”

In astronomical sciences, significant events in 1988 included the discovery of evidence for the existence of gravitational lenses by optical and radio astronomers; the development and implementation of array detectors that provide infrared images of galaxies; the detection of the first visible light echo ever observed from a supernova; and the discovery of one of the fastest rotating pulsars, located in an eclipsing binary system.

Smithsonian Institution

The Smithsonian Institution contributes to the national space program through basic research conducted at the Smithsonian Astrophysical Observatory in Cambridge, MA, and the Center for Earth and Planetary Studies at the National Air and Space Museum (NASM) in Washington, DC. NASM's exhibits, lectures, and education programs also contribute significantly to the public understanding of space research and exploration. A new Laboratory for Astrophysics was established at NASM in 1988 for research concerning the interpretation of infrared observations made from both the ground and space. In November the 10th anniversary of the launch of the Einstein (HEAO-2) X-ray Observatory was celebrated with a special symposium reviewing the results of x-ray astronomy during the previous decade. Other highlights of the year included the obtaining of extremely high-resolution x-ray images of the sun with a rocket-borne camera; the use of the International Ultraviolet Explorer satellite to observe both rare, star-forming galaxies and the Supernova 1987a; the development of a novel method for improving the stability of the atomic clocks used in space tracking experiments; and the geologic mapping of regions on Jupiter's satellite Ganymede and on Mars, with the latter compared to similar areas on Earth.

Department of State

The Department of State represents the United States Government in international negotiations with

other governments concerning space issues, in international organizations involved in space, and in foreign countries. The Department advises the President on international space matters, and is responsible for evaluating and advancing U.S. foreign policy interests in the context of space activity.

The most significant demonstration of international cooperation in space this year was the signing at the Department of State in Washington, DC, on September 29, 1988, of the Space Station Freedom agreements with European, Japanese, and Canadian representatives. The State Department, NASA, and other interested agencies worked closely to develop agreements which could serve as models of international cooperation.

The Department participated with other agencies in formulating the new U.S. space policy signed by President Reagan on January 5, 1988. The Department and NASA continued to work on arrangements with other nations to provide emergency landing facilities for the space shuttle. An agreement between the United States, France, Canada, and the Soviet Union concerning the international search and rescue satellite system (COSPAS-SARSAT) was signed on June 30, 1988. Nineteen eighty-eight was the 30th anniversary of the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS) which was established on the basis of a proposal presented by the United States and 19 other states. Issues studied in COPUOS during the year included remote sensing and nuclear power sources in space.

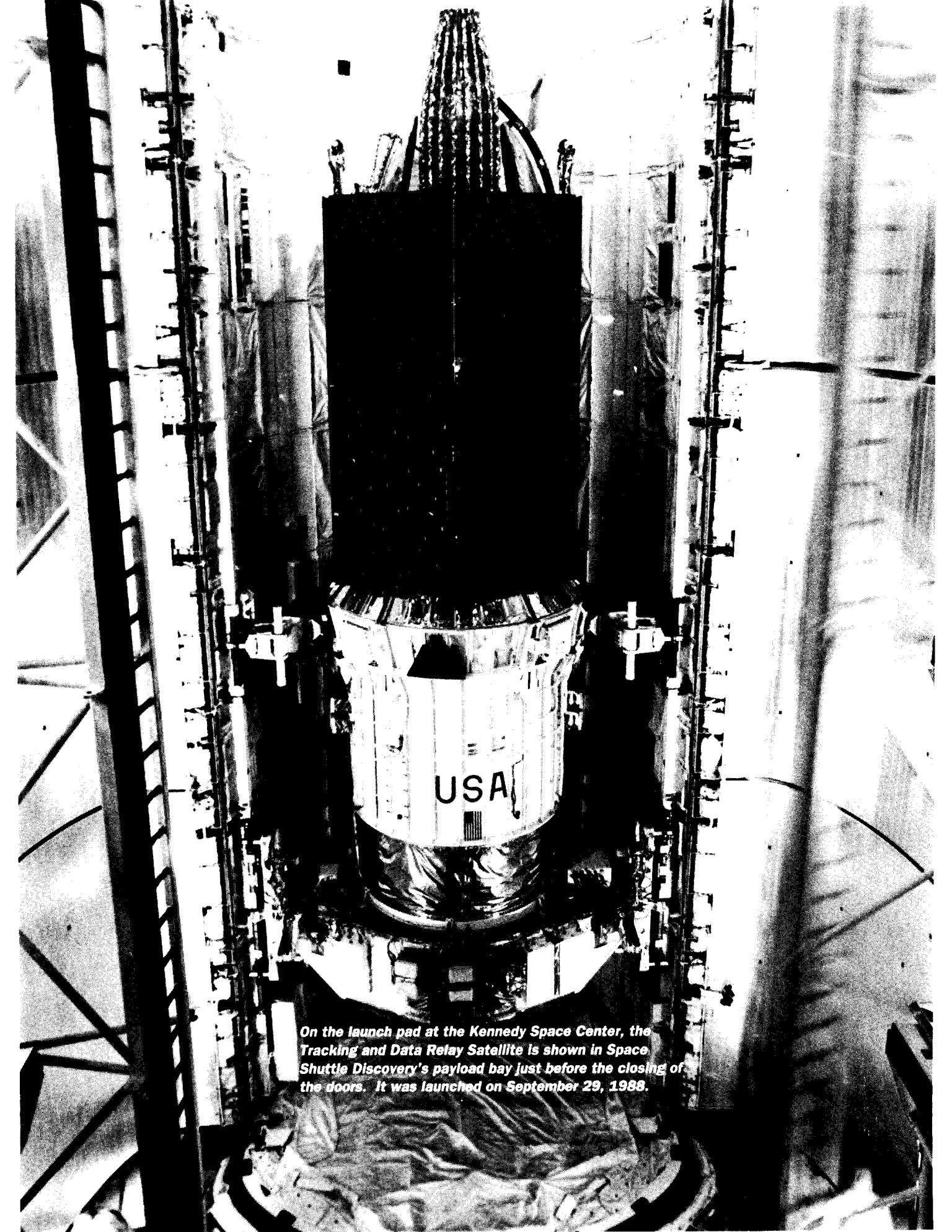
During 1988 the International Telecommunication Union held the Second Session of the Space Services World Administrative Radio Conference at which various improved procedures were agreed upon. During the year both INMARSAT and INTELSAT satellites moved towards broader international services in space.

Arms Control and Disarmament Agency

The U.S. Arms Control and Disarmament Agency (ACDA) has an indirect role in the U.S. civil space program largely concentrating on arms control considerations of space weapons systems, both defensive and offensive. Among other things, ACDA explains and defends the President's Strategic Defense Initiative in multilateral and bilateral fora. ACDA represents the United States in space arms control negotiations at the bilateral U.S.-Soviet Nuclear and Space Talks in Geneva. ACDA also leads the U.S. delegations involved in multilateral considerations of space arms control issues at the First Committee of the United Nation's General Assembly in New York and at the Conference on Disarmament (CD) in Geneva. The CD's ad hoc committee on outer space, established for the first time in March 1985 and renewed in 1987, is the venue for multilateral examination of issues relevant to the prevention of an arms race in outer space. Its non-negotiating mandate is designed to encourage discussion on any proposals that may be made on outer space issues and to review the current space legal regime.

U.S. Information Agency

Despite the enforced lull brought on by the Challenger disaster, the U.S. Information Agency (USIA) conducted an active overseas information program promoting U.S. achievements in space during 1988. Of particular note were four live WORLDNET television interviews on NASA's role in ozone layer research and USIA media's coverage of the Discovery launch. Given foreign interest in most everything related to U.S. space activities, USIA finds a ready audience for its programs and products. USIA has various ways to bring messages on space to the world: It can use its daily WORLDNET TV broadcasts, various Voice of America programs, telephone interviews, and Wireless File stories and statements; it also uses exhibits, video tapes, books, and cultural center and library programs to show U.S. advances in space exploration and technology.



On the launch pad at the Kennedy Space Center, the Tracking and Data Relay Satellite is shown in Space Shuttle Discovery's payload bay just before the closing of the doors. It was launched on September 29, 1988.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA), established in 1958, is responsible for planning, conducting, and managing civilian research and development activities in aeronautics and space. Other federal agencies, state, local, and foreign governments, as well as educational institutions and private industry, also share in NASA's programs.

NASA's mission continues to reflect the intent of Congress in creating the agency; that is, to explore space for peaceful purposes with international cooperation, for the benefit of all humankind. Technological advances have resulted in significant economic and social benefits for the United States and other nations, and remain the catalyst for national pride, progress, and achievement. The continued success of NASA's programs will allow the United States to maintain its leadership status in aeronautics and space.

Space Science and Applications

The NASA Space Science and Applications Program has a broad mandate to use space-based technology for the following: 1) to study the universe, including the sun, the planets, and Earth itself; 2) to solve practical problems on Earth; and 3) to provide the scientific research foundation for expanding human presence beyond Earth into the solar system. Space science and applications disciplines include astrophysics, solar system exploration, space physics, Earth science and applications, life sciences, microgravity science and applications, and space communications and information systems.

Astrophysics

Study of the Distant Universe. The NASA Astrophysics Program studies the origin and evolution of the universe, the fundamental physical laws of nature, and the birth of stars, planets, galaxies, and, ultimately, life. Research in these areas requires observations at wavelengths absorbed by Earth's atmosphere, and therefore must be made from instruments carried into space. The program is centered around a series of space observatories, supported by a research base



The Kuiper Airborne Observatory, a Lockheed C-141 aircraft modified to carry a 36-inch diameter telescope, flies above most of Earth's atmosphere at 41-45,000 feet to perform astronomical observations of the planets and stars at the infrared wavelength.

consisting of instrument developments, suborbital research activities, data analysis, and theoretical studies. The four Great Observatories—the Hubble Space Telescope, the Gamma-Ray Observatory, the Advanced X-ray Astrophysics Facility, and the Space Infrared Telescope Facility—are intended to provide significantly improved sensitivity and resolution over their selected regions of the electromagnetic spectrum. Smaller spacecraft in the Explorer series are used for exploration, all-sky surveys, specific studies, or unique investigations inappropriate for the Great Observatories. As part of the suborbital program, rockets, balloons, and aircraft provide the means to make preliminary observations, conduct selected low-cost investigations, test instrumental concepts, and nurture groups capable of developing instruments for future space missions.

Supernova 1987a. NASA and its international partners continued to study Supernova 1987a (SN 1987a) in 1988 through use of existing spacecraft and radio observatories, as well as rocket, balloon, and

airborne campaigns from the Southern Hemisphere. These observations included two Kuiper Airborne Observatory campaigns with a total of 26 flights flown from Christchurch, New Zealand. These flights resulted in the following: 1) spectrometers and photometers measured the line and continuum spectrum of SN 1987a between 1.5 μm and 100 μm ; 2) variations in the line intensities from ionized hydrogen and iron showed the changes of the temperature, density, and state of ionization in the emitting region between October 1987 to April 1988; 3) high resolution measurements of line shapes indicated an average expansion velocity of 3,000 km/s and possible inhomogeneities of the expanding material; 4) measurements of line emission from iron and cobalt allowed for a determination of the total masses of these heavy elements; and 5) the data showed the reemergence of continuum emission which may be indicative of an echo from circumstellar material. The International Ultraviolet Explorer (IUE) spacecraft discovered the remnant shell from the red supergiant stage of SN 1987a, as well as the changing properties of the ejecta from continuum observations, and made the best determination of the light curve and its implications concerning the nature of the energy source. Gamma-ray spectrometers observing SN 1987a on the Solar Maximum Mission spacecraft and balloon flights made a precise determination of the gamma-ray light curve for the 847 and 1,238 kiloelectron volt lines from cobalt 56 decay; measured the width of nucleosynthesis lines with high resolution spectrometers; and improved theoretical models (enhanced mixing in the mantle and envelope) to fit the observed gamma-ray line and continuum emission.

Hubble Space Telescope. Assembly and retesting of the first of the four Great Observatories, the Hubble Space Telescope (HST), was projected to be completed in 1989. Serviced by the space shuttle, HST is designed to be a long-term, major observatory that will extend our vision of the universe by allowing scientists to see astronomical objects about 10 times more clearly than

can be seen with existing instruments. By looking back in time and space, HST may provide information concerning how galaxies evolved in the initial period after the Big Bang (the hypothesized primal explosion creating the universe). Used to observe the solar system, it could provide the first images of the surfaces of Pluto and its moon, Charon.

Gamma Ray Observatory. Construction continued for the Gamma Ray Observatory (GRO) which was projected to be launched by the space shuttle in 1990. GRO will carry four instruments to explore extraterrestrial gamma rays, the highest energy radiation in the electromagnetic spectrum. Gamma rays cover the energy range from 0.1 million to 30,000 million electron volts. After completing assembly and testing of the four scientific instruments, three of the four were installed onto the observatory in 1988. The fourth instrument was planned to be installed in 1989. Then all observatory systems and instruments would be fully tested and integrated and the observatory would be prepared for launch in 1990.

Advanced X-ray Astrophysics Facility. The Advanced X-ray Astrophysics Facility (AXAF) is the third of the Great Observatories and is to be a space-based facility designed to observe celestial sources of x-rays. AXAF will address fundamental questions in astronomy and astrophysics based upon the knowledge that many of the most exciting and fundamental sources and processes in the universe radiate in x-rays. In 1988, TRW, Inc., was selected by NASA to be the prime contractor for the construction and integration of the AXAF. Development of the high resolution mirror assembly, which is central to the grazing-incidence telescope, began in 1988. This mirror assembly will focus the x-rays on a complement of science instruments whose development was planned for 1990. AXAF is designed to be launched by the space shuttle in 1997.

Space Infrared Telescope Facility. Expected to be the fourth of the Great Observatories, the Space Infrared Telescope Facility (SIRTF) is a meter-class

cryogenically-cooled observatory for astrophysical studies in the scientifically critical infrared spectral region. A major scientific theme of the SIRTf program will be the study of cosmic birth. Regions and phenomena that the facility will explore include the following: small bodies in the solar system into which the history of the formation of our planetary system may literally be frozen; regions within our galaxy where the cosmic gas and dust are condensing into new stars and planetary systems; and infrared-emitting extragalactic objects, including protogalaxies (galaxies in formation), that lie at such distances from Earth as to be close to the edge of the observable universe. Detailed studies have been made of the spacecraft and telescope systems, including analysis of the thermal and dynamic performance of the primary mirror, supporting structure, and chopping secondary mechanism. The instrument definition teams have demonstrated excellent performance for the critical focal plane arrays.

High Energy Astronomy Observatories. Analysis of data from the three missions in this series of x-ray and gamma-ray astronomy projects, known as the High Energy Astronomy Observatories (HEAOs), continued in 1988, with emphasis on activities about creating permanent archives of the most essential data products. In particular, work continued on assembling a source catalog based on the several thousand sources detected with the HEAO-2 (Einstein) satellite. The source catalog will constitute a valuable resource for the broader astronomical community and will provide specific support for such NASA missions as the Roentgen satellite (U.S. observational program), Astro-D, and AXAF. Data from the HEAOs, now part of the Astrophysics Data Program archives, remained in active use by the astrophysics community in 1988. The HEAO data represents the best data set spanning the x-ray through gamma-ray portion of the electromagnetic spectrum.

International Ultraviolet Explorer. The International Ultraviolet Explorer (IUE) was in its eleventh

year of operation. More than 1,000 U.S. astronomers have used this orbiting facility to observe objects at distances ranging from inside the solar system to the edge of the universe. IUE continued to observe Supernova 1987a, discovering the remnant shell from the red supergiant stage of the supernova as well as determining the changing properties of the ejecta from continuing observations, and made the best determination of the light curve and its implications concerning the nature of the energy source.

Cosmic Background Explorer. Development neared completion for the Cosmic Background Explorer (COBE) mission, scheduled for launch in 1989 on a Delta expendable launch vehicle. COBE is designed to sensitively measure microwave and far-infrared radiation in the sky thought to come from the Big Bang that may have marked the creation of the universe. Precisely measuring the spectrum and smoothness of this fossil radiation and by searching for signs of the earliest stars, the COBE mission is expected to show us how matter may have begun to be organized into stars, galaxies, and clusters of galaxies following the Big Bang. In 1988, instrument development was completed, flight hardware was delivered, and the observatory integration was completed.

Explorer Platform Missions. The Explorer Platform is a reusable spacecraft, designed for the servicing and replacement of science payloads in orbit using the space shuttle or the space station. The Extreme Ultraviolet Explorer (EUVE), the first payload to use the platform, was scheduled for launch on a Delta expendable launch vehicle in 1991. EUVE will be used to study celestial sources emitting radiation in the wavelength region between x-rays and ultraviolet light, called the extreme ultraviolet. EUVE will be a two-phase mission, with the first 6 months devoted to scanning the sky to locate and map sources emitting radiation in the extreme ultraviolet range, and the remainder of the mission (about 24 months) devoted to detailed spectroscopy of sources located during the first phase.

During 1988 the University of California at Berkeley, the EUVE science instrument developer, completed the design of the science instruments, began fabrication, and the assembling of the first of four telescopes making up the instrument package. Also during 1988, the design of the Explorer Platform was completed and its fabrication begun. The second user of the Explorer Platform, the X-Ray Timing Explorer (XTE), was scheduled for launch on the space shuttle in 1994. While in orbit, the space shuttle crew will remove the EUVE payload from the Explorer Platform and replace it with the XTE payload. XTE will investigate physical processes in black holes, quasars, and x-ray pulsars that are revealed in variations of their x-ray luminosity in time scales as short as microseconds and as long as years. During 1988, the three instrument developers (Massachusetts Institute of Technology, University of California at San Diego, and NASA Goddard Space Flight Center) continued their definition phase studies anticipating initial development in 1990.

Small-Class Explorer Program. NASA initiated its Small-Class Explorer Program with the release of an Announcement of Opportunity on May 17, 1988. A total of 51 proposals were received and reviewed for acceptance into the flight program. This is an aggressive program designed to provide an opportunity for quick flights of small free-flyers to conduct focused investigations that complement major missions, prove new scientific concepts, or make significant contributions to space science.

Other Explorer Activities

San Marco-D. The San Marco-D mission was a cooperative activity in which the United States provided a Scout launch vehicle, technical advice, and instruments to Italy (University of Rome) for integration with its San Marco-D spacecraft. The spacecraft was successfully launched from the Italian San Marco launch platform located off the coast of Kenya, on March 25, 1988, and reentered on December 6, 1988.

The mission was a success and data analysis was continuing.

Astro-D. The Astro-D mission, which is a new cooperative flight project with Japan, was in the definition phase, with plans for launch in 1993 from Kagoshima Space Center, Japan. The spacecraft was planned to be a small satellite devoted to x-ray astronomy and spectroscopy. This mission would include a lightweight x-ray telescope and a spectroscopic x-ray detector, both built in the United States. Activities during 1988 have been the scientific definition of the Astro-D payload and design of the instruments. The U.S.-built components were planned to be delivered to Japan during 1991.

Roentgen Satellite. The Roentgen satellite (ROSAT), a cooperative flight project with West Germany, will provide a full-sky, x-ray survey with unprecedented sensitivity. ROSAT was originally manifested on the space shuttle, but was reconfigured to be boosted into orbit in 1990 by a Delta-II expendable launch vehicle supplied by the United States. During 1988, the West Germans completed the integration of the scientific instruments into the spacecraft and started both structural and environmental testing. One of the x-ray focal plane instruments, the High Resolution Imager, supplied by the United States, was integrated into the spacecraft.

Infrared Astronomical Satellite. Infrared Astronomical Satellite (IRAS) was one of the most successful space astronomy missions ever conducted. Discoveries made from the IRAS data have produced major advances in astronomy and astrophysics, particularly in our understanding of ultraluminous infrared galaxies. In the three years since the original IRAS data products were released, there have been more than 400 papers published using IRAS data. Scientists continue to process the IRAS data to produce new archival information and to support an extensive program involving members of the original IRAS science team and a large number of guest investigators (approximately 70

groups per year). The catalog for faint sources at high galactic latitudes was published at the end of 1988—it more than doubled the number of cataloged extragalactic infrared sources.

Solar System Exploration

The goals of NASA's solar system exploration programs include the following: 1) to determine the present nature of the solar system, its planets, and its primitive bodies in order to understand how the solar system and its objects formed, evolved, and (in at least one case) produced environments that could sustain life; 2) to better understand the planet Earth by determining and understanding why the "terrestrial" planets of the solar system are so different from each other; and 3) to establish the scientific and technical data base required for understanding major human endeavors in space, by surveying near-Earth resources, characterizing of planetary surfaces, and searching for life on other planets. To accomplish these goals, the solar system exploration program is involved in a number of projects, which are described below.

Pioneer Venus. In December 1988, the Pioneer Venus Orbiter completed 10 years of successful operation and scientific data-gathering at Venus. With one exception, all science instruments were still functioning; however, slowly declining solar cell electric output required that instruments be operated in a time-sharing mode to conserve power. During 1988, investigation of the interaction of the solar wind with the Venus upper atmosphere and ionosphere continued, with particular attention being directed to understanding the chemical and physical processes occurring in the planet's nightside atmosphere. Fourteen guest investigators were added to the Pioneer Venus science team in April 1988; each is pursuing a particular scientific investigation based on the extensive mission dataset not available to the community at large.

The Interplanetary and Interstellar Medium.

Pioneer 10 and 11 were still functioning well as they moved away from the solar system and provided

valuable data on the interstellar medium. Pioneer 10 was beyond 45 astronomical units (AU) from the sun (an AU is the distance between the sun and Earth) and was receding at the rate of 2.8 AU/year. Pioneer 11 was moving in the opposite direction from Pioneer 10 and was 25 AU from the sun and was receding at 2.2 AU per year. To appreciate the distance, it should be noted that at 45 AU, it takes nearly 6 hours for a radio signal from the spacecraft to reach Earth. Both spacecraft are powered by radioisotope thermoelectric generators and their declining power levels are forcing power sharing between the various instruments; however, both spacecraft are projected to be capable of acquiring and transmitting valuable science data well into the 1990s. The major objective of the continuity of the Pioneer missions is the location and definition of the actual boundary of our solar system (the sun's magnetic influence) and the definition of the properties of interstellar space. Voyager 1 and 2 also continued to provide valuable science data on the interplanetary and interstellar medium because they are heading out of the solar system in different directions than the Pioneers.

Mars Observer. During 1988, the Mars Observer payload, still in the design phase, was descoped to bring the estimated cost of the mission back within budgetary guidelines. To accomplish this, one science instrument, the Visible and Infrared Mapping Spectrometer, was deleted from the mission, and another, the Mars Observer Radar Altimeter Radiometer was replaced by the Mars Observer Laser Altimeter. Another major change was the decision to launch on the Titan III expendable launch vehicle, thus removing the requirement for dual launch vehicle capability. Also, as a result of U.S.-Soviet negotiations on cooperation in space, the Mars Observer will carry Soviet/French-provided radio-relay hardware to relay data from balloons that were planned to be deployed on Mars in 1995 by the Soviets. During 1988, the design phase of the Mars Observer spacecraft systems and payload continued. Preliminary design reviews of several major

spacecraft subsystems were completed and the balance of the subsystems were scheduled for review completion in 1989. Preliminary design reviews were also held for all science instruments. Interface control documents were prepared for all the science instruments.

Voyager. Following unprecedented scientific discoveries from the successful Jupiter, Saturn, and Uranus encounters, Voyager 2 continued its epic journey through the solar system. It will make its last encounter with a solar system planet, Neptune, on August 25, 1989.

Voyager 1 was already leaving our solar system since its trajectory was bent in a northerly (upward) direction after the Saturn encounter; in mid-1988, it was 36.5 astronomical units from the sun and receding from Earth at 3.6 astronomical units per year. Voyager 1 was continuing to gather valuable scientific data from the northern half of the celestial sphere.

During 1988, preparations continued for Voyager 2's encounter with Neptune. The Neptune encounter presented even more technical challenges than previous encounters, because of its greater distance from the sun and increased communication distances from Earth. Significant changes in the operational utilization of the Voyager hardware, necessitated by both of these factors, were completed in 1988. These changes included reprogramming the computers to permit longer exposure times for the imaging system; changing the operating modes of the spacecraft's control system to minimize smear during the extended imaging exposures; and upgrading the ground antennas from 64 meters to 70 meters to cope with the increased communication distances.

Nine of 10 new computer loads necessary for the encounter were completed and passed ground simulations and tests. Major tests involving the spacecraft and the ground system to test the required new capabilities were satisfactorily conducted in 1988.

Magellan. Development of Magellan continued toward a 1989 launch on a shuttle/inertial upper stage combination. In 1988, the spacecraft was shipped to

the Kennedy Space Center for final pre-launch processing, and it was scheduled to be mated with the Shuttle Orbiter Atlantis in early 1989.

The Magellan mission is designed to provide global maps of the landforms and geological features of the cloud-shrouded surface of Venus. Using a synthetic aperture radar to penetrate the planet's opaque atmosphere, Magellan could achieve a resolution high enough to identify small-scale features and to address fundamental questions about the origin of the planet, the evolution of its surface, and the similarities and differences between it and similarly sized Earth. Magellan is planned also to obtain altimetry and gravity data to accurately determine the planet's gravity field as well as the internal stresses and density variations within it. With these data, the evolutionary history of Venus can be closely compared with that of Earth.

Galileo. The Galileo mission, a combined orbiter and atmospheric probe, is designed to make a detailed exploration of the giant planet Jupiter and its large family of diverse moons. The mission is comprised of a comprehensive science payload that could extend our scientific knowledge of this system far beyond the breakthrough discoveries made during the earlier flybys of the Pioneer and Voyager missions. During its planned 22 months of operation around Jupiter, Galileo is designed to inject an instrumented probe into Jupiter's atmosphere to make direct analyses. The orbiter could make long-term observations of Jupiter itself and could also make as many as 10 close encounters with various moons of Jupiter.

Galileo development continued toward a planned launch in 1989, using a shuttle/inertial upper stage combination. To reach Jupiter, the spacecraft must make three gravity-assist flyby maneuvers, one with Venus in 1990 and two with the Earth-moon system in 1990 and 1992. The spacecraft is also planned to make close-up observations of two asteroids before arriving at Jupiter in 1995.

Ulysses. The Ulysses mission is a joint program between NASA and the European Space Agency to explore the sun. The spacecraft is designed to carry instruments to make detailed observations of the sun's high latitudes in order to understand the sun's corona, the origin and acceleration of the solar wind into space, and the composition and acceleration of energetic atoms from the sun in solar flares and other violent solar events. Ulysses was being developed for a 1990 launch on a shuttle/inertial upper stage, with payload assist module-S, combination. To reach the sun, the spacecraft must first be launched toward Jupiter to make a gravity-assist swingby around that planet that would head it toward a 1993 flyby over the sun's south pole.

Space Flight Operations Center. This new multimission project, the Space Flight Operations Center, successfully completed a major development milestone in 1988 by delivering a baseline operational system to support the Magellan mission launch. To meet this milestone, the project produced five major software deliveries that were on schedule and within budget. This new generation, state-of-the-art, ground data processing system has demonstrated its operability and stability in extensive testing at the Jet Propulsion Laboratory. The Space Flight Operations Center is the next generation of ground data systems for present and future needs.

Flight Mission Support. In 1988, the Flight Project Support Office at the Jet Propulsion Laboratory continued to provide operations support to the Voyager and Pioneer spacecraft on their journeys toward the limits of the solar system. Other activities included preparations to launch the Magellan spacecraft toward Venus in 1989 and the Galileo spacecraft toward Jupiter in 1989. Preparations were begun for Voyager 2's initial encounter with Neptune in late June 1989 leading to a close flyby of the planet in late August 1989. Modern equipment was purchased for the multimission data records system and general-purpose computer facility, while the multimission image processing system was

modified for Venus and Neptune imaging support. Modifications were also made to the Ulysses real-time telemetry processor.

Space Physics

The NASA Space Physics Division supports investigations concerning the origin, evolution, and interactions of particulate matter and electromagnetic fields in a wide variety of space plasmas. Its studies focus on the upper atmospheres, ionospheres, and magnetospheres of Earth and other planets; the sun as a star and as a source of solar system energy, plasma, and energetic particles; and the acceleration, transport, and interactions of energetic particles and plasmas throughout the solar system and the galaxy. Observations, theory, modeling, simulations, laboratory studies, interactive data analysis, instrument development, and active experiments are all important aspects of the program.

International Solar Terrestrial Physics

Program. In 1988, the implementation of a major international program in solar and space physics continued with participation by NASA, the Japanese Institute of Space and Astronautical Sciences, and the European Space Agency. The U.S. contribution to this effort is NASA's International Solar Terrestrial Physics Program.

A systematic deployment of a group of satellites was planned for the early to mid-1990s by these agencies to measure and test models for the study of the interior and corona of the sun, the origin of the solar wind, the cause-and-effect relations of the flow of energy in Earth's key magnetospheric plasma source and storage regions, and the microphysics of plasma interactions in Earth's magnetosphere.

The Collaborative Solar Terrestrial Research (COSTR) Program supports NASA participation in international cooperative missions as part of the International Solar Terrestrial Physics (ISTP) Program. In particular, this initiative enables NASA to support the Japanese Institute of Space and Aeronautical

Sciences in providing a GEOTAIL satellite mission to monitor the energy storage in Earth's magnetic tail region. In 1988, the United States continued to develop instruments for GEOTAIL. The COSTR Program also supported collaborations with the European Space Agency (ESA) on the Solar and Heliospheric Observatory (SOHO), which was planned to conduct solar seismology and coronal diagnostics at the Earth-sun Lagrangian point. Additionally, ESA and NASA were planning a CLUSTER mission which is a group of four satellites providing three-dimensional measurements of magnetospheric microphysics processes. Four selected U.S. investigations for these missions were to start their Phase B studies for a science confirmation review in 1989. ESA had released its call for proposals for constructing the spacecraft.

Under the Global Geospace Science Program of the ISTP Program, approved as a new initiative in the 1988 budget, NASA was to provide a WIND spacecraft mission to monitor the solar wind input and a POLAR spacecraft mission to monitor the ionospheric plasma source region. The WIND and POLAR spacecraft mission contractor (GE-ASTRO/East Windsor, NJ) was selected in 1988 and the investigations were confirmed for flight. These two missions, in conjunction with the NASA/Department of Defense Combined Release and Radiation Effects Satellite in the equatorial storage region of the magnetosphere and the GEOTAIL mission, would make simultaneous measurements in different regions of geospace to understand geospace as a system.

NASA planned to launch WIND, POLAR, and GEOTAIL on expendable launch vehicles, and SOHO on the space shuttle; CLUSTER would be launched by ESA on an Ariane V development flight. NASA, the Japanese Institute of Space and Aeronautical Sciences, and ESA would share instruments and tracking support. In 1988, NASA and ESA jointly selected investigations for the SOHO and CLUSTER missions and began definition studies.

Solar Maximum Mission. NASA decided not to attempt any type of repair or recovery effort for the Solar Maximum Mission (SMM), predicted to fall from orbit because of atmospheric drag in late 1989. This decision was based on restrictions of the shuttle mission opportunities in that time period. The SMM was launched in 1980, but suffered a failure of its attitude control system only 9 months later. It was repaired in orbit in 1984 by the space shuttle astronaut crew. The SMM investigator groups will continue to operate this mission until it decays from orbit, and then conclude data archiving and in-progress analysis projects. In the meantime, a sixth opportunity for participation in the SMM guest investigator program was planned for release in 1989.

The Soviets and the Americans agreed upon coordinated stereo observations between NASA's SMM and TEREK, a solar x-ray imager/coronagraph experiment on the Soviet Phobos mission, while Phobos was on its transit orbit to Mars. This opportunity was largely lost when Phobos 1 ceased operation shortly after an otherwise flawless launch and orbit injection. However, a limited amount of coordinated data were taken and joint study by U.S. and U.S.S.R. scientists has been initiated.

SOLAR-A Program. Progress on the joint Japanese/NASA mission, SOLAR-A, proceeded satisfactorily in 1988, and launch was scheduled for 1991. The flight mirror for the joint Japanese/NASA Soft X-ray Telescope was delivered from the manufacturer and tested successfully. The Japanese were to develop two instruments entirely on their own, while a third was to be provided by the United Kingdom.

Orbiting Solar Laboratory. In 1988, the Phase B study of the Orbiting Solar Laboratory (OSL) continued satisfactorily. The objectives of OSL (which derives from its predecessor known as the High Resolution Solar Observatory) are to study the detailed magnetic, hydrodynamic, and radiative processes in the sun's photosphere and chromosphere. The main effort in 1988 was to redefine the completed observatory as a

free-flying polar orbiting satellite, expected to consist of up to four main optical units: a diffraction-limited, meter-class telescope (provided by industry); a coordinated instrument package (provided by U.S. and German science institutions); and at least one, but preferably two, additional "strap-on" co-observing instruments. One of these may be provided by NASA, and the other provided by the U.S. Air Force Geophysics Laboratory with possible Italian collaboration.

Tethered Satellite System. Work continued in 1988 on the scientific instrument systems for the first Tethered Satellite System mission scheduled for operation on the shuttle in 1991. This mission is shared with the Italians who supply the satellite to be tethered from the shuttle by a 12-mile wire. The mission is planned to examine the electrodynamic effects of large, conducting space systems.

Advanced Studies. The major new mission for space physics was the Solar Probe Mission, which measures the plasma physics of the sun's inner corona. This priority was established in 1987 by the Committee on Solar and Space Physics of the National Academy of Sciences' Space Science Board in a report entitled, "An Implementation Plan for Priorities in Solar-System Space Physics." A science working group has held one meeting, and expected to continue to meet. In the June 1, 1988 communique, the United States and the Soviet Union agreed to add to the April 1987 space cooperation agreement the study of possible joint missions. Information about a possible cooperative or joint solar probe mission will be exchanged in April 1989 at the second U.S./U.S.S.R. Joint Working Group for Solar Terrestrial Physics in Moscow. The NASA strategy calls for the Solar Probe Mission to be started sometime in the mid-1990s.

During 1988, NASA initiated a feasibility study for a Mercury orbiter mission. Such a mission would complete the global mapping of the Mercury surface and make measurements of the interactions of Mercury with the very intense solar wind.

Further work to define and design the ASTROMAG superconducting magnet facility for the space station occurred in 1988. ASTROMAG is a superconducting magnet to be attached to the space station to analyze the highest energy cosmic rays from our galaxy and the nearby universe. Proposals for instruments to use this facility were undergoing evaluation.

Explorer Missions. In 1988, the International Cometary Explorer (ICE) continued operations in a heliocentric orbit at 1 astronomical unit from Earth. Correlative solar wind measurements were made with IMP-8. Analysis of previous ICE data sets from Comet Giacobini-Zinner and Earth's geotail region continued.

The Dynamics Explorer (DE) spacecraft conducted two campaigns (DE-1 and DE-2) to provide detailed imaging of the atmosphere with simultaneous sounding rocket launches that released large volumes of water to simulate the existence of "snowy comets" postulated by scientists at the University of Iowa. *Reviews of Geophysics* (May 1988) published summaries of results and contributions during the first 5 years of DE operations. Analysis of near simultaneous measurements by DE-1 and DE-2 along the field lines at two different altitudes provided the most definitive evidence yet for the existence of electric fields aligned along these magnetic field lines, long postulated as the driving mechanism for the aurora.

Charge Composition Explorer (CCE) has detected samples of solar magnesium and sulfur in the solar wind for the first time. Knowledge of the amounts of these and other chemical elements in the solar wind provides clues to how the solar wind is produced in the sun. Measurements with the CCE and the Ion Release Module, an on-board instrument, discovered pressure pulses in the solar wind and showed that these pulses cause Earth's magnetic field to "ring" with disturbances seen all the way to Earth's surface. Instruments on the CCE defined for the first time the region in space far out on the night side of Earth in which geomagnetic storms occur, and in which they

accelerate the energetic particles that subsequently spread to fill the magnetosphere.

Sounding Rocket Program. Sounding rockets offer an inexpensive means to perform space-borne experiments; the main advantages of using sounding rockets are that the experiments can be conceived, built, and flown in one or two years, and they can often be recovered and reflown. Thus, the sounding rocket program offers a unique opportunity for universities to train graduate students for advanced experimental research. When Supernova 1987a was reported, the sounding rocket program was able to respond quickly, enabling NASA to carry out meaningful measurements of this new phenomenon in a timely manner. The NASA sounding rocket program supported about 35 to 40 launches a year. Depending on weight and other requirements of the experiments, these launches included small rockets of the Nike class to large ones of the Aries class. The sounding rocket program is managed and operated by NASA Goddard Space Flight Center at Wallops Flight Facility (WFF).

During 1988, discussions began and initial plans were drawn up to comply with the Administration's directive for "commercialization" of flight services. Since the sounding rocket program is an efficient, level-of-effort program that allows the science community to fly payloads from many different rocket ranges around the world, WFF has been serving as the prime contractor for these activities. Plans were being formulated so that qualified launch services vendors could be identified and given responsibility for launch activities without significant impact to the on-going program.

Balloon Program. The balloon program achieved record success in 1988. A total of 46 balloon flights were conducted with only one failure of the balloon system. Four of the science investigations failed because of instrument or operation problems or both. The program included three southern hemisphere campaigns to observe Supernova 1987a from Australia. One of these involved two long duration test flights

that were terminated in Brazil after traveling half-way around Earth. An additional foreign campaign was carried out from Canada, in order to study low energy cosmic rays at high latitudes during the period of solar minimum activity.

Following a 1988 reevaluation of balloon safety, severe constraints have been placed on flights from the National Scientific Balloon Facility in Palestine, TX. These changes resulted from a better understanding of the hazards associated with flight termination and from the increased population density, especially within a few hundred miles of Palestine and in the flight corridor east of the Mississippi River. Consequently, beginning in September 1988 flights were permitted from Palestine only if they had trajectories toward the west, where they could be terminated in sparsely populated regions. Palestine could no longer be used for flights during the winter months or during the turnaround seasons in April-May and September-October, which are the prime times to launch science flights requiring float times of a day or more. In the immediate future, Fort Sumner, NM, would be used as a semi-permanent launch site for turnaround flights, as well as for flights conducted in the winter months.

Earth Science and Applications

The overarching goal of NASA's Earth Science and Applications Program is to obtain a scientific understanding of the entire Earth system by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales. To accomplish this goal, the Earth Science and Applications Program was involved in number of programs, which are described below.

Interdisciplinary Research. NASA issued a research announcement for participation in the interdisciplinary research program in 1988. In this announcement the program was broadened into three principal study topics to understand long-term physical, chemical, and biological changes in Earth's envi-

ronment. The first topic is the role of the hydrological cycle in atmosphere-surface interactions including the fluxes of water and energy between these two boundaries that influence the behaviors of the climate system. The second topic is to determine the fluxes of trace gases from ecosystems and their fate in the troposphere in order to understand the contribution of land-surface biology to a changing atmospheric greenhouse effect. The third topic is research into how to detect global changes that will specifically distinguish between changes in the climate system caused by the man-made "greenhouse effect" and changes caused by other natural processes that alter the climatic state of Earth.

Upper Atmosphere Research Satellite. The Upper Atmosphere Research Satellite (UARS) is designed to provide the global data base necessary for understanding the coupled chemistry and dynamics of the stratosphere and mesosphere, the role of solar radiation in driving their chemistry and dynamics, and the susceptibility of the upper atmosphere to long-term changes in the concentration and distribution of key atmospheric constituents, particularly ozone.

The UARS is a crucial element of NASA's long-term program in upper atmosphere research, a program initiated in response to concerns about stratospheric ozone depletion. This satellite may provide, for the first time, global scale, long-term measurements of the concentrations of key source, sink, and reactive free radical species, direct measurements of winds, and simultaneous measurements of energy input from solar ultraviolet and energetic particle bombardment.

The UARS observatory critical design review was successfully completed in early 1988. The observatory primary structure was fabricated and assembled and was undergoing acceptance testing. All 10 of the UARS instruments completed critical design review. Two instruments completed acceptance testing and the remaining eight were in various phases of final assembly and testing. All instruments were planned to be delivered to observatory integration and testing by the

end of 1989. The first phase of the Central Data Handling Facility was in place. Remote analysis computers for the principal investigators were connected to this Facility, and the instrument teams were developing ground-based software to be used in processing and analysis of flight data. Launch was scheduled for late 1991.

Operational Meteorological Satellites. NASA continued to support the National Oceanic and Atmospheric Administration's (NOAA) Operational Weather Satellite Program by procuring the satellites and instruments needed to acquire the desired environmental observations. Acting as NOAA's agent, NASA also arranged for the launch of these satellites and conducted on-orbit check out before handing them over to NOAA for routine operations. On September 24, 1988, NOAA-H was launched on an Air Force Atlas-E launch vehicle into an 870-kilometer sun-synchronous orbit with a local data acquisition time of 1:40 pm. Upon achieving a successful orbit, this spacecraft was redesignated NOAA-11 and became the operational afternoon satellite on November 8, 1988. NOAA-10, launched on September 17, 1986, continued to function as the morning satellite. NOAA-D was being prepared to replace NOAA-10. It was planned to be ready for launch in 1990. An additional five satellites beyond NOAA-D were under contract. These satellites were projected to provide global polar-orbit coverage through the year 1997.

The GOES-7 geostationary satellite was maneuvered from its nominal East-Coast position of 750 degrees west to a mid-U.S. position in anticipation of a failure of GOES-6, the operating West-Coast satellite. GOES-6 was launched on April 28, 1983 and had already continued to function beyond its 5-year design life. Because of the launch failure of GOES-G in May 1986, there would be no spacecraft available to replace the aging GOES-6 until the launch of GOES-I in 1990. Five additional spacecraft (GOES-I through -M) were under contract. These satellites would be launched on Atlas/Centaurs under a commercial launch services contract.

They are designed to provide geostationary orbit coverage of the Western Hemisphere through the year 2000.

Atmospheric Science Program. Two major scientific assessments were completed in 1988: the Upper Atmosphere Research Program's report to Congress and to the Environmental Protection Agency (Part II, NASA Ref. Pub. 1208), and the Report of the International Ozone Trends Panel. The Congressional report, entitled "Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report," summarizes evidence for changes in the chemical composition and structure of the stratosphere, in particular the abundance and distribution of ozone. This report also contains a critical review of the photochemical processes believed to be important in the stratosphere, as well as results from an international group of scientists using theoretical models of the stratosphere to predict future levels of ozone. In these calculations the chemistry of the atmosphere is predicted to change in response to the increasing atmospheric abundances of trace gases, primarily chlorofluorocarbons, halons, methane, carbon dioxide, and nitrous oxide.

The International Ozone Trends Panel was convened in 1987 to critically assess whether the chemical composition and physical structure of the stratosphere had changed over the last few decades and whether our understanding of the influence of natural phenomena and human activities was consistent with the observed changes. The review of the panel report began in 1987, with a major panel review in January 1988. The executive summary was released on March 15, 1988.

In September 1988, the Upper Atmosphere Theory and Data Analysis Program sponsored a comparison of multi-dimensional models of stratospheric chemistry. The week-long workshop was the largest and most scientifically extensive comparison of stratospheric models to date. The meeting included participation by many of the international research groups involved in

two- and three-dimensional modeling of stratospheric ozone. The theoretical modeling community contributed model results for a well-defined specific set of numerical experiments on the following: 1) fundamental photochemistry, 2) dynamical motions and mechanistic tracer studies, 3) current atmospheric chemistry, and 4) predictions of future ozone change.

The goal of the model comparison was to identify the causes of differences among the models, with the intent of using this information to understand why the models differ in their predictions of stratospheric change for the assessment of future ozone levels. Differences in the chemical or transport formulation between models were identified as having an impact on specific predictions of the models as tested by the four experiments listed above. The model comparison was planned to continue, with the next major international workshop possibly in 1990.

In 1988, NASA successfully completed a major tropospheric chemistry experiment in Alaska during the peak summertime period for biogenic production of methane and other "greenhouse" gases from the tundra, one of the world's major natural sources of methane. Data were being analyzed for first public presentation in 1989. Preliminary analysis of the data indicated that the experiment, which involved aircraft and ground-based measurements supported by satellite meteorology, was an operational success and would likely yield an important new data base on the atmospheric chemistry of this important source region for one of the key "greenhouse" gases.

Land Processes. NASA's Land Processes Program consists of the following four interrelated elements: studies of terrestrial ecosystems, the hydrologic cycle, geology, and remote sensing science. The focus was on the Earth sciences using currently available systems and airborne prototypes for future systems, with some attention given to the development of new instruments and techniques for future scientific and applied use.

A special 3-year program to apply Landsat Thematic Mapper (TM) data to basic scientific research in

geology, hydrology, and biology was completed in 1988. TM data proved to be extremely useful in such diverse studies as mapping the extent of past glaciation and volcanism in the Andes, classifying snow according to grain size and water content classes, documenting changes in vegetation growth patterns in the Sahel, estimating organic carbon and iron concentrations in paleosols in the Pacific Northwest, and inferring nitrogen mineralization in sagebrush ecosystems.

The Airborne Visible Infrared Imaging Spectrometer, a prototype sensor, was flown on NASA's ER-2 research aircraft for a variety of science users. This was the second year of sensor evaluation flights for this instrument. Another prototype, the Synthetic Aperture Radar, was successfully placed into operation on the NASA DC-8 research aircraft. Both research and evaluation flights were conducted. An advanced passive microwave system, the Electronically Steerable Thinned Aperture Radiometer, made its initial engineering flights. There was also considerable research use of other sensors such as the Thermal Infrared Multispectral Scanner, Advanced Solid State Array Spectroradiometer, and several thematic mapper simulators.

Terrestrial Ecology Program. Terrestrial ecosystems research in 1988 focused on the use of remote sensing to study biogeochemical cycling processes, biotic contributions to the global energy balance, and changes in vegetation state and dynamics. Specific activities included the following: 1) analysis of patterns and rates of deforestation in the Amazon Basin using the Advanced Very High Resolution Radiometer vegetation index and thermal data; 2) modeling of net primary productivity and evapotranspiration for a regional watershed using remotely sensed model inputs; 3) development of linked canopy radiative transfer, soil process, and ecosystem dynamics models; 4) initial investigation of the components of canopy structure contributing to the radar response of forested ecosystems; and 5) use of ground methane flux measurements and remotely sensed landscape units to

estimate regional methane production on the North Slope of Alaska. Compilation of an internally consistent, global vegetation index data set continued, and the first examination of global interannual patterns of productivity and vegetation phenology were planned for 1989.

Geology Program. Geologic studies in the Wind River Basin have developed techniques for detailed geologic mapping and structural interpretation from remotely sensed data. Satellite and airborne sensor data were used to construct a stratigraphic section of the Wind River Basin which compares very closely to that constructed by geologists mapping in the field. The rocks of the Wind River Basin were deposited as sediments over 60 million years ago in a continental margin setting. Because the rocks are characteristic of certain depositional environments, it is possible to infer the basin's depositional history from the sequence of rocks preserved therein. The post-sedimentary deformational history of the Wind River Basin can be reconstructed from the present geometry of rock sections observable on a grand scale with satellite imagery and checked with existing seismic data.

Geodynamics. In 1988, the NASA Crustal Dynamics Project completed the upgrades to their satellite laser ranging stations to achieve 1-centimeter accuracies and started cooperative upgrade programs with participating groups in the Federal Republic of Germany, The Netherlands, Israel, France, England, and Australia. Similarly, upgrades to the very-long baseline interferometer (VLBI) systems and analysis techniques have achieved 1-centimeter accuracies for baselines of many thousands of kilometers in length. New stations in China and Australia were added to the VLBI network surrounding the Pacific "Ring of Fire," so named because of the abundant volcanos and frequent earthquakes along the edge of the Pacific plate. Recent analysis of the data from the global laser and VLBI networks have produced much more accurate plate motion velocities and deformations of the boundaries of the colliding plates. The deformations were being

studied in more detail with space geodetic techniques using the Global Positioning System. Special campaigns were conducted in California, Mexico, Central America, South America, and the Caribbean.

Earth Observing System. The Earth Observing System (EOS) Program is an interdisciplinary Earth science mission to provide long-term observations and the supporting information system necessary to develop a comprehensive understanding of the way Earth functions as a natural system. This understanding includes the interactions of the atmosphere, oceans, cryosphere, biosphere, and solid Earth. The comprehensive global approach to the study of these processes in an integrated context is called Earth System Science and has a strong focus on developing the capability to accurately predict the evolution of the Earth system on time scales of decades to a century.

The EOS Program includes space- and ground-based research and a distributed information system and global data base. The EOS Program involves participants from the United States, the European Space Agency (ESA), Japan, Canada, and other nations. U.S. participants include the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS) among others. The space elements associated with the EOS Program include elements within the framework of the Space Station Program (the first NASA Polar Orbiting Platform [POP], the first ESA POP, and space station attached payloads), and elements foreseen to be outside of the Space Station Program (the second NASA POP, the second and subsequent ESA POPs, the first Japanese POP, and other Earth-observation related elements).

During 1988, the EOS Program progressed to the definition and preliminary design phase (Phase B). In January 1988, the EOS Announcement of Opportunity was released. Proposals were received in June and July, and the peer review process completed in November. A total of 457 proposals were received in

three categories: interdisciplinary research proposals, team member/team leader proposals for facility class instruments, and proposals for design and development of principal investigator instruments.

Interagency agreements between NASA and USGS and between NASA and NOAA were negotiated during 1988. The NASA-USGS agreement was finalized and the NASA-NOAA agreement was under discussion. The agreements allow for phased transition of data acquired within the EOS Program from NASA short-term archives to USGS and NOAA long-term, permanent archives.

All NASA-provided EOS instruments were either in Phase A or Phase B studies. NASA EOS facility class instruments included the following: 1) Moderate Resolution Imaging Spectrometer (MODIS), including MODIS-Tilt and MODIS-Nadir; 2) High Resolution Imaging Spectrometer; 3) Geodynamics Laser Ranging System; 4) Synthetic Aperture Radar; 5) Laser Atmospheric Wind Sounder; and 6) the Atmospheric Infrared Sounders. Phase B definition contracts were awarded for MODIS-Nadir, and Phase A contracts were awarded for the Geodynamics Laser Ranging System during 1988. MODIS-Tilt, the High Resolution Imaging Spectrometer, and the Synthetic Aperture Radar were in-house projects being executed by the NASA Goddard Space Flight Center and the Jet Propulsion Laboratory.

During 1988, the Earth Observation International Coordination Working Group was chartered and three meetings were held to address EOS principal investigator instrument selection, planning scenarios for payloads on each platform, common instrument interfaces, and EOS data policy.

Climate Research. During 1988 much public attention was given to the possibility of global climate changes associated with "greenhouse" warming caused by increasing quantities of trace gases added to the atmosphere. Many of the tools and improved scientific understanding developed by NASA will help the nation assess and monitor potential climate changes caused by man-made and natural effects. Since it was estab-

lished by NASA as a separate scientific discipline in 1977, NASA's Climate Research Program has focused on studies of the radiation processes which influence climate and its predictability. The centerpiece of the climate observing system continues to be the Earth Radiation Budget Experiment (ERBE), which has been collecting data since 1984 on the global distribution of solar radiation absorbed by Earth and infrared radiation emitted to space. These measurements, acquired by ERBE instruments carried by a dedicated NASA research satellite and two NOAA operational meteorological satellites, were providing new insight into how Earth stores and transports energy. Research continued on the degree to which clouds contribute to the cooling or heating of Earth. Further evidence acquired by ERBE confirmed the earlier conclusion that global cloudiness tends to cool the planet.

Mesoscale Atmospheric Processes. During 1988, effort was directed toward the planning and design of a networked remote sensor image acquisition, distribution, and processing system called "WetNet." WetNet will be used to make quantitative estimates of global precipitation over land and water, water in liquid and vapor forms within clouds, ice distributions, sea-surface wind stress, a microwave vegetation index, a wet-dry evaluation of surface moisture conditions, and some estimates of snow cover depth and water content. The team of investigators would receive global maps of selected parameters one day after satellite observation via network transmissions directly to their desktop personal computer, which in turn could process the data and display it in color maps for study of regional variations, global trends, or catastrophic local phenomena. The hardware for data acquisition, networking, and local analysis was scheduled to be available for system implementation in 1989.

Global Scale Atmospheric Processes. This research program stresses the development of advanced remote sensing instruments for observing meteorological parameters in Earth's atmosphere,

advanced analysis techniques to improve the utility of existing meteorological satellite data, and improved numerical models capable of both atmospheric diagnosis and prediction. During 1988, the fabrication of a pulsed carbon dioxide lidar system for airborne use was completed. This lidar system will figure prominently in a large-scale aircraft and ground-based measurement program being planned to refine our knowledge of the distribution of aerosols in the lower atmosphere. This information is needed for the design of a spaceborne laser system that will use Doppler frequency shifts of the backscattered laser energy from aerosols moving with the wind to observe those winds. Remote sensing algorithms for several meteorological parameters like temperature and moisture profiles and cloud amounts were improved, and new techniques for retrieving average rain rate and surface pressure from specific satellite observations were developed. Simulated numerical experiments were carried out that determined that the measurement of tropospheric wind profiles and their assimilation into atmospheric models have the potential for significantly improving weather prediction capability.

Oceanic Processes. NASA's oceanography program is focused on obtaining and analyzing remotely sensed satellite data for studying ocean circulation, atmospheric forcing of the ocean surface, biological productivity, and sea ice. NASA planned for a system of satellite sensors to be ready by the early 1990s to support several global experiments including the Tropical Ocean/Global Atmosphere (TOGA) experiment, the World Ocean Circulation Experiment (WOCE), and the Global Ocean Flux Study. Under auspices of the World Climate Research Program, the results of these experiments would help explain the role of the global oceans in Earth's climate. In focusing on these experiments, NASA worked closely with the National Science Foundation, the National Oceanic and Atmospheric Administration, the Navy, and a number of international partners.

NASA pursued two remote sensing space flight projects to support studies like WOCE and TOGA. These projects both measure the surface topography over periods of several years, allowing scientists to better understand ocean currents and begin to learn how they are related to changes in Earth's climate.

The Ocean Topography Experiment (TOPEX/POSEIDON) is an international venture with the French Space Agency to develop a satellite system capable of measuring the surface topography of the oceans with a single-pass tracking accuracy of about 10 centimeters. For the TOPEX/POSEIDON mission, NASA will provide the satellite, the prime sensor—a radar altimeter, and several supporting sensors. The French Space Agency will provide an experimental radar altimeter, a supporting sensor, and the Ariane IV rocket launcher. The satellite system was scheduled for launch in mid-1992 and the prime mission would be conducted for 3 years. During 1988, significant progress was made in the design of the satellite and the various sensor subsystems, as well as in the scientific arena where the U.S. and French teams began planning their collaborative research projects.

The NASA Scatterometer (NSCAT) is a special microwave radar designed to measure the global surface wind velocity field, a primary driving force for ocean currents. During 1987, the Navy Remote Ocean Sensing System Satellite was cancelled; and in 1988, NASA proposed to fly the NASA Scatterometer on the Japanese Space Agency Advanced Earth Observing System (ADEOS) scheduled for launch in 1995. Because of uncertainty regarding the host satellite, NSCAT instrument development was slowed in 1988. However, late in 1988, NASA was notified that NSCAT had been selected to proceed into hardware definition studies for flight on ADEOS. These studies would be performed in 1989 with a corresponding increase in the flight hardware development to follow.

To support polar research, NASA assisted the National Snow and Ice Data Center in Boulder, CO, in establishing a processing and archive center; this

center will give the scientific community access to global sea-ice information derived from the Special Sensor Microwave Imager that was launched in June 1987 aboard one of the Defense Meteorological Satellite Program spacecraft. Looking to the future, NASA's Jet Propulsion Laboratory and the University of Alaska were developing the Alaska Synthetic Aperture Radar Facility in Fairbanks. Synthetic aperture radar observations, capable of providing a detailed view of the Arctic ice pack, would come from the European Space Agency's First European Remote Sensing Satellite, the Japanese First Earth Resources Satellite, and the Canadian Radarsat. During 1988, the 10-meter antenna, receivers, and a high-density tape recorder were installed in Fairbanks.

Life Sciences

Life sciences research extends from basic research to applied clinical practice. It is focused on the development of countermeasures and life-support systems that will enable long-duration human exploration missions and knowledge of the origin, evolution, and distribution of life in the universe. Major subjects of study include space medicine, space biology, biospherics, exobiology, and controlled ecological life-support systems. Investigations are conducted in ground-based and space facilities, on space shuttle missions, and on Soviet biosatellite flights; future flight opportunities include extended duration orbiter missions, a recoverable reentry satellite, the Soviet Mir space station, and Space Station Freedom.

Space Medicine. Through basic and applied research, clinical studies, and flight programs, NASA's Life Sciences Division is investigating the nature and mechanisms of physiological and psychological adaptation, physiological deconditioning, and other risks associated with exposure to space. Knowledge gained from these activities will help life scientists to develop protective measures that will ensure the crew health and productivity during long-duration space missions.

Preparations are being made for missions on space shuttle flights over the next several years to be focused on researching cardiovascular and neurosensory changes. During 1988, ground-based and KC-135 aircraft tests of antimotion-sickness drugs—promethazine, scopolamine, and D-amphetamine—showed that they may help to control space motion sickness. Another antimotion-sickness initiative that made progress in 1988 is the Preflight Adaptation Trainer. Investigations proceeded using a tilt-translation device and a graviceptor stabilization device designed to simulate the rearrangement of stimuli in a spacecraft that alters relationships among visual, vestibular, and somatosensory signals. In a simulated space flight environment, astronauts may be able to preadapt to the stimulus rearrangement of the microgravity environment.

Planning for a Life Sciences Extended Duration Orbiter (EDO) Medical Program began in 1988 to support extended duration flights of up to 16 days beginning in 1992. The program was intended to ensure crew health and safety during extended duration missions by determining whether any aspects of physiological adaptation to microgravity might become more pronounced as missions grow longer, hinder crew operations, or affect performance during entry, landing, and egress. Development and testing of countermeasures to physiological deconditioning would be an important feature of this program. The EDO Medical Program would also monitor occupational health factors such as radiation exposure, air and water quality, surface contamination, and waste management to determine whether extended missions would require enhanced personal hygiene and food systems. In addition, an Extended Duration Crew Operations Program was in the works to permit medical certification of crew members for assignments of 6 months or more on Space Station Freedom.

In 1988, two NASA research announcements were released soliciting proposals for biomedical experiments to be flown on Soviet Cosmos biosatellite

missions in 1989 and 1991 and for experiments to be flown on Spacelab missions in a joint U.S.-French Rhesus Research Facility. Peer reviews of proposals were completed in 1988 and experiments were selected for further definition. One problem to be addressed in some of these investigations is how cosmic radiation may affect life in space. For long-duration flights, radiation exposure may be the ultimate limiting factor unless effective protection methods are developed.

Space Biology. The goals of the NASA Space Biology Program are to determine whether plants and animals undergo normal development and life cycles in microgravity and to define how the microgravity environment can be used as a laboratory to study biological phenomena. Space biology research focuses on cell biology, gravity perception, biological development, and biological adaptation. Cellular growth, development, and function are all affected by exposure to weightlessness. Recent accomplishments in space biology include identification and characterization of the gene in a yeast strain that is involved in the process of chromosomal segregation during cell division, identification of an inhibitor that interdicts gravitropic reception in maize, and demonstration that simulated microgravity changes the ability of vertebrate embryonic cells to mature and to communicate with each other.

Exobiology. NASA's exobiology research concentrates on the pathways of the biogenic elements from the origin of the universe to the evolution of living systems. Studies focus on major epochs in the evolution of life: the cosmic evolution of the biogenic compounds, prebiotic evolution, early evolution of life, and the evolution of advanced life. To pursue its goal, the Exobiology Program was sponsoring ground-based research and developing flight experiments for observational and exploratory space missions.

A project initiation agreement was approved in 1988 for the Exobiology Program's major ground-based initiative, the Search for Extraterrestrial Intelligence

(SETI) Microwave Observing Project. The SETI Microwave Observing Project, which would search for radio signals of extraterrestrial intelligent origin, would be 10 billion times more comprehensive than all previous searches combined. A multichannel spectrum analyzer was being developed for the SETI system; it would be able to scan 10 million radio frequency channels simultaneously using an ultra-high-speed digital signal processing chip developed by Stanford University researchers for the project. A prototype had already been tested, and a second-generation prototype was being developed.

Biospherics. The goal of NASA's Biospherics Program is to understand how biological and planetary processes interact. Biospherics research focuses on the contributions of specific ecosystems to the biosphere: eastern U.S. wetlands, temperate forests, and tropical forests. Biogenic gas production and transport, nutrient flux, and air pollution effects are some of the subjects of study.

In 1988, a wetlands research team completed a field experiment in Alaska to measure nitrogen, sulfur, and carbon cycling in the tundra. Discussions were begun on a joint U.S.-U.S.S.R. biogenic gas (methane) experiment to be conducted in the Soviet Arctic with investigators from NASA and the National Science Foundation.

Biospherics investigators arranged for aircraft overflights of the Yellowstone forest fires of 1988 to acquire remote sensing images. The resulting information was made available to fire control personnel in real time, and it was being analyzed to evaluate how forest fires may affect regional weather patterns and possibly global climate.

The NASA Biospherics Program also sponsored a malaria project, which uses aerial remote sensing data to define the type of environment where malaria-bearing mosquitos breed. Predicting the time and place of mosquito outbreaks is key to the control of malaria epidemics, and the malaria project was intended to develop this capability. In 1988, NASA negotiated an

agreement with Mexican authorities to conduct further studies of areas in Mexico affected by malaria.

Controlled Ecological Life Support Systems. A Controlled Ecological Life Support System (CELSS) will ultimately be necessary to produce food, air, and water for crews on long-term missions without major resupply, by recycling wastes. Bioregenerative life support systems have the potential to meet long-term human needs in space. They can provide food by photosynthesis of plant products in a controlled environment, breathable air through photosynthetic release of oxygen and fixation of carbon dioxide, and clean water by plant transpiration of water that can be condensed for drinking.

A workshop was held at Ames Research Center in 1988 to initiate planning for a "CELSS salad machine" that would produce fresh salad vegetables for crews on Space Station Freedom. CELSS program officials reached agreement in principal last year with officials of Rutgers University (Cook College, Departments of Food Technology and Agronomy) to develop tomato crop science and technology appropriate for a salad machine. Experiments with light-emitting diodes for plant illumination in a CELSS indicated that low-energy, low-heat light-emitting diodes could cut power requirements for Space Station Freedom.

Flight Programs. With shuttle mission STS-26, NASA's Life Sciences Division resumed flight investigations intended to support human health and well-being in space and to address fundamental biological questions about life on Earth and in space. STS-26 included several small-scale life sciences investigations to measure crew members' metabolic, cardiovascular, and neurovestibular function in microgravity and to study pharmacokinetics in space. Future shuttle missions will include similar types of investigations.

In 1988, payload confirmation occurred for Spacelab Life Sciences-1 (SLS-1), to be launched in 1990. SLS-1 would be the first space shuttle mission dedicated to life sciences investigations; experiments would focus on cardiovascular, musculoskeletal, and neurovestibu-

lar adaptation to space. The rebuilding of a Research Animal Holding Facility to be used on SLS-1 was completed in 1988. Work on a General-Purpose Work Station for Spacelab Life Sciences 1 (SLS-1) was also completed and the hardware was shipped to Kennedy Space Center.

Also in 1988, concept studies were completed for a Recoverable Reentry Satellite to be called LifeSat for life sciences missions. LifeSats would carry plant and animal experiments for 30 to 60 days in orbits not accessible by the space shuttle, in order to study radiation exposure and microgravity-induced changes that worsen or only become apparent during missions longer than shuttle flights. And concept studies were completed in 1988 for a 1.8-meter diameter centrifuge, sized to fit in a Spacelab module, that would fly on shuttle missions in the mid-1990s. Scientists would use the centrifuge for variable-gravity experiments with plants and animals.

U.S.-Soviet Cooperation. U.S.-Soviet cooperation in life sciences was advanced in 1988 through meetings of the U.S.-Soviet Joint Working Group on Space Biology and Medicine. Joint U.S.-Soviet experiments were proposed for a Soviet Cosmos biosatellite mission 1989. U.S. and Soviet scientists also agreed to share tissue samples from shuttle and Cosmos missions. A step toward greater interagency cooperation was taken in 1988 by forming a NASA-National Institutes of Health Interagency Working Group on Biomedical Research.

Space Station Experiments. Planning continued in 1988 for the array of experimental hardware that life scientists would need on Space Station Freedom. Space Station Freedom would feature a Health Maintenance Facility (HMF), which would be a compact, combination walk-in clinic and emergency room. A prototype surgical work station for the HMF has been thoroughly tested in microgravity on KC-135 low-gravity aircraft flights. Phase A concept studies also proceeded in 1988 for a cosmic dust collection facility that would fly as an

attached payload on Freedom and for a gas-grain simulation facility that would be installed on board Freedom for exobiology investigations.

Microgravity Science and Applications

The microgravity science and applications program fosters the development of near-Earth space as a national resource by exploiting the near microgravity environment in an orbiting spacecraft. The goals of the program are the following: 1) to advance understanding of the fundamental science that governs processes on Earth, in the solar system, and in the universe; 2) to increase understanding of the influence of gravity on Earth-based processes, leading to better control strategies to improve such processes; 3) to pursue limited production of high-value materials with enhanced properties to serve as benchmarks for comparison with Earth-produced materials or for highly specialized applications; 4) to evolve processes for the eventual commercial production of certain high value-added products in space; and 5) to explore the possibility of processing extraterrestrial materials.

To achieve these goals, it is necessary to develop the requisite infrastructure to facilitate the efficient use of the near-Earth space environment by researchers from the academia, government agencies, and industry.

The microgravity science and applications program sponsors research in the following areas: 1) fundamental sciences, which includes the study of behavior of fluids and of transport phenomena in microgravity, and experiments that use the enhanced measurement precision possible in microgravity to measure physical properties and to challenge contemporary theories of relativity and condensed matter physics; 2) materials science, which includes the processing of electronic and photonic materials, metals, alloys, composites, glasses, ceramics, and polymers, to obtain a better understanding of the role of gravity-induced effects in the processing of such materials with the goal of effecting better control strategies here on Earth; and 3) biotechnology, with emphasis on the growth of

protein crystals and the development of separation techniques for biological materials.

Microgravity Science on STS-26. Five Microgravity science investigations were flown on the STS-26 mission in 1988. These investigations were the following:

1. the Automated Directional Solidification Furnace, designed to process four magnetic alloy samples by directional solidification in the classic Bridgeman mode;
2. the Protein Crystal Growth apparatus, designed to produce larger, more perfect crystals of selected proteins in space than possible on Earth. The goal is to use these space-grown crystals to determine the molecular structures of the proteins to a finer resolution than possible with crystals grown on Earth;
3. the Isoelectric Focusing in Space experiment, which is a type of electrophoresis experiment that separates proteins in an electric field. This experiment was designed to distinguish between electro-osmosis and electro-hydrodynamic effects by varying the surface to volume ratio of the focusing cells;
4. the Phase Partitioning Experiment, designed to clarify the roles of gravity and other forces in the separation or partitioning of biological substances. The experiment consisted of a transparent module with 18 chambers of two-phase systems, each differing in various physical parameters (e.g., viscosity, volume fraction, and interface potentials). The Phase Partitioning Experiment was configured to study two methods of phase separation (natural coalescence and surface tension), and allowed variations in interfacial tension, phase volume ratio, phase system composition, and added particles; and
5. the Aggregation of Red Blood Cells experiment. This experiment was configured to provide information on the formation rates, structure, and organization of red cell clumps, and to investigate the potential beneficial role of microgravity in clinical research and diagnostic testing.

Preliminary analysis of the data received from some of these experiments is as follows:

Protein Crystal Growth: Sixty different experiments in protein crystal growth using the vapor diffusion method were performed on STS-26. Included among these were 11 different proteins, selected because they all display typical crystal growth problems under normal gravity conditions. For example, five droplets of the enzyme reverse transcriptase were flown on this mission. The reverse transcriptase enzyme is specifically responsible for the multiplication—and therefore spread—of the AIDS virus. Without this enzyme, it appears that the AIDS virus will not reproduce in the human body. It is therefore critical to understand this enzyme and its structure; Earth-grown crystals have proven totally inadequate. Presumably, space-grown crystals will allow important advances in understanding the enzyme's action and will point the way to the development of drugs much more effective than today's best therapy. While attempts to grow reverse transcriptase were unsuccessful on this flight, results indicated that better purification of the samples would be needed before crystal growth would be possible. We will continue our efforts on future flights. However, initial x-ray diffraction results indicate that the crystals obtained for four of the other proteins flown display a structural order better than crystals of the same materials obtained on Earth.

Isoelectric Focusing in Space: Additional evidence to support findings on STS-11 experiments was obtained, indicating that the major source of convective turbulence is due to an electro-hydrodynamic effect, not electro-osmosis. Fluid protein behavior in focusing, although not fully explained, indicated even more turbulent behavior than observed in terrestrial controls. The onset of this turbulence was not synchronized with acceleration surges of the shuttle.

Ground-Based Facilities. The ground-based test facilities continued to play a vital role in the microgravity science and applications program. Drop towers and drop tubes can subject material samples and experi-

ment packages to brief periods of near-zero gravity conditions during freefall. Special aircraft flying parabolic trajectories provide reduced gravity conditions for 15-20 seconds. All of these facilities enable timely and cost-effective science research and provide testbeds for evaluation and refinement of prototypical flight hardware.

NASA's Marshall Space Flight Center 100-meter drop tube has been a valuable asset for studying containerless processing. Approximately 600 test drops were made in this facility during 1988. During the same period, over 650 research drops were performed in the 2.2-Second Drop Tower at the Lewis Research Center in support of 15 projects involving combustion science and fluids. The inventory of experiment drop packages had increased from four to 15. Technological advances such as on-board computers, laser sources, and video cameras and recorders were implemented to upgrade data acquisition. In the 5-Second Zero-Gravity Facility, six drop vehicles were in use, and 135 test drops were performed in support of six projects in 1988. Major milestones were reached as test drop number 8,000 was executed in the 2.2-Second Drop Tower, and test drop number 2,000 was performed in the 5-Second Zero-Gravity Facility. Also, 10 visiting scientists participated either independently or jointly with NASA investigators in the performance of NASA-sponsored research.

NASA operates two specially modified aircraft as platforms for microgravity science research. A Learjet, based at Langley Research Center, was flown in excess of 55 hours, providing approximately 75 low-gravity parabolic trajectories in support of over 5 research programs during 1988. A larger KC-135, based at the Johnson Spaceflight Center, accommodated an average of 7 experiments simultaneously, and provided over 70 flight hours of support to the Microgravity Science program.

Plans for the Future. NASA's Microgravity Science and Applications Division was planning a vigorous science program consisting of both ground- and space-

based research. The Division continued to manage the development of over 30 pieces of flight hardware which would be flown aboard the space shuttle. Several of these facilities are multi-user, and can accommodate experiments by different principal investigators. Other flight experiments under development were highly specialized and were being designed for specific investigations. The flight hardware being developed may provide a valuable data base, both in science and technology, which may help the Division prepare for space station facilities.

Major opportunities for flight will be provided on the four U.S. Microgravity Laboratory (USML) missions, the four International Microgravity Laboratory (IML) missions, and the U.S. Microgravity Payload (USMP) missions. In 1988, much effort was devoted to the preparation of an Announcement of Opportunity which will solicit investigations for the USML-1, IML-1, and IML-2 missions planned for the early 1990s.

Space Station-Based Experiment Facilities.

NASA was continuing to define requirements and develop conceptual designs for the six multiuser facilities for the space station: the Space Station Furnace Facility, Modular Containerless Processing Facility, Advanced Protein Crystal Growth Facility, Biotechnology Facility, Modular Combustion Facility, and Fluid Physics/Dynamics Facility. All six of the multiuser facilities were approved to proceed to "Conceptual Design Reviews," at which point scientific justification, conceptual designs, costs, and schedules for the facilities would be thoroughly evaluated.

Communications and Information Systems

The NASA Communications Research Program focuses on developing the high-risk microwave, optical, and digital technologies needed to increase the capacity, flexibility, and interconnectivity of future space communications systems. The goal of the program is to maintain U.S. technological and economic preeminence in space communications and to enable innovative services in support of the satellite

communications industry, NASA's needs, and the needs of the public sector.

The program is structured around the development of advanced technology to more effectively use frequencies and the geosynchronous orbit. This research reduces adoptive risk by industry and improves its competitive posture in the world marketplace. The use of sophisticated communications technology also enables new scientific advancement through extremely efficient wideband space communications. Scientific advancement, in turn, enables and enhances future near-Earth and space exploration missions. The communications program also develops positions and supports U.S. and NASA interests in international and domestic communications regulatory forums. The program uses NASA's resources to provide consultation, perform system studies, and plan and conduct space experiments in support of other government agencies.

Advanced Communications Technology Satellite. The year 1988 was one of programmatic change for the Advanced Communications Technology Satellite (ACTS) program. Responding to Congressional direction to "cap" the program costs, NASA successfully restructured the ACTS program. Changes to the contractual arrangements and the assumption of a more proactive management role by NASA were made, while the momentum in the ACTS development activities continued toward achieving the scheduled shuttle launch readiness date in 1992. Delivery of several engineering and flight model components and the completion of many critical design reviews signaled the shift in emphasis from design to development. Development activities included the engineering model integration and test and the flight model component manufacturing. Great strides were made in 1988 to stabilize the ACTS program, thereby assuring that the technological advancements that ACTS promises would be available in the 1990s and beyond.

Mobile Satellite. The joint mobile satellite program with U.S. industry and other government agencies

would provide two-way, satellite-assisted communication with cars, trucks, trains, boats, and aircraft within the next four or five years. Such a system, offering nationwide voice and data communications, is especially important for mobile users in rural and remote areas of the United States. A significant milestone was reached with the allocation of international frequencies for this application. Licensing approval by the Federal Communications Commission was expected. Preliminary aeronautical mobile satellite experiments were about to begin using NASA-developed hardware.

Search and Rescue. The COSPAS/SARSAT satellite search-and-rescue system completed its sixth year of operation in 1988. Over 1,100 lives have been saved as a result of the use of this system. NASA provided technical advice to support rule-making by the regulatory agencies for increasing use of the distress beacons by new classes of ships and aircraft. Cooperation with foreign partners continued and resulted in the installation of terminal equipment in several additional nations. Technical efforts to reduce the delay between activation of the distress beacon and its detection were in two areas: geostationary satellite system and interferometer experiments.

Advanced Technology and Systems Development. In close coordination with its advisory groups, NASA continued to develop the key technology and systems to address future space communications needs and the increasing demand for communication bandwidths. The agency was developing technologies that would build on the Advanced Communication Technology Satellite, support future requirements of the U.S. commercial space communications industry, and contribute to the technology base needed to support future NASA requirements in near-Earth and deep-space communications. Technologies and systems under study and development included optical communications for high bandwidth; interference-free transmission of data from both near-Earth and deep-space scientific satellite missions, robotics, and lunar and planetary exploration bases; and large,

space-based antennas for Earth sensing and communications applications. The latter would be tested and calibrated using the space station and its near zero-gravity environment and subsequently would be transported to their final positions in space.

Information Systems. The NASA Information Systems Program supports NASA Space Science and Applications flight projects and science programs by operating large-scale computational resources used for data analysis; working with specialized programs to establish data centers for managing and distributing data; and developing computer networks and exploiting advanced technologies to access and process massive amounts of data acquired from successful space missions.

NASA missions, in the next decade, may obtain unprecedented volumes of new data with fine grain temporal, spectral, and spatial resolution. Ultimately, all space science data must flow into a permanent archive. The National Science Space Data Center (NSSDC) has initiated a vigorous policy of establishing project data management plans from flight mission data. These plans specify formats, policies, and schedules to ensure the orderly flow of data into the archive, while satisfying mission data system optimization concerns. The NSSDC has extended these efforts to researchers who produce value-added or analyzed data sets as well.

Space Station Activities

The Space Station Freedom may provide unprecedented opportunities for scientific research in space, especially for materials, life, and Earth sciences. After beginning the design, development, and fabrication phase of the space station in late 1987, the first major activity in 1988 was the preliminary requirements review. To represent user interests and planned and potential science payloads, NASA's Office of Space Science and Applications produced an integrated set of science requirements for the baseline station and polar platform, which took into account planned Space

Station and Space Transportation System capabilities. These requirements were used by the Space Station Program in the preliminary requirements review to identify accommodations issues and areas needing study. Many of these studies were initiated in 1988 and were expected to be completed in time to influence station design decisions. Considerable work was done during 1988 on planning for payloads that could use the station manned base during its assembly phase.

An Announcement of Opportunity for Space Station Attached Payloads was released to the national and international science community in July 1988, and 72 flight and concept proposals were received in response to this solicitation.

A number of advanced utilization and accommodation studies were initiated in areas of contamination, small and rapid response payloads, servicing, launch site payload processing and logistics, and payload pointing systems to guide the planning for use of the manned base. Also, an important activity was begun on international joint science utilization of the pressurized modules, with participation by the international partner science representatives, to look at possibilities of sharing of common facilities and some instrumentation among science users. In 1988, the Space Station Science and Applications Advisory Subcommittee was created under the auspices of the NASA Advisory Council to continue the work of the former Task Force on Scientific Utilization of the Space Station, to advise NASA on the most effective utilization of the new capabilities to be made available by the space station program.

Space Flight

By developing space transportation capabilities and carrying out space flight operations NASA helps implement the goals of U.S. space transportation policy. These goals, as articulated in the President's National Space Policy in January 1988, are as follows: the achievement and maintenance of safe and reliable access to, transportation in, and return from space; the

exploitation of the unique attributes of manned and unmanned launch and recovery systems; the encouragement of U.S. private sector space transportation capabilities; and the reduction of the costs of space transportation and related services.

Throughout 1988, NASA focused on returning the space shuttle to flight, which it accomplished in September with the successful Discovery mission (STS-26). Moreover, the agency moved vigorously to establish a mixed fleet capability which would better assure access to space using both the shuttle and expendable (unmanned) launch vehicles (ELVs). Also, the agency formulated a comprehensive flight schedule (manifest) showing full shuttle and ELV utilization in the future. Another major activity has been NASA's efforts to assist in the commercialization of space use and the encouragement of U.S. private sector space transportation systems as called for by the President's National Space Policy. Finally, the agency continued its ongoing studies of an advanced space transportation infrastructure to support future national requirements, including manned and unmanned exploration of the solar system and the permanent presence of human beings in space. In sum, during 1988 NASA continued the process of maintaining and improving a strong, safe, and reliable U.S. space transportation capability.

Return to Flight of the Space Shuttle

Following the January 1986 Challenger accident, NASA halted shuttle operations, reviewed the entire space shuttle program, and initiated a "return to flight" effort. This effort focused on fixing the solid rocket motor field joint, which had failed during the Challenger mission, and using the available downtime to improve other shuttle hardware and to add new features for extra safety. Moreover, NASA strengthened its space flight organization by establishing central authority and improving internal communications. It also increased the level of safety awareness throughout the agency—especially within the NASA/industry team that builds the shuttle. This thorough, meticulous

return-to-flight effort proved to be worthwhile when NASA successfully returned to flight with two shuttle launches in 1988.

Orbiter. Perhaps NASA's toughest challenge in 1988 was the completion of all the changes in the space shuttle system that had been deemed necessary for a safe return to flight. An extensive review and analysis process undertaken following the Challenger accident had identified 226 changes for the orbiter alone. Of these, 107 were considered mandatory for the September Discovery mission. By July 1988, 261 alterations to Discovery had been completed.

One significant change to the orbiter initiated and completed in 1988 was the crew escape pole. NASA's Office of Space Flight selected the pole in April to be the final part of the crew escape system, which also includes a method for cutting the cabin to allow controlled venting and a capability to jettison the port side hatch and tunnel. Tests conducted during February and March in a C-141 aircraft simulating the orbiter demonstrated that in certain emergency situations, occurring during launch or re-entry, the pole would allow the crew to swing free of the orbiter and parachute to safety.

Another significant change to the orbiter completed over this past year was the redesign of the 17-inch quick-disconnect valve. This valve between the orbiter and the external tank was redesigned because there were indications that it could close shut inadvertently during launch, cutting off the flow of fuel to the main engines. Developmental testing of the redesigned valve was completed in February 1988, and qualification and certification tests for STS-26 were performed from November 1987 through September 1988.

Solid Rocket Booster. The solid rocket motor (SRM) is the major portion of the solid rocket booster and powers the space shuttle into space along with the space shuttle main engines. A flawed joint in the SRM was directly responsible for the explosion that caused the Challenger accident, so it was carefully and extensively redesigned. The redesigned SRM (RSRM)

received intense scrutiny during 1988 and was subjected to a thorough certification process to verify that it worked properly and to qualify the motor for manned flight.

The testing program included five full-scale firings of the RSRM during 1987-88. The final test, Production Verification Motor-1 (PVM-1), occurred in August. Severe artificial flaws were intentionally introduced into the test motor to make sure that the redundant safety features implemented during the redesign effort worked as planned. This rigorous final pre-launch test was necessary to demonstrate the performance of various design elements under less than optimum conditions, and was a major confidence builder for the program.

Space Shuttle Main Engine. Although the space shuttle main engines (SSMEs) have never experienced a problem during a shuttle flight, NASA used the flight downtime to undertake an intensive reexamination and safety margin improvement program for the main engines. As with the SRB, the focus was on testing the SSMEs to insure their readiness for the return to flight. The SSME ground test program was thorough; the engines were fired for 320,000 seconds in total—the equivalent of 205 shuttle launches. Moreover, an August test lasting 2,017 seconds was the longest SSME firing ever and broke the world record for test-firing a rocket engine set over 20 years ago. The SSME testing program for STS-26 exceeded the preparation for the first shuttle launch STS-1 in April 1981.

Consultation With Other Groups. NASA's Office of Space Flight received assistance from various groups throughout its return-to-flight effort. The Rogers Commission validated NASA's own self-assessment and provided specific recommendations for action. The National Research Council (NRC) monitored important parts of the redesign and testing efforts—especially those relating to the RSRM—thereby providing NASA the benefit of the NRC's considerable expertise. The NRC's "Panel on Redesign of Space Shuttle Solid Rocket Booster" submitted a letter to NASA Administra-

tor James Fletcher in September 1988 confirming that the RSRM was ready for a September launch. Moreover, NASA's own Office of Safety, Reliability, Maintainability, and Quality Assurance (SRM&QA) was a major participant in the successful and safe return to flight. After the loss of Challenger, the SRM&QA chief was elevated to the Associate Administrator level—serving directly under the NASA Administrator, and was thus able to play an integral role in decisionmaking leading to the successful STS-26 mission.

1988 Shuttle Missions. On September 29, 1988 the Space Shuttle Discovery (STS-26) successfully lifted off from Kennedy Space Center in Florida and the United States was back in space. Discovery flawlessly accomplished its primary task—the deployment of a tracking and data relay satellite (TDRS-C)—on the first day of the mission. NASA successfully conducted its second 1988 shuttle launch when Atlantis lifted off in December carrying a classified DOD payload.

Future of the Space Shuttle

Improvements Under Way. NASA's return-to-flight effort did not end with the Discovery launch. Other shuttle enhancements that will provide greater safety, reliability, and performance for future flights were also under way in 1988. Foremost among these improvements is the advanced solid rocket motor (ASRM) which will replace the RSRM. The ASRM will be based on a better design than the old rocket motor, contain more reliable safety margins, and utilize automated manufacturing techniques. Moreover, the ASRM will enhance shuttle performance by providing the capability to launch additional payload into orbit.

In March 1988, NASA submitted the "Space Shuttle Advanced Solid Rocket Motor Acquisition Plan" to Congress. This plan reviewed procurement strategy for ASRM and discussed implementation plans and schedules. In July, NASA announced that Yellow Creek—a Tennessee Valley Authority property in Mississippi—and the agency's own Stennis Space Center, also in Mississippi, would be the government-owned sites

available as locations for the new rocket motor production and test facilities, respectively. Finally, in August the agency issued a request for proposals (RFP) to design, develop, test, and evaluate the ASRM. NASA received the proposals from the various competing companies on October 31, and a contract award is anticipated in early 1989. The first flight utilizing the new rocket motor is targeted for 1994.

Another major shuttle improvement activity in 1988 was the extended duration orbiter (EDO). The EDO will have equipment installed that will extend mission duration from seven to 16 days. One of the principal benefits provided by the EDO will be the ability to carry out new science experiments not possible on a seven-day mission. During 1988, long-lead items were ordered. Also, proposals were requested and received for both the regenerative carbon dioxide collection system and the improved waste collection system. Design work on the necessary orbiter modifications was initiated, and the hardware production is scheduled to begin in 1989. The first EDO flight is planned for 1992.

Finally, significant long-term improvements to the SSME progressed during 1988. The technology test bed program at Marshall Space Flight Center successfully accomplished its first test in September. This program provides an independent means to evaluate technology programs and technical advances arising from the development program and to test alternate pumps. Separately, the alternate turbopump development program (ATD) has been under way for two years and component testing is scheduled to begin in mid-1989.

Replacement Orbiter. Work on the new orbiter to replace Challenger (the replacement orbiter, OV-105) proceeded smoothly during 1988, and the new vehicle is scheduled to be delivered by Rockwell International to NASA within the 45 months originally estimated for its completion. Importantly, the new orbiter will incorporate some added features such as a drag chute, an external SSME heat exchanger, and a 14-inch disconnect valve.

In March 1988, NASA initiated a program encouraging school children to participate in naming the new orbiter. All of the other orbiters were named after famous ships of exploration. By July, 15,000 schools across the nation had responded to NASA's invitation to help select a new name. Entries were due by the end of the year and NASA planned to select the name of the new orbiter from among the responses in May 1989. The orbiter naming program is designed to enhance student interest in and enthusiasm for science and space exploration.

Landing Sites. In March, the United States signed an agreement with Gambia allowing NASA's use of that African nation's Banjul International Airport as an emergency landing site for the shuttle. At the same time, NASA began preparing to bring on line another new abort landing site—this one near Ben Guerir, Morocco. Both sites will be used as contingency landing facilities should a transatlantic abort ever become necessary during a shuttle flight.

Expendable Launch Vehicles

1988 Launches. The expendable launch vehicle (ELV) program also had a perfect launch record in 1988: six for six. In February, a Delta ELV lifted a classified DOD payload into orbit. San Marcos DL, a NASA-Italian scientific mission, was launched on board the smaller ELV Scout during March. In April, another Scout put up the SOOS-III, a Navy navigation satellite. And in June, yet another Scout carried the NOVA-II, the third in a series of improved Navy transit navigation satellites, into space. The final Scout launch of the year transported a fourth SOOS mission in August. And finally, in September, an Atlas-E launched NOAA-H, a National Weather Service meteorological satellite.

The Mixed Fleet Strategy. NASA's mixed fleet strategy, codified by the President's January 1988 National Space Policy, calls for manifesting civilian missions on ELVs whenever the unique capabilities of the shuttle were not required. The strategy involves two phases, and in 1988 both were well under way.

Phase I of the strategy covers launches during the 1988-92 and allows for the acquisition of launch services either through DOD or commercially on a non-competitive (or sole-source) basis. Four near-term scientific payloads previously intended to fly on the shuttle (ROSAT, EUVE, CRRES, and Mars Observer) have been designated to launch on ELVs during Phase I. Two Delta IIs have been ordered through DOD to launch the ROSAT and EUVE, an RFP was issued for Titan III commercial launch services to support Mars Observer, and a letter contract was issued to procure Atlas/Centaur commercial launch services for the CRRES mission in 1990.

During Phase II, covering the period after 1992, NASA will procure ELV launch services competitively from the commercial sector whenever feasible. Launch services that are not available commercially, but are under DOD contract, would be acquired through DOD. Launch service ordering agreements have been established in four performance classes: small, medium, intermediate, and large. Goddard Space Flight Center plans to release RFPs for the small and medium class procurements in 1989. The release date for the intermediate-class RFP has not yet been determined. Finally, large-class launch services will be acquired through DOD rather than from the private sector because no large vehicles (Titan IV) are commercially available. Importantly, NASA, acting as NOAA's agent, awarded a firm, fixed-price contract to General Dynamics for ELV launch services for the GOES I, J, and K missions with an option for GOES L and M. The contract, awarded in April 1988, was the first commercial ELV launch service competitively procured by the U.S. Government.

In addition to arranging for the purchase of launch services from the commercial sector, NASA also followed the President's space policy by taking steps to divest itself of an adjunct ELV capability and by making NASA-owned ELV property and services available to the private sector.

During 1988, NASA finalized a barter agreement with General Dynamics that gave the company ownership of NASA's Atlas/Centaur flight and non-flight assets. In exchange, General Dynamics will provide the agency with two Atlas/Centaur launches at no charge. A contract had been signed for the first launch service—supporting the FLTSATCOM F-8 Navy mission. Moreover, a letter contract was completed for a second launch service to support the NASA/DOD CRRES mission.

In addition, NASA transferred its Delta vehicle program to the U.S. Air Force. In May 1988, the agency transferred accountability for Delta Launch Complex 17 at Cape Canaveral to the USAF. A similar approach was taken to transfer accountability for Atlas/Centaur Launch Complex 36 to the USAF.

Finally, enabling agreements were completed to allow ELV companies to negotiate directly with the appropriate NASA field center. During 1988, NASA Headquarters signed enabling agreements with McDonnell Douglas in September, Martin Marietta in October, and LTV in November. The next step was for the company to sign a subagreement with the NASA field center to allow for use of specific property and services. The Kennedy Space Center (KSC) and General Dynamics consummated a subagreement in March 1988 which allowed General Dynamics to take over maintenance and operational responsibility for Launch Complex 36. Three additional subagreements—involving KSC/Martin Marietta, KSC/McDonnell Douglas, and GSFC/McDonnell Douglas—were under final negotiation as 1988 drew to a close.

Upper Stages

Inertial Upper Stage. The inertial upper stage (IUS) is a USAF-developed vehicle that can transport payloads from low to high (geosynchronous) Earth orbit. The IUS can be used on the shuttle, the Titan III, and the Titan IV ELV. NASA ordered three inertial upper stages from the Air Force to accommodate the planetary missions—Galileo, Ulysses, and Magellan—

that were previously scheduled to be boosted by shuttle-Centaur upper stages. It was an IUS that successfully lifted TDRS-C into high Earth orbit on STS-26 in September 1988, and inertial upper stages will support the additional TDRS missions scheduled in the future.

Transfer Orbit Stage. The transfer orbit stage (TOS) developed commercially by the Orbital Sciences Corporation, is designed to place payloads into geosynchronous transfer orbit or other high energy trajectories. It can be used with either the shuttle or Titan III. In 1988, NASA was in the process of procuring two TOS vehicles to support the Mars Observer and ACTS mission, and production continued during the year.

Orbital Maneuvering Vehicle

The orbital maneuvering vehicle (OMV) is a small, reusable, unmanned free-flying spacecraft designed to perform a variety of missions including deploying, retrieving, reboosting, deboosting, servicing, and viewing spacecraft. It will be carried into orbit by the shuttle or an expendable launch vehicle and will be remotely controlled from the ground during rendezvous and docking. A preliminary design review for the OMV was completed in October, with a critical design review scheduled for late 1990. In 1988, NASA's Office of Space Flight undertook a joint study with NASA's Space Station Office to determine the feasibility of resupplying the space station with logistics elements delivered to orbit by ELVs, with the OMV used to transfer these elements to the station. Also, a study on the feasibility of man-rating the OMV was completed.

Solid Propulsion Integrity Program

The Solid Propulsion Integrity Program (SPIP) is working to establish the engineering capability necessary for improving the success rate of U.S.-built Solid Rocket Motors (SRMs). The program seeks to strengthen the scientific foundation for SRM design, manufacture, and evaluation. During 1988, SPIP completed the bulk of the work on a Solid Motor Test

Bed, and this national facility is scheduled to be available and ready for testing in January 1989. Also, SPIP focused on an examination of motor bondlines and nozzles during 1988. For example, in July the program conducted the most highly instrumented SRM nozzle test ever.

Spacelab

Spacelab is a reusable science observatory/laboratory flown in the shuttle payload bay. Developed by the European Space Agency, it includes a pressurized module that provides a shirt-sleeve environment for the crew, as well as an unpressurized platform pallet for research activities not requiring man-tending. During 1988, replacement of Spacelab's on-board computers with units similar to the updated orbiter computers continued. Changes recommended by the Spacelab recertification board were also carried out.

Additionally, management of the Hitchhiker program was consolidated to reduce costs under the responsibility of the Goddard Space Flight Center. The Hitchhiker system creates a simple interface between small experiments and the shuttle, thereby making integration for flight easier and less costly. Finally, the development of the Spacelab enhanced pallet was near completion at the end of 1988. Another important 1988 activity was mission planning and integration required for the resumption of Spacelab missions in 1990.

Tethered Satellite System

The tethered satellite system (TSS) is a satellite anchored to the space shuttle by a tether up to 62 miles long that would be deployed into areas of space that are otherwise difficult to reach. This satellite would be able to perform unique "in situ" science. TSS is a cooperative program between NASA and Italy's space agency.

In 1988, manufacture and qualification of the flight subsystems continued. The 12-meter deployer boom, reel motor, and on-board computer were all qualified and delivered. Also, manufacture of the deployer structure was initiated, and the tether control mecha-

nisms were functionally tested. Importantly, a test program was completed for the satellite structural and engineering models. The flight satellite structure was due for delivery in early 1989. Development of the scientific instruments continued, with delivery of flight satellite instruments scheduled for early 1989. The first TSS mission is scheduled for 1991.

Advanced Programs

Advanced programs focus on the future of space transportation, including improving current and future space transportation operations through the introduction of more advanced technologies and processes, and on servicing and protecting U.S. space assets. The Civil Needs Data Base (CNDB), a compilation of civil space mission needs from 1990 to 2010, is a key tool for advanced program planning.

Next Manned Launch Vehicle. Attention was devoted in 1988 to examining various next-generation manned launch vehicle concepts. Three possible directions were under consideration: shuttle evolution, a personnel launch system, and an advanced manned launch system (AMLS). The evolution concept refers to the option of improving the current shuttle design through the incorporation of upgraded technologies and capabilities. The personnel launch system would be strictly a people carrier and have no capability to launch payloads into space. Finally, AMLS represents the most dramatic possibility as it would take an entirely new approach and devise a "next generation" manned transportation system. Preliminary studies on all three possibilities proceeded in 1988, and were planned to continue for a few years in order to develop sufficient technical data to support a future decision on which path or paths NASA should choose.

Assured Crew Return Capability. NASA continued assessing the need and concepts for an assured crew return capability (ACRC) to transport space station crew members back to Earth in case of an emergency. During 1988, NASA completed an in-house Phase A (conceptual) study to explore various possi-

bilities and planned to initiate a contracted follow-on study in 1989.

Shuttle-C. Shuttle-C is a concept for a large, unmanned launch vehicle that would make maximum use of existing shuttle systems with a cargo canister in place of the orbiter. Studies continued in 1988, including a Phase B definition study to be concluded in 1990. Results to date indicate that Shuttle-C could be developed by the mid-1990s.

Advanced Launch System. The Advanced Launch System (ALS), a joint NASA/DOD effort, is a systems definition and technology advanced development program aimed at defining a new family of launchers for use after 2000, including a new heavy-lift vehicle. President Reagan signed a report to Congress in January 1988 that officially created the program. Within this DOD-funded program, NASA manages the liquid engine system and advanced development efforts.

Advanced Upper Stages. Advanced missions in the future would require even greater capabilities to move from low to high Earth orbit and beyond. During 1988, activity in the advanced upper stages area focused on the space transfer vehicle (STV) and the possibility of upgrading the existing Centaur upper stage. The STV concept involves a cryogenic hydrogen/oxygen vehicle that would be capable of transporting payloads from low Earth orbit to geosynchronous orbit or the lunar surface, as well as for unmanned planetary missions. The STV concept could potentially lead to a vehicle capable of supporting human exploration missions to the moon or Mars.

Advanced Operations. The Advanced Operations effort, initiated in 1987, seeks to identify and demonstrate new and enhanced processes and technologies that can be applied to ground, flight, and on-orbit operations to reduce the operations costs of space transportation systems while ensuring that safe and reliable operations are maintained. The selective application of expert systems, robotics, automation, and other technologies to labor-intensive and hazardous operations has been the major thrust of advanced

operations. During 1988, advanced operations techniques and approaches continued to be studied with emphasis on demonstrating expert and autonomous systems technologies for current and future space transportation vehicles.

Satellite Servicing. The servicing of existing (and future) space assets is perhaps as important as creating new hardware. Thus, in 1988, NASA continued definition of systems and procedures for on-orbit satellite servicing using the shuttle and the planned orbital maneuvering vehicle. Satellite servicing is an emerging capability in the early stages of development, and NASA submitted a report to Congress in March 1988 describing the current scope of its servicing activity. Other 1988 activities included the definition of tankers, couplings, telerobotic servicing aides, and servicing procedures to support on-orbit servicing. An early definition study (pre-Phase B) on a satellite servicer system was under way during 1988.

Transportation Services

Transportation services is the arm of NASA that schedules and oversees the integration of payloads on the space shuttle. This is a complex job because the many payloads involved have wide-ranging schedule and performance requirements. To satisfy the requirements of a diverse group of users, their unique needs must be matched with the capabilities of the available launch systems. Developing a manifest assigning payloads to specific missions is an essential part of this process. Another important task is the planning and engineering necessary to accommodate the payload in the transportation system and to integrate its operational requirements into the flight plan. Finally, if the payload is owned or sponsored by a foreign or commercial entity, NASA negotiates a detailed agreement with the customer covering services to be provided, the responsibilities of each party, and the reimbursements to be paid.

All of these activities gained momentum in 1988 as the space shuttle returned to flight and the mixed fleet

concept was implemented. The latest manifest in 1988 was released at the end of August 1988, superseding the one published in March 1988. The August manifest showed seven flights in 1989 and a total of 50 shuttle missions by the end of 1993, as well as many ELV flights. The timing of the scheduled missions reflects the high priority given to both civil space science and applications payloads and important Department of Defense missions.

Commercial Activities

In addition to procuring commercial launch services on ELVs, NASA moved toward the commercialization of space use in 1988 by playing an integral role in the initiation of two new cooperative ventures with the private sector: the Commercially Developed Space Facility (CDSF) and Spacehab.

The Administration initiated the commercially developed space facility (CDSF) effort in February 1988 as part of the commercial space initiative. The CDSF concept called for the private sector to design, build, test, integrate, and operate the CDSF for government and commercial users. According to this plan, the government would mitigate the risk to the private sector by leasing up to 70 percent of the facility's capability over the first five years of operation.

Initially, the President's decision directed NASA to develop and issue an RFP, select a source for the lease, and negotiate a contract within 150 days. However, later in the year Congress decided that further consideration of the concept was necessary before taking action. Committees with NASA oversight in both the House and Senate directed NASA to contract independent studies with the National Research Council and the National Academy of Public Administration to provide a basis for making subsequent CDSF program decisions. Further CDSF program progress was on hold at the end of 1988 pending decisions on the studies, which were scheduled for completion in 1989.

Spacehab, another venture focused upon in the February 1988 Commercial Space Initiative, is a

pressurized module that is being developed by a private company (SPACEHAB, Inc.) for flight in the space shuttle payload bay. The module will increase the amount of pressurized volume available in the middeck, and thus allow for more commercial ventures and research activities requiring man-tending. Shuttle crew members will enter the module through a tunnel between the shuttle middeck and the module. In August 1988, NASA and SPACEHAB, Inc. signed a Space Systems Development Agreement that provided for six flights of the module on the shuttle beginning in 1991. The company initiated final design and construction and was marketing access to the module and its support facilities on a commercial basis.

Space Flight/Space Station Integration

During 1988, NASA continued to focus on the important task of preparing for the integration of the Space Station Freedom into the space transportation support system. In 1988, the agency undertook several significant projects to support deployment, assembly, and operation of the station. For example, a NASA report to Congress entitled "Space Transportation for the Space Station" examined transportation capabilities and identified areas that need improvements in both the National Space Transportation System (NSTS) and Space Station Programs. As a follow-up to this report, NASA initiated studies to investigate the role of expendable launch vehicles and orbital maneuvering vehicles in supporting the space station manned base's logistics requirements.

Space Station

During 1988 NASA made great strides toward the development of the permanently manned space station mandated by President Reagan in 1984. The President reaffirmed the national commitment to the station in his National Space Policy, revised in January 1988, and in July he christened the station "Freedom." NASA signed hardware design and development contracts for the four work packages in September. The same month, the Intergovernmental Agreement (IGA) was

signed by representatives of the United States, Canada, Japan, and the participating European countries, and Memoranda of Understanding (MOU) were signed by NASA with its counterpart agencies in Canada and Europe, establishing cooperative arrangements for station design, development, operation and utilization work. The Japanese MOU will be signed in 1989, following ratification of the IGA by the Diet. By the end of 1988, program requirements had been reviewed and agreements definitized between the work package contractors to simplify program integration and management. In summary, 1988 marked the movement of the Space Station Freedom program from the definition phase to design and development.

Program Description and Goals

Space Station Freedom will be a versatile facility to support research in a broad spectrum of technical disciplines. For science, the space station will offer laboratories for studying the life sciences, materials sciences, and many other fields where space provides unique research opportunities. In addition, the space station will support research in such areas as astrophysics and the Earth sciences with instruments looking out at the universe and back at Earth. For technology development, Freedom will be a testbed for evaluating technologies and design approaches for potential application in future space systems, and will also support the development and perfection of new products and processes for application here on Earth. In the longer term, Space Station Freedom may evolve to meet additional national requirements as they are defined. For example, support for manned missions to the moon and Mars could be an important role for the space station in the first quarter of the next century. Supporting on-orbit spacecraft assembly and servicing is another potential function of Space Station Freedom that could someday be important.

The program's overarching goals have remained largely unchanged since 1984 but are continually clarified as progress is made.

They are:

- Assure U.S. and Free World leadership in space during the 1990s and beyond;
- Provide a versatile facility for space science and applications;
- Stimulate the development of advanced technologies;
- Provide options for future exploration of space;
- Promote international cooperation;
- Develop the commercial potential of space.

Configuration

The Revised Baseline Configuration established in 1987 did not change in 1988. However, the assembly sequence was revised to allow early man-tended capability. Because of the one-year program schedule delay resulting from budget shortfalls, it was critical to assure significant user capabilities at the earliest possible time. Program plans at the end of 1988 call for the U.S. Laboratory Module to be launched partially outfitted on the fourth assembly flight in the fourth quarter of 1995, and to be fully outfitted on the sixth assembly flight. An Extended Duration Orbiter (EDO) would be used for the seventh assembly flight (second quarter of 1996), enabling the astronauts to perform experiments aboard the man-tended station. This change would allow meaningful research to be performed aboard Space Station Freedom very early in its development.

Program Status

The Space Station Freedom program moved from the definition phase into the design and development phase in 1988, making schedule adjustments where necessitated by revised funding profiles. Program requirements were reviewed and refined, hardware design and development contracts were signed and associate contractor agreements were put in place to simplify program integration.

The Program Requirements Document (PRD) was signed by the Associate Administrator for Space Station in February. This top level document contains require-

ments for station design, assembly, utilization, schedule, safety, evolution, management, and cost. In May, the Program Requirements Review (PRR) began at the Program Office and was completed at the four work package centers by the end of the year. The PRR provided a foundation to begin the detailed design and development process by verifying program requirements and insuring that those requirements could be traced across all levels of the program and could be met within the available technical and fiscal resources. The program specification document was also examined to assure that it was complete and consistent.

Contract activity in 1988 focused on moving forward from definition to design and development. Contracts for each of the four work packages were signed in September 1988. Boeing will develop Work Package 1, which consists of the laboratory and habitation modules and subsystems (Environmental Control and Life Support, Internal Thermal Control and Internal Audio and Video). Work Package 2, consisting of the transverse truss, mobile transporter, airlocks, external thermal control, data management, communications and tracking, guidance, navigation and tracking, propulsion and the shuttle attachment, will be developed by McDonnell Douglas. Parts of Work Package 3, the U.S. polar platform and attached payload accommodation, will be developed by General Electric. Rocketdyne is responsible for the development of Work Package 4, the power system.

The Flight Telerobotic Servicer (FTS) is part of Work Package 3. Phase B definition studies were completed by Grumman and Martin Marietta in August and a non-advocate cost review was held in September. The Phase C/D (detailed design and development) request for proposals (RFP) was issued in November, and contractor selection is expected in 1989.

In addition to the work package contracts, Associate Contractor Agreements (ACA) were established between the contractors late in 1988 to simplify intersite deliveries and place accountability for program success at the lowest level. These agreements establish obliga-

tions such as open exchange of data, coordination and resolution of problems, and engineering and integration support post-delivery among the work package contractors, while maintaining the appropriate level of NASA responsibility and control through a formal management system.

Considerable progress was made on program documentation, beginning with the completion of the first Capital Development Plan in April. This plan will be updated annually. It included the estimated cost of all direct research and development, space flight, control and data communications, construction of facilities and research and program management. Another cost-related report, the "Space Station Program Response to the Fiscal Year 1988 and 1989 Revised Budgets," was submitted to the Congress in April in accordance with the FY 1988 Appropriations Measure.

More detailed program documentation was also produced in 1988. The Program Definition and Requirements Document (PDRD) was intensively reviewed and revised as part of the Program Requirements Review process. The PDRD contains the technical requirements, including functional requirements and derived "design to" requirements, schedules and plans for implementation of the cooperative program. The Program Plan, which details the management structure of the Freedom program, neared completion. This document clearly delineates the work breakdown structure down to Level V of the program.

Because of Freedom's anticipated 30-year lifetime, it is essential that both life-cycle costs and development costs be considered in the design phase of the program. The program has been developing a total cost model which would be used to determine the impact of design requirements and changes to the program. This would ensure that life-cycle cost implications are taken into account as appropriate in all major design decisions. The program also began working in 1988 on examining station hardware with the goal of increasing

commonality and maintainability, thereby reducing future logistics support requirements and costs.

Operations and Utilization Planning

Planning for the operations and utilization of Space Station Freedom remained a high priority in 1988. A great deal of attention is being paid to these areas in the early years of the program in order to keep costs down and maximize the station's potential.

In the area of operations, the program worked toward refining the concepts contained in the April 1987 report of the Space Station Operations Task Force which explored space-based and ground-based operations and support systems. Considerable effort was also devoted to developing procedures and tools for the operational era of the station, as well as defining facilities requirements for utilization and operations.

Maximizing utility and minimizing cost for Freedom Station requires cooperative planning between the Space Station program and other organizations, both within and outside of NASA. To this end, discussions with NASA's Office of Space Flight were initiated on the possibility of sharing/coordinating logistics considerations for the Shuttle and Space Station programs. Meetings held with the Department of Defense have allowed the program to gain insight from DOD on operations and logistics activities in space. Space Station program personnel continued working with the International Polar Orbiting Meteorological Satellite (IPOMS) group to develop an international approach to meteorological data using the NASA and ESA polar platforms. In 1988 a commonality study for the polar platforms was initiated with ESA in the context of the IPOMS group.

Part of the utilization effort is aimed at defining the user environment. The Space Station Microgravity Environment report submitted to Congress in July described the microgravity characteristics expected to be achieved in the U.S. Laboratory and compared

these characteristics to baseline program operations and utilization requirements.

A great deal of the utilization activity of the Freedom program is focused on cooperation with and support of the NASA offices that represent station users. These offices include the Office of Space Science and Applications (OSSA), the Office of Aeronautics and Space Technology (OAST), and the Office of Commercial Programs (OCP). In 1988 these offices named permanent representatives to a variety of Space Station Freedom program panels and boards where they are working cooperatively to see that user needs for the program are met. During the summer NASA also began a multilateral utilization study with its international partners to coordinate utilization planning.

In 1988 the Space Station Freedom program supported and participated in a variety of workshops sponsored by other NASA offices and advisory groups. The OSSA sponsored a workshop in Guntersville in January that focused on updating payload requirements for Freedom Station and preparing input for the PRR trial payload manifest. A broad range of science utilization and operational issues was examined at the Space Station Science and Applications Advisory Subcommittee (SSSAAS) workshop in Hyannis, MA in June—a formal report was presented to NASA in September. Some utilization and operations issues, including potential conflicts between materials science and life science research, were discussed at the National Research Council Committee on Space Station's November workshop in Irvine, CA.

Evolution Planning

The February 11, 1988 Presidential Directive on National Space Policy stated that the "Space Station will allow evolution in keeping with the needs of station users and the long-term goals of the U.S." This Presidential directive reaffirms the NASA approach to design and build a space station that is capable of expanding capabilities and incorporating improved

technologies to meet future needs. The space station design reflects consideration of an extended operational lifetime in support of a changing and growing user community. Therefore, planning for evolution is taking place in parallel with the design and development of the baseline space station.

Accomplishments in 1988 include incorporating various evolution design requirements in the top-level baseline program documentation. These requirements preserve the capability for station growth and evolution. Preliminary work has also begun to define reference evolution concepts that would accommodate potential future initiatives, including expansion of research and development activities on-board the space station, Mission to Planet Earth, and manned and unmanned planetary exploration. NASA and the international partners are coordinating their respective evolution studies in an international working group.

During 1988, the Office of Space Station's advanced development program began fostering and demonstrating technologies that could enhance baseline capabilities with an emphasis on increasing productivity and reliability, reduce operations costs and enable evolution by providing mature technology in areas required to support advanced missions. The advanced development program focused on maturing technologies in the areas of advanced automation, knowledge-based systems, and robotics.

International Cooperation

Negotiations with NASA's international partners on cooperation during design, development, operations and utilization were completed in June. In September 1988, the agreements were signed. The multilateral Intergovernmental Agreement (IGA) was signed by Secretary of State George Shultz and representatives from Canada, Japan, and the nine European countries participating through the European Space Agency (ESA). Bilateral Memoranda of Understanding (MOUs) were signed by Deputy Administrator Dale Myers with ESA and the Canadian Ministry of State for Science and

Technology; the Japanese MOU will be signed in 1989 after the Japanese Diet ratifies the IGA.

Under these agreements, all the partners will provide flight hardware and supporting ground elements. The following hardware will be provided:

- Canada: Mobile Servicing System
- ESA: Attached Pressurized Module, Polar Platform, Man-Tended Free Flyer
- Japan: Japanese Experiment Module (JEM), including a pressurized laboratory, an exposed facility, and experiment logistics modules.

In addition, all partners will participate in the management of the station, with the manned base operating as an integrated unit and the free-flying elements operating more autonomously. Crew members will be provided by each of the partners, and operating costs will be shared.

The international management structure for the Freedom program has been established and is operating. Design and development activities will be managed bilaterally, while operation and utilization activities will be managed multilaterally. The MOUs establish management bodies that coordinate and make decisions on the cooperative activities of the partners. Consensus decision-making is the goal; however, where consensus cannot be achieved, NASA is authorized to make decisions necessary for a safe, efficient, and effective program.

Commercial Participation in Freedom

NASA will foster commercial participation in the development, operation, and utilization of Freedom Station. NASA will ensure that the space station's design, development, and operations are appropriately influenced by commercial considerations and will encourage commercial investment in ventures which use and support the station.

The 1988 National Space Policy mandates the provision for commercial participation in the Freedom program. Commercial participation is possible through two distinct avenues: commercial utilization and com-

mercial infrastructure. Commercial utilization will involve commercial users of Freedom who will conduct space-based research and development activities. Commercial infrastructure involves commercial provision of selected space station-related systems and services on a commercial basis to NASA and space station users. The 1988 Commercial Space Initiatives directed NASA, in coordination with OMB, to clarify and strengthen the Federal commitment to private sector investment in the Space Station Freedom program by revising the guidelines on commercialization. This has been done, and procedures to implement these guidelines have been established. In addition, NASA has established procedures and criteria to evaluate proposals for commercial infrastructure participation in Freedom.

To inform industry of commercial utilization and infrastructure opportunities, the Office of Commercial Programs and the Office of Space Station co-sponsored several Space Station Freedom workshops in 1987 and 1988.

Conclusion

The Space Station Freedom program completed the transition from definition to design and development activities in 1988. Contracts were signed for hardware development in each work package, and arrangements between contractors were refined to facilitate integration. NASA and its international partners signed agreements for cooperation on the development, operations, and utilization of Freedom Station and began coordination work. Utilization and operations planning proceeded steadily. The program revised NASA's commercial guidelines and implemented procedures to accommodate proposals. In summary, at the end of 1988 the Freedom program was well on its way to developing a permanently manned research facility in space.

Commercial Programs

America's space program has embarked on a new beginning. Beyond the efforts leading to the Space Shuttle's return to flight, there is a renewal of our commitment to leadership, and a strong new emphasis on the commercial development of space as a national economic asset.

Fiscal year 1988 opened with a transition to new management in the Office of Commercial Programs (OCP). After a decade of pioneering commercial space manufacturing at McDonnell Douglas Astronautics Corporation, Mr. James T. Rose returned to NASA and was appointed to serve as Assistant Administrator for Commercial Programs.

In February, the Commercial Programs Advisory Committee (CPAC) was formally created and Mr. Edward Donley, Chairman of the Executive Committee, Air Products and Chemicals, Incorporated, was named to serve as its chairman. A distinguished group of corporate chief executive officers and their university counterparts agreed to serve as members of CPAC. The first two meetings of the group were held in July and October. As a subcommittee of the NASA Advisory Council, the new group will assist NASA by reviewing policies and programs and recommending strategies to implement the national space policy goals to promote greater investment and participation by the U.S. private sector in America's civil space program.

Another key management initiative of 1988 was the development of a strategic plan for the next quarter century. This comprehensive plan, primarily aimed at meeting the needs and interests of U.S. industry over the next 25 years, is being prepared with the assistance of the American Institute of Aeronautics and Astronautics and a steering committee composed of senior research executives representing diverse industries.

Commercial Development

The year 1988 saw an expansion of the NASA-industry partnership with the signing of new cooperative agreements. In August, NASA and SPACEHAB,

Incorporated, signed a Space Systems Development Agreement to provide six shared Space Shuttle flights for the firm's privately developed and financed mid-deck augmentation module. The agreement allows the company to pay NASA for standard services on a deferred basis. The SPACEHAB module is a truncated cylinder designed to fit in the Shuttle's cargo bay and expand the pressurized volume of the orbiter. SPACEHAB will provide customers with a variety of locker and rack accommodations, with associated support and integration services. Commercial ventures and sponsored research requiring man-tended access to the space environment will provide the primary target market.

Unocal, which in 1988 continued its cooperative research and development effort with NASA's John C. Stennis Space Center (SSC) under a Proprietary Work Agreement, initiated discussions with OCP on a proposed Joint Endeavor Agreement (JEA). The firm, which is working on the development of a remote sensing instrument to assist the search for energy resources, has expressed interest in development flights aboard both the Space Shuttle and the Space Station Freedom.

Another agreement was signed in 1988 with Corabi International Telemetry, Incorporated, to support commercial development of telemedicine services for Space Station Freedom. Under the agreement, NASA and Corabi will cooperate in the firm's efforts to adapt, for Space Station Freedom use, Corabi's terrestrial-based technology. The technology enables medical specialists to remotely review and analyze biological and other materials via high-resolution video images.

The Joint Endeavor Agreement (JEA) is a no-exchange-of-funds arrangement under which NASA sponsors space flight opportunities for companies that invest corporate resources to test and develop commercially promising concepts. To facilitate early flight experiment opportunities for the NASA Centers for the Commercial Development of Space (CCDS) and their

industrial participants, work began this year on the creation of a new agreement mechanism—a pre-JEA.

NASA also negotiated a Technical Exchange Agreement with Amoco, an industrial affiliate of the Center for Advanced Materials located at Battelle Columbus Laboratories, Columbus, Ohio.

On June 1, 1988, NASA published in *Commerce Business Daily* an invitation for the U.S. private sector to express interest in commercially using the Space Shuttle's jettisoned external tanks. The notice was the first step in implementing one of the specific actions included in the President's Commercial Space Initiative. Proposals remaining after initial screening reviews are currently undergoing thorough technical, safety, and business evaluations.

Before the President's Commercial Space Initiative was announced, two companies had approached NASA expressing interest in using the Space Shuttle's external tanks. In December 1988, NASA signed an agreement with the University Corporation for Atmospheric Research, Boulder, Colorado, supporting their efforts for commercial use of the intertank space within five external tanks for suborbital experiments. The second company, Global Outpost, Incorporated, Alexandria, Virginia, is currently negotiating an agreement with NASA to exchange information on external-tank technology.

Laying a Sound Foundation

Getting U.S. industry into space with the best prospects for long-term commercial success requires laying a sound foundation on the ground. NASA has established CCDSs, which are a nationwide network of unique research organizations which combine industrial interest, university talent, and government sponsorship to investigate and develop areas of commercial potential.

These CCDSs serve as incubators for future commercial space ventures, enabling their industrial affiliates to explore the economic value of space in a program where financial and technical risks are shared. Seven

new CCDSs were started in 1988: the Center for Advanced Space Propulsion, University of Tennessee Space Institute, Tullahoma, Tennessee; the Space Power Institute, Auburn University, Auburn, Alabama; the Center for Autonomous and Man-Controlled Robotic and Sensing Systems, Environmental Research Institute of Michigan, Ann Arbor, Michigan; the Center for Cell Research, Pennsylvania State University, University Park, Pennsylvania; the Center for Bioserve Research, University of Colorado-Boulder, Boulder, Colorado; the Center for Materials for Space Structures, Case Western Reserve University, Cleveland, Ohio; and the Center for Space Power, Texas A&M University, College Station, Texas.

A new management initiative undertaken this year seeks to establish a closer linkage between the CCDSs, and enhance the interactions with NASA field installations. CCDS Directors are now serving on a Commercial Programs Management Council.

The efforts in 1988 of a team of industrial researchers affiliated with the Center for Macromolecular Crystallography, University of Alabama-Birmingham, Birmingham, Alabama, clearly evidence the value and potential of this program. The team's experiment aboard STS-26 performed research that could lead to commercial, in-space production of tiny protein crystals. High-quality crystals were obtained from most of the protein and enzyme samples flown, and new knowledge regarding the samples was obtained. Four of five of the samples grew crystals of exceptional size and quality. Protein crystals grown in space could become vitally important research tools for scientists who are working to develop powerful new drugs to combat cancer, high blood pressure, organ transplant rejection, rheumatoid arthritis, and many other diseases.

Another CCDS, the Consortium for Materials Development in Space, University of Alabama-Huntsville, Huntsville, Alabama, is leading efforts to conduct materials processing research aboard a commercially

provided sounding rocket. The sounding rocket, scheduled for launch in the first part of 1989, will carry a payload of instruments to perform materials processing experiments in the low gravity environment of space. In keeping with the Commercial Space Launch Act, the consortium plans to award a competitive contract for launch services.

CCDS accomplishments include some 615 drop tube/tower microgravity experiments conducted, 21 KC-135 microgravity flight experiments, involvement in 4 Space Shuttle flights, 1 series of Lear Jet flights, and 5 experiments prepared for a sounding rocket flight. Approximately 58 CCDS payloads have been identified for repetitive materials processing testing.

Since initiation of the program in 1985, participation and interest has steadily risen, with the number of CCDS industrial affiliates now totaling well over 100.

Capitalizing on New Ideas from Small Business

OCP launched an effort in 1988 to identify new opportunities for American small businesses to capitalize on their innovative ideas by developing commercial applications of space research. Ways to increase small business participation in the commercial development of space are also being actively explored.

A growing number of small business concerns are initiating new commercial products in many fields as a result of research and development funded through NASA's continuing Small Business Innovation Research (SBIR) Program, a program administered by OCP. Since 1983, NASA has spent or committed \$175 million for 755 Phase I and 299 Phase II SBIR contracts placed with 446 small businesses in 40 states, territories, and the District of Columbia.

During FY 1988, NASA announced the selection of SBIR research proposals resulting in 204 Phase I contract awards from the 1987 Program Solicitation and 85 Phase II awards for continuations of Phase I projects initiated the previous year. Also during FY 1988, OCP completed a comprehensive review assessing the results of Phase II SBIR projects completed to date.

Many of the results and products are being utilized in NASA programs and several have been successfully commercialized.

Expendable Launch Vehicle Privatization and Commercialization

Assuring a highway to space by fostering growth of a U.S. commercial launch industry is another key initiative of the President's new National Space Policy. Over the past few years, NASA's efforts to advocate and encourage development of an ELV industrial base have helped make commercial space transportation services a reality.

There has been a rapid succession of agreements between NASA and the private sector concerning commercial expendable launch vehicle (ELV) development. NASA signed an agreement in 1986 with Space Services, Incorporated, a small firm located in Houston, Texas, for commercial ELV support at the NASA Wallops Flight Facility, Wallops Island, Virginia. NASA's 1987 agreement with General Dynamics marked the first transference of a government-developed ELV (Atlas Centaur) to the private sector. This achievement was followed in 1988 by an agreement with LTV Aerospace and Defense Company, Missiles and Electronics Group, for privatization of the Scout Launch Vehicle Program, as well as agreements between NASA and Martin Marietta Commercial Titan, Incorporated, and McDonnell Douglas Astronautics Corporation, for NASA facility support to the commercial Titan and Delta launch vehicle programs, respectively.

In addition to NASA's provision of support to commercial ELV firms, NASA stands to become an important customer of commercial launch services. In 1988, NASA and the Department of Commerce made history with their award of a \$200 million contract to General Dynamics for the acquisition of a commercial launch service "package" for the National Oceanic and Atmospheric Administration's family of Geostationary Operational Environmental Satellites. This marks the

first U.S. Government procurement of a commercial launch service. Further support to the commercial ELV industry comes from NASA's adoption in 1988 of a mixed-fleet plan, in which unmanned launches, purchased by NASA as a commercial service, will complement Space Shuttle operations. A need has been identified for 30 such commercial launch services through 1994.

NASA and the Consortium for Materials Development in Space, a CCDS in Huntsville, Alabama, awarded a commercial launch services contract to Space Services, Incorporated (SSI). Under the contract, funded through a NASA grant to the CCDS, SSI will launch a materials science experiment payload aboard their sounding rocket vehicle in March 1989. The flight will be the first commercial launch of the firm.

Further Efforts

NASA is also working closely with industry to explore the potential commercial uses associated with the Space Station Freedom, an orbiting complex of modules to be assembled in the 1990s. In November 1987, NASA officials met with more than 200 corporate executives, representing diverse industries, to discuss how the Space Station Freedom can best meet future industry needs. Input from this conference is being used in formal NASA reviews of Space Station Freedom user requirements as work proceeds toward detailed design and development of the orbital facility.

A second Space Station Freedom Commercial Workshop was held in October 1988. Of the 225 attendees, more than 150 representatives from industry participated in workshop activities which included panel discussions on Space Station Freedom policy and procedural matters, as well as technical discussions on the commercial applications relative to life sciences, materials processing in space, and commercial Earth and ocean observations. Attendees from academia, industry, and other government organizations were very impressed by the program, the selected exhibits, high-level management interest, and opportunities for

commercial space activities which were presented at the workshop.

New policy and planning initiatives to review pricing policies, commercial participation in the development of space infrastructure, and criteria for assessing proposed commercial ventures were also begun in 1988. These activities will continue into FY 1989 to further develop NASA's capabilities to respond to commercial interest in space.

Potential commercial applications of remote sensing—the process in which satellite or airborne sensors detect various types of radiation emitted by, or reflected from, objects on Earth—continue to increase. In 1988, NASA selected for funding some 20 applications projects in this area, 9 of which will be managed by the NASA Stennis Space Center Earth Resources Laboratory. This lab is currently exploring ways to use existing remote sensing technology in new commercial products and services and is also helping users develop their own technology.

Technology Utilization

For 25 years, NASA's Technology Utilization Program has been dedicated to promoting and facilitating the application of NASA-developed technologies in the public and private sectors. Building on a solid record of accomplishment in technology transfer, the NASA program is well prepared to meet the challenge of a new federal emphasis on increasing the transfer of government-funded technologies to the private sector as a means of improving U.S. industrial competitiveness.

Recent congressional legislation and Executive Orders have directed Federal agencies to heighten their efforts to move new technologies into the U.S. private sector. One of NASA's first responses was to conduct a thorough review of its program, which has already produced thousands of successful aerospace and nonaerospace "spinoffs" ranging from improved medical care to energy conservation. From that review, a new strategic plan has emerged to serve as a guide-

line for present and future NASA technology transfer activities.

Major steps were taken in 1988 to strengthen and expand the scope of NASA's technology transfer network and the various mechanisms which comprise it. In addition, a series of new initiatives were implemented by the Technology Utilization Division to ensure further progress in advancing the objectives of specific congressional and executive actions mandating more active and consistent technology transfer efforts throughout the Federal Government.

A Nationwide Network

Over the years, NASA's technology transfer network has provided thousands of industrial, university, and government clients with access to NASA-derived technology, information, and personnel, producing thousands of successful spinoffs. These spinoffs have resulted in new and improved goods and services for the American public, stimulating our economy through the generation of new jobs and dollars.

Today, this network reaches into virtually every state of the Union. NASA's group of 10 Industrial Application Centers (IAC) and their affiliates form the heart of this system. Recognizing this, NASA sought in 1988 to significantly increase the capabilities of these IACs, which disseminate NASA-developed technology to a broad range of industrial clients by providing them access to nearly 100 million scientific and technical documents in the NASA data bank. IACs are also provided access to more than 600 other computerized data banks, as well as NASA scientific and technical personnel.

In addition to expanding the IACs' reach to include links with state-sponsored institutions throughout the country, the NASA Technology Utilization Program entered into a blanket agreement with the Federal Laboratory Consortium connecting IACs and their affiliates to the consortium's network of 500 R&D laboratories and its clearinghouse. This agreement has made it possible for U.S. industries and entrepreneurs,

using access points within their home states, to find out what federal technology, relevant to their needs, is available in Federal laboratories throughout the Nation.

Additionally, NASA plans to make the IAC network accessible to clients of other Federal and state-supported industry assistance activities, including the more than 500 Small Business Development Centers, Economic Development Agency Centers, and the proposed Hollings Centers under the aegis of the National Institute of Standards and Technology.

Other recent highlights of the progress of these IACs include a contract signing with Southern University, Baton Rouge, Louisiana, to operate an IAC and provide dissemination/information services primarily in Louisiana and Mississippi, marking the first minority university to join the IAC network.

Although no overall price tag can be placed on the value of the services provided by IACs, an example of their benefit is evident in \$1.25 million saved by the city of Albuquerque, New Mexico, when it utilized the services of the Technical Application Center (TAC), an IAC which specializes in remote sensing and imaging technologies. The TAC provided the city with aerial photographs of an area where a bridge was to be built. The photos allowed the U.S. Army Corps of Engineers, who designed the bridge, to shorten it by 500 feet, thereby reducing its cost.

An ADA software repository and software value-added capability are also being developed in cooperation with the Department of Defense's Joint Projects Office and the Department of Commerce. A technology transfer component will adapt ADA software for application in such areas as flexible computer integrated manufacturing, automation and robotics, and artificial intelligence.

Spreading the Word

NASA's *Tech Briefs*, a publication containing concise descriptions of innovations arising from NASA R&D efforts, has long been a key component of the technology transfer network. Distributed to some 200,000

subscribers annually, it identifies and highlights information on new aerospace technologies which appear to have potential nonaerospace uses.

The publication, which began as a NASA-produced one-page "Flash Sheet" describing new technologies, has evolved into a commercially produced magazine which has published nearly 13,000 new technology reports since its inception. In response to published *Tech Briefs*, more than 1-1/2 million requests from readers have been submitted for Technology Support Packages which provide more detailed information on specific technologies. Reader feedback indicates that dollar savings to industry and government clients are running in the millions. To respond to increased demands, beginning in 1989, the number of issues published per year will increase from 10 to 12.

Likewise, the scope and significance of *NASA Spinoffs*, an annual publication, continues to grow and enhance the technology transfer network. The publication reported some 50 new spinoff items this year, with more than 600 highlighted since its inception.

The public visibility of NASA's many space technology spinoffs is also increasing, as evidenced by numerous trade and media articles and the recently inaugurated Spinoff Hall of Fame in Colorado. Sponsored and managed by the U.S. Space Foundation, the Spinoff Hall of Fame was officially opened in 1988 with the selection of five NASA technologies.

Supporting Technology Applications

NASA directly supports technology application efforts, which are geared toward the solution of public and private sector problems that have been identified by user organizations at the federal, state, and local levels. Currently, some 60 technology application projects are under way at 9 NASA field installations in a variety of disciplines including: automation and robotics, bioengineering and biotechnology, advanced materials and composites, electronics and semiconductors, and rehabilitation.

One such project initiated in 1988 is a joint effort

between NASA and the Johns Hopkins Wilmer Eye Institute to use space technology to develop a device designed to improve the sight of millions of people with low vision.

Applications projects were first established in 1970 to provide direct NASA assistance and primary funding to promote secondary use of aerospace technology. They involve cooperative efforts to build and test prototype hardware if the industrial partner agrees to provide partial funding and is prepared to complete marketing of the transfer. To date, more than 150 projects have been initiated and 75 successful transfers have been completed.

Responses to New Legislative Challenges

As a long time leader among U.S. Government agencies in technology transfer efforts, NASA has welcomed the recent Federal emphasis in this important area.

To further respond to the recent congressional legislation and executive direction regarding technology transfer, NASA officials implemented in 1988 a series of new initiatives aimed at further compliance with the recent mandates. The initiatives were developed following a review of the program which was conducted not only to determine how best the agency could comply, but also how it could retain its traditional leadership status among Federal agencies in the area of technology transfer.

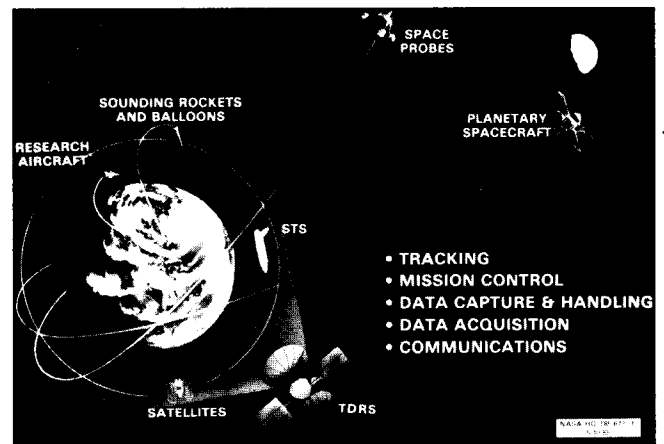
Highlights of accomplishments made toward further compliance with recent legislation include:

- Participation in the Federal Laboratory Consortium for Technology Transfer, as well as transfer of NASA funds to support the project.
- Establishment of the Ames University Consortium, created to provide reciprocal use of services, personnel, equipment, and facilities between NASA's Ames Research Center, Moffett Field, California, and member institutions, presently including relationships with 136 universities nationwide.

- Cooperation with RIMTECH (Research Institute for the Management of Technology), a consortium of technology-based businesses in southern California organized to provide systematic access to the technology of NASA's Jet Propulsion Laboratory, Pasadena, California.
- Distribution of patent royalty income to present and former NASA employee/inventors and distributing a share of these funds to appropriate NASA field installations.
- Granting of 167 awards, to date, to NASA and NASA contractor personnel for scientific and technical contributions which have "significant value in the conduct of aeronautical and space activities." Some of these were directly influenced by the degree of technology transfer and commercialization achieved for nonaerospace industrial purposes.
- Expansion of cooperative efforts for technology transfer with other organizations, including many of the initiatives mentioned above, as well as participation in the Technology Share Project and the establishment of a High Temperature Superconductivity Working Group. The superconductivity group will coordinate ongoing NASA superconductivity research at NASA field installations, assess the impact of new superconducting material on aerospace technology and missions, and determine and recommend to NASA its role in this emerging field. The group is also coordinating its activities with other major Federal agencies.

Assessing the Impacts

In addition, an effort was undertaken in 1988 to assess the economic impact of some of the NASA-derived spinoffs or applications reported in the *NASA Spinoff* publication between 1978 and 1986. Although tangible statistics on the economic impact of technology transfer are often difficult to measure or summarize, researchers tracing nearly 350 applications



Tracking and data acquisitions functions.

publicized in *Spinoff* annual reports have obtained estimated revenues and cost savings that may be attributed in part or in whole to NASA programs. These NASA spinoffs have resulted in economic benefits from contributions to sales or savings approximating \$27 billion since 1978. While work on the study is still in progress, findings thus far dramatically illustrate the benefits of technology transfer to both industry and the Nation at large.

Space Operations

The Space Operations Program continued to provide planning, development, acquisition, and operations of worldwide tracking, data acquisition, data processing and communications systems facilities, and operational support to meet NASA flight-program requirements.

The Space Operations Task Force, which was established in March 1987 to develop options for a space operations implementation and organizational structure, completed its study. Its recommendations and findings were under review by NASA.

Space Network

The transition which began with the first Tracking and Data Relay Satellite (TDRS) from a ground-based



Tracking and Data Relay Satellite (TDRS-3) ready for release from STS-26 on September 29, 1988.

tracking network to a space-based tracking capability for low-Earth orbital missions continued in 1988. Shuttle operations resumed on September 29, 1988, with the successful deployment of TDRS-3, which joined TDRS-1 already in orbit. TDRS-4 was scheduled for launch in 1989. The ground-based tracking network was retained to support low-Earth orbital missions until the TDRS system became operational. The TDRS system will be fully functional when three spacecraft

are in geosynchronous orbit, and the spacecraft and the ground system have completed integrated acceptance tests.

During 1988, the Tracking and Data Relay Satellite in space continued its excellent support of the Landsat, Solar Mesospheric Explorer, Earth Radiation Budget Satellite, and Space Shuttle missions. TDRS-3 was fully functional and supported the STS-27 launch in early December.

The TDRS replacement spacecraft program, to replace the satellite lost in 1986, has continued and will ensure continuity of service in the mid-1990s.

The General Electric Company was selected in October 1988 to develop, fabricate, install, and test the communications hardware and software to implement the Second TDRSS Ground Terminal (STGT) at White Sands, NM. The STGT is not only necessary to eliminate the first ground terminal as a critical single point of failure, but it will also provide the capability to operate more than two TDRSs in orbit, and will allow the first ground terminal facility to be modernized with no interruption of activity. Operational readiness for this facility was planned for 1993.

Ground Networks

The ground-based tracking and data networks, the Spaceflight Tracking and Data Network (STDN), the Deep Space Network (DSN), and the Aeronautics, Balloon, and Sounding Rocket (AB&SR) programs continued to provide support services to all NASA science and engineering missions for vehicles in high-Earth orbit and in deep space.

The Deep Space Network is preparing for a major challenge when the Voyager 2 spacecraft encounters Neptune in August 1989. During 1988, a number of modifications to the DSN were under way to improve its sensitivity to prepare for the Neptune encounter and support of several new spacecraft launches. These launches include the Galileo mission of Jupiter and its moons, the Magellan Venus Mapping mission planned for 1989, and the Mars Observer mapping mission

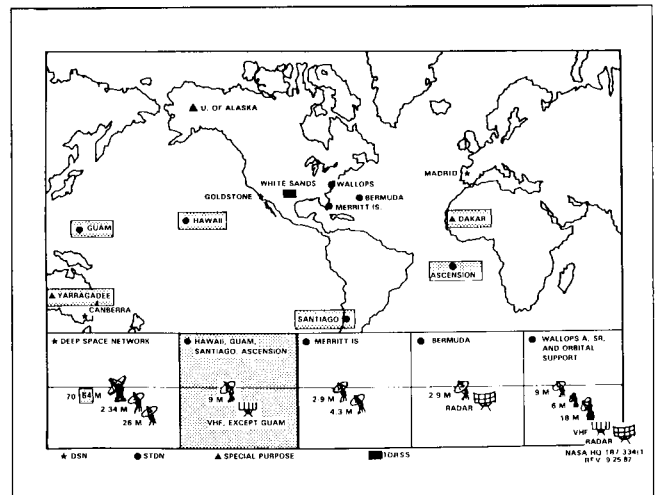
planned for 1992. The 64-meter antennas at each of the DSN sites were increased to 70 meters, with work completed at the Madrid, Spain, and Canberra, Australia, sites in 1987 and at the Goldstone, CA, site in 1988. Modifications to non-NASA antennas in New Mexico, Australia, and Japan were also under way in 1988 to provide increased signal-reception capability for electronic arraying with NASA antennas for the Voyager/Neptune encounter. Image reception from Neptune will travel over the longest television relay ever attempted, with signals requiring more than four hours to reach Earth from the point of Voyager's closest approach to Neptune.

The Spaceflight Tracking and Data Network stations provided near-Earth support in 1988 for shuttle launches and TDRSS deployment. Support was also provided to the Interplanetary Monitoring Platform 8 (IMP-8), International Ultraviolet Explorer (IUE), NIMBUS-7, Solar Maximum Mission (SMM), Geostationary Operational Environment Satellites (GOES) 4, 5, 6, and 7, Dynamic Explorer 1 (DE-1), Solar Mesospheric Explorer (SME), Landsat-4 and -5, Earth Radiation Budget Satellite (ERBS), and National Oceanic and Atmospheric Administration (NOAA) 9, 10, and 11 missions. The STDN will continue low-Earth orbit support until the Space Network becomes operational.

Communications and Data Systems

The basic elements of the Communications and Data Systems program form the vital link between the data acquisition stations and the users and include communications, mission control, and data capture and processing.

Communication services were fully activated and all systems supported the shuttle return-to-flight launch in September. During 1988, the Program Support Communications Network (PSCN) continued serving the agency's institutional and programmatic voice and data requirements. The Communications and Data Systems program continued conceptual design studies and testing in 1988 in preparation for the Cosmic Back-



NASA Space Operations Tracking Networks.

ground Explorer (COBE), Upper Atmospheric Research Satellite (UARS), and the Hubble Space Telescope (HST) launches in 1989 and 1990. Definition studies continued for advanced data handling and command and control systems to meet the challenges of new missions in the mid-1990s.

Aeronautics Research and Technology

The goal of the NASA aeronautics program is to conduct effective and productive aeronautical research and technology development to benefit future U.S. civil and military aviation programs. In 1988, NASA's aeronautical research and technology (R&T) efforts continued to expand the nation's capabilities and contributed significantly to U.S. world aviation leadership and the national security. These efforts range in scope from fundamental disciplinary research in the laboratory to experimental aircraft flight testing.

The U.S. aviation industry is unique because of its positive contribution to the national balance of trade, its importance to national security, and its role as a symbol of American technological strength and national pride. The United States has been the world's



Flight line at the Ames-Dryden Flight Research Facility.

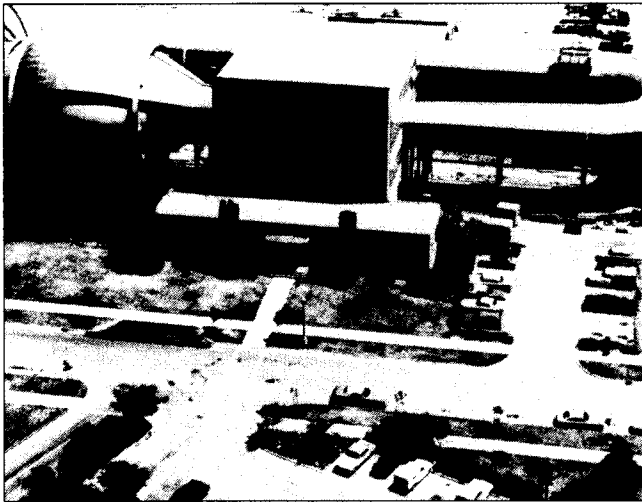
leader in the development and application of aviation technology since the late 1940s with the breaking of the sound barrier. This leadership is the result of a solid national technology base and rapid progress in aeronautics research. In recent years, however, the U.S. dominance in commercial transportation has been challenged by foreign competitors. Foreign aircraft now dominate the feeder airline/medium-size aircraft market and significant thrusts have been made into major commercial airline markets, especially by the European consortium's Airbus series of transport aircraft.

In 1985, the White House Office of Science and Technology Policy (OSTP) published a report entitled "National Aeronautical R&D Goals: Technology for America's Future" which outlined opportunities for significant advances in aeronautics that could reshape civil and military aviation by the turn of the century. In February 1987, the OSTP published a sequel titled "National Aeronautical R&D Goals: Agenda for Achievement" which presented a cohesive strategy and an eight-point action plan to achieve the national goals and retain U.S. leadership in the world aviation

marketplace. NASA has been redirecting its aeronautics program toward many of the technologies mentioned in the first report generally along the lines of the action plan outlined in the sequel. Aeronautics research is now more focused on emerging technologies which offer the potential for order-of-magnitude advances in aircraft capabilities. The major objectives are to provide technology results well in advance of specific application needs and to conduct long-term, independent research.

The Office of Aeronautics and Space Technology at NASA Headquarters in Washington, DC, directs the overall aeronautics research and technology program. The research is conducted at the three aeronautical research centers: Ames Research Center at Moffett Field, CA and Ames Research Center's Dryden Flight Research Facility at Edwards AFB, CA; Langley Research Center in Hampton, VA; and Lewis Research Center in Cleveland, OH. These three centers comprise the most comprehensive and unique set of aeronautical research and test facilities in the world and remain an essential resource for aeronautics research and development in the United States.

NASA is firmly committed to assuring the health and productivity of our national facilities which are crucial to civil and military R&D programs. For several years there had been a growing concern about the deteriorating condition of the NASA wind tunnels. In 1987, an extensive, independent study was conducted to assess the condition of NASA's major wind tunnels and their ability to meet a growing demand. The conclusion was that NASA must revitalize these critical wind tunnels as soon as possible. In response, a comprehensive five-year program was initiated to upgrade the wind tunnels considered critical to aeronautical research and to U.S. development programs. In 1988, work began on the first three wind tunnels selected for the revitalization program: the Ames 12-foot Pressure Wind Tunnel, the Lewis 10-x-10-foot Unitary Plan Tunnel, and the Langley Hypersonic Complex.



12-foot Pressure Wind Tunnel at Ames Research Center, one of the facilities being updated in the Wind Tunnel Revitalization Plan.

NASA's research program includes both fundamental disciplinary research and vehicle specific research. Disciplinary research may be generically applied to all classes of vehicles, whereas vehicle specific research is focused primarily on technology which has the potential for increasing the capabilities of specific classes of vehicles—subsonic transports, rotorcraft, high performance military aircraft, supersonic cruise aircraft, or hypersonic vehicles. The NASA program has long provided a foundation in the traditional aeronautical disciplines (including aerodynamics, propulsion, structures, and controls), but now NASA is also making significant progress in the application of new disciplines (such as artificial intelligence and advanced computational simulation) and in the integration of disciplines (such as flight and propulsion control systems). In addition to the R&T base efforts, NASA has placed additional emphasis on the following specific areas: transatmospheric R&T, numerical aerodynamic simulation, low noise/vibration rotorcraft, composite materials and structures, high angle-of-



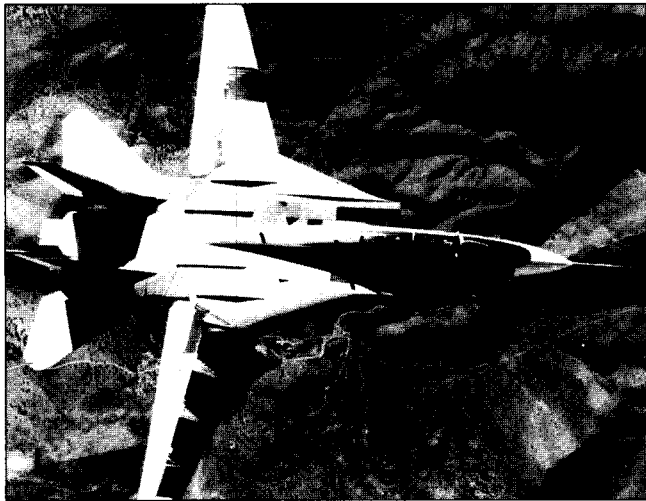
Cray Super Computer at Ames Research Center's Numerical Aerodynamic Simulation Facility.

attack and supermaneuverability research, aircraft automation and safety, computational fluid dynamics code verification, advanced short takeoff and vertical landing aircraft studies, supersonic fan research, high-speed transport studies, small engine technology, and advanced high-temperature engine materials.

Disciplinary Research and Technology

NASA's disciplinary aeronautical research activities seek to improve the understanding of basic physical phenomena and provide the technological base for new concepts and ideas necessary for future advances. The research includes efforts in aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems.

Aerodynamics. The Fluid Mechanics Laboratory at the Ames Research Center has now completed a full year of service and significant progress has been made toward the initial goal of developing sophisticated facilities and computers for integration of aerodynamic theory and experiment. The laboratory enhances Ames'



Natural laminar flow glove being flight tested on a Variable Sweep Wing F-14.

position as an internationally recognized center for innovative research that exploits emerging technologies in the simulation of increasingly complex viscous flows. In particular, the laboratory is engaged in fundamental studies of transitional and turbulent boundary layers and their control with the goal of promoting efficient and economical high-speed flight.

The effect of viscous forces on the prediction of aerodynamic drag is now recognized as a critical unsolved problem in aeronautics. New concepts in drag reduction applicable over a wide range of operating conditions found on modern aerospace vehicles make the study of flow instability and transition of critical importance in meeting national goals. New computational hardware is now available to enable time accurate solutions on very fine grids that are sufficient to resolve many scales of instability. Research is under way to compute through instability, past transition, and into fully developed turbulence. Exciting new concepts are being explored for the reduction of induced drag (drag due to lift) on wings. Crescent-

shaped wing planforms and leading/trailing edge geometry modifications are being explored experimentally and analytically.

Techniques are being investigated for improving the quality and productivity of wind tunnel testing. A flexible wall test section has been developed and installed in a Langley research wind tunnel. The wall automatically adapts to a shape such that the streamlines over the model would be the same as in free air. The elimination of wind tunnel wall effects is a giant step toward "true-fidelity" ground testing.

In the area of aeroacoustics, research efforts have been focused on determining the precise nature of acoustic and structural fatigue loads of supersonic heated flows, i.e., jet engine exhausts. In particular, flight tests were conducted on F-15 and B-1B aircraft to measure twin plume resonance effects on the surrounding structure. The structural damage due to these resonance effects that was observed in the flight tests was also confirmed by wind tunnel tests.

During subsonic flight, approximately one-half of an aircraft's total drag is caused by skin friction. Laminar (smooth) flow over the aircraft's surfaces reduces skin friction. For the past several years, NASA has been researching three different concepts for maintaining laminar flow: passive natural laminar flow (NLF) achieved by careful airfoil design, active laminar flow control (LFC) achieved by suction through tiny slots or perforations in the surface, and hybrid laminar flow control (HLFC) which uses both active and passive techniques. Passive LFC is applicable to small airplanes; active LFC and HLFC are applicable to transports. Research efforts in all three areas have been promising. Previously conducted wind tunnel and flight tests of a full-sized NLF wing on a Cessna 210 aircraft demonstrated that the new airfoil achieved natural laminar flow over 70 percent of the upper and lower surfaces. In another flight test, a contoured NLF "glove" was tested on the wing of a Boeing 757 aircraft in the region of intense acoustic radiation from the turbofan engine and demonstrated that laminar flow

could be maintained in the presence of engine noise and on the moderately swept wings of commercial transports. Active LFC was achieved by two different system concepts during flight evaluations on a Jet Star operating under representative commercial airline operations. In 1987, a NLF glove was flight tested on a variable-sweep wing F-14 aircraft and provided fundamental data on the stability of laminar flow at various sweep angles. A NASA wind tunnel test completed in 1988 showed significant benefits and potential for the use of HLFC to improve the operating efficiency of transport aircraft, and a cooperative research program between NASA, the U.S. Air Force and the Boeing Company is now under way to test a HLFC system. A full-scale flight experiment using a "gloved" HLFC wing section will be flight tested on a Boeing 757 beginning in 1989.

The world's fastest supercomputer, a Cray Y-MP, was installed in the numerical aerodynamic simulation (NAS) facility at Ames Research Center. Capable of exceeding 1 billion computations per second in sustained operation or a peak speed of 2.37 billion operations per second, the computer's vast computational capabilities will permit solutions to aerodynamic problems far too complex to be handled by previous computers. The Cray Y-MP will replicate aircraft and spacecraft flight by virtually "flying" the vehicle inside the computer on a three-dimensional grid. Computer modeling has been used by NASA to advance jet engine designs and efficiency by simulating the complex, fluctuating air flow within aircraft engine turbines and compressors. The new computer became fully operational in November 1988.

Propulsion. Improvements in propulsion technology have historically provided a major share of aircraft system performance improvements and allowed the development of new generations of aircraft and flight vehicles. NASA's propulsion research continues to be focused on the understanding of the governing physical phenomena occurring at the disciplinary, component, and subsystem levels that will lead to future

high-payoff improvements in propulsion system capability, efficiency, reliability, and durability. NASA is emphasizing the development, experimental verification, and application of internal computational fluid mechanics (ICFM) analysis which continues to be an increasingly important tool in achieving propulsion improvements.

In 1988, viscous capability was added to the average passage three-dimensional turbomachinery code which was subsequently used to analyze the flow in three blade rows of a turbine that is representative of the fuel pump turbine in the space shuttle main engine. The analysis revealed vertical flow structures which had not been fully understood previously. Comparison to experimental data confirmed the ability of the code to calculate the important flow physics in the very complex flowfield of advanced high work turbines. In addition, codes were released with the capability of calculating the unsteady flowfield of a turbomachinery rotor/stator interaction and the mixing and reaction of fuel injected into a supersonic airstream. A prototype of a user-friendly interface for advanced ICFM codes was developed and demonstrated. Interfaces of this type will make it possible for users with an average level of propulsion expertise to use, without extensive training, the very complicated codes that are currently under development.

In the area of experimental activities in 1988, the large low-speed centrifugal compressor facility was completed and extensively instrumented to provide a fundamental understanding of viscous flow regions and secondary flows which dominate centrifugal flowfields. In addition, the stratified charge rotary engine experimentally demonstrated a brake-specific fuel consumption of 0.43, a 15 percent improvement. An analytical study of the fuel injector flowfield revealed a source of fuel inefficiency that can reduce the fuel consumption an additional 5 percent. Other experimental accomplishments included the evaluation of small gas turbine combustors designed to allow higher temperatures with minimum cooling require-

ments and the evaluation of a compact radial turbine. The combustor allowed a 200 degree Fahrenheit increase in temperature while improving the temperature pattern by 50 percent. The turbine design reduced the length by 40 percent, and thus reducing the weight, while maintaining the efficiency of a conventional turbine.

Materials and Structures. Composite materials are finding increased use in current and future airframe designs because they are lighter and stiffer than conventional metallic aircraft structural materials. A new thermoplastic composite material developed by Langley Research Center is currently being evaluated by the aircraft industry for design of high temperature composite structures. Low cost fabrication by thermoforming this material system offers the potential for improved aircraft performance with reduced production costs. The objective is to develop the materials and structures technologies for innovative and cost-effective advanced composite airframe structures. This includes development of advanced composite materials for applications to 600 degrees Fahrenheit, development of innovative design concepts, verification of fabrication processes for cost-effective structures, and design validation of sub-scale and large-scale advanced composite structures. The major goals are to reduce structural weight by 50 percent, reduce part count by 25 percent, and reduce manufacturing costs by 30 percent.

NASA is a leader in the development of analytical methods for transonic aeroelastic analysis of advanced aircraft configurations, including the phenomena of divergence and flutter. These analysis codes are used by the aircraft industry to predict unsteady airloads and flutter phenomena which are critical to the successful design of advanced aircraft. A new analytical approach to predict the unsteady aeroelastic response of complete aircraft configurations was developed by Langley Research Center in 1987. This approach is capable of treating complete aircraft geometries with multiple lifting surfaces and is very efficient compared to

previously used analyses. Research in aeroelasticity includes computational methods to predict flutter and performance of aircraft; control concepts to improve performance, enhance stability, and reduce loads; and development and testing of advanced aircraft configurations.

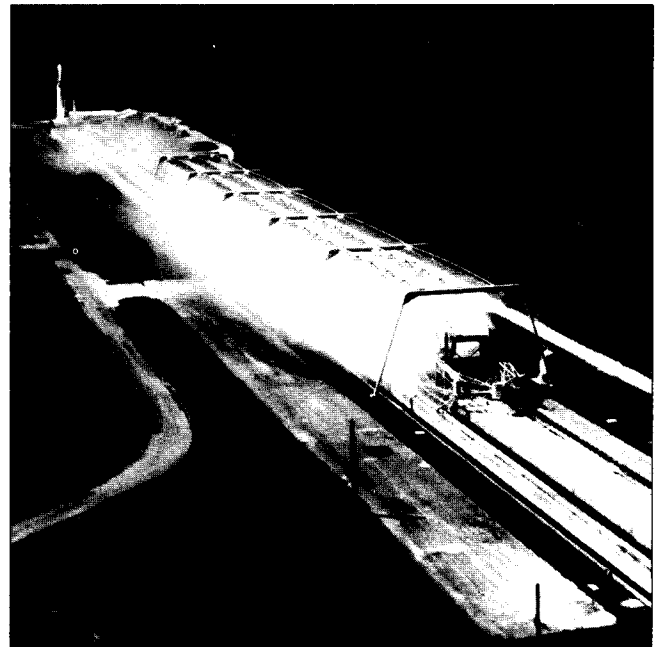
A major new initiative on advanced high temperature engine materials technology started in 1988 at Lewis Research Center. The objective of the program is to develop the technology for revolutionary advances in materials and structural analysis capabilities to enable the development of 21st century transport aircraft propulsion systems having greatly decreased specific fuel consumption, reduced direct operating costs, improved reliability, and extended life. This requires materials capable of operating at much higher temperature and strength levels than now possible. The candidate advanced materials being developed include metal matrix composites, intermetallic matrix composites, ceramic matrix composites, and polymer matrix composites. Significant progress has been made on the fabrication of silicon carbide reinforced titanium aluminide composites by a powder-cloth technique, as well as on silicon carbide reinforced reaction bonded silicon nitride composites. Other aluminide composites such as iron aluminide, nickel aluminide, and niobium aluminide are also under investigation. The titanium aluminide composites are also being considered for hypersonic vehicle applications such as the National Aero-Space Plane because of their high strength/density at elevated temperatures. A major deficiency that still needs to be overcome is their brittle, low ductility behavior. The potential hydrogen compatibility problem of the titanium aluminides under service conditions was identified by Ames Research Center in 1987. Recent efforts have focused on understanding the effects of hydrogen on these materials, other intermetallic matrix composites, and ceramic matrix composites, as well as on developing effective coatings to eliminate this technology barrier for material utilization in new design concepts.

Information Sciences and Human Factors.

NASA is conducting research directed toward improving the safety and efficiency of aircraft which will operate in the future National Airspace System. During 1988, flight testing of a takeoff performance monitoring system was completed. This system provides information to the crew regarding the status of a number of critical systems during takeoff. Analytical models depicting the nature of the wind shear threat and a wind shear hazard index were developed and have been widely accepted by industry. Three airborne windshear detection sensor concepts are being studied and one or more of these will be evaluated in flight during 1990-91. In coordination with the Federal Aviation Administration (FAA), automated decision aids are being developed. In 1988, automated terminal-area flow control concepts were evaluated in simulation with FAA controllers and airline crews.

The objective of the aeronautical human factors research and technology program is to provide the capability to design effective crew-cockpit interfaces and air traffic control interfaces with the aircraft. Advanced automation technologies, along with increased traffic density, challenge human operators and their interface with diverse air and ground systems. The goal of the program is to provide human-centered technology which is safe, productive, efficient, and effective for advanced commercial and military aircraft, rotorcraft, and other national aeronautical applications. A new concept for automated onboard fault management was developed and evaluated in 1988. Future plans include demonstration of an advanced intelligent, error-tolerant cockpit in simulation and flight.

Flight Systems. Improving flight safety through research into the operating environment is viewed by NASA as vital and is being addressed with research related to natural phenomena as well as operational flight systems. Storm hazards research is now concentrating on the effects of heavy rain on aircraft performance while NASA's Aircraft Icing Program is focused on the problems caused by aircraft icing. Heavy rain can



The Aircraft Landing Dynamics Facility at the Langley Research Center.

change airfoil effectiveness, change the airflow, and cause a loss of airplane performance, possibly severe enough to reduce safety margins. Previously conducted tests in the Langley Research Center's 14-x-22-foot wind tunnel using a wing section model revealed that the maximum lift was reduced by 20 percent during periods of very heavy simulated rainfall. In 1988, a 500-foot gantry-mounted water-spray system was installed over a span of track at the Aircraft Landing Dynamics Facility. In order to conduct tests on a section of a full-scale wing, a 10-foot chord wing section has been mounted on a moving carriage which is propelled along a track through the simulated rain provided by the spray system. These tests have been initiated to determine the performance degradation of the wing's performance.

NASA icing research is aimed at understanding the physics of ice accretion on aircraft surfaces, the effects

of ice formation on the aircraft's performance and handling qualities, means to prevent ice accretion, and methods to deice the aircraft if ice does form. Little or no quantitative icing data has previously existed that is useful for the complex engineering analyses which are required to determine these icing effects. Analytical and experimental methods are being used to determine the changes in aircraft performance and handling qualities. These results are being incorporated into the LEWICE prediction code which includes advanced ice accretion, aero-performance, heat transfer, and thermal deicer codes. In addition, a three-dimensional version of LEWICE is also being developed. In addition, icing methodology for rotors and propellers is being developed, as well as methodology for simulating the complete aircraft's response to an icing encounter. In the area of ice protection, evaluation of advanced concepts is continuing; alternate protection systems for rotorcraft are being explored; and NASA continues to support ground deicing studies. Improved cloud instrument monitoring and calibration apparatus and techniques are being developed. Flight tests are used to acquire flight test data to validate these computational fluid dynamics codes and the results obtained in the Icing Research Tunnel (IRT). Two tests which were completed in the IRT are a joint Boeing/NASA test of ground deicing fluids and a joint NASA/Boeing test of a multi-element airfoil. In addition, several cloud instrumentation development efforts were conducted; ice accretion code results were compared among NASA, the French Office National d'Etudes et de Recherches Aeronautiques, and the British Royal Aircraft Establishment; and 12 nozzles were evaluated for the Army's Helicopter Icing Spray System improvement program.

Progress continued this year in utilizing both the power of new aerodynamic computational methods and parameter identification techniques to model low altitude wind shear characteristics. This atmospheric phenomenon, characterized by large, rapid changes in wind magnitude and direction over small changes in

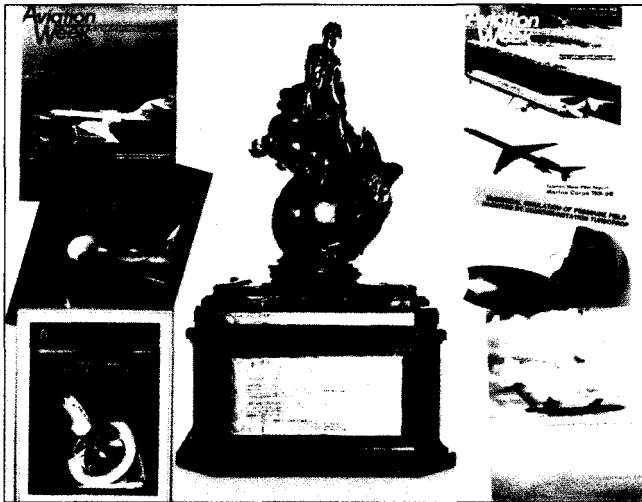
altitude, is a potential hazard to all aircraft, especially during takeoff and landing. In 1987, wind shear computer models were used to develop and evaluate a wind shear hazard warning index to provide aircrews advance warning of hazardous wind shear conditions. During 1988, studies of two candidate airborne sensor concepts, airborne doppler radar and airborne light detection and ranging, were initiated.

Systems Research and Technology

Vehicle specific research is focused primarily on technology which has the potential for increasing the capabilities of specific classes of vehicles: subsonic transports, rotorcraft, high performance/military aircraft, supersonic cruise aircraft, or hypersonic vehicles.

Transports. NASA works closely with aircraft manufacturers, the airlines, the Department of Defense (DOD), and the Federal Aviation Administration (FAA) to advance the technology for subsonic transport aircraft. This close relationship is essential to assure the timely introduction of new technology that will meet the growing challenge from foreign competition for leadership in the world market. The long-range goal of subsonic transport research is to develop the technology that will permit future aircraft designs to be highly competitive in terms of operating efficiency and affordability and safer than today's most advanced aircraft.

In 1988, a NASA/industry turboprop team was presented the prestigious Robert J. Collier Award in recognition for the development and testing of new fuel efficient subsonic aircraft propulsion systems. This technology development effort, which included the flight test of a large-scale propfan propulsion system, has been essentially transferred to U.S. industries for exploitation of its market potential. NASA continued the development of technology for turboprop applications in the areas of propeller code development and validation, turboprop/airframe installation aerodynamics, cabin environment noise and vibration suppres-



Robert J. Collier Award presented to NASA for its work in subsonic aircraft propulsion.

sion, and unducted fan (UDF) technology development. Specific accomplishments in 1988 include the following: comparison of detailed experimental flowfield data against analytical results for counter-rotation propellers; experimental integration of a turboprop powerplant with an advanced technology wing; demonstration of active noise suppression control for aircraft interiors; and flight testing of the UDF on a modified McDonnell-Douglas MD-80 aircraft. The success of these programs will provide the U.S. industry with the technology base to develop turbo-prop-powered subsonic transport aircraft.

In 1988, NASA with Boeing and McDonnell-Douglas conducted studies to assess the market and economic factors associated with the concept of a high-speed civil transport. These studies showed that there is a substantial market for an economically viable and environmentally compatible long-range high-speed civil transport capable of reaching speeds of up to Mach 2.5 or better. These studies also highlighted the need for research in several key areas to bring about the full potential of this aircraft. These areas included environ-

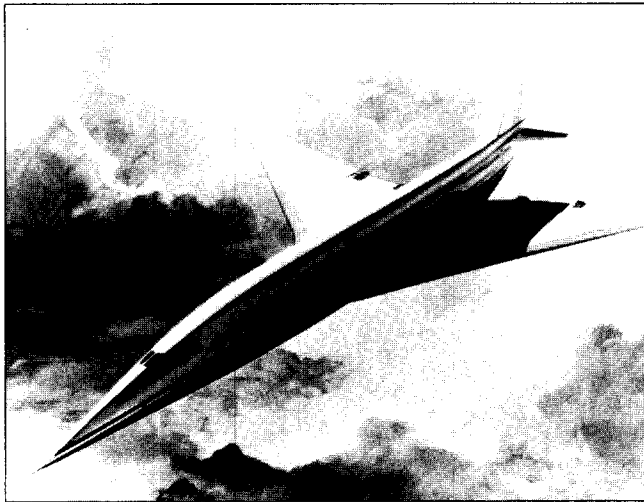


Unducted fan engine on a Boeing 737.

mental concerns resulting from engine emissions and sonic boom effects and efficient engines and lightweight structures capable of sustaining the high-speed conditions.

Rotorcraft. The nation's continued leadership in military and civil rotary wing technology depends on a strong and broad-based research program. NASA, in cooperation with other government agencies and industry, conducts rotorcraft research that addresses the fundamental areas of aerodynamics, structural dynamics, acoustics, guidance, stability and control, propulsion and drive systems, and human factors to exploit the full potential of this unique vehicle class. In 1988, there were a number of significant accomplishments in the key areas of noise reduction, improved rotor performance, and high-speed performance.

Reducing rotorcraft noise is essential for community acceptance and reduction of military detectability. The NASA-developed helicopter noise prediction code, called ROTONET, is currently in use by industry. In 1988 this code was refined to include results of recent wind tunnel and flight validation experiments and the



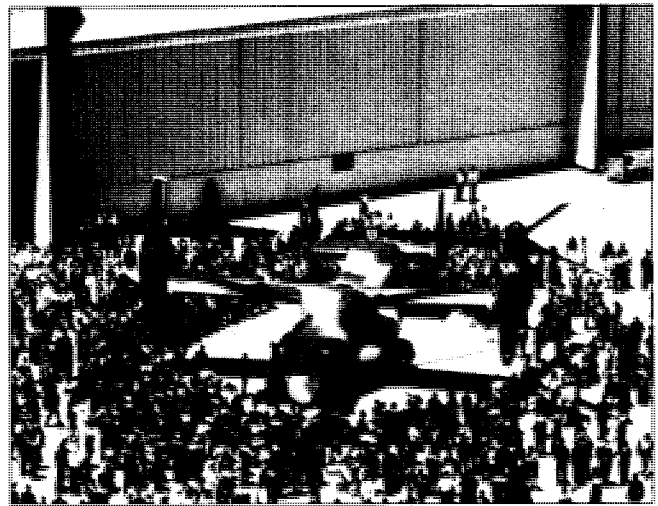
Artist's concept of a Boeing high speed civil transport.

updated version was distributed to users.

Additional wind tunnel tests were conducted to evaluate the feasibility of active control to reduce blade-vortex interaction noise. Computational prediction methods were used to select the specific test conditions which demonstrated an 80 percent (3-4 decibels) reduction in this impulsive noise source.

The 40-x-80-foot and 80-x-120-foot wind tunnels in the Ames Research Center's National Full-Scale Aerodynamics Complex (NFAC) resumed operation in 1987. The first major entry in the 40-x-80-foot wind tunnel was a large-scale model of the V-22 tiltrotor wing/nacelle/rotor system. Demand for access to the NFAC has been great and the current schedule has a series of high priority tests including models of the Army's light helicopter family program.

In 1988 the UH-60 airloads program proceeded with a series of highly instrumented flight experiments. These tests will provide a vital step in the validation of previous small- and large-scale wind tunnel test results and will help provide more accurate design codes for modern helicopter rotors. A workshop was held to

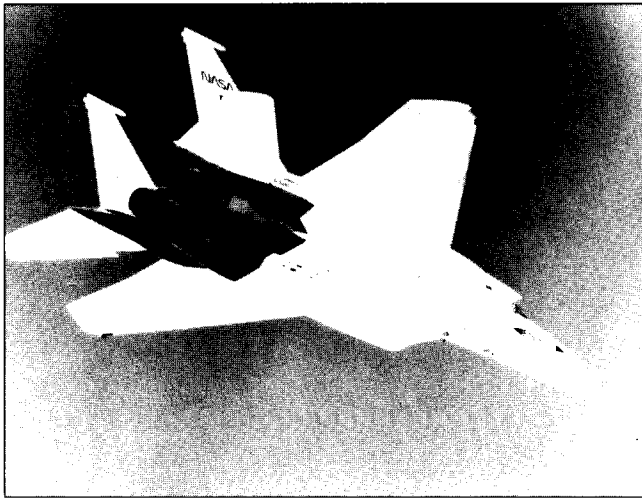


Rollout of the Bell Boeing V-22 tiltrotor.

speed the transfer of this technology to the rotorcraft industry and to refine future test objectives.

The area of high-speed rotorcraft received increasing emphasis in 1988. In-house conceptual studies proceeded and contractual efforts were begun with the goal of identifying those technology barriers which must be overcome to allow rotorcraft with low speed maneuverability and cruise speeds in excess of 400 knots.

The tiltrotor concept gained attention in 1988 with the signing of a Memorandum of Agreement with the Navy to develop a tiltrotor technology base and the signing of a Memorandum of Understanding with the FAA to cooperate in the development of a civil tiltrotor. The NASA tiltrotor research and technology program included control loads determination and envelope expansion of the XV-15 with enhanced performance advanced technology blades. Tiltrotor acoustic measurements were conducted with the XV-15. This flight validation experiment will enable development of a tiltrotor noise prediction module for ROTONET.

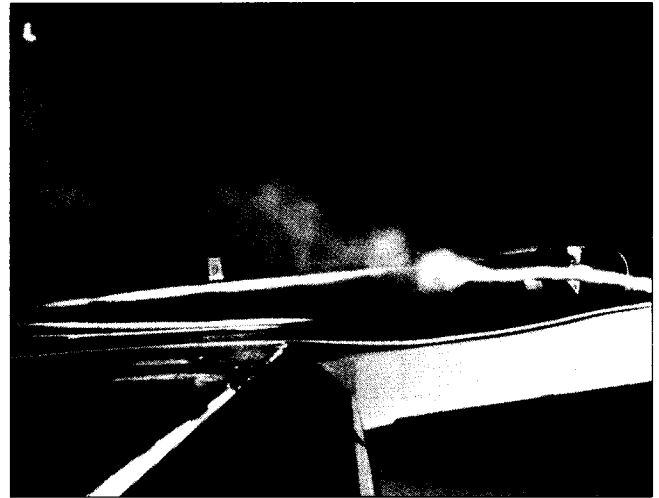


F-15 used in the HIDEC program.

In 1988, Lewis Research Center continued to provide key support to a major Army program in advanced rotorcraft transmissions. This effort will provide the technology base to significantly reduce helicopter drive-train weight, reduce the source of noise of the transmission, and increase its reliability.

High-Performance Aircraft. NASA's high-performance aircraft research develops high-risk technologies applicable to future military aircraft and is planned and conducted in close coordination with the DOD. Much of this research is equally applicable to civil aviation.

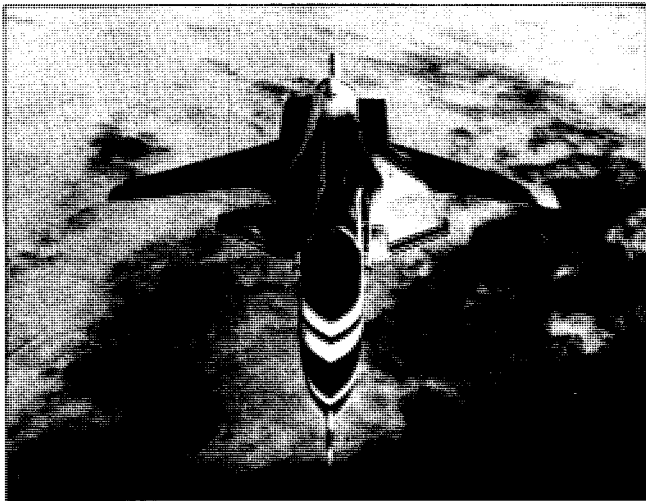
Flight testing of the adaptive engine control system portion of the highly integrated digital electronic control (HIDEC) program was completed at Ames Research Center's Dryden Flight Research Facility. For the first time, an aircraft's propulsion and flight control systems have been integrated. The engine's efficiency was increased by reducing the engine operating stall margin without compromising safe engine operation. Flight testing with two modified engines demonstrated performance improvements of up to 25 percent in



Flow visualization on the F/A-18 high angle-of-attack research vehicle.

certain portions of the flight envelope. The final results were reported to industry in 1988. The self-repairing flight controls system and trajectory guidance portions of the HIDEC program are continuing as is work on a follow-on integrated controls program, called performance seeking controls, which is a potentially revolutionary concept that provides for real-time optimization of aircraft performance.

In 1988, both ground and flight research activities continued to assess high angle-of-attack flight technologies for high-performance aircraft. The objectives of the first phase are to obtain and assess the aerodynamic characteristics of vortex flows at high aircraft angles of attack and to correlate them with the results of computations, wind tunnel experiments, and simulations. The modified and highly instrumented Dryden F/A-18 high-alpha research vehicle (HARV) has been flown up to sustained angles of attack of 40 degrees. The vortex flow around the aircraft forebody and wing leading-edge extension has been made visible on-surface by colored dye and off-surface by natural moisture and smoke. Comparisons with



X-29 forward swept wing aircraft.

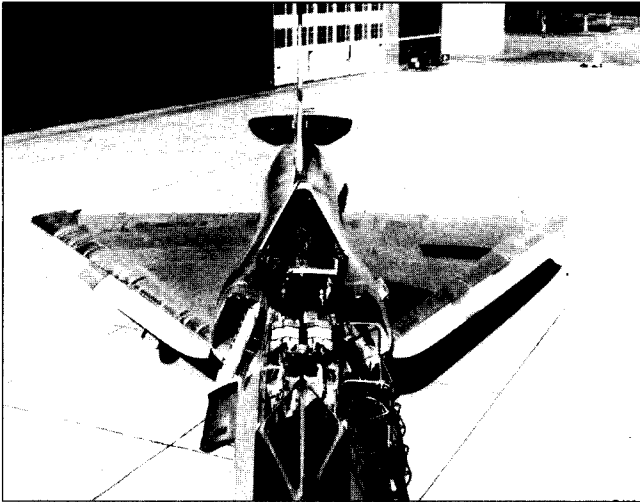
advanced viscous flow calculations and wind tunnel oil flow measurements have significantly enhanced our understanding and ability to predict complex vortex flowfields. Also in 1988, the McDonnell Aircraft Company, under contract, completed the preliminary design for the installation of thrust vectoring devices on the HARV for the next phase of flight testing. The thrust vectoring control system will allow research into the high angles-of-attack (up to 70 degrees) and supermaneuverability flight regimes that have never been explored.

Flight testing of the first X-29 forward swept wing research aircraft was successfully completed in December 1988. This joint NASA/DARPA/USAF program successfully demonstrated the integration of several advanced technologies including: a composite, thin, supercritical, variable camber, aeroelastically tailored forward-swept wing; close-coupled canard; straked flaps; relaxed static margin (up to 35 percent negative); and an advanced fly-by-wire digital flight control system. The 1988 flight test program focused on agility and maneuverability, limited high angle-of-attack

stability and control, low-speed control, and transonic aerodynamic efficiency. The first X-29 aircraft completed a total of 242 flights, surpassing the old record for X-series aircraft of 199 set by the X-15 research aircraft. The second X-29 was modified by the Grumman Corporation with a spin chute and instrumentation to conduct a full-blown high angle-of-attack research program. The aircraft arrived at Dryden in November 1988 and the first flight is expected in the spring of 1989.

The advanced fighter technology integration/F-111 mission adaptive wing program successfully completed flight testing (total of 59 flights) on December 22, 1988. The overall objectives of this joint NASA/USAF program were to demonstrate and evaluate the aerodynamic performance improvements of a smooth variable-camber supercritical wing over a conventional fixed-camber supercritical wing. The areas of research included performance, handling qualities, loads, buffet, and wing pressure distributions. The manual mode phase of the program was completed in June 1987 (total of 26 flights/58 hours) and, after modification, flight testing of four automatic modes began in September 1987. The performance results were even better than predicted. Drag reductions of 8 percent at the design point and up to 20 percent at off-design points were realized over a conventional fixed-camber supercritical wing. The data are being prepared for presentation to industry in April 1989.

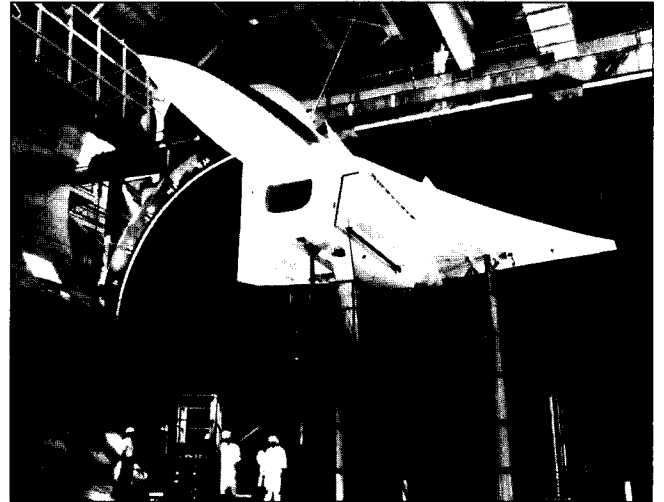
The potential of a 30 percent improvement in lift over drag and concomitant improvements in stability and control and maneuver performance are being explored in a flight research program involving the use of a vortex flap on the leading edge of the wing of the NASA F-106B aircraft at the Langley Research Center. The vortex flap is a sharp-edged mechanical flap with the cross-section of a wedge which extends forward and downward from the leading edge of the wing. It reorients the vortex suction which is formed along the edge of a swept wing. This vortex suction is utilized mainly for lift increase. The vortex flap tilts the lift



F-106 configured for vortex flap flight testing.

vector of the vortex suction in a forward direction, thereby providing a thrust component for drag reduction. The vortex flap, fabricated and installed at Langley, was designed following extensive wind tunnel tests which were complemented by extensive use of computational fluid dynamics codes. Flight tests were initiated in 1988 which will provide a data base for establishing design criteria for increased aircraft performance.

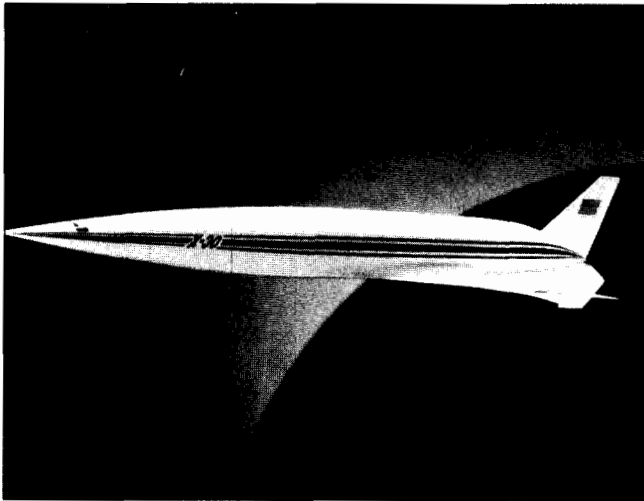
Advances in propulsion system thrust-to-weight ratios, propulsive lift control, and the understanding of low-speed aerodynamics combine to open new opportunities for significant advances in vertical/short takeoff and landing and short takeoff and vertical landing (STOVL) aircraft technologies and concepts. In the mid-1980s, NASA entered into collaborative agreements with the U.S. Department of Defense, the United Kingdom Ministry of Defence, and the Canadian Department of Regional and Industrial Expansion to reduce the technological risks associated with the development of advanced STOVL aircraft in several key areas, including propulsive lift concepts, hot gas



E-7A wind tunnel test in the Ames Research Center's 40-x-80-foot wind tunnel.

ingestion, ground environment aerodynamics, and integrated controls. In November 1988, the U.S./U.K. Joint Assessment and Ranking Team conducted a thorough review of the studies performed by contractors in both countries which are being used to guide future research efforts. In a joint effort with Canada, Ames Research Center installed and began testing a large-scale STOVL model (E-7A) in the 40-x-80-foot section of the new National Full-Scale Aerodynamics Complex. The transonic fighter aircraft configuration model will be used for research on an entrainment-type thrust augmentation system and an integrated flight and propulsion control system.

Hypersonics. One of the key technology thrusts of the aeronautics program being pursued by NASA is the technology foundation for hypersonic vehicles. The program focuses on vehicle configuration studies, propulsion, and materials and structures. Recent NASA accomplishments in these areas, combined with earlier progress in hypersonic research, have contributed to the state of readiness for NASA and the DOD to jointly develop the National Aero-Space Plane (NASP). The



Artist's concept of a National Aero-Space Plane configuration.

NASP program may result in a hypersonic flight research vehicle (X-30) which would be used to validate and demonstrate the successful merging of aeronautics and space technologies into a flightworthy vehicle. NASA maintains a strong research and technology base effort within its aeronautics program in support of the NASP and for future advances in hypersonic flight vehicles.

During 1988, testing in the Langley hypersonic propulsion wind tunnels continued to make advancements in supersonic combustion ramjet (scramjet) engine technology. Significant progress on variable geometry scramjet configurations was achieved with the successful testing of the variable geometry inlet configuration at a Mach number of 4.0 and with the accomplishment of a Navier-Stokes flow analysis for the transition area of the engine combustion section. These 1988 accomplishments are significant steps toward achieving a hypersonic propulsion system that can be operated over broad ranges of speeds and altitudes.

National Aero-Space Plane Program

In February 1986, President Reagan announced the National Aero-Space Plane (NASP) program to Congress and the nation during his State of the Union Address and directed NASA and the DOD to proceed. The goal of the joint NASA/DOD program is to develop and demonstrate hypersonic and transatmospheric technology for a new class of aerospace vehicles powered by airbreathing, rather than rocket, propulsion. The program envisions an experimental flight research vehicle (X-30) capable of taking off from a conventional, horizontal runway and flying single-stage to orbit or cruising at hypersonic speeds within the atmosphere.

The NASA aeronautics and space technology research centers are heavily involved in the extremely complex technical challenges of the NASP program. In 1987, the program entered the preliminary design and component development phase with three airframe (General Dynamics, McDonnell Douglas, and Rockwell International) and two engine (Rocketdyne and the Pratt & Whitney division of United Technologies) contractors. This phase will lead to a decision in late 1990 whether or not to build and test the X-30 research vehicle. This program presents technical challenges in all technologies wherein these NASA engineers and scientists have expertise. The success of the program depends heavily on the technical guidance provided by these people.

Since the X-30 would fly in a hypersonic regime which cannot be adequately simulated in ground facilities, computational fluid dynamics (CFD) will have to be used to extrapolate beyond these facility limits. In 1988, NASA's numerical aerodynamic simulation capability continued to provide vital support to the NASP program. The application of CFD analysis methods has enabled the calculation of pressure contours on baseline and specific NASP configurations which allows analysis and the prediction of vehicle aerodynamic loadings and aerothermodynamic interactions at Mach numbers well beyond the capability of

existing ground test facilities. CFD codes are being developed by NASA to the point of providing three-dimensional, real gas, viscous flow capability with finite rate chemistry. These codes are now being applied by government and contractors for vehicle aerodynamics and internal propulsion flows. Codes for combustors and nozzles are being developed and methods for reducing costly computer time are being implemented. Experimental tests are being conducted for validation of these codes and additional progress has been made. Considerable progress has been made in defining local thermal loads in areas of complex shock interactions. Both analytical and experimental results have now been published and are being used in the contractor design proposals for an X-30 aircraft.

Another critical area in which major work has been started is in boundary layer transition. There is a critical need for analytical means of predicting the length and stability of laminar flow and the onset of transition to turbulent flow in the boundary layer at hypersonic speeds. The validation of the analysis with very specific experimental tests is also critical. Both have been addressed in a program at Langley Research Center. Early results indicate that analysis methods which are successful at transonic speeds may also be successful at hypersonic speeds.

In related structures research, airframes for hypersonic flight will require high strength, light weight, and tough, heat-resistant materials capable of withstanding high external skin temperatures and shock impingement. The five above-mentioned major NASP contractors formed a 30-month, materials consortium program that began in March 1988. Five materials systems were identified that were of greatest importance to the program. Each contractor leads the development effort in one of the materials systems, with participation by the other four consortium contractors. The three NASP airframe contractors identified titanium aluminides, titanium aluminide metal matrix composites, and refractory composites as the materials systems that they consider of greatest importance to the airframe. The

two engine contractors identified two other materials systems necessary for propulsion applications—high specific creep strength materials and high conductivity composites.

In 1988, the organization of the overall NASP national team, composed of members of industry, universities, NASA/DOD, and other government laboratories, was completed. The NASP team of over 5,000 people and some 200 companies in 40 states is pursuing the program with great enthusiasm. The commitment of the NASP engine and airframe contractors is significant and they have demonstrated this by contributing almost one-third of the dollars in the current technology development phase. The NASP program continues to make excellent progress toward its key milestone, the decision to build and test the X-30 flight research vehicle.

Space Research and Technology

The primary goal of the space research and technology program is to develop advanced technologies that enhance and enable our nation's future space missions and, thereby, continue to ensure U.S. preeminence in space and space-related activities. To achieve this goal, a commitment is required to conduct a broad-based research activity which constantly advances the state-of-technology at the concept, system, subsystem, component, and device level; to develop technical strengths in the engineering disciplines within NASA, industry, and academia; and to perform critical technology demonstrations that facilitate the transfer of new technology, with high levels of confidence, to future space missions and applications.

The space research and technology program is composed of two complementary parts: the research and technology (R&T) base program and the focused technology programs. The objective of the R&T base program is to gain new technical knowledge resulting in a better understanding of the fundamental behavior of natural phenomena in critical disciplines related to, and supportive of, the U.S. space program. Through

the R&T base program, and usually in the environment of the laboratory, scientists and engineers develop forecasts regarding the potential applicability, usefulness, and overall benefit associated with the new knowledge. Once the potential applicability and usefulness of the new knowledge is documented, decisions are made to carry selective discoveries into the next stage of technology development—often called focused technology. The R&T base serves as the seedbed for technical progress and capability enhancement.

In the focused programs, technologies are developed for specific applications, and products are delivered in the form of demonstrated hardware, software, and design techniques and methods. Focused development is most often initiated based on the identified needs and potentials of both current and future programs and missions. In 1988 two such programs were under way at NASA: the Civil Space Technology Initiative (CSTI) and Pathfinder.

The CSTI program was initiated by NASA in 1987 as a positive step to reaffirm our nation's space technology leadership. Its objective is to advance the state-of-technology in key areas where capabilities have eroded and stagnated over the last decade. This "gap-filler" program has a short-term perspective—it is designed to address high-priority national and agency needs of the 1990s. The CSTI program includes research in technologies to enable efficient, reliable access to, and operations in, Earth orbit and to support science missions. The program's technology thrusts are divided into three categories: space transportation, space science, and space operations.

The space transportation thrust addresses those technologies that will provide safer and more efficient access to space. They will contribute to the design of a new fleet of space vehicles, including new expendable and partially reusable cargo launch vehicles, fully reusable manned vehicles, and expendable and reusable space transfer vehicles. In some cases, these technologies will provide additional capability for

existing launch vehicles. The thrust has been organized to address the pressing needs in the areas of Earth-to-orbit propulsion, booster technology, and vehicle technology. The vehicle technology area currently includes the aeroassist flight experiment, which is described later. Some of the accomplishments in 1988 included improved rocket engine design methods addressing the behavior of hot gases in the engine and new approaches to developing better components such as damping seals, contact bearings, and turbine blades using more durable materials.

The space science thrust technologies support more effective conduct of scientific missions from Earth orbit. Proposed long-term missions such as the Earth Observing System will require major advances in information sciences such as sensors, data storage and compression, and onboard analysis for success. As the science spacecraft of the future become larger, more complex, and inherently more flexible, they will require that interactions between the control systems and the structure be better understood such that the total structure can be controlled to the required levels of precision. The technical programs initiated to address these areas include: high rate/capacity data systems, sensors technology, precision segmented reflectors, and control of flexible structures. Accomplishments to date include the design of a robust control systems architecture for large (100-foot) precision reflector telescope systems and the fabrication of subscale panels for use in assembling precision reflectors. Contracts were awarded to guest investigators for the control structures interaction technology, and a set of analysis/design problems was defined which identifies common technology needs for continuing development. Significant advances were achieved in space flight optical disk (data storage) technology development.

The technologies to enhance future space operations will lead to increased capability, substantial economies, and improved safety and reliability for both ground and space operations. In space opera-

tions, three technologies are being addressed: tele-robotics, system autonomy, and power. Accomplishments in the first two areas include the successful technology transfer of a force reflecting hand controller and smart end effector to industry; the initial integration of knowledge-based system control with real time, complex, electromechanical systems in a Space Station Freedom testbed; and the demonstration of the integrated communications officer automated system in support of shuttle mission operations. In the electric power area, the development of higher capacity systems, commensurate with increasing mission needs, is proceeding with the development of a higher efficiency, higher power free-piston Stirling cycle engine for use in generating electric energy.

The Pathfinder program, begun in 1988, implements the new national space policy directing that NASA start planning for potential exploration missions beyond the turn of the century. The program is aimed at developing the critical technologies that will be required to enable missions that expand human presence and activities beyond Earth's orbit into the solar system. An important aspect of Pathfinder is that it will prepare the United States to embark on such exciting future missions without having to commit to any specific one at this time. Additionally, Pathfinder—as a partnership between NASA, industry, and academia—will add to our nation's ability to maintain itself at the “cutting edge” of new space technology. The Pathfinder program will develop a broad set of technologies in five major areas to enable future robotic or piloted solar system exploration missions, including the following: surface exploration, in-space operations, humans in space, space transfer vehicles, and mission studies. Proof-of-concept testing for mission-critical engineering designs will be an important product of both the CSTI and Pathfinder programs and will directly support the continuing evolution and maturation of mission plans.

In 1988 increased planning efforts were directed in two new areas of future activity. The first is aimed at

expanding the in-space experiments program to take full advantage of the opportunities provided by the projected deployment of Space Station Freedom. The second area of emphasis will increase research and technology activity in support of future programs associated with monitoring the Earth's global climate change.

In 1988 the research and technology (R&T) base program continued to be concentrated in ten discipline elements: aerothermodynamics, space energy conversion, propulsion, materials and structures, space data and communications, information sciences, controls and guidance, human factors, space flight, and systems analysis. Additionally, a university space research program, funded within the R&T base, continued to enhance and broaden the capabilities of the nation's engineering community to participate more effectively in the U.S. civil space program. Following is a brief summary highlighting the activities within the R&T base program.

Aerothermodynamics. Future aerospace vehicles, such as aeroassist space transfer vehicles, aerospace planes, and hypersonic cruise and maneuver vehicles, must be capable of sustained hypervelocity flight in air densities ranging from the dense, near-Earth atmosphere to the less dense reaches of the upper atmosphere. Because there is a general lack of experimental data and knowledge in the operational regimes of these vehicles, their designs present formidable challenges to current prediction methods. To meet these challenges, the aerothermodynamics program is pursuing the development and application of advanced computational methods and numerical techniques, using very powerful, high-speed computers; the establishment of high-quality ground and flight experimental data bases for computational code validation and verification; and the enhancement of engineering design codes and advanced configuration analysis capabilities to support rapid evaluation of future vehicle concepts.

In 1988 computational approaches to simulate flight conditions for advanced vehicles continued to be developed. These approaches promise to increase confidence for using predictive methods in the design of future vehicles. Specific progress included the development of computer codes to simulate hypersonic vehicle velocities in the rarified (low-density) regions of the upper atmosphere.

Computer simulations for the aeroassist flight experiment were also refined in 1988 and will be used to support the hardware design in areas of structural loading aerodynamics and aerothermodynamics. The data bases being used in the simulations are continually being updated with performance information from traditional wind tunnels, ballistic ranges, shock tubes, and high-velocity flight programs. In the aeroassist concept, space transportation vehicles will use the upper reaches of the atmosphere to decrease their velocity when returning from high-energy orbits, such as from the moon, instead of using retropropulsion which requires fuel. This will allow a reduction in the amount of fuel carried, thereby increasing the payload capability of the vehicle.

Space Energy Conversion. The objective of the space energy conversion program is to develop new technologies to improve the performance, reliability, life, and cost effectiveness of space power systems for applications ranging from manned space operations in Earth orbit to unmanned planetary exploration spacecraft. To meet these challenges, improvements in performance and life-span are being sought in solar power generation (primarily photovoltaics such as solar cells), chemical energy conversion, energy storage, electrical power management and distribution, and thermal management systems. For spacecraft photovoltaic systems, the goal is to improve system efficiencies enough to permit a 50-percent increase in payload mass while not increasing the overall spacecraft mass. Recent developments in photovoltaics include a 22-percent efficient gallium arsenide concentrator solar cell, 19-percent efficient radiation-resistant

indium phosphide solar cells, and an improvement in solar panel specific power to over 130 watts per kilogram. These achievements are significant steps towards the overall performance and life goals.

NASA's Lewis Research Center received a "Research & Development 100" award for demonstrating long-lived nickel-hydrogen battery performance for low orbit applications. This battery, which has about ten times the lifetime of existing systems, will be used on Space Station Freedom and on the Hubble Space Telescope. Research on very high performance rechargeable batteries, such as lithium-titanium-disulfide, demonstrated the potential for achieving 80 watt hours per kilogram, which is about four times current capabilities.

Advanced solar dynamic concentrator technology, having the potential for achieving 25 percent of the mass per unit area of those to be flown on Space Station Freedom, was demonstrated, and receiver concepts with one-half the mass of those to be used on the space station were identified.

Propulsion. The objectives of the propulsion research and technology program are to provide an analytical and experimental technology base for developing advanced propulsion systems. These systems are to be used in surface-to-orbit ascent vehicles, in planetary transfer vehicles, and for orbiting spacecraft auxiliary propulsion systems with capabilities well beyond those that are achievable with today's technology. Also, a part of the program is dedicated to the identification and evaluation of very high-energy advanced propulsion concepts that, if proven feasible and ultimately practical, would provide a quantum leap in propulsion capabilities such that missions heretofore thought to be impossible could be achieved.

The propulsion program is directed toward expansion of fundamental knowledge and understanding of rocket engine behavior and toward improved component and engine systems designs. Fundamental efforts are focused on the development and experimental

verification of combustion instability codes, unified computational fluid dynamics codes, impeller flow models, soft seal rub dynamic models, and fluid dynamic processes in combustion chambers and nozzle boundary layers. In 1988 considerable progress was made in development of analytical representation of these phenomena. Also, work associated with rocket propellants yielded success in gelling and metallizing fuels (with aluminum)—the potential benefits lie in greater bulk densities and improved storability.

In the area of auxiliary or low-thrust propulsion, technology was directed toward improving both performance and life of various propulsion concepts including resistojets, arcjets, ion thrusters, magnetoplasma dynamic thrusters, and gaseous and storable liquid chemical propellant rockets. Applications for these classes of systems range from station-keeping (orientation) for large systems such as the Space Station Freedom, orbit changing (for example, transferring a spacecraft from a 250-mile Earth orbit to a geosynchronous Earth orbit of 22,000 miles), to planetary missions represented by the Voyager spacecraft. The program achieved a number of notable successes in 1988 including the following: (1) increased performance for standard chemical engines; (2) completion of life extending (1000-hour, 500-cycle) tests of an arcjet propulsion system; and (3) completion of a similar life test (1000-hour, 500-cycle) for ion engines.

In 1988 advanced propulsion concepts studies continued to investigate promising capabilities not yet within our reach and included such topics as the status of fission, fusion, antimatter, and unconventional chemical and other revolutionary propulsion concepts. A magnetically confined microwave-induced plasma experiment was initiated at the Massachusetts Institute of Technology as the first experimental effort under the advanced concepts program.

Materials and Structures. The objectives of the program are to provide technology that will enable the development of materials to better withstand the harshness of the space environment across a broad

front of space applications and to develop the structural concepts and capabilities necessary to allow for the in-space construction of large-area space structures.

In the materials science program, efforts were under way to develop theoretically, and to verify experimentally, methods for predicting the properties of tougher and higher temperature polymers for space engine and structural applications and studies to better understand the behavior of solid lubricants in the space environment. In the space durable materials program, contamination studies focused on the development and verification of analytical codes for correlating in-flight data and ground-based experiments. Studies of atomic oxygen, prevalent in low-Earth orbits, and its effects on spacecraft materials, were enhanced with the development of new ground-based atomic oxygen simulation facilities, the calibration of a wide range of ground-based facilities for simulating atomic oxygen exposure in low Earth orbit, and the measurement of long-term atomic oxygen exposure effects on organic composite and polymer materials. In the area of micrometeoroid/debris impact, ground-based experimental studies of hypervelocity impact on metallic and nonmetallic materials continued. In the area of radiation exposure, a new facility was being developed to provide a combined thermal-cycling/electron-radiation materials testing capability. In the aerothermal materials program, processing, fabrication, and testing of various ceramic materials for thermal protection systems were carried out. For hypersonic vehicle applications, work was under way to develop, fabricate, and evaluate very thin-gauge oxidation-resistant intermetallic and carbon-carbon materials for lightly loaded hot structures, such as control surfaces.

The structures technology was focused on erectable and deployable spacecraft structural concepts; methods for in-space construction and repair of large complex structures; dynamics of flexible structures and concepts for active configuration control and vibration suppression; new structural concepts for active cooling of hot structures for hypersonic vehicles and cryogenic tanks

for in-space propellant storage; and efficient analysis and design methodology for advanced space structures, including multidisciplinary analysis and optimization.

Space Data Systems. Efforts continued in 1988 to enhance significantly onboard computational capabilities while, at the same time, improving reliability under spaceflight conditions. In the area of advanced data systems, neural memory devices for high reliability space applications were demonstrated. These memory devices may have the potential to replicate the capability of the human mind for pattern recognition and deductive reasoning. They will be used as hardware-based natural intelligence systems in applications such as spacecraft navigation and autonomous robots. In the area of software engineering, efforts continued to develop and apply life-cycle costing principles to the development, maintenance, and modification of software in order to improve performance, cost, and reliability (risk reduction). A pilot software management environment application was developed and evaluated with positive results. An advanced software life-cycle simulation was developed and is currently being applied to a model of the space station software development environment. These tools are intended to provide software managers with critical aids for evaluation of software development costs and schedules. A reusable software component library in an Ada development laboratory was also demonstrated. Ada is a newer generation computer language which provides enhanced versatility for the software program developer while, at the same time, providing an operational environment conducive to greater system reliability and flexibility.

Communications. The development of microwave and optical communications devices and component technology continued to yield accomplishments. Prototype Ka-band monolithic microwave integrated circuits were designed, fabricated, and tested. These circuits are proposed for use in phased-array antennas for future deep space missions, such as Cassini and the

Mars Rover. An experiment was successfully conducted on a multiple element phased-array microwave antenna feed with electronic compensation for antenna dish distortion resulting in the production of a near-perfect far-field antenna pattern. Such a concept will find application for communications and for large radiometry antennas for Earth remote sensing (in the 10 to 100 Gigahertz frequencies). Continuing tests on gallium-aluminum-arsenide semiconductor lasers indicate the potential to increase the operational lifetime of optical communications systems by four to five years.

For deep space communications applications, a major accomplishment was achieved when a complete monolithic solid-state photodiode with ten amplification stages was fabricated and successfully tested with a yield in gain of 200 at a bandwidth of greater than two Gigahertz. This device represents a technical achievement for reception of space optical communications signals.

Information Sciences. Research activity in this area continued across a broad front in 1988 including work in computer sciences, sensors, and photonics. In the computer sciences area, the distributed access view integrated data base (DAVID) system software was developed and tested. DAVID will provide scientific users transparent access to space data that is stored in dissimilar data bases. Demonstrations of DAVID for astrophysics applications were given. The new center of excellence in space data and information sciences was established at Goddard Space Flight Center in conjunction with the University of Maryland.

In the area of sensor technology, the goal of high spatial imaging with simultaneous sharp energy resolution for X-ray and gamma-ray imaging spectrometers and cosmic-ray drift detectors was advanced. A technique employing a silicon drift detector to achieve better energy resolution was applied over the soft X-ray spectrum for energy levels ranging from 100 to 10,000 electron volts. These concepts have immediate application to the Advanced X-Ray Astronomical

Facility and AstroMag missions planned by NASA. A semiconductor diode laser, fabricated from gallium antimonide with indium and arsenic in various layers, was successfully operated at eye-safe wavelengths.

In the relatively new photonics area, research was focused on components devices and was aimed at improving autonomy and performance of spacecraft systems. An advanced real-time acoustic spectrum analyzer was demonstrated which has immediate potential for use in the search for extraterrestrial intelligence. Also, a liquid crystal spatial light modulator for image subtraction, edge enhancement, and associative memory applications was demonstrated for use in robotic image identification and recognition applications.

Automation and Robotics. The objective of the automation area is to exploit the potential of artificial intelligence and telerobotics to increase the capability, flexibility, and safety of space and ground operations while decreasing associated operating costs. The automation and robotics activities are focused in the following five core technology areas: sensing and perception, control execution, task planning and reasoning, operator interface, and systems architecture and integration. The program is currently being implemented as a sequence of demonstrations using testbeds, mockups, and shuttle and spacecraft operations to verify development progress.

In 1988 first use of an expert system for monitoring shuttle communications during flight was demonstrated. The integrated communications officer (INCO) program developed and demonstrated the application of artificial intelligence; this expert system aided the communications officer in the Mission Control Center at the Johnson Space Center by displaying data in ways that made it quicker and easier for him to make accurate decisions. Problems were graphically displayed on a screen, and failures were traced through to the appropriate system. NASA's first operational use of artificial intelligence occurred when the INCO

system was used during the launch of STS-26 in September 1988.

The space robotics program is focused on providing increased capability and safety in performing on-orbit operations, such as satellite servicing, repair, and assembly. In 1988 the capability to capture a spinning satellite by a telerobot, under human supervision, was demonstrated in a laboratory testbed facility. The telerobot testbed combines machine vision control, advanced dual robot arm control, and conventional force/torque control in its capabilities.

Controls and Guidance. Research in this area is primarily aimed at developing new technologies to enhance the in-space controllability and stability of complex spacecraft such as large flexible antennas, segmented precision optical telescopes and interferometers, multi-instrument Earth observing platforms, and space stations. The activity focused on developing computational tools for spacecraft control system design, analysis, and simulation complemented by technology for advanced sensors and actuators. During the past year, the large flexible vertical-beam antenna test facility at the Marshall Space Flight Center was used to successfully test these new concepts. The fiber-optic control gyro technology program continued to show promise through the successful demonstration of an eight-component optical chip.

For space transportation applications, progress was made in advancing our understanding of adaptive controls for orbit transfer vehicles employing aerodynamically assisted orbit braking which uses the resistance of the atmosphere to slow the vehicle down; precision guidance and navigation through planetary atmospheres to a safe touchdown; and for designing and analyzing highly reliable fault and damage tolerant flight control systems.

Human Factors. In this area, the effort in 1988 continued to emphasize the development of a new generation of high-performance space suits, gloves, end effectors, and tools to improve human effective-

ness in space. Also, to complement this goal, research was conducted to develop more comprehensive guidelines for designing man-machine interfaces for human work stations and extravehicular activities (EVA) by enhancing computer-generated models of human capabilities and performance in low gravity environments.

Accomplishments in 1988 included evaluation of human performance in zero gravity with direct control devices (telerobotics); development and evaluation of a neural network for autonomous motion and spatial sensing using mathematical and computational models of human performance; completion of an initial operating configuration for a virtual work station; and updating the data base on human strength and motion in zero gravity. In the area of EVA suits and tools, accomplishments included testing of a new, high-pressure EVA glove and glove materials and fabrication of a highly dexterous end effector and its test in zero gravity. Installation of a laser-based anthropometric mapping system at the Johnson Space Center was completed and its use initiated.

Space Flight. As indicated earlier, the space flight research and technology program provides the opportunity for researchers and engineers from industry, universities, and NASA to conduct tests in space in support of their respective ground-based research and technology activities. Flight data obtained from such experiments are used to validate and verify analytical models, prediction techniques, and ground test methods and facilities. This program encompasses the identification and definition of in-space flight experiments; the design, fabrication, and flight certification of the experiments prior to flight; and the development of unique, special purpose hardware systems to support in-space experimentation. During 1988, 46 space flight experiments were approved for definition, and it is anticipated that many of them will eventually be conducted in space either on the shuttle or on Space Station Freedom.

A workshop was conducted in December 1988, attended by industry, university, NASA, and other government agency representatives, to determine the critical space technology problems and needs facing the United States and to identify which, if any, will require in-space experimentation for their solution. The workshop findings will be used to guide research and technology development activities as well as providing a basis for initiating future in-space technology experiments.

University Space Research Program. The objective of the university space research program is to enhance and broaden the capabilities of the nation's engineering community through a more intimate participation in the U.S. civil space program. This program is an integral part of the strategy to rebuild the space research and technology base. This program responds to the need to remedy the decline in the availability of qualified space engineers by making a long-term commitment to universities aspiring to play a strong engineering role in the civil space program. This program utilizes technical advisors at NASA Centers to foster collaborative arrangements with participating universities and sponsors the exchange of personnel and sharing of facilities between NASA and the university community. The program elements include the following: the University Space Engineering Research Center Program, which supports interdisciplinary research centers; the university investigators research program, which provides grants to individuals with outstanding credentials; and the university space advanced design program, which funds advanced systems study courses at the undergraduate and graduate levels.

In 1988 the University Space Engineering Research Center Program was initiated to advance the traditional engineering disciplines applicable to space and bring together the knowledge, methodologies, and engineering tools needed to advance future space systems. The research centers promote the kind of multidisciplinary teamwork that systems technological problems de-

mand and bring together individuals from a wide range of engineering and scientific fields into a single research structure. These partnerships provide the universities with a broader charter for independent research and also enable new mission concepts and ideas that might alter NASA's own visions of the civil space program. In April 1988, the Office of Aeronautics and Space Technology selected nine universities from a total of 115 proposers.

Exploration

The Presidential Directive on National Space Policy, signed January 1988, states that a fundamental objective is space leadership, and specific goals are set forth that will guide our Nation toward that leadership. One such goal is "to expand human presence and activity beyond Earth orbit into the solar system."

In June 1987, the NASA Administrator established the Office of Exploration to meet the need for specific activities supporting this long-term goal, which can energize the U.S. civilian space program and stimulate the development of new technology. In 1988, the Office worked to identify viable alternatives and to provide recommendations for an early 1990s Presidential decision on an approach to human exploration of the solar system.

Pathways to Human Exploration

An extensive range of possibilities, primarily focused on the Moon and Mars, exists for human exploration and development. To organize and systematically examine a full spectrum of options, the office identified three strategies, or alternative pathways, for study in 1988. Each strategy presented particular opportunities for satisfying defined exploration themes and objectives. In the coming years, additional pathways will be developed to expand the set of options.

The first strategy addressed human expeditions, emphasizing a significant, visible, successful effort to establish the first human presence on another body in the solar system. The expeditionary pathway would lead to exploration without the burden and overhead

associated with lasting structures and facilities. This pathway has been explored for missions to Mars and its moons.

Establishing a science outpost, the second strategy, emphasized advancing scientific knowledge and gaining operational experience by building and maintaining an extraterrestrial outpost as a permanent observatory. Such a facility, located far from the obscuring effects of Earth's turbulent atmosphere, would tremendously enhance our long-term astronomical studies. The experience gained in the process would serve as a foundation for establishing a permanent human base on another planetary body. This pathway has been explored for a mission to the Moon.

The third pathway, evolutionary expansion, would sustain a methodical, step-by-step program to open the inner solar system for exploration, space science research, extraterrestrial resource development, and ultimately, permanent human presence. This strategy would begin with an outpost on the Moon and progress to similar bases of operations on Mars and its moons.

For each of the three exploration pathways, candidate missions were identified to be systematically examined as "case studies," in order to obtain an understanding of the implications of the potential approaches to exploration. Within the case study framework, detailed mission analyses and system engineering studies were performed to define a full set of concepts and requirements for each case.

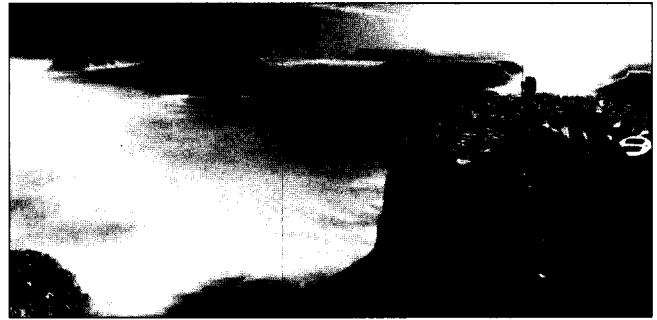
The case study effort included producing actual system design concepts for implementing such missions. This approach builds a context within which diverse exploration strategies can be developed, analyzed, and assessed. Through building this knowledge base, it becomes possible to refine these options in the future.

Human Expedition to Phobos (Case Study 1).

Two approaches to exploring Mars have recently been proposed and studied: (1) a human expedition, and (2) a robotic mission incorporating a highly auton-



Artist's concept of a human expedition to Phobos, with Mars on the horizon.



Artist's concept of human explorers on Mars.

mous rover. An effort to scale down the initial expedition and also achieve the objectives of both approaches has rekindled an interesting idea: a human expedition to Phobos, combined with rovers that are operated by the crew from Mars orbit. Going to Phobos would allow initially simpler, earlier human exploration of the Mars system. An expedition to Phobos would establish early leadership by sending the first human travelers to the Martian moon to explore, conduct resource surveys, and establish a science station. Also, it would provide opportunities to conduct enhanced robotic exploration of Mars itself from the near vicinity (Mars orbit), using tele-operated rovers, penetrators, balloons, and sample collectors, and to return samples of both Mars and Phobos to Earth for detailed analysis. The expedition to Phobos combines human exploration objectives with those of previously studied Mars Rover/Sample Return (robotic) missions, but allows the capability for nearly real-time remote operation of robotic systems.

Human Expeditions to Mars (Case Study 2).

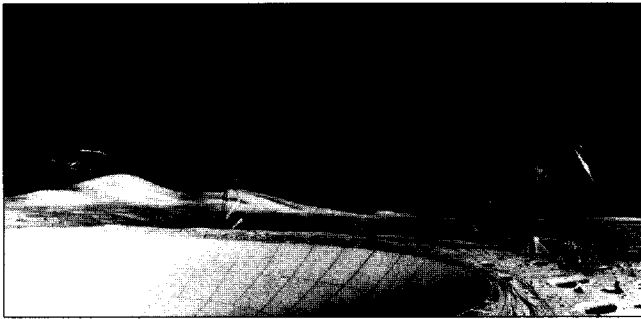
Sending piloted spacecraft to Mars has been an aspiration for decades; it was seriously considered (with accompanying technology investments) as early as 1969, and it has been the centerpiece of many studies since then. Recent activities by the National Commission on Space and the Ride Task Force have renewed national interest in this concept; these two

studies proposed ambitious plans for piloted missions to the surface of our planetary neighbor.

This case study develops a three-mission set of expeditions to send the first human explorers to the martian surface, thereby clearly capturing early leadership in piloted interplanetary exploration. Once there, the crew would scientifically explore the local terrain and geological formations, emplace long-lived geophysical instruments, and collect samples for return to Earth. The Martian moons, Phobos and Deimos, would be explored as well.

Lunar Observatory (Case Study 3). Astronomers have long been frustrated by the fact that, even with the most sophisticated telescopes on Earth, many of the objects that they wish to observe are extremely difficult to see because of the impediments generated by Earth's atmosphere. Telescopes in Earth orbit offer substantial improvement in viewing conditions, but an observatory on the Moon could be orders of magnitude more effective, as larger, more stable instruments and arrays can be emplaced.

The objective of this case study is to understand the effort required to build and operate a long-duration human-tended astronomical observatory on the moon. The moon, which is airless, seismically stable, and provides passive cooling, may be the solar system's best location for such an observatory. In addition, the far side of the moon is shielded from manmade



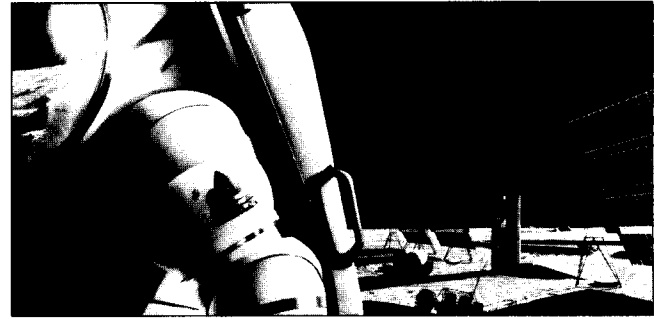
Artist's concept of a lunar observatory on the far side of the moon.

electronic noise and radiation. The facility would consist of optical telescope arrays, stellar monitoring telescopes, and radio telescopes, allowing near-complete coverage of the radio and optical spectra. The observatory would also serve as a base for geologic exploration and for a modest life sciences laboratory.

Lunar Outpost to Early Mars Evolutions (Case Study 4). One of the recommendations of the National Commission on Space was that a “bridge between worlds” be built in the inner solar system to establish human presence on the Moon and Mars, combining a number of different objectives in the process. An underlying goal is to learn to live, first off the lunar land, and eventually the Martian land as well. This case study seeks to realize that goal, by building a capability that would lead to a nearly self-sufficient, sustained human presence beyond low-Earth orbit. The evolutionary approach would provide the impetus for a broad range of technology advancement, evolutionary experience in outpost development and habitation, use of local resources, and the development of facilities that would stimulate further growth.

Beyond Earth's Boundaries

The results of the study effort of 1988 were released in an annual report called “Beyond Earth's Boundaries: Human Exploration of the Solar System in the 21st

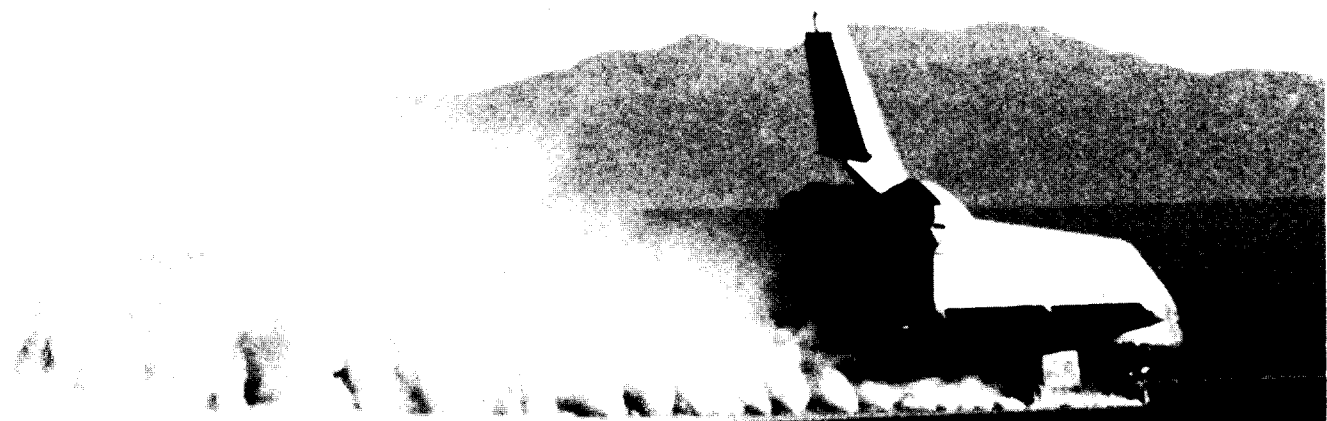


Artist's concept of a lunar outpost.

Century.”

One of the major conclusions of the report is that independent of what type of future exploration course is chosen, the United States must now lay the foundation by beginning a modest but vital effort in detailed research, technology development and concentrated studies. Developing a strategy to implement a program for human exploration of the solar system mandates the consideration of a time period of at least 20 years. Equally important are the near-term investments and studies that keep open promising options and opportunities. A high priority is placed on positioning the United States to accomplish exploration objectives in the first part of the 21st century with near-term investment levels that are reasonable and practical. The report reflects the belief that our strategy must effectively build on current programs (Space Station Freedom, launch vehicle development, precursor science missions, life science research, and Pathfinder technologies), keep the demand for exploration-unique resources at a modest level, and still preserve a capability to act in the first decade of the next century.

This document is an annual report describing work accomplished in developing the knowledge base that will permit informed recommendation and decisions. An in-depth discussion of this year's studies was also published in a separate three-volume series titled, “Exploration Studies Technical Report: FY 1988 Status.”



Landing of the Space Shuttle Atlantis (STS-27) which carried a Department of Defense dedicated mission, on Rogers Dry Lake in the Mojave Desert, December 6, 1988.

Department of Defense

A robust on-orbit space capability of national security systems continued to provide responsive, global capability during 1988 for communications, surveillance, weather sensing, and missile warning. During this year of space launch recovery, a variety of space boosters were employed to meet DoD mission requirements, including Titan-34D launches from both coasts and the first launch of a refurbished Titan II launch in September.

The Shuttle recovery program took a major step forward with the successful mission of Discovery in September 1988 and the flight of Atlantis with a DoD mission in December 1988. The launch rate will continue to expand until a maximum flight rate of 14 per year is achieved when four orbiters are available in 1993.

To meet assured access to space requirements, DoD ELV programs are being expanded and enhanced. The first Titan IV launch is planned for early 1989. By 1995, Titan IV production enhancements and dual pads on each coast will provide a robust capability of up to ten launches. The first of the Delta IIs, built to carry NAVSTAR Global Position System satellites, will also launch early in 1989. The Atlas II launch system is in development to meet the launch needs of the Defense Satellite Communication System (DSCS) beginning in 1991. The Titan II is operational for launch of Defense Meteorological Satellites, as well as other smaller payloads, into unique polar orbits. In addition, the DoD will provide near-term ELV launches on a cost-reimbursement basis to support NASA's mixed fleet launch requirements.

While near-term efforts will narrow the gap between requirements for access to space and capability to launch, merely acquiring additional boosters within today's inventory will not solve longer-term requirements for national assured access. To meet future requirements, a new mixed fleet of launch vehicles must be developed to accommodate a variety of conditions. As a first step in this development process, initial concept definition studies have been completed

for an Advanced Launch System (ALS) to reduce launch costs dramatically, improve operational responsiveness, and meet future demands for assured access to space. NASA and DoD are partners in these efforts. Systems design will continue in 1989, leading toward the objective of a family of lower cost, versatile, and reliable unmanned launch vehicles for the late 1990s and beyond.

Space Activities

Military Satellite Communications

General. The military satellite communications (MILSATCOM) systems are now approaching a critical condition as a result of our inability to have replenishment launches. Both the Fleet Satellite Communications (FLTSATCOM) system and Defense Satellite Communications System (DSCS) space segment require launch replenishment if they are to maintain service to their current critical user community. As an example, for the DSCS space segment, on-orbit reserve satellites are not capable of restoring the current user community if we have an on-orbit satellite failure. As a result of this condition, our top priority effort must be to restore our Space Transportation System (STS) and our Titan-34D launch capability and shorten our launch turnaround time. Additionally, high priority must be placed on the new medium launch vehicle (MLV) acquisition also known as the Atlas II and its associated integrated apogee boost stage (IABS) acquisition. This launch capability is currently planned to commence operation in 1991 to place the remaining DSCS III satellites into synchronous, equatorial orbit. Should this program experience any delay from its currently planned launch vehicle availability date of late 1990, our worldwide command and control and wideband data transfer would be greatly reduced. This same condition exists for the FLTSATCOM user community in that the 1989 planned launch of a FLTSATCOM satellite must take place on schedule.

In 1988, planning the future of the Milstar satellite communications system continued. This system will

employ the Extremely High Frequency (EHF) band to provide highly survivable and enduring essential communications for critical users. Work also progressed on defining an upgraded capability for the DSCS system. Using portions of the EHF technology developed under Milstar, this upgrade will greatly add to communications capacity and survivability for these users.

Fleet Satellite Communications (FLTSATCOM).

FLTSATCOM system provides low capacity, worldwide connectivity for small mobile platforms in the Ultra High Frequency (UHF) band. The system consists of five government-owned Fleet Satellites (FLTSATs) and three contractor-owned Leased Satellites (LEASATs). Launch of the last of the current FLTSAT series, FLTSAT 8, is scheduled for 1989. Both FLTSAT 7 and FLTSAT 8 include an Extremely High Frequency (EHF) package to allow testing of EHF terminals for the Milstar system. In 1988, a contract was awarded to Hughes Aircraft Corporation for a replacement program for FLTSAT known as UHF Follow-On (UFO). A separate contract to add an EHF subsystem starting on the fourth UFO is to be released in 1989. The UFO system will provide the mobil users connectivity through the mid 2000s.

Launch vehicle difficulties, affecting all US space progress, hit the FLTSAT program especially hard in 1987, with effects still being felt in 1988. The launch of the last satellite in the current FLTSAT series is scheduled for late 1989.

Air Force Satellite Communications (AFSATCOM)/Single-Channel Transponder (SCT). The AFSATCOM is a satellite communications capability that provides reliable global communications between and among the National Command Authorities and the nuclear-capable forces. The primary missions supported are dissemination of emergency action and force-directing messages to the deployed forces and the associated report-back communications. The system terminal segment consists of fixed and transportable ground terminals and airborne terminals a

transponder control system. During 1988, the Single Channel Transponder (SCT) on the DSCS III spacecraft and the SCT Injection system (SCTIS) ground segment entered final installation and testing phase. These will provide a more survivable SHF service for the strategic users. The mission areas performed by these systems will be transferred to the Milstar system in the mid 1990s.

Defense Satellite Communications System

(DSCS). DSCS is the long-haul communications system supporting critical worldwide command and control of our forces. In addition, the DSCS supports the transfer of wideband data and the users of the Diplomatic Telecommunications System. The space segment portion of DSCS has been approved as five operational satellites and two on-orbit reserves. The current space segment consists of three DSCS IIIs and two DSCS IIs and two limited-capability DSCS II reserve satellites. Should any of the current operational satellites experience an on-orbit failure, the current reserves would not be able to restore all users traffic. During 1988, contingency plans were drawn up in order to immediately react to an on-orbit failure. These plans were initiated because the current operational space segment has two DSCS II satellites well beyond their mean mission duration and a DSCS III satellite that has already switched more than 75 percent of its backup components into operations and will exceed its mean mission duration in 1989. As a result of these conditions, it is essential that our launch capability through 1995 for DSCS be given a top priority. While the current inability to launch DSCS satellites has impacted our overall level of confidence that the space segment will be capable of supporting the user requirements, it has also impacted the program funding because of unplanned and unfunded satellite storage costs that the program is now incurring. As of January 1989, there will be seven DSCS III satellites in storage. When the remaining DSCS III satellites are launched, we will be capable of supporting the critical user community through 1997. In 1988, concept work was begun on the DSCS III follow-on

program with the objective of achieving FY 92 funding support and a late 1990's launch. Also, increased attention was paid to the development of a common, interoperable, anti-jam, super high frequency (SHF) modem for DSCS terminals.

The control segment provides for near real-time monitoring and control to ensure optimum use of resources, thereby maximizing user support. This control segment was expanded in 1988 with activation of a sixth DSCS Operations Center (DSCSOC) at Ft. Belvoir, VA. Also, three additional deliveries of DSCS Frequency Division Multiple Access Control System (DFCS) equipment were accepted from the contractor for installation at Ft. Detrick, Ft. Belvoir, and Ft. Meade. This equipment, to be installed at each DSCSOC, will provide control of the Frequency Division Multiple Access (FDMA) networks in each satellite area. Management actions were undertaken in 1988 to begin the consolidation of all DSCS operations centers under the Army Space Command. There are also contracts in place to move toward a contingency control capability in the 1991-94 time frame.

The ground segment consists of the family of large, medium, and small Earth terminals with associated communications equipment supporting both the strategic and tactical user communities. In 1988, all 39 new AN/GSC-52 fixed terminals had been accepted for activation through 1991. With these activations, the total terminal population using the DSCS exceeds 500. In addition, actions were continued to define the next generation Earth terminal needed to support the expanded requirements of the late 1990s, and to plan for replacing or upgrading the aging terminals currently within the networks.

Milstar. Milstar is a multichannel, Extremely High Frequency/Ultra High Frequency (EHF/UHF) satellite communications system that will provide survivable, enduring, jam-resistant, and secure voice/data communications for the President, the Joint Chiefs of Staff, and the Commanders in Chief (CINCs) of the Unified and Specified Commands. It will be used for the worldwide

command and control of US strategic and tactical forces in all levels of conflict. Milstar satellites, which contain special survivability features, will be launched into high and low inclination orbits to provide full Earth coverage. Full-scale development of the space and mission control segments continued in 1988 with Critical Design Reviews completed. Detailed planning for payloads and its integration will begin in 1989. Nuclear hardened Milstar terminals will be provided to command facilities, to surveillance outposts, and to strategic and tactical forces during the 1990s. When completed, Milstar will provide the United States with its most survivable wartime communications capability. The Air Force is the lead service for the procurement of Milstar satellites, the dispersed mission control network, and the airborne terminals. The Army and Navy also have terminal development and procurement programs. The terminal programs of all three Services are coordinated through the Navy's Joint Terminal Program Office, which has the responsibility to ensure interoperability and common specifications among the three designs.

The Milstar multiservice terminal segment OT&E was initiated in 1988 through the Phase I interoperability test demonstration. The results validated the frequency-hopping waveform and other terminal technical characteristics, as well as demonstrating operations in some field environments. The three service terminals communicated with each other via a scaled down version of the Milstar space system orbiting on a FLEETSATCOM satellite. Each Service terminal also completed Phase I testing with a bread-board version of the Milstar satellite payload. Land, sea, and airborne terminals included a destroyer, a submarine, and a transport aircraft in the field tests. Requirements for Milstar have been validated and an initial paper loading of the communications nets on the satellite constellation has been completed. Extensive terminal interoperability testing was conducted between the Air Force, Army, and Navy terminals using the EHF package on FLTSAT 7. Integration of the flight

hardware for the Development Flight System (DFS) is well underway and will continue through 1989.

Satellite Laser Communications. The Satellite Laser Communications (SLC) system is a joint technology demonstration effort between the Navy and the Defense Advanced Research Projects Agency (DARPA) to provide the capability to communicate from space to a submerged submarine, using a laser beam as the transmitting medium. To date, the basic capability has been proven by sending messages to a submerged submarine from an aircraft, using green and blue laser lights. An operational system would probably use blue laser light, which provides greater transmission efficiency. An aircraft-to-submarine test using blue laser was completed in the summer 1988, with a final report expected by January 1989.

Strategic Defense Initiative

The Strategic Defense Initiative (SDI) has made tremendous strides since President Reagan's 1983 speech, particularly in the program's organizational maturity and the number of technology options potentially available for a strategic defense system. The SDI program seeks to preserve both near- and long-term defense options. For example, kinetic energy systems (e.g., rocket interceptors)—for use in the initial phase of a defensive system—and directed energy weapons (lasers, particle beams) are being researched with equal dedication. These options are integral to the program's success in countering potential Soviet responses to a deployed strategic defense system.

In 1988, the Department of Defense Acquisition Board (DAB) completed an annual review of progress of the technologies previously selected for the demonstration/validation phase of the Defense Acquisition Process. These technologies, known as Phase I of the Strategic Defense System (SDS), consist of various sensor systems, ground- and space-based ballistic missile interceptors, and battle management, command, control, and communications. Cost reduction has long been recognized as an important component

of the SDI program, and cost-reduction efforts had been emphasized for this year's DAB review in tandem with technology research. By anticipating potential SDI costs, and implementing technology development strategies that focus on reducing costs, we believe the SDS will be affordable.

SDI program accomplishments have increased our confidence that strategic defenses will prove feasible. In past years, the SDI Organization (SDIO) has conducted a series of kinetic energy and directed energy weapon technology tests. Kinetic energy tests have successfully demonstrated the possibility of non-nuclear destruction of enemy ballistic missile before they reach their targets. Recently, the first of a series of "hover tests" of a space-based interceptor was conducted in a ground test facility. These tests help evaluate the capability of fast-acting thrusters to keep a sensor pointed at a target, and the interaction of the sensor and propulsion systems. This past year, the Aerothermal Reentry Experiment demonstrated that kinetic energy weapons can destroy warheads not only with a perfect hit, but also by inflicting damage with a less than perfect collision. The process of self-destruction of a damaged warhead as it enters the atmosphere was demonstrated. Substantial technological advances have been incorporated into the system designs. For example, inertial measurement units have been reduced in weight to six ounces, from 41 pounds about 15 years ago, and in size to a much smaller device. Such a dramatic reduction in weight and size will allow interceptors to be placed into space at reduced cost.

With directed energy experiments, researchers have demonstrated several key principles related to the operation of a large Free Electron Laser, a weapon which could become powerful enough to destroy enemy ballistic missiles in the boost-post-boost phases of flight. Similar experiments are also being conducted using other types of lasers and neutral particle beams. While lasers and particle beams will not be available as soon as some of the kinetic energy systems, their

importance to the overall SDI mission cannot be overstated. Although such systems would build on the capability of a Phase I system, they have a least one new mission: to thwart the effectiveness of a new generation of Soviet ICBMs and other possible counters to an SDS. Kinetic energy systems, lasers, and particle beams form a mutually reinforcing "triad" for defensive systems much like the mutually reinforcing and complementing aspect of the Triad for offensive systems.

Some surveillance and sensor technologies supported by the SDI program address not only SDI but other critical national security needs as well. The capabilities of today's early warning radars and satellites could be greatly improved through advancements in detection capabilities. These new sensors will provide more accurate and reliable surveillance data of objects in space. The Delta-181 experiment demonstrated substantial improvements in our ability to develop sensors necessary for strategic defenses. In that experiment, a payload of sensors and test objects aboard Delta-181 provided a demonstration of effective ways to discriminate between decoys and reentry vehicles. The assortment of active and passive sensing instruments accurately characterized the test objects, and also the launch of a research rocket, in a variety of space environments. Small differences in motion— or wobble:—and also other signatures provide detectable differences between decoys and reentry vehicles.

Tangible, impressive results have given us increased confidence that strategic defenses are feasible. The goal is to present the Nation with the option of moving from a deterrent relationship based solely on nuclear retaliation to one that is increasingly based on effective defenses against attack. During 1988, DNA programs led to the development of a method of producing insulating substrates which will provide the quality of material necessary for circuit fabrication. These improvements, which have led to a x10,000 reduction in material defects, will make it possible to produce the very-large-scale integrated circuits needed for future

DoD strategic systems. This technology was demonstrated by the manufacture of a number of 16K Static Random Access Memory devices.

Aeronautical Activities

Fixed-Wing Programs

B-1B Bomber. In June 1985, the first B-1B was delivered to the Strategic Air Command. By summer 1988, all 100 B-1Bs were delivered to the Air Force, with operational basing at Dyess AFB, Texas; Ellsworth AFB, South Dakota; Grand Forks AFB, North Dakota; and McConnell AFB, Kansas. The B-1B has been on alert as part of the Strategic Air Command's defense force since October 1, 1986. Baseline development and testing of the B-1B continues at Dyess AFB, Texas, and Edwards AFB, California.

B-2 Advanced Technology Bomber. Work has been ongoing on the B-2 with Northrop as the prime contractor; Boeing, LTV, and General Electric Aircraft Engine Group are subcontractors to Northrop. The B-2 employs low-observable, or stealth, technology and is based on a flying wing concept which exhibits high aerodynamic efficiency giving high-payload, long-range capability.

The B-2 was rolled out at Palmdale, California, in November 1988. The first flight of the B-2 is scheduled for the near future. Also, Northrop is well into the assembly phase of aircraft number two.

The first operational B-2 will be delivered to Whiteman AFB, Missouri, in mid-1991. An Initial Operational Capability (IOC) will be achieved in the early 1990s at Whiteman AFB.

Advanced Tactical Fighter (ATF). The ATF program is developing the next generation Air Force fighter to counter the Soviet threat projected for the late 1990s and beyond. As a follow-on to the F-15, the ATF is being designed to penetrate high-threat enemy airspace and support the air-land battle forces with "first-look, first-kill" capability against a technologically advanced, numerically superior enemy. The ATF's improved capabilities will be made possible by signifi-

cant technological advances in the area of signature reduction, aerodynamic design, flight controls, materials, propulsion, sensors, and integrated avionics. It will reach operational capability in the mid-1990s.

In April 1986, the ATF program was restructured to include flying prototypes and ground-based avionics prototypes in the Demonstration/Validation (Dem/Val) phase of the program. The restructured program implements Packard Commission recommendations, emphasizes fly-before-you-buy, competitive contracting, and provides the means to reduce technical and cost risks for entering full-scale development in 1991.

In October 1986, the ATF program completed a Joint Requirements Management Board Milestone I, and received Office of the Secretary of Defense approval to award the Dem/Val contracts. Contracts were awarded to Lockheed and Northrop, and flight demonstrations of their prototype aircraft, designated YF-22A and YF-23A respectively, will begin in 1990. General Electric and Pratt and Whitney are providing the prototype engines for the ATF aircraft.

C-17. The C-17 aircraft is entering its fifth year of full-scale development. Wind tunnel testing is complete, and all major subcontracts have been awarded. More than 90 percent of the detailed engineering drawings for manufacture of the C-17 have been completed. The engines (Pratt and Whitney 2040) for the C-17 are modern, efficient, commercially developed, turbofan engines that are equipped with unique thrust reversers specifically developed for the C-17. The first C-17 engine (military designation F-117) was delivered five months early in May 1987. In addition, the airframe and electronic flight control system critical design reviews were completed in July 1988 and November 1988 respectively. Assembly of the first C-17 began on time in August 1988. The Defense Acquisition Board (DAB), after a December 1988 Milestone IIIA review, approved low-rate initial production. As of December 1988, Congress has approved an appropriation funding for a total of six aircraft (Lots I and II) and a long lead for six aircraft (Lot III).

Remotely Piloted Vehicle. The Navy and Air Force are jointly developing a medium-range, unmanned reconnaissance vehicle. The Navy is developing the unmanned vehicle, and the Air Force is developing an electro-optical sensor suite to be carried by Air Force and Navy manned and unmanned tactical reconnaissance vehicles. In 1989, two contractor will be selected to participate in a competitive fly-off of their unmanned vehicles that will occur during 1990.

Advanced Technology Demonstrators

V-22 Osprey (Formerly JVX). The Osprey is designed to provide the Marine Corps, Navy, and Air Force with a multimission Vertical/Short Takeoff and Landing (V/STOL) capability for the 1990s and beyond. It will satisfy operational requirements such as Marine Corps assault vertical lift, Navy combat search and rescue, and Air Force special operations. In April 1983, the Preliminary Design Phase began; in 1986, a decision leading to full-scale development was made. Powered model, aero-elasticity, and large-scale rotor performance tests were completed. These test results will lead to the first flight of the V-22 in December 1989.

Aeronautics Technology

Microwave Landing System (MLS). MLS is the precision approach landing system of the future. It will replace the existing instrument landing system (ILS) and precision approach radar by the year 2000. Both fixed and mobile MLS ground equipment will be acquired, as well as MLS avionics, for DoD aircraft. The Federal Aviation Administration has overall responsibility for the national MLS program, and the Air Force was designated the lead Service for the DoD. In 1988, the Air Force continued with programs to acquire modified commercial MLS avionics and mobile MLS capabilities. The modified commercial MLS avionics will be used in cargo, tanker, trainer, and support aircraft. The mobile MLS will replace existing mobile precision approach radars. The mobile MLS Request for Proposal was released in 1987, and the contract was

awarded in August 1988. The FAA Fixed Base MLS Request for Proposal will be released in 1989 and will include equipment for the DoD. Contract award is planned for 1990. An MLS avionics architecture study, completed in 1986, considered MLS avionics alternatives that could accommodate the environmental and space constraints that exist in high-performance aircraft. As a result of the study, the Air Force awarded contracts in 1987 to conduct a concept definition effort for a high reliability (20,000-hour mean-time-between-failure) MLS/ILS receiver. Full-scale development is planned to start in Fiscal Year 1989. The ILS capability will be retained until the transition to MLS is completed in the year 2000.

Short Takeoff and Landing/Maneuver Technology Demonstrator (F-15 STOL/MTD). The F-15 STOL/MTD aircraft integrates and flight validates two-dimensional exhaust nozzles, movable canards, and rough field landing gears on an F-15B. The aircraft essentially has an F-15E cockpit and digital fly-by-wire flight control system with no mechanical backup. The result will be an aircraft controlled in the pitch axis by vectored thrust with greatly improved up-and-away maneuver and deceleration performance. It should be able to take off and land on a 1500-ft by 50-ft icy runway with 30-knot crosswinds without the aid of an instrument landing system. The first flight of the F-15 STOL/MTD (without the two-dimensional nozzles) was conducted on September 7, 1988. The two-dimensional thrust vectoring/thrust reversing nozzles are currently undergoing ground testing. They should be installed in the STOL/MTD aircraft in early 1989.

Advanced Flight Technology Integration (AFTI/F-16). In 1987, the AFTI/F-16 started flight testing close air support (CAS) technologies in support of Army/Air Force joint operations. Just recently, the aircraft has completed Phase I flight testing. This consisted of integrating and flight demonstrating digital data link and digital terrain systems technologies in an operational environment. Two Army Scout helicopters, working without a Forward Air Control (FAC), pro-

vided target and threat information to the AFTI/F-16 pilot who, in turn, successfully acquired and attacked targets at high speeds on the first pass. The entire attack was carried out without a spoken word and was very successful. In the past, pilots flying CAS missions, employing similar tactics without these technologies, have had only a 40-50 percent chance of finding similar targets on the first pass. Phase II started in December 1988 and will demonstrate a two-ship internetted attack and manual night attack capability.

X-29 Advanced Technology Demonstrator. The X-29 #1 aircraft has completed flight testing. This unique forward-swept wing aircraft has flown 87 successful flights during 1988, and 247 test flights since flight testing started in December 1984 at NASA's Dryden Flight Research Facility at Edwards AFB, California. The X-29 now holds the record for the most flights of any X-series aircraft. The aircraft demonstrated the viability of forward-swept, aero-elastically tailored composite wings, successful digital control of a 35 percent statically unstable aircraft, and excellent stability and longitudinal control derived from coupled canards. Recent flight test results indicate that a forward-swept wing fighter, constructed using X-29 technologies, would have less drag and be lighter than a conventional aft-swept wing fighter. Based on X-29 #1 aircraft performance data and computer simulations, a forward-swept wing design is predicted to have significant transonic maneuvering performance improvements. These include instantaneous turn and roll control rates at high angles of attack. A follow-on program for a second X-29 aircraft (X-29 #2) has been started. This X-29 #2 aircraft flight test program will evaluate X-29 agility at high angles of attack. The #2 aircraft has been modified with a spin chute and high angle-of-attack instrumentation.

National Aero-Space Plane (NASP). This is a Presidentially-directed, joint Department of Defense (Air Force, Navy, Defense Advanced Research Projects Agency (DARPA), Strategic Defense Initiative Organization/National Aeronautics and Space Administration

(NASA) program. The objective is to develop the enabling technologies for an entirely new generation of flight vehicles including space launch vehicles capable of single-stage-to-orbit with horizontal takeoff and landing, and hypersonic aircraft capable of long-range hypersonic cruise within the atmosphere. The requisite technologies will be integrated into the design and fabrication of an experimental aircraft, the X-30, for flight test and demonstration. These demonstrated technologies would then provide the basis for military and civil vehicles capable of: global unrefueled operation, reaching any point on the Earth in less than two hours; providing routine "on demand" access to near-space; reducing payload-to-orbit costs by at least an order of magnitude; and flexibly based, rapid response (to any azimuth) space launch. Such NASP-derived aerospace systems would provide a revolutionary increase in military capability.

The contractor competition to build the X-30 will not be completed until 1990, but some characteristics can be specified now. The X-30 will be a manned aerospacecraft powered by ramjet/scramjet engines that will be fueled by liquid or slush hydrogen. It will have auxiliary rocket engines for final orbit insertion and on-orbit maneuvering. The vehicle structure will be manufactured from advanced, high strength, lightweight, temperature-resistant materials and critical portions of the structure will be actively cooled with the super-cold hydrogen fuel before it is burned in the engine.

The NASP program is making solid progress with no insurmountable technical obstacles foreseen. All competing airframe and engine contractors have produced X-30 designs that meet the goals of the NASP program. These conceptual designs for airframes and engines have been analyzed and are forming the basis for component hardware fabrication and ground tests that are producing impressive results. Among recent accomplishments are the following:

- Computerized fluid dynamics calculations refined for three-dimensional calculation and validated

with component test data from wind tunnels.

- Several alternative advanced materials have been characterized and successfully joined or welded.
- Critical engine and airframe components have been successfully fabricated and tested under realistic operating conditions.
- Engine test facilities for validating full-scale engine modules at flow conditions up to Mach 8 have been completed and tested.
- Construction of cryogenic liquid-hydrogen tank structures has been initiated.
- Initial applications studies to analyze missions for future NASP-derived vehicles have been completed and detailed follow-on studies are underway.
- An innovative acquisition approach has been taken of establishing a consortium of the major NASP contractors to develop and share information on advanced materials.

During the current phase, the NASP contractors are contributing over \$700M of their own resources to the NASP program.

The next phase, dealing with the detailed design, fabrication, and flight test of an experimental aircraft, is scheduled to begin in 1991. First atmospheric flight of the X-30 experimental flight research vehicle is planned for early 1995, with the first orbital flight planned for late 1996. The goal of Phase III is to accomplish sufficient flight demonstration to provide a verified technological basis for the development of future operational vehicles.

Advanced Short-Takeoff, Vertical Landing Aircraft (ASTOVL). Under a cooperative research initiative involving the Defense Advanced Research Projects Agency, NASA, Navy, and the Air Force, conceptual designs of an ASTOVL fighter aircraft have been developed. The objective of this effort is to determine the potential of an ASTOVL fighter to be the next generation replacement for the current generation of fighter aircraft (F-16, F-18, AV-8B). These aircraft, which constitute the bulk of the US tactical fighter

fleet, were designed in the 1970s and will reach the end of their design lifetime in the first decade of the next century. If current and emerging technology can permit the design of a high-performance fighter that also includes the ability for short takeoff and vertical landing, then it may be possible to use the same airframe in multiple roles and Service missions. The NASA laboratories have supported this initiative through wind tunnel testing, flight/propulsion control concept development, and propulsion definition. An existing Memorandum of Agreement between the DoD, NASA, and the Ministry of Defense of the United Kingdom has resulted in a successful joint research effort with data exchange provisions. If the research initiative continues to show progress, the potential exists to build a research aircraft for concept validation and risk reduction. The existing Memorandum of Understanding (MOU) with the UK and a proposed MOU with Canada form the basis for a potential multinational effort in the fabrication and testing of a multinational research aircraft.

Unmanned Air Vehicle. In 1988, two very important aeronautical milestones have been achieved. The AMBER Unmanned Air Vehicle (UAV) demonstrated record-setting altitude and endurance capability, and the CONDOR, a totally autonomous high-altitude, long-endurance UAV, successfully completed its first flight. These achievements introduce a new dimension that lies between manned patrol aircraft on the one hand and satellites on the other. Such "Slow-Sats" or "Low-Sats" have great potential, not only for reconnaissance, surveillance, and target acquisition in any theater, but they provide an important means for extending the battle space of air defense which is essential for continued effective defense of carrier battle groups as well as air defense of North America.

Enhanced Fighter Maneuverability (EFM). The EFM program is joint development between the United States and the Federal Republic of Germany, initiated under the Nunn-Quayle NATO Cooperative Research and Development Initiative. The two prime contractors

involved in the program are Rockwell International and Messerschmitt-Bolkow-Blohn. The EFM program will integrate and demonstrate a number of emerging technologies that collectively have the potential to significantly increase fighter aircraft agility and to improve close-in-combat (CIC) exchange ratios. The technical challenge is to produce a low-cost flight vehicle that will demonstrate the payoff of high agility at high angles of attack using integrated flight and propulsion control systems. Two X-31A flight demonstrator aircraft will produce data on the technical and military implications of post-stall maneuvering provided by EFM. Flight tests will provide both research data for the relatively unexplored flight regime at high angles of attack, and will also provide a preliminary tactical assessment of post-stall maneuvers for close-in aerial combat. A low-cost approach to flight demonstrators will be used, and a data base for proof-of-concepts flight vehicles will be generated for future application.

The first X-31A aircraft, which is currently being assembled by Rockwell International in Palmdale, California, is scheduled for first flight in late 1989.

Pilot's Associate. The Pilot's Associate program is applying many of the technologies being developed under the DARPA Strategic Computing Program to the problem of real-time combat pilot aiding. The specific technologies being developed and applied include artificial intelligence, automated planning, and the supporting computer processor technology necessary for their implementation. The program seeks to demonstrate the technological feasibility of airborne mission replanning and execution in response to either command redirection or drastic differences between the expected and the encountered situation. A mature Pilot's Associate would provide the pilot of a single-seat fighter aircraft with expert assistance in the highly dynamic and demanding environment of aerial warfare. The program includes increasingly challenging demonstrations in advanced flight simulators representative of the fighter aircraft of the mid-1990s.

Early in 1988, the Pilot's Associate program demonstrated an artificially intelligent mission replanning system which performed mission-level planning and tactics planning directed by expert situation assessment and aircraft status assessment modules. The interface to the pilot was controlled by an artificially intelligent system which modeled pilot behavior in order to determine pilot display requirements. The distributed system was implemented on a network of advanced laboratory processors which formed the link between the flight simulation facility and an experimental cockpit. The system dramatically demonstrated route replanning, observable signature management, threat avoidance, intercept planning, attack planning, sensor management, display management, and aircraft system management at levels of performance which were considered beyond the capability of the unaided pilot. Future demonstrations will include real-time operation for selected, high-value functions.

The program has examined two alternative architectures for integration of distributed intelligent systems. One of these architectures, message passing between actors, has shown highly successful near real-time performance. The second architecture, a partitioned blackboard for data exchange, has helped to identify some of the limitations of that technology for real-time performance.

Other Technologies

Nuclear Hardening. In 1988, a DNA program with Honeywell was culminated with the receipt of 64K Static Random Access Memory (SRAM) devices which demonstrated the highest-ever combination of ionizing radiation hardness and performance (>1 MRAD with 40 nanoseconds access time). These devices were selected by California Institute of Technology scientist for use in the Mars probe experiment and for initial use in the USAF Boost Phase and Surveillance Tracking Satellite (BSTS) program.

In an ongoing program with General Electric, a static random access memory device, which was

developed during the Very High-Speed Integrated Circuit (VHSIC) program, was redesigned to provide a significant improvement and its performance in a radiation environment. These improvements will permit this device to be used in space and strategic applications. The radiation hardening requirements of the initial VHSIC program were satisfactory to support tactical requirements (3000 rads). However, to permit the use of these components in space and strategic environments, additional effort was required.

The Operate Through program goes beyond survivability to insure electronics-based space systems can perform, despite upset and interference. In 1988, the program developed a design approach for computer processors that increases the "virtual hardness" of silicon processors (resistant to >10 Rads(Si)/sec) by at least two orders of magnitude. The program approach is of value to SDI and other space-based developments. A simple code was also demonstrated which shows system response in a multiple nuclear blast environment. Demonstration technology is also planned for space power systems and sensor electronics.

Carbon-Carbon High-Temperature Turbine Demonstration. The Defense Advanced Research Projects Agency has made a long-term investment in the maturation of high-strength carbon-carbon fiber technology for application to turbomachinery. Current aircraft turbines operate at temperatures above the softening point of the metals involved; consequently, cooling air must be supplied from the aircraft engine to maintain the integrity of the turbine. This use of cooling air constitutes a serious loss from the ultimate efficiency of a turbine engine. The DARPA program has successfully demonstrated uncooled turbine wheels of high strength operating in a laboratory environment with surface temperatures of 3100°F. Current plans are to provide these turbine wheels to the Air Force Propulsion Laboratory for evaluation in an experimental cruise missile engine. If the carbon-carbon turbines operate successfully in this dynamic environment of temperature gradients and aerody-

dynamic loading, it will open a whole new class of propulsion designs based on this material. This could span the range from highly efficient electrical power generation turbines to hypersonic vehicle propulsion systems.

Advanced Space Technology Program (LIGHTSAT). The Defense Advanced Research Projects Agency (DARPA) has initiated efforts for the development of advanced technologies to support the use of smaller and lightweight satellite systems, subsystems, and components. These technologies will augment existing satellite systems and improve support to the operational commanders. Two small Ultra-High Frequency (UHF) store-and-forward communications satellites (MACSATs) weighing 150 lbs. each will be launched this summer and will demonstrate the utility of small satellites for remote sensor read-out. The Pegasus Air-Launched Vehicle (a commercially developed launch vehicle) will be demonstrated and evaluated under DARPA sponsorship this summer and will place several government payloads into 400 nautical miles polar orbit. In the fall, seven small (45 lbs.) UHF transponder satellites will be placed into orbit by the second Pegasus flight vehicle and will undergo operational evaluation by the military Services. In addition, DARPA will contract for the commercial development and government evaluation of a Standard Small Launch Vehicle (SSLV) capable of placing 1000-1500 lb. payloads into polar orbit.

Miniature Global Positioning System Receivers (MGR). The Department of Defense has been developing means for obtaining precise geo-positioning and navigation data using the Global Positioning System (GPS) for almost twenty years. DARPA began a research program in the early 1980's to demonstrate the necessary solid-state technology to miniaturize GPS receivers. The DARPA demonstration unit is a GPS receiver the size of a cigarette package. This program was in concert with a United States Marine Corps (USMC) need for a lightweight, low-cost, handheld receiver to support long-range reconnaissance and

other tactical missions. The effort requires significant advances in the state-of-the-art of Gallium Arsenide (GaAs) monolithic microwave integrated circuit (MMIC) technology as well as specialized GPS digital signal processing realization in bulk complementary metal oxide semiconductors (CMOS). The strong USMC weight, size, and endurance requirements dictated the development of a low-power, high-performance radio and intermediate frequency (RF/IF) integrated circuitry in GaAs MMIC technology.

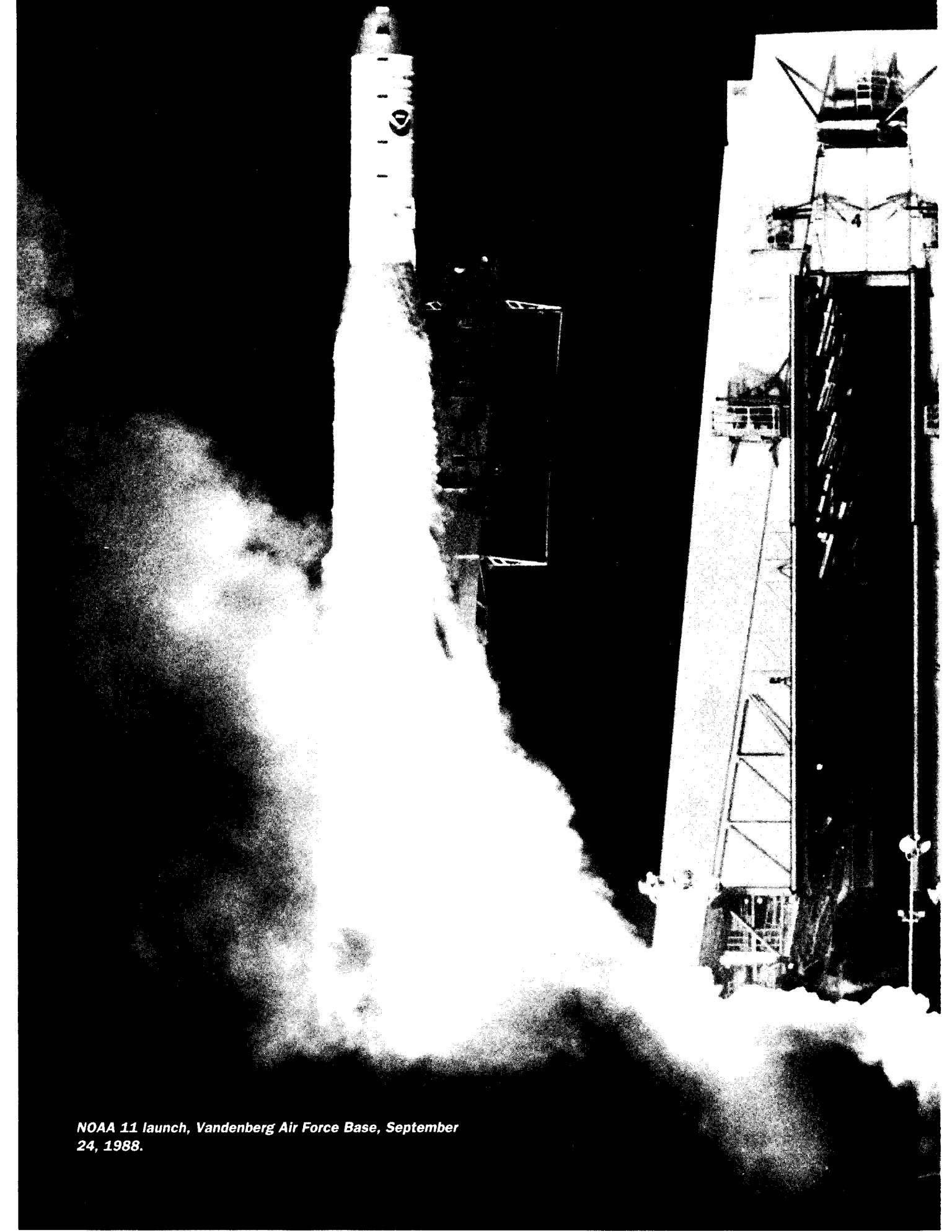
During 1988, Rockwell/Collins (R/C) demonstrated all necessary technology to miniaturize GPS receivers. Specifically, these accomplishments demonstrated the following:

- Successful operation of the first-ever hybrid analog/digital GaAs MMIC chip for received signal amplification, down-conversion and analog-to-digital conversion.
- Successful integration into an operating MGR of the GaAs MMIC chip with a digital P-Code capable tracker/correlator CMOS chip, a bipolar silicon RF synthesizer chip, an advanced architecture, ultra-low-power microprocessor chip, and a multifunction interface chip. These last four silicon chips had been previously developed in the MGR program. In addition, this MGR includes all the necessary software required for full-scale engineering development.

GPS Guidance Package (GGP). The GGP program is directed towards the development of a small, modular, low-cost, lightweight, precision guidance and navigation unit. The components of this navigation unit are: (1) a MGR; (2) a solid-state inertial measurement unit utilizing an advanced fiber optic gyroscope and silicon accelerometers; and, (3) a data integration, guidance and control processor. The GGP technical objectives will support a broad spectrum of tactical reconnaissance missions, and precise, long-range non-nuclear strike applications, including those which will employ highly maneuverable hypersonic vehicles.

Three DARPA contractor teams began preliminary work in FY 88 to produce a design for the basic GGP package, with emphasis on the development and fabrication of an Interferometric FOG (IFOG) brass-board within three years. This six-month study ended late third-quarter and the three contractors final reports arrived late August 1988. Two of the three companies show very good progress in their overall GGP design work and describe IFOG experimental result indicating bias stabilities less than 0.1 degrees/hour, random

noise less than 0.01 degrees/root-hour, and scale factor linearities less than 50ppm. The expected near-term goal of a GGP had been a bias stability of 0.1 degree/hour. These demonstrations, along with other experiments performed by all contractor teams, indicate that the DARPA GGP goal of a 0.01 degree/hour drift rate will be achievable from IFOGs today and that of a 0.001 degree/hour drift rate will be reachable in the future.



*NOAA 11 launch, Vandenberg Air Force Base, September
24, 1988.*

Department of Commerce

Agencies of the Department of Commerce that contributed to the nation's aeronautics and space program during 1988 were the National Oceanic and Atmospheric Administration (NOAA); National Telecommunications and Information Administration (NTIA); and National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards.

The National Oceanic and Atmospheric Administration (NOAA) conducts research, gathers, stores, and analyzes data about the oceans, atmosphere, space, and sun, and applies this knowledge in environmental forecasting and enhancement of knowledge of environmental processes. These functions are performed by NOAA's National Weather Service, National Ocean Service, National Marine Fisheries Service, Environmental Research Laboratories, and National Environmental Satellite, Data, and Information Services (NESDIS). The satellite data so obtained and utilized originates from NOAA's own polar-orbiting (NOAA) and geostationary spacecraft (GOES) operated by NESDIS and from the satellites of other agencies or governments.

The National Telecommunications and Information Administration (NTIA), the principal communications adviser to the President, develops and coordinates Executive Branch policy in telecommunications and information. NTIA also is responsible for managing the radio spectrum assigned for Federal use and provides technical assistance to other federal agencies. An important NTIA role is to help develop U.S. policy in space communications.

The National Institute of Standards and Technology (NIST) establishes and maintains national standards of measurement and provides measurement services and fundamental physical, chemical, engineering, and material data to serve national goals. NIST supports a variety of aeronautical and space programs.

NOAA Satellite Operations

During 1988, NOAA, through its National Environmental Satellite, Data, and Information Service (NESDIS), continued to operate its polar-orbiting and geostationary spacecraft for remote sensing of the earth's environment, collection and relay of data from in-situ observing platforms, search and rescue, and sensing of the space environment. In full operation, the polar-orbiting system consisted of two NOAA (sometimes called Advanced TIROS-N) spacecraft, one each in sun-synchronous morning and afternoon orbits at a nominal height of 850 KM. The geostationary system, called GOES for Geostationary Operational Environmental Satellite, also consisted of two spacecraft, one at 75x W, the other at 135x W.

Instruments carried by the polar-orbiting spacecraft included an Advanced Very High Resolution Radiometer (AVHRR) to obtain visible and infrared imagery; a TIROS Operational Vertical Sounder (TOVS) for profiling atmospheric temperature from the earth's surface to the stratosphere; an Earth Radiation Budget Experiment (ERBE); a Solar Background Ultra-Violet (SBUV) sensor for measuring ozone distribution and concentration; a Space Environment Monitor (SEM) for observing near-earth charged-particle spectra; a Search and Rescue (SAR) package to detect and locate emergency distress signals; and an ARGOS Data Collection System (DCS) to collect, relay, and position-determine observations sensed by moving and other platforms such as buoys and balloons.

The instrument complement of the GOES satellites included a VISSR Atmospheric Sounder (VAS) for visible and infrared imaging and sounding; a Space Environment Monitor (SEM); an experimental Search and Rescue (SAR) package; and a Data Collection System (DCS) to collect and relay observations from fixed stations such as river gages, tide gages, anchored buoys, and the like. The communications systems

aboard GOES were also used to broadcast a weather facsimile (WEFAX) service, consisting of pictures, charts, and other environmental information.

The NOAA-9, NOAA-10, and NOAA-11 satellites provided the polar-orbiting service during the year. When NOAA-11 was launched September 24, 1988, it became the operational afternoon 210 satellite.

GOES-6, at 135x W, and Goes-7 at 75x W, provided the NESDIS geostationary service in 1988, Goes-6 in an increasingly uncertain state, having exceeded its expected life in June. (GOES-6 would actually last until January 1989).

GOES-4, an eight-year-old spacecraft, was deactivated after four years of cooperatively supporting the European Space Agency's Data Collection System operations. Using its remaining propellant, the spacecraft was boosted above its normal geostationary altitude to keep from increasing the satellite debris in this busy corridor.

During 1988, the Ford Aerospace and Communications Corporation continued its design and development of the next generation GOES spacecraft, GOES I-M, and associated ground equipment. Launch of the first in this new series of spacecraft is expected in 1990.

Pursuant to the Land Remote Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) operated both the Landsat 4 and 5 remote sensing satellite systems for NOAA in 1988. During this time, these systems acquired 40,000 scenes for domestic use, while providing 280,000 scenes to foreign ground stations. On April 1, 1988, EOSAT and the Department of Commerce signed a contract to develop the follow-on Landsat 6 space and ground system.

NOAA Application of Satellite Observations

In 1988, as in previous years, the imagery, sounding data, and other observations sensed or collected by NOAA's polar-orbiting and geostationary spacecraft



Artist's concept of GOES I-M, NOAA's next-generation geostationary satellite series.

were applied nationally, mainly by the National Weather Service and Department of Defense, and internationally, via the nations of the World Meteorological Organization (WMO) to environmental forecasting of both a routine and special-warning nature.

The year's highlights in NOAA's use of its own satellites or of others included:

Atmospheric Temperature and Moisture Soundings

The year marked the ninth of operational atmospheric sounding production from NOAA's polar-orbiting satellites. These soundings are used as input to numerical weather forecast models. The retrieval

processing has been upgraded from an original, purely statistical, technique to a physical method which retrieves both the vertical temperatures and moisture profiles simultaneously. During the first half of 1988, a global Baseline Upper Air Network (BUAN) feasibility study was conducted by NESDIS, the National Weather Service and the World Meteorological Organization to study techniques for improving the quality of sounding products.

GOES-VISSR Atmospheric Sounder (VAS) Data

In 1988, special emphasis was placed on defining moisture and its transport from the Gulf of Mexico into the south-central United States where it fuels the severe weather of the spring as well as the convection responsible for the majority of summer rainfall. Vertical moisture distribution (in broad layers) derived from the VAS radiance measurements has been demonstrated to be a significant improvement upon other routinely available moisture data used to initialize weather forecast models. In addition, hourly "images" of moisture and atmospheric stability were provided to the National Severe Storm Forecast Center (Kansas City, Mo.) where they were used in defining outlooks and watch areas for severe weather. After 8 years of development and implementation, the VAS soundings now routinely contribute to the daily operational mission of NOAA.

Operational Global Vegetation Index

An experimental global vegetation index product from AVHRR data was begun at NESDIS in 1982. The product was disseminated to researchers from 1982 through 1987 and became the focus of research interest in the area of climate assessment, agricultural monitoring, and large scale ecological studies. These global vegetation index maps sufficiently demonstrated their usefulness to be made an operational NESDIS product in the spring of 1988. Their primary use will be for climate monitoring and assessment by the Climate Analysis Center of the National Weather Service.

Climate Applications

Experimental products derived from its Advanced Very High Resolution Radiometer (AVHRR) sensors were provided by NESDIS to the U.S. Agency for International Development during the 1988 growing season and covered selected areas of Africa. Products included (1) the estimation of the location of the Intertropical Convergence Zone, (2) estimates of soil moisture, and (3) estimates of the yield of millet and sorghum. These developmental products are the subject of continuing research at the NESDIS Climate Applications Branch with the objective of gaining a fuller understanding of the capabilities and limitations of satellite-derived information for evaluation of drought conditions. Detection and evaluation of drought offers the opportunity to alleviate famine conditions through early warning of food shortages and planned food distribution policies.

Aerosols

During the year, NESDIS laid the basis for producing an experimental product of aerosol optical thickness over oceans beginning in 1989. It is based on radiative transfer model interpretation of the radiance of reflected radiation. Weekly contour maps of aerosol optical thickness will be produced together with digital archive data tapes, also weekly and monthly analyzed fields at a grid resolution of 100 km. These products will be available through one or more of the NESDIS Data Centers. They will be useful for accounting for the effects of aerosols on remote sensing of other parameters; weather and climate; air and water quality; and on military and civil aviation operations.

Yellowstone Smoke Plume Effect

Forest fires in Yellowstone National Park, Wyoming, during the summer of 1988 caused considerable smoke to be transported to surrounding states, so much so that on two days the plume was thick enough over northeast Colorado to reduce the solar radiation sensed at the surface by 20 to 40 percent of that sensed on clear days. Investigation of the impact of this smoke

cover, observed by NOAA satellites, on near-surface air temperatures and on the development of local thermally-induced circulations and convective cloud formation is under way by the Regional and Mesoscale Meteorology Branch of NESDIS.

Ozone

Total, level, and layer ozone observations were obtained from the Solar Backscatter Ultraviolet Radiometer (SBUV/2) on the NOAA-9 (afternoon) polar-orbiting satellite for the NASA Goddard Space Flight Center (GSFC), NOAA Environmental Research Labs (ERL), and National Weather Service (NWS). During 1988, the first two years (1985 and 1986) of NOAA 9 SBUV/2 data using the latest ozone algorithm and calibration techniques were processed. In 1989 the remaining NOAA 9 data will be processed. These ozone data will be used along with other ozone data sources to determine trends in world ozone amounts.

GOES-TAP

GOES-TAP, a program enabling government and non-government users to acquire high quality meteorological satellite data over point-to-point telephone circuits, continued to expand with approximately 12 new primary user connections in 1988. There are presently nearly 350 primary and over 500 secondary users who include the National Weather Service, the military, the Federal Aviation Agency, and other civilian agencies, private companies, universities, and television stations. GOES-TAP data consists of visible and infrared facsimile images from the GOES satellites, and from NOAA (polar-orbiting), GMS (Japanese), and European spacecraft.

Satellite Altimetry

Sea-surface altimetry data from the 1978 NASA SEASAT flight, converted to gravity anomaly data, became available in 1988 from the NESDIS National Geophysical Data Center (NGDC). It consists of a shaded-relief image, contour maps, and gridded numeric data on magnetic tape. The shaded-relief image, published by NGDC for the Navy, shows a

number of seafloor features represented by variations in the height of the sea surface that were previously poorly documented in bathymetric surveys but later verified by additional surveys. Also in 1988, NGDC continued, along with the NESDIS National Oceanographic Data Center (NODC), to provide the public domain version of the Navy's GEOSAT satellite altimetry. To enhance service to the user, NGDC reorganized its inventory of satellite altimetry, gravity, and magnetic anomaly data into one data base.

Solar Geophysical Data

In 1988, NGDC staff presented review papers on solar-terrestrial activity as a cause of satellite anomalies and demonstrated the NGDC "Spacecraft Anomaly Manager" (SAM) software at national and international meetings. The anomaly database has tripled in size, now including more than 3,000 events. Results from the anomaly data base and SAM include (1) changed operating procedures for currently orbiting satellites, (2) tighter specifications for future spacecraft, and (3) the realization that improved environmental observations are needed to fill gaps in current data collection during all levels of solar activity.

Search and Rescue

During 1988, COSPAS/SARSAT, the international satellite search and rescue service provided by Canada, France, the United States and the USSR, was responsible for the rescue of approximately 200 people, bringing the total of lives saved through this cooperative program to well over 1200. Greater international recognition of the program was achieved by the signing of an Inter-governmental Agreement between the four countries in Paris in July.

Satellite Applications Training

NESDIS continued to work with the World Meteorological Organization (WMO) and National Weather Service (NWS) to develop needed courses for foreign meteorologists and oceanographers. Planning was begun to hold a basic satellite imagery interpretation course for countries with WEFAX (weather facsimile)

capability in Africa and the Caribbean during 1989. NWS, NESDIS, and WMO developed a plan to provide copies of the polar-orbiter imagery interpretation program to WMO-member nations. NWS and NESDIS also began preparing a handbook on interpreting tropical clouds and weather systems from satellite imagery. When completed in 1989, the handbook will be shared with WMO and its members.

During 1988, the Satellite Applications Laboratory (SAL) of NESDIS collaborated with the National Weather Service (NWS), the Air Force, and the Navy to ensure coordinated satellite training. Two courses were taught for the Air Force. Workshops were provided to NWS, television weathercasters, and others. By the end of the year, more than 900 persons had received satellite applications training from 32 such NOAA workshops.

The joint NWS and NESDIS training program on satellite imagery interpretation continued. Following the creation of a handbook on imagery interpretation and collection of a series of videotapes depicting various aspects of imagery analysis, NWS and NESDIS prepared a correspondence course tied to these training materials. The course was distributed throughout the NWS, the Air Force, and the Navy during 1988.

The script-slide program on polar orbiter interpretation (completed in 1987) was distributed during 1988. A three-part videotape training program on convection was completed. Work continued on additional exercises on tropical cyclones, downbursts, local wind regimes, ocean cyclogenesis, oceanographic analysis, and satellite applications for assessing numerical model initial analysis. Working with the National Weather Association, NESDIS ensured widespread availability of Forecasting Handbook #6, "Satellite Imagery Interpretation for Forecasters", and of the polar-orbiter interpretation slide program to universities, television weathercasters, and other satellite data users.

Aviation Applications

Research conducted by NESDIS regarding aeronautical weather includes three significant developments, all making use of environmental satellite data. A method has been developed to target areas having a high probability of thunderstorms with accompanying downburst or microburst winds. It uses data from GOES sounders to sense areas of potential instability that should be closely monitored. A Turbulence Index, derived from satellite water vapor and infrared data (plus upper air observations), identifies high-level turbulence areas. Finally, two different GOES satellite infrared channels are being used to identify areas of fog and cloud formation during nighttime hours. Fog and low clouds typically are at or near the temperature of the surrounding land making them difficult to detect at night. The advantage of this new technique is that the additional satellite-borne channel is sensitive to the cloud composition and more accurately identifies their presence.

Rapidly Developing Storms

Weather patterns along with satellite and surface observations associated with storms that intensify or develop rapidly have been under study. Because most of these storms occur along the East Coast of the U.S. where conventional observations are limited, satellites appear to be the key to better forecasting of such hazardous events on coastal and marine communities.

Tornado Research

NESDIS is investigating how better to understand and detect tornado-producing super-cells. Research based on satellite imagery and aircraft flights, coupled with Doppler radar data analysis and ground-based visual observations of tornado-producing thunderstorms, is helping to explain why a severe storm evolves and how it produces tornado activity. Aircraft flights into low-level outflow boundaries produced by

thunderstorm activity show that the flow of air associated with those boundaries is characterized by both strong wind shear and intense upward motion. When such boundaries are acted upon by the updraft of a strong thunderstorm, intense tornado activity is often the result. However many severe thunderstorms that produce tornadoes do not interact with any pre-existing boundary detectable in satellite imagery. Many of those storms, often termed super-cells, develop rotation at mid-levels detectable by Doppler radar; such rotation is often observed before the super-cell enters its tornado phase. Additionally, ground based observations near tornadoes show the development of a strong downdraft along the rear flank of the super-cell occurring prior to tornado development. Satellite observations of supercells, coupled with the aircraft investigations of cloud lines, are helping to provide considerable insight into the likely mechanism responsible for the formation of the rear downdraft, the final crucial phase in tornado storm development. In the ongoing research effort, satellite data are being used to observe the existence of cool low-level outflow air immediately to the rear of the super-cell, and, then, to infer the development of a rear flank downdraft.

Kinematic Global Positioning System (GPS)

The National Geodetic Survey (NGS) of NOAA's National Ocean Service (NOS) has developed and demonstrated GPS techniques whereby moving instrumentation platforms, including ground vehicles, ships and aircraft, have been positioned by satellite to better than 5 cm in horizontal as well as vertical coordinates. Tests conducted in cooperation with the states of Texas and Washington have shown the utility of the technique for more rapid and economical photogrammetry. The same technique has also been jointly demonstrated with the Naval Research Laboratory to support airborne gravimetric measurements. Development continues along with a software package to transfer these techniques to other users.

Global Positioning System Orbit Tracking Network

The computation of precise GPS orbits requires a continuously operating GPS tracking network. NGS has organized a Cooperative International GPS Network (CIGNET) for the purpose of establishing a global GPS tracking network. The participating stations include Westford, Massachusetts, Richmond, Florida, Kokee Park, Hawaii, and Mojave, California, operated by NGS; Yellowknife, Canada, operated by the Geodetic Survey of Canada; Tromsø, Norway, and Onsala, Sweden, operated by the Norwegian Statens Kartverk; Wettzell, Germany, operated by the Institute for Applied Geodesy, Federal Republic of Germany; and Tsukuba, Japan, operated by the Geographical Survey Institute of Japan. The data is delivered to NGS each week where it is archived, reformatted, and distributed upon request. GPS orbits are also computed from this network and distributed by NGS.

GEOSAT

During the past four years, the U.S. Navy altimeter satellite GEOSAT has provided nearly continuous measurements of global sea level, wind speed, and sea state. Under agreement with the U.S. Navy, the NOAA GEOSAT project prepares and distributes raw data and products from this revolutionary mission. About 2 billion measurements have been processed by the project into geophysical data records (GDRs), and the first-ever complete determination of sea level variation during an El Niño has been made. Several hundred scientists in more than 40 institutions and countries receive the GDR's on a regular basis.

The GEOSAT project is a key element of the NOAA Climate and Global Change (C&GC), program, in particular, the NOS Sea Level portion. Satellite altimetry is the only way to obtain global and detailed determinations of sea level variations such as those associated with El Niño. In addition to providing data for oceanographic research, the GEOSAT mission has enabled the first operational monitoring of sea level over entire

ocean basins. NOAA presently publishes sea level maps of both the Pacific and Indian Oceans in near-real time. The project will be enhanced in the future as additional satellites become available. In the next decade it is likely that global sea level will be monitored as routinely as the weather is today.

Fisheries Use of Satellite Data

Satellite ocean remote sensing continues to play an important role in the activities of NOAA's National Marine Fisheries Service (NMFS). Satellite observations provide synoptic information for studying the effects of the ocean environment on the abundance and distribution of fish populations.

The NMFS Auke Bay, Alaska, Laboratory is developing a tracking system to monitor several hundred radio-tagged adult salmon using satellite techniques. The data obtained permits tracing the migration of the salmon and studying environmental characteristics in the salmon spawning areas. The information obtained from these studies is intended for use in managing salmon stocks in transboundary rivers as part of the Pacific Salmon Treaty between the U.S. and Canada.

NOAA fisheries scientists in the Northwest and Alaska regions are collaborating with the NOAA Pacific Marine Environmental Laboratory and academic institutions in a Fisheries Oceanography Coordinated Investigation (FOCI) of the Gulf of Alaska and Bering Sea. Part of the Investigation is to study effects of the ocean environment on larval distribution and survival of walleye pollock, a valuable commercial fish stock. The present research studies use AVHRR data from the NOAA polar-orbiting satellites and from the Coastal Zone Color Scanner (CZCS) on NASA's Nimbus 7.

NMFS scientists from the Southwest Fisheries Center and the University of Oregon continue to evaluate the feasibility of using satellite measurements of ocean temperature and color to determine the best time to release salmon smolts from Columbia River salmon hatcheries. The objective is to time the release of smolts during ocean environmental conditions which

would be favorable for their survival and, thereby, improve their chances for subsequent recruitment into the salmon fisheries. Southwest Fisheries Center scientists also are completing a case study using NASA SEASAT Scatterometer wind stress measurements to define locations of oceanic convergence and divergence which are important in determining the availability of albacore tuna off the coast of North America.

Recent satellite-related research at the NOAA Southeast Fisheries Center is focused on using satellite data to aid in locating adult and juvenile forms of commercially important species in the Gulf of Mexico and Caribbean. Some of these include bluefin tuna, yellowfin tuna, butterfish, king mackerel, menhaden, and shrimp. A pilot study was conducted in the Gulf of Mexico using thermal data acquired from NOAA satellites to assist fishermen in locating commercial concentrations of butterfish.

The Northeast Fisheries Center (NEFC) continues to participate in the activities of the Northeast Area Remote Sensing System (NEARSS), an association of government, academic, and private institutions. NEARSS provides a forum for the exchange of information and a support base for meeting regional satellite and aircraft data and information needs; it facilitates the maintenance of a communication network between users of remote sensing data and data/information sources. NEFC scientists continue to use data from NOAA satellites in combination with other data sets in describing near real-time and long-term variations in marine environmental conditions affecting the fisheries of the Northeastern U.S.

National Telecommunications and Information Administration

World Administrative Radio Conference

World Administrative Radio Conferences (WARCS) are conducted under the aegis of the International Telecommunication Union (ITU). The National Telecommunications and Information Administration (NTIA) participates in the planning for them and

represents the U.S. Government when they are held. In 1988, NTIA led the preparation for and served on the delegation to the WARC "Use of the Geostationary Satellite Orbit and the Planning of Space Services Utilizing It"—also known as the Space WARC—which was of major importance to U.S. space interests. This WARC developed new planning methods and improved and simplified regulatory procedures for gaining access to a limited geostationary orbit by all interested countries. As a key participant in the development of U.S. positions, proposals, and strategy, NTIA worked to protect present and planned U.S. satellite systems with results that were highly acceptable to U.S. interests. In 1989, an assessment will be made of the results of the Space WARC, looking towards future U.S. needs.

PEACESAT

NTIA and NOAA/NESDIS are working on reestablishing the Pan-Pacific Educational and Communications Experiments by Satellite (PEACESAT) program. Begun in 1971, PEACESAT used a retired NASA experimental satellite, ATS-1, to provide two-way voice, data, and slow-scan video services accessed by small, affordable, earth stations in the Pacific Basin region. These services provided otherwise unavailable educational, medical, cultural, and emergency communications to more than 100 sites in 22 countries. NASA decommissioned the ATS-1 in 1985 due to orbital drift. The satellite has since drifted one revolution around the earth and is again being used by the PEACESAT community on an interim basis. NOAA/NESDIS will loan its GOES-3 which was launched in 1978 and ceased meteorological services in 1981, to reestablish communications service. NTIA has been provided funding to reestablish the PEACESAT network and to make recommendations for supporting the program. In 1988, NTIA began a study of satellite replacement options for both the short and long term.

Advanced Communications Technology Satellite

Planning continued for experiments that NTIA will conduct utilizing the Advanced Communications Technology Satellite (ACTS) under development by NASA for a mid-1992 launch. These experiments will center on communication system performance with measurements to evaluate network and switching performance. This planning will continue in 1989 with further refinement of the system performance experiments and the development of a complementary experiment to characterize the channel transfer function for an advanced communications technology satellite.

Millimeter-wave Frequencies

In 1988, NTIA began deploying a measurement system to study propagation effects at millimeter-wave frequencies on a simulated earth-space path. The measurements will concentrate on characterizing the effects of adverse weather so that techniques can be developed to enhance the utilization of millimeter waves in earth-space telecommunications. Special attention is being given to the potential for interference that may have an impact on geosynchronous orbit and ground station allocations. In 1989, measurements will continue and the dynamics of signal fading will be studied.

National Institute of Standards and Technology

During 1988, the National Institute of Standards and Technology (NIST) carried out activities in the following areas of space support and space and atmospheric research. Space support work was performed on the characterization of the platinum-neon sealed hollow cathode lamp used in the space telescope. Procedures were developed and a meter designed and constructed for characterizing and calibrating these lamps. The following particulars were determined for a sample lamp: warmup time, stability, emission as a function of current, repeatability with ignition, spatial characteris-

tics, impurity lines, signal as a function of pitch and yaw.

An improved material ($\text{Al}_2\text{O}_3/\text{PEEK}$) was evaluated for use in thermal isolation straps employed in satellites for long-term containment of cryogenics for sensor cooling.

In certain space applications, pure indium and an indium-lead alloy are used as solders. Owing to failures in the solder joints, NIST has been measuring their properties and conducting metallurgical studies.

In cooperation with NASA and the University Corporation for Atmospheric Research (UCAR), NIST has been studying the feasibility of using orbiting space shuttle external tanks (ETs). These expanded external fuel tanks are being considered for orbiting laboratory space. At a NASA/UCAR workshop, NIST provided information on the structural modifications which would be required for a safe working environment at minimum cost.

Work is under way for the Air Force to identify the actual, inflight, dynamic behavior of large space structures. The work is important because information on the dynamic behavior, as estimated by analytical modelling, may not be accurate enough to allow for the effective performance of control systems.

NIST has searched the scientific and engineering literature for references applicable to spacecraft fire safety. The review covered specific subjects, suggested by the experiments defined for technology development missions in the Space Station. The result is a bibliographic document containing 375 references related to spacecraft fire safety. These references were added to the Center for Fire Research bibliographic database FIREDOC. A final report was published, "Spacecraft Fire Detection and Extinguishment: A Bibliography," NASA CR-180880/NBSIR 88-3712.

A study is ongoing to develop a theoretical model capable of predicting the radiative ignition of a cellulosic material (for example, a paper) and subsequent flame spread over the sample in a microgravity envi-

ronment. The results will be used to improve the fire safety in spacecraft.

NIST is evaluating for NASA existing pure substances, including commercially marketed heat transfer fluids, for potential use in two-phase thermal-control systems in manned spacecraft. Stringent constraints are imposed on candidate fluids. Among these are nontoxicity, nonflammability, chemical stability, and a good thermal performance. Ultimately, the development of a new fluid may be required. In view of the likely high cost, long-term, and complexity of such a development, an extensive and quantitative evaluation is required to establish the need and/or specifications for that development.

Space and Atmospheric Research

The accuracy of a number of geophysical and astronomical studies based on microwave distance measurements is limited mainly by the uncertainty in correcting for water vapor in the atmosphere. NIST scientists are developing a microwave-optical system to improve the accuracy in the correction of microwave distance measurements for this factor.

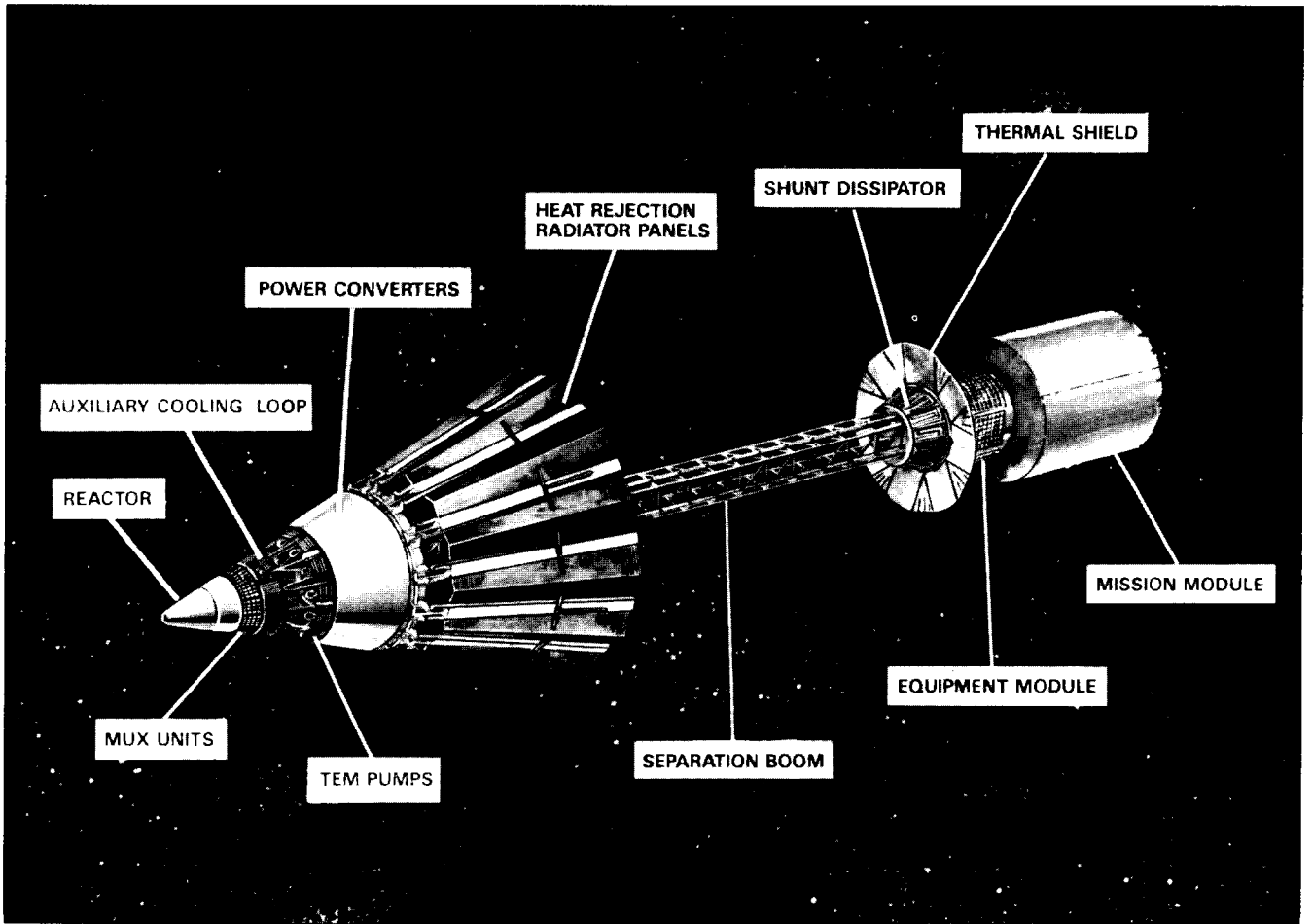
NIST continues its project to determine accurate values for the atmospheric parameters of hot stars. The goal is the generation of new astronomical detectors to obtain very high signal-to-noise line profiles, which will then be analyzed using photospheric models that incorporate all physical processes thought to be of relevance. The intent is to provide sufficiently accurate constraints on the theory of stellar evolution that the effect of the physical uncertainties in that theory can be evaluated and ultimately removed. NIST scientists and a colleague from Oxford University have completed work on a set of detailed models for the outer atmosphere of solar type stars. These models described the amount of emitting material in the chromosphere, transition region and corona.

Personnel from NIST and Goddard Space Flight Center have several projects underway to measure

microwave emission from stars. They have now completed a survey of microwave emission from 39 of the closest stars that are more luminous and cooler than the Sun. This survey at 5 and 15 GHz was made using the National Radio Astronomy Observatory's Very Large Array.

NIST is pursuing a major program to measure surface magnetic fields on stars cooler than the Sun. It has succeeded in making magnetic field measurements

on stars much cooler than was heretofore possible. It has also developed an analysis technique to take into account the saturation of optically thick absorption lines. These measurements confirm the hypothesis that magnetic fields are at the heart of solar-like phenomena by showing that stars with the most energetic phenomena, for example, flares and enormous starspots, also have the strongest measured field strengths and spatial coverage.



Artist's concept of the SP-100 space reactor.

Department of Energy

The U.S. Department of Energy provides nuclear power sources for highly specialized applications of the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD). Such power units have enabled these user agencies to accomplish some of the most spectacular astronomical events undertaken by the United States over the years, such as the Voyager and Pioneer missions to the outer planets, and the Apollo scientific investigations on the lunar surface. These missions have provided us with detailed photographs and data on a variety of planetary bodies including Jupiter and its moons, and the discovery of the first extraterrestrial volcanos on the moon Io.

In the past, the majority of the power sources used on these missions has been relatively low power Radioisotope Thermoelectric Generators (RTGs), capable of producing between 2 and 200 watts of electricity (0.002 to 0.2 kilowatts). RTGs convert the heat from a decaying radioisotope into electricity by the use of thermoelectric materials. However, since some planned missions will require higher power levels, a more efficient dynamic energy conversion process (Turbine Energy Conversion System) is also being developed for isotopic power systems, in the 1 to 10 kilowatt range. Finally, for the higher end of this range (5-10 kilowatts electric [kWe]) and above, nuclear reactors are being developed and tested. Programs of this type include the SP-100 space reactor technology that is applicable over the range of 10s of kWe to 100s of kWe. Also included is the Multimewatt (MMW) Space Nuclear Reactor System, which is in the first phase of studying the feasibility of various concepts, and which can eventually extend the range from 10s to 100s of megawatts (MWe).

Space Nuclear Power Systems

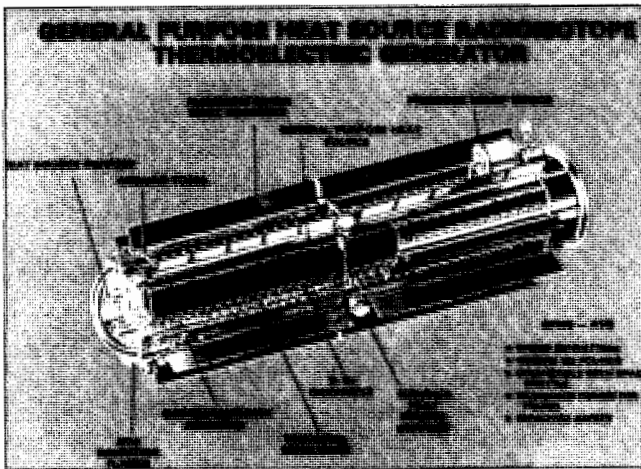
Thus far, radioisotope power units have used thermoelectric energy converters to provide electrical power for spacecraft operations. Over time, the amount of power capable of being provided by these

devices has increased from the 3 watts provided by the SNAP-3 for the Transit program in 1961, to the 64 watts provided for the NASA Apollo lunar program in 1970, to the 150 watts for NASA's Voyager program in 1976 using the Multi-Hundred Watt unit, and to the 285-watt General Purpose Heat Source unit for NASA's Galileo and Ulysses flights planned for launch in 1989 and 1990. In order to extend the practical application of radioisotope power sources and to make possible the next increases in power level, significant progress on dynamic converters is being made to supply electric power in the 1-to-10 kilowatt range.

In addition to the use of radioisotope power sources, nuclear reactors can make available a higher power source capability for space operations purposes. One 500-watt reactor power unit, the SNAP-10A, was flown in 1965 and development was started on other units of up to about 300 kilowatts. However, because the earlier planned space missions needed only the power levels available from radioisotopes or from solar power units, the space reactor program was discontinued in the early 1970s. Recently, because of increasing power needs of both NASA and DOD, well beyond those obtainable from radioisotopes or solar power, space reactor development has been re-activated through the cooperation of NASA, DOD, and DOE. Discussion of the progress made in the space reactor program during the past year will follow the sections on radioisotope space power. The principal space reactor program currently in development is the SP-100, of which a current design is illustrated.

Radioisotope Thermoelectric Generators

The United States has successfully used 34 radioisotope thermoelectric generators (RTGs) on 19 spacecraft launches covering a variety of different space applications. An RTG is a static device (i.e., has no moving parts), which directly converts the heat from the decay of the radioisotope Plutonium-238 to electricity. Pu-238, a non-weapons material, was selected due to its relatively long half-life (about 87.6 years) and ease of



General Purpose Heat Source Radioisotope Thermoelectric Generator.

containing the alpha particles (helium atoms) emitted during normal decay, plus the fact that no special shielding is required for these heat sources.

Research and development has increased the conversion efficiencies of radioisotope power systems from less than 5 percent to almost 7 percent, which increases the power output or reduces the weight of the power supply, both of which are critical design factors. RTGs have demonstrated the long lifetimes, self-sufficiency, environmental independence and operational flexibility demanded by a variety of space missions, including the capability to operate well beyond specified mission lifetimes and above design power levels. For example, the Pioneer 10 and 11 spacecraft that were launched in March 1972 and April 1973 used RTGs to successfully power the spacecraft for their encounters with Jupiter and Saturn. Both spacecraft are still operating, about 16 years after launch, and are sending technical data back to Earth. They will be the first man-made objects to leave our solar system. In a similar demonstration, the multi-hundred watt RTG on the Voyager 2 spacecraft,

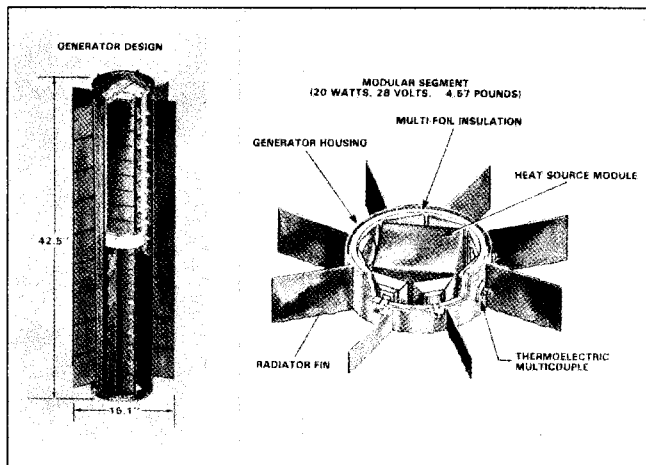


Artist's concept of Galileo spacecraft to Jupiter which will use General Purpose Heat Source Radioisotope Thermoelectric Generators.

launched in August 1977, continues to operate after its encounters with Jupiter, Saturn, and Uranus and is scheduled to fly by Neptune in 1989, and continue on into space.

A new model RTG with a more efficient fuel design, called the General Purpose Heat Source (GPHS), is the latest in a series of nuclear power sources developed for space applications by the Department of Energy. The first two General Purpose Heat Source RTGs will be used to provide the electrical power for the Galileo spacecraft to Jupiter to be launched from the Kennedy Space Center, Florida, on the Space Shuttle in October 1989. In addition, one GPHS generator will power the joint NASA/European Space Agency Ulysses spacecraft to study the polar regions of the sun, also to be launched on the Space Shuttle, which is scheduled for launch in October 1990.

Each of the GPHS RTGs will produce at least 250 watts of electric power continuously for a period of five years or longer. These generators are also fueled with Plutonium-238. The electrical output of each GPHS generator is about double that of previous RTGs



Modular RTG design parameters.

such as those used on the Voyager spacecraft. The higher electric conversion efficiency of today's RTGs provides the highest specific power in the lowest specific volume now available.

Significant program activities on this power system in 1988 included tests on design performance characteristics of RTG components, and revision (and issuance in December 1988) of the Final Safety Analysis Report (FSAR), which contains risk analyses of postulated accidents for the Galileo mission. In addition to various tests conducted regarding potential accidents from launch to aborted orbit, safety tests and analyses, especially potential impacts from solid rocket motor fragments and changes in the NASA mission profiles and launch vehicles, were conducted. Independent review and analysis of the FSAR and related safety tests and analyses were initiated in 1988 by the Interagency Nuclear Safety Review Panel, made up of representatives from DOE, DOD, and NASA. In the spring of 1989, upon completion of their independent review activities, the panel will issue a safety evaluation report, which will be used by the Office of the Presi-

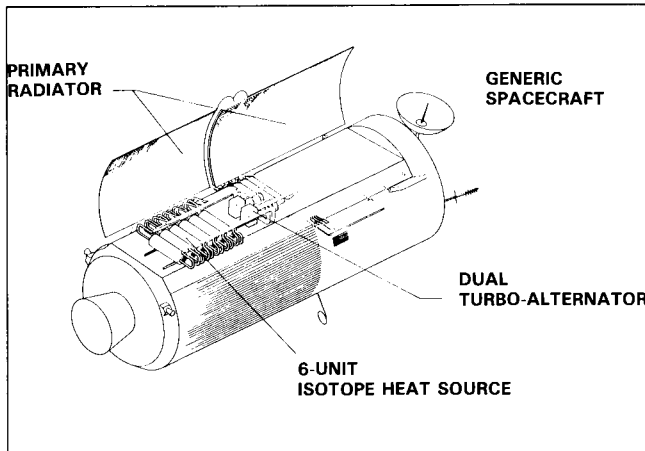
dent in making the decision on whether to launch the nuclear powered spacecraft.

Supporting this decision will be life testing of the GPHS qualification RTG unit, which continued successfully for a period of over 35,000 hours. Life testing has provided valuable data in support of the long-term performance and reliability predictions of the flight RTGs, and the power output matches the engineering predictions very well.

In 1988, additional development of advanced technology RTGs for future space missions continued. The modular radioisotope thermoelectric generator program (MOD-RTG) focused on the design, development, manufacture, and test of an electrically heated engineering test unit. Over 6,000 hours of system test data have been collected. The figure depicts the general concept of modular "building blocks" for an RTG system. The MOD-RTG design will provide a significant advance in RTG specific power (watts/kilograms) and improved efficiency for use in NASA's Mariner Mark II and DOD missions during the next decade.

Dynamic Conversion/Turbine Energy Conversion System

Dynamic energy conversion systems, which employ a rotating turbine/alternator system, offer efficiencies approaching 18-25 percent. For higher power requirements (e.g., 1-10 kW), this improved efficiency could translate into higher specific power and lower per unit power costs, because a smaller amount of radioisotope fuel per unit of power output would be needed. Despite a small weight penalty over thermoelectric converters at the lowest power ranges, dynamic converters are at least three times as efficient as the best thermoelectric systems, minimizing the requirement for isotope fuel. Thus, the survivability, reliability, and compactness of the nuclear power system is retained in the 1 to 10 kW range, below the power level generally considered for reactor applications. Shown in the illustration is a typical integration of the



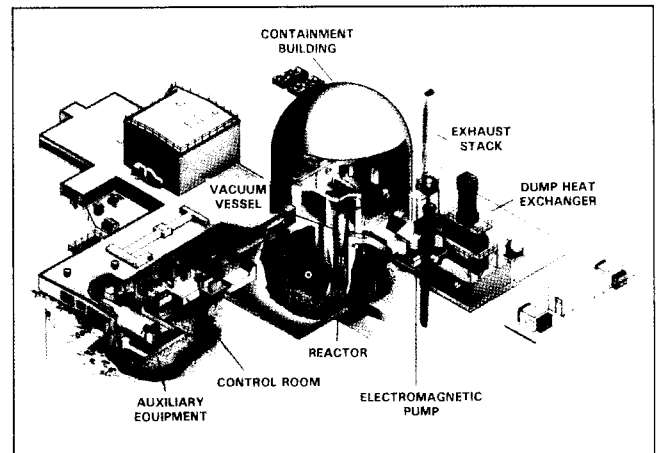
Dynamic isotope power system: turbine energy conversion system (TECS) integrated with a generic spacecraft.

dynamic conversion system on a generic spacecraft. This compact power source is highly survivable, does not interfere with spacecraft maneuvering and better maintains its power conversion capability over time as compared to solar systems in high radiation environments.

DOE has initiated a technology development program for a Turbine Energy Conversion System. During 1988 the Brayton energy conversion system was selected for this application, requirements specifications were written, several critical design studies were completed, and the system design was widely reviewed. Rockwell-Rocketdyne of Canoga Park, California was awarded a contract for development of the dynamic conversion system. Allied Signal Corporation (Tempe, Arizona) received a subcontract from Rockwell to fabricate the TECS portion of the conversion system.

SP-100 Space Reactor Program

The purpose of the SP-100 program is to develop and demonstrate technology for space power in the 10s to 100s of kWe power range for use by NASA and

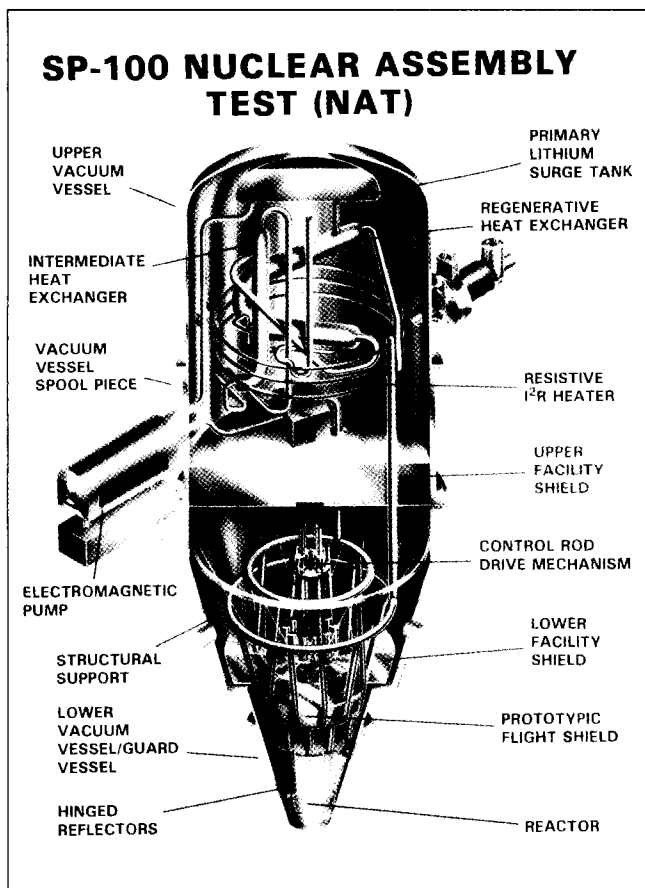


SP-100 Ground Engineering System Test Site.

DOD. This program was initiated in 1983 and is sponsored by NASA, DOD, and DOE. In 1985, the three agencies selected a technology for the reactor and power conversion system, resulting in the prime contractor, General Electric Company, initiating engineering and design work in 1986.

The program has entered into the design and fabrication stage with significant progress being made in all areas, including component testing. The SP-100 reactor and power system design has progressed and safety studies and analyses have been conducted. Significant progress has also been made in the areas of hardware design, development, and fabrication over the past year.

The definitive design of a 2.5 megawatts (thermal) reactor and modifications to an existing containment facility in which the reactor will be tested are nearing completion. The figure shows the layout of the Nuclear Assembly Test (NAT) site at Hanford near Richland, Washington. Details of the SP-100 NAT arrangement are also shown in the next illustration.



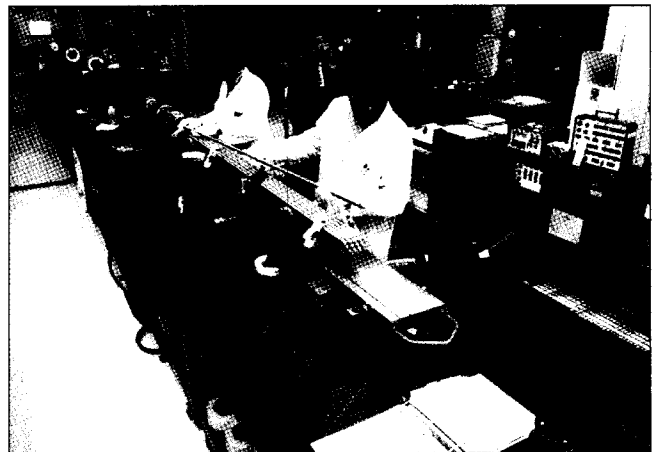
SP-100 Nuclear Assembly Test (NAT).

About half of the fuel for the test has been fabricated at the Los Alamos National Laboratory. The following figure shows work being performed in a portion of the fuel element production facilities at the laboratory. The next figure shows the preparation for testing of SP-100 fuel pins in the Fast Flux Test Facility (FFTF) at Hanford, Washington.

In the lifetime testing program, fuel and structural materials for the reactor have been exposed to simulated space reactor operating environments. By the end of 1988, the SP-100 fuel had achieved about 85 percent

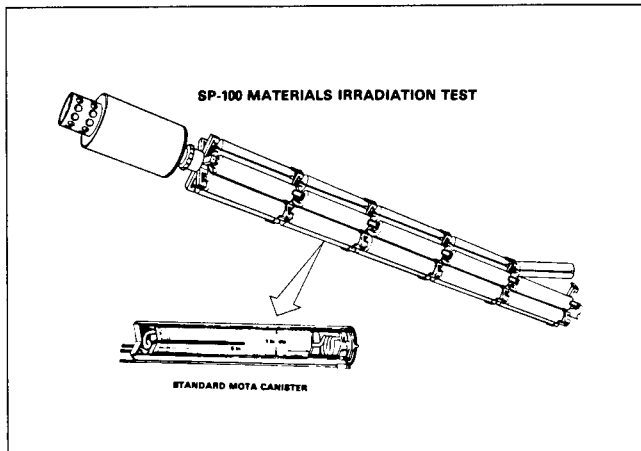


Fuel element production facilities at the Los Alamos National Laboratory.



Preparation for testing SP-100 fuel pins in the Fast Flux Test Facility at Hanford, Washington.

of its lifetime burnup in the FFTF, and up to 100 percent in some fuel pins in the EBR-II reactor in Idaho. The configuration of the materials irradiation test capsules is illustrated. These capsules permit testing of many test specimens in each capsule. Importantly, in-core monitoring equipment for FFTF



Configuration of the SP-100 materials irradiation test capsules.

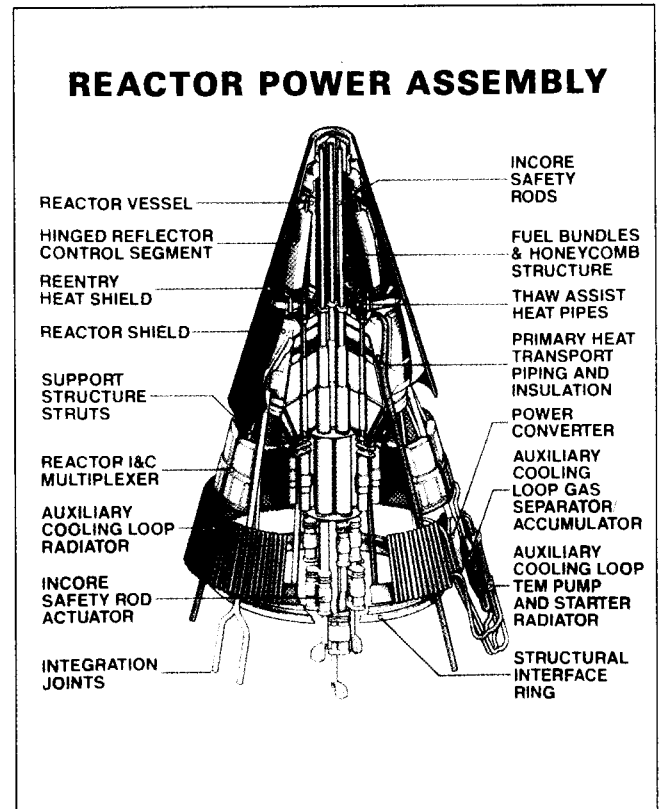
has indicated good results for the high temperature/thermal tests of special materials to be utilized in the SP-100 technology.

Development of the thermoelectric converters that transform the reactor's heat to electricity is also progressing. Recent work has concentrated on verifying the performance of basic elements of the converter.

The next figure shows details of the SP-100 reactor power assembly. Components which are now under test or being fabricated include the control actuators, the thermoelectric electromagnetic pump, the shield, and reactor honeycomb and baffle components.

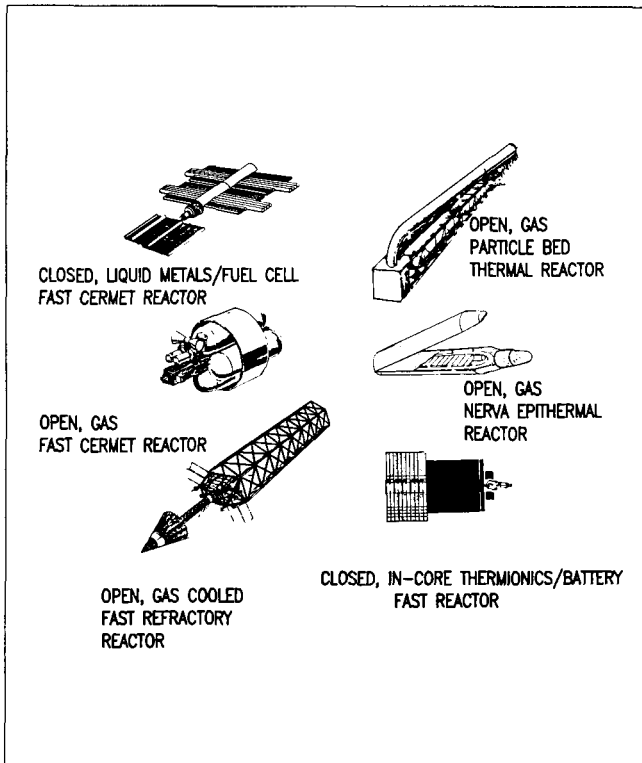
Multimegawatt Space Reactor Program

The Multimegawatt (MMW) program is a joint DOD-DOE effort established in 1985. The primary purpose of the MMW program is to identify nuclear power technology which could fulfill the very high power needs of future advanced Strategic Defense Initiative (SDI) applications. NASA is also interested in the program and, while not presently a sponsor, is participating in the various studies and planning for the MMW program, especially at the lower MMW power levels.



Reactor power assembly.

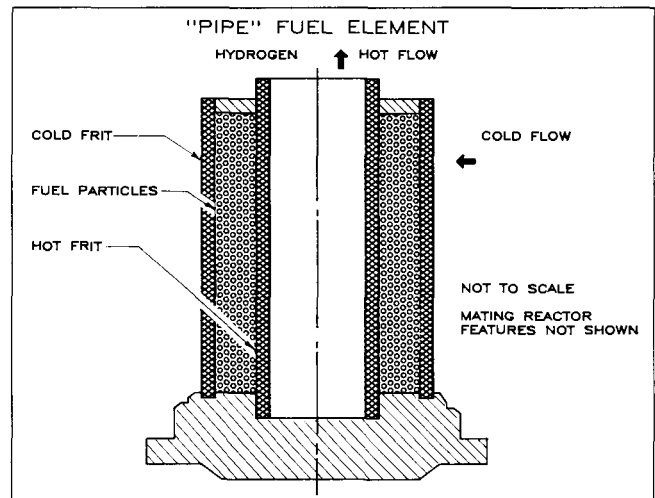
The power range being evaluated varies from tens of megawatts to hundreds of megawatts. In 1988 an evaluation of three general types of MMW space power systems was established. These types are tens of megawatts for short periods (minutes), tens of megawatts for up to 1 year, and hundreds of megawatts for short periods. Concepts in which a low power, MMW nuclear system is coupled with electrical energy storage to meet total energy requirements are included in the program. NASA is expected to be primarily interested in these systems for future applications such as large electric propulsion systems to cut interplanetary transport times and launch weights, or for providing power at manned bases on solar system



Multimegawatt concept application configurations.

bodies. The ability of MMW nuclear systems to provide long life power is also an important NASA MMW requirement.

The year 1988 saw considerable progress in concept definition, refinements, and assessments. Six industrial teams are at work in a competition to provide for the selection of the best systems for further development. Phase I of the concept evaluation is essentially complete and phase II proposals are expected early in 1989. Most of the available energy conversion technologies are addressed in these studies. These include Brayton, Rankine, and thermionics as well as battery and fuel cell energy storage. The external configuration of several of these concepts is shown in the figure.

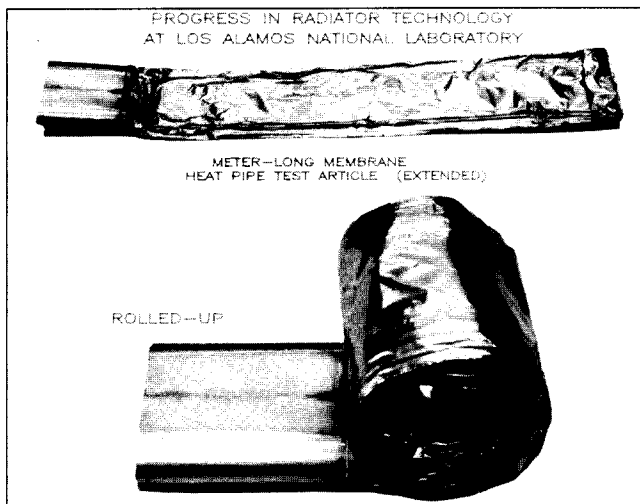


"Pipe" fuel element.

The major technology accomplishments during 1988 have been in the areas of advanced, lightweight heat pipe radiators, refractory reactor materials, and in fabrication and testing of particle-bed reactor materials and components, including in-core tests of MMW-type particle-bed fuel element assemblies. The next figure shows the internal design of the particle-bed test fuel elements, and the following one shows the advanced, lightweight heat pipe being developed at the Los Alamos National Laboratory.

Thermionic Fuel Element Verification Program

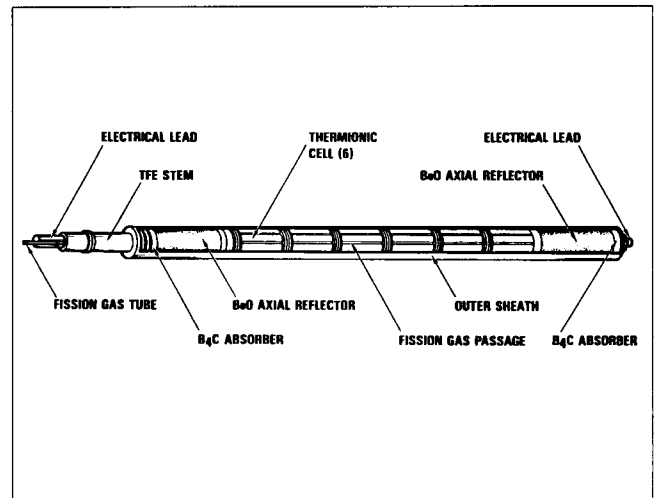
Thermionics, like thermoelectrics, is a means of converting heat directly to electricity without the need



Progress in radiator technology at Los Alamos National Laboratory.

of moving parts. It has the potential advantages of modularity, smaller heat rejection radiators, and lower vulnerability to various threats. The next figure shows a thermionic fuel element (TFE) assembly. The TFE program arose from the need to verify that the unit thermionic cells could be successfully integrated into complete nuclear fuel assemblies and be operated reliably for several years to satisfy user requirements for space missions. Thermionic technology promises to provide relatively higher efficiency than the thermoelectric energy converters being used in the SP-100 reactor.

The past year has seen progress in re-establishing the capability to make and test this type of converter in order to resolve the key issues regarding the technical viability of this concept. During 1988, tests on various TFE components were conducted in a nuclear reactor to verify their performance. The primary goal is to demonstrate a 7-year lifetime (equivalent) for TFE components.



Thermionic fuel element.

Nuclear Detonation Detection

Another important DOE responsibility in the space arena is providing the specialized sensors needed to satisfy national requirements for detection, identification, location, and characterization of nuclear detonations (NUDETs) in space as well as in Earth's atmosphere. The concept of satellite-borne nuclear explosion surveillance came about during interagency discussions from 1959 to 1962 and led to the Vela Hotel (later called the Vela Satellite) Program. Six pairs of Vela satellites were launched from 1963 to 1970. The last Vela operated reliably until it was intentionally turned off in September 1984.

From the beginning, this program has been a joint effort of the DOD and the DOE. Development, design, and production of the nuclear explosion detection instrumentation were responsibilities of the DOE, while the rest of the satellite hardware, launch, telemetry, and day-to-day operations were responsibilities of the DOD, which also had the overall coordination and

scheduling role. Both the DOD and the DOE have shared in special operations and tests and in data interpretation and use.

The program today has three primary objectives:

- Verification of compliance with the Limited Test Ban Treaty (1963) and the Nuclear Non-Proliferation Treaty (1968) wherein nuclear testing was banned in the atmosphere, under water, and in space and the non-weapons states pledged not to manufacture or otherwise acquire nuclear weapons or explosive devices.
- Provision of intelligence information on nuclear tests that occur outside the jurisdiction of the treaties or clandestinely in violation thereof.
- Detection and location of multiple atmospheric and near-Earth nuclear bursts for strategic battle management in time of war.

The information required for each of these objec-

tives is similar and, thus, the DOE has developed detector suites to simultaneously address all three.

The DOE laboratories maintain continuous technology development efforts for improving the underlying technologies. The goals of these efforts include better energy resolution, faster response times, wider spectra coverage, greater survivability, and the development of advanced sensor concepts. In 1988, emphasis was placed on improved radiation hardening and miniaturization of the spaceborne electronic systems, and on data compression logic to minimize communication channel demands. Considerable research is also being devoted to the study of satellite operating environments in order to enhance event discrimination and prevent false alarms. Many such developmental experiments are flown aboard NASA satellites, and many are conducted in cooperation with the space programs of other countries.



This simulated perspective view of El Capitan, a prominent feature in Yosemite National Park, California, was produced from a digitized high-resolution natural color aerial photograph merged with digital elevation data of the same area.

Department of the Interior

As the Nation's principal conservation agency, the Department of the Interior (DOI) is responsible for most of the nationally owned public lands and natural resources. This responsibility entails fostering the wisest use of land and water resources, protecting fish and wildlife, preserving the environmental and cultural values of national parks and historical places, and ensuring the enjoyment of life through outdoor recreation. The Department monitors energy and mineral resources to ensure that their development is in the Nation's best interest. Also, the Department has a major responsibility for residents of American Indian reservations and Island Territories under the administration of the United States.

The Department uses data acquired by satellite and aircraft sensors to inventory natural resources and monitor changes on lands under its management, and the Department supports an active program of research and technique development in remote sensing, digital cartography, and geographic information systems. During 1988, bureaus and agencies of the Department of the Interior participating in remote sensing and digital data applications included the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Bureau of Mines (BOM), Bureau of Reclamation (BOR), Minerals Management Service (MMS), National Park Service (NPS), Office of Surface Mining Reclamation and Enforcement (OSMRE), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS).

Remotely Sensed Data Acquisition and Processing

Satellite Data

Landsat. The USGS continued to use the EROS Data Center in Sioux Falls, South Dakota, as the principal facility for archiving, processing, and distributing Landsat data under agreement with and funding from the National Oceanic and Atmospheric Administration (NOAA), in support of the Earth Observation Satellite (EOSAT) Company, the commercial Landsat operator. During 1988, approximately 44,000 Landsat

Multispectral Scanner (MSS) and Thematic Mapper (TM) scenes were received, processed, and archived. Currently, over 878,000 scenes of Landsat data are archived and geographically referenced, and information is also maintained on more than 1,650,000 scenes that were received and archived at foreign Landsat stations. In 1988, over 17,000 film and digital products with a sales value of over \$7.6 million were produced and distributed to users around the world.

Advanced Very High Resolution Radiometer.

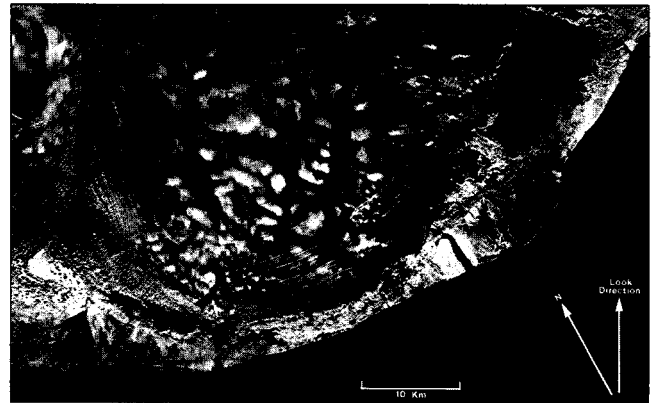
The Advanced Very High Resolution Radiometer (AVHRR) Data Acquisition and Processing System at the USGS Earth Resources Observation Systems (EROS) Data Center receives, processes, and archives AVHRR data from the NOAA-9, NOAA-10, and NOAA-11 satellites for land science applications in DOI and other Federal agency research projects. Federal Government agencies acquire and use AVHRR data for a wide variety of research activities, including the National Aeronautics and Space Administration (NASA) International Satellite Land Surface Climatology Project; Corps of Engineers Great Lakes Ice Mapping; National Weather Service (NWS) Snow Mapping; and a Northern Great Plains Fire Danger Rating and Vegetation Monitoring Cooperative Project conducted with the NWS, Nebraska Forest Service, and the Rocky Mountain Fire Council.

Civil Satellite Data Purchasing. The USGS has established purchasing agreements to assist Federal agencies in obtaining civil satellite data products and services from the EOSAT Company and the Satellite Pour l'Observation de la Terre (SPOT) Image Corporation, the commercial operators of Landsat and SPOT satellite systems. These purchasing agreements have eliminated the requirement for each Federal agency or office to establish, administer, and maintain separate agreements, and are estimated to have saved the U.S. Government over \$600,000 to date. Twenty-five Federal agencies have purchased data worth over \$12 million through these agreements since 1985, with nearly \$4 million expended by 20 agencies in 1988.

Aerial Photographs

The growing interest in high-resolution, color-infrared aerial photographs for a wide variety of applications such as agriculture, forestry, soils, land and resource management, mapping, and earth science studies has led to a reassessment of Federal and State agency needs for this type of photography. As a result, a new program, the National Aerial Photography Program (NAPP), was begun in 1987 to provide higher resolution and larger scale photographs of uniform quality for the 48 conterminous United States. The NAPP replaced the previous National High Altitude Photography (NHAP) Program, after NHAP coverage of the conterminous 48 States was completed in 1988. NAPP photographs are being acquired according to a planned strategy for acquiring coverage of a State or sector of a State approximately every 5 years. Some revisions to the plan are anticipated depending on availability of funds and the priority expressed by State and Federal contributors to the program. The new program promises to meet the aerial photography needs of State and Federal organizations engaged in key projects of national interest.

NAPP photographs are being acquired from a flying height of 20,000 feet with a single 6-inch focal-length camera exposing color-infrared film at a scale of 1:40,000. The resulting photographs are centered on quarter sections of standard USGS 7.5-minute quadrangle maps. The ground resolution of NAPP photographs is approximately 1.5 meters. The first NAPP photographs became available in the fall of 1987, and NAPP photographs were being acquired during 1988 in all or parts of Ohio, Kentucky, Georgia, Virginia, Illinois, Nebraska, Colorado, Oregon, and California. NAPP is guided by a multiagency steering committee composed of representatives from the DOI, Department of Agriculture, and Tennessee Valley Authority. The program is administered by the USGS on behalf of the State and Federal cooperators.



A side-looking airborne radar (SLAR) image of Malaspina Glacier, Alaska. The surface of the glacier appears as mottled light (higher relief areas) and dark (lower relief areas) tones. The surface relief is thought to subtly mimic the subglacial morphology at depths as great as 600 meters.

The USGS National Cartographic Information Center (NCIC) has completed a Compact Disc-Read Only Memory (CD-ROM) project to provide more rapid, flexible access to the Aerial Photography Summary Record System (APSRS). APSRS currently contains over 2.3 million computer records describing over 12 million aerial photographs (including type of photograph, geographic location, flight date, and agency source). Access to the existing system is currently limited to computer inquiries made only from USGS NCIC offices to the mainframe-based information system, or by the use of microfiche. By converting the APSRS data files to the CD-ROM medium, access to the system will be open to anyone with a suitable personal computer, a CD reader, and appropriate software. The potential benefits from the use of CD-ROM technology include improved productivity through rapid, flexible access to the data, avoidance of costs associated with communications to and use of the mainframe computer, and elimination of the manual task of generat-

ing, duplicating, and maintaining large files of microfiche.

Side-Looking Airborne Radar Data

Since the USGS Side-Looking Airborne Radar (SLAR) program began in 1980, coverage of more than 34 percent of the United States has been acquired and made available to the public. The USGS selects approximately twenty 1-degree by 2-degree areas for SLAR coverage each year on the basis of a technical review of proposals submitted by State geological surveys, Federal agencies, the academic community, and the private sector.

The USGS has supported more than 100 research studies on the use of SLAR data for geologic, hydrologic, engineering, and cartographic applications. SLAR data are currently being used for locating fracture zones in Connecticut, siting high-yield water wells in Georgia, identifying large (up to 50 square kilometers) rockslides in the Appalachian Mountains of Virginia for earth-hazards studies, and analyzing the surface features of Malaspina Glacier in Alaska for application to global change research.

Remote Sensing Applications

Renewable Resources

Resource Inventory and Assessment. The BIA is conducting natural resource applications projects that make extensive operational use of satellite data through both visual interpretation and digital analysis. Projects conducted during 1988 include (1) mapping of elk habitat on the Fort Apache (Arizona) Reservation; (2) detection and mapping of noxious weeds at the Sisseton (South Dakota) Reservation; (3) post-wildfire assessment on the Northern Cheyenne (Montana) Reservation; (4) drought assessment on the Wind River (Wyoming) Reservation; (5) land cover/land use mapping on the Warm Springs (Oregon) Reservation; and (6) production of satellite image maps for the Pine Ridge (South Dakota), Nambe (New Mexico), and Tulalip (Washington) Reservations. The data generated

by these projects are permanently archived as part of the digital data base that supports BIA resource management programs.

The BOR used aerial photographs and satellite data during 1988 for inventory and environmental assessment and major water development projects. Work was completed on the Green River in Utah and Colorado to map backwater habitat using large-scale, color-infrared aerial photographs as part of a multi-agency effort to protect the endangered Colorado River squawfish. Low-flow conditions on the Green River during the summer drought of 1988 provided an opportunity to map 480 kilometers of backwater habitat. Airborne video imagery acquired in conjunction with the large-scale aerial photographs is being evaluated for its usefulness in mapping backwater habitat. Aerial photographs are being used to map the San Juan River corridor in New Mexico to provide baseline resource information and maps of river habitats for use by the New Mexico Game and Fish Department to plan the sampling of critical fish habitat. The Fontenelle Dam Tailwaters Study (Utah) was also completed during 1988. Aerial photographs taken before and after flood releases from the dam were used to develop a data base to quantify environmental impacts and determine the net change in fishery habitat and riparian vegetation.

The BOR used aerial photographs to map the effects of irrigation canal construction on native vegetation and to record the presence of desert riparian vegetation associated with seepage from unlined canals. Projects completed in 1988 included short reaches of the All-American Canal in California and the Granite Reef Aqueduct in Arizona. Changes in vegetation communities above and below a 48-kilometer unlined segment of the Coachella Canal in California were mapped using historic and current aerial photographs.

The BOR used SPOT and Landsat MSS data to map irrigated agricultural lands in the Upper Gunnison Basin of Colorado. Field boundaries, delineated from

high-altitude aerial photographs, were transferred to satellite images acquired at the peak of the growing season. Vegetation greenness transformations were applied to the satellite images to develop a data base of irrigated lands.

Land Cover Mapping in Alaska. Over the past 8 years, the USGS has worked cooperatively with Federal and State resource management agencies to produce land cover and terrain maps throughout Alaska. Approximately 1 million square kilometers of land, or over 60 percent of the State of Alaska, have been mapped using Landsat and digital terrain data. In 1988, USGS and BLM personnel analyzed digital Landsat MSS and TM data to produce land cover data bases for planning and wildlife habitat assessment in the Steese-White Mountains and Kuskokwim Management Areas. The USGS and USFWS cooperated to use data from a variety of satellite sensors for resource assessment in Alaska. AVHRR data of the north coast of Alaska were analyzed to examine environmental conditions relevant to caribou and polar bear habitat. Landsat TM data of the Arctic National Wildlife Refuge were analyzed to produce a vegetation map. SPOT data of the Central Arctic Coastal Plain were analyzed to produce land cover information for waterfowl habitat assessment.

The USGS Interim Land Cover Mapping Program has been started to convert the Alaska land cover information into a standard statewide classification system for presenting and reporting land cover information to State and Federal agencies and to Congress for land use planning and management activities. Digital data bases consisting of land cover and terrain variables have been prepared for six 1:250,000-scale quadrangles, and paper maps were printed as part of the research phase of the program. Based on the positive response of the Alaska user community to these products, approval has been given to produce digital data bases (and maps if users will support preparation) for six more quadrangles in 1989.

Wildfire Mapping. The USGS and NPS cooperated to use Landsat TM data to measure the extent of the

wildfires that burned in and near Yellowstone National Park during the summer of 1988. Several enhanced and geometrically registered images were made from satellite data acquired before, during, and after the fires. A July 1988 image shows small areas that were burned in 1987 or early in 1988. The September 1988 image shows the presence of considerable smoke and several actively burning fire fronts. The October 1988 image, acquired after most fires were extinguished, was analyzed to distinguish between burned and unburned areas. Data acquired after the 1988 fire season will be analyzed to monitor vegetation re-growth.

Hydrology

The USGS, BOR, and NWS are cooperating through the National Remote Sensing Hydrology Program to investigate the utility of AVHRR data for near realtime mapping of snow-cover areas in the San Juan Mountains of Colorado. Digital image processing techniques have been developed to analyze spring 1987 and 1988 AVHRR data with the associated digital elevation model. The snow mapping process involves four steps: image preprocessing, cloud/snow discrimination, snow classification, and area calculation. The final product is a snowpack classification image that defines the areal extent of (1) open, continuous snow cover; (2) discontinuous snow cover or snow cover in conifer forests; and (3) snow under cloud cover. This image can be registered to a map of surface water drainage basins to calculate basin snow-cover percentages. Results of this cooperative project are being used by the NWS to develop an operational snow-cover area monitoring program. Knowledge of the areal extent of snow cover, especially during the spring snow-melt season, aids in reservoir operation decisionmaking.

The BOR continued to use the National Wildlife Refuge Monitoring Program to provide a base of information on natural peak-water-flow conditions before the Garrison Diversion Project directs irrigation return flows into the James River Basin. Remotely sensed data

and geographic information systems have been used to map emergent and submergent vegetation. Sonar was used for the first time in 1988 in conjunction with aerial photographs to delineate submergent vegetation. The BOR continued to develop models to map reservoir surface-water temperature, turbidity, and chlorophyll-a concentrations using Landsat TM and MSS data. Work in 1988 continued at Lake Mead, between Arizona and Nevada, to refine the ability of the model to determine spatial and temporal variations in the water parameters. BOR scientists developed methods using Landsat MSS and SPOT data of the Upper Gunnison Basin of Colorado to determine reservoir surface areas for evaporation estimation studies.

Oceanography

The MMS uses satellite data, including satellite telemetry, extensively in its Offshore Environmental Studies Program. The MSS Alaska Outer Continental Shelf Region and NOAA have a long-term, ongoing environmental satellite data program. Landsat TM and MSS data and AVHRR data are used to study the forms, seasonal distribution, and movement of sea ice. In a joint effort with the U.S. Navy and NOAA, the Alaska Region also is using satellite telemetry techniques to study the movement of sea ice in the Beaufort and Chukchi Seas. Signal-emitting buoys are placed in the ice and tracked through the international ARGOS satellite telemetry system.

The remaining three MMS Outer Continental Shelf Regions use satellite data, primarily in the form of AVHRR-derived sea-surface temperature images, to delineate major circulation and mass transport features such as thermal fronts, currents, upwellings, and eddies. This information is important to an understanding of the physical oceanography of the regions and is used to develop and improve computer simulation circulation models. The MMS Atlantic Region uses sea-surface temperature data to study the spatial and temporal variability and frontal dynamics of the Gulf Stream, including associated features such as mean-

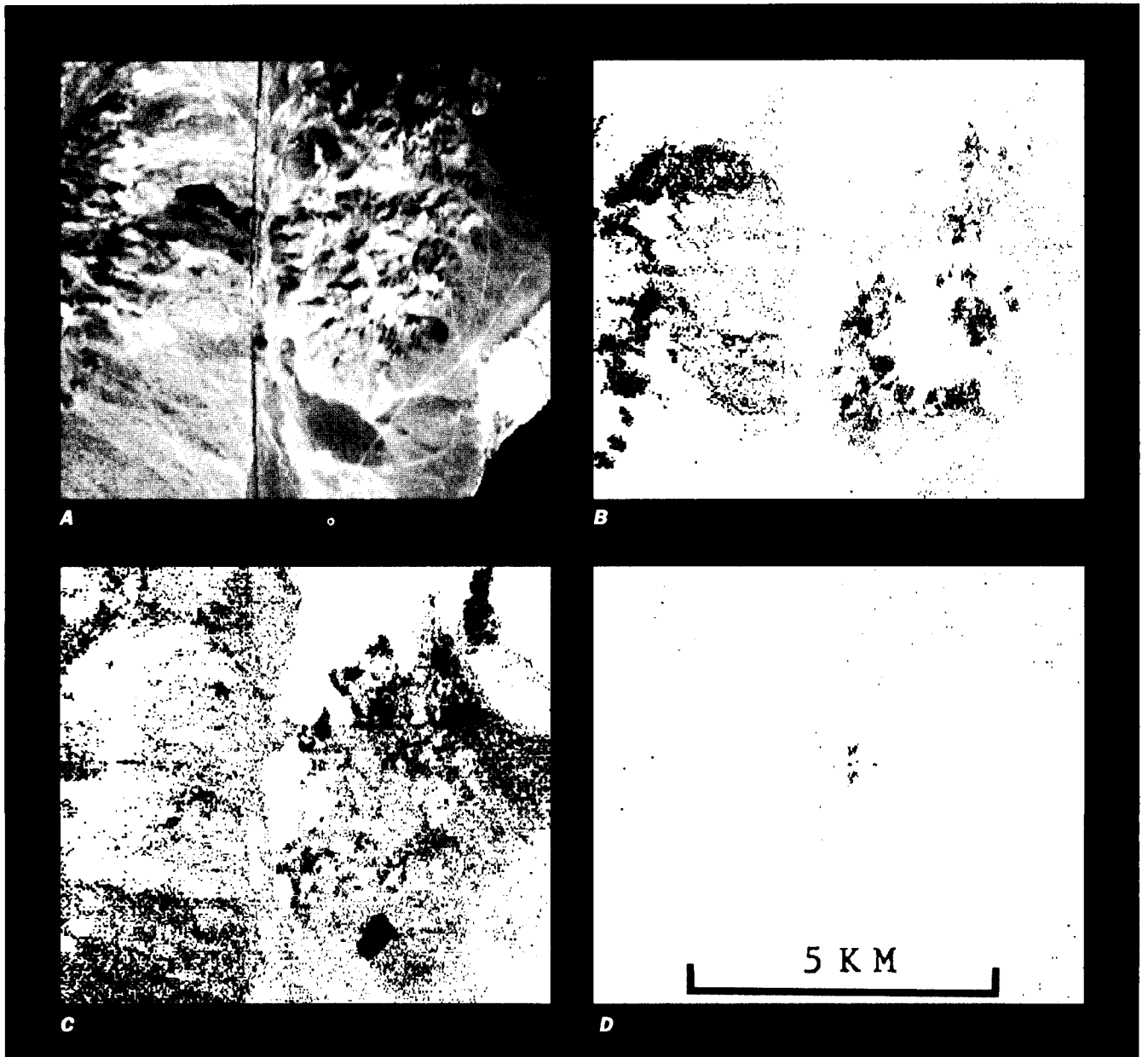
ders, filaments, and warm-core and cold-core eddies. The Atlantic Region also is using satellite telemetry through the ARGOS system to track drifter buoys to better understand Gulf Stream frontal dynamics. The Gulf of Mexico Region is using satellite-derived sea-surface temperature data to track and monitor eddies that break off from the Loop Current as it moves through the Gulf. The Pacific Region is using sea-surface temperature data to study eddy dynamics, thermal fronts, and upwelling along the California coast.

Geology

Mineral Resource Assessment. USGS geologists participated in the NASA Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) Data Evaluation and Technology Assessment Program. The purpose of the investigation was to evaluate the utility of AVIRIS data for geologic mapping in semiarid terrains. The primary effort was to demonstrate methods for display and analysis, for correction for atmospheric scattering and absorption, for extraction of reflectance spectra, and for compilation of maps of mineralogical and chemical compositions. These studies demonstrated the significant potential of AVIRIS data for rock type discrimination and mineral identification where the ground surface is reasonably well exposed.

In related research, USGS geologists developed procedures to extract maximum geologic information from Landsat TM and SPOT data. The procedures involve digitally combining the spectral information in TM data with two opposite-viewing, SPOT 10-meter resolution panchromatic images, and displaying and analyzing these data sets as stereoscopic images.

The USGS has been investigating the use of airborne imaging spectrometers to detect and identify mineral deposits. Imaging spectrometers have 64 to 224 spectral channels of data in the spectral region where the Landsat TM sensor has only 6 channels. Imaging spectrometer data have been used to identify many individual minerals for areas in which Landsat TM data



Airborne imaging spectrometer image (a) of Cuprite, Nevada, used to identify several minerals that could be indicators of valuable mineral deposits. Shown are alunite (b), kaolinite (c), and buddingtonite (d).

could detect only the presence of several very broad groups of minerals. For example, imaging spectrometer data of Cuprite, Nevada, were analyzed to identify several important minerals. Using data from 31 separate spectrometer channels in the spectral region where there is only one Landsat TM channel, several minerals were identified, including alunite, kaolinite, and buddingtonite. These minerals are commonly associated with hydrothermally altered rocks and may be indicators of potential base-and precious-metal deposits. Much new information about mineral deposits is being extracted from data from imaging spectrometers. Application of this technology using a satellite-based instrument will provide an added advantage for inventorying mineral resources on a global basis.

The USGS recently used data from the NASA Thermal Infrared Multispectral Scanner (TIMS) to map geology of the gold-bearing Carlin district in Nevada. This technique uses the thermal properties of rocks to identify subtle differences in rock type that cannot be detected with Landsat data or airborne imaging spectrometer data. Studies of the Carlin district indicate that, because of the greater density of TIMS data relative to traditional ground-based observations that are used to map most potential mineral deposits, TIMS data can be used to improve geologic map accuracy and to assist in identifying possible targets for mineral explorations.

Mine Development and Safety Monitoring. The BOM has continued studies of the correlation between geologic lineaments interpreted from Landsat data and ground hazards in underground coal mines. In a northern Alabama study site, lineaments and the geologic structures that underlie them have been found to influence the location of ground control problems in mines. At one mine, the number of known roof falls decreases exponentially with increasing distance from lineaments. Some lineaments relate to known faults, which offset the coal seam and limit recoverable reserves, and shear zones, which often contain large

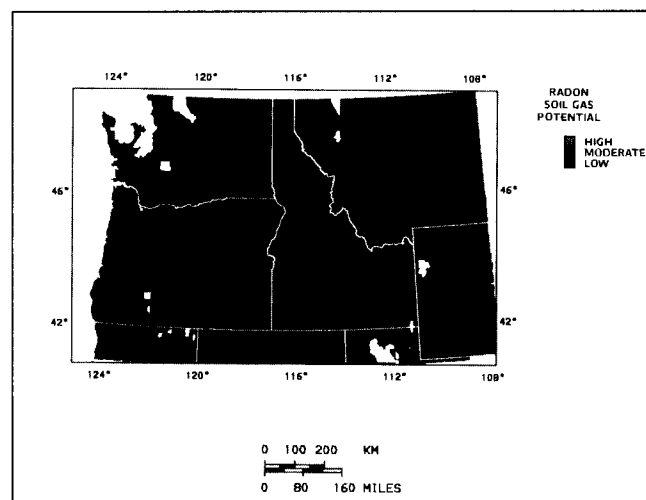
quantities of methane and water that can expose miners to safety hazards during mining. Results of these studies should improve mine planning to optimize coal recovery and mine safety. In an effort to upgrade the BOM remote sensing research capabilities for these studies, laboratory facilities at the BOM Denver Research Center are being expanded with acquisition of a new minicomputer for large image processing jobs and an image processing workstation for geographic information system analysis in conjunction with remote sensing studies. These improvements will permit the integration of a wide range of data types with remotely sensed data and allow more comprehensive applications of remote sensing technology to safe and economic exploitation of mineral resources.

The OSMRE uses remotely sensed data, mainly aerial photographs, as part of its programs with coal mining companies and State regulatory agencies in designing, monitoring, and reclaiming surface coal mines. Remote sensing has been included in training courses for OSMRE and State Regulatory Authority employees to improve their inspection and monitoring capabilities. In some OSMRE offices, aerial photographs of individual coal mines are taken as often as once a year. During 1988, aerial photographs were used as the base for topographic maps to facilitate preparation of mine development plans and to aid in calculating earthwork volumes. Aerial photographs were used to identify the extent of a coal refuse pile fire and to determine the amount of material that had to be moved to extinguish it. Other design uses include evaluating the soil resources of areas to be mined, determining the success of prime farmland reclamation, and assisting in mapping the stratigraphy of a sensitive mining site by identifying the location of pre-mining drill hole sites.

Aerial photographs are used to determine regulatory compliance by identifying and monitoring areas of disturbance, spoil ridges, areas reclaimed, areas under facility construction, and acid mine drainage. They are

also being used to determine changes to the ground surface profile due to underground mining. In one case, aerial photographs were used to identify and map hazardous surface cracks resulting from underground mining. Aerial photographs taken in 1979 and 1987 over an abandoned underground mine in Ohio were compared to determine if subsidence was continuing. Aerial photographs are used for bond forfeiture cases and abandoned mine land projects to provide the basis for before and after comparisons. They are used in designed the reclamation of bond forfeiture sites by developing reclamation specifications and cost estimates. Aerial photographs were also used in an extensive survey of abandoned mines in the North Branch Potomac River watershed to identify coal mine drainage sources and to develop preliminary abatement plans and costs.

Radon Hazard Assessment. The USGS is assessing the radon potential of rocks and soils across the United States for the U.S. Environmental Protection Agency. Rocks and soils are the principal source of indoor radon. The radon potential of rocks and soils is primarily controlled by their radium content and permeability. During the Department of Energy's National Uranium Resource Evaluation (NURE) program, aerial gamma-ray data were gathered for the entire conterminous 48 States and parts of Alaska. Gamma-ray data from bismuth-214 were gathered during these surveys to detect the presence of uranium-238, the principal isotope of naturally occurring uranium. However, bismuth-214 is also a decay product of radon-222, the radon isotope of primary concern in indoor air. Using the NURE gamma-ray data, the USGS has completed maps of the entire United States showing the apparent radium-226 (the immediate predecessor of radon-222) content of the surface materials. Although the coverage of the United States is close to 100 percent, the broad spacing of the aircraft flight lines in this survey makes these maps best suited for estimating the radium content of soils at regional scales (1:1,000,000). These radium maps



Map showing the relative radon soil gas potential in the Pacific Northwest. (White areas indicate no data.)

provide a first-order estimate of the radon potential of various areas of the United States, although other factors such as soil and rock permeability (where the permeability is very low or very high) are critical.

Planetary Studies. USGS research activities in planetary science during 1988 emphasized more detailed, site-specific studies as well as broad studies that support upcoming planetary missions. Prelaunch planning for the U.S. Magellan Mission to Venus (1989) involved geologic interpretation of high-resolution radar images of Venus that were acquired by the Soviet Venera 15 and 16 spacecraft. This work produced a geologic map of the northern quadrant of Venus at a scale of 1:15,000,000. In addition, a mosaic of Venus at 1:15,000,000 scale was completed by using the Venera data. The topographic data base derived from the U.S. Pioneer Venus altimetry data has been improved and supplemented by the Venera altimetry data.

USGS also supported studies of human travel to the Moon for the establishment of permanent science and industrial bases. An operational strategy was devel-

oped that employs teleoperated robots for lunar geologic field work. This technique will enable human involvement in surface exploration while minimizing the risks to humans from solar radiation and micrometeorite bombardment. Site selection was also completed for a lunar base. Mare Smythii was shown to have several advantages such as geologic diversity, access to the lunar far side, and mineral resources (titanium- and aluminum-rich soils).

Research activities have also increased in support of the Mars Observer Mission (scheduled for a 1992 launch) and in support of advanced planning of a Mars Rover/Sample Return Mission. USGS activities in 1988 included preparation of 1:500,000-scale photomosaics, compilation of a topographic map series at 1:2,000,000 scale for the entire planet, generation of a new global color mosaic with 1-km resolution, and completion of several geologic maps at 1:500,000 scale that include candidate landing sites. Other activities included the application of new computer-enhancement and topographic-extraction techniques to high-resolution images of specific Martian regions, and the interpretation of these data to determine the geologic and tectonic history of each region. Significant efforts have focused on determining of the origin and evolution of the Martian climate, particularly of the planet's water content and hydrologic processes. The USGS is also involved in the development and implementation of new spacecraft sensors for the Mars Observer Mission and in the science-planning phase for the Mars Rover/Sample Return Mission.

The USGS has developed techniques to generate a digital image of the entire surface of Mars through a NASA-sponsored project. Local views of this image will have accurate scale and negligible distortion. The image will have a total size of 92,000 X 46,000 pixels and a resolution of 1/256th of a degree (equivalent to 230 meters) of latitude and longitude. The entire image will be contained on seven Compact Disc-Read Only Memory (CD-ROM). Local high-resolution (250 meters) views of any place on Mars will be available. A similar

technique is being used to produce a companion digital topographic model of the entire planet with 1/64th of a degree resolution, equivalent to a little than 1 kilometer. These products will be used for planning surveys to be made by the Mars Observer Mission. Similar techniques are being applied to digital mapping of other planets and their satellites. A digital image mosaic of Venus, based on the Magellan radar investigation, will have four times the number of pixels as the Mars image and will require approximately 25 CD-ROM's for data storage.

USGS scientists have continued to study Jupiter's volcanically active satellite, Io. The global distribution and abundance of sulfur dioxide frost has been modeled and mapped from Voyager spacecraft data and Earth-based observations. Studies have shown that the sulfur dioxide is concentrated in an equatorial band on Io, rather than at the poles as was expected because of Io's dominantly sulfur dioxide atmosphere. This suggests that a more volatile substance, perhaps hydrogen sulfide (buffered by polar deposits), may be the major atmospheric gas. This hypothesis has been corroborated recently by spectroscopic evidence. The presence of significant hydrogen sulfide along with sulfur dioxide implies that magmatic water in Io has not been entirely degassed as was previously thought.

Cartography

Satellite Image Mapping. The USGS continued its satellite image mapping program in 1988 in which false-color satellite images are mosaicked, registered to a topographic base map, and printed. Landsat MSS image maps were printed for the following 1:250,000-scale quadrangles: Harrisburg, Pennsylvania; Shiprock and Aztec, New Mexico; and Limon, Durango, Denver, Greeley, and Sterling, Colorado. A 1:50,000-scale SPOT image map of the Washington, D.C., area was prepared by merging and mosaicking SPOT multispectral and panchromatic data. Similar techniques were used to prepare a 1:24,000-scale SPOT image map of the Point Loma, California, quadrangle, which includes

part of the city of San Diego. This is the first satellite image map produced to match a standard USGS 1:24,000-scale topographic map.

Digital Orthophotoquads. The USGS continued research on the development of a digital system to produce orthophotoquads, which are image-based maps in which distortion due to terrain relief has been removed and all land features are in their true map position. The digital orthophotoquad is produced from USGS digital elevation models and aerial photographs that have been converted to digital data by optical scanning. Present efforts are concentrated on producing both color-infrared and black-and-white digital orthophotoquads from National Aerial Photography Program photographs. The output of this process is a geometrically corrected digital image that can be used on image processing systems or integrated into a geographic information system. A secondary output is a color or black-and-white photographic print, or a separation for offset printing. Experimental orthophotoquads have been produced for Portland, Oregon; Dane County, Wisconsin; and McCall, Idaho.

Digital Image Processing. The USGS is cooperating with the NPS to demonstrate new applications of remotely sensed data for national parks. SPOT satellite data were used to prepare an up-to-date 1:24,000-scale image map of Yosemite Valley to complement the existing 1958 topographic map. A digital elevation model was used to remove distortions due to terrain relief. As part of the same project, computer-generated simulated flights through Yosemite Valley were produced using a series of perspective views derived from two types of remotely sensed data. In one simulated flight, perspective views were created from the SPOT image map and USGS digital elevation model data. A second simulated flight around El Capitan, a prominent feature in Yosemite Valley, was produced from digitized large-scale color aerial photographs and a high-resolution digital elevation model. Both techniques—image mapping and simulated flights from multiple perspective views—are being evaluated by



This simulated perspective view of El Capitan, a prominent feature in Yosemite National Park, California, was produced from a digitized high-resolution natural color aerial photograph merged with digital elevation data of the same area.

the NPS for operational use in other parks for a variety of planning, resources management, and interpretation applications.

The USGS has developed procedures for producing a single digital image from two separate satellite images to enhance the detection of land cover changes between dates. The procedures provide an image that is readily useable by interpreters having little or no image processing experience. The procedures include (1) registering one image to another; (2) processing to adjust for differences between image dates that are due to factors such as sun angle and atmospheric conditions and not to land cover changes; and (3) processing to enhance particular surface features or conditions. These procedures have been evaluated using Landsat TM color-composite images of the Chernobyl (U.S.S.R.) nuclear power plant, which was the site of the reactor accident on April 23, 1986. An image was

prepared to show land cover changes that occurred since the accident. Comparison of images acquired 3 days and approximately 1 year after the accident shows numerous changes resulting from (1) severe radiation damage to the conifer trees adjacent to the plant, (2) Soviet mitigation efforts such as removal of trees and creation of water impoundments, and (3) the cessation of agricultural activities in the region. Procedures such as these will be particularly useful for monitoring land cover changes that reflect the impact of global and regional climatic change.

The USGS has been investigating automated extraction of cultural features from digitized aerial photographs as an adjunct to the primary topographic mapping process. A spatial requirements analysis was recently completed which determined that, for extraction of roads from 1:25,000-scale color-infrared photographs, a scanning resolution of 3 meters would result in the lowest amount of road distance being omitted from the actual roads. Current research is aimed at establishing quantitative indicators to ensure that image quality is always sufficient for extracting the appropriate level of map detail from digital images.

Global Positioning System. In 1988, the Global Positioning System (GPS) was used to provide both horizontal and vertical control for a number of USGS mapping projects. The decision to use GPS for vertical control was based on in-house tests, which confirmed that the system could obtain the necessary accuracy. The USGS continued to use the system for monitoring the San Andreas fault in California. New software was obtained that provided positional accuracies of a few parts in one hundred million using orbit-improvement techniques.

The GPS was used by the USGS for ground-water well site location and land subsidence studies. Over the past 3 years, a GPS network spanning the entire Sacramento Valley of California was established for monitoring land subsidence. USGS also participated in a number of interagency projects using GPS for crustal motion determination. Some development efforts were

postponed until 1989 when the launch of operational GPS satellites will begin.

Global Change

During 1988, the USGS cooperated with nine other Federal agencies to create a comprehensive U.S. Global Change Program. As part of this major Federal, national, and international initiative, each participating organization has been reorienting or establishing programs and projects that are focused on scientific problems relevant to global change. Because of the regional impact of various aspects of global change, remotely sensed data from existing and future aircraft and satellite sensors, in conjunction with direct field measurements, will play an important role in USGS global change research. In particular, space-based observations have now become an essential means for monitoring global change.

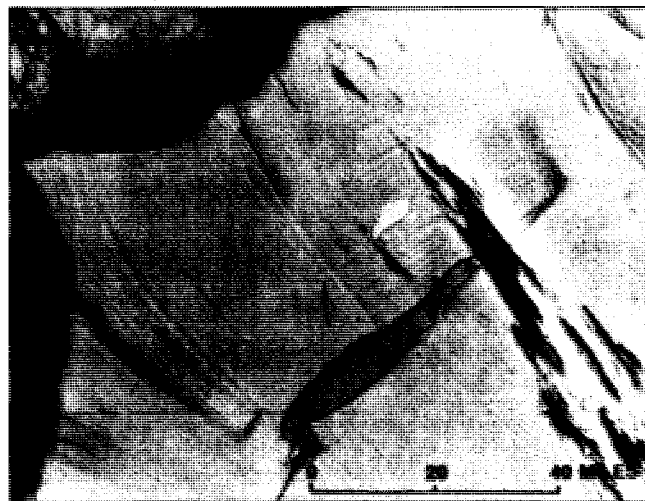
Global Ice Monitoring. Scientists from the USGS and NASA completed a study of variations in Arctic, Antarctic, and global sea ice cover using observations from the Nimbus 7 scanning multichannel microwave radiometer during 1978-87. Over the 9-year period, no significant trends were found in the total area of either the Arctic and Antarctic ice packs, or in their sum, the global ice area. However, a significant downward trend was found in the maximum extent of global ice boundaries. This trend during 1978-87 appears to continue a downward trend observed between 1973 and 1976, based on additional analysis of monochromatic microwave observations obtained by the Nimbus 5 spacecraft. The trend for the combined 15-year period is a 6-percent reduction in global maximum ice extent. This study, in conjunction with recent studies of global temperature change, lends support to the belief that changes in global average temperature might be detectable by observing variations in global sea ice extent.

Landsat and AVHRR images acquired during the past 15 years have been used by USGS glaciologists to document and measure large ice calving events along

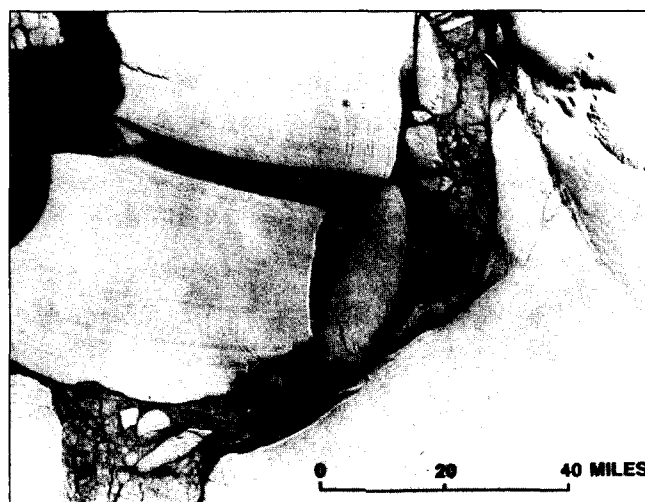
the margin of the Antarctic ice sheet. In 1986, two large icebergs (11,225 square kilometers) calved into the ocean from the Larsen Ice Shelf, and a group of three large icebergs (10,700 square kilometers) calved from the Filchner Ice Shelf. In 1987, another large iceberg (5,508 square kilometers) calved from the Ross Ice Shelf. From available ice-thickness measurements, it was concluded that 7,110 cubic kilometers of ice was discharged from just these three ice shelves during 1986-87, or an amount that is more than twice the estimated annual snowfall (water equivalent) on the entire Antarctic continent during the same period. These large calving events on the Filchner and Ross Ice Shelves are probably cyclical. However, the reduction in area and volume of the more northerly situated ice shelves on the Antarctic Peninsula (for example, the Larsen Ice Shelf and the Wordie Ice Shelf) probably represent long-term changes in response to global climatic warming. Long-term (over many decades) resurveys every 2 years of the coastal regions of Antarctica using satellite images are necessary to ascertain whether or not the changes are truly cyclical. Antarctica contains 91 percent of the volume of glacier ice on Earth, so even a slight change in its volume in response to climate warming would produce a rise in sea level.

Nearly 10 years ago, the USGS began to prepare a Satellite Image Atlas of Glaciers, a long-term project involving more than 55 scientists from the United States and 29 other countries to document, monitor, and study the glacial regions of the Earth from Landsat MSS images acquired primarily during the middle to late 1970's and ancillary data. The present areal distribution of glaciers in each geographic area is compared, wherever possible, with historical information about their past extent. The first chapter, covering Antarctica, was published in 1988. More than 10,000 Landsat images of Antarctica, which cover the continent from the coast to about 81 degrees south latitude, were evaluated for possible inclusion in the chapter. Fifty-eight annotated Landsat images and image mosaics, 38

November 11, 1973



October 18, 1986



Landsat MSS images acquired before (November 11, 1973) and after (October 18, 1986) a major ice calving event on the Filchner Ice Shelf, Antarctica. The area that has calved is just slightly less than the size of the State of Connecticut.

oblique aerial photographs, maps, and other data provide a comprehensive review of the diversity of glaciological features and the vastness of the Antarctic ice sheet. When completed, the atlas will provide an accurate regional inventory of the areal extent of glacier ice on Earth and will be another contribution to the growing international scientific effort to measure global change in response to natural and anthropogenic processes.

Coastal Erosion Processes and Sea Level Change. Since 1986, the USGS and the Louisiana Geological Survey have been studying the geologic development of barrier islands and the most critical processes that cause their erosion. The Louisiana coast was selected as a study area because relative sea level is currently rising rapidly there (as much as 1 centimeter a year) from a combination of land subsidence and world wide sea level rise (an estimated 15 centimeters during the last 100 years). Successive sets of vertical and oblique aerial photographs, acquired by various Federal, State, and other agencies during the past 50 years, are being used to map historic changes in coastal sections of Louisiana and as a reference base for comparing present and future changes. The effects of hurricanes, tropical storms, and cyclones on the erosion of Louisiana's barrier islands are being studied by pre- and post-storm aerial videotape surveys, vertical and oblique aerial photographs, and field investigations (beach profiles). An analysis of these data substantiates the fact that major storms often cause breaches in the islands, and substantial beach and dune erosion.

Regional Vegetation Monitoring. In 1988, the USGS began to develop a comprehensive AVHRR data base for the Northern Great Plains to support cooperative research with the NWS and U.S. Forest Service. There are three primary objectives of this research: the use of vegetation indexes derived from AVHRR data for monitoring changes of the land surface (primarily vegetation) that are caused by the interaction of climatic and human factors; vegetation condition as it

relates to fire danger; and other effects of drought conditions throughout the Northern Great Plains region. The data base includes AVHRR data acquired daily through the 1988 growing season from April through October, which have been geometrically registered to known ground coordinates. The individual daily AVHRR scenes were composited to provide nearly cloudfree weekly data sets for the study area.

Spectral Change and Climate as Influenced by Irrigation. As part of NASA's International Satellite Land Surface Climatology Project, the USGS is examining the change over several years in spectral data from satellite sensors and possible effects on climate resulting from irrigation development in western Nebraska. Existing Landsat MSS and AVHRR data are being used to assess spectral changes that may be related to land cover change on a regional scale. A technique was demonstrated to use acreage estimates of irrigated land area from Landsat data to calibrate acreage estimates made from AVHRR data to improve regional surveys that can be accomplished only with AVHRR data. Weather data from the past 40 years for 33 stations within the region have been analyzed for trends in climate elements that may be related to irrigation development. Maps from these analyses show decreases in climate parameters (precipitation, daily maximum minus minimum temperature, and evaporation) in areas downwind of irrigation development. A procedure was also developed for using satellite measurements of land cover and weather station data to produce estimates of evapotranspiration over the study area, a potentially significant climatic effect due to irrigation development. These results show promise for describing climatologically important properties of the land surface on a spatial basis to serve the information needs of regional and global climate models.

International Activities

Africa. During 1988, the USGS was involved in several projects in Africa funded by the U.S. Agency for International Development (USAID) to provide

technical assistance in either remote sensing or geographic information systems. The largest and most visible effort involved the production of vegetation condition maps for use in locust control efforts in Mauritania, Mali, Niger, Chad, Sudan, Algeria, Tunisia, and Morocco. This activity is a continuation of a 1987 pilot project in which a procedure to monitor seasonal vegetation patterns was developed, tested, and evaluated. AVHRR satellite data are used to produce vegetation greenness maps every 2 weeks during the rainy season to show the current distribution of vegetation. Copies of each map are used by each participating country to help locust control teams look for potential locust breeding areas.

The USGS also provided technical assistance for the USAID Famine Early Warning System (FEWS) and the Agriculture, Hydrology, and Meteorology (AGHRYMET) Requirement Needs Analysis projects. FEWS was established 3 years ago by USAID to identify and assess human populations likely to experience food shortages and famine in seven Sahelian Africa nations. FEWS relies heavily on geographic information system technology and AVHRR satellite data to make assessments of available food resources. USGS contributed to a major redesign of the FEWS program by defining geographic information system capabilities and equipment specifications. A new data base design will be implemented in early 1989, and FEWS field representatives will receive training by USGS specialists in the use of these new data sources for famine vulnerability assessments. The AGHRYMET project was established in the 1970's to provide timely climatic and weather data to decisionmakers in nine West African countries. Under USAID sponsorship, AGHRYMET is entering a phase to modernize data processing and establish a capability to receive, process, and distribute AVHRR satellite data. The AGHRYMET Requirement Needs Analysis report outlined the key products and capabilities that will be needed over the next 5 years as part of this modernization.

Middle East. The USGS continues to support remote sensing activities in the Middle East. The USGS supports the Saudi Arabia Directorate General for Mineral Resources Remote Sensing facility in mineral resource and general geologic mapping studies. Image maps (scale 1:50,000) are being produced in Abu Dhabi to support ground-water studies and general geologic mapping. The Government of Jordan receives assistance from the USGS, through USAID, in the use of remotely sensed data to support general geologic mapping for the entire country. The USGS also assisted the Governments of Jordan and Qatar in establishing remote sensing laboratories. At the request of the Yemen Government and USAID, the USGS is providing assistance in the application of airborne and satellite remotely sensed data to mineral resource assessments in North Yemen.

The People's Republic of China. A protocol of cooperation has been in existence for 4 years between the USGS and The People's Republic of China's National Bureau of Surveying and Mapping. During 1988, scientific exchanges in the two countries focused on developing and implementing geographic information systems and on digital image processing techniques for preparing satellite image maps and land cover maps. During 1988, SPOT and Landsat TM data for the Mei Tan Ba and Ning Xiang 1:50,000-scale quadrangle maps in the Hunan Province of China were digitally mosaicked and enhanced, and preliminary satellite image maps were produced. Joint work between USGS and Chinese scientists concentrated on alternative methods for developing digital land cover spectral statistics, refining classifications, using digital elevation data, and assessing classification accuracy. The results of these joint efforts will be applied in developing digital approaches for updating land cover maps and monitoring land cover change within The People's Republic of China.

Iceland. The USGS is cooperating with NASA's Goddard Space Flight Center and the National Re-

search Council of Iceland in a study of active volcanic zones and glaciers of Iceland using side-looking airborne radar and airborne laser altimeter (ALA) data. ALA data, acquired by a NASA P-3 aircraft in conjunction with a simultaneous differential offset Global Positioning System (GPS) survey, permitted precise plotting on base maps of all ALA profiles. The GPS data also allowed the plotting of profiles of the land surface with an error of less than 1 meter. High-resolution side-looking airborne radar images of several sites in Iceland were acquired in 1987 and in 1988. The 1988 survey acquired the first radar images of an active volcanic zone from three different look directions to determine if look direction introduces a directional bias in the analysis of such images. The most important result of the work in Iceland is the use of a GPS receiver on the NASA aircraft to permit precise plotting of the ground track of the flight path and correction of the changing aircraft orientation to produce accurate terrain profiles.

Latin America. In 1988, the BOR provided consultation to the Brazilian Ministry of Irrigation on the use of land remote sensing satellite data and geographic information systems technology to compile basic environmental information for planning irrigation develop-

ment in the arid northeast region of Brazil.

The USGS cooperated with the U.S. Customs Service and the International Boundary and Water Commission to produce image maps along the entire border between the United States and Mexico. Natural-color aerial photographs at 1:25,000 scale were used to prepare 203 orthophotoquads that provide the most up-to-date information about the border area from San Diego, California, to the Gulf Coast of Texas.

Data merging techniques were used by the USGS to produce a Landsat TM/SPOT image map of the Viedma, Argentina, area, which has been proposed as the site for relocating Argentina's national capital from Buenos Aires, 800 kilometers to the northeast. This image map was printed at 1:50,000 scale by the USGS and the Instituto Geografico Militar of Argentina under the auspices of the Pan American Institute of Geography and History as part of a cooperative project to evaluate the usefulness of remote sensing technology for mapping in Latin America. A second phase of the project, digital land cover classification of the same data set used for the image map, was not completely successful, suggesting that visual interpretation of merged Landsat TM and SPOT images may be more useful where detailed mapping is required.



Department of Agriculture

During 1988, agencies of the U.S. Department of Agriculture (USDA) continued to develop and refine airborne and space-based remote sensing systems which have become vital information sources for agricultural assessment and resource management. Applications research proceeded steadily, with a balanced approach that stressed development of computer-aided interpretive procedures. Significant achievements during the year included implementation of geographic information systems (GIS) using digitized remotely sensed data as a primary component, use of satellite data in the analysis of the drought in the United States and flood damage to crops in South Asia, and testing and development of satellite electronic positioning equipment for forest management tasks.

Agricultural Assessment

Throughout the 1988 crop season, remote sensing specialists assisted the Department's drought assessment effort with analysis of crop conditions in the winter wheat, spring wheat, and corn belts of the United States. Analysis of satellite data, weather information, and soil moisture model results were integrated to provide the Secretary of Agriculture and management officials with a series of updates which aided definition of different levels of drought impact at the county and crop district levels.

Detection and monitoring of summer floods in Bangladesh, India, and Pakistan was also assisted by satellite coverage. The remotely sensed data provided critical information to U.S. embassy personnel in their on-site evaluation of damage to coarse grains, rice, and cotton crops. Washington-based analysts also benefited from the information, with the result that a more moderate and realistic assessment could be prepared.

With primary responsibility for providing domestic agricultural statistics, the National Agricultural Statistics Service (NASS) has long used remotely sensed data as an aid in locating and establishing plots for stratified sample surveys. The value of Landsat satellite data in

combination with conventional ground-gathered data in obtaining more precise and timely crop area estimates has been demonstrated in both pilot and large-area tests, and a developmental program operated from 1980 through 1987. Early in 1988, a decision was made to emphasize research and to focus resources on preparations for future satellite sensors. In order for NASS to take advantage of the new and more advanced sensors, research is required to assess their feasibility so that when data become available, the anticipated improvement in the accuracy of the results will be cost effective. The advanced sensor data from the commercial systems of the 1990s will contain improved spatial, spectral, and temporal information. To NASS, this will translate into more accurate acreage estimates and also crop condition or yield assessments, if procedures can be fully developed.

In 1988, the remote sensing research program in NASS specifically considered winter wheat estimation in Kansas. A statistical comparison of three different sensors was made for the crop. Preliminary results show the Landsat Thematic Mapper (TM) to be significantly better than other satellite sensors, for example, Landsat Multispectral Scanner or SPOT. Similar studies are planned for corn, soybeans, rice, and cotton.

Resource Management

The Department's Forest Service is charged with the management of 190 million acres of land, often rugged, remote country, located throughout the United States. Of prime importance is the necessity that all management objectives be considered in decisionmaking: timber production, grazing, recreation, wildlife management, and watershed protection. Mineral exploration, fire, and insect and disease infestations are also important subjects that must be considered.

Because the land area of the Forest Service is so large and the tasks of management are so diverse, and because so many of the tasks require a knowledge of location, the potential contributions of satellite electronic positioning technology are great. One good

example is timber sale preparation. Sales require a preliminary survey of the area to establish the species to be cut and the volume of timber available; a plan must be made which prescribes cutting objectives and methods; roads and assembly points for logs must be designated; and trees to be left to provide seed for reforestation must be marked. All these activities require position or area determination.

Other tasks that will benefit from better position location include establishment of forest inventory plots, soil sampling in critical areas, delineation of mining claims, and marketing disease and insect infestations, archeological areas, and delineating areas containing endangered plant and animal species.

All these tasks require a varying degree of location accuracy, which satellite electronic positioning equipment can supply. Because this procedure holds such promise, the Forest Service embarked on an ambitious project to determine how the equipment could be incorporated into ongoing operational programs. After a market and literature search to learn what equipment might help accomplish Forest Service tasks, a survey of potential users in the Forest Service was conducted to determine specific requirements for a field location system. Some 46 separate uses were identified for improved location systems, including timber plot locations, boundaries between leasable and non-leasable land, road and trail locations, timber sale areas, and location of work crews in emergencies.

Two satellite electronic positioning systems are being tested. One system, the NAVSTAR-Global Positioning System (GPS), is operated by the Department of Defense as a weather navigation and position-fixing system. When fully operational, 18 satellites (with 3 active spares) will continuously circle Earth, transmitting coded signals to receivers on the ground, which then calculate the user's position.

A commercial system which uses three geosynchronous satellites to relay information to the central computer facility, is also under consideration. In this system the position of user transceivers will be deter-

mined by a central computer, based on signals relayed from users via satellite to the central computer. The calculated position will be sent back through the satellite and displayed at the user's transceiver.

In 1988, after test and development, the Forest Service moved to operational status for applying satellite electronic positioning systems for many uses, and activity is now in progress to establish numerous applications for resource management.

With greater budgetary constraints, forest managers must increasingly make use of remote sensing in forest inventories and other forest management applications. Remote sensing is used in a number of ways, including delineation of forested areas to be inventoried and monitored; delineation of soil and vegetation types; and preparation of sampling frames, among others.

All types of remotely sensed data from airborne and space-based sensors are used. In addition to regular aerial photography, newer sources of data include optical bar photography; high altitude photography; laser profilers; radar data; video recorders; and satellite imagery, such as that provided by the Landsat system and meteorological satellites.

Data from meteorological satellites, specifically, the NOAA polar-orbiting satellites, now appear to have significant potential for large-scale forest mapping and monitoring, particularly when up-to-date information is needed on changes in forested areas. Developmental testing of imagery from the Advanced Very High Resolution Radiometer (AVHRR) sensor carried by NOAA's series of polar-orbiting meteorological satellites was carried out in 1988, with the AVHRR used as a data source for statewide estimates of forest area in Mississippi, Louisiana, and Arkansas. Results indicate that basic land cover classes can be mapped with reasonable accuracy, compared with forest surveys prepared by conventional means. It is concluded that digital AVHRR image data also can be used advantageously for operational forest area monitoring. Although limited in information content by the low resolution, the advantages (low cost, less data, large-



Data are collected on the ground at the Maricopa Agricultural Center to compare data acquired by satellite sensors.

area coverage, and frequent repeat cycle) are great and AVHRR imagery is receiving increased attention as one of the components of forest inventory updating systems.

Both the Forest Service and the Soil Conservation Service, which is responsible for soil and water conservation, including natural resource surveys and management and protection of community resources, are using digital remotely sensed data as an input to Geographic Information Systems (GIS). Simply stated, a GIS is an information processing system that enables the user to enter, store, search, modify, analyze, and retrieve spatial resource data. Digitized remotely sensed data, especially data from Earth-observation satellites, can be merged in computers with other digitized geographic data, for example, vegetation types, boundaries, soil types, and topography. The resource manager can quickly analyze the current situation and, if needed, create a map or other graphic for planning or other tasks.

In 1988, after extensive testing and evaluation, the Soil Conservation Service selected the Geographic

Resources Analysis Support System (GRASS) as the agency-supported geographic information system. GRASS is highly interactive, graphics oriented software developed by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory. In addition to performing typical GIS functions, GRASS provides the ability to input, display, and classify Landsat MSS and TM, SPOT, and digitized photography. This imagery capability in GRASS will be useful for providing a photoimage background for various thematic maps, or for automated classification of imagery to produce new map layers. In conjunction with this effort, SCS is developing software and procedures to provide scanned aerial photography to field offices.

Many Forest Service units have experimented with GIS technology with the goal of meeting specific local and regional land management needs. Future operational applications in the Forest Service will be aided by an agency-wide program initiated in 1988 for implementation of GIS.

Applications Research

Applications research provides the essential "bridge" that enables data from aircraft and satellite sensors to become meaningful information for decisionmaking. The Remote Sensing Research Laboratory, a component of the Department's Agricultural Research Service (ARS) located at Beltsville, Maryland, is engaged in a broad-based research program to develop new techniques to incorporate remotely sensed data into agricultural and resource information systems. This program is a part of a larger activity which includes other remote sensing projects at ARS field locations.

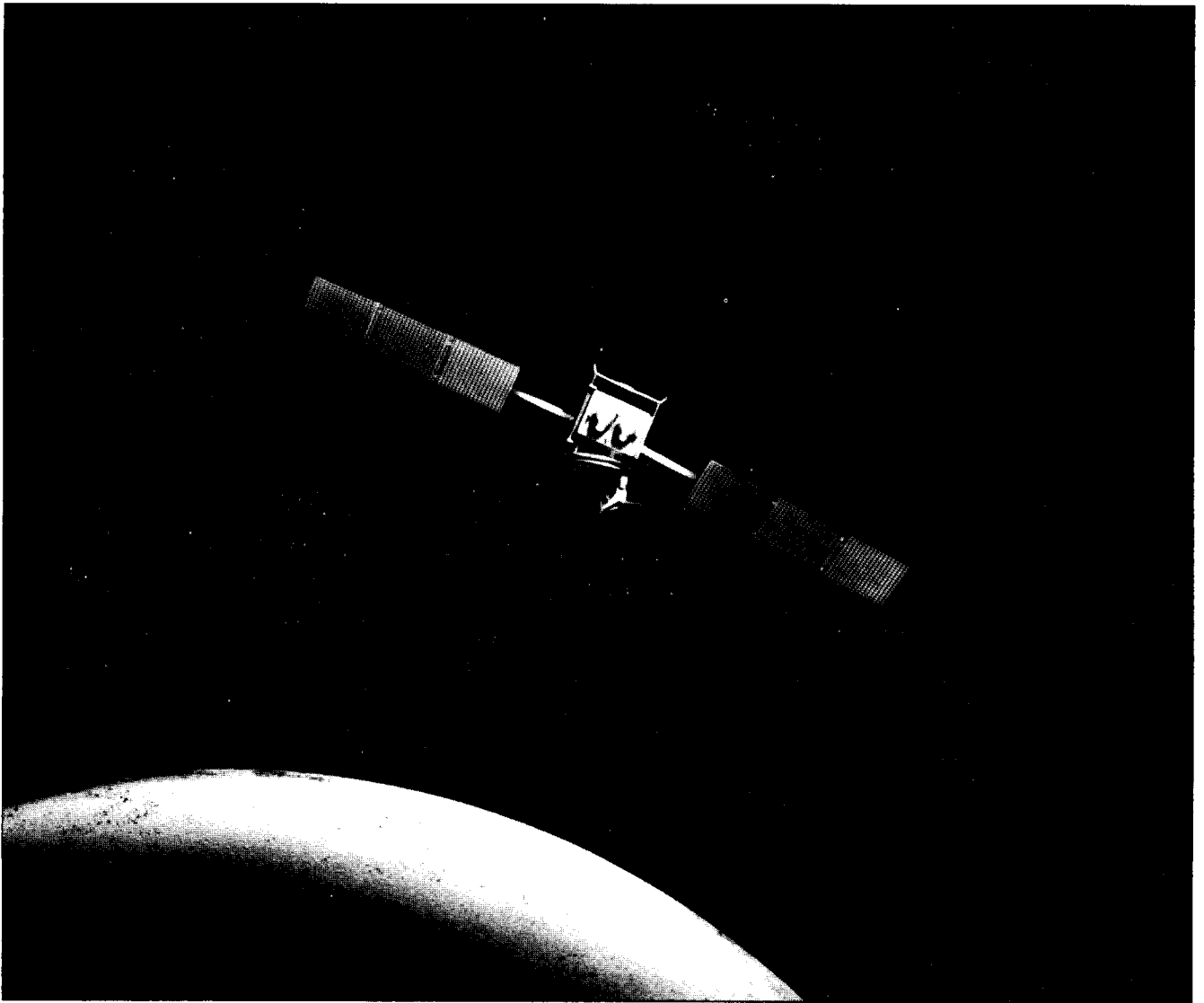
Although much of the research extends over several years, several units have reported significant results in 1988. For example, results from a multidisciplinary field experiment conducted June 11-13, 1988, at the University of Arizona's Maricopa Agricultural Center demonstrated that ground reflectance factors can be obtained from SPOT data, if the data are corrected for

atmospheric scattering and absorption. This experiment, which included ARS researchers from both Phoenix, Arizona, and Beltsville, MD, provided considerable insight necessary for the interpretation of satellite-based surface reflectance data taken at off-nadir view angles, and will aid in the improvement of procedures to assess crop conditions using satellite data.

At Weslaco, TX, a computer-based crop model was developed from satellite data that is capable of using both canopy reflectance and thermal information in simulating growth and yield. The model does not need soil moisture, rainfall, or irrigation data to determine evapotranspiration and water stress effects. Evaluations involving wheat and corn indicate that canopy temperatures may be as important as light absorption in estimating yield from remotely-sensed data. In a second study, it was shown that yield reductions due

to flooding of rice by a typhoon can be estimated from Landsat TM observations. The research improves current procedures to assess crop yield potential using satellite data.

Satellite data users may occasionally experience difficulties in associating a geographic location with a specific path/row catalog identifier. A user may want to determine the date when an acquisition may have occurred or when one may occur in the future, or match collection dates for Landsat, AVHRR and SPOT acquisitions. These questions are now made easier for satellite data users with an MS-DOS compatible accession aid program. The program—called SATCOV—provides basic information in response to menu-driven user inputs. SATCOV was developed in 1988 at the Remote Sensing Research Laboratory in Beltsville.



PAS-1 satellite. Launched June 15, 1988. First U.S. international satellite system separate from INTELSAT.

Federal Communications Commission

Communications Satellites

International Commercial Communications Satellites

At the beginning of 1988, the International Telecommunications Satellite Organization (INTELSAT) global communications system consisted of thirteen satellites in orbit: one INTELSAT IV, one INTELSAT IV-A, four INTELSAT V's, four INTELSAT V-M's and three INTELSAT V-A's. During the year, one IV was retired and ejected into a higher orbit. One INTELSAT V-B (F-13) was launched on May 17, 1988, by an Ariane IV rocket and placed in orbit at 307 degrees East Longitude. At the end of 1988, INTELSAT maintained thirteen satellites in geosynchronous orbit: one IV-A, three V's, one V-M, two V-A's and one V-B in the Atlantic Ocean region; two V-M's and one V-A in the Indian Ocean region; and one V and one V-M in the Pacific Ocean region. The IV-A satellite has already exceeded its estimated maneuver life.

In 1988, the Federal Communications Commission approved the construction and operation of 18 new Earth station facilities to access the INTELSAT system in the Atlantic and Pacific Ocean Regions for the provision of INTELSAT Business Service (IBS) and television transmission and 5 stations for multipurpose service.

On September 30, 1987, the Commission issued a final construction permit and launch authority for Pan American Satellite Corporation's (PanAmSat) "Simon Bolivar" (PAS-1) satellite in accordance with the Commission's policy statement in CC Docket No. 84-1299 which was released in 1985. On June 15, 1988, PAS-1 was launched aboard an Ariane IV rocket and placed in orbit at 45 degrees West Longitude. On November 7, 1988, the Commission issued a final order allowing PanAmSat to use six 11/14 GHz transponders on its PAS-1 satellite for service to selected countries in Europe. Orion Satellite Corporation has also reached agreement with a foreign correspondent, the United Kingdom. The United States and the United Kingdom initiated consultation with INTELSAT in December

1988, for service between those two countries as well as other possible services between North America and Europe.

Domestic Commercial Communications Satellites

In 1988, the Commission authorized the construction and launch of nine new domestic fixed-satellites. It also authorized the construction and launch of ten satellites to replace ones that are currently in orbit. The newly authorized satellites will provide domestic satellite capacity through the 1990s and will offer users a wide range of services including video services, high speed data services, private network services, and audio services.

The 1988 grants increased the total number of authorized in-orbit domestic satellites to 42. These satellites are operating in the 4/6 GHz and 12/14 GHz frequency bands. By the end of 1988, 29 domestic satellites were in orbit and located between 69 degrees West Longitude and 143 degrees West Longitude on the geostationary orbital arc. Three satellites were launched in 1988, one of which is not currently in its proper orbit.

Maritime Satellite Service

National and international efforts to establish a future global maritime distress and safety system are continuing. The International Maritime Organization (IMO) is developing the system which will use Standard A, Standard M, and Standard C ship Earth stations through INMARSAT as well as satellite emergency-position-indicating radio beacons (satellite EPIRBs), which will provide initial distress alerting information from ships to rescue coordination centers. Although present plans include satellite EPIRBs through the polar orbiting SARSAT (a NOAA Weather Service satellite for search-and-rescue satellite data tracking) and the Soviet equivalent called COSPAS, the IMO Maritime Safety Committee is also considering use of L-band EPIRBs through INMARSAT (geostationary orbit). The global maritime and safety systems are expected to be phased in between 1992 and 1999.

Currently, INMARSAT is leasing two in-orbit satellites from the European Space Agency, a spare MARECS A in the Pacific Ocean region and an operational MARECS B-2 in the Atlantic Ocean region; four in-orbit INTELSAT piggy-back Maritime Communications Subsystem (MCS) satellite packages, the spare MCS B (F-6) in the Atlantic, the operational MCS A (F-8) in the Pacific, and the operational MCS A (F-5) in the Indian Ocean region; and three MARISAT back-up spare satellites leased from Comsat General—the MARISAT F-1 in the Atlantic, the MARISAT F-3 in the Pacific, and the MARISAT F-2 in the Indian Ocean, which are also for special purpose use.

Second-generation satellites, the first of which is projected to become operational in late 1989 or early 1990, are being built under INMARSAT specifications and will have a capacity about triple that of the present leased satellites. INMARSAT serves over 8,000 vessels through its 55 member-country organization. Twenty coast stations in fourteen countries are in operation, with seven more planned for 1989.

Aeronautical Satellite Service

The process of adopting amendments to the International Maritime Satellite Organization (INMARSAT) convention and operating agreement, which will allow it to offer aeronautical services, continues. The amendments will take effect 120 days after two-thirds of member countries representing two-thirds of the total INMARSAT investment shares have filed notices of acceptance. INMARSAT's four second-generation spacecraft are being constructed with three megahertz of bi-directional bandwidth in the Aeronautical Mobile-Satellite Service (R) band. The International Civil Aviation Organization through its subcommittee on Future Air Navigation Systems has been discussing standards for aeronautical satellites and other issues involving the use of satellites in a coordinated program for civil aviation. The aviation community is actively developing, through the Airlines Electronic Engineering Committee, aeronautical satellite standards for voice

and data services. The aviation industry, in cooperation with INMARSAT, is developing aircraft antennas and avionics needed for this service. Aeronautical Radio, Inc., is pursuing international aeronautical services via INMARSAT by interconnecting its terrestrial VHF network with satellite facilities for oceanic coverage. In addition, the American Mobile Satellite Consortium is proposing to provide aeronautical service on its system.

Direct Broadcast Satellite Service

The Commission authorized the Direct Broadcast Satellite service in July 1982, in order to provide satellite delivery of video programming directly to homes via small (two 3-foot diameter), relatively inexpensive (\$300 to \$500) receiving stations. The Commission granted the first several conditional construction permits later that year. Two of those original permittees continue to hold their permits and are currently scheduled to begin operations by late 1992. United States Satellite Broadcasting Company, Inc., is authorized to provide eight channels of service to each half of the United States from two 8-channel satellites in separate orbital locations. Dominion Video Satellite, Inc., is authorized to provide eight channels of service to each half of the United States from one 16-channel satellite, splitting its capacity.

Several additional parties have subsequently received conditional construction permits, and two of those parties continue to hold their permits and should begin operations in three to four years. Hughes Communications Galaxy, Inc. (Hughes) is authorized to provide 16 channels of service to each half of the United States from two 16-channel satellites from the same orbital location. Advanced Communications Corporation (Advanced) is authorized to provide 16 channels of service to each half of the United States from two 16-channel satellites from separate orbital locations. Advanced has requested a single orbital location for both of its satellites. Both Advanced and Hughes propose to spread each of their 32 channels

over the entire United States if signal strength is adequate and interference problems are not created.

In 1988, six additional applications for new Direct Broadcast Satellite service authorizations were filed and are pending. These applications have been "cut-off" and no additional applications will be considered in conjunction with these six. Each applicant proposes service via two 16-channel satellites from one or two orbital locations, depending on availability. The parties are: Continental Satellite Corporation; Direct Broadcast Satellite Corporation; DIRECTSAT Corporation; EchoStar Satellite Corporation; Orbital Broadcasting Company; and TEMPO Satellite, Inc. Any construction permits granted will be conditioned on initiation of construction within one year and completion and launch within six years. Minimum construction time would be 32 to 40 months.

New Satellite Services

In 1988, the radiodetermination satellite service (RDSS) continued to develop. This service was authorized in 1986 and allows subscribers to determine latitude, longitude, and altitude, and to exchange brief coded messages using hand-held or vehicle-mounted transceivers. Although two of the authorized companies turned in their licenses in 1987, the remaining licensee, Geostar Positioning Corporation, began to provide start-up service in 1988 when the Spacenet III domestic fixed-satellite, carrying an RDSS payload, was launched in March. Geostar has also begun construction of three of its own dedicated RDSS satellites.

Progress was also made toward implementing a mobile-satellite service (MSS). In 1986, the Commission allocated 27 MHz of spectrum in the L-Band and established licensing policies for MSS. This service is expected to provide telephone service to rural areas; long-range vehicle dispatch and location service; emergency communications service; service to industries operating in remote locations; and aeronautical communications service. The Commission concluded that only one system could be licensed for the first

generation system, and that joint ownership of this system would best permit a variety of mobile-satellite services to be made available to the public in an expeditious manner. The Commission directed all qualified applicants to negotiate a joint venture contract and propose a mobile-satellite system. A consortium of eight qualified applicants, the American Mobile Satellite Consortium, submitted a technical proposal and joint operating agreement in 1988. The Commission expects to act on this application in 1989.

International Conference Activities

The year 1988 saw the culmination of over eight years' worth of work oriented toward the concluding Second Session of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of the Space Services Utilizing It (WARC-ORB[2]-88).

During the months leading up to the conference, Commission engineers and regulatory experts traveled to several countries, meeting with representatives of governments and international organizations influential on the outcome of the conference. These meetings included an ad hoc group of international satellite cooperatives, a permanent telecommunications committee of the Organization of American States, a seminar organized by the International Telecommunication Union (ITU) for African countries, and a global information meeting also organized by the ITU.

At home, the Commission completed the collection of U.S. satellite industry views concerning conference priorities and strategies. Its staff analyzed and promoted changes that supported U.S. interests for incorporation into the software under development at the ITU to be used for conference planning. In addition, Commission staff provided support for efforts of NASA's Lewis Research Center in their efforts to create computer programs that could also aid in the orbital planning of positions for virtually all of the world's countries. The Commission cooperated closely with NASA and the Departments of State, Commerce, and

Defense, as U.S. positions were finalized.

The six-week WARC-ORB(2)-88 conference was, by almost any measure, a success. An allotment plan was established which guarantees, in practice, to all countries an orbital position at which they can operate a communications satellite using particular frequency bands. The conference also improved the international procedures used to provide orderly access to the

geostationary-satellite orbit in other frequency bands. While satisfying concerns of some countries about a lack of equity in access to the geostationary-satellite orbit resource, the United States was able to protect the considerable investment of the U.S. satellite industry and ensure continued technological innovation in this important telecommunications area.



An IBM engineer does air traffic simulation with a new advanced automation workstation being developed for the Federal Aviation Administration.

Department of Transportation

Federal Aviation Administration

The Federal Aviation Administration (FAA) is a modal component of the U.S. Department of Transportation. Under the Federal Aviation Act of 1958, as amended, the FAA is charged with the dual mission of regulating air safety and fostering civil aviation. In pursuit of these objectives, the agency operates the national airspace system used by both civil and military aircraft. The FAA conducts a broad range of research and development programs, which can be grouped into two categories: those concerned with increasing safety, and those aimed at enhancing the efficiency of air navigation and air traffic control.

Aviation Safety

Traffic Alert and Collision Avoidance System

During 1988, the FAA made significant progress in implementing the Traffic Alert and Collision Avoidance System (TCAS) concept adopted in June 1981. The TCAS approach is aimed at providing a range of aircraft collision avoidance equipment alternatives to afford some degree of added collision protection for the full spectrum of airspace users. The TCAS equipment would utilize air-to-air interrogations between transponder-equipped aircraft and operate without dependence on ground facilities. The TCAS family includes three versions: TCAS I, a system that generates traffic advisories and provides the pilot with the bearing, range, and altitude of the intruder aircraft; TCAS II, which generates traffic advisories with bearing, range, and altitude of the intruder and provides resolution advisories in the vertical plane; and TCAS III, which generates traffic advisories with bearing, range, and altitude of the intruder and provides resolution advisories in both the vertical and horizontal planes.

TCAS I. The Technical Standard Order (TSO) that will permit active TCAS I to be manufactured under the TSO approval system was issued in August 1988. The FAA announced that a cost-sharing contract will be

awarded in 1989 to design, fabricate, and evaluate TCAS I units as part of an FAA/Industry TCAS I Limited Installation Program (LIP). Several aircraft belonging to regional commuter airlines will be used for the flight evaluation. At the end of 1988, the FAA was close to issuing a rule requiring all turbine-powered commuter aircraft with 10 to 30 passenger seats to carry TCAS I within six years of the effective date.

TCAS II. The TCAS II program is now in its certification-implementation phase. In October 1988, the FAA issued a final TSO and an Advisory Circular providing aircraft certification guidance. The agency continued the Limited Installation Program designed to permit evaluation of production-quality TCAS II equipment by a number of airlines under normal scheduled operations. In support of this program, cost-sharing contracts were awarded in 1984 to Bendix (now Bendix/King) and Sperry Dalmo Victor (now part of Honeywell) to design and fabricate TCAS II units, as well as to evaluate them on air carrier aircraft. On July 31, 1988, United Airlines completed a six-month in-service evaluation of Bendix TCAS II units on board a B-737 and DC-8. Northwest Airlines began flying Honeywell units on two MD-80 aircraft in September 1988 in an evaluation that will run through March 1989. Results to date indicate that the TCAS II concept is safe and operationally effective in all flight regimes and under all visibility conditions.

On December 30, 1987, the President signed Public Law 100-223, which requires TCAS II to be installed on all airline aircraft having more than 30 passenger seats by December 30, 1991. As 1988 came to a close, FAA was in the final stages of preparing a rule implementing this requirement.

TCAS III. Flight testing of version two of the TCAS III collision avoidance logic, using experimental TCAS III units, was completed at the FAA Technical Center in April 1988. Version three of the logic is being designed, and engineering tests and operational flight tests of this logic are planned to begin in 1989. The

flight tests will provide the Radio Technical Commission for Aeronautics (RTCA) with the engineering basis for the specification of TCAS III in Minimum Operational Performance Standards (MOPS). Completion of the final draft MOPS for the system is expected in September 1989. Although there is no requirement at this time for mandatory installation of TCAS III, a decision was made to conduct a Limited Installation Program for TCAS III similar to that described above for TCAS II. Honeywell and Bendix/King are expected to upgrade their TCAS II production units to the TCAS III level of performance, starting in late 1989. The airline flight program is scheduled to begin in early 1991.

Aircraft Crashworthiness

In 1988, the FAA issued final rules for the dynamic evaluation of seat and restraint systems for transport and general aviation aircraft. These rules were based on an extensive program of research, development, testing, and evaluation. As another part of its ongoing efforts to improve occupant survivability, the agency generated important data on the crashworthiness characteristics of the advanced composite materials developed for aircraft applications. This data base will be significantly expanded in the coming year with the results from actual drop tests on a commuter class aircraft.

The FAA began the development of advanced, non-destructive inspection equipment for detecting defective or weak bonds in both composite and metallic aircraft structures. It also initiated research on low-cycle and high-cycle fatigue in composite materials. To expedite its research and development efforts in the field of composite aircraft structures, the FAA signed new interagency agreements to continue cooperation with the Army, Navy, and Air Force. The agency will work with the Army on a study of the crash impact characteristics of composite structures. The joint effort with the Air Force will focus on the causes and mechanisms of failures of composite aircraft structures.



A Federal Aviation Administration planner configures air traffic on a computer model of New York's LaGuardia Airport, taking his data from actual traffic.

The FAA will work with the Navy in a joint evaluation of existing data on the strength and fatigue life of composite structures.

Aviation Weather

Windshear. The hazard of windshear, a sudden change in wind speed and direction, is among aviation's most serious safety problems. Usually associated with thunderstorms, hazardous windshear occurs both in gust fronts and in small, intense downdrafts known as microbursts. An aircraft flying through a microburst encounters a headwind, followed by a tailwind. The resulting reduction in airspeed and loss of lift may sometimes cause an accident. In conjunction with other Federal agencies, the FAA is addressing the windshear question through a variety of detection, warning, and flight guidance programs.

During 1988, the FAA continued to improve the Low Level Wind Shear Alert System (LLWAS), the ground-based wind shear detection system now in operational use. LLWAS provides windshear alerts to air traffic

controllers, who, in turn, issue advisories to the pilots of arriving and departing aircraft. The system uses computer processing to compare wind speed and direction from sensors, usually six in number, located at the airport. The basic version of LLWAS generates an alert whenever the center-field wind data differs from a sensor located at the airport perimeter by a pre-established threshold. In the upgraded version, an alert results whenever wind at a particular sensor location deviates from temporal and spatial values of the network average. The upgraded version has more sophisticated computer algorithms that reduce the number of false alarms and provide improved microburst detection. It also has onsite recording capability. By the end of 1988, the upgraded version was in operation at 58 airports.

In addition to upgrading six-sensor LLWAS, the FAA is deploying a version that employs an expanded network of 8 to 22 sensors. This version has full microburst detection capability, and allows the controller to distinguish between microbursts and gust fronts. Windshear advisories provided to pilots are in terms of runway-oriented headwind gain or loss. Specific approach and departure wind directions and wind speeds are also available to the pilot. The first expanded-network LLWAS system was commissioned at Denver Stapleton Airport in January 1988, and the second at New Orleans Moisant Airport in November of that year. During 1989, expanded-network LLWAS systems will be procured to replace six-sensor systems at 12 other high-use airports. These systems will be installed in 1990.

Terminal Doppler Weather Radar. During 1988, the FAA conducted an operational evaluation of Doppler weather radar at Denver's Stapleton Airport. During the evaluation, the Denver air traffic controllers received information on two types of windshear (microbursts and gust fronts), including their areas and intensity of precipitation, as well as prediction of when winds would shift at the airport. This information was automatically generated by computers analyzing the

radar data, and presented in a form that the controllers could read directly to the pilots. Because of this, the controllers did not have to interpret weather information, and could concentrate on their primary mission of separating aircraft.

The operational evaluation showed that Doppler weather radar can reliably and automatically detect windshear, and that the resulting warnings to controllers and pilots are timely and useful. The FAA therefore awarded a contract for production and installation of 45 operational systems at major airports, as well as for two support systems at FAA's Technical Center and Aeronautical Center. Installation is scheduled for the 1992 to 1994 period. Research will continue to enhance the performance of these Doppler weather radars so that they will be able to detect turbulence and tornados as well as provide accurate predictions of the formation of windshear conditions.

Airborne Windshear Program. Another part of the FAA's efforts to combat windshear is the Airborne Windshear Detection and Avoidance Program. This program is developing the system requirements for "forward-looking" airborne devices that could use radar, lasers, or infrared sensors to scan some distance in front of an aircraft and warn of hazardous windshear ahead. In order to apply the best combination of national resources to this task, the FAA entered into a five-year cooperative agreement with the National Aeronautics and Space Administration in 1986. The joint FAA/NASA program concentrates on three interrelated areas: (1) hazard definition, including a thorough understanding of the atmospheric phenomena and their effects on aircraft; (2) sensors, including the mechanics of building such devices; and (3) flight management, an investigation of how to incorporate sensor data into the flight deck environment.

During 1988, as during the previous year, the Airborne Program concentrated on defining the hazard and assessing the technological opportunities. The program formulated a quantitative definition of how windshear affects aircraft, a definition that is consistent

with industry developments in reactive devices, as well as with the work that is envisioned for forward-looking devices. In addition, the program gained greater insight into how the lowest 2,000 feet of the atmosphere behaves in a microburst. The technology assessments revealed that radar and lidar showed the greatest promise. A proof-of-concept study is underway for infrared to see if it can work in normal operation without false alarm. Since the hazard definition is completed and the first assessments of sensor technology have been done, the next step is to see what the requirements are for presenting the information to the flight crew. In 1989, therefore, the Airborne Program plans to emphasize the flight management aspect of the project.

In order for the Airborne Program to be successful, the FAA and NASA have ensured a good working relationship with the industry that is designing, manufacturing, certifying, and marketing airborne windshear devices. So far, there are dozens of organizations from around the world working with the Airborne Program. This enables the results of government efforts to be channeled into the appropriate areas for the fastest possible implementation.

Automated Weather Observing System. Most airports within the United States do not have a local weather reporting capability, and this lack restricts commercial operations under instrument flight rules at over 1,300 locations. This situation can be improved through the Automated Weather Observing System (AWOS), which uses automated sensors to make surface observations of aviation-critical weather data. The system processes and disseminates this data, using computer-generated voice to broadcast current weather to pilots by radio. Users may also contact AWOS by telephone, and the system has the ability to transmit observations to the data bank within the national weather network. AWOS I, the basic version of the system, is able to compute density altitude and has sensors to measure wind speed and direction, ambient and dewpoint temperature, and altimeter setting.

AWOS II includes the AWOS I sensors plus a visibility sensor, and AWOS III adds a cloud height sensor to the AWOS II capabilities.

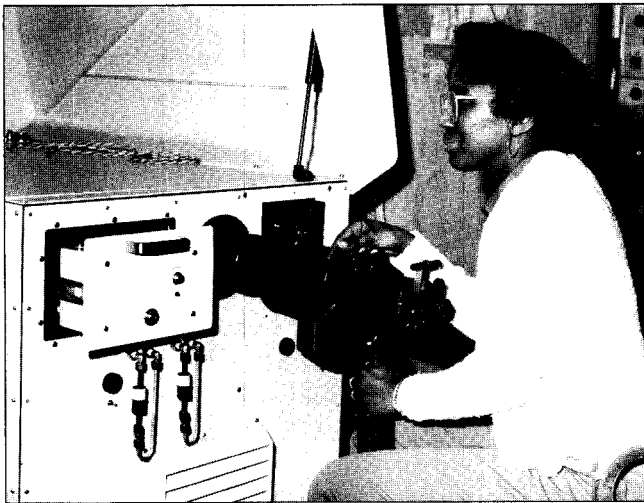
State and local airport authorities may apply for partial funding of AWOS under the Airport Improvement Program. The FAA certificated three companies as suppliers of the system during 1987, and in 1988 the agency awarded a contract to one of these firms for 160 of the AWOS III systems. These Federally owned systems will be installed at airports without towers, where they will provide an early enhancement of the safety and efficiency of flight operations. The FAA also continues to coordinate with the National Oceanic and Atmospheric Administration (NOAA) on the procurement and operation of additional and more sophisticated Automated Surface Observing Systems (ASOS). The ASOS equipment will be used at airports where FAA personnel currently take observations, and at additional non-towered airports. The agency has a planned requirement for 537 ASOS's, with a potential requirement for an additional 204 systems.

Atmospheric Electrical Hazards. The FAA concluded its evaluation of lightning simulation techniques. The agency also co-sponsored an international conference on lightning and static electricity that generated 103 papers on electromagnetic research. In addition, the agency issued an Advisory Circular on the protection of avionics systems against the indirect effects of lightning, and another on high energy radio frequency fields.

Icing. The FAA conducted a study of a deicing system for aircraft that uses electromagnetic impulses. The agency concluded that such systems would be suitable for use on metallic aircraft wings, but could pose problems for composite wings.

Aviation Security

During 1988, the FAA took significant steps toward fielding new systems to solve threats against civil aviation. Airport testing was completed on two designs of thermal neutron analysis systems used to detect



A chemist at the Federal Aviation Administration Technical Center works with a device that can sense traces of vapor emitted by plastic compounds and explosives.

explosives in checked baggage and air cargo. Based on testing of over 30,000 passenger bags, a decision was made to procure a limited number of these systems for deployment at selected airports. A contract for procurement of five of these systems was signed in August. Deployment of this technology will provide the first automated explosives detection system.

In October, research on detecting explosives carried by a passenger proceeded to prototype testing at Boston Logan Airport of a system using the chemiluminescence detection technique. False alarms were well below one percent, and public acceptance of the system was excellent. Additional work is underway on the system, as well as on competing technologies, in an attempt to further increase the ability to detect explosives while decreasing the processing time.

Significant progress has been made in research to improve security at the concourse screening checkpoints. A Phase I Small Business Innovative Research Effort solicitation resulted directly in a commercial

product that should dramatically improve the effectiveness of x-ray inspection system operators. The product is a false image projection device to motivate the operators and measure their performance. State-of-the-art metal detectors and x-ray systems were also evaluated during 1988. A new set of smaller weapons, fabricated from a cross section of materials, was procured for detector calibration. Use of these calibration weapons will bring airport security checkpoints into compliance with the Undetectable Firearms Act of 1988. In addition, technology was identified that has shown in laboratory conditions the ability to detect nonmetallic weapons carried by an individual.

In conclusion, the FAA is approaching the problem of detection of the terrorist's tools—weapons and explosives—by focusing on detecting the fundamental properties of the threat. Mature technologies such as thermal neutron analysis have undergone extensive airport testing, and a limited number of systems are being procured. Other technologies are being pursued in anticipation of potential threats such as the nonmetallic handgun. The objective of the program is to develop capabilities for the total airport security system to deter and defeat threats against civil aviation.

Aviation Medicine

During 1988, FAA continued its study of toxicity from burning or smoldering materials of the type used in aircraft cabins. Three individual toxic gases were studied: carbon monoxide (CO), hydrogen cyanide (HCN), and acrolein. Two gas mixtures (CO plus HCN, and CO plus acrolein) were also studied. Mathematical relationships were derived to describe the toxic effects of these various gases. This information is used to guide decisions on types of materials to be used in aircraft interiors.

In the area of medical certification, research was conducted during 1988 on functional color vision requirements for Air Traffic Controllers. Future air traffic control systems will embody color radar displays. It is important, therefore, to determine if this

equipment will require specific color vision capabilities that will have to be screened for in the initial medical examination of air traffic controller applicants.

Airport Pavement Research

In 1988, through an Interagency Agreement with the Army Corps of Engineers, the FAA completed research to update criteria on the design of overlays for deteriorated airport pavements constructed of portland concrete cement (PCC). The agency also completed a study to assess the importance of the yielding of base pavements on satisfactory compaction of asphaltic concrete surface courses necessary to assure pavement longevity. Research also provided criteria for recycling of PCC pavements. Theoretical study of aircraft arresting systems employing soft ground was completed in 1988. Devices for rapid assessment of pavement properties onsite for use in design and strength evaluation were completed. In addition, studies on the effect on pavement performance of pavement layer separation were completed.

The FAA continued work on methods for strengthening weak subgrade soil through the use of lime, cement, flyash, and polymers. The agency continued to develop a statistical monitoring system to assure that pavement criteria provide the intended level of pavement performance. The FAA also continued to obtain information on how to prevent premature cracking of pavements in cold climates, and to assess the value of foam insulation in decreasing frost heave and thaw weakening of airport pavements. Research and development in the area of runway surface roughness provided various methods of providing smooth runways and taxiways.

A rapid and accurate method of measuring runway profiles was verified during 1988. The agency conducted a simulation study of the use of straightedges of various lengths to determine if runway surfaces have excessive undulations. These techniques were applied to an operational airport runway that was reported to provide "rough" rides to airline crew and passengers.

The results of the investigation verified the "rough" condition and recommended suitable runway repair.

Other Safety Developments

General Aviation Fuels. In 1988, the FAA completed its evaluation of the use of automobile gasoline in general aviation aircraft. The study concluded that these aircraft could avoid vapor lock, detonation, and other potential problems associated with automobile gasoline by operating at reduced power, provided that the engine had an adequate power margin. The study also reported no evidence of a valve wear problem due to the use of unleaded automobile gasoline.

Safety Fuels. The FAA signed an agreement in 1988 with the Coordinating Research Council, an organization that coordinates research among petroleum, equipment, and transportation industries. Under the agreement, the Council will serve as an advisor to the agency in its continuing efforts to develop jet fuels that will reduce the hazards of postcrash fires. The agency conducted preliminary evaluations of two safety fuel candidates in 1988, and has scheduled screening tests on others for 1989.

Jet Engine Bird Hazard Program. Data obtained by FAA from its bird ingestion programs in 1988 indicate, as expected, that high bypass turbofan engines, with their large inlet areas, are more likely to ingest birds than low bypass turbofan engines or turbojet engines. The data also indicate that the current medium bird size used in engine certification (1.5 pounds) may not be sufficient, and FAA is reviewing a possible increase in this size. The agency also initiated a study of the bird ingestion patterns of the new, very high bypass ratio turbofan engines that are used on the latest transport aircraft models (Boeing's 747-400, 757, and 767, and Airbus Industrie's A-320).

Rotorcraft Safety. In a cooperative effort with the Army and Navy, the FAA began work on the development of lightweight "soft wall" containment materials that can absorb and contain fragments from a helicopter turbine engine that is disintegrating. The agency

reviewed and analyzed the causes and effects of uncontained turbine engine failures in the civil helicopter fleet through 1984 and, in 1989, will examine and analyze the data on such failures through 1987. The FAA also developed and published an Emergency Medical Services Advisory Circular (AC 135-14) for prospective and current helicopter operators providing this type of service. Generated during several meetings with industry, this document focuses on safety enhancement.

Aircraft Rescue and Firefighting. Current firefighting agents have been found ineffective against three-dimensional magnesium fires. The FAA performed tests with a new agent called Borolon, which has shown promise in upgrading our ability to fight aircraft magnesium fires. The agency is also evaluating a new concept, the use of heavy-duty hydrocarbon agents that are plunged into burning fuel to form a water-in-oil emulsion that acts as a skin to smother the fire. Tests to date have concentrated on the four most promising of these agents. Another significant accomplishment was the determination of the cause of deteriorating performance of certain firefighting agents in the field. The FAA also extended the firefighting test envelope of dry powder agents to more difficult fire scenarios.

Cabin Fire Safety. Late in 1988, the FAA completed its ground and flight evaluations of new concepts for evacuating cabin smoke during in-flight fires. Preliminary results indicate that exhaust valves installed in the cabin roof, where smoke accumulates, are more effective than exhaust valves now installed in the belly of transport aircraft.

Low Impact Resistance Structures. The FAA continued its development of Low Impact Resistance Structures (LIRS) designed to reduce the damage sustained by aircraft that might collide with air navigation equipment and supports. Work proceeded on the mathematical model and on design and test criteria for LIRS, including Fixed Offshore Frangible Structures. During 1988, the agency completed static-type tests of

a land-based plastic tower that is 20 feet high and strong enough to support Microwave Landing System equipment. Dynamic tests of the tower's top platform were also completed. Preparations were made to conduct a series of laboratory impact tests of the tower's structural shape components. These tests will establish the dynamic response characteristics and fracture behavior of the structural shapes and the integral break-away mechanisms. A wing from a light aircraft will be procured and instrumented for a dynamic impact test of the instrumented 20 foot tower that is scheduled for October 1989.

Also during 1988, the FAA completed a draft report, "Static and Dynamic Strength of Electrical Conductors Specified for Airport Approach Lighting Structures" (DOT/FAA/PS-88-13), and began review in preparation for publication in 1989. The report covers the design and fabrication of the dynamic test apparatus developed to measure the energy and force required to break the electrical cables that are part of the structures that could damage an impacting aircraft.

Air Navigation and Air Traffic Control

National Airspace System Plan

Host Computer System. The FAA completed a major step in implementing the National Airspace System (NAS) Plan, a technological blueprint for modernizing and increasing the capacity of nation's system of air navigation and air traffic control, when it commissioned the Host Computer System at the Salt Lake City air route traffic control center (ARTCC) in June 1988. This was the twentieth and final ARTCC to receive the new system, and the event marked the successful completion of the program. While using the same basic instruction package as the IBM 9020 computers that they replaced, the Host systems are ten times faster and have four times the capacity. They will be able to handle the air traffic workload projected for 1995 using less than 40 percent of their capacity. Besides allowing for unforeseen growth, this capacity margin will enable the FAA to add new automation

functions and to upgrade such existing capabilities as conflict alert and en route traffic metering.

Advanced Automation System. The Advanced Automation System (AAS) is a totally new system designed to replace the air traffic control automation equipment now used in air route traffic control centers and terminal radar approach control facilities. AAS will include new controller workstations called "sector suites," new computer software, and new processors to improve productivity, processing capacity, and reliability, and to provide the flexibility necessary for future improvement in air traffic control automation.

In July 1988, the FAA awarded an acquisition contract to IBM after a four-year design competition between IBM and Hughes Aircraft Company. The award was suspended for three months due to a protest by Hughes. The government successfully defended the award before the General Services Administration Contract Board of Appeals, and work resumed on the contract in November. The AAS will be phased into the National Airspace System, beginning in 1991 with replacement of obsolete interface equipment, and ending in 2001 with commissioning of the last equipment in air traffic control towers.

Voice Switching and Control System. The Voice Switching and Control System (VSCS) program will provide controllers at air traffic control centers with computer controlled voice switching for air-ground communications and intercom and interphone communications within and between FAA facilities. VSCS will be faster and more flexible, reliable, and economical to maintain than the present electromechanical switching system.

Design and development of the new system began in October 1986 with the award of competitive contracts to AT&T Technologies and Harris Corporation. A critical design review was conducted on the two competing prototypes early in 1988, and a request for proposals for the acquisition contract was issued in November. An acquisition contract to produce and

install 24 systems will be awarded in late 1989 to one of the competing contractors. The first system is expected to be operational in 1991.

New York TRACON. Work proceeded under a contract awarded in 1986 to UNISYS for upgrading the automated air traffic control system at the New York Terminal Radar Approach Control Facility (TRACON). Upgrading is required to increase the capacity of the current system, which services three major airports and 40 satellite airports in the New York Metropolitan area. Because of the complexity of the effort, the project is being undertaken in two stages. Stage I will provide tracking of 1,700 aircraft within a 15,000 square mile area. Stage II will increase the tracking capability to 2,800 aircraft.

In January 1988, an interim capacity upgrade became operational to provide near-term capacity until Stages I and II can be implemented. In the course of the year, hardware testing was completed at the FAA Technical Center for Stage I, and the first system was delivered to the field. Stage II equipment will be delivered to FAA for test and evaluation early in 1989.

Airport Visual Aids and Lights

During 1988, visual guidance activities at the FAA Technical Center emphasized the development and testing of lighting and marking systems to provide guidance under the lower visibility weather conditions. Evaluation of present standard taxiway sign devices to determine performance under natural conditions of very low visibility continued whenever fog occurred. New and unique taxiway centerline markings, which warn pilots of an approach to critical taxiway intersections, were evaluated under simulated low-visibility fog conditions. The FAA completed development and refinement of an in-pavement lighting system to warn pilots of the point at which they must hold clear of an intersecting runway when given a "cleared to land but hold short" clearance. The system will be installed for in-service testing at an air carrier airport during 1989. Additional work in support of FAA regional offices,

principally in providing solutions to field-encountered problems with visual aids, continued throughout 1988.

Airport Capacity

Task Force Studies on Airport Capacity Enhancement and Delay Reduction. This continuing FAA program provides site-specific analysis of current airport conditions that cause delay. The Task Forces are made up of representatives from the FAA, major and commuter airlines, the general aviation industry, airport sponsors, airport consultants, and local planning agencies. These groups evaluate current conditions and proposals for airport improvements in order to optimize capacity and reduce delay. Each Task Force uses computer simulation modeling techniques to analyze present and future levels of operations. Task Forces have identified the need for new runways, changes in operational procedures, and modification of taxiway and gate structures. In 1988, Task Force studies were completed at Miami, St. Louis, Detroit, and Memphis. Studies continued at Boston, Phoenix, Salt Lake City, and Kansas City, while new studies began at Washington/Dulles, Seattle, and Orlando.

Airspace and Airport Simulation Models. The FAA recognizes the urgent need for improved computer models to study airspace congestion near airports and in multi-airport terminal areas. The agency is vigorously developing simulation capabilities that will accurately depict the consequences of new procedures and designs affecting airspace and airports.

In 1988, computer simulation modeling was used as a tool in addressing several critical capacity and delay problems and issues in the Los Angeles Basin. Modeling was used in identifying and evaluating potential solutions to congestion and delay. Included were evaluation of operational alternatives involving realigning airspace, redesigning aircraft routings, and revising procedures to enhance the efficiency and safety of air traffic operations. Simulation capabilities were used to quantify delay, travel time, capacity, and sector load-

ing, as well as the operating cost impacts of proposed new airspace structures, routings, and procedures.

Using FAA's Airport/Airspace Delay and Fuel Consumption Simulation Model (SIMMOD), the capacity of Los Angeles International Airport was determined. Delays were quantified for air traffic passing through narrow flight corridors in order to avoid airspace reserved for military special use. Over 30 hours of daily delay are attributed to the problem of special-use airspace. Alternative routing and procedures were evaluated for efficiency and delay reduction. The priorities for reserving large quantities of airspace for the military near population centers must be changed.

NASPAC (National Airspace System Performance Analysis Capability), a prototype model that simulates air traffic through the NAS, was developed in 1988. The model aids in developing limiting factors in the NAS that cause congestion and delay. This enables planners to work toward solutions to reduce choke points and limitations. Applications of NASPAC will provide an integrated, in-house operations research capability to respond to questions on system performance, capacity, and flow management. Additionally, NASPAC will enable airspace system planners to vary operating conditions that affect capacity and delay, and allow them to develop optimal solutions for meeting air traffic requirements.

In 1988, the FAA upgraded its Dynamic Ocean Tracking System (DOTS), a model which computes the most fuel-efficient track and vertical profile, taking into account the weather, aircraft performance, separation rules, and airspace availability, for each aircraft entering the track system. An agreement between the U.S. and Japan was reached, and an Annex signed to permit testing of DOTS in the central Pacific. A Traffic Display System at the Oakland air route traffic control center has undergone installation, demonstration, and evaluation in preparation for the upcoming testing of aircraft position reports in Japanese-controlled airspace.

Precision Runway Monitor Program Plan. This program is a response to the rapid growth of air traffic, which is forecast to increase at 6 percent annually, and the consequent urgent need for airport capacity solutions that can be implemented within the next five years. At airports with parallel runways, "dependent" approaches are required when runway separation and weather conditions dictate that controllers maintain diagonal separation between aircraft on the parallel runways, as well as in-trail separation between aircraft on the same runway. Capacity (arrivals per hour) can be increased by an average of 40 percent if the distance between the runways is sufficient to remove the diagonal separation requirements and thus allow the arrival streams to be independent of each other. Under visual flight conditions, independent approaches are permitted with runways separated by as little as 700 feet. Under instrument flight conditions, however, runways must be separated by at least 4,300 feet to allow independent approaches.

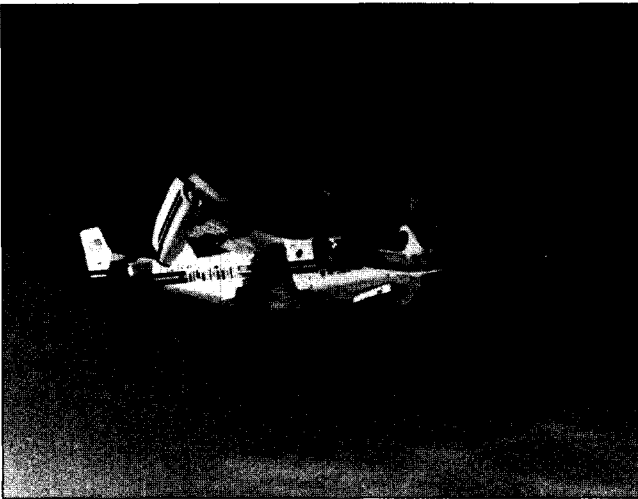
Recent studies have suggested that independent approaches to parallel runways separated by as little as 3,000 feet can be safely conducted under instrument conditions if arriving aircraft are monitored by a precise radar system that will update aircraft position faster than the 4.8 second rate of existing approach radar systems. This capability will reduce capacity problems at ten candidate airports. About 50 additional airports will benefit if the concept can be applied to converging runways. In addition, independent approaches to closely spaced parallel runways will open possibilities for new runway construction at other airports with land-limited conditions. To meet these objectives, the FAA has undertaken a comprehensive demonstration program involving two different technical approaches to finding a suitable sensor for monitoring closely spaced independent parallel approaches. Both approaches are based on application engineering of existing technology, and hence can be implemented in the near term.

One approach is to modify the new Mode S beacon system, presently being procured for installation at all major airports, by adding another antenna. The back-to-back, mechanically rotating antenna will double the update interval of the Mode S system, so that it will "see" a target once every 2.4 seconds. The other approach is to develop a very high update rate sensor that will use a fixed, circular, electronically scanned (E-Scan) phased array antenna. This antenna is a derivative of a circular antenna developed for the Navy. Aircraft tracking algorithms and software were extracted from the TCAS collision avoidance program described earlier in this report. The electronically scanned antenna will be able to see each approaching aircraft once every half second.

Operational demonstration of the Mode S system began in August 1988, in Memphis, Tennessee. The E-Scan system will be delivered to Raleigh-Durham, North Carolina, in February 1989, for a demonstration that will continue through 1990.

Air Traffic Control Radar Training. The FAA is constantly faced with the challenging task of maintaining a highly trained air traffic controller workforce. This task has become increasingly difficult in recent years due to the large influx of new air traffic control (ATC) personnel and a significant increase in traffic. In 1986, the agency initiated a research project to explore the basic feasibility of exploiting "expert systems" computer technology for controller training. The initial analysis was promising, and the FAA proceeded to develop a prototype system during 1987 and 1988. Working closely with ATC personnel from Boston Logan International Airport, the contractor developed a prototype system that utilizes a low-cost personal computer and expert system logic to emulate the pilots and the instructor during radar training simulation exercises.

The prototype loads the expert system with "rules" from the controller's handbook regarding aircraft separation minima, interfacility letters of agreement,



An XV-15 tiltrotor research aircraft built by Bell Helicopter Textron.

internal procedures, noise abatement procedures, restricted areas, and any other "rule" the training department wishes to teach. The controller trainee is supported by a pseudo-pilot who uses keyboard entries to "fly" the aircraft. The computer reacts to the data entries with appropriate "pilot" responses through a voice generator. Also, the expert system monitors the position and altitude of every aircraft and, using a different voice, alerts the trainee to any rule violations.

A contract is being let for an independent evaluation during 1989 that will include an estimate of the training effectiveness of an expert system technology application based on a personal computer. If the application is found effective, the contractor will provide the foundation for defining the functional requirements associated with a major acquisition of production-level systems.

Rotorcraft/Power Lift Vehicles Program

In addition to the actions discussed in the Rotorcraft Safety section above, the FAA took a number of steps

to assist the development and efficient operation of helicopters and power lift vehicles, including tiltrotor aircraft.

Heliports. In July 1988, a joint FAA/Industry committee was formed to assess design standards for large heliports and for vertiports intended for tiltrotor operations. The FAA appointed Regional Heliport Development Coordinators to carry out mission responsibilities to industry in the area of heliport and vertiport development. These coordinators will serve as a focal point for development concerns within specific geographic areas.

Heliport Approach Lighting Systems. Approach lighting systems intended to support both precision and non-precision helicopter instrument approach operations were tested under simulated low-visibility conditions to develop visibility credits that may be allowed for installed lighting systems. Validation testing of these systems will continue during the next year.

Helicopter Routes. Helicopter operations were significantly improved with the development and publication of new helicopter charts for use under visual flight rules. The most recent of these were the charts for Washington, D.C., and Chicago, Illinois. These charts enhance helicopter operations in and around terminal control areas by allowing equal access to available air space. They comply with environmental concerns, and consider travel flow and helicopter use needs.

Helicopter Wake Vortex Study. In 1988, the FAA and the Department of Transportation completed their joint study of the characteristics of helicopter wake vortices. The final report will be published in 1989. The FAA will use the data to develop air traffic control standards for helicopters operating in terminal areas.

Civil Tiltrotor. In 1988, the FAA, NASA, Department of Defense, and Department of Commerce began to pursue the development and implementation of a coordinated civil tiltrotor transportation plan. The goal of the plan is to make the U.S. civil air transportation system ready for introduction of the civil tiltrotor in

1995, with early demonstrations beginning in 1992. In order to accomplish this, development and support of airport, airway, and air traffic infrastructure was initiated. Certification of aircraft and airmen was also begun.

Rotorcraft Government/Industry Cooperation.

The FAA Technical Center hosted an FAA/Industry Rotorcraft forum. The forum provided information to the industry on FAA accomplishments, rotorcraft technology to be fielded in the 1990's, an overview of heliport and vertiport development, and public awareness on such issues as noise and other environmental concerns.

Rotorcraft Aeronautical Decisionmaking.

During 1988, the FAA continued to develop and distribute aeronautical decisionmaking materials (ADM), publications designed to increase skills in choosing the best available option. Expanding on the ADM training manual for helicopter pilots, the agency developed new training materials for pilots, operators, and hospital administrators involved in helicopter emergency medical services. The FAA began developing an Advisory Circular on ADM general applications, and initiated a feasibility study to ascertain whether ADM techniques can be applied to air traffic control.

Commercial Space Transportation

The Office of Commercial Space Transportation (OCST), established by the Secretary of Transportation in 1984, is charged by Executive Order 12465 and the Commercial Space Launch Act of 1984 with overseeing and coordinating the U.S. commercial space transportation industry. This mandate includes the responsibilities for establishing a policy environment that serves to enhance the industry's position in world markets and for defining regulatory guidance that ensures safe and responsible launch operations.

During 1988, OCST continued to enter new areas and break new ground to create the foundations for guiding privately conducted launch activities in

preparation for the commercial launch operations that were to begin in 1989.

Policy and Legislation

Since 1984, when OCST was created, several major Federal policy decisions have reinforced the Government's support for commercial space enterprise in general and for a vigorous commercial space transportation industry in particular. For its part, OCST has worked to ensure that Federal policies affecting this industry lead to continued growth, diversified services and reliable access to space at reasonable cost.

National Space Policy. The release of the President's National Space Policy in February 1988 recognized for the first time a distinct commercial space sector which, along with the military and civilian Government sector, forms an integral part of the overall national effort to maintain U.S. space leadership. Concurrently, with the release of the national space policy, the Administration announced a 15-point plan on commercial space initiatives. The new policy was aptly named "Space Policy and Commercial Space Initiative to Begin the Next Century."

The Amendments to the Commercial Space Launch Act. Having advanced to the point where it had successfully secured its first launch contracts, the commercial space transportation industry was almost immediately confronted with a serious issue: potentially open-ended exposure to liability for damages associated with launch operations. Such exposure threatened to undermine the position of U.S. firms vis-a-vis their foreign competitors.

The Administration and the Congress successfully crafted a legislative initiative to address this concern. Building on work conducted by OCST in the area of risk assessment and management, the Commercial Space Launch Act Amendments of 1988 established a Government/industry risk sharing scheme that will permit companies to acquire insurance at rates that do not render them uncompetitive, thus helping to assure U.S. access to space through commercial providers.

In other areas, the 1988 Amendments helped clarify the types of costs for which commercial users must reimburse the national launch ranges, established incentives for the launch of certain eligible satellites on U.S. launch vehicles, provided protection from arbitrary Government preemption of commercial launch slots, gave instructions to DOT to study more efficient and commercially reasonable scheduling of commercial launches at national ranges, gave the sense of Congress that the United States should pursue guidelines for fair international competition in commercial space activities, and assigned NASA the responsibility of designing a program to support research into launch system component technologies.

Status of the U.S. Commercial Space Transportation Industry

Taken together, these policy initiatives have created an environment that is more conducive to private investment in and business commitments to commercial launch activities. At present, at least eight domestic launch firms are actively marketing their services: three major aerospace manufacturers—Martin Marietta, McDonnell Douglas and General Dynamics—and five smaller firms: Space Services, Inc.; American Rocket Company; Orbital Sciences Corporation; E'Prime Aerospace Corporation; and Conatec, Inc. As of June 1988, these commercial launch companies have contracts worth nearly a billion dollars in potential revenues.

As of the end of 1988, these private sector firms have already invested almost \$500 million in commercial launch activities. The greatest portion of this investment was made by the three largest commercial launch companies; however, a significant amount of capital has been invested by each of the smaller firms as well.

Regulatory Program

DOT shoulders primary responsibility for ensuring commercial launch activities are conducted safely and responsibly.

Licensing Regulations. The Licensing Programs Division of OCST is responsible for issuing launch licenses for commercial launch activities. The purpose of this licensing process is to protect public health and safety, property, and U.S. national security and foreign policy interests, and to ensure compliance with U.S. international obligations. Final licensing regulations were issued on April 4, 1988. The regulations address the wide range of activities for which OCST is responsible—launches, launch site operations, and certain payload activities—and are intended to provide the means for ensuring that each proposal is thoroughly, but promptly, reviewed.

In 1988, OCST issued two launch licenses: one to Conatec, Inc., covering two sub-orbital microgravity payloads to be launched from the White Sands Missile Range in New Mexico; and one to McDonnell Douglas Astronautics Company for launch of a telecommunications satellite for the Government of India (INSAT 1-D) from Cape Canaveral, Florida.

In addition to issuing two licenses, DOT has also completed mission reviews for Martin Marietta's proposed launch of two communications satellites, SKYNET and JCSAT, aboard its Titan launch vehicle.

Insurance Requirements. By 1988, OCST had recommended, as a matter of policy, to establish insurance requirements for commercial launch activities based on an assessment of the actual risks associated with each proposed activity.

In 1988, OCST established insurance requirements for four companies. The office issued both third-party liability and Government property insurance requirements to Conatec, Inc. The office also completed the analytical work upon which to base Government property insurance requirements for the three major launch firms.

Research for Regulatory Functions. By 1988, the safety problems associated with this industry had become more clearly defined. OCST efforts subsequently shifted from data collection to research and

analysis of specific issue areas. Primary focus was on areas where public safety was most immediately affected or industry advancements would most likely require a new body of Federal safety knowledge, including the following: issues associated with characterization of commercial launch risks; new flight concepts; flight safety equipment; range safety practices; personnel qualifications; and debris reentry. Some examples of research in 1988 follow.

International Activities

The year 1988 saw greatly increased activity in the world space launch market. OCST was an important participant in international negotiations concerning the competitive conditions under which this market will operate in the future.

European Space Agency Talks. In July and October, 1987 and July 1988, the U.S. and the European Space Agency held informal talks to determine if negotiations to establish trade rules, or "rules of the road," for the space launch services industry would be advisable. During 1988, OCST co-chaired the U.S. Interagency Working Group which, along with its European counterpart, attempted to fashion a comparative assessment of policies and practices that constitute direct Government supports.

Chinese Commercial Launch Services. A development of major importance for the U.S. commercial space transportation industry was the entry of the People's Republic of China (PRC) into active competition for launch customers. DOT/OCST became concerned about the impact that allowing U.S.-made satellites to be launched on Chinese launch vehicles at potentially arbitrarily low prices could have on the U.S. commercial space launch industry. Building on the President's National Space Policy, the Department argued that a broad range of national interests, including long-term national security, are advanced by a strong, diversified commercial launch sector. Unfair competition would undermine the industry and U.S. strategic interests as well.

On the recommendation of SIG-Space and the Economic Policy Council, and recognizing the strategic advantages of a strong U.S. commercial space transportation industry, the President notified Congress on September 12, 1988, of his intent to approve two pending satellite export license applications, contingent on the PRC's agreement to three conditions. The first two conditions related to liability and technology transfer. The third condition required completion of a U.S.-PRC agreement to protect the U.S. launch industry from unfair Chinese pricing or trade practices. No licenses would be issued until all three conditions had been met and COCOM had approved the exports. The U.S. entered negotiations with the Chinese in October 1988. These negotiations were concluded and the agreement signed by the end of January 1989.

Special Issues

Allocation of Critical Resources. Approximately one-half of the U.S. capability to produce ammonium perchlorate (AP), which is used for solid rocket motor fuel, was destroyed in an explosion of the PEPCON facility in May 1988.

In September 1988, DOT asked the Federal Emergency Management Agency (FEMA) to determine that the commercial space launch sector should receive equal priority with NASA and the Department of Defense for purposes of the allocation of this critical resource. FEMA's positive response authorized "the commercial space launch program to receive priorities and allocations support under Title 1 of the Defense Production Act."

Commercial Space Transportation Infrastructure. U.S. firms currently rely upon the existing national launch infrastructure to support commercial operations. This infrastructure consists of several launch sites and facilities made available on a direct-cost, reimbursable basis to commercial launch firms, but which are nonetheless subject to first-priority Government usage. Thus, an exciting development in 1988 was the stated intention of two states to consider

development of commercial spaceports. These states committed to expend relatively large sums of state funds to assess their feasibility. OCST played an active role in supporting these initiatives through the provision of information and ongoing efforts to study and clarify issues pertaining to commercial range operations.

In February 1988, a consulting firm completed a study for the State of Hawaii and selected Palima Point and Kahilipali Point as the sites with the best potential to be commercial spaceports. Subsequently, the State announced plans to award a contract for the preparation of a master plan and environmental impact statement for a commercial expendable launch vehicle complex and associated facilities for all classes of boosters.

On March 1988, the Governor of Florida announced plans to establish a commercial spaceport. Spaceport Florida would be a launch services and payload processing facility for the use of commercial orbital and sub-orbital launch operations. Florida selected a consulting firm to formulate a master development and business plan for Spaceport Florida.

In addition, the Commonwealth of Virginia indicated its commitment to encouraging commercial launches from NASA's Wallops Flight Facility within the next five years.

Outreach Activities

A critical ingredient to the success of the commercial space launch initiative is OCST's ability to communicate how it intends to regulate commercial space transportation activities and identify resources it has developed through its research program for that purpose.

In June 1988, OCST and NASA jointly sponsored a highly successful symposium titled "Future of the U.S. Space Transportation Industry." This event brought together senior officials from Government and industry to discuss future issues affecting the industry.

In October 1988, OCST, NASA and the Air Force jointly sponsored the "Commercial Space Risk and Insurance Symposium." This symposium was targeted to the insurance community for the purpose of describing OCST's technical approach to the risks associated with space transportation.



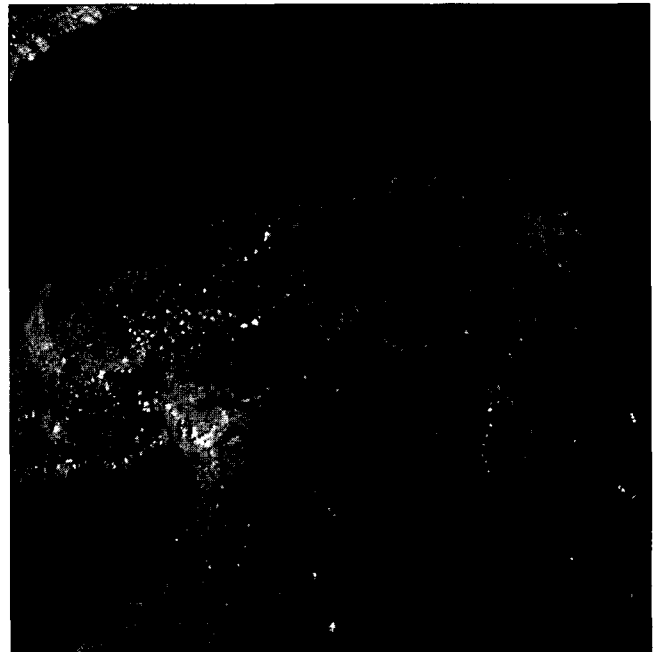
Photointerpretation analysis of hazardous waste site using large-scale vertical aerial photography.

Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA), through its Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV), routinely conducts research and technical support using remote sensing as part of an overall environmental monitoring program. Large scale aerial photography is collected and interpreted to support the provisions of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); medium scale photography is collected and interpreted to support non-point pollution studies, wetlands protection, coastal zone studies, and forest ecosystem decline due to acid deposition; and high altitude photography is interpreted for broad area studies in the coastal zone and to contribute land use/land cover information in risk assessment studies. Airborne and satellite multispectral scanner data are collected and interpreted to support water quality, non-point pollution, hazardous waste, and acid deposition investigations. Airborne laser systems are developed which contribute to air and water monitoring, and a geographic information system (GIS) is used to integrate multiple data sets in support of all EPA programs.

Hazardous Waste

Large scale aerial photography is used to develop site wharacterization data during the remedial investigation/feasibility study (RI/FS) portion of remedial actions under CERCLA (the SUPERFUND). Aerial photographs are collected from a variety of archival sources which may date from the late 1920's and continue to the present. A site history is developed by visually interpreting the historical photography, annotating changes at the site. This provides vital information on the location of drums, pits, and lagoons, as well as the level of activity at the site over time. Further photographic interpretations provide documentation of cleanup progress and are sometimes used to monitor post-cleanup status. The same photo-



Landsat Multispectral Scanner image showing turbidity plume at left flowing north from the Welland Canal into Lake Ontario in the upper part of the image. The eastern tip of Lake Erie is visible in the lower left.

graphs are also used to develop detailed topographic maps of each site which are critical to the cleanup process.

Aerial photography is also used to support site selection and monitoring at hazardous waste facilities operating under RCRA. During the site selection process, aerial photographs, airborne multispectral scanner data, and satellite imagery are interpreted to develop a detailed site characterization. The interpretations are then used with collateral data (such as soils, geology, and groundwater data) to determine applicability under the site selection criteria. Aerial photography is routinely used to monitor development, operation, and closure activities once a site has been approved for operation.

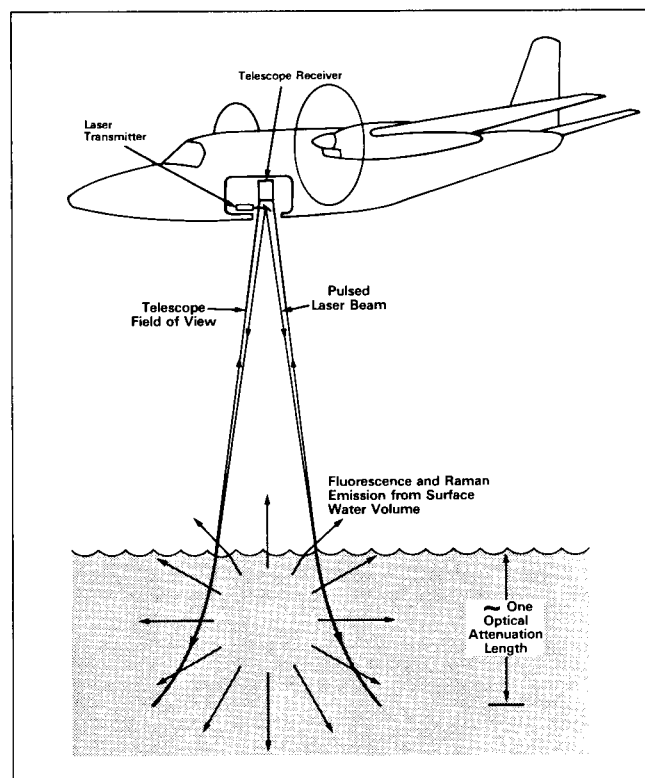
Aerial photography also supports emergency actions during spills and accidents. Photographs are acquired through local contractors and are interpreted and sent to the field within 24 to 48 hours of an accident or spill. These photographs of existing conditions form a permanent record of the on-scene conditions and are used to develop control and remedial strategies.

Water Quality

Remote sensing systems are developed and used by EPA to support the provisions of the Clean Water Act. The Landsat satellite system and an airborne multispectral scanner are used in conjunction with water samples to map the extent of Chlorophyll a, Secchi depth, turbidity, dissolved organic carbon, and a variety of other water quality parameters in both freshwater lakes and near-coastal marine environments.

A Laser Fluorosensor, developed by EPA, is an airborne profiling system that is capable of measuring an array of water related features in all fresh, estuarine and marine waters. These include chlorophyll a, dissolved organic carbon, the optical attenuation coefficient, water body mixing, estuarine salinity and the density of blue green algal blooms. The primary use for this sensor is to provide regional scale water quality coverage through extrapolation of limited concurrent "ground truth" data sets obtained from grab samples or in situ measurements. As a logical extension of this activity, the same data can be used to "calibrate" airborne and satellite multispectral scanner data gathered over extensive spatial scales.

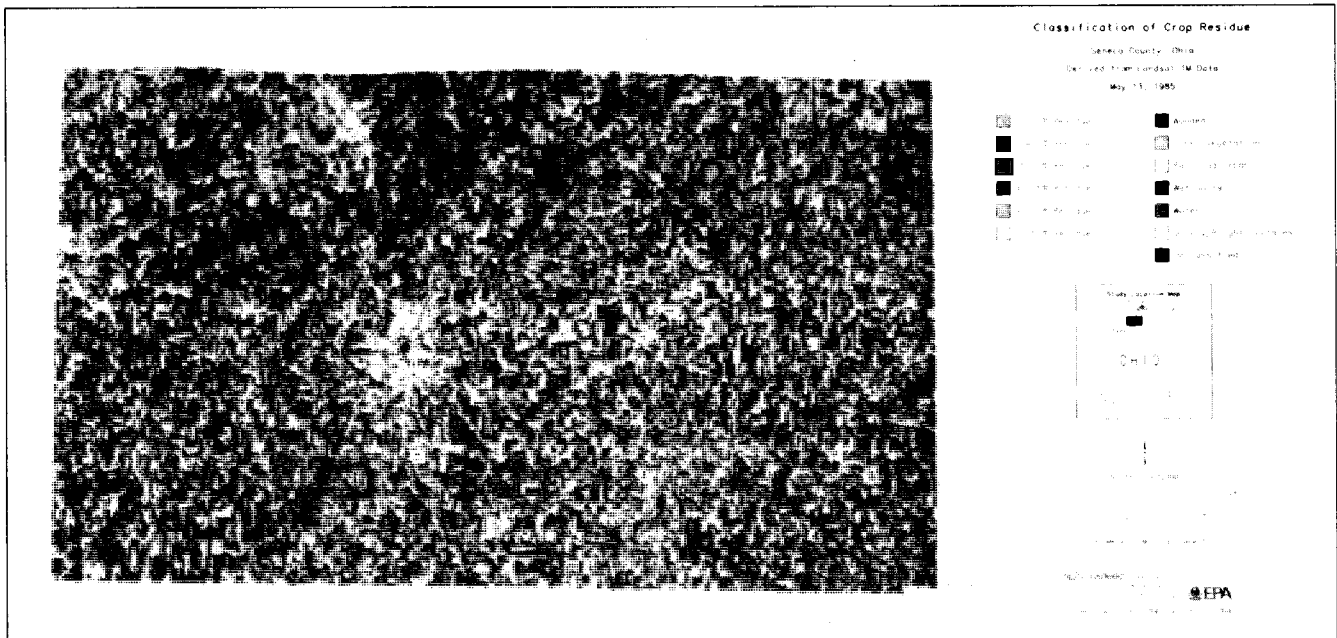
Aerial photography and satellite data also support non-point pollution studies. Satellite imagery provides the broad view of land cover, while aerial photographs provide detailed interpretations of the distributions of feeder lots, poultry farms, and other activities requiring high spatial resolution. These data are input to models, such as Purdue University's "Answers Model" to determine nutrient loadings to aquatic ecosystems.



Laser Fluorosensor.

Air Quality

EPA is currently using an airborne two-frequency Light Detection and Ranging (LIDAR) system to monitor particulates associated with point source plumes, major urban plumes and air masses. In development (with partial NASA support) is an airborne Ultraviolet Differential Absorption LIDAR (UV DIAL) to simultaneously measure ozone, sulfur dioxide, and particulates. These instruments provide range-resolved profiles under the aircraft which can be used to monitor pollutant transport especially in coastal areas and complex terrain where models perform poorly and where air pollution transport problems are most severe.



Seneca County, Ohio. Classification of agricultural lands into crop residue categories using Landsat Thematic Mapper data. These data were required as input to a nonpoint source runoff model which was used to determine nutrient loadings into rivers and lakes.

EPA, in conjunction with the U S National Park Service, is also conducting remote measurements of visibility in Class I areas (National Parks and Wilderness Areas). Photographic and electro-optical sensors are deployed to monitor scenic vistas to determine atmospheric extinction coefficients. Variations in extinction coefficients are then related to variations in air pollutant levels.

Wetland Protection

An area of increasing environmental concern is the protection of the Nations wetlands. A major problem facing legislators and program administrators is the availability of accurate and rapidly updateable spatial information on the status and trends of wetland resources on both a National and regional scale. The EPA is attempting to fill this void through implementa-

tion of a Nation wide environmental monitoring and assessment program (EMAP) for wetland resources. Remote sensing and GIS research is being conducted by EPA to provide advance wetland identification and spatial data analysis analysis techniques in support of the program.

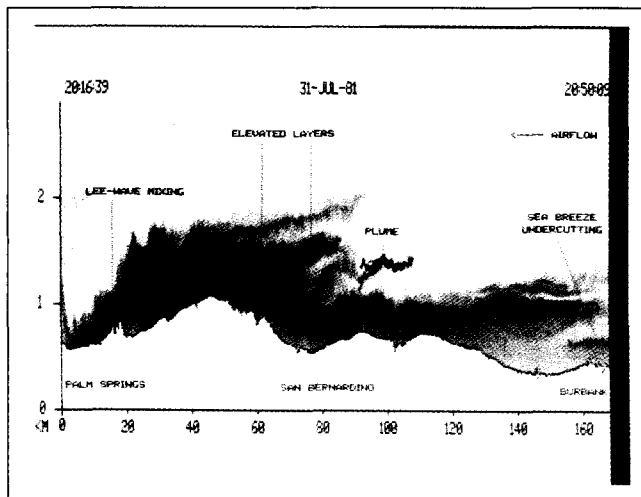
EPA is using single date and multi-temporal Landsat Thematic Mapper (TM) data and GIS technology to delineate wetlands for wetland advance identification, change detection, and spatial distribution analysis.

Current applications include the use of multi-temporal TM data to delineate the past and current extent of regional bottom land hardwood (BLH) wetland resources. GIS data analysis of satellite data products will provide maps and statistical information on the rate of BLH wetlands destruction, the spatial

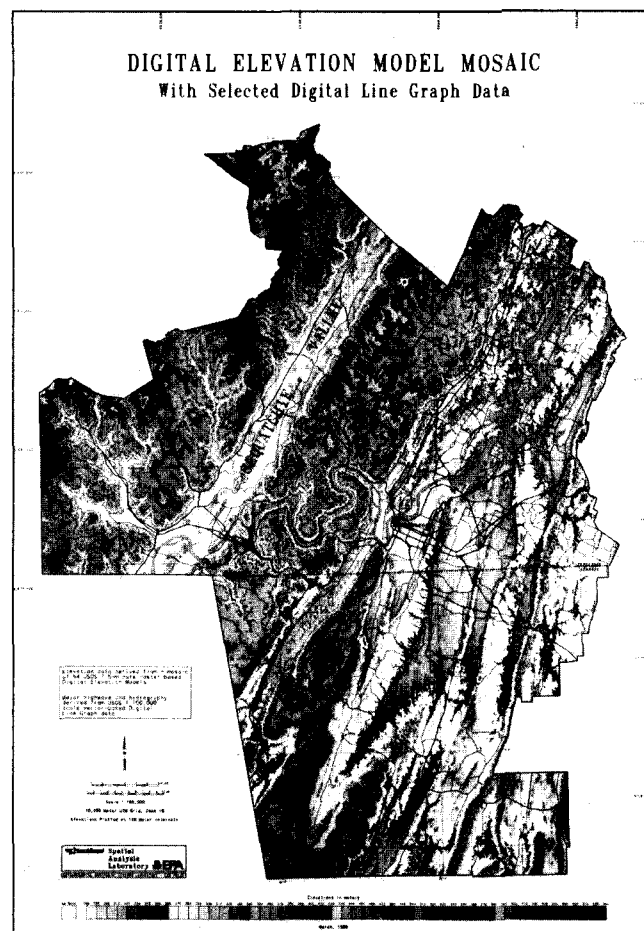
distribution of BLH losses, and facilitate a prediction of future rates and spatial distributions of BLH losses. Spatial information derived from the studies will provide a valuable tool to law makers responsible for stewardship of the Nation's wetland and to Regional decision makers responsible for administration of the Clean Water Act, Section 404 program.

Data Integration

Often, single-media monitoring and modeling do not provide sufficient scientific explanation of the complex environmental phenomena which affect human and ecological health. A geographic information system (GIS) is being implemented in EPA to provide a tool for multi-media data integration and analysis. The GIS is used to overlay and combine data from remote sensing, existing spatial databases, and tabular data from state, local, and EPA national databases to provide analyses of complex environmental situations for programs such as wetlands and estuarine protection, water quality, acid deposition, global climate, and hazardous waste cleanup.



Example of Light Detection and Ranging (LIDAR) system graph.



GIS data integration: Geographic Information Systems (GIS) provide a common framework to integrate and relate multiple layers, or themes of data. This example shows the integration of digital elevation model data with transportation and hydrography digital line graph data layers.

National Science Foundation

Atmospheric Sciences

The world's most powerful sodium resonance lidar system was developed at the University of Illinois in Urbana, Illinois, in 1988. The high power of this system puts it among the most powerful Rayleigh scatter lidars in the world. The combination of these two techniques allows high time resolution measurements of the structure and dynamics of the atmosphere from 30 to 110 km during both the day and night. Initial results from the system have shown rapid high-density changes associated with meteors, large perturbations due to gravity waves, and other previously unseen changes in the density structure of the upper atmosphere. Planned use of the system should go far in increasing our understanding of perturbations that are important in applications related to re-entry vehicles (shuttle, satellite debris) and in deducing the links between changes in lower and upper atmosphere weather systems.

A new meteorological hazard (the "downburst") for aviation was postulated by Professor Theodore Fujita, University of Chicago, using flight data recovered from a commercial aircraft that crashed at Kennedy International Airport in 1975. The National Science Foundation (NSF) supported three subsequent field experiments—in Illinois, Colorado, and Alabama—designed to verify the existence, structure, and evolution of the downburst postulated by Fujita. These experiments verified his predictions and provided much additional detail showing that a hierarchy of downbursts did exist and that they could be a serious hazard to aircraft, especially during landing and take-off. This new knowledge has been incorporated into various pilot training programs that teach pilots to avoid or minimize the effects of downbursts.

In addition, the role of Doppler radar in the detection of microbursts has been greatly expanded through the use of polarization in identifying the existence and distribution of ice and water precipitation particles.

Evaporation of such particles and the resulting cooling of the air are thought to be a major cause of downbursts.

The National Science Foundation has completed installation of a network of stations for monitoring ultraviolet radiation levels at Earth's surface under the Antarctic "ozone hole." This year, the last of four monitoring systems was installed at Ushuaia, Argentina; the others are located at the U.S. Antarctic Program stations at the South Pole, McMurdo, and Palmer. Data from this network will be used to determine the extent of ultraviolet (especially UV-B) radiation enhancement caused by the Antarctic ozone depletion and to assess the biological consequences thereof on organisms and personnel in Antarctica.

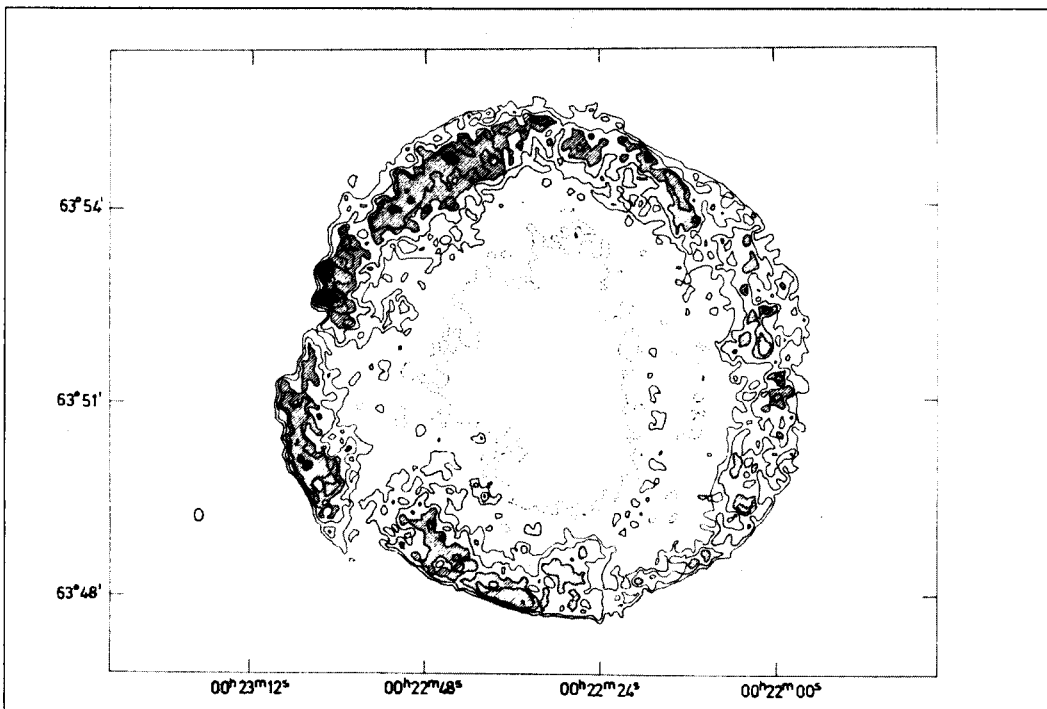
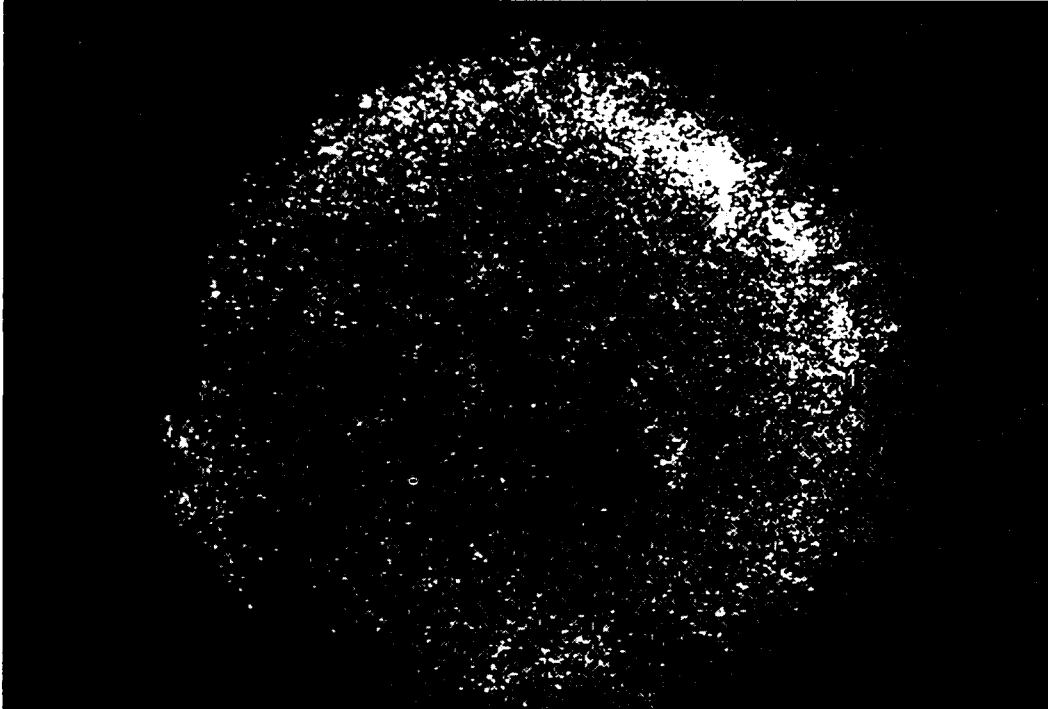
Astronomical Sciences

Gravitational lenses refer to massive objects that bend the light of more distant celestial sources located along the same line of sight. Their existence follows from Einstein's Theory of General Relativity. Independent evidence for the existence of gravitational lenses has been reported by optical and radio astronomers. Optical astronomers discovered extremely long, luminous arcs in two clusters of galaxies. Several theories have been proposed to explain the nature of these objects, but present evidence appears to indicate strongly that they are produced by gravitational lensing. A group of radio astronomers discovered an elliptically shaped source, which appears to be the gravitationally lensed image of a radio galaxy.

Astronomers developed and put into operation array detectors that are causing a revolution in infrared astronomy. Infrared images of galaxies that previously required ten hours of observations can now be obtained in seconds. In combination with other instruments, the detectors provide images of interacting galaxies, molecular clouds which are the sites of star formation, and solar systems in states of evolution different from our own.

The first visible light echo ever observed from a supernova has been detected. This phenomenon consists of two expanding, luminous arcs, which originate in light reflected off interstellar clouds located in the vicinity of Supernova 1987A in the Magellanic Clouds.

One of the fastest rotating pulsars, located in an eclipsing binary system, was discovered. Measurements of the orbital motion of the system indicate that the pulsar's companion is not massive enough for nuclear reactions to begin in its interior and, therefore, that it is a substellar object, possibly a brown dwarf.



Two views of the remnant of an exploded star known as “Tycho's Supernova” (observed by Tycho Brahe in 1572). The upper view is an x-ray image made by the HEAO-2 (Einstein) satellite; the lower view is a map of radio emission from the same object. Both views show the expanding “bubble” of hot, gaseous material ejected into space by the stellar explosion. (Smithsonian Astrophysical Observatory photo)

Smithsonian Institution

The Smithsonian Institution contributes to national space goals through the basic research programs of the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts, and the Center for Earth and Planetary Studies (CEPS) at the National Air and Space Museum (NASM) in Washington, DC. NASM also contributes significantly to public understanding of space research and exploration through its exhibits, lectures, and education programs.

A Laboratory for Astrophysics was established at NASM in 1988 as a research facility concentrating on interpretation of infrared observations from both Earth-based and spacecraft experiments. An objective of the Laboratory is to prepare museum personnel to present the results of astronomical research to the public.

Space Science

High-Energy Astrophysics

During 1988, SAO continued to reduce and analyze x-ray data obtained by spacecraft such as the Einstein Observatory (HEAO-2). Approximately 125 scientists from around the world used the Einstein Data Bank maintained by SAO. In November, on the 10th anniversary of the Einstein launch, a special symposium was convened to review the results of x-ray astronomy during the past decade and discuss potential research initiatives that could follow launch of the Advanced X-Ray Astrophysics Facility (AXAF) in the 1990s.

One of SAO's major goals is to catalog all observed x-ray objects and map the distribution of sources of cosmic x-rays. Such maps already are providing the basis for systematic studies of stars, galaxies, clusters of galaxies, and quasars.

For example, clusters of galaxies, the largest aggregations of matter yet recognized in the universe, can be studied by observing the x-ray emissions from the very hot gas filling the space between individual galaxies. SAO scientists used x-ray images from the Einstein Observatory satellite and visible light observa-

tions of both large clusters and smaller groups of galaxies to compare the amount of matter found in the galaxies with that seen in the medium between them. They found a much larger percentage of gas in the large clusters, thus suggesting that galaxy formation (by condensation out of the gaseous medium) may be more efficient in smaller clusters.

Further studies will be aimed at determining how much of the intercluster gas is primordial—left over from the early formation of the universe—and how much has been produced more recently by processes inside the stars. Indeed, SAO scientists examining images of nearby galaxies have already found some evidence that explosive forces in galactic centers may be driving gas out into the surrounding space.

Although the Sun is not a particularly copious emitter of x rays, its two-million-degree-Centigrade gaseous outer atmosphere, or corona, does radiate strongly at these wavelengths. This year, a novel SAO-built x-ray telescope equipped with a modified Hasselblad camera and special high-sensitivity film was flown aboard a suborbital sounding rocket to make extremely high spatial resolution images of the hot corona.

The attempt to observe x rays from Supernova 1987A with a balloon-borne telescope failed when the instrument's pointing mechanism jammed during a flight over Australia. A subsequent flight of the instrument from New Mexico obtained data from several x-ray sources and demonstrated the effectiveness of the experimental package. The telescope is prepared for a reflight in 1989 to observe the supernova.

SAO scientists and engineers are working with NASA and industry on detailed definition and design studies of AXAF. In addition, SAO developed a high-resolution imaging x-ray detector for flight on the West German-UK-US Roentgen Satellite (ROSAT), scheduled for launch in 1990. In cooperation with the Goddard Space Flight Center, SAO will operate the US ROSAT

Data Center which will use a portable x-ray analysis software system now under development.

Solar Physics

One of the major puzzles of solar physics is what process heats the Sun's outer atmosphere, or corona, and creates the powerful flow of gas and supercharged particles called the solar wind that sweeps over all the planets. An SAO-conceived instrument called an Ultraviolet Coronagraph Spectrometer (UVCS), designed to create artificial eclipses allowing continuous observation of the solar corona and study of the solar wind, has been selected for flight aboard the international Solar Heliospheric Observatory (SOHO) in the mid-1990s.

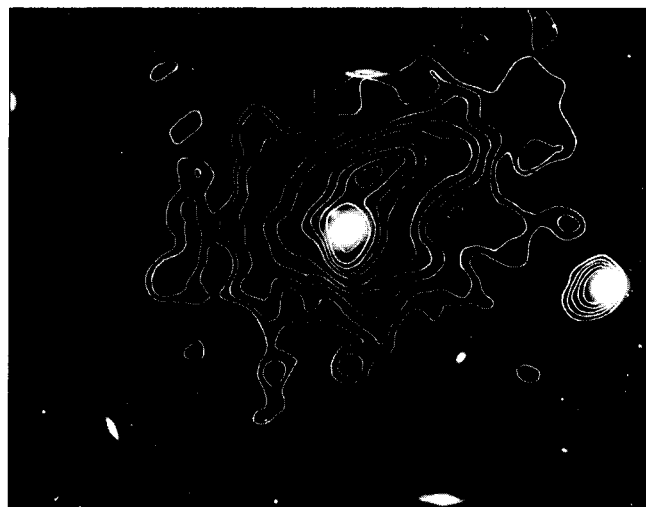
Ultraviolet Astronomy

One of the most intriguing problems in modern cosmology is the detection of very young and distant galaxies that are forming stars for the first time. One key to the search for these "primeval galaxies" is a knowledge of their special spectral characteristics. Using the International Ultraviolet Explorer (IUE) satellite, SAO scientists observed five star-forming galaxies and confirmed earlier findings that primeval galaxies may not display distinctive signatures in ultraviolet light.

The IUE satellite was also used extensively for continuing observations of the Supernova 1987A, with the ultraviolet data contributing significantly to our understanding of the physical processes occurring within the expanding shell of the exploded star.

Space Technology

Atomic clocks are being designed and built at SAO in support of the NASA deep space tracking program, as well as very long baseline interferometer radio astronomy programs and the time-keeping efforts of the U.S. Naval Observatory. In 1988, a novel method was developed to isolate hydrogen atoms in certain desired atomic states, thus improving the stability of the atomic clocks. Experiments with a hydrogen maser



Galactic halos: Contour lines defining the x-ray emission from an extended corona of hot gas are superimposed on an optical image of the elliptical galaxy M86 (NGC 4406) in Virgo. The distortion of the lines results from the stripping of hot gas from the corona by the rapid passage of this galaxy through the center of the Virgo cluster of galaxies. A second strong x-ray-emitting galaxy, M84 (NGC 4374), is seen at the right. (Optical photograph from the National Geographic-Palomar sky survey; x-ray contours from the Smithsonian Astrophysical Observatory)

clock cryogenically cooled to one-half degree above absolute zero have suggested that such "cold clocks" could keep time a thousand times more accurately than similar clocks operating at room temperature.

SAO scientists have also designed a dual optical interferometer for space flight that might measure the position of stars with an accuracy a thousand times better than ground-based systems.

Studies of the dynamics of tethered satellite systems, as well as their potential electromagnetic wave generation, continued in anticipation of the first tethered satellite mission aboard a Shuttle sometime early next decade.

Planetary Sciences

During 1988, research at CEPS resulted in the completion of a geologic map of Nicholson Regio on Jupiter's satellite Ganymede (mapped jointly with personnel at SAO), and in newly found evidence for structural events that have modified the surface of Mars.

In the Mangala Vallis region of Mars, for instance, mapping based on high-resolution Viking Orbiter images suggests several periods of faulting, the oldest of which may have resulted from lateral offsets of the crust, the first clearly documented fault of that type seen on Mars. Continuing model studies of compression of the Martian crust indicate that several layers of lava flows must be present in the plains regions. Such relatively thin layers in deformation are consistent with

the geologic setting of similar folds seen in the Columbia basalt plateau of central Washington State.

Research continued in 1988 at SAO on the wealth of data provided by the European Space Agency's Giotto mission to Comet Halley in 1986, and a new study is under way on the likely mode and place of comet birth.

Terrestrial Studies

A long-term study at CEPS of terrestrial deserts incorporated orbital measurements of color changes of dune and interdune sand to determine the stability of wind-blown deposits. Using a 16-year record of Landsat and SPOT data, dune movement and surface changes were mapped in parts of Egypt, Sudan, Mali, and Botswana.

Department of State

The Department of State is responsible for evaluating and advancing U.S. foreign policy interests in the context of space activity. In this capacity, it considers space programs, policies and agreements, and advises the President on international space matters. It also represents the U.S. Government in international government-to-government negotiations concerning space topics, in international organizations involved in space, and in foreign countries.

In 1988, the United States reached agreement with its partners on international participation in the multi-billion dollar, permanently manned Space Station project. Working closely with other interested agencies, State Department and NASA officials negotiated agreements governing long-term cooperation on the detailed design, development, operation, and utilization of the Space Station with European, Japanese, and Canadian representatives. These agreements were signed in Washington on September 29, 1988. The Department of State strongly supports the Space Station as a concrete demonstration of U.S. leadership in space, a stimulus for exploring new areas of science and technology, and a model for cooperation with friends and allies on large-scale, high-technology endeavors.

As part of a major Government-wide effort, the State Department worked with other agencies in producing a new U.S. space policy signed by President Reagan on January 5, 1988. The Department of State and NASA continued to co-chair an interagency group that supervises the implementation of the U.S.-Soviet space cooperation agreement of 1987. Two items were added to the list of areas of cooperation during the Moscow summit meeting of June 1988.

The Department also worked with NASA on arrangements with other nations on emergency landing facilities for the space shuttle.

The COSPAS-SARSAT agreement was signed on June 30, 1988, making this search and rescue satellite system permanent.

In addition to U.S. policy formulation and bilateral negotiations, the Department of State represents the U.S. Government in international organizations involved in space issues. Among these international bodies are the United Nations and related organizations such as the International Telecommunication Union, and INTELSAT and INMARSAT.

Activities with the United Nations

Committee on the Peaceful Uses of Outer Space

The year 1988 marked the 30th anniversary of the establishment within the United Nations of an appropriate international body for cooperation in the study and utilization of outer space for peaceful purposes. It was three decades ago when the General Assembly adopted Resolution 1348 (XIII), the Twenty Power Resolution, which was introduced by the United States and 19 other states. The resolution established the Ad Hoc Committee on the Peaceful Uses of Outer Space (COPUOS) and laid the foundation for today's permanent committee.

At the February 1988 Scientific and Technical Subcommittee, member states focused on the practical applications of remote sensing and satellite communications of particular relevance to the needs of developing countries. The Subcommittee decided to pay particular attention in 1989 to the use of space technology for combating environmental problems. The Legal Subcommittee met in March 1988 to consider questions relating to the use of nuclear power sources in space, utilization of the geostationary orbit, and the delimitation of outer space.

After two years of debate, the subcommittee agreed on a new agenda item for dealing with the application of the principle that space exploration should be carried out for the benefit of all countries, taking particular account of the needs of developing countries. The United States, with the support of other Western countries, in 1988 continued efforts to make the work of COPUOS and the Subcommittee more

relevant to the present state of space exploration. To this end, at its June 1988 meeting, member states accepted a U.S. proposal to add to the COPUOS agenda an item on the secondary applications of space technology for addressing problems on Earth, (i.e., "spin-offs").

COSPAS/SARSAT

On June 30, 1988, representatives of the United States (principally, the NOAA Administrator), the Soviet Union, France, and Canada signed an Agreement at Paris extending and expanding the COSPAS/SARSAT system of space satellite-based global search and rescue for 15 years. The signing climaxed two and one-half years of intensive negotiations among the four nations which manage the interoperable system regarding liability, meeting structure, contributions, etc. COSPAS/SARSAT began in 1979 as an experimental program between the Soviet Union (COSPAS) which provided two satellites with processors and repeaters and the United States (SARSAT) which provided two satellites along with French repeaters and Canadian processors. To date, over 1,000 lives have been saved by the interoperable Soviet and Western system.

International Maritime Satellite Organization

The United States accepted the 1985 amendments to the INMARSAT Convention, thus permitting INMARSAT to offer satellite-based aircraft communication services. The development of further amendment proposals that, if adopted, would permit INMARSAT to offer satellite-based communications to vehicles on land are also being supported by the United States.

International Radio Conference

In August-October 1988, the International Telecommunication Union held the Second Session of the

Space Services World Administrative Radio Conference (WARC). The Space WARC successfully concluded its planning exercises for the use of additional radio spectrum allocated to the Fixed Satellite Service (the primary type of commercial communications satellite), largely as a result of the U.S. contribution of computer software developed by NASA's Lewis Research Center. In addition, improved procedures governing the use of the orbit and radio spectrum by conventional communications satellites were adopted in a manner consistent with the U.S. philosophy of retaining flexibility to accommodate new technologies and services. The Final Acts of the Conference will be submitted by the Department of State to the U.S. Senate for ratification.

International Telecommunications Satellite Organization

In October 1988, an Extraordinary Assembly of Parties of the International Telecommunications Satellite organization (INTELSAT) (115 members) approved a proposal allowing Pan American Satellite Corporation (PanAmSat) to provide satellite communication services between the United States and certain European countries, separate from INTELSAT services. Following earlier approvals of PanAmSat service to certain Latin American countries, this development provides the first satellite-based competition to INTELSAT for transoceanic services. Extensive U.S. diplomatic activities are leading to broader acceptance of the U.S. policy, (based on Presidential Determination 85-4) and opening new markets for U.S. commercial participation.

Arms Control and Disarmament Agency

The U.S. Arms Control and Disarmament Agency (ACDA) has an indirect role in the U.S. civil space program largely concentrating on arms control considerations of space weapons systems, both defensive and offensive. Among other things, ACDA explains and defends the President's Strategic Defense Initiative (SDI) in multilateral and bilateral fora. ACDA represents the United States in space arms control negotiations at the bilateral U.S.-Soviet Nuclear and Space Talks in Geneva. ACDA also leads the U.S. delegations involved in multilateral considerations of space arms control issues at the First Committee of the United Nations General Assembly in New York and at the Conference on Disarmament (CD) in Geneva. The CD's ad hoc committee on outer space, established for the first time in March 1985 and renewed in 1987, is the venue for multilateral examination of issues relevant to the prevention of an arms race in outer space. Its nonnegotiating mandate is designed to encourage discussion on any proposals that may be made on outer space issues and to review the current space legal regime.

Nuclear and Space Talks

During 1988 at the Defense and Space Talks the United States sought agreement to facilitate the joint management of a stable transition to an increasing reliance on effective defenses against strategic ballistic missiles, should they prove feasible. To this end, the United States tabled a draft Defense and Space (D&S) Treaty in January. In March, the United States tabled a Predictability Protocol which calls for, on a reciprocal and comparable basis, a range of confidence-building measures designed to provide predictability for each side regarding the strategic ballistic missile defense programs of the other. The United States made other initiatives in the Defense and Space talks during the year regarding activities permitted during and after a period of nonwithdrawal from the ABM Treaty. For its part, the Soviet Union tabled a draft Defense and

Space agreement in April; however, the Soviet Union has refused to develop a Joint Draft Text of an agreement. Regarding predictability measures, the Soviet Union also proposed in April to focus predictability measures exclusively on verification in order to ensure compliance with the ABM Treaty and the D&S agreement being negotiated. The two sides are working on a Joint Draft Text of a Protocol that addresses predictability measures.

Multilateral Discussions on Space Arms Control

ACDA leads the U.S. Delegation to the Conference on Disarmament (CD). The Delegation is composed of members from interested agencies and as such is responsible for the CD's work, including that on outer space issues. The CD's ad hoc Committee, whose mandate was to "continue to examine and to identify ... issues relevant to the prevention of an arms race in outer space," was reestablished during 1988 and met regularly during the two CD sessions. The United States participated actively in the meetings which considered, among other things, measures identified at the CD that potentially could form the basis for negotiating further multilateral arms control agreements that apply to outer space. Progress has been slow but steady. ACDA has played an active role in keeping the ad hoc committee focused on feasible and acceptable approaches to the question of arms control in outer space. The United States has not, however, during the course of this work, identified additional issues appropriate for outer space arms control negotiations other than those worth consideration in the bilateral nuclear space talks.

Space Policy

ACDA is involved extensively in the formulation of U.S. space policy. For example, the agency chairs the Interagency Group on Defense and Space, which addresses space arms control issues. Also, it is a

member of the Interagency Group that addresses U.S. policy on the Strategic Defense Initiative (SDI). In addition, ACDA provides administrative support, senior representatives, advisors, and legal experts to U.S. arms control negotiations.

The agency participates in the Senior Interagency Group on Space that addresses a range of issues involving space. There are a number of other inter-

agency groups in which ACDA participates that review topics relative to space, such as bilateral governmental space activities and cooperation, and the sale of space-related items. Also, ACDA contributes to U.S. consideration of technical collection assets for verifying compliance with arms control agreements; these include space-based assets that are part of the national technical means of verification.

United States Information Agency

Despite the enforced lull brought on by the Challenger disaster, the United States Information Agency (USIA) conducted an active overseas information program promoting U.S. achievements in space during 1988. Of particular note were four live Worldnet television interviews on NASA's role in the ozone layer research and USIA media's coverage of the Discovery launch. Given foreign interest in most everything related to U.S. space activities, USIA finds a ready audience for its programs and products. USIA has various ways to bring messages on space to the world: it can use its daily WORLDNET TV broadcasts, various Voice of America programs, telephone interviews, and Wireless File stories and statements; it also uses exhibits, video tapes, books, and cultural center and library programs to show U.S. advances in space exploration and technology.

Television

USIA's Television and Film Service (TV) and NASA cooperate very closely. As a result, every major NASA undertaking receives significant worldwide exposure. WORLDNET, USIA's television network, links Washington via satellite with U.S. embassies and other host-country organizations throughout the world. News clips, "Science World," and offerings of films and videos to U.S. embassies also promote NASA activities.

WORLDNET dialogues of live unrehearsed telepress conferences brought leading foreign officials, experts, and media together with various NASA experts. An Hispanic astronaut reached millions through the retransmittal of his interview to four Latin American countries. Another astronaut's multi-regional program went live to Bonn, Paris, Ottawa, Monrovia, and Jakarta. A scientist from the Global Habitability Project appeared four different times to discuss the worldwide preoccupation with the protection of the ozone layer. Two NASA scientists and an expert from the Goddard Space Flight Center also participated in WORLDNET programs.

USIA's TV news magazine, "America Today," covered a variety of NASA events and produced an ongoing series on the agency's space programs. In conjunction with its live coverage of the launch of Discovery, "America Today" also aired an overview report on the events leading up to the launch. "Science World" produced weekly programs on space exploration and other NASA research projects, including segments on spin-off technologies that have an impact on everyday lives. News clips included in TV's weekly "Satellite File" found use by over 150 broadcasters in 99 countries.

NASA films and videos acquired by TV continued to be enjoyed in USIA's cultural centers and libraries throughout the world. Overseas audiences received a timely preview on the launch of Discovery in NASA's "Return to Space," which focused on the modifications and improvements made to the shuttle to ensure a successful launch.

Voice of America

The worldwide broadcasting service of the Voice of America (VOA) uses a variety of formats to report on NASA activities. VOA's English, Russian, Spanish, Chinese, Urdu, and Indonesian language services broadcast the launch of Discovery live on September 29. Reporters from the Ukrainian, Czech, French, Bengali, and Portuguese services also covered the event. VOA correspondents at the Kennedy and Johnson space centers file continuous "update" reports in English during missions and these reports are translated into VOA's 42 other languages for newscasts of varying lengths.

VOA's regular programs and series on science reporting, frequently feature NASA's activities. "New Horizons," VOA's English-language flagship science program, took 20-minute weekly in-depth looks at the Galileo and Ulysses probes, the anniversary of Super-nova 1987-A, preparations for America's return to manned space flight, remote sensing, the Search and

Rescue Satellite-Aided Tracking System, and U.S. space goals. Modified forms of "New Horizons" go out in Spanish, French, Russian, and other languages. The VOA also makes tapes of these broadcasts available to foreign radio stations for later re-broadcasts. Science feature scripts of three to five minutes also include space topics.

VOA's Special English service also frequently uses space subjects on its daily 4-minute science program and on its two weekly 15-minute programs "Science in the News" and "Space and Man." These programs, and newscasts, use a simplified vocabulary and syntax geared to those learning English.

VOA foreign language broadcasters often generate their own programs of interest to their listeners. For example, following a recent two-day trip to the Wallops Flight Facility, reporters from the Special English, Hindi, Spanish, Khmer, Russian, Vietnamese, and Ukrainian services produced 27 short features and several 15-minute programs.

Electronic Dialogues

Reporters from four Japanese newspapers and a leading TV station interviewed a high-level NASA scientist on protecting the ozone layer in the Tokyo American embassy's first-ever two-way video hook-up. The Satellite Speakers' staff also used the talents of NASA personnel on its telephone press conferences: a Voyager engineer spoke with journalists in Mexico; NASA's Associate Administrator for Policy and Planning talked with scientists and media leaders in Tel Aviv and Singapore; and NASA's Director for Program Support and Special Projects impressed Indian audiences on the future of the U.S. space program.

Press and Publications

Through fast international data transmission systems, USIA's Press and Publications Service provide our embassies with a steady stream of articles, official statements, and American press play on issues of

importance to the United States, including NASA's space activities. USIA officers and local employees place these materials in foreign media outlets and distribute them to government officials and other opinion leaders.

During this past year, the Press Branch concentrated on covering NASA rocket tests and the launch of Discovery. It also prepared articles on the agreement between the United States and 11 allied countries to build a permanently manned space station, U.S.-Soviet space cooperation, the establishment of a lunar outpost, and a manned expedition to Mars.

Three in-depth articles were of particular interest to our overseas posts: one examined the role of American women astronauts on the fifth anniversary of the first American woman to fly in space; a second examined the development of U.S. space technology over the last 27 years to show the major benefits reaped by mankind (photovoltaic cells powering refrigerators at medical clinics in Africa, special eyeglasses that restore normal vision to people suffering degenerative eye disease, etc.); and a third looked at experiments performed aboard Discovery to help scientists develop drugs to battle AIDS, emphysema, and cancer.

USIA magazines dedicated various articles to NASA and space. *America Illustrated* contained a feature on NASA's support to amateur radio through Project OSCAR, and a picture story on "Images from Space," showing computer-generated views of Earth's surface. The magazine also ran a large, fold-out poster called "Space Explorers," featuring all astronauts and cosmonauts to date. *Al Majal* had illustrated stories on a Huntsville, Alabama, space camp and a proposed network of space outposts.

The Text Services Branch regularly produced space-related materials, including one special packet of seven articles on "Studying Space" for USIA's overseas posts. Other articles included topics such as NASA's plans for the 21st century, peaceful uses of space, and think-

tanks in space. The Visual Services Branch produced a picture story containing 13 color shots of Earth from the space shuttle.

American Participant Program

Under the American Participant program, which involves USIA's sending prominent Americans to foreign countries to meet with foreign government

officials, scientists, scholars, and journalists, five NASA astronauts traveled in 1988. Their tours included visits to several cities in Indonesia, extensive travel in India and Singapore, as well as trips to Ecuador, Venezuela, Romania, and Uruguay. In addition, USIA's overseas posts arranged programs for six other astronauts and various other NASA officials and scientists who traveled overseas under other auspices.

Appendixes

APPENDIX A-1

U.S. Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

| Calendar Year | Earth Orbit ^a | | Earth Escape ^a | | Calendar Year | Earth Orbit ^a | | Earth Escape ^a | |
|---------------|--------------------------|---------|---------------------------|----------------|---------------|--------------------------|---------|---------------------------|---------|
| | Success | Failure | Success | Failure | | Success | Failure | Success | Failure |
| 1957 | 0 | 1 | 0 | 0 | 1972 | 33 | 2 | 8 | 0 |
| 1958 | 5 | 8 | 0 | 4 | 1973 | 23 | 2 | 3 | 0 |
| 1959 | 9 | 9 | 1 | 2 | 1974 | 27 | 2 | 1 | 0 |
| 1960 | 16 | 12 | 1 | 2 | 1975 | 30 | 4 | 4 | 0 |
| 1961 | 35 | 12 | 0 | 2 | 1976 | 33 | 0 | 1 | 0 |
| 1962 | 55 | 12 | 4 | 1 | 1977 | 27 | 2 | 2 | 0 |
| 1963 | 62 | 11 | 0 | 0 | 1978 | 34 | 2 | 7 | 0 |
| 1964 | 69 | 8 | 4 | 0 | 1979 | 18 | 0 | 0 | 0 |
| 1965 | 93 | 7 | 4 | 1 | 1980 | 16 | 4 | 0 | 0 |
| 1966 | 94 | 12 | 7 | 1 ^b | 1981 | 20 | 1 | 0 | 0 |
| 1967 | 78 | 4 | 10 | 0 | 1982 | 21 | 0 | 0 | 0 |
| 1968 | 61 | 15 | 3 | 0 | 1983 | 31 | 0 | 0 | 0 |
| 1969 | 58 | 1 | 8 | 1 | 1984 | 35 | 3 | 0 | 0 |
| 1970 | 36 | 1 | 3 | 0 | 1985 | 37 | 1 | 0 | 0 |
| 1971 | 45 | 2 | 8 | 1 | 1986 | 11 | 4 | 0 | 0 |
| | | | | | 1987 | 9 | 1 | 0 | 0 |
| | | | | | 1988 | 16 | 1 | 0 | 0 |
| | | | | | TOTAL | 1,137 | 144 | 79 | 15 |

^aThe criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from the Earth.

^bThis Earth-escape failure did attain Earth orbit and therefore is included in the Earth-orbit success totals.

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)

| Calendar Year | United States | U.S.S.R. | France | Italy | Japan | People's Republic of China | Australia | United Kingdom | European Space Agency | India | Israel |
|---------------|---------------|--------------|-----------|----------------|-----------|----------------------------|-----------|----------------|-----------------------|----------|----------|
| 1957 | | 2 | | | | | | | | | |
| 1958 | 5 | 1 | | | | | | | | | |
| 1959 | 10 | 3 | | | | | | | | | |
| 1960 | 16 | 3 | | | | | | | | | |
| 1961 | 29 | 6 | | | | | | | | | |
| 1962 | 52 | 20 | | | | | | | | | |
| 1963 | 38 | 17 | | | | | | | | | |
| 1964 | 57 | 30 | | | | | | | | | |
| 1965 | 63 | 48 | 1 | | | | | | | | |
| 1966 | 73 | 44 | 1 | | | | | | | | |
| 1967 | 57 | 66 | 2 | 1 | | | 1 | | | | |
| 1968 | 45 | 74 | | | | | | | | | |
| 1969 | 40 | 70 | | | | | | | | | |
| 1970 | 28 | 81 | 2 | 1 [*] | 1 | 1 | | | | | |
| 1971 | 30 | 83 | 1 | 2 [*] | 2 | 1 | | 1 | | | |
| 1972 | 30 | 74 | | 1 | 1 | | | | | | |
| 1973 | 23 | 86 | | | | | | | | | |
| 1974 | 22 | 81 | | 2 [*] | 1 | | | | | | |
| 1975 | 27 | 89 | 3 | 1 | 2 | 3 | | | | | |
| 1976 | 26 | 99 | | | 1 | 2 | | | | | |
| 1977 | 24 | 98 | | | 2 | | | | | | |
| 1978 | 32 | 88 | | | 3 | 1 | | | | | |
| 1979 | 16 | 87 | | | 2 | | | 1 | | | |
| 1980 | 13 | 89 | | | 2 | | | | | 1 | |
| 1981 | 18 | 98 | | | 3 | 1 | | 2 | | 1 | |
| 1982 | 18 | 101 | | | 1 | 1 | | | | | |
| 1983 | 22 | 98 | | | 3 | 1 | | 2 | | 1 | |
| 1984 | 22 | 97 | | | 3 | 3 | | 4 | | | |
| 1985 | 17 | 98 | | | 2 | 1 | | 3 | | | |
| 1986 | 6 | 91 | | | 2 | 2 | | 2 | | | |
| 1987 | 8 | 95 | | | 3 | 2 | | 2 | | | |
| 1988 | 12 | 90 | | | 2 | 4 | | 7 | | | 1 |
| TOTAL | 879 | 2,107 | 10 | 8 | 36 | 23 | 1 | 1 | 23 | 3 | 1 |

*Includes foreign launches of U.S. spacecraft.

Successful U.S. Launches—1988

| Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle | Mission Objectives, Spacecraft Data | Apogee and Perigee (km), Period (min), Inclination to Equator(°) | Remarks |
|---|---|--|--|
| Feb. 2 DMSP F-9 6A Atlas E | Objective: To launch meteorological observation satellite into planned orbit. Spacecraft: Same basic configuration as DMSP F-6. Weight: 1421 kg. | 826 815 101.3 98.7 | In orbit, returning data. |
| Feb. 8 8A DOD-2 Delta 181 | Objective: To demonstrate effective ways to discriminate between decoys and reentry vehicles. Spacecraft: Not announced. | 333 223 90.1 28.6 | Successful test of technology. Reentered Mar. 1, 1988. Launched by NASA for the Strategic Defense Initiative. |
| Mar. 25 San Marco D/L 26A Scout | Objective: To launch satellite into low earth orbit to explore relationship between solar activity and meteorological phenomena by studying dynamic processes occurring in the troposphere, stratosphere, and thermosphere. Spacecraft: Spherical, 96.5 cm in diameter with four canted 48 cm monopole antennas for telemetry and command. Weight: 237 kg. | 615 263 93.4 3.0 | Launched by NASA as a joint research mission with the Italian Space Commission. Launch took place from the San Marco Range. Reentered over central Africa and was consumed Dec. 6, 1988. |
| Apr. 25 SOOS-3 33D Scout | Objective: To place the Navy satellite into a successful orbit. Spacecraft: Configuration not announced. Weight: 141 lbs. | Not available. | NASA launched U.S. Navy navigation satellite. Stacked Oscar on Scout (SOOS) part of Navy's long-established, continuous all-weather global navigation system. Still in polar orbit. |
| 33E | Objective: To place the Navy satellite into a successful orbit. Spacecraft: Configuration not announced. Weight: 141 lbs. | Not available. | Second of two satellites launched by NASA for U.S. Navy. Still in polar orbit. |
| Jun. 16 NOVA-II 52A Scout | Objective: To place Navy satellite into an orbit which will enable the successful achievement of the Navy objectives. Spacecraft: Cylindrical main body, four solar panels extending from main body, with extendable boom from central part of satellite. Weight: 375.8 lbs. | 1199 1150 108.9 90.0 | Third in series of improved Transit navigation satellites launched by NASA for the U.S. Navy. Still in orbit. |
| Aug. 25 SOOS-4 74A Scout | Objective: To place Navy satellite into a successful orbit. Spacecraft: Configuration not announced. Weight: 141 lbs. | 1176 1032 107.4 90.0 | Stacked Oscar on Scout (SOOS) launched by NASA for U.S. Navy into polar orbit. Still in orbit. |
| Aug. 25 74B | Objective: To place Navy satellite into a successful orbit. Spacecraft: Configuration not announced. Weight: 141 lbs. | 1178 1032 107.4 90.0 | Second of two satellites launched for the U.S. Navy. Still in polar orbit. |
| Sep. 2 DOD 77A Titan 34D | | Not available. | In orbit. |
| Sep. 5 DOD 78A Titan II | | Not available. | In orbit. |

Successful U.S. Launches—1988

| Launch Date (GMT), Spacecraft Name, COSPAR Designation, Launch Vehicle | Mission Objectives, Spacecraft Data | Apogee and Perigee (km), Period (min), Inclination to Equator(°) | Remarks |
|---|--|--|--|
| Sep. 24 89A NOAA-11 Atlas E | Objective: To launch satellite into sun-synchronous orbit. Spacecraft: Launch configuration: 491 cm high, 188 cm in diameter, weight: 1712 kg. Weight on orbit: 1038 kg. | 863 845 102.0 98.9 | Fourth of the advanced TIROS-N spacecraft. Funded by the National Oceanic and Atmospheric Administration (NOAA) and successfully launched by NASA. To replace NOAA-9 as afternoon satellite in NOAA's two polar satellite system. Also onboard Search and Rescue instruments. Still in orbit, returning data. |
| Sep. 29 Space Shuttle Discovery (STS-26) 91A | Objective: To deploy the Tracking and Data Relay Satellite-C/Inertial Upper Stage. Spacecraft: Shuttle orbiter carrying satellite as well as experiments. Automated Directional Solidification Furnace (ADSF), Aggregation of Red Blood Cells (ARC), Earth Limb Radiance Experiment (ELRAD), Isoelectric Focusing Experiment (IEF), Infrared Communication Flight Experiment (IRCFE), Mesoscale Lightning Experiment (MLE), Protein Crystal Growth (PCG), Phased Partitioning Experiment (PPE), and Physical Vapor Transport of Organic Solids (PVTOS). Additionally 3 Shuttle Student Involvement Project (SSIP) experiments. Weight: 38,774 lbs. | 336 306 91.0 28.5 | Twenty-sixth flight of Space Transportation System. First since Challenger accident, Jan. 28, 1986. Piloted by Frederick H. Hauck and Richard O. Covey. Mission specialists John M. Lounge, David C. Hilmers, and George D. Nelson. Discovery launched KSC 11:37 a.m., EDT. Satellite deployed and experiments conducted. Shuttle landed at Edwards AFB, CA, 12:37 p.m., EDT, Oct. 3. Mission duration 4 days, 1 hr. |
| Sep. 29 TDRS 3 91B | Objective: To deliver TDRS satellite to stationary geosynchronous orbit. Spacecraft: Three-axis stabilized, momentum-biased configuration with two sun-oriented solar panels attached. TDRS measures 57.17 ft tip to tip of deployed solar panels, TDRS composed of 3 modules: (1) equipment module houses attitude control, electrical power, propulsion, telemetry, tracking, and command subsystems; (2) payload module consists of processing and frequency-generation equipment; (3) antenna module supports dual deployable and fixed antennas, multiple-access array, and remainder of telecommunications hardware. Weight at launch, including IUS upper stage: 37, 699 lbs. Weight in orbit: 4,637 lbs. 46.6 ft from outer edge-to-edge of single axis antennas. | 35,803 35,779 1436.3 0.2 | Launched Sep. 29 from Shuttle orbiter Discovery. Third of a series. Completes two satellite constellation, located at 171° W. Leased by NASA from Continental Telephone Company (CONTEL). |
| Nov. 6 DOD 99A Titan 34D | Objective: Development of spaceflight techniques and technology. Spacecraft: Not announced. | Not available. | In orbit. |
| Dec. 2 Space Shuttle Atlantis 106A | Objective: To launch classified DOD Payload. Spacecraft: Shuttle orbiter carrying DOD satellite. | 453 443 93.6 57.0 | Twenty-seventh flight of Space Transportation System. Piloted by Robert "Hoot" Gibson and Guy Gardner. Mission specialists Mike Mullane, Jerry Ross, and Bill Shepherd. Atlantis launched KSC 9:30 a.m., EST. Satellite deployed. Landed at Edwards AFB, CA, Dec. 6. 3:37 p.m., PST. Mission duration 4 days, 9 hrs, 6 min. |
| Dec. 2 DOD 106B | Objective: Development of spaceflight technique and technology. Spacecraft: Not announced. | Not available. | In orbit. |

U.S.-Launched Applications Satellites, 1982-1988

| Date | Name | Launch Vehicle | Remarks |
|-----------------------|-------------------|-------------------------|---|
| COMMUNICATIONS | | | |
| Jan. 16, 1982 | RCA-Satcom 4 | Thor-Delta (TAT) | Fifth in series for RCA. |
| Feb. 26, 1982 | Westar 4 | Thor-Delta (TAT) | First in a series of second-generation for Western Union Co. |
| Mar. 5, 1982 | Intelsat V F-4 | Atlas-Centaur | Fourth in series; positioned over Pacific. |
| Apr. 10, 1982 | Insat 1A | Thor-Delta (TAT) | First in series for India Department of Space. |
| June 9, 1982 | Westar 5 | Thor-Delta (TAT) | Second in series of second-generation for Western Union Co.; replaces Westar 2. |
| Aug. 26, 1982 | Anik D-1 | Thor-Delta (TAT) | Launched for Telesat Canada as replacement for in-orbit satellites. |
| Sept. 28, 1982 | Intelsat V F-5 | Atlas-Centaur | Fifth in series; positioned over Indian Ocean. |
| Oct. 27, 1982 | RCA-Satcom 5 | Thor-Delta (TAT) | Joined 4 operational satellites launched for RCA. |
| Oct. 30, 1982 | DSCS II, DSCS III | Titan III(34) D/IUS | Defense communications (dual launch), including first in series of updated satellites. |
| Nov. 11, 1982 | SBS 3 | Space Shuttle, PAM-D | Third in series for Satellite Business Systems. |
| Nov. 12, 1982 | Anik C-3 | Space Shuttle, PAM-D | Second in new series for Telesat Canada. |
| Apr. 4, 1983 | TDRS 1 | Space Shuttle, IUS | First in series. System to provide continuous satellite communication. Leased by NASA from Space Communications Co. (Spaccomm). |
| Apr. 11, 1983 | RCA-Satcom 6 | Delta 3924 | Replacement for RCA-Satcom 1, launched for RCA. |
| May 19, 1983 | Intelsat V F-6 | Atlas-Centaur | Sixth in series; positioned over Atlantic Ocean. |
| June 18, 1983 | Anik C-2 | Space Shuttle, PAM-D | Launched for Telesat Canada. |
| June 19, 1983 | Palapa B-1 | Space Shuttle, PAM-D | Indonesian domestic communications. |
| June 28, 1983 | Galaxy 1 | Delta 3920/PAM-D | Launched for Hughes Communications, Inc. |
| July 28, 1983 | Telstar 3A | Delta 3920/PAM-D | Launched for American Telephone and Telegraph Co. |
| Aug. 31, 1983 | Insat 1-B | Space Shuttle, PAM-D | Indian domestic communications. |
| Sept. 8, 1983 | RCA-Satcom 7 | Delta 3924 | Replacement for RCA-Satcom 2, launched for RCA. |
| Sept. 22, 1983 | Galaxy 2 | Delta 3920/PAM-D | Second in series, launched for Hughes Communications, Inc. |
| Feb. 3, 1984 | Westar-6 | Space Shuttle, PAM-D | Launched for Western Union, PAM-D failed to fire properly, satellite retrieved by Shuttle, and returned to earth for refurbishment. |
| Feb. 6, 1984 | Palapa-B2 | Space Shuttle, PAM-D | Launched for Indonesia, booster motor failed, satellite retrieved and returned to Earth by Shuttle. |
| Mar. 1, 1984 | Uosat-2 | Delta 3920 | Secondary payload with Landsat-5, for amateur radio communications. |
| June 9, 1984 | Intelsat V F-9 | Atlas-Centaur | Seventh in series, launch vehicle failure, satellite reentered Oct. 24. |
| Aug. 31, 1984 | SBS-4 | Space Shuttle, PAM-D | Launched for Satellite Business Systems, Inc. |
| Aug. 31, 1984 | Syncom IV-2 | Space Shuttle | Launched for Hughes Communications, Inc. |
| Sept. 1, 1984 | Telstar-3C | Space Shuttle, PAM-D | Launched for American Telephone and Telegraph Co. |
| Sept. 21, 1984 | Galaxy-3 | Delta 3920/PAM-D | Third in series, launched for Hughes Communications, Inc. |
| Nov. 9, 1984 | Anik-D2 | Space Shuttle, PAM-D | Launched for Telsat Canada. |
| Nov. 10, 1984 | Syncom IV-1 | Space Shuttle | Launched for Hughes Communications, Inc. |
| Nov. 14, 1984 | NATO IIIID | Delta 3914 | NATO defense-related communications satellite. |
| Mar. 22, 1985 | Intelsat VA F-10 | Atlas-Centaur | First in series of six improved satellites. |
| Apr. 12, 1985 | Telesat-I | Space Shuttle | Launched for Telsat Canada. |
| Apr. 13, 1985 | Syncom IV-3 | Space Shuttle | Launched for US Navy. |
| June 17, 1985 | MORELOS-A | Space Shuttle | Launched for Mexico. |
| June 18, 1985 | Arabsat-1B | Space Shuttle | Launched for Arab Satellite Communication Organization (ASCO). |
| June 19, 1985 | Telstar-3D | Space Shuttle | Launched for the American Telephone and Telegraph Company (AT&T). |
| June 30, 1985 | Intelsat VA F-11 | Atlas-Centaur | Second in series of improved satellites launched for INTELSAT. |
| Aug. 27, 1985 | AUSSAT-1 | Space Shuttle | Launched for Australia's National Satellite Company. |
| Aug. 27, 1985 | ASC-1 | Space Shuttle | Launched for American Satellite Company. |
| Aug. 29, 1985 | Syncom IV-4 | Space Shuttle | Launched for US Navy. |

U.S.-Launched Applications Satellites, 1982-1988

| Date | Name | Launch Vehicle | Remarks |
|--|------------------|------------------|---|
| COMMUNICATIONS <i>continued</i> | | | |
| Sep. 29, 1985 | Intelsat VA F-12 | Atlas-Centaur | Launched for INTELSAT. |
| Nov. 27, 1985 | MORELOS-B | Space Shuttle | Launched for Mexico. |
| Nov. 27, 1985 | AUSSAT-2 | Space Shuttle | Second satellite launched for Australia's National Satellite Company. |
| Nov. 28, 1985 | RCA Satcom K-2 | Space Shuttle | Launched for RCA American Communications, Inc. |
| Jan. 12, 1986 | RCA Satcom K-1 | Space Shuttle | Launched for RCA American Communications, Inc. |
| Dec. 5, 1986 | Fltsatcom 7 | Atlas-Centaur | Launched for DoD. |
| Mar. 20, 1987 | Palapa B-2P | Delta 182 | Indonesia domestic communications. |
| WEATHER OBSERVATION* | | | |
| Dec. 21, 1982 | DMSP F-6 | Atlas E | DoD meteorological satellite. |
| Mar. 28, 1983 | NOAA-8 | Atlas E | Joined NOAA 7 as part of 2-satellite operational system; launched for NOAA. |
| Apr. 28, 1983 | GOES 6 | Delta 3914 | Launched for NOAA, operational as GOES-West. |
| Nov. 18, 1983 | DMSP F-7 | Atlas E | Second in block 5D-2 series, DoD meteorological satellite. |
| Dec. 12, 1984 | NOAA-9 | Atlas E | Launched for NOAA, to replace NOAA-7. |
| Sep. 17, 1986 | NOAA-10 | Atlas E | Launched for NOAA. |
| Feb. 26, 1987 | GOES 7 | Delta 179 | Launched for NOAA, operational as GOES-East. |
| June 20, 1987 | DMSP F-8 | Atlas E | Third in block 5D-2 series, DoD meteorological satellite. |
| Feb. 2, 1988 | DMSP F-9 | Atlas E | DoD meteorological satellite. |
| Sep. 24, 1988 | NOAA-11 | Atlas E | Launched for NOAA, to replace NOAA-9. |
| EARTH OBSERVATION | | | |
| July 16, 1982 | Landsat-4 | Thor-Delta (TAT) | Fourth experimental earth resources satellite. First use of thematic mapper (TM). |
| Mar. 1, 1984 | Landsat-5 | Delta 3920 | Fifth experimental earth resources satellite, to replace ailing Landsat-4. |
| GEODESY | | | |
| Mar. 13, 1985 | GEOSAT | Atlas E | Measure ocean surface height. |
| NAVIGATION* | | | |
| July 14, 1983 | Navstar-8 | Atlas E | Global Positioning System satellite. |
| Feb. 5, 1984 | IRT | Space Shuttle | Balloon to test Shuttle rendezvous radar. |
| June 13, 1984 | Navstar-9 | Atlas E | Global Positioning System satellite. |
| Sept. 8, 1984 | Navstar-10 | Atlas E | Global Positioning System satellite. |
| Oct. 12, 1984 | Nova-3 | Scout | Second of improved Transit system satellites, for DoD. |
| Aug. 3, 1985 | Oscar 24 | Scout | Part of Navy Transit System. |
| Aug. 3, 1985 | Oscar 30 | Scout | Part of Navy Transit System. |
| Oct. 9, 1985 | Navstar-11 | Atlas E | Global Positioning System satellite. |
| Apr. 25, 1988 | SOOS-3 | Scout | Dual satellites, part of Navy navigation system. |
| Jun. 16, 1988 | NOVA-2 | Scout | Third of improved Transit system satellites, for DoD. |
| Aug. 25, 1988 | SOOS-4 | Scout | Dual satellites, part of Navy navigation system. |

*Does not include Department of Defense weather satellites that are not individually identified by launch.

U.S.-Launched Scientific Satellites, 1982-1988

| Date | Name | Launch Vehicle | Remarks |
|---------------|--|----------------|---|
| Jan. 26, 1983 | IRAS | Delta 3910 | Infrared sky survey. |
| May 26, 1983 | EXOSAT | Delta 3914 | European Space Agency study of x-ray sources. |
| June 22, 1983 | SPAS 01 | Space Shuttle | Reusable free-flying platform deployed and retrieved during STS 7; 6 scientific experiments from West Germany, 2 from ESA. NASA experiments tested spacecraft technology. |
| June 27, 1983 | HILAT (P83-1) | Scout | Propagation effects of disturbed plasma on radar and communication systems, for DoD. |
| Apr. 6, 1984 | Long Duration Exposure Facility (LDEF-1) | Space Shuttle | Scientific experiments designed for retrieval from space by Shuttle. |
| Aug. 16, 1984 | Charge Composition Explorer (CCE) | Delta 3924 | Measurement of Earth's magnetosphere, one of three satellites composing Active Magnetosphere Particle Tracer Explorers Mission (AMPTE). |
| Aug. 16, 1984 | Ion Release Module (IRM) | Delta 3924 | Second of three satellites of AMPTE Mission, launched by same vehicle. |
| Aug. 16, 1984 | United Kingdom Satellite (UKS) | Delta 3924 | Third of three satellites of AMPTE Mission, launched by same vehicle. |
| Oct. 5, 1984 | Earth Radiation Budget Satellite (ERBS) | Space Shuttle | First of three satellites in Earth Radiation Budget Experiment Research Program. NOAA-9 and NOAA-G carrying other instruments in Program. |
| Apr. 29, 1985 | NUSAT-1 | Space Shuttle | Northern Utah Satellite (air traffic control radar system calibrator). |
| June 20, 1985 | Spartan-1 | Space Shuttle | Reusable free-flying platform. |
| July 29, 1985 | Plasma Diagnostic Package (PDP) | Space Shuttle | Reusable experimental platform. |
| Oct. 30, 1985 | GLOMR | Space Shuttle | Global Low Orbiting Message Relay satellite. |
| Nov. 14, 1986 | Polar Bear | Scout | Experiments to study radio interference caused by Aurora Borealis, for DoD. |
| Mar. 25, 1988 | San Marco D/L | Scout | International satellite to study earth's lower atmosphere. |

U.S.-Launched Space Probes, 1975-1988

| Date | Name | Launch Vehicle | Remarks |
|---------------|-----------------|--------------------|---|
| Aug. 20, 1975 | Viking 1 | Titan IIIE-Centaur | Lander descended, landed safely on Mars on Plains of Chryse, Sept. 6, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of atmosphere. |
| Sept. 9, 1975 | Viking 2 | Titan IIIE-Centaur | Lander descended, landed safely on Mars on Plains of Utopia, July 20, 1976, while orbiter circled planet photographing it and relaying all data to Earth. Lander photographed its surroundings, tested soil samples for signs of life, and took measurements of the atmosphere. |
| Jan. 15, 1976 | Helios 2 | Titan IIIE-Centaur | Flew in highly elliptical orbit to within 41 million km of Sun, measuring solar wind, corona, electrons, and cosmic rays. Payload had same West German and U.S. experiments as Helios 1 plus cosmic-ray burst detector. |
| Aug. 20, 1977 | Voyager 2 | Titan IIIE-Centaur | Jupiter and Saturn flyby mission. Swung around Jupiter in July 1979, arrived Saturn in 1981, going on to Uranus by 1986, Neptune by 1989. |
| Sep. 5, 1977 | Voyager 1 | Titan IIIE-Centaur | Jupiter and Saturn flyby mission. Passing Voyager 2 on the way, swung around Jupiter in Mar. 1979, arrived at Saturn in Nov. 1980, headed for outer solar system. |
| May 20, 1978 | Pioneer Venus 1 | Atlas-Centaur | Venus orbiter; achieved Venus orbit Dec. 4, returning imagery and data. |
| Aug. 8, 1978 | Pioneer Venus 2 | Atlas-Centaur | Carried 1 large, 3 small probes plus spacecraft bus; all descended through Venus atmosphere Dec. 9, returned data. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|------------------------|----------------|---|-------------------------------|--|
| Vostok 1 | Apr. 12, 1961 | Yuriy A. Gagarin | 0 : 1 : 48 | First manned flight. |
| Mercury- Redstone 3 | May 5, 1961 | Alan B. Shepard, Jr. | 0 : 0 : 15 | First U.S. flight; suborbital. |
| Mercury- Redstone 4 | July 21, 1961 | Virgil I. Grissom | 0 : 0 : 16 | Suborbital; capsule sank after landing; astronaut safe. |
| Vostok 2 | Aug. 6, 1961 | German S. Titov | 1 : 1 : 18 | First flight exceeding 24 h. |
| Mercury-Atlas 6 | Feb. 20, 1962 | John H. Glenn, Jr. | 0 : 4 : 55 | First American to orbit. |
| Mercury-Atlas 7 | May 24, 1962 | M. Scott Carpenter | 0 : 4 : 56 | Landed 400 km beyond target. |
| Vostok 3 | Aug. 11, 1962 | Andriyan G. Nikolayev | 3 : 22 : 25 | First dual mission (with Vostok 4). |
| Vostok 4 | Aug. 12, 1962 | Pavel R. Popovich | 2 : 22 : 59 | Came within 6 km of Vostok 3. |
| Mercury-Atlas 8 | Oct. 3, 1962 | Walter M. Schirra, Jr. | 0 : 9 : 13 | Landed 8 km from target. |
| Mercury-Atlas 9 | May 15, 1963 | L. Gordon Cooper, Jr. | 1 : 10 : 20 | First U.S. flight exceeding 24 h. |
| Vostok 5 | June 14, 1963 | Valeriy F. Bykovskiy | 4 : 23 : 6 | Second dual mission (with Vostok 6). |
| Vostok 6 | June 16, 1963 | Valentina V. Tereshkova | 2 : 22 : 50 | First woman in space; within 5 km of Vostok 5. |
| Voskhod 1 | Oct. 12, 1964 | Vladimir M. Komarov Konstantin P. Feoktistov Boris G. Yegorov | 1 : 0 : 17 | First 3-man crew. |
| Voskhod 2 | Mar. 18, 1965 | Pavel I. Belyayev Aleksey A. Leonov | 1 : 2 : 2 | First extravehicular activity (Leonov, 10 min). |
| Gemini 3 | Mar. 23, 1965 | Virgil I. Grissom John W. Young | 0 : 4 : 53 | First U.S. 2-man flight; first manual maneuvers in orbit. |
| Gemini 4 | June 3, 1965 | James A. McDivitt Edward H. White II | 4 : 1 : 56 | 21-min extravehicular activity (White). |
| Gemini 5 | Aug. 21, 1965 | L. Gordon Cooper, Jr. Charles Conrad, Jr. | 7 : 22 : 55 | Longest-duration manned flight to date. |
| Gemini 7 | Dec. 4, 1965 | Frank Borman James A. Lovell, Jr. | 13 : 18 : 35 | Longest-duration manned flight to date. |
| Gemini 6-A | Dec. 15, 1965 | Walter M. Schirra, Jr. Thomas P. Stafford | 1 : 1 : 51 | Rendezvous within 30 cm of Gemini 7. |
| Gemini 8 | Mar. 16, 1966 | Neil A. Armstrong David R. Scott | 0 : 10 : 41 | First docking of 2 orbiting spacecraft (Gemini 8 with Agena target rocket). |
| Gemini 9-A | June 3, 1966 | Thomas P. Stafford Eugene A. Cernan | 3 : 0 : 21 | Extravehicular activity; rendezvous. |
| Gemini 10 | July 18, 1966 | John W. Young Michael Collins | 2 : 22 : 47 | First dual rendezvous (Gemini 10 with Agena 10, then Agena 8). |
| Gemini 11 | Sept. 12, 1966 | Charles Conrad, Jr. Richard F. Gordon, Jr. | 2 : 23 : 17 | First initial-orbit docking; first tethered flight; highest Earth-orbit altitude (1,372 km). |
| Gemini 12 | Nov. 11, 1966 | James A. Lovell, Jr. Edwin E. Aldrin, Jr. | 3 : 22 : 35 | Longest extravehicular activity to date (Aldrin, 5 hrs 37 min). |
| Soyuz 1 | Apr. 23, 1967 | Vladimir M. Komarov | 1 : 2 : 37 | Cosmonaut killed in reentry accident. |
| Apollo 7 | Oct. 11, 1968 | Walter M. Schirra, Jr. Donn F. Eisele R. Walter Cunningham | 10 : 20 : 9 | First U.S. 3-man mission. |
| Soyuz 3 | Oct. 26, 1968 | Georgiy T. Beregovoy | 3 : 22 : 51 | Maneuvered near unmanned Soyuz 2. |
| Apollo 8 | Dec. 21, 1968 | Frank Borman James A. Lovell, Jr. William A. Anders | 6 : 3 : 1 | First manned orbit(s) of moon; first manned departure from Earth's sphere of influence; highest speed attained in manned flight to date. |
| Soyuz 4 | Jan. 14, 1969 | Vladimir A. Shatalov | 2 : 23 : 23 | Soyuz 4 and 5 docked and transferred 2 cosmonauts from Soyuz 5 to Soyuz 4. |
| Soyuz 5 | Jan. 15, 1969 | Boris V. Volynov Aleksey A. Yeliseyev Yevgeniy V. Khrunov | 3 : 0 : 56 | |
| Apollo 9 | Mar. 3, 1969 | James A. McDivitt David R. Scott Russell L. Schweickart | 10 : 1 : 1 | Successfully simulated in Earth orbit operation of lunar module to landing and takeoff from lunar surface and rejoining with command module. |
| Apollo 10 | May 18, 1969 | Thomas P. Stafford John W. Young Eugene A. Cernan | 8 : 0 : 3 | Successfully demonstrated complete system including lunar module descent to 14,300 m from the lunar surface. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|------------|----------------|--|-------------------------------|---|
| Apollo 11 | July 16, 1969 | Neil A. Armstrong Michael Collins Edwin E. Aldrin, Jr. | 8 : 3 : 9 | First manned landing on lunar surface and safe return to Earth. First return of rock and soil samples to Earth, and manned deployment of experiments on lunar surface. |
| Soyuz 6 | Oct. 11, 1969 | Georgiy Shonin Valeriy N. Kubasov | 4 : 22 : 42 | Soyuz 6, 7, and 8 operated as a group flight without actually docking. Each conducted certain experiments, including welding and Earth and celestial observation. |
| Soyuz 7 | Oct. 12, 1969 | Anatoliy V. Filipchenko Viktor N. Gorbatko Vladislav N. Volkov | 4 : 22 : 41 | |
| Soyuz 8 | Oct. 13, 1969 | Vladimir A. Shatalov Aleksey S. Yeliseyev | 4 : 22 : 50 | |
| Apollo 12 | Nov. 14, 1969 | Charles Conrad, Jr. Richard F. Gordon, Jr. Alan L. Bean | 10 : 4 : 36 | Second manned lunar landing. Explored surface of moon and retrieved parts of Surveyor 3 spacecraft, which landed in Ocean of Storms on Apr. 19, 1967. |
| Apollo 13 | Apr. 11, 1970 | James A. Lovell, Jr. Fred W. Haise, Jr. John L. Swigert, Jr. | 5 : 22 : 55 | Mission aborted; explosion in service module. Ship circled moon, with crew using LM as "lifeboat" until just before reentry. |
| Soyuz 9 | June 1, 1970 | Andriyan G. Nikolayev Vitaliy I. Sevastyanov | 17 : 16 : 59 | Longest manned spaceflight to date. |
| Apollo 14 | Jan. 31, 1971 | Alan B. Shepard, Jr. Stuart A. Roosa Edgar D. Mitchell | 9 : 0 : 2 | Third manned lunar landing. Mission demonstrated pinpoint landing capability and continued manned exploration. |
| Soyuz 10 | Apr. 22, 1971 | Vladimir A. Shatalov Aleksey S. Yeliseyev | 1 : 23 : 46 | Docked with Salyut 1, but crew did not board space station launched 19 Apr. Crew recovered Apr. 24, 1971. |
| Soyuz 11 | June 6, 1971 | Nikolay N. Rukavishnikov Georgiy T. Dobrovolskiy Vladislav N. Volkov Viktor I. Patsayev | 23 : 18 : 22 | Docked with Salyut 1 and Soyuz 11 crew occupied space station for 22 days. Crew perished during final phase of Soyuz 11 capsule recovery on June 30, 1971. |
| Apollo 15 | July 26, 1971 | David R. Scott Alfred M. Worden James B. Irwin | 12 : 7 : 12 | Fourth manned lunar landing and first Apollo "J" series mission, which carried Lunar Roving Vehicle. Worden's inflight EVA of 38 min 12 sec was performed during return trip. |
| Apollo 16 | Apr. 16, 1972 | John W. Young Charles M. Duke, Jr. Thomas K. Mattingly II | 11 : 1 : 51 | Fifth manned lunar landing, with Lunar Roving Vehicle. |
| Apollo 17 | Dec. 7, 1972 | Eugene A. Cernan Harrison H. Schmitt Ronald E. Evans | 12 : 13 : 52 | Sixth and final Apollo manned lunar landing, again with roving vehicle. |
| Skylab 2 | May 25, 1973 | Charles Conrad, Jr. Joseph P. Kerwin Paul J. Weitz | 28 : 0 : 50 | Docked with Skylab 1 (launched unmanned May 14) for 28 days. Repaired damaged station. |
| Skylab 3 | July 28, 1973 | Alan L. Bean Jack R. Lousma Owen K. Garriott | 59 : 11 : 9 | Docked with Skylab 1 for more than 59 days. |
| Soyuz 12 | Sept. 27, 1973 | Vasilij G. Lazarev Oleg G. Makarov | 1 : 23 : 16 | Checkout of improved Soyuz. |
| Skylab 4 | Nov. 16, 1973 | Gerald P. Carr Edward G. Gibson William R. Pogue | 84 : 1 : 16 | Docked with Skylab 1 in long-duration mission; last of Skylab program. |
| Soyuz 13 | Dec. 18, 1973 | Petr I. Klimuk Valentin V. Lebedev | 7 : 20 : 55 | Astrophysical, biological, and earth resources experiments. |
| Soyuz 14 | July 3, 1974 | Pavel R. Popovich Yuriy P. Artyukhin | 15 : 17 : 30 | Docked with Salyut 3 and Soyuz 14 crew occupied space station. |
| Soyuz 15 | Aug. 26, 1974 | Gennadiy V. Sarafanov Lev. S. Demin | 2 : 0 : 12 | Rendezvoused but did not dock with Salyut 3. |
| Soyuz 16 | Dec. 2, 1974 | Anatoliy V. Filipchenko Nikolay N. Rukavishnikov | 5 : 22 : 24 | Test of ASTP configuration. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|---------------|----------------|--|-------------------------------|---|
| Soyuz 17 | Jan. 10, 1975 | Aleksay A. Gubarev Georgiy M. Grechko | 29 : 13 : 20 | Docked with Salyut 4 and occupied station. |
| Anomaly | Apr. 5, 1975 | Vasiliy G. Lazarev Oleg G. Makarov | 0 : 0 : 20 | Soyuz stages failed to separate; crew recovered after abort. |
| Soyuz 18 | May 24, 1975 | Petr I. Klimuk Vitaliy I. Sevastyanov | 62 : 23 : 20 | Docked with Salyut 4 and occupied station. |
| Soyuz 19 | July 15, 1975 | Aleksey A. Leonov Valeriy N. Kubasov | 5 : 22 : 31 | Target for Apollo in docking and joint experiments of ASTP mission. |
| Apollo (ASTP) | July 15, 1975 | Thomas P. Stafford Donald K. Slayton Vance D. Brand | 9 : 1 : 28 | Docked with Soyuz 19 in joint experiments of ASTP mission. |
| Soyuz 21 | July 6, 1976 | Boris V. Volynov Vitaliy M. Zholobov | 48 : 1 : 32 | Docked with Salyut 5 and occupied station. |
| Soyuz 22 | Sept. 15, 1976 | Valeriy F. Bykovskiy Vladimir V. Aksenov | 7 : 21 : 54 | Earth resources study with multispectral camera system. |
| Soyuz 23 | Oct. 14, 1976 | Vyacheslav D. Zudov Valeriy I. Rozhdestvenskiy | 2 : 0 : 6 | Failed to dock with Salyut 5. |
| Soyuz 24 | Feb. 7, 1977 | Viktor V. Gorbatko Yuriy N. Glazkov | 17 : 17 : 23 | Docked with Salyut 5 and occupied station. |
| Soyuz 25 | Oct. 9, 1977 | Vladimir V. Kovalenok Valeriy V. Ryumin | 2 : 0 : 46 | Failed to achieve hard dock with Salyut 6 station. |
| Soyuz 26 | Dec. 10, 1977 | Yuriy V. Romanenko Georgiy M. Grechko | 37 : 10 : 6 | Docked with Salyut 6. Crew returned in Soyuz 27; crew duration 96 days 10 hrs. |
| Soyuz 27 | Jan. 10, 1978 | Vladimir A. Dzhanibekov Oleg G. Makarov | 64 : 22 : 53 | Docked with Salyut 6. Crew returned in Soyuz 26; crew duration 5 days 22 hrs 59 min. |
| Soyuz 28 | Mar. 2, 1978 | Aleksey A. Gubarev Vladimir Remek | 7 : 22 : 17 | Docked with Salyut 6. Remek was first Czech cosmonaut to orbit. |
| Soyuz 29 | June 15, 1978 | Vladimir V. Kovalenok Aleksandr S. Ivanchenkov | 79 : 15 : 23 | Docked with Salyut 6. Crew returned in Soyuz 31; crew duration 139 days 14 hrs 48 min. |
| Soyuz 30 | June 27, 1978 | Petr I. Klimuk Miroslaw Hermaszewski | 7 : 22 : 4 | Docked with Salyut 6. Hermaszewski was first Polish cosmonaut to orbit. |
| Soyuz 31 | Aug. 26, 1978 | Valeriy F. Bykovskiy Sigmund Jaehn | 67 : 20 : 14 | Docked with Salyut 6. Crew returned in Soyuz 29; crew duration 7 days 20 hrs 49 min. Jaehn was first German Democratic Republic cosmonaut to orbit. |
| Soyuz 32 | Feb. 25, 1979 | Vladimir A. Lyakhov Valeriy V. Ryumin Nikolay N. Rukavishnikov | 108 : 4 : 24 | Docked with Salyut 6. Crew returned in Soyuz 34; crew duration 175 days 36 min. |
| Soyuz 33 | Apr. 10, 1979 | Georgi I. Ivanov | 1 : 23 : 1 | Failed to achieve docking with Salyut 6 station. Ivanov was first Bulgarian cosmonaut to orbit. |
| Soyuz 34 | June 6, 1979 | (unmanned at launch) | 73 : 18 : 17 | Docked with Salyut 6, later served as ferry for Soyuz 32 crew while Soyuz 32 returned unmanned. |
| Soyuz 35 | Apr. 9, 1980 | Leonid I. Popov Valeriy V. Ryumin | 55 : 1 : 29 | Docked with Salyut 6. Crew returned in Soyuz 37. Crew duration 184 days 20 hrs 12 min. |
| Soyuz 36 | May 26, 1980 | Valeriy N. Kubasov Bertalan Farkas | 65 : 20 : 54 | Docked with Salyut 6. Crew returned in Soyuz 35. Crew duration 7 days 20 hrs 46 min. Farkas was first Hungarian to orbit. |
| Soyuz T-2 | June 5, 1980 | Yuriy V. Malyshev Vladimir V. Aksenov | 3 : 22 : 21 | Docked with Salyut 6. First manned flight of new-generation ferry. |
| Soyuz 37 | July 23, 1980 | Viktor V. Gorbatko Pham Tuan | 79 : 15 : 17 | Docked with Salyut 6. Crew returned in Soyuz 36. Crew duration 7 days 20 hrs 42 min. Pham was first Vietnamese to orbit. |
| Soyuz 38 | Sept. 18, 1980 | Yuriy V. Romanenko Arnaldo Tamayo Mendez | 7 : 20 : 43 | Docked with Salyut 6. Tamayo was first Cuban to orbit. |
| Soyuz T-3 | Nov. 27, 1980 | Leonid D. Kizim Oleg G. Makarov Gennadiy M. Strekalov | 12 : 19 : 8 | Docked with Salyut 6. First 3-man flight in Soviet program since 1971. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|--|---------------|---|-------------------------------|--|
| Soyuz T-4 | Mar. 12, 1981 | Vladimir V. Kovalenok Viktor P. Savinykh | 74 : 18 : 38 | Docked with Salyut 6. |
| Soyuz 39 | Mar. 22, 1981 | Vladimir A. Dzhanibekov Jugderdemidiyn Gurragcha | 7 : 20 : 43 | Docked with Salyut 6. Gurragcha first Mongolian cosmonaut to orbit. |
| Space Shuttle Columbia (STS 1) | Apr. 12, 1981 | John W. Young Robert L. Crippen | 2 : 6 : 21 | First flight of Space Shuttle, tested spacecraft in orbit. First landing of airplanelike craft from orbit for reuse. |
| Soyuz 40 | May 14, 1981 | Leonid I. Popov Dumitru Prunariu | 7 : 20 : 41 | Docked with Salyut 6. Prunariu first Romanian cosmonaut to orbit. |
| Space Shuttle Columbia (STS 2) | Nov. 12, 1981 | Joe H. Engle Richard H. Truly | 2 : 6 : 13 | Second flight of Space Shuttle, first scientific payload (OSTA 1). Tested remote manipulator arm. Returned for reuse. |
| Space Shuttle Columbia (STS 3) | Mar. 22, 1982 | Jack R. Lousma C. Gordon Fullerton | 8 : 4 : 49 | Third flight of Space Shuttle, second scientific payload (OSS 1). Second test of remote manipulator arm. Flight extended 1 day because of flooding at primary landing site; alternate landing site used. Returned for reuse. |
| Soyuz T-5 | May 13, 1982 | Anatoliy Berezhovoy Valentin Lebedev | 211: 9 : 5 | Docked with Salyut 7. Crew duration of 211 days. Crew returned in Soyuz T-7. |
| Soyuz T-6 | June 24, 1982 | Vladimir Dzhanibekov Aleksandr Ivanchenkov Jean-Loup Chretien | 7 : 21 : 51 | Docked with Salyut 7. Chretien first French cosmonaut to orbit. |
| Space Shuttle Columbia (STS 4) | June 27, 1982 | Thomas K. Mattingly II Henry W. Hartsfield, Jr. | 7 : 1 : 9 | Fourth flight of Space Shuttle, first DoD payload, additional scientific payloads. Returned July 4. Completed orbital flight testing program. Returned for reuse. |
| Soyuz T-7 | Aug. 19, 1982 | Leonid Popov Aleksandr Serebrov Vance D. Brand | 7 : 21 : 52 | Docked with Salyut 7. Savitskaya second Soviet woman to orbit. Crew returned in Soyuz T-5. |
| Space Shuttle Columbia (STS 5) | Nov. 11, 1982 | Robert F. Overmyer Joseph P. Allen William B. Lenoir | 5 : 2 : 14 | Fifth flight of Space Shuttle, first operational flight; launched 2 commercial satellites (SBS 3 and Anik C-3); first flight with 4 crew members. EVA test cancelled when spacesuits malfunctioned. |
| Space Shuttle Challenger (STS 6) | Apr. 4, 1983 | Paul J. Weitz Karol J. Bobko Donald H. Peterson Story Musgrave | 5 : 0 : 24 | Sixth flight of Space Shuttle, launched TDRS 1. |
| Soyuz T-8 | Apr. 20, 1983 | Vladimir Titov Gennady Strekalov Aleksandr Serebrov | 2 : 0 : 18 | Failed to achieve docking with Salyut 7 station. |
| Space Shuttle Challenger (STS 7) | June 18, 1983 | Robert L. Crippen Frederick H. Hauck John M. Fabian Sally K. Ride Norman T. Thagard | 6 : 2 : 24 | Seventh flight of Space Shuttle, launched 2 commercial satellites (Anik C-2 and Palapa B-1), also launched and retrieved SPAS 01; first flight with 5 crew members, including first woman U.S. astronaut. |
| Soyuz T-9 | June 28, 1983 | Vladimir Lyakhov Aleksandr Aleksandrov | 149: 9 : 46 | Docked with Salyut 7 station. |
| Space Shuttle Challenger (STS 8) | Aug. 30, 1983 | Richard H. Truly Daniel C. Brandenstein Dale A. Gardner Guion S. Bluford, Jr. William E. Thornton | 6 : 1 : 9 | Eighth flight of Space Shuttle, launched one commercial satellite (Insat 1-B), first flight of U.S. black astronaut. |
| Space Shuttle Columbia (STS 9) | Nov. 28, 1983 | John W. Young Brewster W. Shaw Owen K. Garriott Robert A. R. Parker Byron K. Lichtenberg Ulf Merbold | 10 : 7 : 47 | Ninth flight of Space Shuttle, first flight of Spacelab 1, first flight of 6 crew members, one of whom was West German, first non-U.S. astronaut to fly in U.S. space program. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|------------------------------------|---------------|---|-------------------------------|---|
| Space Shuttle Challenger (STS-41B) | Feb. 3, 1984 | Vance D. Brand Robert L. Gibson Bruce McCandless Ronald E. McNair Robert L. Stewart | 7 : 23 : 16 | Tenth flight of Space Shuttle, two communication satellites failed to achieve orbit. First use of Manned Maneuvering Unit (MMU) in space. |
| Soyuz T-10 | Feb. 8, 1984 | Leonid Kizim Vladimir Solovov Oleg Atkov | 62 : 22 : 43 | Docked with Salyut 7 station. Crew set space duration record of 237 days. Crew returned in Soyuz T-11. |
| Soyuz T-11 | Apr. 3, 1984 | Yuriy Malyshev Gennadiy Strekalov Rakesh Sharma | 181 : 21 : 48 | Docked with Salyut 7 station. Sharma first Indian in space. Crew returned in Soyuz T-10. |
| Space Shuttle Challenger (STS-41C) | Apr. 6, 1984 | Robert L. Crippen Frances R. Scobee Terry J. Hart George D. Nelson James D. van Hoften | 6 : 23 : 41 | Eleventh flight of Space Shuttle, deployment of LDEF-1, for later retrieval, Solar Maximum Satellite retrieved, repaired, and redeployed. |
| Soyuz T-12 | July 17, 1984 | Vladimir Dzhanibekov Svetlana Savitskaya Igor Volk | 11 : 19 : 14 | Docked with Salyut 7 station. First woman extravehicular activity. |
| Space Shuttle Discovery (STS-41D) | Aug. 30, 1984 | Henry W. Hartsfield Michael L. Coats Richard M. Mullane Steven A. Hawley Judith A. Resnick Charles D. Walker | 6 : 0 : 56 | Twelfth flight of Space Shuttle. First flight of U.S. non-astronaut. |
| Space Shuttle Challenger (STS-41G) | Sept. 5, 1984 | Robert L. Crippen Jon A. McBride Kathryn D. Sullivan Sally K. Ride David Leestma Paul D. Scully-Power Marc Garneau | 8 : 5 : 24 | Thirteenth flight of Space Shuttle, first flight of 7 crewmembers, including first flight of two U.S. women and one Canadian. |
| Space Shuttle Discovery (STS-51A) | Nov. 8, 1984 | Frederick H. Hauck David M. Walker Joseph P. Allen Anna L. Fisher Dale A. Gardner | 7 : 23 : 45 | Fourteenth flight of Space Shuttle, first retrieval and return of two disabled communications satellites (Westar 6, Palapa B2) to Earth. |
| Space Shuttle Discovery (STS-51C) | Jan. 24, 1985 | Thomas K. Mattingly Loren J. Shriver Ellison S. Onizuka James F. Buchli Gary E. Payton | 3 : 1 : 33 | Fifteenth STS flight. Dedicated DoD mission. |
| Space Shuttle Discovery (STS-51D) | Apr. 12, 1985 | Karol J. Bobko Donald E. Williams M. Rhea Seddon S. David Griggs Jeffrey A. Hoffman Charles D. Walker E. J. Garn | 6 : 23 : 55 | Sixteenth STS flight. Two communications satellites. First U.S. Senator in space. |
| Space Shuttle Challenger (STS-51B) | Apr. 29, 1985 | Robert F. Overmyer Frederick D. Gregory Don L. Lind Norman E. Thagard William E. Thornton Lodewijk Vandenberg Taylor Wang | 7 : 0 : 9 | Seventeenth STS flight. Spacelab-3 in cargo bay of shuttle. |
| Soyuz T-13 | June 5, 1985 | Vladimir Dzhanibekov Viktor Savinykh | 112 : 3 : 12 | Repair of Salyut-7. Dzhanibekov returned to Earth with Grechko on Soyuz T-13 spacecraft, Sept. 26, 1985. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|--|----------------|---|-------------------------------|---|
| Space Shuttle Discovery (STS-51G) | June 17, 1985 | Daniel C. Brandenstein John O. Creighton Shannon W. Lucid John M. Fabian Steven R. Nagel Patrick Baudry Sultan bin Salman bin Abdul-Aziz Al-Saud | 7 : 1 : 39 | Eighteenth STS flight. Three communications satellites. One reusable payload, Spartan-1. First U.S. flight with French and Saudi Arabian crewmen. |
| Space Shuttle Challenger (STS-51F) | July 29, 1985 | Charles G. Fullerton Roy D. Bridges Karl C. Henize Anthony W. England F. Story Musgrave Loren W. Acton John-David F. Bartoe | 7 : 22 : 45 | Nineteenth STS flight. Spacelab-2 in cargo bay. |
| Space Shuttle Discovery (STS-51I) | Aug. 27, 1985 | Joe H. Engle Richard O. Covey James D. van Hoften William F. Fisher John M. Lounge | 7 : 2 : 18 | Twentieth STS flight. Launched three communications satellites. Repaired Syncom IV-3. |
| Soyuz T-14 | Sept. 17, 1985 | Vladimir Vasyutin Georgiy Grechko Aleksandr Volkov | 64 : 21 : 52 | Docked with Salyut-7 station. Viktor Savinykh, Aleksandr Volkov and Vladimir Vasyutin returned to Earth Nov. 21, 1985, when Vasyutin became ill. |
| Space Shuttle Atlantis (STS-51J) | Oct. 3, 1985 | Karol J. Bobko Ronald J. Grabe Robert A. Stewart David C. Hilmers William A. Pailles | 4 : 1 : 45 | Twenty-first STS flight. Dedicated DoD mission. |
| Space Shuttle Challenger (STS-61A) | Oct. 30, 1985 | Henry W. Hartsfield Steven R. Nagel Bonnie J. Dunbar James F. Buchli Guion S. Bluford Ernst Messerschmid Reinhard Furrer Wubbo J. Ockels | 7 : 0 : 45 | Twenty-second STS flight. Dedicated German Spacelab D-1 in shuttle cargo bay. |
| Space Shuttle Atlantis (STS-61B) | Nov. 27, 1985 | Brewster H. Shaw Bryan D. O'Connor Mary L. Cleve Sherwood C. Spring Jerry L. Ross Rudolfo Neri Vela Charles D. Walker | 6 : 22 : 54 | Twenty-third STS flight. Launched three communications satellites. First flight of Mexican astronaut. |
| Space Shuttle Columbia (STS-61C) | Jan. 12, 1986 | Robert L. Gibson Charles F. Bolden, Jr. Franklin Chang-Diaz Steven A. Hawley George D. Nelson Roger Cenker Bill Nelson | 6 : 2 : 4 | Twenty-fourth STS flight. Launched one communications satellite. First member of U.S. House of Representatives in space. |
| Soyuz T-15 | Mar. 13, 1986 | Leonid Kizim Vladimir Solovyov | 125 : 1 : 1 | Docked with MIR space station on May 5/6 transferred to Salyut 7 complex. On June 25/26 transferred from Salyut 7 back to MIR. |
| Soyuz TM-2 | Feb. 5, 1987 | Yuriy Romanenko Aleksandr Laveykin | 174 : 3 : 26 | Docked with MIR space station. Romanenko established long distance stay in space record of 326 days. |

U.S. and Soviet Manned Spaceflights, 1961–1988

| Spacecraft | Launch Date | Crew | Flight Time (days:hrs:min) | Highlights |
|------------|---------------|--|-------------------------------|--|
| Soyuz TM-3 | July 22, 1987 | Aleksandr Viktorenko Aleksandr Aleksandrov Mohammed Faris | 160 : 7 : 16 | Docked with MIR space station. Aleksandr Aleksandrov remained in MIR 160 days, returned with Yuriy Romanenko. Viktorenko and Faris returned in Soyuz TM-2, July 30 with Aleksandr Laveykin who experienced medical problems. Mohammed Faris first Syrian in space. |
| Soyuz TM-4 | Dec. 21, 1987 | Vladimir Titov Musa Manarov Anatoliy Levchenko | 180 : 5 | Docked with MIR space station. Crew of Yuriy Romanenko, Aleksandr Aleksandrov, and Anatoliy Levchenko returned Dec. 29 in Soyuz TM-3. |
| Soyuz TM-5 | Jun. 7, 1988 | Viktor Savinykh Anatoly Solovyev Aleksandr Aleksandrov | 9 : 20 : 13 | Docked with MIR space station, Aleksandrov first Bulgarian in space. Crew returned Jun. 17 in Soyuz TM-4. |
| Soyuz TM-6 | Aug. 29, 1988 | Vladimir Lyakhov Valeriy Polyakov Abdul Mohmand | 8 : 19 : 27 | Docked with MIR space station, Mohmand first Afghanistan in space. Crew returned Sep. 7 in Soyuz TM-5 |
| STS-26 | Sep. 29, 1988 | Frederick H. Hauck Richard O. Covey John M. Lounge David C. Hilmers George D. Nelson | 4 : 1 | Twenty-sixth STS flight. Launched TDRS 3. |
| Soyuz TM-7 | Nov. 26, 1988 | Aleksandr Volkov Sergey Krikalev Jean-Loup Chretien | In progress. | Docked with MIR space station. Volkov and Krikalev in orbit at end of 1988. Soyuz TM-6 returned with Chretien, Vladimir Titov and Musa Manarov. Titov and Manarov completed 366-day mission, Dec. 21. |
| STS-27 | Dec. 2, 1988 | Robert "Hoot" Gibson Guy S. Gardner Richard M. Mullane Jerry L. Ross William M. Shepherd | 4 : 9 : 6 | Twenty-seventh STS flight. Dedicated DoD mission. |

U.S. Space Launch Vehicles

| Vehicle | Stages/(engines) | Propellant ^a | Thrust (kilonewtons) | Max. Dia. x Height (m) | Max. Payload (kg) ^b | | | First Launch ^c |
|--|---|---|-------------------------|----------------------------------|---|---------------------------------|-------------------------------------|------------------------------|
| | | | | | 185-Km Orbit | Geosynch.- Transfer Orbit | Circular Sun- Synch. Orbit | |
| Scout | 1. Algol IIIA | Solid | 431.1 | 1.14x22.9 | 255 | -- | 155 ^d | 1979(60) |
| | 2. Castor IIA | Solid | 285.2 | | 205 ^d | | | |
| | 3. Antares IIIA | Solid | 83.1 | | | | | |
| | 4. Altair IIIA | Solid | 25.6 | | | | | |
| Delta 3900 Series (Thor-Delta) ^e | 1. Thor plus | LOX/RP-1 | 912.0 | 2.44x35.4 | 3,045 | 1,275 | 2,135 ^d | 1982(60) |
| | 9 TX 526-2 | Solid | 375 | | 2,180 ^d | | | |
| Delta | 2. Delta | N ₂ O ₄ /Acrozine-50 ... | 44.2 | | | | | |
| | 1. Atlas booster (MA-3) & sustainer | LOX/RP-1 | 1,722.0 | 3.05x28.1 | 2,090 ^{d,f} | -- | 1,500 ^d | 1972(59) |
| Atlas-Centaur | 1. Atlas booster (MA-5) & sustainer | LOX/RP-1 | 1,913.0 | 3.05x45.0 | 6,100 | 2,360 | -- | 1984(72) |
| | 2. Centaur | LOX/LH ₂ | 146.0 | | | | | |
| | | | | | 185-Km Orbit | 24-Hour Polar Orbit | Sun-synch. Transfer Orbit | |
| Titan II | 1. (LR-87[2]) | N ₂ O ₄ /Acrozine-50 | 2,108.4 | 3.05x28.5 | 2,200 | -- | -- | 1962 |
| | 2. (LR-91) | N ₂ O ₄ /Acrozine-50 | 444.8 | | 1,905 ^d | | | |
| Titan IIIB-Agena | 1. (LR-87) | N ₂ O ₄ /Acrozine | 2,341.0 | 3.05x48.4 | 3,600 ^d | | 3,060 ^d | 1966 |
| | 2. (LR-91) | N ₂ O ₄ /Acrozine | 455.1 | | | | | |
| | 3. Agena | IRFNA/UDMH | 71.2 | | | | | |
| Titan III(34)D/IUS | 1. Two 5 1/2-segment, 3.05 m dia | Solid | 11,564.8 | 3.05x48.0 | 14,920 | 1,850 ^d | -- | 1982 |
| | 2. LR-87 | N ₂ O ₄ /Acrozine | 2,366.3 | | | | | |
| | 3. LR-91 | N ₂ O ₄ /Acrozine | 449.3 | | | | | |
| | 4. IUS 1st stage | Solid | 275.8 | | | | | |
| | 5. IUS 2nd stage | Solid | 115.7 | | | | | |
| Titan III(34)D/ Transtage | Same as Titan III(34)D plus: 4. Transtage | N ₂ O ₄ /Acrozine | 69.8 | 3.05x46.9 | 14,920 | 1,855 ^d | -- | 1984 ^h |
| | | | | | 280- to 420-Km Orbit | | | |
| Space Shuttle (reusable) | 1. Orbiter; 3 main engines (SSMEs) fire in parallel with SRBs | LOX/LH ₂ | 1,670 each | 23.79x37.24 wing long span | 24,900 in full performance configuration | | | 1981 |
| | 2. Two solid-fueled rocket boosters (SRBs) fire in parallel with SSMEs Mounted on external tank (ET) | AL/NH ₄ ClO ₄ / PBAN | 11,790 each | 3.71x45.45 8.40x46.88 | | | | |

^a Propellant abbreviations used are as follows: liquid oxygen and a modified kerosene = LOX/RP,RJ; solid propellant combining in a single mixture both fuel and oxidizer = Solid; inhibited red-fuming nitric acid and unsymmetrical dimethylhydrazine = IRFNA/UDMH; nitrogen tetroxide and UDMH/N₂H₄ = N₂O₄/acrozine; liquid oxygen and liquid hydrogen = LOX/LH₂; aluminum, ammonium perchlorate, and polybutadiene acrolonitrile terpolymer = AL/NH₄ClO₄/PBAN.

^b Due east launch except as indicated.

^c The date of first launch applies to this latest modification with a date in parentheses for the initial version.

^d Polar launch.

^e Maximum performance based on 3920, 3920/PAM configurations. PAM = payload assist module.

^f With dual TE 364-4.

^g With 96° flight azimuth.

^h Initial operational capability in December 1982; launch to be scheduled as needed.

NOTE: Data should not be used for detailed NASA mission planning without concurrence of the director of Space Transportation System Support Programs.

Space Activities of the U.S. Government

HISTORICAL BUDGET SUMMARY—BUDGET AUTHORITY

(in millions of dollars)

| Fiscal Year | NASA | | Defense | Energy | Com- merce | Interior | Agricul- ture | NSF | DOT | Total Space |
|-------------------------|----------------------|----------------------|----------|--------|---------------|----------|------------------|-----|-----|----------------|
| | Total | Space ^a | | | | | | | | |
| 1959 | 330.9 | 260.9 | 489.5 | 34.3 | ... | ... | ... | ... | ... | 784.7 |
| 1960 | 523.6 | 461.5 | 560.9 | 43.3 | ... | ... | ... | 0.1 | ... | 1,065.8 |
| 1961 | 964.0 | 926.0 | 813.9 | 67.7 | ... | ... | ... | 0.6 | ... | 1,808.2 |
| 1962 | 1,824.9 | 1,796.8 | 1,298.2 | 147.8 | 50.7 | ... | ... | 1.3 | ... | 3,294.8 |
| 1963 | 3,673.0 | 3,626.0 | 1,549.9 | 213.9 | 43.2 | ... | ... | 1.5 | ... | 5,434.5 |
| 1964 | 5,099.7 | 5,016.3 | 1,599.3 | 210.0 | 2.8 | ... | ... | 3.0 | ... | 6,831.4 |
| 1965 | 5,249.7 | 5,137.6 | 1,573.9 | 228.6 | 12.2 | ... | ... | 3.2 | ... | 6,955.5 |
| 1966 | 5,174.9 | 5,064.5 | 1,688.8 | 186.8 | 26.5 | ... | ... | 3.2 | ... | 6,969.8 |
| 1967 | 4,965.6 | 4,830.2 | 1,663.6 | 183.6 | 29.3 | ... | ... | 2.8 | ... | 6,709.5 |
| 1968 | 4,587.3 | 4,430.0 | 1,921.8 | 145.1 | 28.1 | 0.2 | 0.5 | 3.2 | ... | 6,528.9 |
| 1969 | 3,990.9 | 3,822.0 | 2,013.0 | 118.0 | 20.0 | 0.2 | 0.7 | 1.9 | ... | 5,975.8 |
| 1970 | 3,745.8 | 3,547.0 | 1,678.4 | 102.8 | 8.0 | 1.1 | 0.8 | 2.4 | ... | 5,340.5 |
| 1971 | 3,311.2 | 3,101.3 | 1,512.3 | 94.8 | 27.4 | 1.9 | 0.8 | 2.4 | ... | 4,740.9 |
| 1972 | 3,306.6 | 3,071.0 | 1,407.0 | 55.2 | 31.3 | 5.8 | 1.6 | 2.8 | ... | 4,574.7 |
| 1973 | 3,406.2 | 3,093.2 | 1,623.0 | 54.2 | 39.7 | 10.3 | 1.9 | 2.6 | ... | 4,824.9 |
| 1974 | 3,036.9 | 2,758.5 | 1,766.0 | 41.7 | 60.2 | 9.0 | 3.1 | 1.8 | ... | 4,640.3 |
| 1975 | 3,229.1 | 2,915.3 | 1,892.4 | 29.6 | 64.4 | 8.3 | 2.3 | 2.0 | ... | 4,914.3 |
| 1976 | 3,550.3 | 3,225.4 | 1,983.3 | 23.3 | 71.5 | 10.4 | 3.6 | 2.4 | ... | 5,319.9 |
| Transitional Quarter... | 931.8 | 849.2 | 460.4 | 4.6 | 22.2 | 2.6 | 0.9 | 0.6 | ... | 1,340.5 |
| 1977 | 3,817.8 | 3,440.2 | 2,411.9 | 21.7 | 90.8 | 9.5 | 6.3 | 2.4 | ... | 5,982.8 |
| 1978 | 4,060.1 | 3,622.9 | 2,738.3 | 34.4 | 102.8 | 9.7 | 7.7 | 2.4 | ... | 6,518.2 |
| 1979 | 4,595.5 | 4,030.4 | 3,035.6 | 58.6 | 98.4 | 9.9 | 8.2 | 2.4 | ... | 7,243.5 |
| 1980 | 5,240.2 | 4,680.4 | 3,848.4 | 39.6 | 92.6 | 11.7 | 13.7 | 2.4 | ... | 8,688.8 |
| 1981 | 5,518.4 | 4,992.4 | 4,827.7 | 40.5 | 87.0 | 12.3 | 15.5 | 2.4 | ... | 9,977.8 |
| 1982 | 6,043.9 ^b | 5,527.6 | 6,678.7 | 60.6 | 144.5 | 12.1 | 15.2 | 2.0 | ... | 12,440.7 |
| 1983 | 6,875.3 ^c | 6,327.9 | 9,018.9 | 38.9 | 177.8 | 4.6 | 20.4 | ... | ... | 15,588.5 |
| 1984 | 7,248.0 | 6,648.3 | 10,194.9 | 34.1 | 236.0 | 3.0 | 19.4 | ... | ... | 17,135.7 |
| 1985 | 7,572.6 | 6,924.9 | 12,767.9 | 34.0 | 422.9 | 2.0 | 14.8 | ... | ... | 20,166.5 |
| 1986 | 7,766.0 | 7,165.0 | 14,126.0 | 34.6 | 308.9 | 2.0 | 22.9 | ... | ... | 21,659.4 |
| 1987 | 10,507.0 | 9,809.0 ^e | 16,286.8 | 47.6 | 277.9 | 7.6 | 18.5 | ... | 0.5 | 26,447.9 |
| 1988 | 9,025.8 | 8,302.4 | 17,678.7 | 240.8 | 351.5 | 13.6 | 18.3 | ... | 1.4 | 26,606.7 |
| 1989 [est.] | 10,969.0 | 10,097.5 | 17,906.1 | 239.8 | 362.4 | 14.4 | 20.5 | ... | 2.8 | 28,643.5 |
| 1990 [est.] | 12,322.3 | 11,393.1 | 19,382.4 | 190.3 | 243.0 | 15.5 | 23.4 | ... | 3.5 | 31,251.2 |

^aExcludes amounts for air transportation (subfunction 402).

^bIncludes \$33.5 million unobligated funds that lapsed.

^cIncludes \$37.6 million for reappropriation of prior year funds.

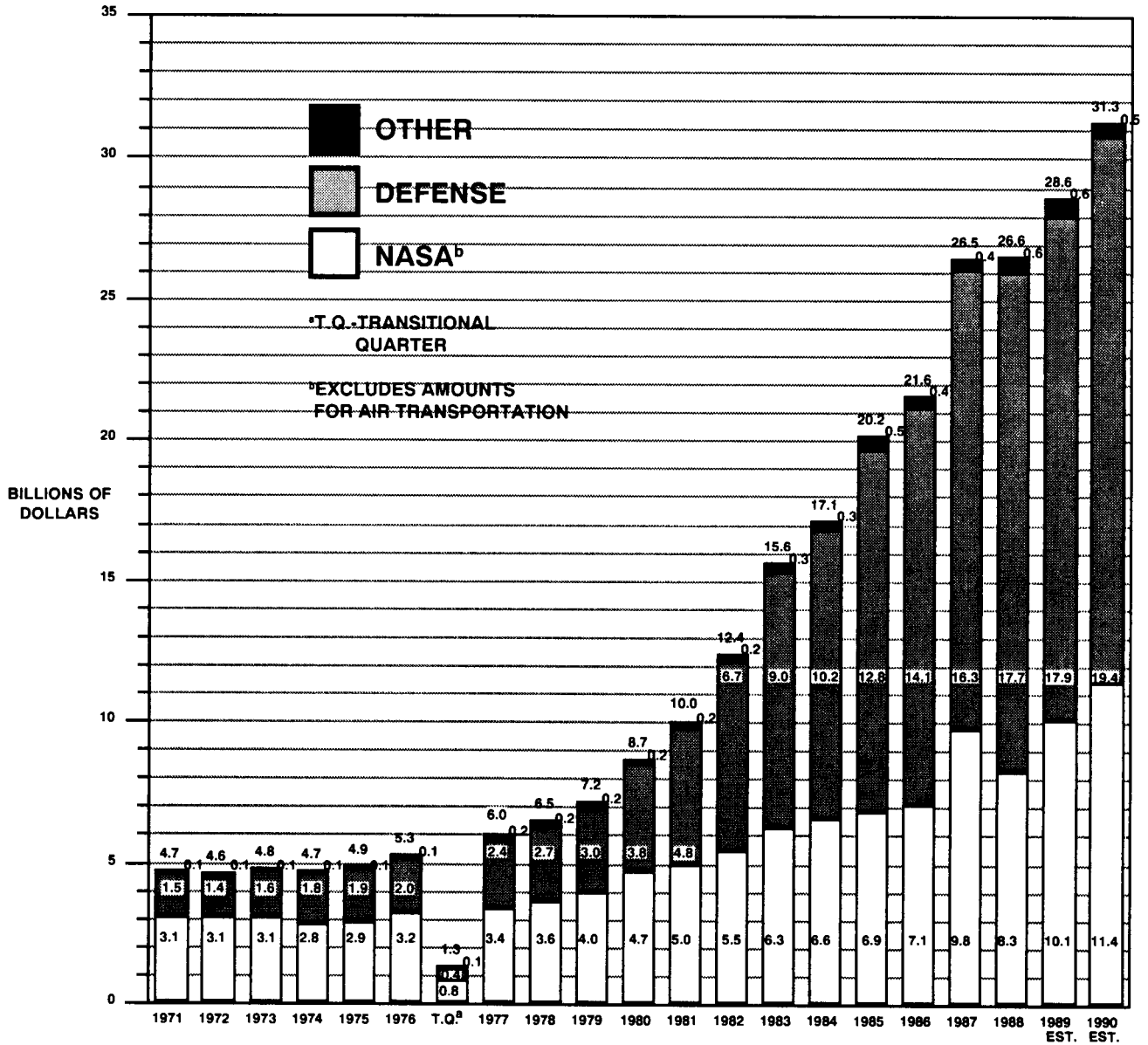
^dNSF funding of balloon research transferred to NASA.

^eIncludes \$2.1 billion for replacement of shuttle orbiter Challenger.

SOURCE: Office of Management and Budget.

U.S. Space Budget—Budget Authority FY 1971-1988

(may not add because of rounding)



SOURCE: OFFICE OF MANAGEMENT AND BUDGET

APPENDIX E-2

Space Activities Budget

(in millions of dollars by fiscal year)

| Federal Space Programs | Budget Authority | | | Budget Outlays | | |
|-------------------------|------------------|------------------|------------------|-----------------|------------------|------------------|
| | 1988 Actual | 1989 Estimate | 1990 Estimate | 1988 Actual | 1989 Estimate | 1990 Estimate |
| Federal agencies: | | | | | | |
| NASA ^a | 8,302.4 | 10,097.5 | 11,393.1 | 8,450.5 | 10,195.2 | 11,111.3 |
| Defense | 17,678.7 | 17,906.1 | 19,382.4 | 14,397.4 | 14,264.5 | 15,457.6 |
| Energy | 240.8 | 239.8 | 190.3 | 199.1 | 236.7 | 210.9 |
| Commerce | 351.5 | 362.4 | 243.0 | 333.9 | 344.3 | 230.9 |
| Interior | 13.6 | 14.4 | 15.5 | 13.6 | 14.4 | 15.2 |
| NSF ^b | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Agriculture | 18.3 | 20.5 | 23.4 | 18.3 | 20.5 | 23.4 |
| Transportation | 1.4 | 2.8 | 3.5 | 1.3 | 1.7 | 3.1 |
| TOTAL | 26,606.7 | 28,643.5 | 31,251.2 | 23,414.1 | 25,077.3 | 27,052.4 |

^aExcludes amounts for air transportation.^bNSF funding for balloon research transferred to NASA.

SOURCE: Office of Management and Budget.

APPENDIX E-3

Aeronautics Budget

(in millions of dollars by fiscal year)

| Federal Aeronautics Programs | Budget Authority | | | Budget Outlays | | |
|---|------------------|------------------|------------------|----------------|------------------|------------------|
| | 1988 Actual | 1989 Estimate | 1990 Estimate | 1988 Actual | 1989 Estimate | 1990 Estimate |
| NASA ^a | 723.4 | 871.5 | 929.2 | 678.8 | 855.3 | 913.2 |
| Department of Defense ^b | 4,988.7 | 8,240.4 | 8,551.8 | 4,448.3 | 6,335.3 | 7,711.4 |
| Department of Transportation ^c | 1,261.5 | 1,544.1 | 1,891.3 | 1,212.7 | 1,215.7 | 1,367.8 |
| TOTAL | 6,973.6 | 10,656.0 | 11,372.3 | 6,339.8 | 8,406.3 | 9,992.4 |

^aResearch and Development, Construction of Facilities, Research and Program Management.^bResearch, Development, Testing, and Evaluation of aircraft and related equipment.^cFederal Aviation Administration: Research, Engineering, and Development; Facilities, Engineering, and Development.

SOURCE: Office of Management and Budget.

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release

February 11, 1988

FACT SHEET

Presidential Directive on National Space Policy

The President approved on January 5, 1988, a revised national space policy that will set the direction of U.S. efforts in space for the future. The policy is the result of a five-month interagency review which included a thorough analysis of previous Presidential decisions, the National Commission on Space report, and the implications of the Space Shuttle and expendable launch vehicle accidents. The primary objective of this review was to consolidate and update Presidential guidance on U.S. space activities to provide a broad policy framework to guide U.S. space activities well into the future.

The resulting Presidential Directive reaffirms the national commitment to the exploration and use of space in support of our national well being. It acknowledges that United States space activities are conducted by three separate and distinct sectors: two strongly interacting governmental sectors (Civil, and National Security) and a separate, non-governmental Commercial Sector. Close coordination, cooperation, and technology and information exchange will be maintained among sectors to avoid unnecessary duplication and promote attainment of United States space goals.

GOALS AND PRINCIPLES

The directive states that a fundamental objective guiding United States space activities has been, and continues to be, space leadership. Leadership in an increasingly competitive international environment does not require United States preeminence in all areas and disciplines of space enterprise. It does require United States preeminence in key areas of space activity critical to achieving our national security, scientific, technical, economic, and foreign policy goals.

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

- The directive states that United States space activities shall be conducted in accordance with the following principles:

- The United States is committed to the exploration and use of outer space by all nations for peaceful purposes and for the benefit of all mankind. "Peaceful purposes" allow for activities in pursuit of national security goals.
- The United States will pursue activities in space in support of its inherent right of self-defense and its defense commitments to its
- The United States rejects any claims to sovereignty by any nation over outer space or celestial bodies, or any portion thereof, and rejects any limitations on the fundamental right of sovereign nations to acquire data from space.
- The United States considers the space systems of any nation to be national property with the right of passage through and operations in space without interference. Purposeful interference with space systems shall be viewed as an infringement on sovereign rights.
- The United States shall encourage and not preclude the commercial use and exploitation of space technologies and systems for national economic benefit without direct Federal subsidy. These commercial activities must be consistent with national security
- The United States shall encourage other countries to engage in free and fair trade in commercial space goods and services.
- The United States will conduct international cooperative space-related activities that are expected to achieve sufficient scientific, political, economic, or national security benefits for the nation. The United States will seek mutually beneficial international

CIVIL SPACE POLICY

The directive states that:

- The United States civil space sector activities shall contribute significantly to enhancing the Nation's science, technology, economy, pride, sense of well-being and direction, as well as United States world prestige and leadership. Civil sector activities shall comprise a balanced strategy of research, development, operations, and technology for science, exploration, and appropriate applications.

- The objectives of the United States civil space activities shall be (1) to expand knowledge of the Earth, its environment, the solar system, and the universe; (2) to create new opportunities for use of the space environment through the conduct of appropriate research and experimentation in advanced technology and systems; (3) to develop space technology for civil applications and, wherever appropriate, make such technology available to the commercial sector; (4) to preserve the United States preeminence in critical aspects of space science, applications, technology, and manned space flight; (5) to establish a permanently manned presence in space; and (6) to engage in international cooperative efforts that further United States space goals.

COMMERCIAL SPACE POLICY

The directive states that the United States government shall not preclude or deter the continuing development of a separate, non-governmental Commercial Space Sector. Expanding private sector investment in space by the market-driven Commercial Sector generates economic benefits for the Nation and supports governmental Space Sectors with an increasing range of space goods and services. Governmental Space Sectors shall purchase commercially available space goods and services to the fullest extent feasible and shall not conduct activities with potential commercial applications that preclude or deter Commercial Sector space activities except for national security or public safety reasons. Commercial Sector space activities shall be supervised or regulated only to the extent required by law, national security, international obligations, and public safety.

NATIONAL SECURITY SPACE POLICY

The directive further states that the United States will conduct those activities in space that are necessary to national defense. Space activities will contribute to national security objectives by 1) deterring, or if necessary, defending against enemy attack; 2) assuring that forces of hostile nations cannot prevent our own use of space; 3) negating, if necessary, hostile space systems; and 4) enhancing operations of United States and Allied forces. Consistent with treaty obligations, the national security space program shall support such functions as command and control, communications, navigation, environmental monitoring, warning, and surveillance (including research and development programs which support these functions).

INTER-SECTOR POLICIES

This section contains policies applicable to, and binding on, the national security and civil space sectors:

- The United States Government will maintain and coordinate separate national security and civil operational space systems where differing needs of the sectors dictate.
- Survivability and endurance of national security space systems, including all necessary system elements, will be pursued commensurate with their planned use in crisis and conflict, with the threat, and with the availability of other assets to perform the mission.
- Government sectors shall encourage, to the maximum extent feasible, the development and use of United States private sector space capabilities without direct Federal subsidy.
- The directive states that the United States Government will: (1) encourage the development of commercial systems which image the Earth from space competitive with or superior to foreign-operated civil or commercial systems; (2) discuss remote sensing issues and activities with foreign governments operating or regulating the private operation of remote sensing systems; and (3) continue a research and development effort for future advanced, remote sensing technologies. Commercial applications of such technologies will not involve direct Federal subsidy.
- The directive further states that assured access to space, sufficient to achieve all United States space goals, is a key element of national space policy. United States space transportation systems must provide a balanced, robust, and flexible capability with sufficient resiliency to allow continued operations despite failures in any single system. The goals of United States space transportation policy are: (1) to achieve and maintain safe and reliable access to, transportation in, and return from, space; (2) to exploit the unique attributes of manned and unmanned launch and recovery systems; (3) to encourage to the maximum extent feasible, the development and use of United States private sector space transportation capabilities without direct Federal subsidy; and (4) to reduce the costs of space transportation and related services.
- The directive also states that communications advancements are critical to all United States space sectors. To ensure necessary capabilities exist, the directive states that the United States Government will continue research and development efforts for future advanced space communications technologies. These technologies, when utilized for commercial purposes, will be without direct Federal subsidy.
- The directive states that it is the policy of the United States to control or prohibit, as appropriate, exports of equipment and/or technology that would make a significant contribution to a foreign country's strategic military missile programs. Certain United States friends and allies will be exempted from this policy, subject to appropriate non-transfer and end-use assurances.
- The directive also states that the United States will consider and, as appropriate, formulate policy positions on arms control measures governing activities in space, and will conduct negotiations on such measures only if they are equitable, effectively verifiable, and enhance the security of the United States and its allies.
- The directive further states that all space sectors will seek to minimize the creation of space debris. Design and operations of space tests, experiments and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness.

IMPLEMENTING PROCEDURES

The directive states that normal interagency procedures will be employed wherever possible to coordinate the policies enunciated in this directive. To provide a forum to all Federal agencies for their policy views, to review and advise on proposed changes to national space policy, and to provide for orderly and rapid referral of space policy issues to the President for decisions as necessary, a Senior Interagency Group (SIG) on Space shall continue to meet. The SIG(Space) will be chaired by a member of the National Security Council staff and will include appropriate representatives of the Department of State, Department of Defense (DOD), Department of Commerce (DOC), Department of Transportation (DOT), Director of Central Intelligence (DCI), Organization of the Joint Chiefs of Staff, United States Arms Control and Disarmament Agency, the National Aeronautics and Space Administration (NASA), Office of Management and Budget, and the Office of Science and Technology Policy. Other Executive agencies or departments will participate as the agenda of meeting shall dictate.

POLICY GUIDELINES AND IMPLEMENTING ACTIONS

The directive also enumerates Policy Guidelines and Implementing Actions to provide a framework through which the policies in the directive shall be carried out. Agencies are directed to use this section as guidance on priorities, including preparation, review, and execution of budgets for space activities, within the overall resource and policy guidance provided by the President. Within 120 days of the date of this directive, affected Government agencies are directed to review their current policies for consistency with the directive and, where necessary, establish policies to implement the practices contained therein.

CIVIL SPACE SECTOR GUIDELINES

- The directive specifies that in conjunction with other agencies: NASA will continue the lead role within the Federal Government for advancing space science, exploration, and appropriate applications through the conduct of activities for research, technology, development, and related operations; the National Oceanic and Atmospheric Administration will gather data, conduct research, and make predictions about the Earth's environment; DOT will license and promote commercial launch operations which support civil sector operations.
- Space Science. NASA, with the collaboration of other appropriate agencies, will conduct a balanced program to support scientific research, exploration, and experimentation to expand understanding of: (1) astrophysical phenomena and the origin and evolution of the universe; (2) the Earth, its environment and its dynamic relationship with the Sun; (3) the origin and evolution of the solar system; (4) fundamental physical, chemical, and biological processes; (5) the effects of the space environment on human beings; and (6) the factors governing the origin and spread of life in the universe.
- Space Exploration. In order to investigate phenomena and objects both within and beyond the solar system, the directive states that NASA will conduct a balanced program of manned and unmanned exploration.
 - Human Exploration. To implement the long-range goal of expanding human presence and activity beyond Earth orbit into the solar system the policy directs NASA to begin the systematic development of technologies necessary to enable and support a range of future manned missions. This technology program (Pathfinder) will be oriented toward a Presidential decision on a focused program of manned exploration of the solar system.
 - Unmanned Exploration. The policy further directs NASA to continue to pursue a program of unmanned exploration where such exploration can most efficiently and effectively satisfy national space objectives by among other things: achieving scientific objectives where human presence is undesirable or unnecessary; exploring realms where the risks or costs of life support are unacceptable; and providing data vital to support future manned missions.
- Permanent Manned Presence. The directive states that NASA will develop the Space Station to achieve permanently manned operational capability by the mid-1990s. The directive further states that the Space Station will: (1) Contribute to United States preeminence in critical aspects of manned spaceflight; (2) provide support and stability to scientific and technological investigations; (3) provide early benefits, particularly in the materials and life sciences; (4) promote private sector experimentation preparatory to independent commercial activity; (5) allow evolution in keeping with the needs of Station users and the long-term goals of the United States; (6) provide opportunities for commercial sector participation; and (7) contribute to the longer term goal of expanding human presence and activity beyond Earth orbit into the solar system.
- Manned Spaceflight Preeminence. The directive specifies that approved programs such as efforts to improve the Space Transportation System (STS) and return it to safe flight and to develop, deploy, and use the Space Station, are intended to ensure United States preeminence in critical aspects of manned spaceflight.
- Space Applications. The policy directs NASA and other agencies to pursue the identification and development of appropriate applications flowing from their activities. Agencies will seek to promote private sector development and implementation of applications. The policy also states that:
 - Such applications will create new capabilities, or improve the quality or efficiency of continuing activities, including long-term scientific observations.
 - NASA will seek to ensure its capability to conduct selected critical missions through an appropriate mix of assured access to space, on-orbit sparring, advanced automation techniques, redundancy, and other suitable measures.
 - Agencies may enter cooperative research and development agreements on space applications with firms seeking to advance the relevant state-of-the-art consistent with United States Government space objectives.
 - Management of Federal civil operational remote sensing is the responsibility of the Department of Commerce. The Department of Commerce will: (1) consolidate Federal needs for the civil operational remote sensing products to be met either by the private sector or the Federal government; (2) identify needed civil operational system research and development objectives; and (3) in coordination with other departments or agencies, provide for the regulation of private sector operational remote sensing systems.
- Civil Government Space Transportation. The policy states the unique Space Transportation System (STS) capability to provide manned access to space will be exploited in those areas that offer the greatest national return, including contributing to United States preeminence in critical aspects of manned spaceflight. The STS fleet will maintain the Nation's capability and will be used to support critical programs requiring manned presence and other unique STS capabilities. In support of national space transportation goals, NASA will establish sustainable STS flight rates to provide for planning and budgeting of Government space programs. NASA will pursue appropriate enhancements to STS operational capabilities, upper stages, and systems for deploying, servicing, and retrieving spacecraft as national and user requirements are defined.
- International Cooperation. The policy guidelines state that the United States will foster increased international cooperation in civil space activities by seeking mutually beneficial international participation in its civil space and space-related programs. The SIG(Space) Working

Group on Space Science Cooperation with the U.S.S.R. shall be responsible for oversight of civil space cooperation with the Soviet Union. No such cooperative activity shall be initiated until an interagency review has been completed. The directive provides that United States cooperation in international civil space activities will:

- Be consistent with United States technology transfer laws, regulations, Executive Orders and presidential directives.
- Support the public, nondiscriminatory direct readout of data from Federal civil systems to foreign ground stations and the provision of data to foreign users under specific conditions.
- Be conducted in such a way as to protect the commercial value of intellectual property developed with Federal support. Such cooperation will not preclude or deter commercial space activities by the United States private sector, except as required by national security or public safety.

COMMERCIAL SPACE SECTOR GUIDELINES

- The directive states that NASA, and the Departments of Commerce, Defense, and Transportation will work cooperatively to develop and implement specific measures to foster the growth of private sector commercial use of space. A high-level focus for commercial space issues has been created through establishment of a Commercial Space Working Group of the Economic Policy Council. SIG(Space) will continue to coordinate the development and implementation of national space policy.
- To stimulate private sector investment, ownership, and operation of space assets, the directive provides that the United States Government will facilitate private sector access to appropriate U.S. space-related hardware and facilities, and encourage the private sector to undertake commercial space ventures. The directive states that Governmental Space Sectors shall, without providing direct Federal subsidies:
 - Utilize commercially available goods and services to the fullest extent feasible, and avoid actions that may preclude or deter commercial space sector activities except as required by national security or public safety. A space good or service is “commercially available” if it is currently offered commercially, or if it could be supplied commercially in response to a government service procurement request. “Feasible” means that such goods or services meet mission requirements in a cost-effective manner.
 - Enter into appropriate cooperative agreements to encourage and advance private sector basic research, development, and operations while protecting the commercial value of the intellectual property developed;
 - Provide for the use of appropriate Government facilities on a reimbursable basis;
 - Identify, and eliminate or propose for elimination, applicable portions of United States laws and regulations that unnecessarily impede commercial space sector activities;
 - Encourage free trade in commercial space activities. The United States Trade Representative will consult, or, as appropriate, negotiate with other countries to encourage free trade in commercial space activities. In entering into space-related technology development and transfer agreements with other countries, Executive Departments and agencies will take into consideration whether such countries practice and encourage free and fair trade in commercial space activities.
 - Provide for the timely transfer of Government-developed space technology to the private sector in such a manner as to protect its commercial value, consistent with national security.
 - Price Government-provided goods and services consistent with OMB Circular A-25.
- The directive also states that the Department of Commerce (DOC) will commission a study to provide information for future policy and program decisions on options for a commercial advanced earth remote sensing system. This study, to be conducted in the private sector under DOC direction with input from other Federal Agencies, will consist of assessments of the following elements: (1) domestic and international markets for remote sensing data; (2) financing options, such as cooperative opportunities between government and industry in which the private sector contributes substantial financing to the venture, participation by other government agencies, and international cooperative partnerships; (3) sensor and data processing technology and; (4) spacecraft technology and launch options. The results of this study will include an action plan on the best alternatives identified during the study.

NATIONAL SECURITY SPACE SECTOR GUIDELINES

- General. The directive states that:
 - The Department of Defense (DOD) will develop, operate, and maintain an assured mission capability through an appropriate mix of robust satellite control, assured access to space, on-orbit sparing, proliferation, reconstitution or other means.
 - The national security space program, including dissemination of data, shall be conducted in accordance with Executive Orders and applicable directives for the protection of national security information and commensurate with both the missions performed and the security measures necessary to protect related space activities.
 - DOD will ensure that the military space program incorporates the support requirements of the Strategic Defense Initiative.
- Space Support. The directive states that:
 - The national security space sector may use both manned and unmanned launch systems as determined by specific mission requirements. Payloads will be distributed among launch systems and launch sites to minimize the impact of loss of any single launch system or launch site on mission performance. The DOD will procure unmanned launch vehicles or services and maintain launch capability on both the East and West coasts. DOD will also continue to enhance the robustness of its satellite control capability through an appropriate mix of satellite autonomy and survivable command and control, processing, and data dissemination systems.
 - DOD will study concepts and technologies which would support future contingency launch capabilities.

- Force Enhancement. The directive states that the national security space sector will develop, operate, and maintain space systems and develop plans and architectures to meet the requirements of operational land, sea, and air forces through all levels of conflict commensurate with their intended use.
- Space Control. The directive also states that:
 - The DOD will develop, operate, and maintain enduring space systems to ensure its freedom of action in space. This requires an integrated combination of antisatellite, survivability, and surveillance capabilities.
 - Antisatellite (ASAT) Capability. DOD will develop and deploy a robust and comprehensive ASAT capability with programs as required and with initial operational capability at the earliest possible date.
 - DOD space programs will pursue a survivability enhancement program with long-term planning for future requirements. The DOD must provide for the survivability of selected, critical national security space assets (including associated terrestrial components) to a degree commensurate with the value and utility of the support they provide to national-level decision functions, and military
 - The United States will develop and maintain an integrated attack warning, notification, verification, and contingency reaction capability which can effectively detect and react to threats to United States space systems.
- Force Application. The directive states that the DOD will, consistent with treaty obligations, conduct research, development, and planning to be prepared to acquire and deploy space weapons systems for strategic defense should national security conditions dictate.

INTER-SECTOR GUIDELINES

The directive states that the following paragraphs identify selected, high priority cross-sector efforts and responsibilities to implement plans supporting major United States space policy objectives:

- Space Transportation Guidelines.
 - The United States national space transportation capability will be based on a mix of vehicles, consisting of the Space Transportation System (STS), unmanned launch vehicles (ULVs), and in-space transportation systems. The elements of this mix will be defined to support the mission needs of national security and civil government sectors of United States space activities in the most cost effective manner.
 - As determined by specific mission requirements, the national security space sector will use the STS and ULVs. In coordination with NASA, the DOD will assure the Shuttle's utility to national defense and will integrate missions into the Shuttle system. Launch priority will be provided for national security missions as implemented by NASA-DOD agreements. Launches necessary to preserve and protect human life in space shall have the highest priority except in times of national security emergency.
 - The STS will continue to be managed and operated in an institutional arrangement consistent with the current NASA/DOD Memorandum of Understanding. Responsibility will remain in NASA for operational control of the STS for civil missions, and in the DOD for operational control of the STS for national security missions. Mission management is the responsibility of the mission agency.
 - United States commercial launch operations are an integral element of a robust national space launch capability. NASA will not maintain an expendable launch vehicle (ELV) adjunct to the STS. NASA will provide launch services for commercial and foreign payloads only where those payloads must be man-tended, require the unique capabilities of the STS, or it is determined that launching the payloads on the STS is important for national security or foreign policy purposes. Commercial and foreign payloads will not be launched on government owned or operated ELV systems except for national security or foreign policy reasons.
 - Civil Government agencies will encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services directly from the private sector or with DOD.
 - NASA and the DOD will continue to cooperate in the development and use of military and civil space transportation systems and avoid unnecessary duplication of activities. They will pursue new launch and launch support concepts aimed at improving cost-effectiveness, responsiveness, capability, reliability, availability, maintainability, and flexibility. Such cooperation between the national security and civil sectors will ensure efficient and effective use of national resources.
- The directive lists guidelines for the federal encouragement of commercial unmanned launch vehicles (ULVs):
 - The United States Government fully endorses and will facilitate the commercialization of United States unmanned launch vehicles
 - The Department of Transportation (DOT) is the lead agency within the Federal Government for developing, coordinating, and articulating Federal policy and regulatory guidance pertaining to United States commercial launch activities in consultation with DOD, State, NASA, and other concerned agencies. All Executive departments and agencies shall assist the DOT in carrying out its responsibilities, as set forth in the Commercial Space Launch Act and Executive Order 12465.
 - The United States Government encourages the use of its launch and launch-related facilities for United States commercial launch
 - The United States Government will have priority use of Government facilities and support services to meet national security and critical mission requirements. The United States Government will make all reasonable efforts to minimize impacts on commercial operations.
 - The United States Government will not subsidize the commercialization of ULVs, but will price the use of its facilities, equipment, and services with the goal of encouraging viable commercial ULV activities in accordance with the Commercial Space Launch Act.

- The United States Government will encourage free market competition within the United States private sector. The United States Government will provide equitable treatment for all commercial launch operators for the sale or lease of Government equipment and
- NASA and DOD, for those unclassified and releasable capabilities for which they have responsibility, shall, to the maximum extent feasible:
- Use best efforts to provide commercial launch firms with access, on a reimbursable basis, to national launch and launch-related
- Develop, in consultation with the DOT, contractual arrangements covering access by commercial launch firms to national launch and launch-related property and services they request in support of their operations;
- Provide technical advice and assistance to commercial launch firms on a reimbursable basis, consistent with the pricing guidelines herein; and
- Conduct, in coordination with DOT, appropriate environmental analyses necessary to ensure that commercial launch operations conducted at Federal launch facilities are in compliance with the National Environmental Policy Act.
- The directive lists government ULV Pricing Guidelines. The price charged for the use of United States Government facilities, equipment, and service, will be based on the following principles:
 - Price all services (including those associated with production and launch of commercial ULVs) based on the direct costs incurred by the United States Government. Reimbursement shall be credited to the appropriation from which the cost of providing such property or service was paid.
 - The United States Government will not seek to recover ULV design and development costs or investments associated with any existing facilities or new facilities required to meet United States Government needs to which the U.S. Government retains title;
 - Tooling, equipment, and residual ULV hardware on hand at the completion of the United States Government's program will be priced on a basis that is in the best overall interest of the United States Government, taking into consideration that these sales will not constitute a subsidy to the private sector operator.
- The directive also states that commercial launch firms shall:
 - Maintain all facilities and equipment leased from the United States Government to a level of readiness and repair specified by the United States Government;
 - Comply with all requirements of the Commercial Space Launch Act, all regulations issued under the Act, and all terms, conditions or restrictions of any license issued or transferred by the Secretary of Transportation under the Act.
- The directive establishes the following technology transfer guidelines:
 - The United States will work to stem the flow of advanced western space technology to unauthorized destinations. Executive departments and agencies will be fully responsible for protecting against adverse technology transfer in the conduct of their programs.
 - Sales of United States space hardware, software, and related technologies for use in foreign space projects will be consistent with relevant international and bilateral agreements and arrangements.
- The directive states that all Sectors shall recognize the importance of appropriate investments in the facilities and human resources necessary to support United States space objectives and maintain investments that are consistent with such objectives. A task force of the Commercial Space Working Group, in cooperation with OSTP, will conduct a feasibility study of alternate methods for encouraging, without direct Federal subsidy, private sector capital funding of United States space infrastructure such as ground facilities, launcher developments, and orbital assembly and test facilities. Coordinated terms of reference for this study shall be presented to the EPC and SIG(Space).
- The directive notes that the primary forum for negotiations on nuclear and space arms is the Nuclear and Space Talks (NST) with the Soviet Union in Geneva. The instructions to the United States Delegation will be consistent with this National Space Policy directive, established legal obligations, and additional guidance by the President. The United States will continue to consult with its Allies on these negotiations and ensure that any resulting agreements enhance the security of the United States and its Allies. Any discussions on arms control relating to activities in space in fora other than NST must be consistent with, and subordinate to, the foregoing activities and objectives.
- Finally the directive states that using NSC staff approved terms of reference, an SIG(Space) working group will provide recommendations on the implementation of the Space Debris Policy contained in the Policy section of this directive.

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release

February 11, 1988

FACT SHEET

The President's Space Policy and Commercial Space Initiative To Begin the Next Century

The President today announced a comprehensive "Space Policy and Commercial Space Initiative to Begin the Next Century" intended to assure United States space leadership.

The President's program has three major components:

- Establishing a long-range goal to expand human presence and activity beyond Earth orbit into the Solar System;
- Creating opportunities for U.S. commerce in space; and
- Continuing our national commitment to a permanently manned Space Station.

The new policy and programs are contained in a National Security Decision Directive (NSDD) signed by the President on January 5, 1988, the FY 1989 Budget the President will submit shortly to Congress, and a fifteen point Commercial Space Initiative.

I. EXPANDING HUMAN PRESENCE BEYOND EARTH ORBIT

In the recent NSDD, the President committed to a goal of expanding human presence and activity in the Solar System. To lay the foundation for this goal, the President will be requesting \$100 million in his FY 1989 Budget for a major new technology development program "Project Pathfinder" that will enable a broad range of manned or unmanned missions beyond the Earth's orbit.

Project Pathfinder will be organized around four major focuses:

- Exploration technology;
- Operations technology;
- Humans-in-space technology; and
- Transfer vehicle technology.

This research effort will give the United States know-how in critical areas, such as humans in the space environment, closed loop life support, aero braking, orbital transfer and maneuvering, cryogenic storage and handling, and large scale space operations, and provide a base for wise decisions on long term goals and missions.

Additional highlights of the NSDD are outlined in Section IV of this fact sheet.

II. CREATING OPPORTUNITIES FOR U.S. COMMERCE IN SPACE

The President is announcing a fifteen point commercial space initiative to seize the opportunities for a vigorous U.S. commercial presence in Earth orbit and beyond — in research and manufacturing. This initiative has three goals:

- Promoting a strong U.S. commercial presence in space;
- Assuring a highway to space; and
- Building a solid technology and talent base.

Promoting a Strong U.S. Commercial Presence in Space

1. *Private Sector Space Facility*: The President is announcing an intent for the Federal Government to lease space as an "anchor tenant" in a orbiting space facility suitable for research and commercial manufacturing that is financed, constructed, and operated by the private sector. The Administration will solicit proposals from the U.S. private sector for such a facility. Space in this facility will be used and/or subleased by various Federal agencies with interest in microgravity research.

The Administration's intent is to award a contract during mid-summer of this year for such space and related services to be available to the Government no later than the end of FY 1993.

2. *Spacehab*: The Administration is committing to make best efforts to launch within the Shuttle payload bay, in the early 1990s, the commercially developed, owned, and managed Shuttle middeck module: Spacehab. Manifesting requirements will depend on customer demand.

Spacehab is a pressurized metal cylinder that fits in the Shuttle payload bay and connects to the crew compartment through the orbiter airlock. Spacehab takes up approximately one-quarter of the payload bay and increases the pressurized living and working space of an orbiter by approximately 1,000 cubic feet or 400 percent in useable research volume. The facility is intended to be ready for commercial use in mid-1991.

3. *Microgravity Research Board*: The President will establish, through Executive Order, a National Microgravity Research Board to assure and coordinate a broader range of opportunities for research in microgravity conditions.

NASA will chair this board, which will include senior-level representatives from the Departments of Commerce, Transportation, Energy, and Defense, NIH, and NSF; and will consult with the university and commercial sectors. The board will have the following responsibilities:

- To stimulate research in microgravity environments and its applications to commercial uses by advising Federal agencies, including NASA, on microgravity priorities, and consulting with private industry and academia on microgravity research opportunities;
- To develop policy recommendations to the Federal Government on matters relating to microgravity research, including types of research, government/industry/and academic cooperation, and access to space, including a potential launch voucher program;
- To coordinate the microgravity programs of Federal agencies by:
 - reviewing agency plans for microgravity research and recommending priorities for the use of Federally-owned or leased space on microgravity facilities; and
 - ensuring that agencies establish merit review processes for evaluating microgravity research proposals; and
- To promote transfer of federally funded microgravity research to the commercial sector in furtherance of Executive Order 12591.

NASA will continue to be responsible for making judgments on the safety of experiments and for making manifesting decisions for manned space flight systems.

4. *External Tanks*: The Administration is making available for five years the expended external tanks of the Shuttle fleet at no cost to all feasible U.S. commercial and nonprofit endeavors, for uses such as research, storage, or manufacturing in space.
NASA will provide any necessary technical or other assistance to these endeavors on a direct cost basis. If private sector demand exceeds supply, NASA may auction the external tanks.
5. *Privatizing Space Station*: NASA, in coordination with the Office of Management and Budget, will revise its guidelines on commercialization of the U.S. Space Station to clarify and strengthen the Federal commitment to private sector investment in this program.
6. *Future Privatization*: NASA will seek to rely to the greatest extent feasible on private sector design, financing, construction, and operation of future Space Station requirements, including those currently under study.
7. *Remote Sensing*: The Administration is encouraging the development of commercial remote sensing systems. As part of this effort, the Department of Commerce, in consultation with other agencies, is examining potential opportunities for further Federal procurement of remote sensing data from the U.S. commercial sector.

Assuring a Highway to Space

8. *Reliance on Private Launch Services*: Federal agencies will procure existing and future required expendable launch services directly from the private sector to the fullest extent feasible.
9. *Insurance Relief for Launch Providers*: The Administration will take administrative steps to address the insurance concerns of the U.S. commercial launch industry, which currently uses Federal launch ranges. These steps include:
 - *Limits on Third Party Liability*: Consistent with the Administration's tort policy, the Administration will propose to Congress a \$200,000 cap on noneconomic damage awards to individual third parties resulting from commercial launch accidents;
 - *Limits on Property Damage Liability*: The liability of commercial launch operators for damage to Government property resulting from a commercial launch accident will be administratively limited to the level of insurance required by the Department of Transportation.
If losses to the Government exceed this level, the Government will waive its right to recover for damages. If losses are less than this level, the Government will waive its right to recover for those damages caused by Government willful misconduct or reckless disregard.
10. *Private Launch Ranges*: The Administration will consult with the private sector on the potential construction of commercial launch range facilities separate from Federal facilities and the use of such facilities by the Federal Government.
11. *Vouchers for Research Payloads*: NASA and the Department of Transportation will explore providing to research payload owners manifested on the Shuttle a one time launch voucher that can be used to purchase an alternative U.S. commercial launch service.

Building a Solid Technology and Talent Base

12. *Space Technology Spin-Offs*: The President is directing that the new Pathfinder program, the Civil Space Technology Initiative, and other technology programs be conducted in accordance with the following policies:

- Federally funded contractors, universities, and Federal laboratories will retain the rights to any patents and technical data, including copyrights, that result from these programs. The Federal Government will have the authority to use this intellectual property royalty free;

- Proposed technologies and patents available for licensing will be housed in a Pathfinder/CSTI library within NASA; and
 - When contracting for commercial development of Pathfinder, CSTI and other technology work products, NASA will specify its requirements in a manner that provides contractors with maximum flexibility to pursue innovative and creative approaches.
13. *Federal Expertise on Loan to American Schools:* The President is encouraging Federal scientists, engineers, and technicians in aerospace and space related careers to take a sabbatical year to teach in any level of education in the United States.
 14. *Education Opportunities:* The President is requesting in his FY 1989 Budget expanding five-fold opportunities for U.S. teachers to visit NASA field centers and related aerospace and university facilities.
In addition, NASA, NSF, and DoD will contribute materials and classroom experiments through the Department of Education to U.S. schools developing "tech shop" programs. NASA will encourage corporate participation in this program.
 15. *Protecting U.S. Critical Technologies:* The Administration is requesting that Congress extend to NASA the authority it has given the Department of Defense to protect from wholesale release under the Freedom of Information Act those critical national technologies and systems that are prohibited from export.

III. CONTINUING THE NATIONAL COMMITMENT TO THE SPACE STATION

In 1984, the President directed NASA to develop a permanently manned Space Station. The President remains committed to achieving this end and is requesting \$1 billion in his FY 1989 Budget for continued development and a three year appropriation commitment from Congress for \$6.1 billion. The Space Station, planned for development in cooperation with U.S. friends and allies, is intended to be a multi-purpose facility for the Nation's science and applications programs. It will permit such things in space as: research, observation of the solar system, assembly of vehicles or facilities, storage, servicing of satellites, and basing for future space missions and commercial and entrepreneurial endeavors in space.

To help ensure a Space Station that is cost effective, the President is proposing as part of his Commercial Space Initiative actions to encourage private sector investment in the Space Station, including directing NASA to rely to the greatest extent feasible on private sector design, financing, construction, and operation of future Space Station requirements.

IV. ADDITIONAL HIGHLIGHTS OF THE JANUARY 5, 1988 NSDD

- *U.S. Space Leadership:* Leadership is reiterated as a fundamental national objective in areas of space activity critical to achieving U.S. national security, scientific, economic and foreign policy goals.
- *Defining Federal Roles and Responsibilities:* Government activities are specified in three separate and distinct sectors: civil, national security, and nongovernmental. Agency roles and responsibilities are codified and specific goals are established for the civil space sector; those for other sectors are updated.
- *Encouraging a Commercial Sector:* A separate, nongovernmental or commercial space sector is recognized and encouraged by the policy that Federal Government actions shall not preclude or deter the continuing development of this sector. New guidelines are established to limit unnecessary Government competition with the private sector and ensure that Federal agencies are reliable customers for commercial space goods and services.
- The President's launch policy prohibiting NASA from maintaining an expendable launch vehicle adjunct to the Shuttle, as well as limiting commercial and foreign payloads on the Shuttle to those that are Shuttle-unique or serve national security or foreign policy purposes, is reaffirmed. In addition, policies endorsing the purchase of commercial launch services by Federal agencies are further strengthened.
- *National Security Space Station:* An assured capability for national security missions is clearly enunciated, and the survivability and endurance of critical national security space functions is stressed.
- *Assuring Access to Space:* Assured access to space is recognized as a key element of national space policy. U.S. space transportation systems that provide sufficient resiliency to allow continued operation, despite failures in any single system, are emphasized. The mix of space transportation vehicles will be defined to support mission needs in the most cost effective manner.
- *Remote Sensing:* Policies for Federal "remote sensing" or observation of the Earth are established to encourage the development of U.S. commercial systems competitive with or superior to foreign-operated civil or commercial systems.