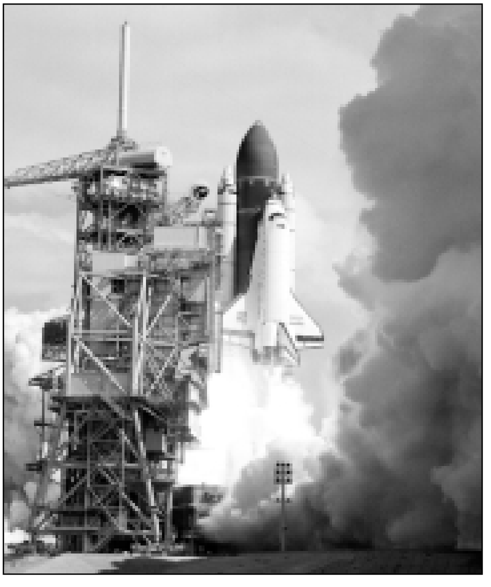

CHAPTER TWO

SPACE APPLICATIONS

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SPACE APPLICATIONS

Introduction

From NASA's inception, the application of space research and technology to specific needs of the United States and the world has been a primary agency focus. The years from 1979 to 1988 were no exception, and the advent of the Space Shuttle added new ways of gathering data for these purposes. NASA had the option of using instruments that remained aboard the Shuttle to conduct its experiments in a microgravity environment, as well as to deploy instrument-laden satellites into space. In addition, investigators could deploy and retrieve satellites using the remote manipulator system, the Shuttle could carry sensors that monitored the environment at varying distances from the Shuttle, and payload specialists could monitor and work with experimental equipment and materials in real time.

The Shuttle also allowed experiments to be performed directly on human beings. The astronauts themselves were unique laboratory animals, and their responses to the microgravity environment in which they worked and lived were thoroughly monitored and documented.

In addition to the applications missions conducted aboard the Shuttle, NASA launched ninety-one applications satellites during the decade, most of which went into successful orbit and achieved their mission objectives. NASA's degree of involvement with these missions varied. In some, NASA was the primary participant. Some were cooperative missions with other agencies. In still others, NASA provided only launch support. These missions are identified in this chapter.

Particularly after 1984, NASA's role in many applications missions complied with federal policy to encourage the commercial use of space and to privatize particular sectors of the space industry, while keeping others under government control.[1] Congress supported President Ronald

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[1]See Title VII, "Land Remote-Sensing Commercialization Act of 1984," Public Law 98–365, 98th Cong., 2d sess., July 17, 1984; "National Space Strategy," White House Fact Sheet, August 15, 1984.

Reagan's proposal to move land remote sensing (Landsat) to the private sector but insisted that meteorological satellite activities remain a government enterprise. Legislation spelled out intentions of Congress in these areas.

This chapter discusses the applications missions that were launched from 1979 through 1988 in which NASA had a role. It also addresses other major missions that NASA developed during the decade but were not launched until later.

The Last Decade Reviewed (1969–1978)

From 1969 to 1978, NASA added monitoring the state of the environment to its existing applications programs in advanced communications and meteorology research. Geodetic research was a fourth responsibility. The Office of Applications divided these areas of responsibility into four program areas (called by different names during the decade): weather, climate, and environmental quality; communications; Earth resources survey; and Earth and ocean dynamics.

Meteorology

NASA conducted advanced research and development activities in the field of meteorology and served as launch vehicle manager for the fleet of operational satellites of the National Oceanic and Atmospheric Administration (NOAA). In addition, NASA actively participated in the Global Atmospheric Research Program, an international meteorological research effort.

NASA's major meteorology projects consisted of TIROS (Television Infrared Observation Satellite), the Synchronous Meteorological Satellites (SMS), and Nimbus. TIROS began with the ESSA 9 polar-orbiting satellite in 1969. The decade ended with the 1978 launch of TIROS N, a new TIROS prototype. This satellite preceded the group of NOAA satellites that NASA would launch in the following decade. The advantage of SMS over TIROS was its ability to provide daytime and nighttime coverage from geostationary orbit. NASA funded and managed the SMS project but turned it over to NOAA for its operations. Following SMS 1 and 2, this operational satellite was called Geostationary Operational Environmental Satellite (GOES). Three GOES satellites were launched through 1978.

Communications

NASA's research and development activities during this decade were limited to the joint NASA-Canadian Communications Technology Satellites (CTS) and experiments flown on Applications Technology Satellites (ATS). CTS demonstrated that powerful satellite systems could bring low-cost television to remote areas almost anywhere on the globe.

The remaining fifty-eight communications satellites NASA launched were operational satellites that provided commercial communications, military network support, or aids to navigation. NASA provided the launch vehicles, the necessary ground support, and initial tracking and data acquisition on a reimbursable basis. During this period, NASA expanded its communications satellite launching service to include foreign countries, the amateur ham radio community, and the U.S. military. The International Telecommunications Satellite Organization (Intelsat), established in August 1964, was the largest user of NASA communications launch services.

Applications Technology Satellites

The ATS program investigated and flight-tested technology common to a number of satellite applications. NASA launched six ATS spacecraft during the 1970s. These spacecraft carried a variety of communications, meteorology, and scientific experiments. ATS 1 and ATS 3, launched in 1966 and 1967, respectively, provided service into the 1980s.

Earth Observations

The Earth Observations program emphasized the development of techniques to survey Earth resources and changes to those resources and to monitor environmental and ecological conditions. It consisted of three projects: (1) Skylab; (2) the Earth Resources Survey program, consisting of specially equipped aircraft that tested cameras and remote-sensing equipment; and (3) the Earth Resources Technology Satellite (ERTS) program, later renamed Landsat. ERTS and Landsat spacecraft were the first satellites devoted exclusively to monitoring Earth's resources.

The Skylab project was a series of four orbital workshops that were occupied by astronaut crews. A primary objective was to study the long-term effects of weightlessness on humans. In addition, crew members conducted experiments in many discipline areas, providing investigators with hundreds of thousands of images, photographs, and data sets.

An ERTS/Landsat-type program was first conceived in the 1960s. The program grew with input from the Department of Agriculture, the U.S. Geological Survey, NASA, the Department of the Interior, the Department of Commerce, and academia. NASA's efforts focused on sensor development, and the agency launched ERTS 1 in 1972, followed by three Landsat satellites—all of which surpassed their predicted operational lifetimes. Investigators applied satellite data obtained from sensors aboard these satellites to agriculture, forestry, and range resources; cartography and land use; geology; water resources; oceanography and marine resources; and environmental monitoring.

Other Earth Observation Activities

NASA launched five other Earth-observation-type missions during the 1970s: Seasat 1, a satellite designed to predict ocean phenomena; the Laser Geodynamics Satellite (LAGEOS), which demonstrated the capability of laser satellite tracking techniques to accurately determine the movement of Earth's crust and rotational motions; GEOS 3, which studied Earth's shape and dynamic behavior; TOPO 1 for the U.S. Army Topographic Command; and the Heat Capacity Mapping Mission, which was the first in a series of applications explorer missions. All were successful except Seasat 1, which failed 106 days after launch.

Space Applications (1979–1988)

As in the previous decade, most of the applications missions that NASA launched from 1979 to 1988 were commercial missions or missions that were managed by other government agencies. Table 2–1 lists all of the applications satellites that NASA launched during this decade. Only the Stratospheric Aerosol and Gas Experiment (SAGE or AEM-2) and the Magnetic Field Satellite (Magsat or AEM-C), both of which were part of the Applications Explorer Mission (AEM), and the Earth Radiation Budget Satellite (ERBS) were NASA satellites. NASA's other applications missions took place aboard the Space Shuttle. Table 2–2 lists these missions. Additional applications experiments conducted on the Shuttle are discussed under the appropriate STS mission in Chapter 3, "Space Transportation/Human Spaceflight," in Volume V of the *NASA Historical Data Book.*

Environmental Observations

NASA launched two satellites as part of its Applications Explorer Mission. SAGE, launched from Wallops Flight Facility, Virginia, in February 1979, profiled aerosol and ozone content in the stratosphere. The satellite observed the violent eruptions of the volcano La Soufriere in the Caribbean in April 1979, the Sierra Negra volcanic eruption on the Galapagos Islands, and the eruption of Mount St. Helens. Magsat, launched later in 1979, was part of NASA's Resource Observations program.

NASA's other environmental observations missions consisted of two series of meteorological satellites that were developed, launched, and operated in conjunction with NOAA. The new polar-orbiting series of satellites succeeded the TIROS system. This two-satellite weather satellite system obtained and transmitted morning and afternoon weather data. The GOES series continued the group of geosynchronous satellites that began with SMS in the 1970s. Also intended to operate with two satellites, one located near the east coast of the United States and the other near the west coast, GOES provided almost continuous coverage of large areas.

In addition, Nimbus 5, launched in 1972, continued to operate until April 1983. Nimbus 6, launched in 1975, ceased operations in September 1983. Nimbus 7, launched in October 1978, provided useful data until the end of 1984. Its Total Ozone Monitoring System (TOMS) provided the first global maps of total ozone with high spatial and temporal resolution. This was the first time investigators could study short-period dynamic effects on ozone distribution. A series of these measurements provided information related to long-term, globally averaged ozone changes in the atmosphere of both natural and human origin.

NASA also continued to participate in the Global Weather Experiment as part of the Global Atmospheric Research Program. The goal of the program was to devise a way to improve satellite weather forecasting capabilities.

In 1984, NASA launched the ERBS, the first part of a three-satellite system comprising the Earth Radiation Budget Experiment (ERBE). (Other ERBE instruments flew on NOAA 9 and NOAA 10.) Part of NASA's climate observing program, ERBS data allowed scientists to increase their understanding of the physical processes that governed the interaction of clouds and radiation.

The effects of ozone on the upper atmosphere received increasing attention during the 1980s. The Nimbus series of satellites continued to provide data on ozone levels from its backscatter ultraviolet instrument. The Upper Atmospheric Research Satellites (UARS) program, which NASA initiated with an Announcement of Opportunity in 1978, also moved ahead. The program would make integrated, comprehensive, long-term measurements of key parameters and would improve investigators' abilities to predict stratospheric perturbations.

NASA reported to Congress and the U.S. Environmental Protection Agency in January 1982 (as required by the Clean Air Act Amendments of 1977) its assessment of what was known about key processes in the stratosphere, especially about the effect of human-produced chemicals on the ozone layer. This assessment was developed from the findings of a workshop sponsored by NASA and the World Meteorological Organization, in which approximately 115 scientists from thirteen countries participated. The scientists concluded that a continued release of chlorofluorocarbons 11 and 12 (Freon-11 and -12) at 1977 rates would decrease total global ozone by 5 to 9 percent by about the year 2100, but the effects of other changes in atmospheric composition could modify that result.

During 1984, Congress approved the UARS mission, and work began on the observatory and ground data-handling segments of the program. UARS, initially scheduled for launch in late 1989 and later moved to 1991, would be the first satellite capable of simultaneous measurements of the energy input, chemical composition, and dynamics of the stratosphere and mesosphere. The discovery of an Antarctic ozone hole in 1985 and Arctic ozone depletion in 1988 further emphasized the urgency of the mission.

Resource Observations

NASA launched the Magsat satellite in October 1979. Magsat was part of the Applications Explorer Mission and the first spacecraft specifically designed to conduct a global survey of Earth's vector magnetic field. Placed into a significantly lower orbit than previous magnetic field-measuring satellites, it provided more detailed and precise information about the nature of magnetic anomalies within Earth's crust than earlier missions and improved large-scale models of crustal geology.

Data obtained through remote sensing from space attracted a growing number of government and private-sector users during this decade. New ground stations were brought on-line and began receiving data transmitted from the Landsat satellites. Remote-sensing techniques were also used for geologic mapping as part of the NASA-Geosat Test Case Project, a joint research project with private industry. The results indicated that an analysis of remote-sensing measurements could yield geological information not commonly obtained by conventional field mapping.

President Jimmy Carter announced in 1979 that NOAA would manage all space-based operational civilian remote-sensing activities. NASA would continue its involvement in these activities, centered primarily in the Landsat program, through the launch and checkout of the spacecraft. The Land Remote-Sensing Commercialization Act of 1984, passed during the Reagan administration, moved remote-sensing activities from the public to the private sector. In accordance with this legislation, the Earth Observation Satellite Company (EOSAT) was chosen to begin operating the Landsat system. EOSAT initiated the development of a satellite-receiving center and an operations and control center that captured and processed data and flight control for the next-generation Landsat 6 and future spacecraft.

NASA launched Landsat 4 and Landsat 5 in 1982 and 1984, respectively. The Thematic Mapper instrument aboard these satellites, developed by NASA, provided data in several additional spectral bands and had better than twice the resolution of the Multispectral Scanner, which was the instrument used on earlier Landsat spacecraft. The satellites were turned over to NOAA following their checkout and to EOSAT after it assumed operation of the system.

Congress approved the AgRISTARS project in 1979. This multi-agency project—NASA, the Department of Agriculture, the Department of the Interior, NOAA, and the Agency for International Development—was to develop and test the usefulness of remote sensing for providing timely information to the Department of Agriculture. NASA was responsible for the selected research and development, exploratory and pilot testing, and support in areas in which it had specialized capabilities. It served as the lead agency for the Supporting Research project and the Foreign Commodity Production Forecasting project, both of which involved using remote-sensing techniques related to crop production and development. In 1982, Congress reduced the scope of AgRISTARS to focus it primarily on the Department of Agriculture's priority needs. NASA phased out its participation in 1984, but the space agency also conducted investigations in geodynamics and materials processing during this period.

Communications

From 1979 to 1988, NASA's role in the communications satellite field was primarily as a provider of launch services. The agency launched sixty-five operational communications satellites. Operational satellites included: ten Intelsat, four Westar, eight RCA Satcom, four Satellite Business Systems (SBS), one Comstar, three Telstar, five Anik/Telesat (Canada), one Arabsat (Saudi Arabia), two Morelos (Mexico), and two Aussat (Australia). The government of India reimbursed NASA for the launch of two Insat satellites, and the Republic of Indonesia paid for the launch of three Palapa satellites. NASA launched one NATO defense-related communications satellite. For the U.S. Department of Defense (DOD), NASA launched six Fleet Satellite Communications (Fltsatcom) satellites (U.S. Navy and Air Force) and four Leasat/Syncom satellites. In addition, NASA launched seven navigation satellites for the U.S. Navy: four SOOS and three Nova satellites. It also launched four other DOD communications satellites with classified missions.

These commercial missions enabled NASA to use some of its launch capabilities for the first time. SBS-1 was the first to use the Payload Assist Module (PAM) in place of a conventional third stage. The launch of SBS-3 marked the first launch from the Shuttle's cargo bay.

NASA's communications activities centered around its Search and Rescue Satellite-Aided Tracking system (SARSAT), its development of the Advanced Communications Technology Satellite (ACTS), its continued work on its mobile satellite program, and its development of an information systems program to handle the huge quantities of data returned from space missions. In addition, NASA's ATS program carried over into the 1980s. ATS 1, launched in 1966, and ATS 3, launched in 1967, continued to provide important communications services, especially in areas unreachable by more traditional means. ATS 1 operated until it was shut down in October 1985; ATS 3 was still operating into 1996.

SARSAT was an ongoing international project that used satellite technology to detect and locate aircraft and vessels in distress. The United States, the Soviet Union, Canada, and France developed the system. Norway, the United Kingdom, Sweden, Finland, Bulgaria, Denmark, and Brazil were other participants. The Soviet Union contributed a series of COSPAS satellites, beginning with the launch of COSPAS 1 in 1982. This was the first spacecraft that carried instruments specifically to determine the position of ships and aircraft in distress. It was interoperable with the SARSAT equipment on U.S. satellites and ground stations. During the 1980s, the United States operated instruments on NOAA's polar-orbiting spacecraft. The first was NOAA 8, which launched in March 1983.

The system became fully operational in 1984 and succeeded in saving more than 1,000 lives during the 1980s.

Work on NASA's ACTS began in 1984. ACTS was to allow large numbers of U.S. companies, universities, and government agencies to experiment with spot beams, hopping beams, and switchboard-in-the-sky concepts that were to enter the marketplace by the mid-1990s. The mission was originally planned to launch in 1988 but was delayed until September 1993. The program was canceled and resurrected several times; it was restructured in 1988 in response to congressional direction to contain costs.

The joint mobile satellite program among NASA, U.S. industry, and other government agencies was to provide two-way, satellite-assisted communication with a variety of vehicles in the early 1990s. As of the close of 1988, international frequencies had been allocated, and licensing approval by the Federal Communications Commission was expected shortly.

NASA's information systems program, which had become part of the newly formed Communications and Information Systems Division in 1987, operated large-scale computational resources used for data analysis. It also worked with specialized programs to establish data centers for managing and distributing data and developed computer networks and exploited advanced technologies to access and process massive amounts of data acquired from space missions. NASA established the National Science Space Data Center at the Goddard Space Flight Center to archive data from science missions and coordinate management of NASA data at distributed data centers.

Management of the Applications Program at NASA

From 1971, NASA managed applications missions independently from science missions, first through the Office of Applications and then, from 1977, through the Office of Space and Terrestrial Applications (OSTA). In November 1981, OSTA and the Office of Space Science merged into the Office of Space Science and Applications (OSSA).

OSTA's objective was to "conduct research and development activities that demonstrate and transfer space-related technology, systems and other capabilities which can be effectively used for down-to-earth practical benefits."[2] It was divided into divisions for materials processing in space, communications and information systems, environmental observation, research observation, and technology transfer (Figure 2–1). Anthony J. Calio, who had assumed the position of associate administrator in October 1977, continued leading OSTA until the new OSSA was formed. John Carruthers led the Materials Processing in Space Division until mid-1981, when Louis R. Testardi became acting division director. John

[2]"Office of Space and Terrestrial Applications," *Research and Development Fiscal Year 1981 Estimates, Budget Summary* (Washington, DC: NASA, 1981).

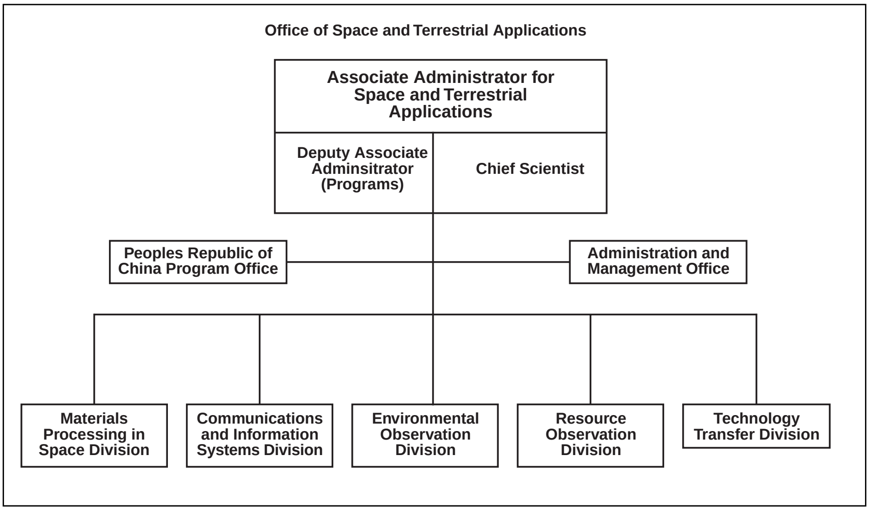

Figure 2–1. Office of Space and Terrestrial Applications

McElroy served as director of the Communications Division until late 1980, when Robert Lovell became division chief. Pitt Thome led the Resource Observation Division, Floyd Roberson served as director of the Technology Transfer Division, and Lawrence Greenwood led the Environmental Observation Division.

Andrew Stofan, who had been head of the Office of Space Science, became associate administrator of the new OSSA until he was replaced by Burton Edelson in February 1982. Edelson remained at the post until he resigned in February 1987. Lennard A. Fisk was appointed to the position in April of that year.

Initially, two OSSA divisions and two offices handled applications—the Environmental Observation and Communications Divisions and the Information Systems and Materials Processing Offices (Figure 2–2). The Information Systems Office was responsible for NASA's long-term data archives, institutional computer operations in support of ongoing research programs, and advanced planning and architecture definition for future scientific data systems. Anthony Villasenor served as acting manager of this office until Caldwell McCoy, Jr., assumed the position of manager in 1983. McCoy held the post until the office merged with the Communications Division in 1987.

Robert Lovell led the Communications Division until he left in early 1987. The division director position remained vacant until Ray Arnold became acting division director later that year. He was appointed permanent director of the division, which had merged with the Information Systems Office in September 1987 to become the new Communications and Information Systems Division. This new division handled all the communications and data transmission needs of OSSA.

Shelby G. Tilford led the Environmental Observation Division until it was disestablished in January 1984. He then assumed leadership of the

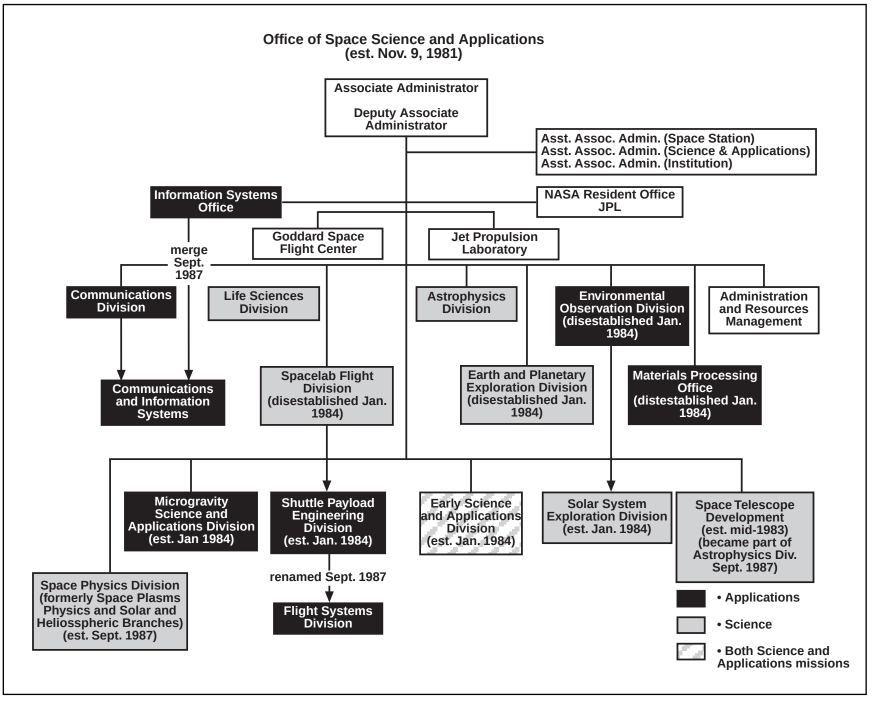

Figure 2–2. Office of Space Science and Applications

newly established Earth Science and Applications Division. He remained at that post throughout the decade.

Louis R. Testardi managed the Materials Processing Office through 1982, when he left the position. The post remained vacant until Richard Halpern became manager in the first half of 1983. He led the office until it was disestablished in January 1984 and then led the new Microgravity Sciences and Applications Division, where he remained until mid-1986. The position of director of the Microgravity Science and Applications Division then remained vacant until Kathryn Schmoll became acting director in early 1987. Robert Naumann assumed the post of division director in early 1988 and remained until later that year, when Frank Lemkey replaced him as acting division director.

The Shuttle Payload Engineering Division evolved from the Spacelab Flight Division, which had managed the science-related elements of the Spacelab missions. The new division had responsibility for developing and integrating all science- and applications-related Space Shuttle payloads. Michael Sander led the new Shuttle Payload Engineering Division until late 1985, when Robert Benson became acting director of the division. Benson became permanent division director in 1987 and continued leading the renamed Flight Systems Division.

Money for Space Applications

Budget data (request or submission, authorization, and appropriation) for the major budget categories are from the annual Budget Chronological Histories. Request or submission data for the more detailed budget items come from the annual budget estimates produced by NASA's budget office. No corresponding authorization or appropriations data were available. All programmed (actual) figures come from NASA's budget estimates. It should be noted that the amounts in this section reflect the value of the funds at the time that they were submitted; inflation has not been added. The funding histories of NASA applications from 1979 through 1988 appear in Tables 2–3 through 2–54.

Applications Programs

Space Shuttle Payloads

As with NASA's science missions, the Space Shuttle was a natural environment for many applications investigations. NASA conducted three on-board applications missions under the management of OSTA: OSTA-1 in 1981, OSTA-2 in 1983, and OSTA-3 in 1984. It also participated in the Spacelab missions described in Chapter 4, "Space Science," in Volume V of the *NASA Historical Data Book* and in OAST-1, which was managed by the Office of Aeronautics and Space Technology and is addressed in Chapter 3, "Aeronautics and Space Research and Technology," in this volume.

OSTA-1

OSTA-1 flew on STS-2, the second Space Shuttle test flight. It was the Space Shuttle's first science and applications payload. The objectives of OSTA-1 were to:

- Demonstrate the Shuttle for scientific and applications research in the attached mode
- Operate the OSTA-1 payload to facilitate the acquisition of Earth's resources, environmental, technology, and life science data
- Provide data products to principal investigators within the constraints of the STS-2 mission

The experiments selected for the OSTA-1 payload emphasized terrestrial sciences and fit within the constraints of the STS-2 tests. Experiments relating to remote sensing of Earth resources, environmental quality, ocean conditions, meteorological phenomena, and life sciences made up the payload. Five of the seven experiments were mounted on a Spacelab pallet in the Shuttle payload bay (Figure 2–3); two were carried in the Shuttle cabin. The Spacelab Program Office at the Marshall

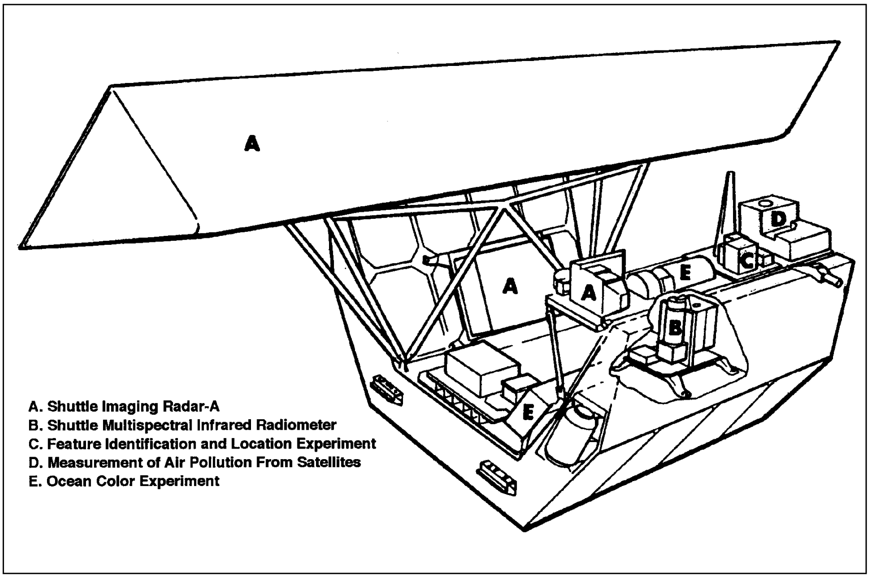

Figure 2–3. OSTA-1 Payload Location

Space Flight Center was responsible for the design, development, and integration of the overall orbital flight test pallet system. Table 2–55 lists the principal investigators and a description of the experiments, including the first Shuttle Imaging Radar (SIR-A), which is depicted in Figure 2–4.

During the flight, *Columbia* assumed an Earth-viewing attitude called Z-axis local vertical, in which the instruments carried in the payload bay were aimed at Earth's surface. Figure 2–5 shows the payload ground coverage and ground resolution of each instrument.

Although most investigation objectives were accomplished, certain conditions affected the quantity and quality of some of the data. During the first twenty-eight hours of the mission, experiment data collection was affected by the loss of one fuel cell and the crew's focus on the orbiter power situation. Instrument operations were restricted to minimize orbiter power usage, and some targets were missed. In addition, the final orbiter maneuvering system burn was delayed for one orbit because of power considerations, which caused the time over specific Earth locations to change and the need to develop new instrument on/off times.

The delay in launch of two hours, forty minutes changed solar illumination conditions along the ground track and the Sun elevation angle, which affected the Ocean Color Experiment, the Shuttle Multispectral Infrared Radiometer, and the Feature Identification and Location Experiment. Cloud cover also affected the Ocean Color Experiment and Shuttle Multispectral Infrared Radiometer targets.

In addition, the shortened mission and intense crew activity limited opportunities for the crew to operate the Nighttime/Daylight Optical Survey of Thunderstorm Lightning (NOSL) experiment. The limited amount of data collected did not allow this experiment to achieve its

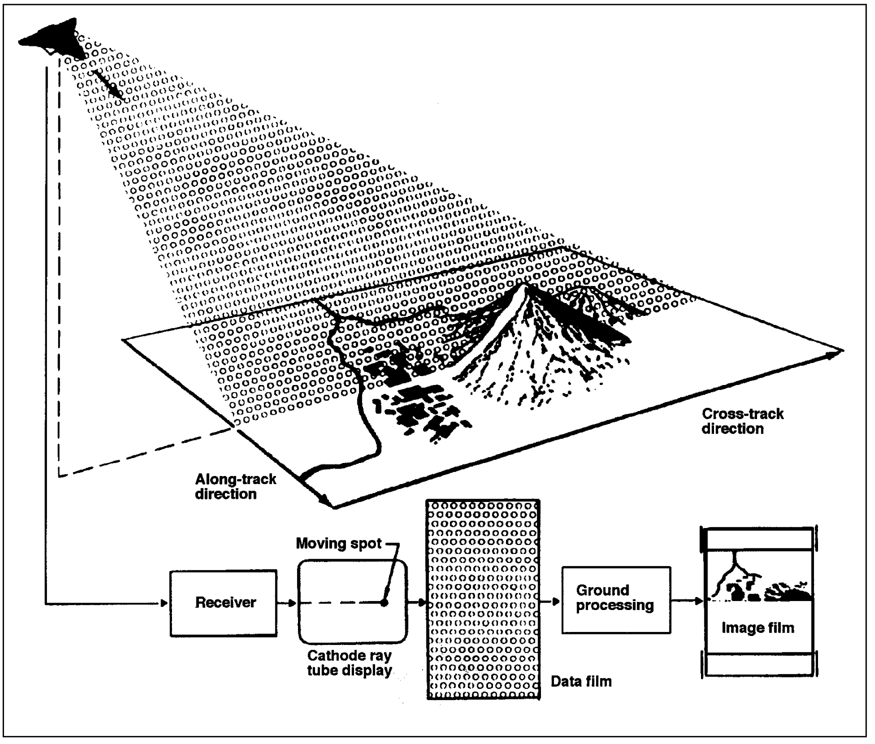

Figure 2–4. Shuttle Imaging Radar-A
(The beam of the SIR-A side-looking radar hit the ground at an angle, giving the resultant image perspective and showing vertical objects in shadowed relief. The intensity of the echoes from the target surface controlled the brightness of a spot tracing a line across a cathode ray tube. An overlapping succession of these lines was recorded on a strip of photographic film moving past the cathode ray tube at a rate proportional to the speed of the Shuttle. Thus, the terrain echo was recorded on the data film with the cross-track dimension across the width of the film. Complex ground processing transformed the data film into an image of the terrain.)

objective of surveying lightning and thunderstorms from space, but the data collected did demonstrate the feasibility of collecting thunderstorm data with the equipment used on this mission. The experiment was reflown on STS-6. The shortened mission also did not allow sufficient time for the Heflex Bioengineering Test to achieve its objective of determining plant growth as a function of initial soil moisture. A mission duration of at least four days was required to permit sufficient growth of the seedlings. This experiment was successfully reflown on STS-3.

OSTA-2

OSTA-2 flew on STS-7. It was the first NASA materials processing payload to use the orbiter cargo bay for experimentation and the initial flight of the Mission Peculiar Equipment Support Structure

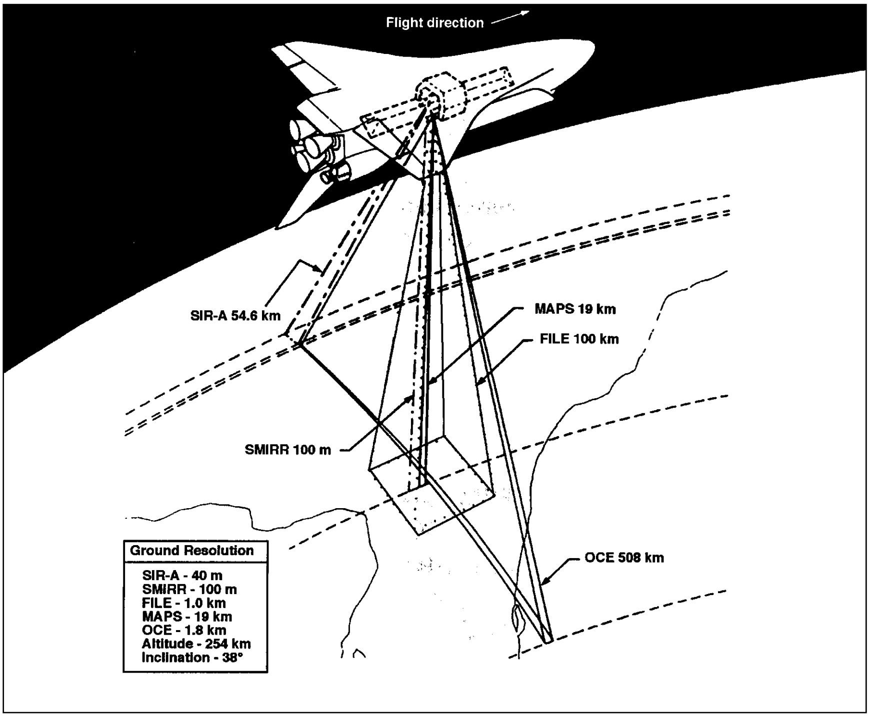

Figure 2–5. OSTA-1 Payload Ground Coverage

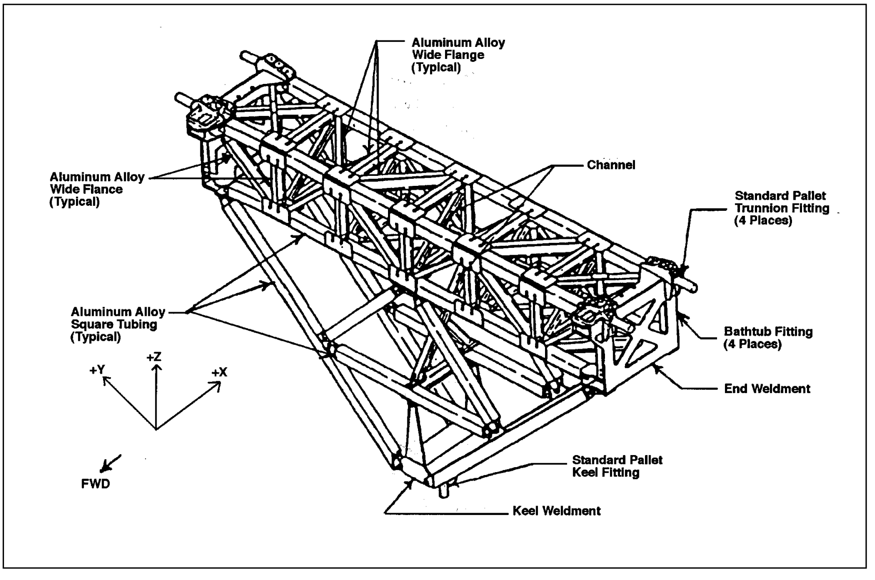

Figure 2–6. Mission Peculiar Equipment Support Structure (MPESS)

(MPESS) carrier (Figure 2–6) and the Materials Experiment Assembly (MEA) payload.

OSTA-2 was a cooperative payload with the Federal Republic of Germany and included three German Project MAUS payloads sponsored by the German Ministry for Research and Technology.[3] The Marshall Space Flight Center developed the NASA facility, and the German facility was developed under the management of the German Aerospace Research Establishment. The primary objectives of OSTA-2 were engineering verifications of the following:

- The MEA facility for the conduct of materials processing experiments
- Materials processing experiment furnaces and apparatus
- The Mission Peculiar Equipment Support Structure system as a carrier of attached payloads

One secondary objectives was to obtain MEA materials science experiment specimens processed in a low-gravity space environment and flight experiment data for scientific investigation. Another secondary objective was to exchange results from MEA and MAUS data analysis between NASA and the German Ministry for Research and Technology.

The elements of the OSTA-2 payload were located on an MPESS in the orbiter carrier bay. In addition to mechanical support, the MPESS provided a near-hemispherical space view for the MEA payload thermal radiator. Payload on/off command switches were activated by the Shuttle crew. Figure 2–7 shows the location of the payload on the MPESS.

The NASA payload, the MEA, was a self-contained facility that consisted of a support structure for attachment to the MPESS and thermal, electrical, data, and structural subsystems necessary to support experiment apparatus located inside experiment apparatus containers. The MEA contained three experiment apparatus that were developed for the Space Processing Applications Rocket project and modified to support OSTA-2 MEA experiments. Two of the three experiment furnaces in the MEA were successfully verified, and scientific samples were processed for analysis. The MEA experiments were selected from responses to an Announcement of Opportunity issued in 1977. The MEA flew again with the German D-1 Spacelab mission on STS 61-A in 1985. The payload demonstrated and verified a cost-effective NASA-developed carrier system. In addition, it demonstrated the reuse of materials processing experiment hardware on the Shuttle that had been developed for suborbital, rocket-launched experiments.

The MAUS experiments were part of the German materials science program, which was established, in part, by the opportunity to fly in Get Away Special (GAS) canisters on a low-cost, space-available basis. The three containers had autonomous support systems, and each container had

[3]The acronym MAUS stands for the German name: Materialwissenschaftliche Autonome Experimente unter Schwerelosigkeit.

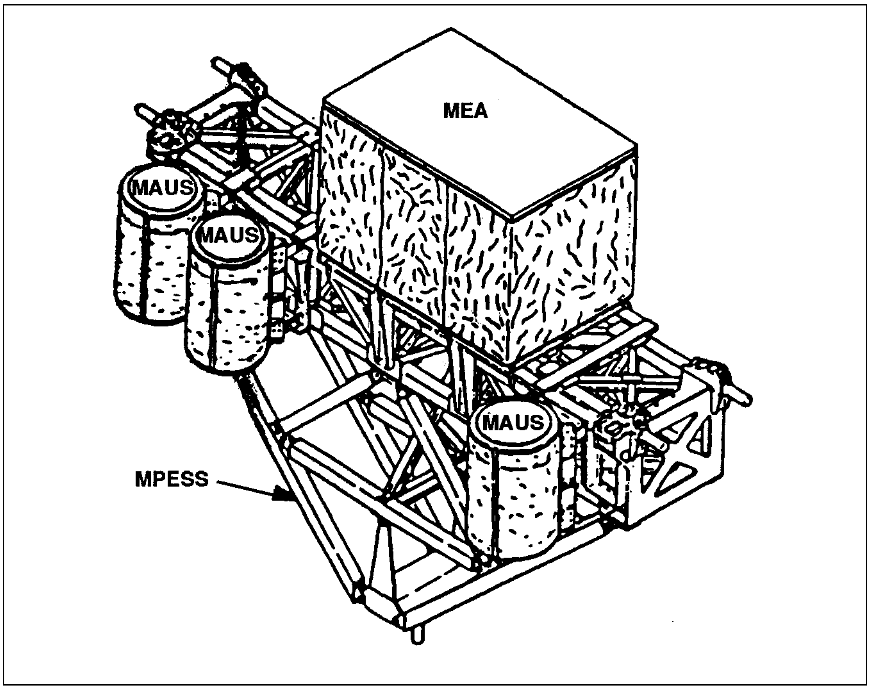

Figure 2–7. OSTA-2 Integrated Payload

its own service module containing experiment hardware, electrical power, experiment control, data acquisition, and storage, as well as housekeeping sensors. Two of the Get Away Special canisters contained identical experiments. The first operated for almost the full programmed duration of approximately eighty hours and shut down automatically. The second shut down prematurely following the first experiment processing cycle. The MEA and MAUS experiments are identified in Table 2–56.

OSTA-3

OSTA-3 was the second in a series of Earth observation payloads that flew on the Shuttle. It flew on STS 41-G. The mission objectives were to:

- Evaluate the utility of advanced remote-sensing systems for various types of Earth observations
- Use remote observations of Earth's surface and its atmosphere to improve current understanding of surficial processes and environmental conditions on Earth

The OSTA-3 payload consisted of four experiments: SIR-B, the Large Format Camera, Measurement of Air Pollution From Satellites (MAPS), and Feature Identification and Landmark Experiment (FILE). All except the Large Format Camera had flown on OSTA-1 on STS-2. SIR-B, MAPS, and FILE were mounted on a pallet carrier (Figure 2–8).

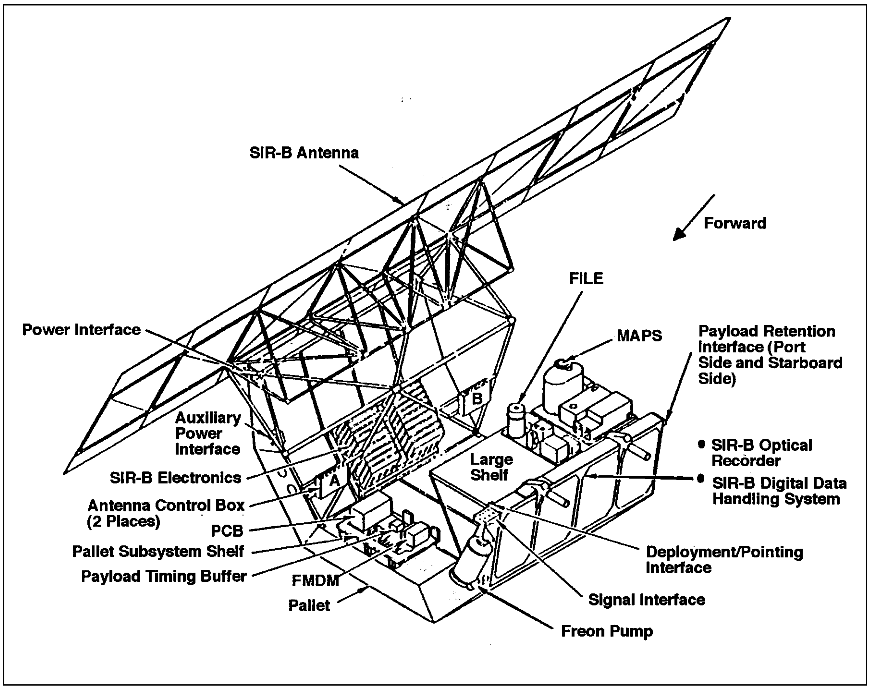

Figure 2–8. OSTA-3 Payload Configuration With FILE, MAPS, and SIR-B

The Large Format Camera was mounted on an MPESS, such as the one used on OSTA-2. It used orbital photography for cartographic mapping and land-use studies at scales of 1:50,000. It obtained 2,289 photographic frames.

The MAPS experiment determined the distribution of carbon monoxide in Earth's lower atmosphere on a global basis, developed an improved understanding of the sources and sinks of atmospheric carbon monoxide, and monitored long-term changes in the total abundance of carbon monoxide within Earth's atmosphere. The data sets of atmospheric carbon monoxide concentration it collected at the start and conclusion of the mission provided the first opportunity to study *in situ* temporal variations in carbon monoxide distribution.

FILE evaluated the utility of multispectral measurements obtained in two spectral channels for classifying surface features or clouds. It was part of an effort to develop advanced sensor systems that in the future could be preprogrammed to acquire imagery of specific types of natural terrain in an automatic fashion. The experiment acquired 240 images over a wide range of environments and successfully classified these scenes.

SIR-B was to use radar imagery acquired under different surface-viewing conditions for various types of surface observations, determine the extent to which subsurface radar penetration occurred in arid environments, and develop improved models of radar backscatter from vegetated terrain and marine areas. The plan was to obtain forty-two hours of digital data that would be analyzed by a science team of forty-three investigators, and eight hours of optical data could be collected as backup. SIR-B actually acquired only seven and a half hours of digital data and eight hours of optical data. Three problems affected the amount of data collected:

1. The Ku-band antenna gimbal failed. It could transmit only prerecorded tape data through the Tracking and Data Relay Satellite System (TDRSS) with special orbiter attitudes. This resulted in acquiring only 20 percent of the planned science data. Therefore, only fifteen investigators received sufficient data (50 to 75 percent) to meet their objectives, twenty-three investigators received a limited amount of data (10 to 50 percent), and six investigators received only a token amount of data.
2. The TDRSS link was lost for twelve hours, forty-two minutes during the mission.
3. Anomalies in the radio frequency feed system to the SIR-B antenna reduced transmitter power and, therefore, degraded the data.

Environmental Observations Program

NASA's Environmental Observations program focused on obtaining and interpreting processes in the magnetosphere, atmosphere, and oceans and extending the capability to predict long- and short-term environmental phenomena and their interaction with human activities. NASA launched two satellite missions in this area—the Stratospheric Aerosol and Gas Experiment (SAGE) and the Earth Radiation Budget Satellite (ERBS)—and worked toward a 1991 launch of the Upper Atmospheric Research Satellite (UARS). In addition, NASA participated in the development and launch of a series of meteorological satellites with NOAA: the NOAA polar-orbiting satellites and the Geostationary Operational Environmental Satellites (GOES).

Stratospheric Aerosol and Gas Experiment

SAGE was part of NASA's Applications Explorer Mission. It represented the first global aerosol data set ever obtained. The experiment complemented two other aerosol satellite experiments—the Stratospheric Aerosol Measurement, flown on Apollo during the Apollo-Soyuz Test Project in 1975, and the Stratospheric Aerosol Measurement II, flown on Nimbus 7, which was launched in 1978 and gathered data at the same time as SAGE. SAGE obtained and used global data on stratospheric aerosols and ozone in various studies concerning Earth's climate and environmental quality. It mapped vertical profiles in the stratosphere of ozone, aerosol, nitrogen dioxide, and molecular extinction in a wide band around the globe. The ozone data extended from approximately nine to forty-six kilometers, the aerosol data ranged from the cloud tops to thirty-five kilometers, the nitrogen dioxide went from about twenty-five to forty kilometers, and the molecular extinction was from about fifteen to forty kilometers. The mission obtained data from tropical to high latitudes for more than three years.

SAGE obtained its information by means of a photometric device. The photometer "looked" at the Sun through the stratosphere's gases and aerosols each time the satellite entered and left Earth's shadow. The device observed approximately fifteen sunrises and fifteen sunsets each twenty-four-hour day—a total of more than 13,000 sunrises and sunsets during its lifetime. The photometer recorded the light in four color bands each time the light faded and brightened. This information was converted to define concentrations of the atmospheric constituents in terms of vertical profiles.

The spacecraft was a small, versatile, low-cost spacecraft that used three-axis stabilization for its viewing instruments. The structure consisted of two major components: a base module, which contained the necessary attitude control, data handling, communications, command, and power subsystems for the instrument module, and an instrument module. The instrument module consisted of optical and electronic subassemblies mounted side by side. The optical assembly consisted of a flat scanning mirror, Cassegrain optics, and a detector package. Table 2–57 contains the instrument module's characteristics. Two solar panels for converting sunlight to electricity extended from the structure. Figure 2–9 shows the SAGE orbit configuration.

SAGE detected and tracked five volcanic eruption plumes that penetrated the stratosphere. It determined the amount of new material each volcano added to the stratosphere. (Mount St. Helens, for example,

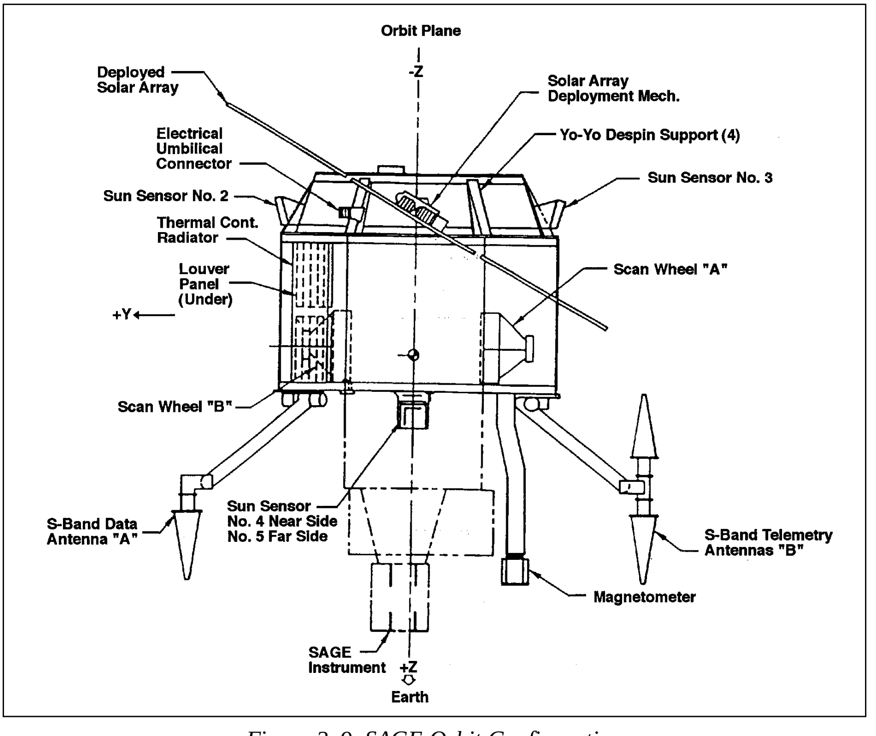

Figure 2–9. SAGE Orbit Configuration

contributed about 0.5 x 10^6 metric tons for a 100-percent enhancement in background stratospheric aerosol mass.) The characteristics of SAGE are listed in Table 2–58.

Earth Radiation Budget Satellite

ERBS was part of NASA's three-satellite Earth Radiation Budget Experiment (ERBE), which investigated how energy from the Sun is absorbed and re-emitted, or reradiated, by Earth. This process of absorption and reradiation, or reflectance, is one of the principal drivers of Earth's weather patterns. The absorbed solar radiation is converted to heat energy, which increases Earth's temperature and heat content. Earth's heat energy is continuously emitted into space, thereby cooling Earth. The relationship among incident solar energy, reflected solar energy, and Earth-emitted energy is Earth's radiation or energy budget (Figure 2–10). Although observations had been made of incident and reflected solar energy and of Earth-emitted energy, data that existed prior to the ERBE program were not sufficiently accurate to provide an understanding of climate and weather phenomena and to validate climate and long-range weather prediction models. The ERBE program provided observations with increased accuracy, which added to the knowledge of climate and weather phenomena.

Investigators also used observations from ERBS to determine the effects of human activities, such as burning fossil fuels and the use of chlorofluorocarbons, and natural occurrences, such as volcanic eruptions on Earth's radiation balance. The other instruments of the ERBE program were flown on NOAA 9 and NOAA 10.

ERBS was one of the first users of the TDRSS. It was also one of the first NASA spacecraft designed specifically for Space Shuttle deploy-

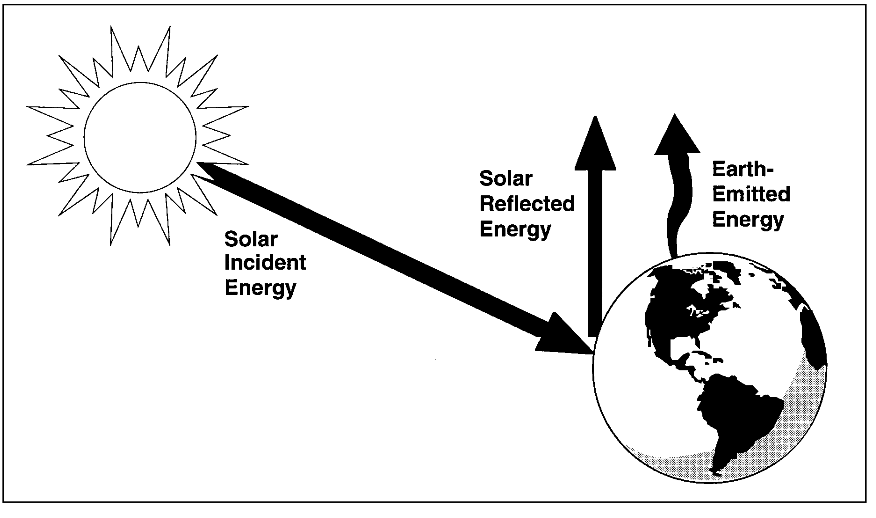

Figure 2–10. Components of the Earth Energy Budget

ment; it was deployed using the Shuttle's Remote Manipulator System. The satellite was equipped with three scientific instruments: SAGE II, the ERBE Non-Scanner, and the ERBE Scanner. Each instrument had one or more contamination doors that protected the instrument's sensitive detectors and optics from accumulating outgassing products from the ERBS spacecraft. Table 2–59 lists the instrument's characteristics.

ERBS provided scientists with the first-ever long-term global monitoring of stratospheric aerosols, including critical ozone data. Investigators used the data to study atmospheric dynamics, ozone chemistry, and ozone depletion. The characteristics of ERBS are in Table 2–60.

Upper Atmospheric Research Satellite

The UARS program continued NASA's investigations of the upper atmosphere carried out by the SAGE and ERBE programs. The national mandate for UARS dates to 1976, when Congress, responding to the identification of new causes of ozone depletion, amended the Space Act and directed NASA to undertake a comprehensive program of research into the upper atmosphere. In 1977, Congress directed NASA to carry out such research "for the purpose of understanding the physics and chemistry of the stratosphere and for the early detection of potentially harmful changes in the ozone in the stratosphere."

NASA stated that the purpose of the mission was to better understand Earth's upper atmosphere, specifically the response of the ozone layer to changes and the role of the upper atmosphere in climate and climate variability. The mission would focus on comprehensive investigations of Earth's stratosphere, mesosphere, and lower thermosphere to understand Earth's upper atmosphere. The major areas to be studied would include energy flowing into and from the upper atmosphere, how sunlight drives chemical reactions in the upper atmosphere, and how gases moved within and between layers of the atmosphere.

NASA's Goddard Space Flight Center would provide the design and definition work with contractor support from the General Electric Space Division. The contractor would be responsible for integrating the instrument module with the bus and flight instruments, conducting environmental testing of the observatory, integrating the observatory into the Space Shuttle, and providing post-launch checkout support. The Goddard Space Flight Center would furnish the Multimission Modular Spacecraft (MMS) bus and flight instruments and design the UARS ground station and data handling facility. Goddard would award a contract for the Central Data Handling Facility, remote analysis computers, and the development of software to perform UARS-unique systems functions.

NASA released its Announcement of Opportunity for the mission in 1978, and the agency selected sixteen experiments and ten theoretical investigations from seventy-five proposals for definition studies in April 1980. In November 1981, NASA narrowed this down to nine instrument experiments, two instruments flown on "flights of opportunity," and ten theoretical investigations. (One "instrument of opportunity," the solar backscattered ultraviolet sensor for ozone, was deleted from the payload in 1984 because an identical instrument was designated to be flown on an operational NOAA satellite during the same timeframe.)

Congress funded the experiments in its fiscal year 1984 budget and approved funding for UARS mission development in its fiscal year 1985 budget. NASA awarded the major observatory contract to General Electric in March 1985 and initiated the execution phase in October 1985. Following the *Challenger* accident, safety concerns led to a redesign of one of the instruments and rebaselining of the mission timeline, with launch rescheduled for the fall of 1991.

Initially, the program concept involved two satellite missions, each with a nominal lifetime of eighteen months and launched one year apart. It was reduced to a single satellite mission in 1982.

In its final configuration, the mission would use the MMS to place a set of nine instruments in Earth orbit to measure the state of the stratosphere and provide data about Earth's upper atmosphere in spatial and temporal dimensions. The remote atmospheric sensors on UARS would make comprehensive measurements of wind, temperature, pressure, and gas species concentrations in the altitude ranges of approximately nine to 120 kilometers. In addition, a tenth instrument, not technically a part of the UARS mission, would use its flight opportunity to study the Sun's energy output. Table 2–61 describes the instruments carried on aboard UARS, what they measured, and their principal investigators. The spacecraft and its instruments were considerably larger than other remote-sensing spacecraft flown up to that time. Figure 2–11 compares the size of UARS with two earlier missions, Nimbus 7 and Landsat-D; Figure 2–12 shows the instrument placement and the MMS.

A chronology of events prior to the September 1991 launch is presented in Table 2–62. It is notable that even with the redesign of one instrument and a rebaselining of the mission timeline because of the *Challenger* accident, NASA launched UARS approximately $30 million below its final budget estimate of $669.5 million and with no schedule delays.

Meteorological Satellites

NASA and NOAA launched and operated two series of meteorological satellites: the NOAA polar-orbiting satellites and the Geostationary Operational Environmental Satellites (GOES)—a group of geosynchronous satellites. A NASA-Department of Commerce agreement dated July 2, 1973, governed both satellite systems and defined each agency's responsibilities. NOAA had responsibility for establishing the observational requirements and for operating the system. NASA was responsible for procuring and developing the spacecraft, instruments, and associated ground stations, for launching the spacecraft, and for conducting an on-orbit checkout of the spacecraft.

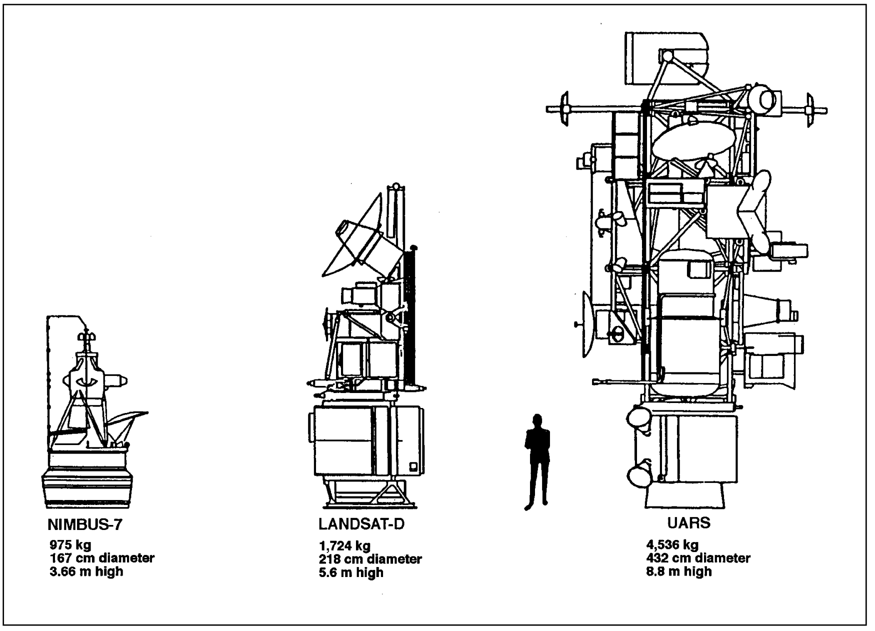

Figure 2–11. Relative Sizes of Nimbus-7, Landsat D, and UARS (The width of UARS was essentially that of the Shuttle bay.)

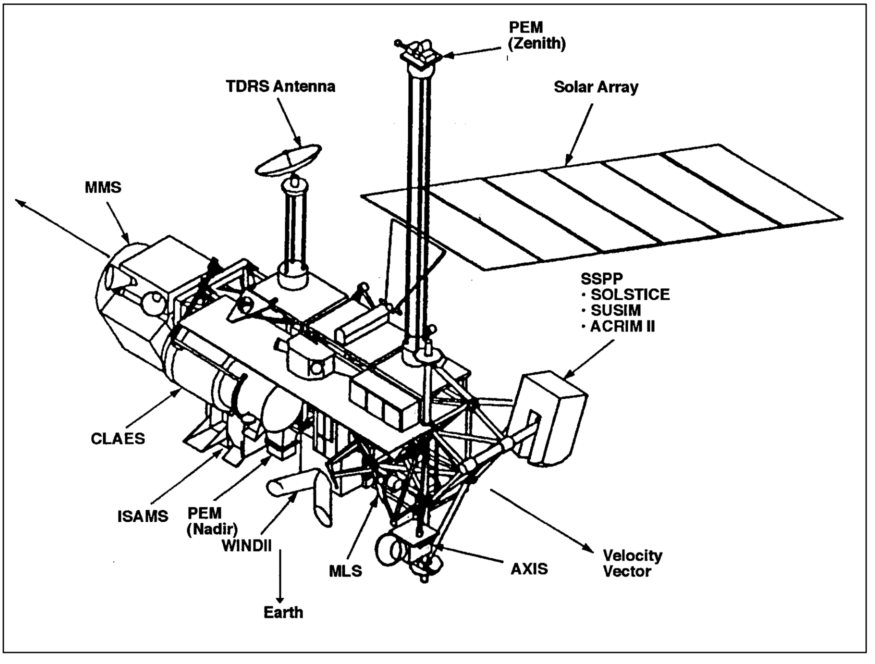

Figure 2–12. View of the UARS Spacecraft (From the anti-Sun side, this shows instrument placement, solar array, and the Multimission Modular Spacecraft. The Halogen Occultation Experiment (HALOE) and High Resolution Doppler Images instruments cannot be seen from this view.)

NOAA Polar-Orbiting Satellites

The series of polar-orbiting meteorological satellites that operated during the late 1970s and into the 1990s began with TIROS-N, launched in October 1978. TIROS-N was the operational prototype for the third generation of low-Earth orbiting weather satellites designed and developed by NASA to satisfy the increasing needs of the operational system. The satellites in this TIROS-N series were Sun synchronous, near polar-orbiting spacecraft, and operated in pairs, with one crossing the equator near 7:30 a.m. local time and the second crossing the equator at approximately 1:40 p.m. local time. Operating as a pair, these satellites ensured that nonvisible data for any region of Earth was no more than six hours old.

The NOAA series of satellites was a cooperative effort of the United States (NOAA and NASA), the United Kingdom, and France. NASA funded the development and launch of the first flight satellite (TIROS-N); subsequent satellites were procured and launched by NASA using NOAA funds. The operational ground facilities, including the command and data acquisition stations, the Satellite Control Center, and the data processing facilities (with the exception of the Data Collection System processing facility), were funded and operated by NOAA. The United Kingdom, through its Meteorological Office, Ministry of Defense, provided a stratospheric sounding unit, one of three sounding instruments for each satellite. The Centre Nationale d'Études Spatiales (CNES) of France provided the Data Collection System instrument for each satellite and the facilities needed to process and make the data obtained from this system available to users. CNES also provided facilities for the receipt of sounder data during the blind orbit periods. Details of the TIROS-N satellite can be found in Volume III of the *NASA Historical Data Book*.[4] The satellites launched from 1979 through 1988 are described below.

Instruments on these satellites measured the temperature and humidity of Earth's atmosphere, surface temperature, surface and cloud cover, water-ice-moisture boundaries, and proton and electron flux near Earth. They took atmospheric soundings, measurements in vertical "slices" of the atmosphere showing temperature profiles, water vapor amounts, and the total ozone content from Earth's surface to the top of the atmosphere. Sounding data were especially important in producing global weather analyses and forecasts at the Weather Service's National Meteorological Center. Table 2–63 summarizes the orbit and instrument complement of the NOAA satellites.

The TIROS-N satellites also collected environmental observations from remote data platforms—readings such as wave heights on the oceans, water levels in mountainous steams, and tidal activity. The spacecraft also monitored solar particle radiation in space used, in part, to warn

[4]Linda Neuman Ezell, *NASA Historical Data Book, Volume III: Programs and Projects, 1969–1978* (Washington, DC: NASA SP-4012, 1988).

Space Shuttle missions and high-altitude commercial aircraft flights of potentially hazardous solar radiation activity. The NOAA 6 and NOAA 7 satellites were almost identical to the 1978 TIROS-N. The NOAA 8, 9, 10, and 11 satellites were modified versions of TIROS-N and were called Advanced TIROS-N.

The Advanced TIROS-N generation of satellites included a new complement of instruments that emphasized the acquisition of quantitative data of the global atmosphere for use in numerical models to extend and improve long-range (three- to fourteen-day) forecasting ability. In addition, the instruments on these satellites could be used for global search and rescue missions, and they could map ozone and monitor the radiation gains and losses to and from Earth.

NOAA 6. This was the second of eight third-generation operational meteorological polar-orbiting spacecraft. It was the first NOAA-funded operational spacecraft of the TIROS-N series. The satellite greatly exceeded its anticipated two-year lifetime and was deactivated on March 31, 1987. Identical to TIROS-N, NOAA 6 adapted applicable parts of the Defense Meteorological Satellite Program Block 5D spacecraft, built by RCA Corporation and first launched in 1976.

NOAA 6 filled in data-void areas, especially over the oceans, by crossing the equator six hours after TIROS-N, in effect doubling the amount of data made available to the National Meteorological Center in Suitland, Maryland. TIROS-N and NOAA 6, each viewing every part of the globe twice in one twenty-four-hour period, were especially important in providing information from remote locations where more traditional weather-gathering methods could not be used conveniently. Table 2–64 lists the characteristics of NOAA 6.

NOAA B. This satellite went into a highly elliptical rather than the planned circular orbit of 756 kilometers. This was because of one of the Atlas F booster engines developing only 75 percent thrust. The satellite could not operate effectively. It was to have been the second NOAA-sponsored TIROS-N satellite. Its characteristics are in Table 2–65.

NOAA 7. With the successful launch of NOAA 7, designed to replace TIROS-N and join NOAA 6, meteorologists had two polar-orbiting satellites in orbit returning weather and environmental information to NOAA's National Earth Satellite Service. Together, NOAA 6 and NOAA 7 could view virtually all of Earth's surface at least twice every twenty-four hours.

In addition to the data transmitted by earlier NOAA satellites, NOAA 7 provided improved sea-surface temperature information that was of special value to the fishing and marine transportation industries and weather forecasters. Its scanning radiometer, the Advanced Very High Resolution Radiometer (AVHRR), used an additional fifth spectral channel to gather visual and infrared imagery and measurements. Table 2–66 lists the characteristics of each channel. The satellite also carried a joint Air Force-NASA contamination monitor that assessed possible environmental contamination in the immediate vicinity of the spacecraft resulting from its propulsion systems.

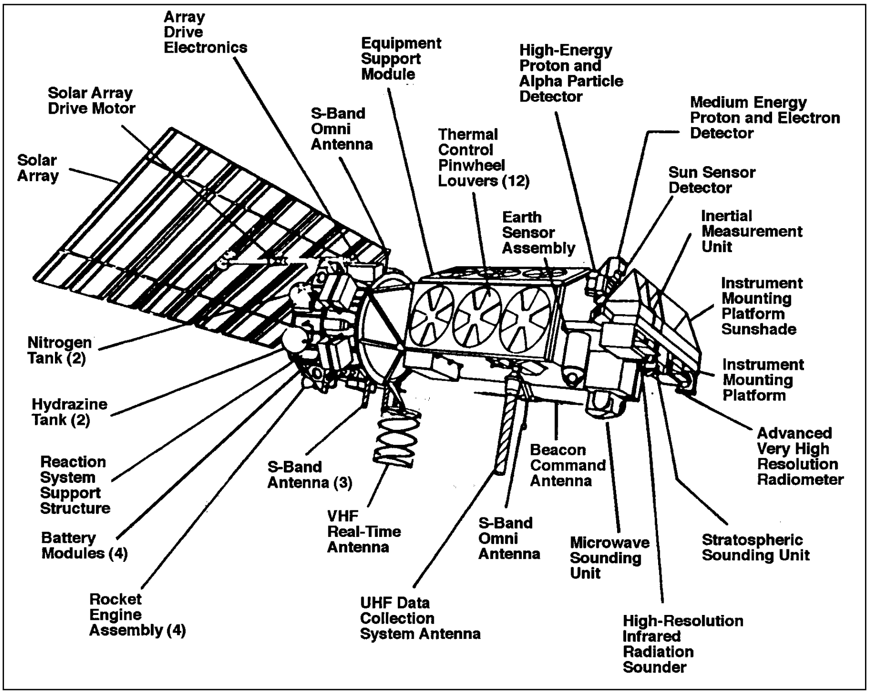

Figure 2–13. NOAA 6 and NOAA 7 Spacecraft Configuration

NOAA 6 and NOAA 7 also served a communications function and could distribute unprocessed sensor data to Earth stations in more than 120 countries in real time as the spacecraft passed overhead. Figure 2–13 shows the NOAA 6 and 7 spacecraft configuration.

NOAA 7 was put in standby mode when its sounder failed and its power system degraded. It was deactivated in June 1986 when the power system failed. Its characteristics are listed in Table 2–67.

NOAA 8. This was the fourth NOAA-funded operational spacecraft of the TIROS-N series to be launched. It was a “stretched” version of the earlier NOAA TIROS-N spacecraft (although not larger in size) and was the first advanced TIROS-N spacecraft with expanded capabilities for new measurement payloads. Because of the need to get an early flight of the Search and Rescue (SAR) mission, NOAA 8 was launched prior to NOAA-D, which did not have a SAR capability.

The satellite experienced problems beginning in June 1984, about 14 months after launch, when it experienced a “clock interrupt” that caused the gyros to desynchronize. Continued clock disturbances interfered with the meteorological instruments, preventing investigators from obtaining good data. In July 1984, NASA and NOAA announced that the satellite appeared to have lost its latitude control system and was tumbling in orbit and unable to relay its signal effectively to Earth. Engineers were able to stabilize the satellite in May 1985, when the defective oscillator gave out and scientists could activate a backup oscillator and reprogram the satellite remotely. It resumed transmission of data and was declared operational in July 1985. It tumbled again on October 30, 1985, and was recovered and reactivated on December 5. Use of the satellite was finally lost on December 29, 1985, following clock and power system failures. Table 2–68 lists NOAA 8's characteristics.

NOAA 9. This was the fifth NOAA-funded operational spacecraft of the TIROS-N series and the second in the Advanced TIROS-N spacecraft series. It carried two new instruments, as well as a complement of instruments on previous NOAA satellites. The Solar Backscatter Ultraviolet (SBUV)/2 spectral radiometer acquired data to determine atmospheric ozone content and distribution. It was the successor to the SBUV/1, which flew on Nimbus 7. The Earth Radiation Budget Experiment (ERBE) provided data complementing the Earth Radiation Budget Satellite (ERBS) that NASA launched in October 1984. It made highly accurate measurements of incident solar radiation, Earth-reflected solar radiation, and Earth-emitted longwave radiation at spatial scales ranging from global to 250 kilometers and at temporal scales sufficient to generate accurate monthly averages. Figure 2–14 shows the NOAA 9 spacecraft configuration.

This satellite also carried SAR instrumentation provided by Canada and France under a joint cooperative agreement. It joined similarly equipped COSPAS satellites launched by the Soviet Union. The spacecraft replaced NOAA 7 as the afternoon satellite in NOAA's two polar satellite system. Its characteristics are in Table 2–69.

NOAA 10. This spacecraft circled the globe fourteen times each day, observing a different position on Earth's surface on each revolution as Earth turned beneath the spacecraft's orbit (Figure 2–15). It replaced NOAA 6 as the morning satellite in NOAA's two polar orbit satellite system and restored NOAA's ability to provide full day and night environmental data, including weather reports, and detect aircraft and ships in distress after one of the two TIROS-N satellites shut down in December 1985. (NOAA 6 had been reactivated when NOAA 8 failed.) It was the third of the Advanced TIROS-N spacecraft. The spacecraft was launched from a twenty-five-year-old refurbished Atlas E booster, a launch that had been delayed sixteen times during the previous year because of a series of administrative changes and technical difficulties.

To continue initial support for SAR using the 121.5/243 megahertz (MHz) system and to begin the process for making the system operational for the 406-MHz system, NOAA 10 carried special instrumentation for evaluating a satellite-aided SAR system that would lead to the establishment of a fully operational capability. Less than twenty-four hours after being put into operation on NOAA 10, SARSAT (Search and Rescue Satellite-Aided Tracking) equipment on board picked up the first distress signals of four Canadians who had crashed in a remote area of Ontario. NOAA's characteristics are in Table 2–70.

NOAA 11. This satellite replaced NOAA 9 as the afternoon satellite in NOAA's two polar satellite system. The satellite carried improved instrumentation that allowed for better monitoring of Earth's ozone layer. The launch of NOAA 11 had originally been scheduled for October 1987,

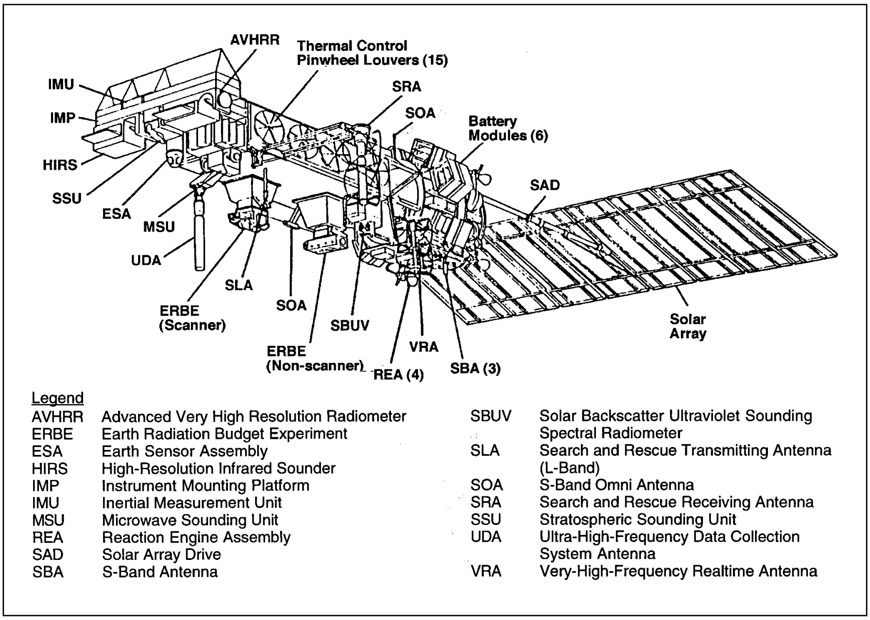

Figure 2–14. NOAA 9 Spacecraft Configuration

but it had been postponed eight times because of management and technical delays.

The Advanced TIROS-N system of satellites normally operated with four gyroscopes—three for directional control and one backup. One gyro on NOAA 11 failed in August 1989, and the backup was put into service. A second gyro failed in 1990, but NASA had developed and transmitted to the satellite software instructions that permitted the satellite to operate fully on two gyros. The characteristics of NOAA 11 are in Table 2–71.

Geosynchronous Operational Environmental Satellites

The impressive imagery of cloud cover produced by the GOES series, as viewed from geostationary (or geosynchronous) orbit, has become a highlight of television weather forecasts. The GOES program has been a joint development effort of NASA and NOAA. NASA provided launch support and also had the responsibility to design, engineer, and procure the satellites. Once a satellite was launched and checked out, it was turned over to NOAA for its operations.

The GOES program has provided systematic, continuous observations of weather patterns since 1974. The pilot Synchronous Meteorological Satellite, SMS-A, was launched in 1974, followed by a second prototype, SMS-B, and an operational spacecraft, SMS-C/GOES-A. Subsequently, GOES-B was successfully launched in 1977, with GOES-C launched in 1978. The GOES spacecraft obtained both day and night information on Earth's weather through a scanner that formed images of Earth's surface and cloud cover for transmission to regional

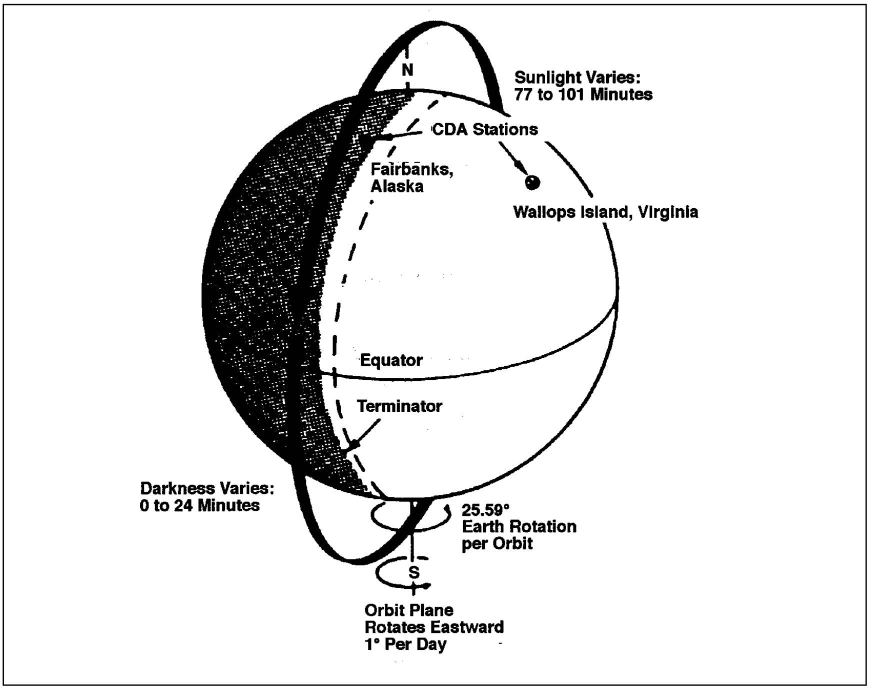

Figure 2–15. NOAA 10 Orbit

data-user stations for use in weather prediction and forecasting.

The GOES satellites during this period (GOES 4 through 7) had similar configurations (Figure 2–16). Beginning with the launch of GOES 4 in 1980 and continuing throughout the series, the instrument complement included an improved Visible/Infrared Spin Scan Radiometer (VISSR) (Figure 2–17). The new VISSR, called the VISSR Atmospheric Sounder, could receive the standard operational VISSR data and also sound the atmosphere in twelve infrared bands, enabling meteorologists to acquire temperature and moisture profiles of the atmosphere (Table 2–72).

Normally, two GOES satellites operated concurrently. GOES-East satellites were stationed at seventy-five degrees west longitude, and GOES-West satellites were located at 135 degrees west longitude. GOES-East observed North and South America and the Atlantic Ocean. GOES-West observed North America and the Pacific Ocean to the west of Hawaii. Together, these satellites provided coverage for the central and eastern Pacific Ocean, North, Central, and South America, and the central and western Atlantic Ocean.

GOES 4. This was the sixth satellite in the GOES series. It provided continuous cloud cover observations from geosynchronous orbit. Initially located at ninety-eight degrees west longitude, it was moved into a geostationary orbit located at 135 degrees west longitude in February 1981 to replace the failing GOES 3 (also known as GOES-C) as the operational GOES-West satellite. GOES 4 was the first geosynchronous satellite capable of obtaining atmospheric temperature and

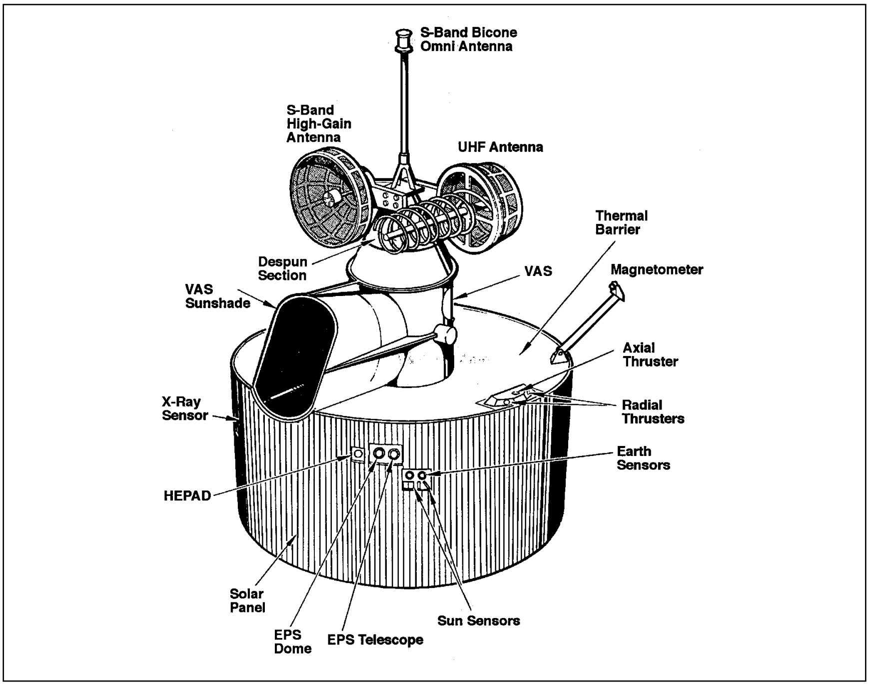

Figure 2–16. GOES Satellite Configuration

water vapor soundings as a function of altitude in the atmosphere. The data were extremely important in forecasting and monitoring the strength and course of highly localized severe storms. It also had the same imaging capability as previous GOES spacecraft.

GOES 4 experienced several anomalies while in orbit. The most serious occurred on November 25, 1982, when the VISSR Atmospheric Sounder's scan mirror stopped during retrace after exhibiting excessively high torque. Efforts to restore either the visible or infrared capability were unsuccessful. The characteristics of GOES 4 are in Table 2–73.

GOES 5. This satellite was placed into a geostationary orbit located seventy-five degrees west longitude and became the operational GOES-East satellite. The satellite failed on July 29, 1984, and GOES 6 (launched in April 1983) was moved into a central location over the continental United States. Table 2–74 lists the characteristics of GOES 5.

GOES 6. This was placed into geostationary orbit located at 135 degrees west longitude and acted as the operational GOES-West satellite. It was moved to ninety-eight degrees west longitude to provide coverage after GOES 5 failed. After the successful launch and checkout of GOES 7 in 1987, it was returned to its original location. GOES 6 failed in January 1989. The satellite's characteristics are in Table 2–75.

GOES G. This satellite, which was planned to become the eastern operational GOES satellite designated as GOES 7, did not reach operational orbit because of a failure in the Delta launch vehicle. NASA attributed this failure to an electrical shortage that shut down the engines on the

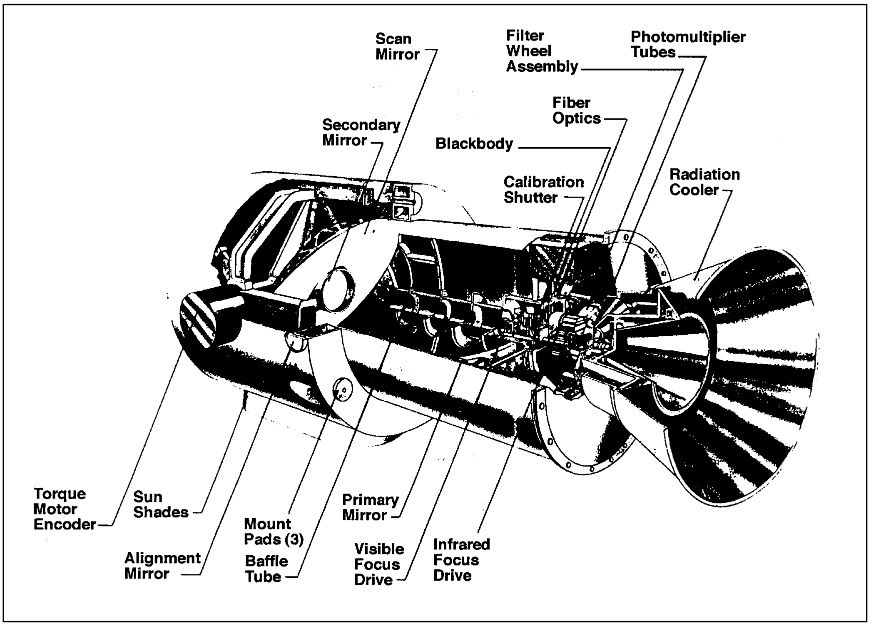

Figure 2–17. VISSR Atmospheric Sounder

launch vehicle. GOES G had the same configuration and instrument complement as earlier GOES spacecraft; its characteristics are in Table 2–76.

GOES 7. The GOES 7 spacecraft was placed into a geostationary orbit located at seventy-five degrees west longitude and acted as the operational GOES-East satellite beginning on March 25, 1987. Its placement allowed GOES 6 to return to its normal position of 135 degrees west longitude from its location at ninety-eight degrees west longitude. GOES 7 was equipped with two encoders: one with two of the same type of tungsten-filament lamps as in the previous GOES spacecraft and the other with light-emitting diodes, which had a longer life expectancy than the original lamps.

The spacecraft was moved to ninety-eight degrees west longitude in July 1989 following the January 1989 failure of GOES 6. It was moved back to 108 degrees west in November 1989. It underwent several more relocations during its more than eight-year lifetime. It was finally shut down in January 1996. The characteristics of GOES 7 are in Table 2–77.

Resource Observations Program

The goals of the Resource Observations program was to assist in solving Earth resources problems of national and global concern through the development and application of space technology and techniques and to conduct research and observations to improve our understanding of the dynamic characteristics of Earth. The program focused on developing and transferring remote-sensing techniques to federal agencies, state, regional, and local governments, private industry, and the scientific community, where these techniques would enhance or supplant existing capabilities or provide a new capability. From 1979 to 1988, NASA launched three resource observations satellites: two Landsat satellites and Magsat.

Landsat Satellites

The Landsat program began in the late 1960s. NASA launched Landsat 1 in July 1972, followed by the launch of Landsat 2 in January 1975 and Landsat 3 in March 1978. These three satellites successfully used the Multispectral Scanner (MSS) to collect and measure the energy reflected or emitted in discrete intervals of the electromagnetic spectrum. The MSS surveyed both renewable and nonrenewable Earth resources. It monitored the reflected solar energy in the green, red, and near-infrared parts of the spectrum and added to the ability to monitor and understand the dynamics and character of the various features and materials on and below the surface of Earth.

The data acquired by Landsat were used worldwide by government agencies, research institutions, and other organizations and individuals seeking information to assist in oil and mineral exploration; agriculture, forestry, and water management; map making; industrial plant site identification and location; and general land-use planning. When Landsat 4 launched, eleven nations could receive and process data directly from the satellite. In addition, more than 100 nations used Landsat data for resource development and management.

NASA was responsible for operating the Landsats through the early 1980s. In January 1983, operations of the Landsat system were transferred to NOAA. In October 1985, the Landsat system was commercialized, and NOAA selected the Earth Observation Satellite Company (EOSAT) to operate the system under a ten-year contract. Under the agreement, EOSAT would operate Landsats 4 and 5, build two new spacecraft (Landsats 6 and 7), have exclusive rights to market Landsat data collected prior to the date of the contract (September 27, 1985) until its expiration date of July 16, 1994, have exclusive right to market data collected after September 27, 1985, for ten years from date of acquisition, and receive all foreign ground station fees.

Landsat 4. This was fourth in a series of near-polar-orbiting spacecraft. In addition to the MSS flown on the earlier Landsat missions, Landsat 4 introduced the Thematic Mapper (TM), whose configuration is shown in Figure 2–18. The TM extended the data set of observations provided by the MSS. It provided data in seven spectral bands, with significantly improved spectral, spatial, and radiometric resolution. Table 2–78 compares the major characteristics of the two instruments.

Both Landsat 4 instruments imaged the same 185-kilometer swath of Earth's surface every sixteen days. The two instruments covered all of Earth, except for an area around the poles, every sixteen days. Image data were transmitted in real time via the Tracking and Data Relay Satellite (TDRS) to its ground terminal at White Sands, New Mexico, beginning August 12, 1983. Prior to that time, the downlink communications mode for MSS data was through the Landsat 4 direct-access S-band link. TM data were transmitted directly to the ground through the X-band.

Landsat 4 consisted of NASA's standard Multimission Modular Spacecraft and the Landsat instrument module (Figure 2–19). The TM was located between the instrument module and the Multimission Modular Spacecraft modular bus, and the MSS was located at the forward end of the instrument module.

NASA launched and checked out the spacecraft, established the precise orbit, and demonstrated that the system was fully operational before transferring management to NOAA. NOAA was responsible for controlling the spacecraft, scheduling the sensors, processing and distributing data from the MSS, and reproducing and distributing public domain data from the TM. NOAA assumed operational responsibility for Landsat 4 on January 31, 1983. The TM remained an experimental development project under direct NASA management.

On February 15, 1983, the X-band transmitter on the spacecraft, which sent data from the TM to ground stations, failed to operate. No further data from the TM would be provided until the TDRS began transmitting TM data in August 1983. The less detailed pictures, which were transmitted from the Multimission Modular Spacecraft on the S-band, continued to be sent. Another problem occurred in 1983 when two solar panels failed. The system was able to continue operating with only two solar panels, but preparations were made to move the spacecraft into a lower orbit, and Landsat D' (D "prime," to become Landsat 5) was readied for a March 1984 launch. However, it was decided to allow Landsat 4 to continue operating, which it did into the 1990s. The satellite's characteristics are in Table 2–79.

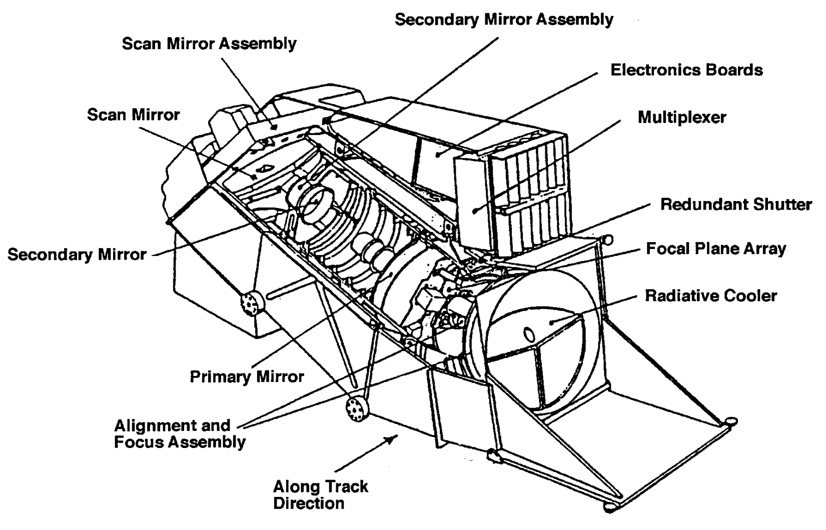

Figure 2–18. Thematic Mapper Configuration

Landsat 5. NASA developed Landsat 5 as Landsat D'. It was intended first to back up and then to replace Landsat 4 when it seemed that Landsat 4's operational days were numbered. However, Landsat 4 continued operating, and Landsat 5 was able to double the amount of remote-sensing data that the system transmitted by providing eight-day rather than sixteen-day repeat coverage. It was virtually identical to Landsat 4, but was modified to prevent the failures experienced on Landsat 4.

Image data were transmitted in real time through the Ku-band via the TDRS to its ground terminal at White Sands, New Mexico. Image data could also be transmitted directly to ground stations through the X-band in addition to or in lieu of transmission via the TDRS. A separate S-band direct link compatible with Landsats 1 through 4 was also provided to transmit MSS data to those stations equipped for receiving only S-band transmissions.

Landsat 5 was turned over to NOAA for management and operations on April 6, 1984. It continued to transmit data into the 1990s. Table 2–80 lists its characteristics.

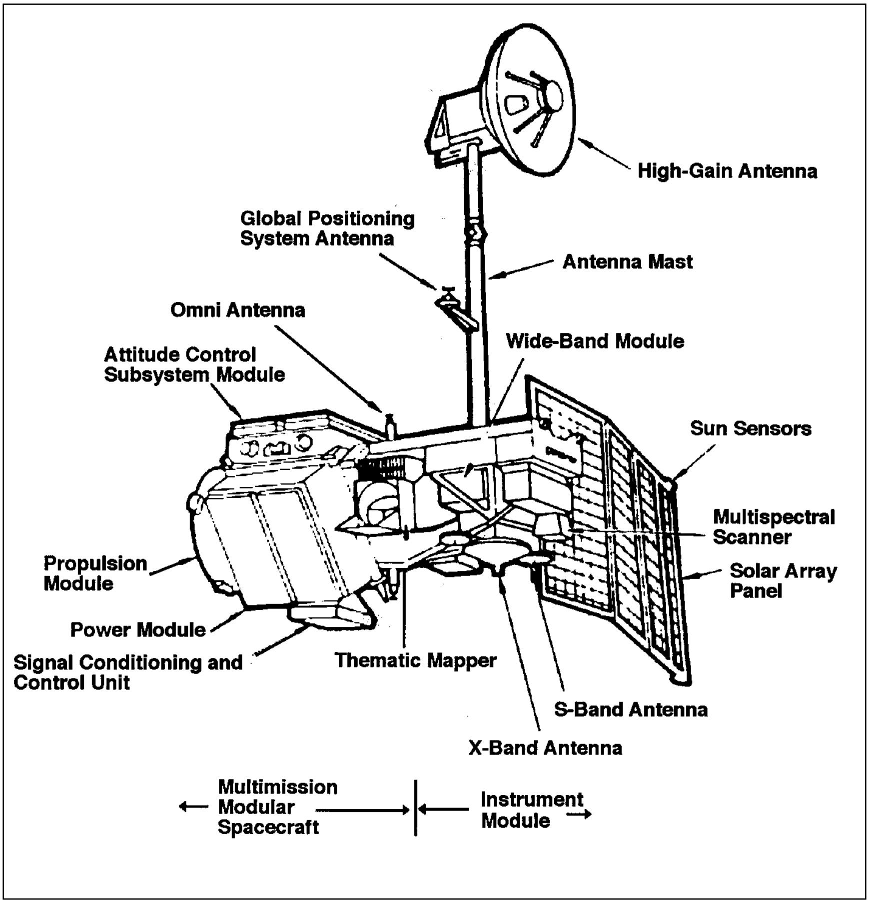

Figure 2–19. Landsat 4 Flight Configuration

Magsat (AEM-C)

Magsat (Magnetic Field Satellite) was the third spacecraft in the Applications Explorer Mission series. From its launch on October 30, 1979, until its reentry on June 11, 1980, its instruments continually measured the near-Earth magnetic field. Magsat was the first spacecraft in near-Earth orbit to carry and use a vector magnetometer to resolve ambiguities in field modeling and magnetic anomaly mapping. The anomalies measured reflected important geologic features, such as the composition and temperature of rock formation, remnant magnetism, and geologic structure on a regional scale. Magsat provided information on the broad structure of Earth's crust with near-global coverage.

Prior to the satellite era, magnetic data from many geographic regions were nonexistent or sparse. The Polar Orbiting Geophysical Observatory (POGO) and the Orbiting Geophysical Observatories 2, 4, and 6 satellites made global measurements of the scalar field from October 1965 through June 1971, and several geomagnetic field models based on POGO data were published. Their magnetometers provided measurements of the scalar field magnitude approximately every half second over an altitude range of about 400 to 1,500 kilometers.

These satellite geomagnetic field measurements mapped the main geomagnetic field originating in Earth's core, determined the long-term temporal, or secular, variations in that field, and investigated short-term field perturbations caused by ionospheric currents. Early in the POGO era, it was thought to be impossible to map crustal anomalies from space. However, while analyzing data from POGO, investigators discovered that the lower altitude data contained separable fields because of anomalies in Earth's crust, thus allowing for the development of a new class of investigations. Magsat data enhanced POGO data in two areas:

1. Vector measurements were used to determine the directional characteristics of anomaly regions and resolved ambiguities in their interpretation.
2. Lower altitude data provided increased signal strength and resolution for detailed studies of crustal anomalies.

Magsat was made of two modules. The base module housed the electrical power supply system, the telemetry system, the attitude control system, and the command and data handling system. The instrument module comprised the optical bench, star cameras, attitude transfer system, magnetometer boom and gimbal systems, scalar and vector magnetometers, and precision Sun sensor. Figure 2–20 shows the orbital configuration.

Magsat's lifetime exceeded its planned minimal lifetime by nearly three months, and it met or exceeded all the accuracy requirements of the scalar and vector magnetometers as well as attitude and position determination. The program was a cooperative effort between NASA and the

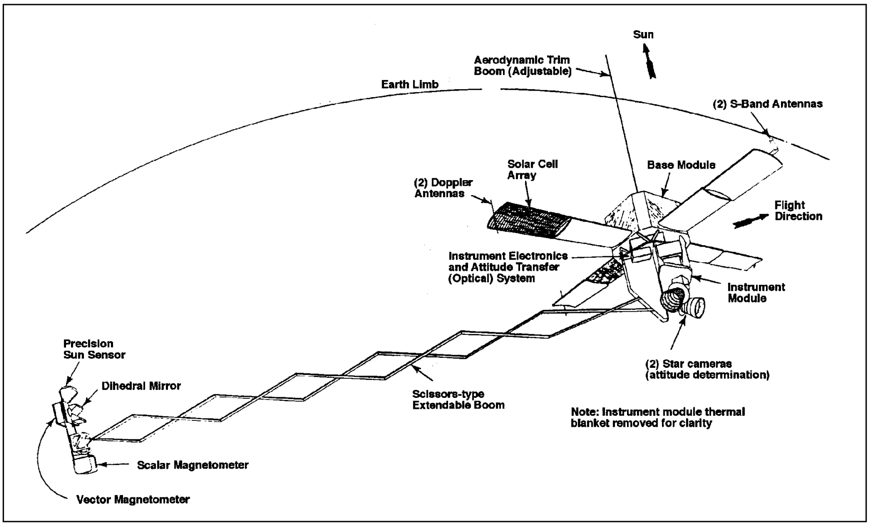

Figure 2–20. Magsat Orbital Configuration

U.S. Geological Survey, which used the Magsat observations and models to update the regional and global magnetic charts and maps that it published. Table 2–81 lists Magsat's characteristics, and Table 2–82 contains the satellite's investigations.

Communications Program

Advanced Communications Technology

NASA's participation in communications satellite programs had been severely curtailed in 1973 because of budget constraints. Not until late 1979, when it became apparent that current communications capabilities would be inadequate to meet the rising demand foreseen for the 1990s, did NASA decide to renew its programs directed at advanced communications satellite research and technology. It gave the Lewis Research Center the lead responsibility for a program that NASA hoped would culminate in the development and launch of a sophisticated communications satellite in 1985 or 1986. NASA concluded that emphasis needed to be placed on developing technology that would open the thirty/twenty-gigahertz (GHz) frequency band (Ka-band) for commercial use. The major advantage of the thirty/twenty-GHz band was the broad frequency range allocated to communications satellite use—five times the band allocated at the C-band and Ku-band that were presently in use.

Although both NASA and Congress agreed on the necessity for such a program, they debated for the next few years over whether the effort should be funded primarily by the government or by industry. Funding for ground-based research, already in the budget, would continue, but money for a flight demonstration, which NASA and industry were convinced would soon be necessary, was removed from both the initial fiscal year 1982 and fiscal year 1983 budget requests. Congress contended that industry should bear more of the cost, but industry representatives responded that, while they were willing to contribute, the cost of a flight demonstration was beyond their means. In hearings before the House Space Subcommittee in July 1981, NASA Associate Administrator Dr. Anthony Calio stated that the United States was already behind Japan and Europe when it came to developing the thirty-twenty-GHz technology. He also agreed that, given the small profit share awarded to satellite builders, industry could not justify funding the demonstration itself.

The initiative was popular with some members of Congress, however, in spite of the Reagan administration's statement that flight testing was not in NASA's mandate. In April 1982, experts in the communications field testified that unless NASA was allowed to continue the program, foreign competitors were likely to gain significantly in the communications market. In May 1982, the Senate Committee on Appropriations earmarked $15.4 million of NASA's fiscal year 1982 budget for work on a thirty/twenty-GHz test satellite by adding to the Urgent Supplemental Bill.

In January 1983, funding for a new Advanced Communications Technology Satellite (ACTS) was placed in the fiscal year 1984 budget. In March, the Lewis Research Center released a request for proposal for the design, development, building, and launch of ACTS, which was then scheduled for a 1988 launch by the Space Shuttle. In August 1984, NASA awarded an industry team headed by RCA's Astro-Electronics Division a $260.3 million contract for the design, development, and fabrication of ACTS. Other major participants were TRW Electronics System Group, Communications Satellite Corporation (Comsat), Motorola Inc., Hughes Aircraft Company, and Electromagnetic Sciences Inc. The ACTS program was to develop advanced satellite communications technologies, including satellite switching and processing techniques and multibeam satellite antennas, using the thirty/twenty-GHz bands. The program would make the ACTS spacecraft and ground systems capabilities for experimentation available to corporations, universities, and government agencies.

The program still did not progress smoothly, however, as funding levels fluctuated during the next few years (see Tables 2–45 and 2–51). NASA more than once reduced its funding request in response to the Reagan administration's attempt to terminate the program. Congress directed NASA to continue the program as planned and restored its funding. These disputes took their toll, and ACTS was not launched until September 1993.

Search and Rescue

NASA's other major communications initiative was in the area of search and rescue. In the Search and Rescue Satellite-Aided Tracking (SARSAT) System, survivors on the ground or on water send up an Emergency Position Indicating Radio Beacon (EPIRB). Distressed planes use the Emergency Locator Transmitter (ELT) to the SARSAT satellite.

A satellite equipped with SARSAT equipment receives the message from the EPIRB or ELT unit and relays it to the Local User Terminal (LUT). The LUT then relays the message to a mission control center, which alerts the Rescue Coordination Center. The Rescue Coordination Center team radios a search-and-rescue unit to look for the missing or distressed persons or vehicles.

The instruments on COSPAS/SARSAT satellites (COSPAS satellites were the Soviet search-and-rescue satellites) were designed to receive 121.5/243- and 406-MHz distress signals from Earth. Signals sent on the 121.5/243-MHz frequencies allowed for location determination within twenty kilometers of the transmission site. These signals were received by the search-and-rescue repeater and transmitted in real time over 1,544.5 MHz to the LUT on the ground.

The instruments could determine the frequency of the distress signal "Doppler shift" caused by the motion of the spacecraft in relation to the beacon. This shift provided a measurement for computation of the emergency location. The distress location alerts were then relayed from the spacecraft to the LUTs on the ground and from there to the mission control centers. With four operational satellites in orbit (NOAA and Soviet satellites), the time until contact between an individual in an emergency situation and a satellite varied from a few minutes to a few hours. Figure 2–21 shows the basic concept of satellite-aided search and rescue.

The use of meteorological satellites for search-and-rescue operations was first envisioned in the late 1950s. NASA began to experiment with "random-access Doppler tracking" on the Nimbus satellite series in the 1970s. In these experiments, instruments located and verified transmissions from remote terrestrial sensors (weather stations, buoys, drifting balloons, and other platforms). The first operational random-access Doppler system was the French ARGOS on the NOAA TIROS satellite series. The 406-MHz search-and-rescue system evolved from this ARGOS system.

The COSPAS/SARSAT program became an international effort in 1976, with the United States, Canada, and France discussing the possibilities of satellite-aided search and rescue. Joint SARSAT testing agreements in 1979 stated that the United States would supply the satellites, Canada would supply the spaceborne repeaters for all frequencies, and France would supply the spaceborne processors for the 406-MHz frequency. The Soviet Union joined the program in 1980, with the Ministry of Merchant Marine agreeing to equip their COSMOS satellites with COSPAS repeaters and processors. Norway joined the program in 1981, also representing Sweden.

COSPAS/SARSAT experimental operations began in 1982. The first COSPAS launch took place on June 30, 1982, and the operations of four North American ground stations began following a period of joint checkout by the United States, the Soviet Union, Canada, and France. The first satellite-aided rescue occurred not long after the launch. The United Kingdom also joined the program. The first SARSAT satellite, NOAA 8, was launched in 1983.

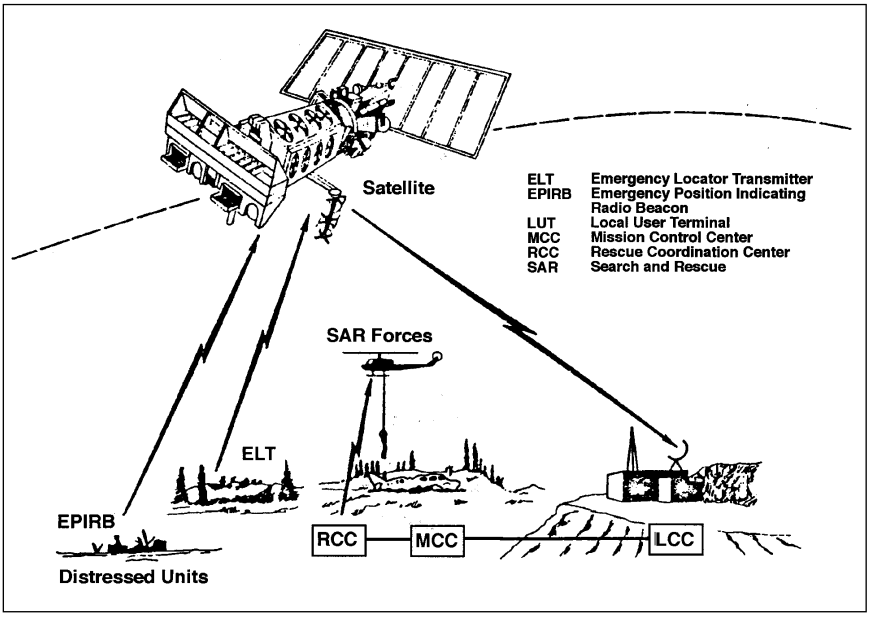

Figure 2–21. Basic Concept of Satellite Search and Rescue

By 1984, the system constellation consisted of two COSPAS and two SARSAT satellites. Bulgaria and Finland also joined the program in 1984. A second SARSAT-Soviet agreement was signed that year, which extended cooperation to 1990. In 1984, NASA turned over the U.S. SARSAT leadership to NOAA, but the space agency continued its role in the areas of research and development.

The full use of the 406-MHz system, designed for global coverage by satellite, was initiated in 1985. Signals sent on the 406-MHz frequency allowed for location determination within five kilometers of the transmission site. In addition, on-board memories stored the 406-MHz data for later transmission in case the signals that were sent in real time were not within range of a ground station. This resulted in global coverage.

The search-and-rescue mission objectives were to:

1. Continue the initial operational use of a spaceborne system to acquire, track, and locate the existing ELTs and EPIRBs that were in the field operating on 121.5 MHz and 243 MHz

2. Demonstrate and provide for operational use of the improved capability for detecting and locating distress incidents utilizing new ELT/EPIRBs operating on 406 MHz (This new capability would provide higher probability of detection and location, greater location accuracy, and coded user information and allow for the necessary growth of an increased population of users. In addition, this capability would allow for global coverage by providing spaceborne processing and storage of the 406-MHz data.)

Operational Communications Satellites

NASA's role in the many operational communications satellites that were launched from 1979 to 1988 was generally limited to providing launch services, with NASA being paid for providing those services. The satellite systems were developed, owned, and operated by commercial enterprises, government agencies from other countries, various commercial or commercial-government consortiums, or the U.S. military. The following sections describe these communications satellites.

ASC Satellites. The American Satellite Company (ASC) began operations in 1974. It was a partnership between Fairchild Industries and Continental Telecom, Inc. Its satellites supplied voice, data, facsimile, and videoconferencing communications services to U.S. businesses and government agencies. Service was provided through an ownership position in the Westar Satellite System and a network of more than 170 Earth stations located in the continental United States, Hawaii, Guam, and Puerto Rico.

Because of the increased demand for ASC's services, in 1981, the company filed an application with the Federal Communications Commission to operate two wholly owned commercial communications satellites. In March 1983, a contract was awarded to RCA Astro Electronics in Princeton, New Jersey, for construction of two ASC spacecraft and the components for a third spacecraft to serve as a ground spare. NASA launched ASC 1 from the Space Shuttle in August 1985 (Table 2–83). ASC 1 operated in both the six/four-GHz (C-band) and fourteen/twelve-GHz (Ku-band) frequencies.

AT&T Satellite System. The American Telephone and Telegraph (AT&T) satellite system consisted of the Comstar satellites and the Telstar satellites. The system began operations in 1976 using the Comstar satellites. The development of the Telstar 3 satellites began in 1980, with the first launch in 1983. Traffic was transferred from the older Comstars to the Telstars, with AT&T maintaining a four-satellite constellation composed of three Telstars and one Comstar. AT&T used its satellites for long-distance high-capacity voice links, television service, and high-speed data and videoconferencing.

Comstar Satellites. Comstar D-4, the only Comstar launched during the 1979–1988 period, was the last in a series of four Comstar satellites that NASA launched for Comsat General Corporation (Table 2–84). Fully leased to AT&T, the satellite had twelve transponders (channels), each capable of relaying 1,500 two-way voice circuits, giving it an overall communications capability of 18,000 simultaneous high-quality, two-way telephone transmissions. Comstar used the same platform as the earlier Intelsat IV series of satellites—the Hughes HS 351.

Telstar 3 Satellites. The Telstar 3 satellites were the second generation of satellites in the AT&T system. AT&T procured them directly rather than through the lease arrangement used for the Comstars. The satellites had the same configuration as the Anik C and SBS satellites and could be launched from a Delta launch vehicle or the Space Shuttle (Tables 2–85, 2–86, and 2–87).

Galaxy Satellites. NASA launched Galaxy 1, 2, and 3 during the early 1980s. The satellites formed the initial elements of the Hughes Communications system of commercial satellites. These vehicles provided C-band television services as well as audio and business telecommunications services. Hughes added to the system in 1988, when it acquired the orbiting Westar 4 and Westar 5 satellites.

The Galaxy spacecraft used the Hughes HS 376 spacecraft. Similar satellites were used for the SBS system, the Telesat satellite system, the Indonesian Palapa satellites, AT&T's Telstar satellites, and the Western Union satellites. Figure 2–22 shows the basic Galaxy spacecraft design.

Each Galaxy satellite had twenty-four transponders and operated in the six/four-GHz C-band. Hughes sold the transponders on Galaxy 1 and Galaxy 3 to private programming owners for the life of each satellite. Galaxy 2 transponders were offered for sale or lease. Galaxy 1 was devoted entirely to the distribution of cable television programming and relayed video signals throughout the contiguous United States, Alaska, and Hawaii (Table 2–88). Galaxy 2 and Galaxy 3 relayed video, voice, data, and facsimile communications in the contiguous United States (Tables 2–89 and 2–90).

RCA Satcom Satellites. RCA American Communications (RCA Americom) launched eight RCA Satcom satellites during the 1979–1988 period. The C-band satellites were Satcom 3, 3R, 4, 5, 6, and 7. The Ku-band satellites were Satcom K-1 and Satcom K-2.

The RCA Satcom satellites formed a series of large, twenty-four-transponder communications satellites. They consisted of a fixed, four-reflector antenna assembly and a lightweight transponder of high-efficiency traveling wavetube amplifiers and low-density microwave filters. The twenty-four input and output multiplex filters and the waveguide sections and antenna feeds were composed of graphite-fiber epoxy composite. Figure 2–23 shows the major physical features of the RCA Satcom satellites.

RCA Americom of Princeton, New Jersey, managed the RCA Satcom program, including the acquisition of the spacecraft and the associated tracking, telemetry, command systems, and launch vehicle support. Spacecraft development and production were the responsibility of RCA's Astro Electronics Division. The Delta Project Office at NASA's Goddard Space Flight Center in Greenbelt, Maryland, was responsible to NASA's Office of Space Transportation Operations for overall project management of the launch vehicle. The Cargo Operations Office at NASA's Kennedy Space Center in Florida was responsible to Goddard for launch operations management. All launch costs incurred by NASA, including the vehicle hardware and launch services, were reimbursed by RCA Americom. The Payload Assist Module (PAM) was procured by RCA directly from the manufacturer, McDonnell Douglas Corporation.

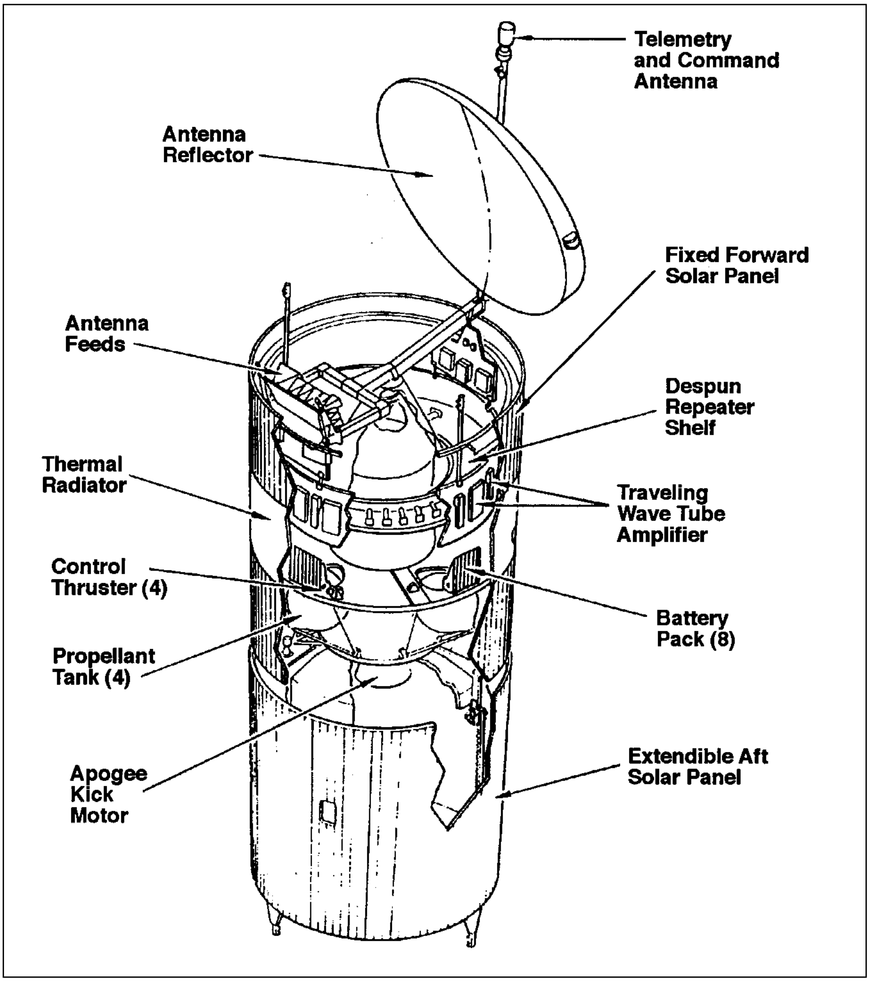

Figure 2–22. Galaxy Components

Satcom 3 was designed for launch by the Delta 3914 (Table 2–91). Beginning with Satcom 3-R, the satellites were designed to be launched either by the Delta 3910/PAM-D or by the Space Shuttle (Table 2–92). (See Table 2–93 for information on Satcom 4.) Satcom 5 was the first RCA satellite to use the Delta 3924 launch vehicle configuration, which used the extended long tank Thor booster, nine Castor IV strap-on motors, and the new Aerojet AJ-118 second stage, but it used the Thiokol TE-364-4 third stage rather than the McDonnell Douglas PAM-D stage (Table 2–94). See Tables 2–95 and 2–96 for information on Satcom 6 and Satcom 7, respectively.) Satcom K-1 and Satcom K-2 (launched in reverse sequence) were heavier spacecraft that were launched by the Space Shuttle, with assistance from a PAM-DII upper stage (Tables 2–97 and 2–98).

SBS Satellites. Satellite Business Systems (SBS) was created on December 15, 1975, by IBM, Comsat, and Aetna Life and Casualty, Inc.

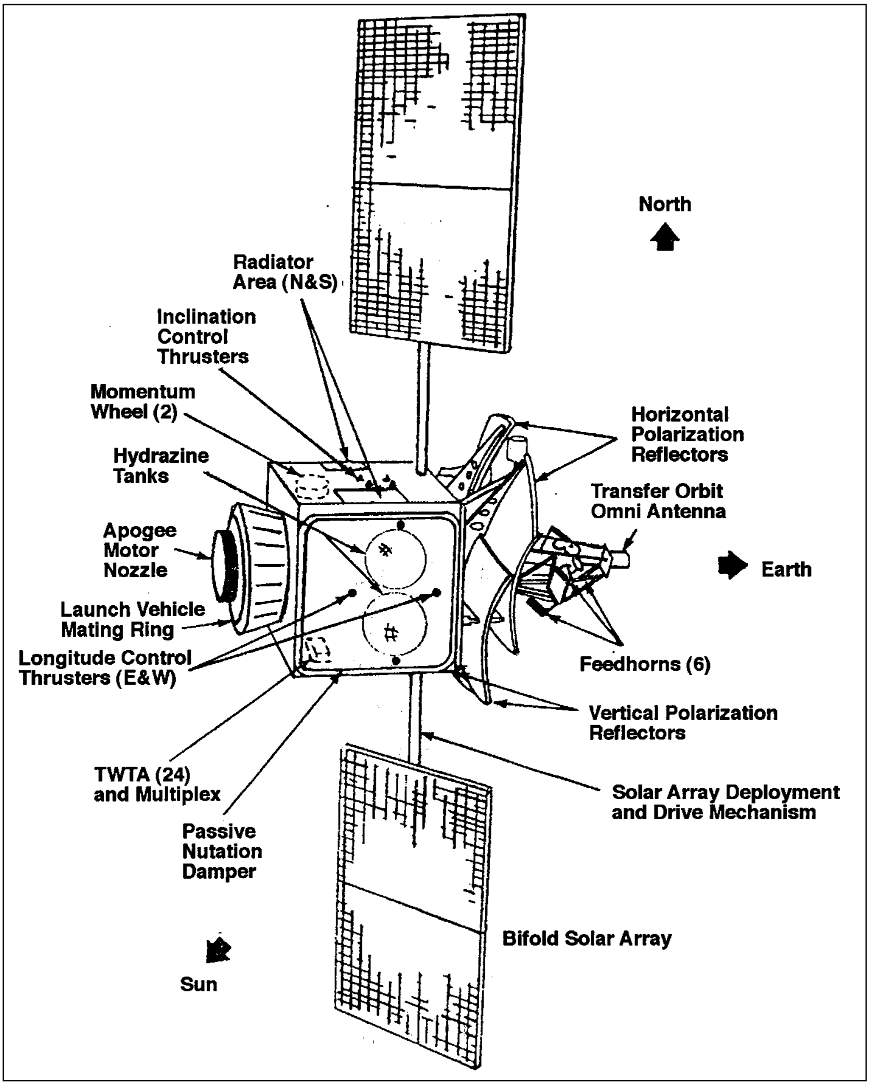

Figure 2–23. RCA Satcom 3, 3R, and 4
(Satcom 5, 6, and 7 were similar, but the solar panels were in three sections.)

It was the first private professional satellite digital communications network and the first domestic system to use the twelve- and fourteen-GHz frequencies. In July 1984, Comsat left the consortium and sold its shares to the other two partners. Four satellites were then in orbit. In 1985, IBM and Aetna sold SBS to MCI Communications Corporation. Aetna received cash, and IBM received MCI stock plus ownership of SBS 4, 5, and 6, which it transferred to its subsidiary IBM Satellite Transponder Leasing Corporation. (SBS 5 and SBS 6 had not yet been launched.) The subsidiary and its three satellites were sold to Hughes Communications in 1989.

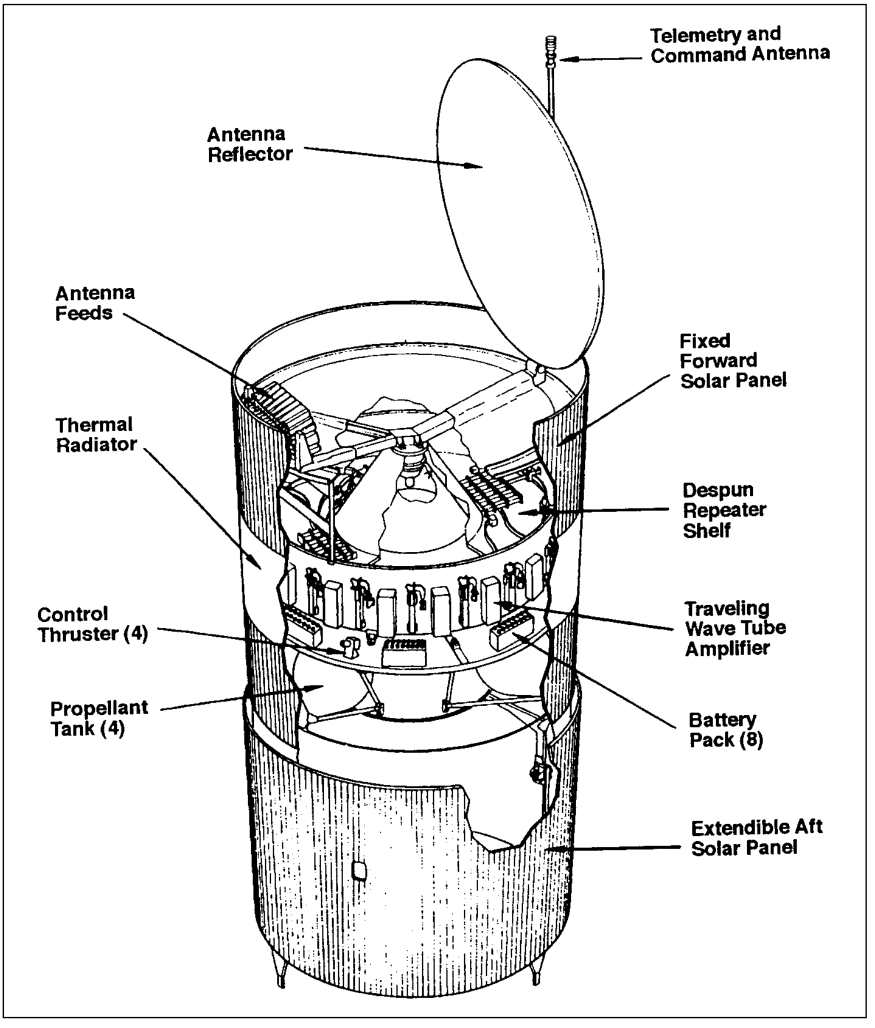

Figure 2–24. SBS Satellite Features

SBS 1 through SBS 5 were very similar in design to the Anik C and several other domestic satellites. (Figure 2–24 illustrates the satellite features.) During launch, the satellite was a compact cylinder. In orbit, the satellite unfolded from one end, and a cylindrical solar array was deployed axially at the other end. When the solar array was deployed, it revealed the main cylindrical body of the satellite, which was also covered with solar cells, except for a mirrored band that served as a thermal radiator. The satellites had ten channels and a capacity for 1,250 two-way telephone conversations per channel, ten simultaneous color television transmissions, or a combination of both. SBS 1 through SBS 4 were launched from NASA vehicles (Tables 2–99, 2–100, 2–101, and 2–102). SBS 5 was launched from an Ariane in September 1988 and is not addressed here.

Westar Satellites. Originally established by Western Union, the Westar satellite system was the first U.S. domestic satellite system. The system relayed data, voice, video, and fax transmissions throughout the continental United States, Hawaii, Puerto Rico, Alaska, and the Virgin Islands. Western Union ended its role as a satellite service provider when it sold the Westar satellites to Hughes Communications in 1988. At the time of the sale, the Westar 3, 4, and 5 satellites were operational. Westar 1 and Westar 2 had already been retired from service (Westar 1 in April 1983 and Westar 2 in 1984). Westar 6 failed to achieve geostationary orbit following its deployment from STS 41-B in February 1984. NASA provided the launch services for the satellites.

Westar 6 was captured and retrieved by an astronaut crew on STS 51-A in February 1984 and returned to Earth for refurbishment. Following its return, the satellite's insurers resold the spacecraft to the Pan Am Pacific Satellite Corporation, which in turn resold it to Asia Satellite, who renamed it AsiaSat 1. The satellite was relaunched in April 1990 aboard a Long March rocket.[5]

The Westar 6S satellite, procured by Western Union as a replacement for Westar 6, was still under development when Western Union was bought out by Hughes. The vehicle was subsequently renamed Galaxy 6.

Westar 1, 2, and 3 were nearly identical to the Canadian Anik A satellites (discussed in Volume III of the *NASA Historical Data Book*). The satellites were spin-stabilized, and the body and all equipment within it spun; only the antenna was despun. The antennas were one and a half meters in diameter and were fed by an array of three horns that produced a pattern optimized for the continental United States. A fourth horn provided a lower-level beam for Hawaii. The communications subsystems had twelve channels with a bandwidth of thirty-six MHz each. Each of twelve spacecraft transponders could relay 1,200 voice channels, one color television transmission with program audio, or data at fifty megabytes per second.

Westar 4, 5, and 6 were larger and had more capacity than the earlier satellites, with twenty-four available channels. Except for communications subsystem details, the satellites were the same as the SBS satellites (addressed above). They had a cylindrical body that was covered with solar cells, except for a band that was a thermal radiator (Figure 2–25). A cylindrical array that surrounded the main body during launch and was deployed in orbit generated additional power. The antenna and the communications equipment were mounted on a platform that was despun during satellite operations. Table 2–103 compares the features of the first generation and the second generation Westar satellites. The characteristics of the Westar 3, 4, 5, and 6 satellites are in Tables 2–104, 2–105, 2–106, and 2–107, respectively.

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[5]Donald H. Martin, *Communication Satellites, 1958–1992* (El Segundo, CA: The Aerospace Corporation, December 31, 1991), pp. 150–51.

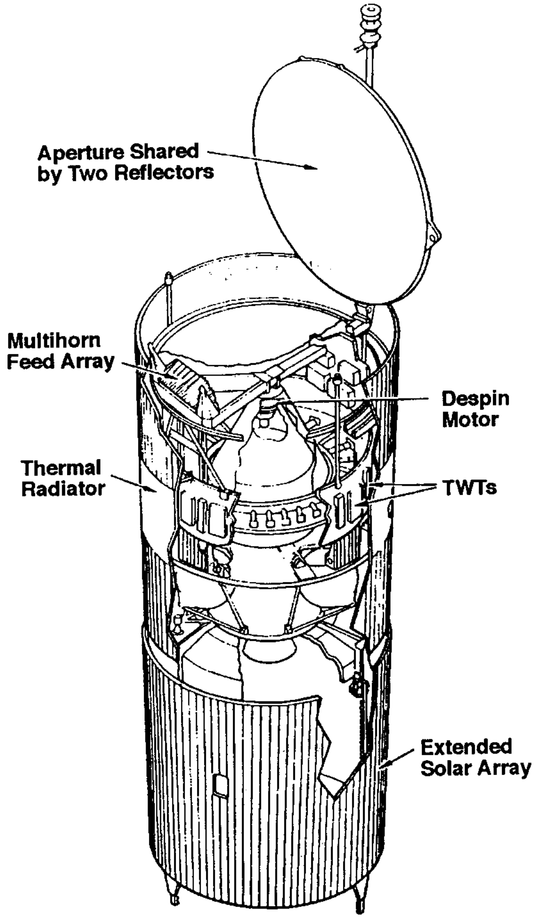

Figure 2–25. Westar 4, 5, and 6 Configuration

Intelsat Satellites. Intelsat (the International Telecommunications Satellite Organization) is an extremely reliable (more than 99 percent) global network of satellites that has provided nearly universal communications coverage except in the polar regions. Intelsat began developing satellites for international public use as soon as the early experimental communications satellite technology had been proven. Starting from a single satellite in 1964, the system grew to a global network using many satellites. Six generations of satellites have been brought into service.

All nations may join Intelsat, and the organization has more than 100 member nations (see Table 2–108). Ownership percentages reflect national investments in Intelsat and are adjusted to reflect each country's use of the system. When Intelsat began, the U.S. ownership was more than 60 percent. As more nations began using the system, this percentage dropped and has been 22 to 27 percent since the late 1970s. Australia, Canada, France, Germany, Italy, Japan, South Korea, and the United Kingdom are the other large owners, with percentages between 2 and 14 percent.[6]

Intelsat was created through the adoption of interim agreements signed by eleven countries that established a global commercial communications satellite system. Since February 12, 1973, Intelsat has operated under definitive agreements, with an organizational structure consisting of an Assembly of Parties (governments that are parties to the Intelsat agreement), a Meeting of Signatories (governments or their designated telecommunications entities that have signed the Operating Agreement), a Board of Governors (responsible for decisions relating to the design, development, construction, establishment, operations, and maintenance of the Intelsat space segment), and an Executive Organ headed by a Director General. The members of the Board of Governors represent countries or groups of countries with relatively large ownership percentages and geographic regions where countries do not have large ownership percentages.

The Intelsat communications system includes the satellites themselves, a large number of ground terminals, and a control center. Intelsat owns the satellites, but each member owns its own terminals. The system has Atlantic, Pacific, and Indian Ocean regions.[7] The number of ground terminals has increased yearly since the system became operational in 1965. Intelsat handles telephone, telegraph, data, and television traffic. Telephone has been the major portion of the traffic. In the early years, almost all Intelsat traffic was voice, but with the growth of television transmissions and, more recently, the surge in nonvoice digital services, revenue. Television accounted for about 10 percent of the revenues, except in months with events of worldwide interest, such as the Olympic Games. The Atlantic region has always had the majority of all Intelsat traffic, almost 70 percent in the early years and decreasing later to about 60 percent. The Pacific region began earlier than the Indian Ocean region because of earlier satellite availability. However, Indian Ocean traffic surpassed Pacific traffic when considerable Hawaiian and Alaskan traffic was transferred to U.S. domestic systems. Pacific traffic, however, has

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[6] *Ibid.*, p. 83.

[7] Intelsat has four service regions. The Atlantic Ocean Region serves the Americas, the Caribbean, Europe, the Middle East, India, and Africa and generally covers locations from 307 degrees east to 359 degrees east longitude. The Indian Ocean Region serves Europe, Africa, Asia, the Middle East, India, and Australia and covers 327 degrees east to 66 degrees east. The Asia Pacific Region serves Europe, Africa, Asia, the Middle East, India, and Australia and covers 72 degrees east to 157 degrees east. The Pacific Ocean Region serves Asia, Australia, the Pacific, and the western part of North America from 174 degrees east to 183 degrees east. In most discussions, the Asia Pacific Region and the Pacific Ocean Region are treated as a single region.

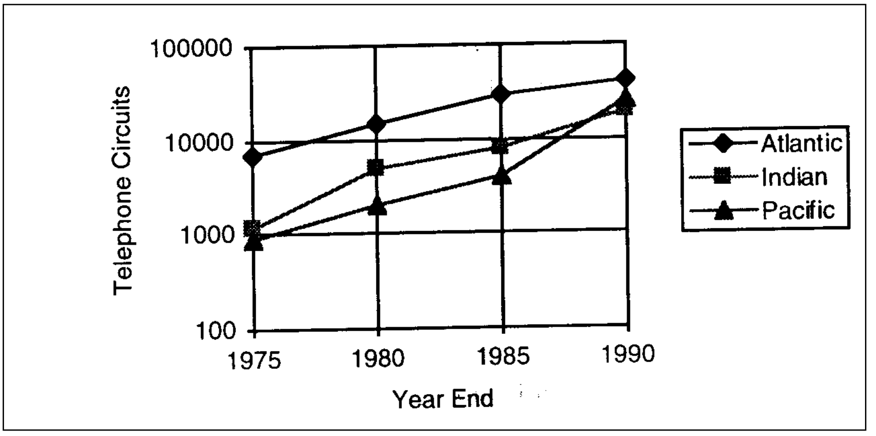

Figure 2–26. Growth of Intelsat Traffic (1975–1990)

continued to grow, as many small nations have begun to use the system.[8] Figure 2–26 shows the growth of Intelsat traffic from 1975 to 1990.

NASA's Lewis Research Center (now Glenn Research Center) managed the Atlas-Centaur launches. Comsat was responsible for firing the apogee kick motor that placed the satellites into near geosynchronous orbit.

Intelsat V. The Intelsat IV-A satellites that were first used in 1975 had a capacity of 6,000 voice circuits and two television channels. They provided a moderate capacity increase over previous satellites without requiring significant ground terminal changes. However, further capacity increases were not practical with a simple stretching of the Intelsat IV/IV-A design, so the development of a new satellite began in 1976. The new series of satellites (Intelsat V) had a capacity of 12,000 voice circuits and two television channels. It has been used in all the Intelsat regions.

The Intelsat V satellites incorporated several new features. These were:

- Frequency reuse through both spatial isolation and dual polarization isolation
- Multiband communications—both fourteen/eleven GHz and six/four GHz
- A contiguous band output multiplexer
- Maritime communications subsystem
- Use of nickel hydrogen batteries in later spacecraft

Two of the new design features required significant ground terminal changes. The use of dual-polarization uplinks and downlinks in the four- and six-GHz bands required improvements at all ground terminals to ensure isolation between the two polarizations. The dual-polarization uplinks and downlinks tripled the satellite capacity in the four- and six-

[8]Martin, *Communication Satellites*, pp. 83–85.

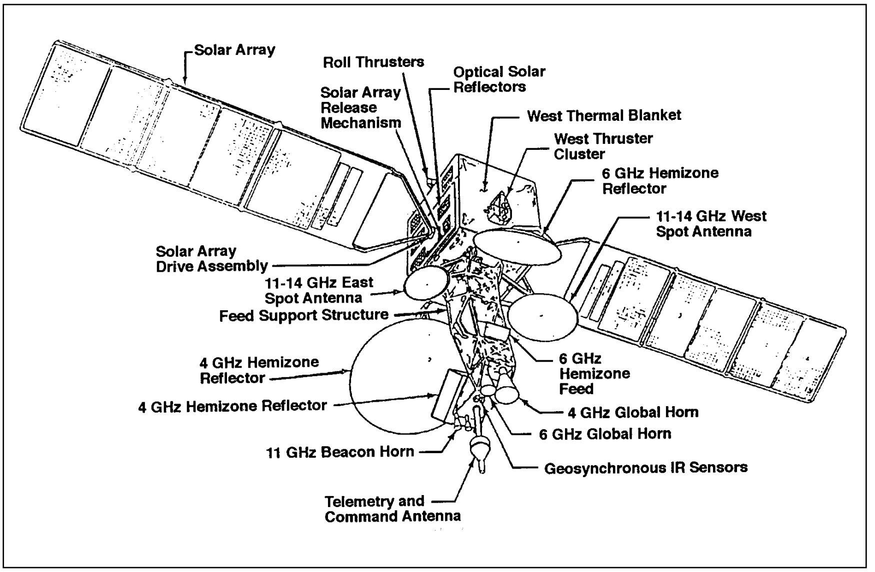

Figure 2–27. Intelsat 5 Spacecraft

GHz bands, compared with the Intelsat IV design. Also, the nations with the largest traffic volumes used the new eleven- and fourteen-GHz bands and two independent beams and needed to construct new terminals for them.[9]

The Intelsat V satellites had a rectangular body of more than one and a half meters across. The Sun-tracking solar arrays, composed of three panels each, were deployed in orbit. An antenna tower on the Earth-viewing face of the body held both the communications and telemetry, tracking, and command antennas and the feed networks for the large reflectors. The tower was fixed to the satellite body, but the three largest reflectors deployed in orbit. The tower was more than four and a half meters tall and was constructed almost entirely of graphite fiber/epoxy materials for strength, light weight, and thermal stability. The entire satellite weighed about 1,928 kilograms at launch and 998 kilograms in orbit and spanned about fifteen and a half meters across the solar array (Figure 2–27).

The initial Intelsat V contract that was awarded to Ford Aerospace and Communications Corporation of the United States called for seven satellites; later an eighth and a ninth were added to the contract. An international team of manufacturers served as subcontractors. Members of the international manufacturing team and their areas of concentration are listed in Table 2–109.

The first Intelsat V launch was in December 1980; the last, the only failure, was in 1984. The eight satellites successfully launched were still in use at the end of 1990. The Intelsat V characteristics are summarized in Tables 2–110 through 2–116.

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[9]*Ibid.,* pp. 56–57.

Intelsat V-A Series. Intelsat V-A F-10 was the first in the Intelsat V-A series of satellites. Intelsat V-A was a modified Intelsat V design. Its development started in late 1979. As with previous changes to Intelsat satellites, the primary goal was to increase satellite capacity to keep ahead of traffic growth in the Atlantic region. Intelsat V-A satellites had a capacity of 13,500 two-way voice circuits, plus two television channels.

Externally, the satellite was almost identical to Intelsat V. Internally, several changes were made to improve performance, reliability, and communications capacity. Several weight-saving measures compensated for the additional communications hardware. The internal arrangement of the communications hardware was modified for thermal balance. Intelsat V-A satellites did not have the maritime communication subsystem, which was added to Intelsat V-5 launched in September 1982 and Intelsat V-6 through Intelsat V-9. (Intelsat V-7 and V-8 were not launched by NASA.)

The first Intelsat V-A was launched in March 1985 (Table 2–117). Two others were launched later in 1985 (Tables 2–118 and 2–119). A fourth was lost in a launch vehicle failure in 1986. The last two were launched in 1988 and 1989. Only the three 1985 satellites were NASA launches.

Fltsatcom Satellites. The Fltsatcom system (Fleet Satellite Communications) provided worldwide, high-priority, ultrahigh frequency (UHF) communications among naval aircraft, ships, submarines, and ground stations and between the Strategic Air Command and the national command authority network. It supplied military communications capability for the U.S. Air Force with narrowband and wideband channels and the U.S. Navy for fleet relay and fleet broadcast channels. The satellites provided two-way communication, in the 240- to 400-MHz frequency band, between any points on Earth visible from their orbital locations. Between 1979 and 1988, NASA furnished launch services for six

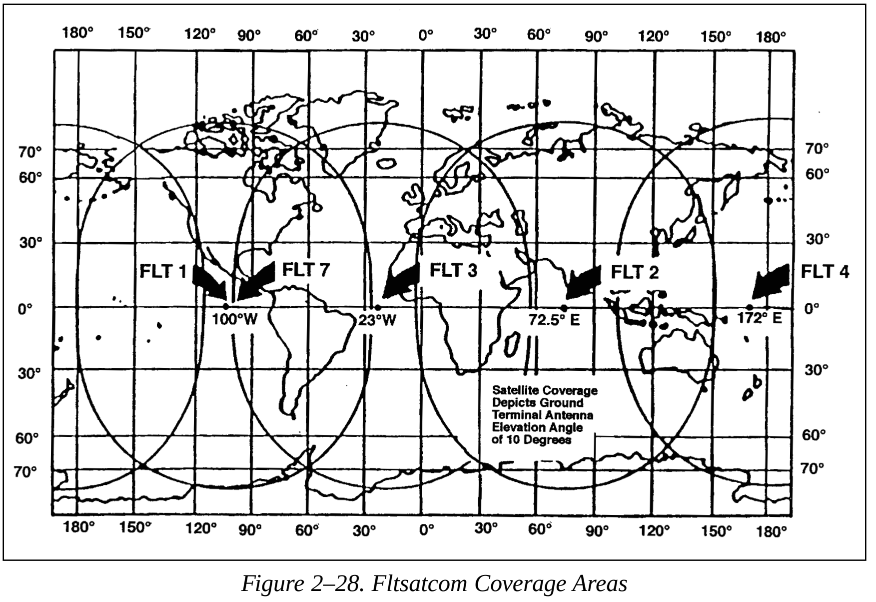

Figure 2–28. Fltsatcom Coverage Areas

Fltsatcom satellites for the U.S. Department of Defense, Fltsatcom 2 through Fltsatcom 7 (Tables 2–120 through 2–125).

Fltsatcom and the Air Force Satellite Communications System shared a set of four Fltsatcom satellites in synchronous equatorial orbits. Figure 2–28 shows the coverage areas of the five operational Fltsatcom satellites.

The Fltsatcom satellites had an hexagonal body with two modules—a spacecraft module and a payload module (Figure 2–29). Fltsatcom 7 had a third module for the extremely high frequency (EHF) communications package that it carried. The spacecraft module contained the attitude control, power, and tracking, telemetry, and command subsystems, as well as the apogee motor. The two solar arrays were mounted on booms attached to this module. The satellite was three-axis stabilized by means of redundant reaction wheels and hydrazine thrusters. This arrangement allowed the antennas to face Earth continuously while being directly attached to the satellite body. The payload module contained the communications subsystem. The transponders on board each satellite carried twenty-three UHF communications channels and one superhigh frequency uplink channel. The Navy used ten of the channels for communications among its land forces, ships, and aircraft. The Air Force used twelve of the channels as part of its satellite communications system for command and control of nuclear forces. One channel was reserved for U.S. national command authorities.

Leasat Satellites. The Leasat satellites (also known by the name Syncom) were leased by the Department of Defense from Hughes Communications Services to replace older Fltsatcom spacecraft for

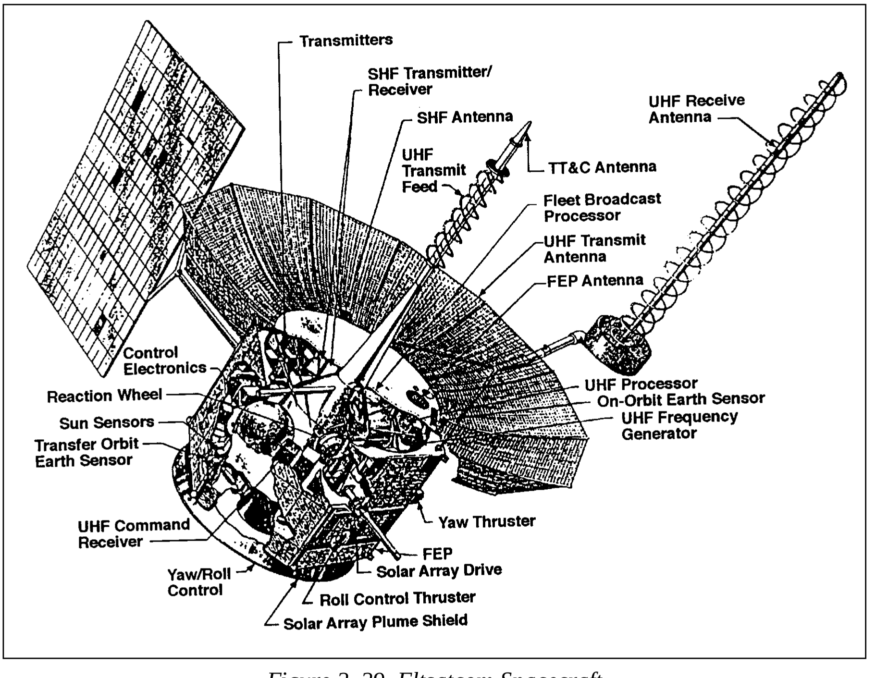

Figure 2–29. Fltsatcom Spacecraft

worldwide UHF communications among ships, planes, and fixed facilities. The spacecraft were designed expressly for launch from the Space Shuttle and used the "frisbee" or rollout method of deployment.

A cradle structure helped install the spacecraft in the orbiter payload bay. This cradle permitted the spacecraft to be installed lying on its side, with its retracted antennas pointing toward the nose of the orbiter and its propulsion system pointing toward the back. Mounting the antennas on deployable structures allowed them to be stowed for launch.

The Leasat satellites did not require a separately purchased upper stage. They contained their own unique upper stage to transfer them from the Shuttle deploy orbit to a geosynchronous circular orbit over the equator.

The satellites used the Hughes HS 381 bus. They were spin-stabilized, with the spun portion containing the solar array and the Sun and Earth sensors for attitude determination and Earth pointing reference, three nickel cadmium batteries for eclipse operation, and all the propulsion and attitude control hardware. The despun platform contained two large helical UHF Earth-pointing communications antennas, twelve UHF communications repeaters, and the majority of the telemetry, tracking, and command equipment.

The contract for Leasat development was awarded in September 1978 to Ford Aerospace and Communications Corporation. The first launch was scheduled for 1982. However, delays in the Shuttle program postponed the launch dates and resulted in a two-year suspension of work on the satellites. Work resumed in 1983, and NASA launched the first two satellites in 1984. NASA launched the third Leasat in April 1985, but the satellite failed to turn on. The Shuttle crew carried out a rescue attempt but was unsuccessful. NASA launched the fourth Leasat in August 1985. The same Shuttle mission then rendezvoused with Leasat 3 and carried out a successful repair, allowing ground controllers to turn the satellite on and orient it. After ensuring that the propellants were warm, Leasat 3 was placed into geosynchronous orbit in November 1985 and began operations in December. Unfortunately, Leasat 4 failed shortly after arriving in geosynchronous orbit, and the wideband channel on Leasat 2 failed in October 1985. The characteristics of these four satellites are in Tables 2–126 through 2–129. NASA launched the fifth and last Leasat in January 1990.[10]

NATO IIID. NATO IIID was the fourth and final NATO III satellite placed in orbit by NASA for the U.S. Air Force and its Space Division acting as agents for NATO. The satellite was spin-stabilized with a cylindrical body and a despun antenna platform on one end. All equipment was mounted within the body, and a three-channel rotary joint connected the communications subsystem with the antennas (Figure 2–30). The spacecraft transmitted voice, data, facsimile, and telex messages among military ground stations.

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[10]*Ibid.,* p. 115.

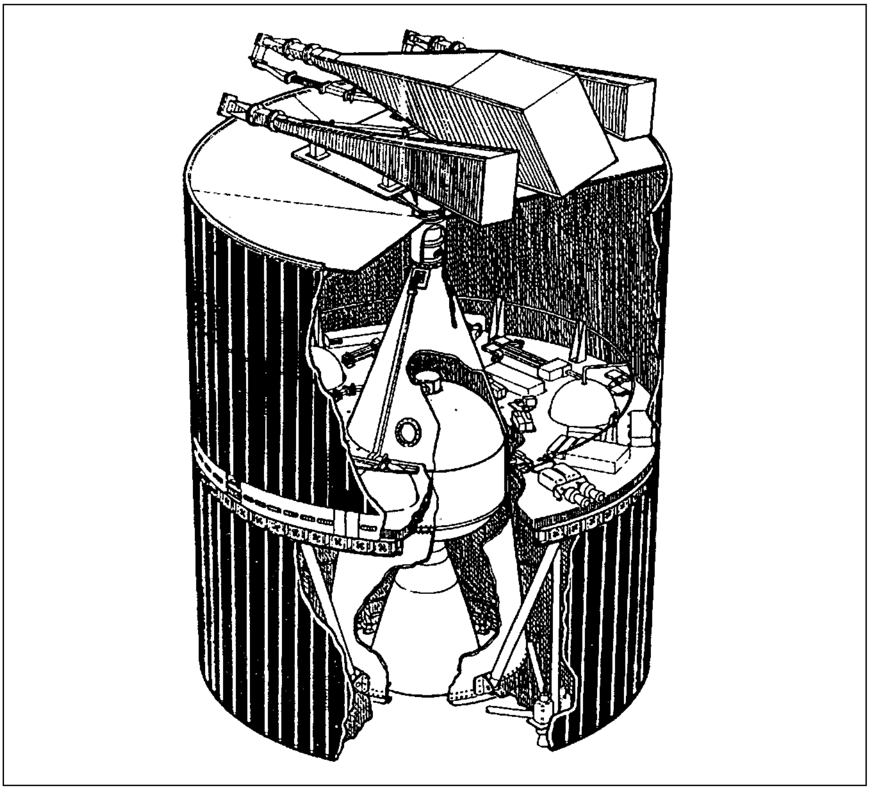

Figure 2–30. NATO III Spacecraft

The NATO communications satellite program began in 1967. The first NATO satellite was launched in 1970. A second satellite was launched in 1971. The NATO III satellites were larger and had significantly greater capabilities than the earlier NATO satellites. NASA launched NATO IIIA in April 1976. NATO IIIB was launched in January 1977 as an orbiting spare. NATO loaned it to the United States to fill the east Pacific operating location of the Defense Space Communications System (DSCS) until at least four DSCS II satellites were available, which occurred in December 1978 with the launch of DSCS II. The United States removed DSCS traffic from NATO IIIB and returned the satellite to its station over the Atlantic Ocean. NATO traffic was switched to NATO IIIB in December 1982, and NATO IIIA was used for ground terminal testing. The flight qualification model was reworked into the third flight model and launched in November 1978; it was put into a dormant state known as orbital storage. NATO IIIC was reactivated and became the primary NATO spacecraft in December 1986, and NATO IIIB became a test vehicle. In 1980, a follow-on contract was issued for a fourth satellite, which NASA launched in November 1984 as NATO IIID (Table 2–130).[11]

[11]*Ibid.*, pp. 105–07.

Anik Satellites. Telesat Canada Corporation operated the series of Anik satellites and reimbursed NASA for the cost of its launch services. (Anik means “little brother” in Inuit.) The system began operations in Canada at the beginning of 1973. The first three satellites were designated the Anik A series. Anik A-1 was the world’s first geostationary communications satellite launched into orbit for a commercial company. The satellites provided all types of communications services throughout Canada. A single Anik B satellite supplemented the A series and provided additional experimental channels.

The Anik D series replaced the A satellites. The Anik C satellites operated at the same time as Anik D but had a different function. They added to terrestrial communications on high-traffic-density paths and used the twelve- and fourteen-GHz frequencies for service to terminals in urban areas. The four- and six-GHz bands that were used by Anik D were unacceptable because of interference from other users of the band.[12]

The Anik satellites were designed for launch from either a Delta launch vehicle or the Space Shuttle. The characteristics of the Anik C satellites are in Tables 2–132, 2–133, and 2–135, while those of the Anik D satellites are in Tables 2–131 and 2–134; these satellite descriptions are in order of launch date.

Anik C Satellites. Anik C was a spin-stabilized satellite. When in orbit, the antenna was deployed from one end of the satellite, and a cylindrical solar panel was extended from the opposite end. The communications subsystem had sixteen repeaters and used the twelve- and fourteen-GHz bands. Figure 2–31 shows the Anik C configuration.

The Anik C satellites covered only the southern half of Canada because they were designed to connect Canada’s urban centers. The use of the twelve- and fourteen-GHz bands allowed the ground terminals to be placed inside cities without interference between the satellite system and terrestrial microwave facilities. Anik C complemented the Anik A and Anik D satellites, which covered all of Canada and were best suited to the distribution of national television or message services that required nationwide access.

The development of Anik C began in April 1978. The first launch (Anik C-3) took place from STS-5 in November 1982. Anik C-3 was the first C series satellite launched because the other C satellites were not as readily accessible; they had been put into ground storage awaiting launch vehicle availability. The second C satellite was launched in June 1983, and the third in April 1985. Traffic did not grow as much as expected when the C series was planned, and Anik C-1 was put into orbital storage and offered for sale. A purchase agreement was made in 1986 by a group that planned to use it for transpacific services, but the agreement was canceled in 1987. By 1989, Telesat began to use the satellite in a limited way, and in 1990, additional traffic was transferred to it in preparation for the introduction of Anik E-1.[13]

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[12] *Ibid.,* p. 131.
[13] *Ibid.,* p. 136.

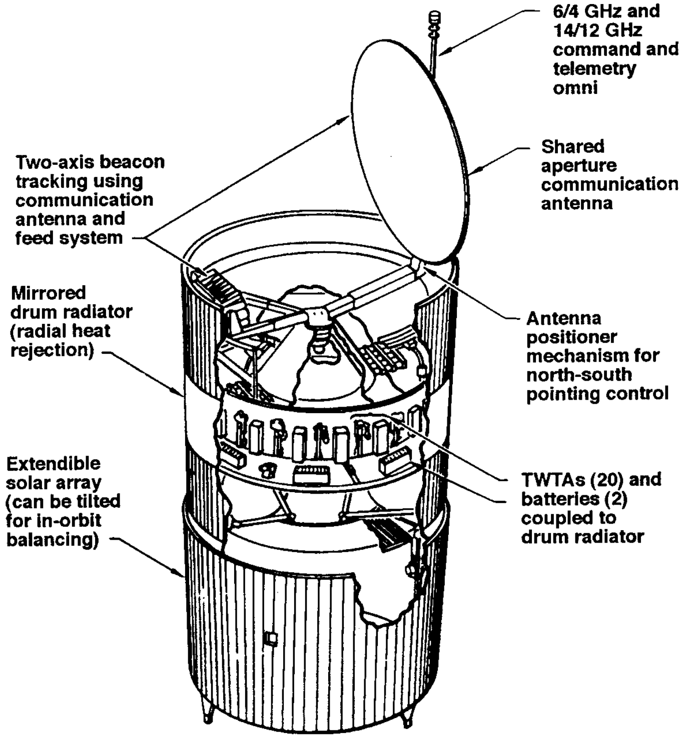

Figure 2–31. Anik C Configuration

Anik D Satellites. The Anik D satellites replaced the Anik A satellites. The satellites were also spin-stabilized, and the structure, support subsystems, thermal radiator, and deployable solar array were almost identical to those of Anik C.

The major difference between the two satellites was in the communications subsystem. Anik D had twenty-four repeaters in the four- and six-GHz bands as compared to the sixteen repeaters in the twelve- and fourteen-GHz bands on Anik C. Figure 2–32 shows the typical geographical coverage of the Anik D satellites from an approximate location of 104 degrees west longitude.

Arabsat Satellite. NASA launched Arabsat-1B from the Space Shuttle in June 1985 (Table 2–136). It was the second in a series of satellites owned by the Arabsat Satellite Communications Organization (or Arabsat). (Arabsat-1A was launched from an Ariane in February 1984.) It was a communications satellite with a coverage area that included the Arab-speaking countries of North Africa and the Middle East (Figure 2–33).

Arabsat was formed in 1976. Saudi Arabia had the largest investment share. The objective of the system was to promote economic, social, and cultural development in the Arab world by providing reliable communications links among the Arab states and in rural areas, developing Arab

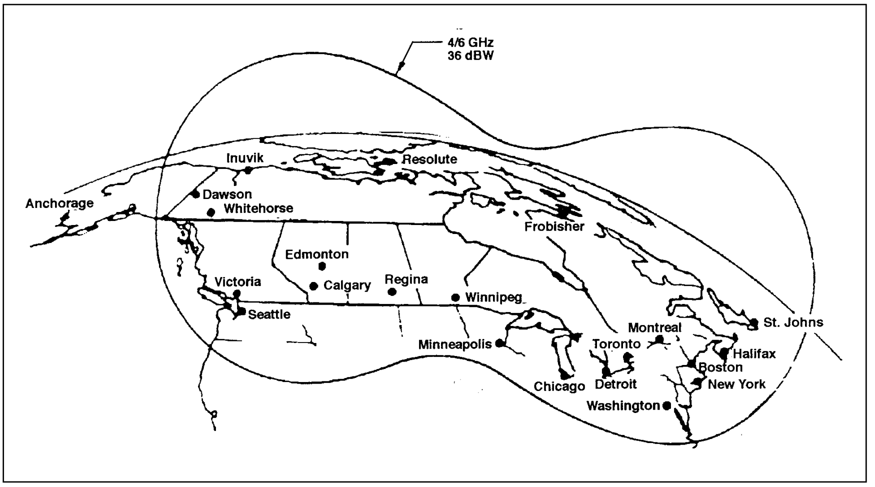

Figure 2–32. Anik D Geographical Coverage at 104 Degrees West Longitude

industrial capabilities in space-related technologies, and introducing new communications services to the area.

The Arabsat Organization purchased the satellites, launch services, and major ground facilities but developed some of the ground equipment within the member nations. The organization awarded a contract to Aerospatiale in May 1981 for three satellites. The satellites included equipment used for other satellites, particularly the Intelsat V series and Telecom 1. It was a three-axis-stabilized design with solar arrays and antennas. The solar arrays were partially deployed in the transfer orbit; the antennas were deployed in synchronous orbit. The satellites contained twenty-five C-band transponders and one television (C/S-band) transponder.[14]

Aussat Satellites. Australia first considered a domestic satellite system in 1966. In 1969, the country began routing some transcontinental telephone circuits through the Intelsat system. During 1970, experiments were conducted using ATS 1 to gather data that would be useful in planning a domestic satellite system.

Studies continued throughout the 1970s. In mid-1979, the government decided to institute a satellite system. In the fall of 1979, the Canadian Hermes satellite (actually CTS) was used for demonstrations of television broadcasting to small terminals at numerous locations. The distribution of television to fifty isolated communities began in 1980 using an Intelsat satellite. Between mid-1979 and April 1982, satellite specifications were developed, a government-owned operating company, Aussat Proprietary, Ltd., was formed, and a satellite contract was signed with Hughes Communications International to develop Australia's first satellite program. Under the contract, Hughes Space and Communications Group built three satellites and two telemetry, tracking, command, and

[14]*Ibid.,* p. 268.

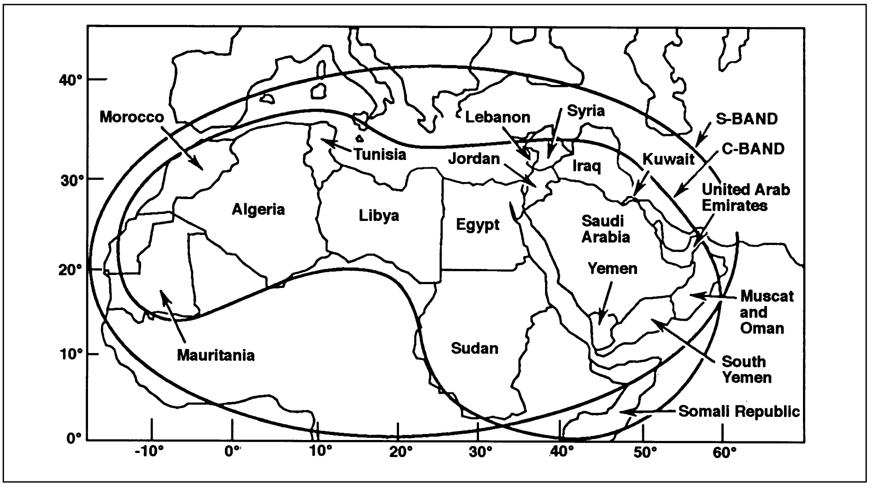

Figure 2–33. Arabsat Coverage Area

monitoring stations. The contract also provided for launch and operational services and ground support.

Aussat provided a wide range of domestic services to the entire continent, its offshore islands, and Papua, New Guinea. This included direct-television broadcast to homesteads and remote communities, high-quality television relays among cities, digital data transmission for both telecommunications and business use, voice applications for urban and remote areas, centralized air traffic control services used as a very high-frequency (VHF) repeater station, and maritime radio coverage.

NASA launched two Aussat satellites for Aussat Proprietary. The system used the Hughes HS 376 spacecraft, the same spacecraft used by Anik, Telstar, Galaxy, and Palapa. Aussat 1 and Aussat 2 were located at geosynchronous orbits at the equator just north of Papua, New Guinea, at 156 degrees east and 164 degrees east longitude (Table 2–137 and 2–138). The satellites were designed to be launched from the Space Shuttle, a Delta, or an Ariane. The Aussat satellites carried fifteen channels, each forty-five MHz wide.

Insat Satellites. NASA launched the Insat satellites for the India Department of Space. The satellites were multipurpose telecommunications/meteorology spacecraft with the capability for nationwide direct broadcasting to community television receivers in rural areas. The spacecraft were built by Ford Aerospace and Communications Corporation under a joint venture of the Department of Space, the Posts and Telegraphs Department of the Ministry of Communications, the India Meteorological Department of the Ministry of Tourism and Civil Aviation, and the Doordarshan of the Ministry of Information and Broadcasting.

The satellites included twelve transponders operating at 5,935–6,424 MHz (Earth-to-satellite) and 3,710–4,200 MHz (satellite-to-Earth) for thick route, thin route, and remote area communications and television program distribution. They also had two transponders operating at 5,855–5,935 MHz

(Earth-to-satellite) and 2,555–2,635 MHz (satellite-to-Earth) for direct-television broadcasting to augmented low-cost community television receivers in rural areas for which direct-television broadcast coverage has been identified as more economical, radio program distribution, national television networking, and disaster warning. The telecommunications component could provide more than 8,000 two-way long-distance telephone circuits potentially accessible from any part of India.

NASA launched Insat 1A from a Delta launch vehicle in 1982 (Table 2–139). The space agency also launched Insat 1B from the Space Shuttle in 1983 (Table 2–140). Insat 1C was launched from an Ariane in 1988 and is not addressed here.

Morelos Satellites. Mexico started domestic use of satellite communications in 1980 by leasing Intelsat capacity on a satellite that was moved to 53 degrees west longitude to provide domestic services for the Western Hemisphere. Mexico also owned one transponder on a U.S. domestic satellite that was used for transmission of television to the United States. In the spring of 1983, Mexico awarded a contract for the construction of a Mexican domestic communications satellite to Hughes Communications. The satellite and the satellite system were called Morelos in honor of a notable person in Mexican history.

The satellite system provided advanced telecommunications to the most remote parts of Mexico, including educational television, commercial programs over the national television network, telephone and facsimile services, and data and business transmissions. The system used eighteen channels at C-band and four channels at Ku-band. The satellites used the popular Hughes HS 376 design.

NASA launched two satellites for the Secretariat of Communications and Transportation, Mexico. Morelos 1 was launched in June 1985, and all traffic from the Intelsat satellite was transferred to it (Table 2–141). NASA launched Morelos 2 in November 1985 (Table 2–142). It was put into a drifting storage orbit just above synchronous altitude. In 1986, it was stabilized at 116 degrees longitude in an orbit with a few degrees inclination. That orbit was phased so that the inclination decreased to zero by 1990 from natural forces. This allowed the satellite to use its scheduled launch date yet not use fuel for stationkeeping until its communications services were required.

Palapa Satellites. The Palapa satellites form Indonesia's domestic satellite system. Meaning "fruits of labor," Palapa satellites provided regional communications among the country's more than 6,000 inhabited islands. The system was operated by a government-owned company, Perumetel until 1993, when a private Indonesian company took over system management.

NASA launched Palapa A1 on July 8, 1976. Operational service began the following month. Palapa A1 and Palapa A2 were removed from service in July 1985 and January 1988, respectively, following the introduction of the Palapa B series, which increased coverage to include the Philippines, Malaysia, and Singapore. Palapa B-1 was launched on STS-7 in 1983

(Table 2–143). Palapa B-2, originally launched by NASA from STS 41-B in February 1984, did not successfully reach orbit and was subsequently retrieved by STS 51-A in November 1984 (Table 2–144). Following the failure of Palapa B-2, Perumetel ordered an identical replacement satellite, Palapa B-2P, which NASA launched in March 1987 on a Delta launch vehicle (Table 2–145). The satellite was sold by its insurers to Sattel Technologies; it was refurbished, relaunched in April 1990, and then resold to Perumetel, with which it was known as Palapa B-2R.[15]

The Palapa B satellites were four times more powerful and twice the size of the Palapa A series. They were based on the frequently used Hughes HS 376 design. Each carried twenty-four C-band transponders and six spares.

UoSAT Satellites. The UoSAT satellites were part of the Oscar program of HAM radio satellites. (Oscar stood for Orbiting Satellite Carrying Amateur Radio.) The satellites were carried as secondary payloads on missions that had excess payload space. NASA launched UoSAT 1 with the Solar Mesospheric Explorer (Table 2–146) and UoSAT 2 with Landsat 5 (Table 2–147).

The UoSATs emphasized microelectronics technology and involved direct contact with the satellites from simple ground terminals located at schools of all levels. UoSAT 1 was the ninth Oscar launch and the first satellite built by the University of Surrey in England. The goal of UoSAT 1 and the UoSAT program was to demonstrate the development of low-cost sophisticated satellites and to use these satellites to promote space science and engineering in education. The satellite was the first satellite designed to transmit data, including pictures of Earth’s surface, in a form that could be readily displayed on a domestic television set. It carried a voice synthesizer for “speaking” (in English) information on telemetry, experimental data, and spacecraft operations. The synthesizer had a vocabulary of approximately 150 words, and most standard amateur VHF receivers could listen in with a simple fixed antenna. It carried a series of radio beacons transmitting at different frequencies, two particle counters that provided information on solar activity and auroral events, a magnetometer for measuring the Earth’s magnetic field, and an Earth-point camera that covered an area of 500 square kilometers and transmitted images that could be received and stored by simple receivers and displayed on home television sets.

UoSAT 2 was the eleventh Oscar launch. It carried a particle wave experiment, a store-and-forward digital communications experiment, a solid-state slow-scan imaging experiment, VHF/UHF and superhigh frequency (SHF) data downlinks, a multichannel command decoder, a microprocessor-based housekeeping system and data collection facility, digital Sun sensors, horizon sensors, a navigation magnetometer, three axis magnetorquers, a gravity-gradient stabilization system, and an experimental telemetry system.

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[15]*Ibid.*, p. 256.

Navigational Satellites

NASA launched two series of navigational satellites from 1979 to 1988: the NOVA satellites and the SOOS satellites. Both series were launched for the Navy Transit System from Scout launch vehicles, and both used Oscar spacecraft. The Transit Program was an operational navigation system used by the U.S. Navy and other vessels for worldwide ocean navigation.

Transit was developed at Johns Hopkins University's Applied Physics Laboratory from 1958 to 1962 to provide precision periodic position fixes for U.S. Navy submarines. Subsequently, several commercial companies were contracted to build production models of the spacecraft, which were kept in controlled storage until needed, as well as signal receiver and position computer equipment.

The constellation consisted of two types of spacecraft designated as Oscar and NOVA. The satellites were launched into a polar orbit with a nominal 1,112-kilometer altitude. The last Transit satellite launch was SOOS-3 in August 1988. The program was terminated on December 31, 1996.

NASA and DOD entered into agreements in June 1962 that established the basis for joint utilization of the Scout launch vehicle. These initial agreements were reflected in a memorandum of understanding between NASA and the Air Force Systems Command, dated April 19, 1977. Under this agreement, NASA maintained the Scout launch vehicle system, and DOD used the system capabilities for appropriate missions. DOD requested that NASA provide Scout launches for the Navy Transit and NOVA programs. The Navy reimbursed NASA for the cost of the Scout launch vehicles, Western Strategic Missile Command launch services and mission support requirements, and supporting services, as required.

NOVA Satellites. NOVA was the new-generation, improved Transit navigation satellite. RCA Astro-Electronics performed the initial hardware work under contract to the U.S. Navy's Strategic Systems Project Office, but because of contractual changes, the satellites were returned to the Applied Physics Laboratory at Johns Hopkins University for completion and processing for launch. NASA launched the satellites on a four-stage Scout vehicle into an initial orbit of 342.6 kilometers by 740.8 kilometers. A multiple-burn hydrazine motor then raised and circularized the orbit.

The NOVA spacecraft was an improved Oscar. Improvements included electronics hardened against the effects of radiation, a disturbance compensation system designed to provide stationkeeping capability and remove atmospheric drag and radiation pressure effects, and greater data storage capacity that permitted retention of a long-arc, eight-day navigation message. The NOVA transmitting system consisted of dual five-MHz oscillators, phase modulators, and transmitters operating at 400 MHz and 150 MHz. Dual incremental phase shifters were used to control oscillator offset. The characteristics of the three NOVA satellites are in Tables 2–148, 2–149, and 2–150.

SOOS Satellites. SOOS stands for “Stacked Oscars on Scout.” The Navy SOOS mission configuration consisted of two Transit satellites in a stacked configuration. The stacked launch of two satellites and a separation technique placed the two Oscars in virtually the same orbit plane. To make the piggyback launch possible, the lower Oscar spacecraft was modified with a permanently attached graphite epoxy cradle that supported the upper spacecraft in the launch configuration. The characteristics of the four SOOS satellites are in Tables 2–151 through 2–154.

Table 2–1. Applications Satellites (1979–1988)

Launch Date	Satellite	Type of Mission	Owner/ Sponsor	Launch Vehicle
Feb. 18, 1979	SAGE (AEM-2)	Explorer	NASA	Scout
May 4, 1979	Fltsatcom 2	Communications	Dept. of Defense	Atlas Centaur
June 27, 1979	NOAA 6	Meteorological	NOAA	Atlas-F
Aug. 9, 1979	Westar 3	Communications	Western Union	Delta
Oct. 30, 1979	Magsat (AEM-C)	Explorer	NASA	Scout
Dec. 6, 1979	RCA Satcom 3*	Communications	RCA Corp.	Delta
Jan. 17, 1980	Fltsatcom 3	Communications	Dept. of Defense	Atlas Centaur
May 29, 1980	NOAA B*	Meteorological	NOAA	Atlas-F
Sept. 9, 1980	GOES 4	Meteorological	NOAA	Delta
Oct. 30, 1980	Fltsatcom 4	Communications	Dept. of Defense	Atlas Centaur
Nov. 15, 1980	SBS 1	Communications	Satellite Business Systems	Delta
Dec. 6, 1980	Intelsat V F-2	Communications	Intelsat	Atlas Centaur
Feb. 21, 1981	Comstar D-4	Communications	AT&T Corp.	Atlas Centaur
May 15, 1981	NOVA 1	Navigational	U.S. Navy	Scout
May 21, 1981	GOES 5	Meteorological	NOAA	Delta
May 23, 1981	Intelsat V F-1	Communications	Intelsat	Atlas Centaur
June 23, 1981	NOAA 7	Meteorological	NOAA	Atlas-F
Aug. 6, 1981	Fltsatcom 5	Communications	Dept. of Defense	Atlas Centaur
Sept. 24, 1981	SBS 2	Communications	Satellite Business Systems	Delta
Nov. 19, 1981	RCA Satcom 3R	Communications	RCA Corp.	Delta
Dec. 15, 1981	Intelsat V F-3	Communications	Intelsat	Atlas Centaur
Jan. 16, 1982	RCA Satcom 4	Communications	RCA Corp.	Delta
Feb. 25, 1982	Westar 4	Communications	Western Union	Delta
March 4, 1982	Intelsat V F-4	Communications	Intelsat	Atlas Centaur
April 10, 1982	Insat 1A	Communications	India	Delta
June 8, 1982	Westar 5	Communications	Western Union	Delta
July 16, 1982	Landsat 4	Remote Sensing	NOAA	Delta
Aug. 25, 1982	Anik D-1	Communications	Canada	Delta
Sept. 28, 1982	Intelsat V F-5	Communications	Intelsat	Atlas Centaur
Oct. 27, 1982	RCA Satcom 5	Communications	RCA Corp.	Delta
Nov. 11, 1982	SBS 3	Communications	Satellite Business Systems	STS-5
Nov. 12, 1982	Anik C-3	Communications	Canada	STS-5
March 28, 1983	NOAA 8	Meteorological	NOAA	Atlas-E
April 11, 1983	RCA Satcom 6	Communications	RCA Corp.	Delta

Table 2–1 continued

Launch Date	Satellite	Type of Mission	Owner/ Sponsor	Launch Vehicle
April 28, 1983	GOES 6	Meteorological	NOAA	Delta
May 19, 1983	Intelsat V F-6	Communications	Intelsat	Atlas Centaur
June 18, 1983	Anik C-2	Communications	Canada	STS-7
June 18, 1983	Palapa B-1	Communications	Indonesia	STS-7
June 28, 1983	Galaxy 1	Communications	Hughes Communications	Delta
July 28, 1983	Telstar 3-A	Communications	AT&T Corp.	Delta
Aug. 31, 1983	Insat 1B	Communications	India	STS-8
Sept. 8, 1983	RCA Satcom 7	Communications	RCA Corp.	Delta
Sept. 22, 1983	Galaxy 2	Communications	Hughes Communications	Delta
Feb. 3, 1984	Westar 6*	Communications	Western Union	STS 41-B
Feb. 6, 1984	Palapa B-2	Communications	Indonesia	STS 41-B
March 1, 1984	Landsat 5	Remote Sensing	NOAA	Delta
March 1, 1984	UoSAT 2	Communications	University of Surrey	Delta
June 9, 1984	Intelsat V F-9*	Communications	Intelsat	Atlas Centaur
Aug. 31, 1984	SBS 4	Communications	Satellite Business Systems	STS 41-D
Aug. 31, 1984	Leasat 2 (Syncom IV-2)	Communications	Hughes (leased by Dept. of Defense)	STS 41-D
Sept. 1, 1984	Telstar 3-C	Communications	AT&T Corp.	STS 41-D
Sept. 21, 1984	Galaxy 3	Communications	Hughes Communications	Delta
Oct. 5, 1984	Earth Radiation Budget Satellite (ERBS)	Environmental Observations	NASA	STS 41-G
Oct. 12, 1984	NOVA 3	Navigational	U.S. Navy	Scout
Nov. 9, 1984	Anik D-2	Communications	Canada	STS 51-A
Nov. 10, 1984	Leasat 1 (Syncom IV-1)	Communications	Hughes (leased by Dept. of Defense)	STS 51-A
Nov. 13, 1984	NATO IIID	Communications	NATO	Delta
Dec. 12, 1984	NOAA 9	Environmental Observations	NOAA	Atlas-E
Jan. 24, 1985	DOD	n/a	Dept. of Defense	STS 51-C
March 22, 1985	Intelsat V-A F-10	Communications	Intelsat	Atlas Centaur
April 12, 1985	Anik C-1	Communications	Canada	STS 51-D
April 13, 1985	Leasat 3 (Syncom IV-3)	Communications	Hughes (leased by Dept. of Defense)	STS 51-D
June 17, 1985	Morelos 1	Communications	Mexico	STS 51-G
June 18, 1985	Arabsat-1B	Communications	Saudi Arabia	STS 51-G
June 19, 1985	Telstar 3-D	Communications	AT&T Corp.	STS 51-G
June 29, 1985	Intelsat V-A F-11	Communications	Intelsat	Atlas Centaur

Table 2–1 continued

Launch Date	Satellite	Type of Mission	Owner/ Sponsor	Launch Vehicle
Aug. 3, 1985	SOOS-I (Oscar 24 and 30)	Navigational	U.S. Navy	Scout
Aug. 27, 1985	ASC 1	Communications	American Satellite Corp.	STS 51-I
Aug. 27, 1985	Aussat 1	Communications	Australia	STS 51-I
Aug. 29, 1985	Leasat 4 (Syncom IV-4)	Communications	Hughes (leased by Dept. of Defense)	STS 51-I
Sept. 28, 1985	Intelsat V-A F-12	Communications	Intelsat	Atlas Centaur
Oct. 3, 1985	DOD	n/a	Dept. of Defense	STS 51-J
Nov. 26, 1985	Morelos 2	Communications	Mexico	STS 61-B
Nov. 27, 1985	Aussat 2	Communications	Australia	STS 62-B
Nov. 28, 1985	RCA Satcom K-2	Communications	RCA Corp.	STS 61-B
Dec. 12, 1985	AF-16	n/a	Dept. of Defense	Scout
Jan. 12, 1986	RCA Satcom K-1	Communications	RCA Corp.	STS 61-C
May 5, 1986	GOES G*	Meteorological	NOAA	Delta
Sept. 5, 1986	DOD (SDI)	n/a	Dept. of Defense	Delta
Sept. 17, 1986	NOAA 10	Meteorological	NOAA	Atlas-E
Dec. 4, 1986	Fltsatcom F-7	Communications	Dept. of Defense	Atlas Centaur
Feb. 26, 1987	GOES 7	Meteorological	NOAA	Delta
March 20, 1987	Palapa B-2P	Communications	Indonesia	Delta
March 26, 1987	Fltsatcom F-6*	Communications	Dept. of Defense	Atlas Centaur
Sept. 16, 1987	SOOS-2	Navigational	U.S. Navy	Scout
April 25, 1988	SOOS-3	Navigational	U.S. Navy	Scout
June 16, 1988	NOVA 2	Navigational	U.S. Navy	Scout
Aug. 25, 1988	SOOS-4	Navigational	U.S. Navy	Scout
Sept. 24, 1988	NOAA 11	Meteorological	NOAA	Atlas-E
Sept. 29, 1988	DOD	n/a	Dept. of Defense	STS-27

*Mission failed

Table 2–2. Science and Applications Missions Conducted on the Space Shuttle

Date	Payload	STS Mission
Nov. 12, 1981	OSTA-1	STS-2
March 22, 1982	OSS-1 (primarily science payload with some applications experiments)	STS-3
June 18, 1983	OSTA-2	STS-7
Nov. 28, 1983	Spacelab 1 (international mission with ESA)	STS-9
Aug. 30, 1984	OAST-1 (sponsored by the Office of Aeronautics and Space Technology with some experiments contributed by OSTA)	STS 41-D
Oct. 5, 1984	OSTA-3	STS 41-G
April 29, 1985	Spacelab 3 (international mission with ESA)	STS 51-B
July 29, 1985	Spacelab 2 (international mission with ESA)	STS 51-F
Oct. 30, 1985	Spacelab D-1 (German Spacelab with NASA oversight)	STS 61-A

Note: OAST-1 is addressed in Chapter 3, "Aeronautics and Space Research and Technology." OSS-1 and the Spacelab missions are addressed in Chapter 4, "Space Science," in Volume V of the *NASA Historical Data Book.*

Table 2–3. Total Space Applications Funding History (in thousands of dollars)

Year	Request	Authorization	Appropriation	Programmed (Actual)
1979	274,300	280,300	*a*	274,800 *b*
1980	332,300	338,300	*c*	331,620 *d*
1981	381,700	372,400	331,550 *e*	331,550
1982	372,900 *f*	398,600	328,200 *g*	324,267 *h*
1983	316,300 *i*	336,300	341,300	347,700
1984	289,000	313,000	293,000	314,000
1985	344,100	390,100	384,100	374,100
1986	551,800	537,800	519,800 *j*	487,500
1987	491,100 *k*	552,600	578,100	562,600
1988	559,300	651,400	641,300	567,500 *l*

a Undistributed. Total R&D amount = $3,477,200,000.

b Included Resource Observations, Environmental Observations, Applications Systems, Technology Transfer, Materials Processing in Space, and Space Communications funding categories.

c Undistributed. Total R&D amount = $4,091,086,000.

d Communications funding category renamed Communications and Information Systems.

e Reflected recission.

f Amended submission. Original FY 1982 budget submission = $472,900,000.

g Reflected general supplemental appropriation approved September 10, 1982.

h Programmed funding for FY 1982 included Solid Earth Observations, Environmental Observations, Materials Processing in Space, Communications, and Information Systems funding categories. Reflects merger of OSS and OSTA.

i The Offices of Space Science and Space and Terrestrial Applications merged to form the Office of Space Science and Applications. Budget amounts reflected only items that were considered applications. Remaining OSSA budget items (science) can be found in Chapter 4.

j Reflected general reduction of $5,000,000 as well as other cuts made by Appropriations Committee.

k Revised submission. Original FY 1987 budget submission = $526,600,000.

l New Earth Science and Applications funding category incorporated Solid Earth Observations and Environmental Observations.

Table 2–4. Programmed Budget by Major Budget Category (in thousands of dollars)

Budget Category/Fiscal Year	1979	1980	1981	1982	1983
Space Applications	274,800	331,620	331,550	324,267	347,700
Earth Observations	139,400	150,953	151,350	149,400	128,900
Environmental Observations	67,750	105,990	104,100	133,023	156,900
Applications Systems	13,950	24,567	18,100		
Technology Transfer	10,700	10,087	8,100		
Materials Processing in Space	20,400	19,768	18,700	16,244	22,000
Communications	22,600	20,255	31,200	21,300	32,400
Information Systems					7,500

Budget Category/Fiscal Year	1984	1985	1986	1987	1987
Space Applications	314,000	374,100	487,500	562,600	567,500
Solid Earth Observations	76,400	57,600	70,900	72,400	*a*
Environmental Observations	162,000	212,700	271,600	318,300	*b*
Earth Science and Applications					389,200
Materials Processing in Space	25,600	27,000	31,000	47,300	62,700
Communications	41,100	60,600	96,400	103,400	94,800
Information Systems	8,900	16,200	17,600	21,200	20,800

a Combined with Environmental Observations to form new Earth Science and Applications funding category.

b Combined with Solid Earth Observations to form new Earth Science and Applications funding category.

Table 2–5. Resource Observations/Solid Earth Observations Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	139,150I *b*	*c*	*d*	139,400 *e*
1980	141,400	143,400	*f*	150,953 *g*
1981	170,300 *h*	182,600	151,350 *i*	151,350
1982	165,400 *j*	165,400	165,400	149,400 *k*
1983	132,200	132,200	132,200	128,900
1984	74,400	83,400 *l*	75,400 *m*	76,400 *n*
1985	63,600	63,600	63,600	57,600 *o*
1986	74,900	74,900	74,900	70,900
1987	74,100	74,100	74,100	72,400
1988	76,900	80,800	76,800	*p*

a Renamed Solid Earth Observations beginning with FY 1982 programmed funding.

b Source of data is the NASA Budget Office's *FY 1980 Budget Estimate*. The *Chronological History* for the FY 1979 budget did not include submission or authorization data for the Resource Observations funding category.

c See note b above. FY 1979 authorization categories and amounts as stated in the *Chronological History FY 1979 Budget Estimates* were: Earth Resources Detection and Monitoring—$157,500,000; Earth Dynamics Monitoring and Forecasting—$8,600,000; Ocean Condition Monitoring and Forecasting—$12,400,000; Environmental Quality Monitoring—$20,200,000; Weather Observation and Forecasting—$22,800,000; Climate Research Program—$12,200,000; and Applications Explorer Missions—$4,200,000.

d Undistributed. Total FY 1979 R&D appropriation = $3,477,200,000.

e Included Landsat D, Operational Land Observing System, Magnetic Field Satellite, Shuttle/Spacelab Payload Development, Extended Mission Operations, Geodynamics, Applied Research and Data Analysis, AgRISTARS, Landsat 3, and Heat Capacity Mapping Mission.

f Undistributed. Total R&D appropriation = $4,091,086,000.

g Removed Landsat 3 and Heat Capacity Mapping Mission from total Resource Observations funding.

h Amended submission. Original budget submission = $162,300,000.

i Reflected recission.

j Amended submission. Original budget submission = $187,200,000.

k Removed Payload Development from Solid Earth Observations program funding category. Magsat now included in Extended Operations funding category.

l House Authorization Committee added $4,000,000 for Research and Analysis to support applications studies related to spaceborne radars and the Global Resource Information System, $2,000,000 to partially restore the OMB reduction of NASA's request for AgRISTARS, and $3,000,000 for Technology Transfer activities, specifically for tests to verify and demonstrate the validity and usefulness of space applications systems. The Senate Authorization Committee added $5,000,000 more to Research and Analysis funding, $1,000,000 to AgRISTARS, and no additional funds to Technology Transfer. The Conference Committee modified this to allow $4,000,000 for Research and Analysis, $2,000,000 for AgRISTARS, and $3,000,000 for Technology Transfer.

m The Senate Appropriations Committee added $1,000,000 for the multispectral linear array and eliminated all other additional funding.

n Removed Extended Missions Operations and AgRISTARS from Solid Earth Observations program funding category

o Removed Landsat 4 from Solid Earth Observations program funding category

p Programmed amount (calculated in FY 1989) included under new program category: Earth Science and Applications. See Table 2–13.

Table 2–6. Landsat D/Landsat 4 Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	97,500	97,500
1980	98,663	104,413
1981	88,500	88,500
1982	83,900	81,900
1983	61,700	58,400
1984	16,800	16,800

Table 2–7. Magnetic Field Satellite Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,900	3,900
1980	1,600	1,600
1981	500	500

a Included under Extended Mission Operations beginning with FY 1982.

Table 2–8. Shuttle/Spacelab Payload Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	6,000	6,200
1980	1,850	2,031
1981	2,000	2,000
1982	3,300	12,300
1983	13,800	14,500
1984	16,000	17,000
1985	12,100	12,100
1986	23,100	21,800
1987	21,600	21,400 *a*
1988	20,800 *b*	27,700 *c*

a Renamed Payload and Instrument Development.

b Submission did not reflect integration of Solid Earth Observations and Environmental Observations into new Earth Sciences Payload and Instrument Development funding category.

c This amount reflected new Earth Science and Applications funding category. There was now one Earth Science Payload and Instrument Development category that encompassed both the former Solid Earth Observations and Environmental Observations Payload and Instrument Development.

Table 2–9. Extended Mission Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	350	358
1980	1,582	1,904
1981	2,700	2,700
1982	2,800	2,800 *a*
1983	1,800	1,100

a Included funding for the operation of Magsat.

Table 2–10. Geodynamics Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	8,200	8,200
1980	12,600	12,600
1981	23,400	23,400
1982	22,900	22,900
1983	26,200	28,100
1984	28,000	28,000
1985	29,900	29,900
1986	31,700	30,000
1987	32,100	31,600
1988	32,400	32,300 *a*

a Included under Earth Science and Applications Program funding category.

Table 2–11. Geodynamics Research and Data Analysis Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1979	22,200	22,242
1980	12,908	12,405
1981	12,800	12,800
1982	19,500	15,500
1983	13,700	11,800
1984	14,600	14,600
1985	15,600	15,600
1986	20,100	19,100
1987	21,900	19,400
1988	21,100	21,400 *b*

a Beginning in FY 1982, all applied research and data analysis funding categories were renamed Research and Analysis.

b Renamed Land Processes Research and Analysis and included in Earth Science and Applications Program funding.

Table 2–12. AgRISTARS Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1980	16,000	16,000
1981	31,400	21,450
1982	14,000	14,000
1983	15,000	15,000

Table 2–13. Environmental Observations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	67,900 *a*	*b*	*c*	67,750 *d*
1980	117,200	121,200	*e*	105,990 *f*
1981	109,600 *g*	112,600	104,100 *h*	104,100 *i*
1982	135,300 *j*	145,300	*k*	133,023 *l*
1983	128,900	128,900	128,900	156,900 *m*
1984	163,000	170,000 *n*	164,000 *o*	162,000
1985	220,700	220,700	220,700	212,700 *p*
1986	317,500	311,500	290,500	271,600
1987	336,900 *q, r*	313,900	346,900	318,300 *s*
1988	393,800	393,800	378,000	389,200 *t*

a Source of data is the NASA Budget Office's *FY 1980 Budget Estimate*. The *Chronological History* for the FY 1979 budget does not include submission and authorization data for the Environmental Observations funding category.

b See note a above. FY 1979 authorization categories and amounts as stated in the *Chronological History FY 1979 Budget Estimates* were: Earth Resources Detection and Monitoring—$157,500,000; Earth Dynamics Monitoring and Forecasting—$8,600,000; Ocean Condition Monitoring and Forecasting—$12,400,000; Environmental Quality Monitoring—$20,200,000; Weather Observation and Forecasting—$22,800,000; Climate Research Program—$12,200,000; and Applications Explorer Missions—$4,200,000

c Undistributed. Total FY 1979 R&D appropriation = $3,477,200,000.

d Included Upper Atmosphere Research Program, Applied Research and Data Analysis, Shuttle/Spacelab Payload Development, Operational Satellite Improvement Program, ERBE, Halogen Occultation Experiment, Extended Mission Operations, National Oceanic Satellite System (NOSS), TIROS N, Nimbus 7, and Seasat.

e Undistributed. Total R&D appropriation = $4,091,086,000.

f Removed TIROS N and Seasat from Environmental Observations funding total.

g Amended submission. Original budget submission = $137,600,000.

h Reflected recission.

i Removed Nimbus 7 from Environmental Observations funding total and added NOSS.

j Amended submission. Original budget submission = $194,600,000.

k Undistributed. Total FY 1982 R&D appropriation = $4,740,900,000.

l Removed Applied Research and Data Analysis from Environmental Observations funding category. Added Upper Atmosphere Research Satellite (UARS) Experiments and Mission Definition to Environmental Observations funding category.

m Removed Halogen Occultation Experiment from Environmental Observations funding history.

n The House Authorization Committee added $2,000,000 for Technology Development and $1,000,000 for the Sun-Earth Interaction Study to the NASA submission. The Senate Authorization Committee added $2,000,000 for Space Physics/Technology Development, specifically for university research teams conducting experiments on the origin of plasmas in the Earth's neighborhood (OPEN), $4,000,000 for UARS Experiments, $2,000,000 for Atmospheric Dynamics, and $2,000,000 for Oceanic Research and Analysis to the NASA submission. The Conference Committee modified this authorization to allow $2,000,000 for OPEN and $5,000,000 for UARS Experiments and Atmospheric and Ocean Sensors.

Table 2–13 continued

o The Senate Appropriations Committee added $2,000,000 to the NASA submission for UARS/OPEN Definition Studies. The Conference Committee reduced this by $1,000,000.

p Added Payload and Instrument Development, Interdisciplinary Research and Analysis, Tethered Satellite System, and Scatterometer to Environmental Observations program funding category. Removed Operational Satellite Improvement Program from Environmental Observations program funding category.

q Revised submission. Original FY 1987 budget submission = $367,900,000.

r Submission, authorization, and appropriation data did not reflect new program budget category: Earth Science and Applications. See Table 2–5.

s Removed ERBE and added Ocean Topography Experiment and Airborne Science and Applications funding categories.

t Renamed Earth Science and Applications Program. New funding category incorporated Geodynamics from former Solid Earth Observations category and combined Payload and Instrument Development from both Solid Earth Observations and Environmental Observations funding categories.

Table 2–14. Upper Atmospheric Research Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	(14,500)	(14,500) *a*
1980	12,500	12,400
1981	13,500	13,500
1982	13,000	20,500 *b*
1983	27,700	27,700
1984	28,500	28,435
1985	31,000	31,000
1986	33,000	31,100
1987	33,400	32,700
1988	32,700	32,700

a Program was transferred from Space Science to Space Applications in January 1979; FY 1979 funding was not included in total.

b Renamed Upper Atmosphere Research and Analysis with FY 1984 budget submission and FY 1982 actuals.

Table 2–15. Upper Atmospheric Research and Data Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	33,876	33,726
1980	48,670	48,750
1981	48,100	48,100
1982	47,000	*a*

a Programmed amounts found under new funding categories: Atmospheric Dynamics and Radiation Research and Analysis (Table 2–25) and Oceanic Processes Research and Development (Table 2–26)

Table 2–16. Interdisciplinary Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1985	1,000	1,000
1986	1,000	1,000
1987	1,100	1,100
1988	1,100	1,100

Table 2–17. Shuttle/Spacelab Resource Observations Payload Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	7,750	7,750
1980	9,600	9,600
1981	1,700	1,700
1982	4,100	4,100
1983	3,700	3,700
1984	7,600	7,600
1985	7,800	7,800 *a*
1986	5,600	5,300
1987	12,000	9,700
1988	4,100 *b*	27,700 *c*

a Renamed Payload and Instrument Development.

b Payload and Instrument Development funding category was only for Environmental Observations Program and did not reflect new funding category of Earth Science and Applications Program.

c Incorporated amounts from both Solid Earth Observations and Environmental Observations Payload and Instrument Development funding categories.

Table 2–18. Operational Satellite Improvement Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	6,100	6,100
1980	7,400	7,400
1981	9,200	7,200
1982	6,000	6,000
1983	6,000	6,000
1984	600	600

Table 2–19. Earth Radiation Budget Experiment Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	7,000	7,000
1980	17,000	13,720
1981	20,300	20,300
1982	24,000	24,000
1983	24,000	24,000
1984	15,500	15,500
1985	8,100	8,100
1986	—	1,900

Table 2–20. Halogen Occultation Experiment Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,600	3,600
1980	8,000	8,000
1981	4,500	4,500
1982	5,000	5,000

Table 2–21. Halogen Occultation Extended Mission Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	1,250	1,250
1980	5,800	5,800
1981	8,000	8,000
1982	11,400	16,100
1983	22,800	22,800
1984	27,400	27,400
1985	29,500	29,500
1986	37,000	35,000
1987	33,600	33,600 *a*
1988	14,800	14,700

a Renamed Mission Operations and Data Analysis.

Table 2–22. National Oceanic Satellite System Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1981	5,800	800

Table 2–23. Nimbus 7 Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,624	3,624
1980	500	500

Table 2–24. Upper Atmospheric Research Satellite Experiments and Mission Definition Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	6,000	6,000
1983	14,000	14,000 *a*
1984	20,000	20,000
1985	55,700	55,700
1986	124,000	114,000
1987	114,200	113,800
1988	89,600	89,200

a Renamed Upper Atmosphere Research Satellite Mission.

Table 2–25. Atmospheric Dynamics and Radiation Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	22,300
1983	26,500	26,500
1984	27,500	27,465
1985	28,500	28,500
1986	30,300	28,700
1987	31,900	31,300
1988	31,400	31,400

a Included under Applied Research and Data Analysis (see Table 2–15).

Table 2–26. Oceanic Processes Research and Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	*a*	16,900
1983	17,000	17,000
1984	18,200	18,200
1985	19,400	19,400
1986	20,600	17,400
1987	20,800	18,000
1988	20,200	20,100

a Included under Applied Research and Data Analysis (see Table 2–15).

Table 2–27. Space Physics/Research and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1982	No submission	12,123
1983	15,200	15,200
1984	16,700	16,800
1985	16,700	16,700
1986	17,800	16,800
1987	21,000	20,800

Table 2–28. Tethered Satellite System Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1985	3,000	3,000
1986	4,500	6,400
1987	1,000	5,500 *a*

a Renamed Tethered Satellite Payloads.

Table 2–29. Scattermometer Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1985	12,000	12,000
1986	14,000	14,000
1987	32,900	32,900
1988	22,700	22,600

Table 2–30. Ocean Topography Experiment Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1987	19,000	18,900
1988	75,000	74,500

Table 2–31. Airborne Science and Applications Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1987	No submission	(27,600) *a*
1988	21,900	21,800

a Previously funded under Physics and Astronomy Suborbital Program funding category.

Table 2–32. Applications Systems Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	15,700	*a*		13,950 *b*
1980	24,200	24,200	*c*	24,567
1981	18,100	18,100	18,100 *d*	18,100 *e*
1982	13,200 *f*	13,200	13,200	*g*
1983	11,700	11,700	11,700	*h*

a Applications Systems funding category did not appear in *Chronological History* of FY 1979 budget.

b Included Airborne Instrumentation Research Program, Shuttle/Spacelab Mission Design and Integration, and NASA Integrated Payload Planning.

c Undistributed. Total FY 1980 R&D appropriation = $4,091,086,000.

d Reflected recission.

e Included only Airborne Instrumentation Research Program.

f Amended submission. Original budget submission = $14,400,000.

g Programmed amounts for Applications Systems appropriation included with Suborbital Program in Physics and Astronomy funding category (Space Science funding).

h Applications System Airborne Instrumentation Research Program efforts continued under Suborbital Program (Space Science funding). Program budget category eliminated in FY 1982.

Table 2–33. Airborne Instrumentation Research Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	5,800	6,530
1980	15,547	15,567
1981	18,100	18,100
1982	13,200	*a*

a Programmed amounts for Applications Systems appropriation included with Suborbital Program in Physics and Astronomy funding category (Space Science funding).

Table 2–34. Shuttle/Spacelab Mission Design and Integration Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1979	6,400	6,260
1980	7,300	7,300

a Funding responsibility for FY 1981 and subsequent years transferred from Space Applications to Space Science.

Table 2–35. NASA Integrated Payload Planning Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1979	2,000	1,160
1980	1,700	7,400

a Funding responsibility for FY 1981 and subsequent years transferred from Space Applications to Space Science.

Table 2–36. Materials Processing in Space Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	20,400	20,400	*a*	20,400 *b*
1980	19,800	19,800	*c*	19,768 *d*
1981	22,200	24,900	18,700 *e*	18,700 *f*
1982	27,700 *g*	31,700	*h*	16,244 *i*
1983	23,600	28,600	23,600	22,000
1984	21,600	26,600	23,600	25,600
1985	23,000	28,000	23,000	27,000
1986	34,000	36,000	34,000	31,000 *j*
1987	39,400 *k*	43,900	39,400	47,300
1988	45,900	50,000	65,900	62,700

a Undistributed. Total FY 1979 R&D appropriation = $3,477,200,000.

b Included Space Processing Applications Rocket (SPAR) project, Applied Research and Data Analysis, and Shuttle/Spacelab Payload Development.

c Undistributed. Total FY 1980 R&D appropriation = $4,091,086,000.

d Added Materials Experiment Operations to FY 1980 Materials Processing funding categories.

e Reflected recission.

f Removed SPAR project from Materials Processing funding categories.

g Amended submission. Original FY 1982 budget submission = $32,100,000.

h Undistributed. Total FY 1982 R&D appropriation = $4,740,900,000.

i Removed Shuttle/Spacelab Payload Development funding category

j Added Microgravity Shuttle/Space Station Payloads funding category. Removed Materials Experiment Operations funding category from Materials Processing in Space.

k Revised submission. Original FY 1987 budget submission = $43,900,000.

Table 2–37. Materials Processing Research and Data Analysis Project Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	4,400	4,850
1980	6,450	7,200
1981	10,950	9,230
1982	12,000	14,000
1983	13,100	13,100
1984	11,000	11,000
1985	11,700	11,700
1986	12,400	12,100
1987	13,900	13,900
1988	12,900	12,900

Table 2–38. Shuttle/Spacelab Materials Processing Payload Development Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	12,400	11,950
1980	11,218	10,468
1981	10,750	8,157
1982	8,800	*a*

a Activities and funding transferred to the Physics and Astronomy Shuttle Payload Development and Mission Management area.

Table 2–39. Materials Processing Experiment Operations (Microgravity Shuttle/Space Station Payloads) Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1980	—	(533) *b*
1981	(1,900) *c*	1,310
1982	3,000	4,244
1983	8,900	8.900
1984	12,600	14,600
1985	15,300	15,300
1986	22,600	18,900 *d*
1987	34,000	33,400
1988	49,800	49,800

a Renamed Microgravity Shuttle/Space Station Payloads in FY 1986.
b Included under Materials Processing Shuttle/Spacelab Payload Development funding category.
c Included under Materials Processing Shuttle/Spacelab Payload Development funding category.
d Funding category was renamed and restructured as Microgravity Shuttle/Space Station Payloads. This category consolidated ongoing activities that provided a range of experimental capabilities for all scientific and commercial participants in the Microgravity Science and Applications program. These included Shuttle mid-deck experiments, the Materials Experiment Assembly, and the Materials Science Laboratory, which was carried in the orbiter bay. Included activities had been included under Materials Experiment Operations.

Table 2–40. Technology Transfer Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	10,950 *a*	n/a	n/a	10,700 *b*
1980	10,300	10,300	*c*	10,087 *d*
1981	7,500 *e*	11,500	8,100	8,100
1982 *f*	5,000	—	—	—

a Source of data is the FY 1979 current estimate found in the FY 1980 budget estimates. No Technology Transfer funding category appears in the *Chronological History* of the FY 1979 budget submissions. Therefore, no authorization or appropriations figures are available.
b Included Applications Systems Verification and Transfer, Regional Remote Sensing Applications, User Requirements and Supporting Activities, and Civil Systems.
c Undistributed. Total FY 1980 funding category = $4,091,086,000.
d Removed Civil Systems from Technology Transfer funding total.
e Amended submission. Original submission = $12,500,000.
f Technology Transfer program funding eliminated beginning with FY 1982.

Table 2–41. Applications Systems Verification and Transfer Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	1,150	900
1980	1,700	1,700
1981	1,400	700

Table 2–42. Regional Remote Sensing Applications Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,500	3,500
1980	3,657	3,655
1981	2,700	2,400
1982	2,000	*a*

a Funding eliminated.

Table 2–43. User Requirements and Supporting Activities Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	4,500	4,500
1980	4,730	4,732
1981	6,000	5,000
1982	3,000	*a*

a Funding eliminated.

Table 2–44. Civil Systems Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	1,800	1,800

Table 2–45. Space Communications Funding History
(in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1979	22,000	22,000	*a*	22,600 *b*
1980	19,400	19,400	*c*	20,255 *d, e*
1981	29,000	29,000	31,200 *f*	31,200 *g*
1982	20,900 *h*	34,000	*i*	21,300 *j, k*
1983	19,900	34,900 *l*	39,900 *m*	32,400
1984	21,100	24,100	21,100	41,100 *n*
1985	20,600	60,600 *o*	60,600	60,600
1986	106,200	101,200	101,200	96,400
1987	19,500	99,500 *p*	96,500	103,400 *q*
1988	20,500	104,500 *r*	97,500	94,800 *s*

a Undistributed. Total FY 1979 R&D appropriation = $3,477,200,000.

b Included Search and Rescue Mission, Technical Consultation and Support Studies, Applied Research and Data Analysis, Follow-On Data Analysis and Operations, Applications Data Service Definition, Data Management, and Adaptive Multibeam Phased Array (AMPA) System.

c Undistributed. Total FY 1980 R&D appropriation = $4,091,086,000.

d Referred to as Communications and Information Systems in FY 1980 programmed budget data material and NASA FY 1982 budget estimate.

e Removed Follow-On Data Analysis, Applications Data Service Definition, and Data Management from FY 1980 Communications and Information Systems funding total.

f Reflected recission.

g Added Experiment Coordination and Operations Support and Information Systems funding categories.

h Final revised submission. Original FY 1982 budget submission (January 1981) = $35,600,000. Amended submission (March 1981) = $30,300,000.

i Undistributed. Total FY 1982 R&D appropriation = $4,740,900,000.

j Added Experiment Coordination and Operations Support to Communications funding category.

k Budget category referred to as Communications Program in FY 1984 NASA budget estimate (FY 1982 actual cost data).

l The House Authorization Committee added $5,000,000 for 30/20-GHz test and evaluation flights. The Senate Authorization Committee added $15,000,000 to allow for a large proof-of-concept of communications operations in the 30/20-GHz frequency range. The final authorization added a total of $15,000,000 to NASA's budget submission.

m The Appropriations Committee restored the entire $20,000,000 addition to NASA's budget submission. See Table 2–51.

n Large difference between programmed and appropriated amounts reflected an increase in funding to the ACTS program. See Table 2–51.

o Increase reflected Authorization Committee disagreement with NASA's restructuring of ACTS flight program. The Committee directed NASA "to proceed with the flight program and make the necessary future requests for budget authority as required." See Table 2–51.

p The Authorization Committee directed NASA to continue the ACTS program in spite of the Reagan administration's attempts to terminate it.

q Technical Consultation and Support Studies renamed Radio Science and Support Studies. Research and Analysis renamed Advanced Communications Research.

r The Authorization Committee once again restored funds for the ACTS program that were removed by the Reagan administration. See Table 2–51.

s Added Communications Data Analysis funding category.

Table 2–46. Space Communications Search and Rescue Mission Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	8,000	8,000
1980	5,000	2,530
1981	4,800	4,800
1982	2,300	2,300
1983	3,700	3,700
1984	3,800	3,800
1985	2,400	2,400
1986	1,300	1,100
1987	1,000	1,385
1988	1,300	1,300

Table 2–47. Space Communications Technical Consultation and Support Studies Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,100	3,100
1980	2,982	3,182
1981	3,100	3,145
1982	2,600	2,600
1983	2,600	2,600
1984	2,700	2,700
1985	2,900	2,900
1986	2,600	2,518
1987	3,200	3,050 *a*
1988	2,542	2,586

a Renamed Radio Science and Support Studies.

Table 2–48. Space Communications Research and Data Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	3,900	3,900
1980	6,200	6,200
1981	16,600	16,600
1982	10,000	15,400
1983	5,100	5,100
1984	8,500	8,500
1985	9,100	9,100
1986	10,400	9,770
1987	13,000	13,384 *a*
1988	14,136	13,992

a Renamed Advanced Communications Research.

Table 2–49. Communications Data Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1988	1,322	1,322

Table 2–50. Applications Data Service Definition Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1979	No category listed	100
1980	2,400	2,245
1981	—	*a*

a Funding category not broken out separately.

Table 2–51. Advanced Communications Technology Satellite Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1983	20,000	20,000
1984	5,000 *a*	25,000
1985	45,000	45,000
1986	85,000	81,900
1987	85,000	84,600
1988	75,600	75,600

a Reflected NASA's restructuring of the program to encompass only an experimental ground test program. Congress disagreed with the restructuring and directed NASA to continue with the program as originally planned. See Table 2–45.

Table 2–52. Information Systems Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Appropriation	Programmed (Actual)
1981	Included in Communications and Information Systems figures (see Table 2–45)			
1982	Included in Communications and Information Systems figures (see Table 2–45)			
1983 *a*	7,500 *b*	Included in Communications and Information Systems figures (see Table 2–45)		7,500
1984 *c*	8,900	8,900	8,900	8,900 *d*
1985	16,200	16,200	16,200	16,200
1986	19,200	19,200	19,200	17,600
1987	21,200	21,200	21,200	21,200
1988	22,300	22,300	22,300	20,800

a Included only Data Systems funding category.
b New program-level funding category.
c FY 1984 was the first year that the Information Systems Program appeared as a separate appropriation in the *Chronological History* budget submissions. Previous programmed amounts were a subcategory under the Communications and Information Systems appropriation category.
d Information Systems Program included Data Systems and Information Systems funding categories.

Table 2–53. Data Systems Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed (Actual)
1980	4,500	10,600
1981	No category	
1982	No submission	4,300
1983	7,500 *a*	7,500
1984	7,900	7,900
1985	8,400	8,400
1986	9,000	8,500
1987	9,400	10,000
1988	9,700	9,600

a Included in Information Systems funding category.

Table 2–54. Information Systems Funding History (in thousands of dollars) a

Year (Fiscal)	Submission	Programmed (Actual)
1984	1,000	1,000
1985	7,800	7,800
1986		9,100
1987		11,200
1988		11,200

a Information Systems funding category was a subcategory under the Information Systems program.

Table 2–55. OSTA-1 Payload

Principal Investigator	Institution	Experiment
Charles Elachi	Jet Propulsion Laboratory, Pasadena, California	Shuttle Imaging Radar-A (SIR-A) evaluated using spaceborne imaging radar for geologic exploration, with emphasis on mineral and petroleum exploration and fault mapping. A secondary goal was to determine the capability to combine SIR-A data with Landsat data and improve the usefulness of both (Figure 2–4).
Alexander F.H. Goetz	Jet Propulsion Laboratory, Pasadena, California	Shuttle Multispectral Infrared Radiometer obtained radiometric data in 10 spectral bands from a statistically significant number of geological areas around the world.
Roger T. Schappell	Martin Marietta Aerospace, Denver, Colorado	Feature Identification and Location Experiment developed video techniques to provide methods for identifying, spectrally classifying, and physically locating surface features or clouds.
Henry G. Reichle, Jr.	NASA Langley Research Center, Hampton, Virginia	Measurement of Air Pollution From Satellites measured the distribution of carbon monoxide in the middle and upper troposphere and traced its movement between the Northern and Southern Hemispheres.
Hongsuk H. Kim	NASA Goddard Space Flight Center, Greenbelt, Maryland	Ocean Color Experiment evaluated a passive ocean color sensing technique for mapping the concentration of chlorophyll-producing phytoplankton in the open ocean.
Bernard Vonnegut	State University of New York at Albany	Night-Day Optical Survey of Lightning studied the convective circulation in storms and the relationship to lightning discharges using a motion picture camera to film the lightning flashes of nighttime thunderstorms.
Allan H. Brown	University of Pennsylvania	Heflex Bioengineering Test determined the effect of near weightlessness and soil moisture content on dwarf sunflower growth.

Table 2–56. OSTA-2 Experiments

Investigation	Principal Investigator	Institution
	MEA Experiments	
Liquid Phase Miscibility Gap Materials	Stanley H. Gelles	S.H. Gelles Associates, Columbus, Ohio
Vapor Growth of Alloy-Type Semiconductor Crystals	Herbert Wiedemeier	Rensselaer Polytechnic Institute, Troy, New York
Containerless Processing of Glass Forming Melts	Delbert E. Day	University of Missouri–Rolla
	MAUS Experiments	
Stability of Metallic Dispersions	Guenther H. Otto	German Aerospace Research Establishment (DVFLR), Federal Republic of Germany
Particles at a Solid/Liquid Interface	Hermann Klein	German Aerospace Research Establishment (DVFLR), Federal Republic of Germany

Table 2–57. OSTA-2 Instrument Module Characteristics

Detector wavelength	0.385, 0.45, 0.6, 1.0 microns
Field of view	0.15 milliradians (0.5 km)
Altitude range	10 km to 100 km above Earth horizon
Altitude resolution	1 km
Detector operating temperature	19 degrees to 30 degrees C
Scan rate	15 km/sec
Sampling rate	64 samples/sec
Information bandwidth	1 Hz/km/channel
Radiometer resolution	3,000:1
Signal-to-noise ratio (1.0 micron channel)	1.5 x 15^5 at peak

Table 2–58. SAGE (AEM-2) Characteristics

Launch Date	February 18, 1979
Launch Vehicle	Scout
Range	Wallops Flight Center
Lead NASA Center	Goddard Space Flight Center/Langley Research Center
Owner	NASA
NASA Mission Objectives	Determine a global database for stratospheric aerosols and ozone and use these data sets for a better understanding of Earth's environmental quality and radiation budget; specifically: • Develop a satellite-based remote-sensing technique for measuring stratospheric aerosols and ozone • Map vertical extinction profiles of stratospheric aerosols and ozone from 78 degrees south to 78 degrees north latitude • Investigate the impact of natural phenomena, such as volcanoes and tropical upwellings, on the stratosphere • Investigate the sources and sinks of stratospheric ozone and aerosols
Orbit Characteristics	
Apogee (km)	661
Perigee (km)	548
Inclination (deg.)	54.9
Period (min.)	96.7
Weight (kg)	147
Dimensions	Base module: 65 cm; overall height including antenna: 161.85 cm; six-sided prism
Power Source	Solar paddles and batteries
Instruments	Four-spectral channel radiometer
Contractor	Ball Aerospace Systems Division, Ball Corp.; Boeing Aerospace Company
Remarks	The satellite was turned off April 15, 1982, after the spacecraft's battery failed. It decayed in April 1989.

Table 2–59. ERBS Instrument Characteristics

Sensor	Measured Quantities	No. of Channels/ Frequencies	Spectral Range/Frequency Range	Resolution
ERBE Non-Scanner	Total energy of Sun's radiant heat and light	1–4	0.2–3.5 µm 1.2–50.0 µm 0.2–50.0 µm	100 km across swath Full solar disk
ERBE Scanner	Reflected solar radiation, Earth-emitted radiation			
SAGE II	Stratospheric aerosols, O_3, NO_2, water vapor	7	0.385–1.02 µm	0.5 km

Table 2–60. Earth Radiation Budget Satellite Characteristics

Launch Date	October 5, 1984
Launch Vehicle	STS 41-G (*Challenger*)
Range	Kennedy Space Center
Lead NASA Center	Goddard Space Flight Center; Langley Research Center
Owner	NASA
NASA Mission Objectives	Increase knowledge of Earth's climate and weather systems, particularly how climate is affected by radiation from the Sun by measuring the distribution of aerosols and gases in the atmosphere
Orbit Characteristics	
Apogee (km)	603
Perigee (km)	602
Inclination (deg.)	57.0
Period (min.)	96.8
Weight (kg)	2,307 at launch
Dimensions	4.6 m x 3.8 m x 1.6 m
Power Source	Solar panels and batteries
Instruments	ERBE Non-Scanner had five sensors: two wide field-of-view sensors viewed the entire disc of Earth from limb to limb; two medium field-of-view sensors viewed a 10-degree region; and the fifth sensor measured the total output of radiant heat and light from the Sun. ERBE Scanner instrument was a scanning radiometer that measured reflected solar radiation and Earth-emitted radiation. Stratospheric Aerosol and Gas Experiment (SAGE II) was a Sun-scanning radiometer that measured solar radiation attenuation caused by the constituents in the atmosphere.
Contractor	TRW Defense and Space Systems; Ball Brothers
Remarks	It was still operating as of October 1994.

Table 2–61. UARS Instruments and Investigators

Instrument	Description and Primary Measurements	Principal Investigator	Institution
UARS Species and Temperature Measurements			
CLAES (Cryogenic Limb Array Etalon Spectrometer)	Neon and CO_2 cooled interferometer sensing atmospheric infrared emissions; T, CF_2, Cl_2, $CFCl_3$, $ClONO_2$, CH_4, O_3, NO_2, N_2O, HNO_3, and H_2O	A.E. Roche	Lockheed Palo Alto Research Laboratory, Palo Alto, California
ISAMS (Improved Stratospheric and Mesospheric Sounder)	Mechanically cooled radiometer sensing atmospheric infrared emissions; T, O_3, NO, NO_2, N_2O, HNO_3, H_2O, CH_4, and CO	F.W. Taylor	Oxford University, Oxford, United Kingdom
MLS (Microwave Limb Sounder)	Microwave radiometer sensing atmospheric emissions; ClO and H_2O_2	J.W. Waters	Jet Propulsion Laboratory, Pasadena, California
HALOE (Halogen Occultation Experiment)	Gas filter/radiometer sensing sunlight occulted by the atmosphere; HF and HCl	J.M. Russell, III	NASA Langley Research Center, Hampton, Virginia
UARS Wind Measurements			
HRDI (High Resolution Doppler Imager)	Fabry-Perot spectrometer sensing atmospheric emission and scattering; two-component wind: 10–110 km	P.B. Hays	University of Michigan, Ann Arbor, Michigan
WINDII (Wind Imaging Interferometer)	Michelson interferometer sensing atmospheric emission and scattering; two-component wind: 80–110 km	G.G. Shepherd	York University, York, Canada

Table 2–61 continued

Instrument	Description and Primary Measurements	Principal Investigator	Institution
UARS Energy Input Measurements			
SUSIM (Solar Ultraviolet Spectral Irradiance Monitor)	Full disk solar irradiance spectrometer incorporating on-board calibration; solar spectral irradiance: 120–400 nm	G.E. Brueckner	Naval Research Laboratory, Washington, D.C.
SOLSTICE (Solar Stellar Irradiance Comparison Experiment)	Full disk solar irradiance spectrometer incorporating stellar comparison; solar spectral irradiance: 115–440 nm	G.J. Rottman	University of Colorado, Boulder, Colorado
PEM (Particle Environment Monitor)	X-ray proton and electron spectrometers; *in situ* energetic electrons and protons; remote sensing of electron energy deposition	J.D. Winningham	Southwest Research Institute, San Antonio, Texas
Instrument of Opportunity			
ACRIM II (Active Cavity Irradiance Monitor II)	Full disk solar irradiance radiometer; continuation of solar constant measurements	R.C. Willson	Jet Propulsion Laboratory, Pasadena, California

Table 2–62. UARS Development Chronology

Date	Event
1978	The UARS project concept is developed. The objective of UARS, as stated by OSSA, is to provide the global database necessary for understanding the coupled chemistry and dynamics of the stratosphere and mesosphere, the role of solar radiation in driving the 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. OSSA defines the project as a crucial element of NASA's long-term program in upper atmospheric research—a program initiated in response to concerns about ozone depletion.
July 1978	UARS Science Working Group final report is published.
Sept. 1978	UARS Announcement of Opportunity is released.
April 25, 1980	NASA selects 26 investigations to be studied for possible inclusion on the UARS mission proposed for the late 1980s. Of the 26 investigations, 23 are from the United States, 2 are from the United Kingdom, and 1 is from France. Each country is responsible for funding its investigation. The initial study phase cost to the United States, including its investigations, is estimated to be $5 million over the next 2 years. The mission is to have two satellites launched 1 year apart from the Space Shuttle.
Feb. 18, 1981	The current cost of UARS is estimated at $400–$500 million.
May 12, 1981	Because of a $110 million cutback in space applications funding, the development of instruments for UARS is delayed.
Nov. 1981	NASA selects nine experimental and ten theoretical teams for UARS. The experimental teams are to develop instruments to make direct measurements of upper atmospheric winds, solar ultraviolet irradiance, energetic particle interactions with the upper atmosphere, and densities of critical chemical species as a function of altitude. The theoretical teams are to develop and apply models of the upper atmosphere, which, when combined with the new data to be acquired, should increase understanding of the upper atmospheric chemistry and dynamics and improve the capability to assess the impact of human activities on the delicate chemical processes in the stratosphere.
Dec. 24, 1981	UARS instrument developers are selected.
Jan. 26, 1982	NASA reprograms FY 1982 funds so that the UARS experiment budget is increased from $5 million to $6 million to enhance the long lead development work on selected payloads.
Aug. 1982	The mission is reduced from two to one spacecraft. The project now calls for 11 instruments. Instruments (including one each from Britain and France) enter Phase C/D development (Design and Development or Execution). Run-out cost for instruments through projected 1988 launch is estimated at $200 million. Total estimated mission cost of $500 million includes procurement of the MMS (at $200 million).
Aug. 4, 1982	Goddard Space Flight Center director states hope that UARS will receive FY 1984 new start funding. The UARS would use the MMS. The spacecraft was planned to be launched in 1988.

Table 2–62 continued

Date	Event
Aug. 31, 1982	NASA officials state that UARS could be helpful in understanding the cloud of volcanic dust currently covering the lower latitudes of the globe and that UARS will provide insight on how this volcanic cloud affects climate.
Feb. 3, 1983	NASA declares that it does not need the fifth orbiter for UARS. UARS mission is not included by OMB (Office of Management and Budget) in FY 1984 budget. NASA proceeds with instrument development and now expects to seek UARS as a FY 1985 new start.
Feb. 10, 1983	OMB wants NASA to find a way to reduce the price of the design for UARS. Because funding for instruments was previously approved, eventual project approval is not in question.
Feb. 17, 1983	Goddard investigates modifying the command and data handling module of the MMS so it will be compatible with UARS.
Sept. 9, 1983	Goddard announces plans to issue a preliminary RFP, for industry comment, for system design of the UARS observatory and design and fabrication of an instrument module compatible with the MMS bus.
Aug. 19, 1983	NASA announces plans to build UARS on a spare MMS bus. It will also include a refurbished attitude control system from the Solar Maximum Mission. The mission now includes nine instruments. The launch date has been delayed until the fall of 1989 because UARS is not included in the FY 1984 budget.
Dec. 1983	Objectives state that UARS will study energy flowing into and from the upper atmosphere, chemical reactions in the upper atmosphere, and how gases are moved within and between layers of the atmosphere. UARS will be located 600 kilometers high. The current estimated costs are \$570–\$670 million. NASA currently has \$27.7 million for upper atmosphere research and \$14 million for UARS experiments and definition. By using the MMS design, NASA hopes to save \$30–\$36 million.
Jan. 31, 1984	NASA requests FY 1985 funding for UARS.
March 1984	RFP is issued for system design of UARS observatory and design and fabrication of instrument module compatible with MMS bus.
April 9, 1984	Lockheed Missile and Space Co. begins building the CLAES sensor, which will be used on UARS. The instrument is designed to measure concentrations of nitrogen oxides, ozone, chlorine compounds, carbon dioxide, and methane, among other atmospheric constituents, and to record temperatures.
May 31, 1984	NASA states that using the MMS attitude control module will save 75 percent of the costs over building a new attitude control module.
July 1984	UARS Execution Phase Project Plan is approved.
July 1984	NASA proposes that the WINDII instrument replaces the French WINTERS instrument.
Nov. 7, 1984	Goddard announces plans to award a sole source contract to Fairchild Space Co. to build the MMS for UARS.
Feb. 4, 1985	NASA's FY 1985 budget includes UARS.
March 6, 1985	NASA awards a \$145.8 million contract to General Electric Co.'s Valley Forge Space Center in Philadelphia for UARS observatory. The GE Space Center will be responsible for the design of the observatory system and the design and fabrication of a module compatible with the MMS. The launch is scheduled for October 89.

Table 2–62 continued

Date	Event
April 18, 1985	The estimated cost for UARS is currently at $630–$700 million.
June 25, 1985	A review of UARS Support Instrumentation Requirements Document is requested. The document requests a review of the deep space network as a backup to TDRSS for emergency support.
Aug. 27, 1985	Goddard awards a $16.3 million contract to the Fairchild Space Co. in Germantown, Maryland. Fairchild will be responsible for providing the MMS for UARS. Under the contract, Fairchild will fabricate the structure and harness for the spacecraft, refurbish a spare Communications and Data Handling Mode, and integrate and test the assembled spacecraft. Fairchild will also be responsible for the refurbishing of the thermal louvers on the Solar Max module.
Oct. 1985	Observatory work plan review is complete; execution phase is initiated.
Nov. 1985	The central data handling facility contract is awarded to Computer Sciences Corporation.
Jan. 1986	The WINDII contract is awarded.
June 1986	The central data handling facility hardware contract is awarded to Science Systems and Applications, Inc.
March 1987	The CLAES cryogen redesign is to comply with recommendations arising from the *Challenger* investigation.
April 1987	Observatory Preliminary Design Review is conducted.
Fall 1987	Rebaseline results from the *Challenger* accident; launch is rescheduled for the fall of 1991.
March 1988	Observatory Critical Design Review is conducted.
Jan. 1989	Technicians at Goddard make final adjustments to the MMS being fitted for the UARS spacecraft. UARS is scheduled for deployment from the Space Shuttle *Discovery* in September 1991.
July 6, 1989	ACRIM II is delivered.
July 21, 1989	SOLSTICE is delivered.
July 27, 1990	The United States and the Soviet Union announce that they will share the information they have regarding the hole in the ozone layer over Antarctica. The Soviet Union has been acquiring information about the hole in the ozone layer through its Meteor-3; the United States has been collecting information through NASA's TOMS (Total Ozone Mapping Spectrometer).
Aug. 22, 1989	SUSIM is delivered.
Sept. 13, 1989	HALOE is delivered.
Dec. 19, 1990	NASA announces the crew members for UARS, which is scheduled for launch in November 1991.
March 21, 1991	The projected launch date for UARS is October 1991. The Tracking Data Relay Satellite mission originally scheduled to launch in July has been pushed to August. The Defense support mission has been moved from August to December. These changes were made to preserve the NASA's capability to fly *Discovery* with the UARS payload during its required science window.
Sept. 12, 1991	UARS is launched from STS-48 (*Discovery*).

Table 2–63. NOAA Satellite Instruments (1978–1988)

Satellite	Orbit	AVHRR *a*	HIRS/2	MSU	SSU	ERBE	SBUV/2	SEM	DCS	SAR
TIROS N	PM	1	X	X	X			X	X	
NOAA 6	AM	1	X	X	X			X	X	
NOAA 7	PM	2	X	X	X			X	X	
NOAA 8	AM	1	X	X	X			X	X	X
NOAA 9	PM	2	X	X	X	X	X	X	X	X
NOAA 10	AM	1	X	X	X	X		X	X	X
NOAA 11	PM	2	X	X	X		X	X	X	X

Legend: AVHRR—Advanced Very High Resolution Radiometer; DCS—Data Collection and Location System; ERBE—Earth Radiation Budget Experiment; HIRS—High-Resolution Infrared Radiation Sounder; MSU—Microwave Sounding Unit; SAR—Search and Rescue; SBUV—Solar Backscatter Ultraviolet Spectral Radiometer; SEM—Space Environment Monitor; and SSU—Stratospheric Sounding Unit.

a Two versions of the AVHRR were flown. The AVHRR/1 had four channels, and the AVHRR/2 had five channels, resulting in different response functions.

Table 2–64. NOAA 6 Characteristics

Launch Date	June 27, 1979
Launch Vehicle	Atlas F
Range	Western Test Range
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements and conduct an in-orbit evaluation and checkout of the spacecraft
NOAA Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the National Operational Environmental Satellite System (NOESS) to improve forecasting ability
Orbit Characteristics	
Apogee (km)	801
Perigee (km)	786
Inclination (deg.)	98
Period (min.)	100.7
Weight (kg)	1,405
Dimensions	3.71 m high and 1.88 m diameter unstowed; 4.91 m high and 2.37 m diameter with solar arrays extended
Power Source	Solar array and two 30 AH nickel cadmium batteries
Instruments	1. Advanced Very High Resolution Radiometer (AVHRR) provided digital data for each of four spectral intervals. 2. Data Collection and Location System (DCS) was a random-access system that located and/or collected data from remote fixed and free-floating terrestrial and atmospheric platforms. 3. High Energy Proton-Alpha Detector (HEPAD) sensed protons and alphas from a few hundred MeV up through relativistic particles above 850 NeV 4. Medium Energy Proton Electron Detector (MEPED) sensed protons, electrons, and ions with energies from 30 keV to several tens of MeV. 5. Space Environment Monitor (SEM) was a multichannel charged-particle spectrometer that provided measurements on the population of Earth's radiation belts and on particle precipitation phenomena resulting from solar activity. 6. Total Energy Detector (TED) used a programmed swept electrostatic curved-plate analyzer to select particle type/energy and a channeltron detector to sense/qualify the intensity of the sequentially selected energy bands.

Table 2–64 continued

	7. TIROS Operational Vertical Sounder (TOVS) determined radiances needed to calculate temperature and humidity profiles of the atmosphere from the planetary surface into the stratosphere. It consisted of three instruments: HIRS/2, SSU, and MSU. – High Resolution Infrared Sounder (HIRS/2) measured incident radiation in 20 spectral regions of the infrared spectrum, including long and short wave regions. – Stratospheric Sounding Unit (SSU) used a selective absorption technique to make temperature measurements in three channels. – Microwave Sounding Unit (MSU) provided four channels for the TOVS in the 60-GHz oxygen absorption region. These were accurate in the presence of clouds. The passive microwave measurements could be converted into temperature profiles of the atmosphere from Earth's surface to 20 km.
Contractor	RCA Astro Electronics

Table 2–65. NOAA B Characteristics

Launch Date	May 29, 1980
Launch Vehicle	Atlas F
Range	Western Space and Missile Center
Lead NASA Center	Goddard Space and Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements and to conduct an in-orbit evaluation and checkout of the spacecraft
NOAA Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the NOESS to improve forecasting ability
Orbit Characteristics	Did not reach proper orbit
Weight (kg)	1,405
Dimensions	3.71 m high and 1.88 m diameter unstowed; 4.91 m high and 2.37 m diameter with solar arrays extended
Power Source	Solar array and two 30 AH nickel cadmium batteries
Instruments	Same as NOAA 6
Contractor	RCA Astro Electronics

Table 2–66. Advanced Very High Resolution Radiometer Characteristics

Characteristics	Channels 1	2	3	4	5
Spectral range (micrometers)	0.58 to 0.68	0.725 to 1.0	3.55 to 3.93	10.3 to 11.3	11.4 to 12.4
Detector	Silicon	Silicon	InSb	(HgCd)Te	(HgCd)Te
Resolution (km at nadir)	1.1	1.1	1.1	1.1	1.1
Instantaneous field of view (milliradians)	1.3 sq.	1.3 sq.	1.3 sq.	1.3 sq.	1.3 sq.
Signal-to-noise ratio at 0.5 albedo	>3:1	>3:1	—	—	—
Noise-equivalent temperature difference at (NEΔT) 300 degrees K	—	—	<0.12 K	<0.12 K	<0.12 K
Scan angle (degrees)	±55	±55	±55	±55	±55
Optics—8-inch diameter afocal Cassegrain telescope					
Scanner—360-rpm hysteresis synchronous motor with beryllium scan mirror					
Cooler—Two-stage radiant cooler, infrared detectors controlled at 105 or 107 degrees K					
Data output—10-bit binary, simultaneous sampling at 40-kHz rate					

Table 2–67. NOAA 7 Characteristics

Launch Date	June 23, 1981
Launch Vehicle	Atlas F
Range	Western Space and Missile Center
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements and to conduct an in-orbit evaluation and checkout of the spacecraft
NOAA Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the NOESS to improve forecasting ability
Orbit Characteristics	
Apogee (km)	847
Perigee (km)	829
Inclination (deg.)	98.9
Period (min.)	101.7
Weight (kg)	1,405
Dimensions	3.71 m high and 1.88 m diameter unstowed; 4.91 m high and 2.37 m diameter with solar arrays extended
Power Source	Solar array and two 30 AH nickel cadmium batteries
Instruments	Same as NOAA 6 with the exception of the AVHRR, which had five channels rather than four. In addition, the U.S. Air Force provided a contamination monitor to assess contamination sources, levels, and effects for consideration on future spacecraft. This instrument flew for the first time on this mission.
Contractor	RCA Astro Electronics

Table 2–68. NOAA 8 Characteristics

Launch Date	March 28, 1983
Launch Vehicle	Atlas E
Range	Western Space and Missile Center
Lead NASA Center	Goddard Space and Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements and to conduct an in-orbit evaluation and checkout of the spacecraft
NOAA Mission Objectives	To collect and send data of Earth's atmosphere and sea surface as part of the NOESS to improve forecasting ability
Orbit Characteristics	
Apogee (km)	825.5
Perigee (km)	805
Inclination (deg.)	98.6
Period (min.)	101.2
Weight (kg)	1,712
Dimensions	3.71 m high and 1.88 m diameter unstowed; 4.91 m high and 2.37 m diameter with solar arrays extended
Power Source	Solar array and two 30AH nickel cadmium batteries
Instruments	Same as NOAA 6 instruments with the addition of the Search and Rescue (SAR) system. The SAR on NOAA 8 could detect and locate existing emergency transmitters operating at 121.5 MHz and 245 MHz, as well as experimental transmitters operating at 406 MHz (see "Communications Program" section in this chapter).
Contractor	RCA Astro Electronics

Table 2–69. NOAA 9 Characteristics

Launch Date	December 12, 1984
Launch Vehicle	Atlas E
Range	Vandenberg Air Force Base
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	• Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements, conduct an in-orbit evaluation and checkout of the spacecraft, and, upon completion of this evaluation, turn the operational control of the spacecraft over to the NOAA National Environmental Satellite Data and Information Service (NESDIS) • Successfully acquire data from the Earth Radiation Budget Experiment (ERBE) instruments for application in scientific investigations aimed at improving our understanding of the processes that influence climate and climate changes • Acquire data from the Solar Backscatter Ultraviolet (SBUV/2) instrument to determine stratospheric ozone concentrations on a global basis
NOAA Mission Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the NOESS in acquiring daily global weather information for the short- and long-term forecasting needs of the National Weather Service
Orbit Characteristics	
Apogee (km)	863
Perigee (km)	839
Inclination (deg.)	99.1
Period (min.)	102.2
Weight (kg)	1,712
Dimensions	4.91 m high; 1.88 m diameter with solar array extended
Power Source	Solar array and two 30AH nickel cadmium batteries

Table 2–69 continued

Instruments	Same instruments as NOAA 8 with the addition of SBUV/2 and ERBE: • ERBE consisted of a medium and wide field-of-view nonscanning radiometer and a narrow field-of-view scanning radiometer. The radiometers would measure Earth radiation energy budget components at satellite altitude; make measurements from which monthly average Earth radiation energy budget components can be derived at the top of the atmosphere on regional, zonal, and global scales; and provide an experimental prototype for an operational ERBE instrument for future long-range monitoring programs. • SBUV/2 consisted of two instruments: the Monochrometer and the Cloud Cover Radiometer. The Monochrometer was a spectral scanning ultraviolet radiometer that could measure solar irradiance and scene radiance (back-scattered solar energy) over a spectral range of 160 to 400 nanometers. The Cloud Cover Radiometer detected clouds that would contaminate the signal. Experiment objectives were to make measurements from which total ozone concentration in the atmosphere could be determined to an accuracy of 1 percent, make measurements from which the vertical distribution of atmospheric ozone could be determined to an accuracy of 5 percent, and measure the solar spectral irradiance from 160 to 400 nanometers.
Contractor	RCA Astro Electronics

Table 2–70. NOAA 10 Characteristics

Launch Date	September 17, 1986
Launch Vehicle	Atlas E
Range	Vandenberg Air Force Base
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements, conduct an in-orbit evaluation and checkout of the spacecraft, and, upon completion of this evaluation, turn the operational control of the spacecraft over to the NOAA NESDIS
NOAA Mission Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the NOESS to improve forecasting ability
Orbit Characteristics	
Apogee (km)	823
Perigee (km)	804
Inclination (deg.)	98.7
Period (min.)	101.2
Weight (kg)	1,712
Dimensions	4.91 m high; 1.88 m diameter with solar panels expanded
Power Source	Solar array and two 30 AH nickel cadmium batteries
Instruments	Same as NOAA 9 instruments, including NASA's ERBE, but with a "dummy" SBUV and a "dummy" SSU. The SSU, which was provided by the United Kingdom through its Meteorological Office, Ministry of Defense, was flown only on "afternoon" satellites beginning with NOAA 9.
Contractor	RCA Astro Electronics

Table 2–71. NOAA 11 Characteristics

Launch Date	September 24, 1988
Launch Vehicle	Atlas E
Range	Western Space and Missile Center
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the spacecraft into a Sun-synchronous orbit of sufficient accuracy to enable it to accomplish its operational mission requirements, to conduct an in-orbit evaluation and checkout of the spacecraft, and upon, completion of this evaluation, to turn the operational control of the spacecraft over to the NOAA NESDIS
NOAA Mission Objectives	Collect and send data of Earth's atmosphere and sea surface as part of the NOESS to improve forecasting ability
Orbit Characteristics	
Apogee (km)	865
Perigee (km)	849
Inclination (deg.)	98.9
Period (min.)	102.1
Weight (kg)	1,712
Dimensions	4.91 m high; 1.88 m diameter
Power Source	Solar array and two 30 AH nickel cadmium batteries
Instruments	Same instruments as NOAA 9 with the exception of ERBE
Contractor	RCA Astro Electronics

Table 2–72. VISSR Atmospheric Sounder Infrared Spectral Bands

Spectral Band	Central Wavelength (mm)	Spatial Resolution (km)	Weighting Function Peak (mb)	Absorbing Constituent
1	14.73	13.8	70	CO_2
2	14.48	13.8	125	CO_2
3	14.25	6.9 and 13.8	200	CO_2
4	14.01	6.9 and 13.8	500	CO_2
5	13.33	6.9 and 13.8	920	CO_2
6	4.525	13.8	850	CO_2
7	12.66	6.9 and 13.8	Surf.	H_20
8	11.17	6.9 and 13.8	Surf.	Window
9	11.17	6.9 and 13.8	600	H_20
10	6.725	6.9 and 13.8	400	H_20
11	4.444	13.8	300	CO_2
12	3.945	13.8	Surf.	Window

Table 2–73. GOES 4 Characteristics

Launch date	September 9, 1980
Launch vehicle	Delta 3914
Range	Eastern Test Range
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the satellite into a synchronous orbit of sufficient accuracy to enable the spacecraft to provide the capability for continuous observations of the atmosphere on an operational basis, flight-test the satellite in orbit and, when checked out, turn the spacecraft over to NOAA for operational use, and demonstrate, validate, and assess the temperature and moisture soundings from the VISSR Atmospheric Sounder
NOAA Mission Objectives	Collect and relay weather data to enable forecasters and other scientists to study severe storms and storm-spawned phenomena, such as hail, flash floods, and tornadoes, by monitoring weather over Canada, the United States, and Central and South America
Orbit Characteristics	
Apogee (km)	35,795
Perigee (km)	35,780
Inclination (deg.)	4.1
Period (min.)	1,436.2
Weight (kg)	444 (in orbit)
Dimensions	4.43 m high from the S-band omni antenna rod to the apogee boost motor nozzle aperture; 2.15 m diameter spin-stabilized drum
Power Source	Solar panels and two nickel cadmium batteries

Table 2–73 continued

Instruments	1. VISSR Atmospheric Sounder was capable of simultaneous imaging in the visible portion of the spectrum with a resolution of 0.9 km and the infrared portion of the spectrum with a resolution of 6.9 km, multispectral imaging simultaneously in five spectral bands (one visible and four selectable from the 12 infrared bands), and a dwell sounding mode from which moisture, temperature, and vertical structure of the atmosphere may be determined. 2. Space Environmental Monitor (SEM) provided direct quantitative measurements of the major effects of solar activity for use in real-time solar forecasting and subsequent research, detected unusual solar flares with high levels of radiation, measured the strength of solar winds, and measured the strength and direction of Earth's magnetic field. 3. Data Collection and Location System (DCS) provided communications relay from data collection platforms on land, at sea, and in the air to the Command and Data Acquisition Station (CDA), as well as the interrogation of platforms from the CDA via the satellite. 4. Telemetry, Tracking, and Command used S-band frequencies for transmission of wideband visual data to the CDA, for relay of "stretched" data from the CDA via the spacecraft to facilities operated by NOAA, and for transmission of weather facsimile data to local ground stations equipped to receive S-band automatic picture transmission data; UHF for transmissions from data collection platforms to the spacecraft and then to the CDA on the S-band; and VHF and S-band for commanding the spacecraft, for telemetry, and for transmitting the space environment monitoring data.
Contractors	Hughes Aircraft, Ball Aerospace, Panametrics, Ford Aerospace and Communications Corp.

Table 2–74. GOES 5 Characteristics

Launch date	May 22, 1981
Launch vehicle	Delta 3914
Range	Eastern Test Range
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the satellite into a synchronous orbit of sufficient accuracy to enable the spacecraft to provide the capability for continuous observations of the atmosphere on an operational basis, flight test the satellite in orbit and, when checked out, turn the spacecraft over to NOAA for operational use, and continue the demonstration and validation of the temperature and moisture soundings from the VISSR Atmospheric Sounder
NOAA Mission Objectives	Collect and relay weather data to enable forecasters and other scientists to study severe storms and storm-spawned phenomena such as hail, flash floods, and tornadoes, by monitoring weather over Canada, the United States, and Central and South America
Orbit Characteristics	
Apogee (km)	35,792
Perigee (km)	35,782
Inclination (deg.)	1.2
Period (min.)	1,435.9
Weight (kg)	444 (in orbit)
Dimensions	4.43 m high from the S-band omni antenna rod to the apogee boost motor nozzle aperture; 2.15 m diameter spin-stabilized drum
Power Source	Solar panels and two nickel cadmium batteries
Instruments	Same as GOES 4
Contractors	Hughes Aircraft, Ball Aerospace, Panametrics, Ford Aerospace and Communications Corp.

Table 2–75. GOES 6 Characteristics

Launch date	April 28, 1983
Launch vehicle	Delta 3914
Range	Eastern Space and Missile Center
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the satellite into a synchronous orbit of sufficient accuracy to enable the spacecraft to provide the capability for continuous observations of the atmosphere on an operational basis and flight-test the satellite in orbit and, when checked out, turn the spacecraft over to NOAA for operational use
NOAA Mission Objectives	Collect and relay weather data to enable forecasters and other scientists to study severe storms and storm-spawned phenomena such as hail, flash floods, and tornadoes, by monitoring weather over Canada, the United States, and Central and South America
Orbit Characteristics	
Apogee (km)	35,891
Perigee (km)	35,776
Inclination (deg.)	0.1
Period (min.)	1,436.4
Weight (kg)	444 in orbit
Dimensions	4.43 m high from the S-band omni antenna rod to the apogee boost motor nozzle aperture; 2.15 m diameter spin-stabilized drum
Power Source	Solar panels and two nickel cadmium batteries
Instruments	Same as GOES 4
Contractors	Hughes Aircraft, Ball Aerospace, Panametrics, Ford Aerospace and Communications Corp.

Table 2–76. GOES G Characteristics

Launch date	May 3, 1986
Launch vehicle	Delta 3914
Range	Cape Canaveral Air Force Station
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the satellite into a synchronous orbit of sufficient accuracy to enable the spacecraft to provide the capability for continuous observations of the atmosphere on an operational basis, flight-test the satellite in orbit and, when checked out, turn the spacecraft over to NOAA for operational use, and determine usefulness of instant alert capabilities of geosynchronous search and rescue systems and to develop and test processing techniques for geosynchronous search and rescue data
NOAA Mission Objectives	Collect and relay weather data to enable forecasters and other scientists to study severe storms and storm-spawned phenomena, such as hail, flash floods, and tornadoes
Orbit Characteristics	Did not achieve orbit
Weight (kg)	1,712 at launch
Dimensions	4.43 m high from the S-band omni antenna rod to the apogee boost motor nozzle aperture; 2.15 m diameter spin-stabilized drum
Power Source	Solar panels and two nickel cadmium batteries
Instruments	Same as GOES 4
Contractors	Hughes Aircraft, Ball Aerospace, Panametrics, Ford Aerospace and Communications Corp.

Table 2–77. GOES 7 Characteristics

Launch date	February 26, 1987
Launch vehicle	Delta 3924
Range	Cape Canaveral Air Force Station
Lead NASA Center	Goddard Space Flight Center
Owner	National Oceanic and Atmospheric Administration
NASA Mission Objectives	Launch the satellite into a geosynchronous orbit of sufficient accuracy to enable the spacecraft to provide the capability for continuous observations of the atmosphere on an operational basis, flight-test the satellite in orbit and, when checked out, turn the spacecraft over to NOAA for operational use, determine the usefulness of instant alert capabilities of geosynchronous search and rescue systems, and develop and test processing techniques for geosynchronous search and rescue data
NOAA Mission Objectives	Transmit cloud cover images from a geosynchronous orbit and atmospheric temperature profiles, collect space environmental data, and conduct an experiment for detecting emergency distress signals on the ground from geosynchronous orbit
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,783
Inclination (deg.)	4.3
Period (min.)	1,436.2
Weight (kg)	456 in orbit
Dimensions	4.43 m high from the S-band omni antenna rod to the apogee boost motor nozzle aperture; 2.15 m diameter spin-stabilized drum
Power Source	Solar array and two nickel cadmium batteries
Instruments	Same as GOES 4
Contractors	Hughes Aircraft, Ball Aerospace, Panametrics, Ford Aerospace and Communications Corp.

Table 2–78. Landsat 4 Instrument Characteristics

	Thematic Mapper		Multispectral Scanner	
Spectral Band	**Micrometers**	**Radiometric Sensitivity (NE∆P) %**	**Micrometers**	**Radiometric Sensitivity (NE∆P) %**
1	0.45–0.52	0.8	0.5–0.6	0.57
2	0.52–0.60	0.5	0.6–0.7	0.57
3	0.63–0.69	0.5	0.7–0.8	0.65
4	0.76–0.9	0.5	0.8–1.1	0.70
5	1.55–1.75	1.0		
6	2.08–2.35	2.4		
7	10.40–12.50	0.5K (NE∆T)		
Ground IFOV	30M (bands 1–6)		83M (bands 1–4)	
Data Rate	85 Mb/s		15 Mb/s	
Quantization Levels	256		64	
Weight (kilograms)	246		58	
Size (meters)	1.1 x 0.7 x 2.0		0.35 x 0.4 x 0.9	
Power (watts)	345		81	

Table 2–79. Landsat 4 Characteristics

Launch Date	July 16, 1982
Launch Vehicle	Delta 3920
Range	Vandenberg Air Force Base
Lead NASA Center	Goddard Space Flight Center
Customer/Sponsor	National Oceanic and Atmospheric Administration
Mission Objectives	• Acquire multispectral, high-spatial resolution images of solar radiation reflected from Earth's surface and, for the Thematic Mapper, the emitted radiation in the thermal infrared region of the electromagnetic spectrum • Provide continuing Earth remote-sensing information and to encourage continued national and international participation in land remote-sensing programs • Assess the capabilities of the new Thematic Mapper sensing system and to exploit new areas of the infrared and visible light spectrum at higher resolution • Establish a technical and operational proficiency that can be used to help define the characteristics necessary for potential future operational land remote-sensing systems
Orbit Characteristics	
Apogee (km)	700
Perigee (km)	699
Inclination (deg.)	98.2
Period (min.)	98.8
Weight (kg)	1,941
Dimensions	4 m long; 2 m wide (deployed)
Power Source	Solar array and batteries
Instruments	1. Multispectral Scanner (MSS) scanned cross-track swaths of 185 km imaging six scan lines across in each of the four spectral bands simultaneously, focusing the scanned Earth image on a set of detectors. The instantaneous field of view of each detector subtended an Earth area square of 83 cm. 2. Thematic Mapper (TM) was a seven-band multispectral high-resolution scanner that collected, filtered, and detected radiation from Earth in a swath 185 km wide.
Contractor	General Electric (Landsat 4 spacecraft), Hughes Aircraft (TM and MSS), Fairchild Industries (Multimission Modular Spacecraft)

Table 2–80. Landsat 5 Characteristics

Launch Date	March 1, 1984
Launch Vehicle	Delta 3920
Range	Western Test Range
Lead NASA Center	Goddard Space Flight Center
Customer/Sponsor	National Oceanic and Atmospheric Administration
Mission Objectives	• Acquire multispectral, high-spatial resolution images of solar radiation reflected from Earth's surface and, for the TM, the emitted radiation in the thermal infrared region of the electromagnetic spectrum • Launch the spacecraft into a polar orbit of sufficient accuracy to enable the spacecraft to provide the capability of acquiring MSS and TM scenes on a global basis for a period of 1 year • Flight-test the spacecraft in orbit and, when checked out, turn the spacecraft and MSS over to NOAA for operational use • Demonstrate the capability to process up to 50 TM scenes per day to produce tapes and film masters and complete the transfer of TM operations and data processing to NOAA as agreed to by NASA and NOAA • Perform evaluations of TM and MSS data quantifying some of the observational advantages of TM versus MSS imagery
Orbit Characteristics	
Apogee (km)	700
Perigee (km)	699
Inclination (deg.)	98.2
Period (min.)	98.8
Weight (kg)	1,941
Dimensions	4 m long, 2 m wide (deployed)
Power Source	Solar array and batteries
Instruments	Same as Landsat 4
Contractor	General Electric (spacecraft), Hughes Aircraft (TM and MSS), Fairchild Industries (MMS)

Table 2–81. Magsat Characteristics

Launch Date	October 30, 1979
Launch Vehicle	Scout
Date of Reentry	June 11, 1980
Range	Western Test Range
Customer/Sponsor	NASA Office of Space and Terrestrial Applications and U.S. Geological Survey
Lead NASA Center	Goddard Space Flight Center
Mission Objectives	Develop a worldwide vector magnetic field model suitable for the U.S. Geological Survey update and refinement of world and regional magnetic charts, compile crustal magnetic anomaly maps with spatial resolution of 350 km or better, interpret anomalies in conjunction with correlative data in terms of geologic/geophysical models of Earth's crust, and increase understanding of the origin and nature of the geomagnetic field and its temporal variations
Orbit Characteristics	
Apogee (km)	551
Perigee (km)	350
Inclination (deg.)	96.8
Period (min.)	93.6
Weight (kg)	183
Dimensions	Instrument module: height—874 cm with trim boom extended, diameter—77 cm with solar panels and magnetometer boom extended, width—340 cm tip to tip with solar array deployed, length—722 cm along flight path with magnetometer boom and solar array deployed Base module: diameter—66 cm, height—61 cm
Power Source	Solar panels
Instruments	1. Scalar Magnetometer was a dual lamp cesium vapor magnetometer that measured the magnitude of Earth's crustal magnetic field. 2. Vector Magnetometer was a three-axis fluxgate magnetometer that measured magnetic field direction as well as magnitude.
Experiments	Thirty-two investigations were selected in response to an Announcement of Opportunity issued September 1, 1978. They included 13 foreign investigations from Australia, Brazil, Canada, France, India, Italy, Japan, and the United Kingdom, as well as investigations from the United States. The general resources categories were: geophysics, geology, field modeling, marine studies, magnetosphere/ionosphere, and core/mantle studies. Data distribution was through the National Space Science Data Center. Table 2–82 lists the investigations.
Contractor	Applied Physics Laboratory, Johns Hopkins University

Table 2–82. Magsat Investigations

Principal Investigator	Organization	Research Area
Geophysics		
R.L. Coles	The Geomagnetic Service of Canada	Reduction, Verification, and Interpretation of Magsat Data Over Canada
B.N. Bhargava	Indian Institute of Geomagnetism	Magnetic Anomaly and Magnetic Field Map Over India
W.J. Hinze	Purdue University	Processing and Interpretation of Magnetic Anomaly Data Over South America
G.R. Keller	University of Texas, El Paso	Synthesis of Data for Crustal Modeling of South America
P. Gasparini	University of Naples, Italy	Crustal Structures Under the Active Volcanic Areas of the Mediterranean
N. Fukushima	University of Tokyo	Proposal From Japanese National Team for Magsat Project
C.R. Bentley	University of Wisconsin	Investigation of Antarctic Crust and Upper Mantle
M.A. Mayhew	Business and Technology Systems, Inc., Seabrook, Maryland	Magsat Anomaly Field Inversion and Interpretation for the United States
J.L. leMouel	Institut de Physique du Globe, Toulouse, France	Data Reduction, Studies of Europe, Central Africa, and Secular Variation
J.C. Dooley	Bureau of Mineral Resources, Canberra, Australia	The Regional Field and Crustal Structure of Australia and Antarctica
B.D. Johnson	Macquarie University, Australia	Crustal Properties of Australia and Surrounding Regions
Geology		
R.S. Carmichael	University of Iowa	Crustal Structure and Mineral Resources in the U.S. Midcontinent
D.H. Hall	University of Manitoba, Canada	Lithostratographic and Structural Elements in the Canadian Shield
I. Gill Pacca	Universidade de Sao Paulo, Brazil	Structure, Composition, and Thermal State of the Crust in Brazil
D.A. Hastings	Michigan Technological University	Precambrian Shields and Adjacent Areas of West Africa and South America
D.W. Strangeway	University of Toronto, Canada	Analysis of Anomaly Maps Over Portions of the Canadian and Other Shields

Table 2–82 continued

Principal Investigator	Organization	Research Area
I.J. Won	North Carolina State University, Raleigh, North Carolina	Compatibility Study of the Magsat Data and Aeromagnetic Data in the Eastern Piedmont, United States
S.E. Haggerty	University of Massachusetts, Amherst, Massachusetts	The Mineralogy of Global Magnetic Anomalies
M.R. Godiver	ORSTROM, Paris, France	Magnetic Anomaly of Bangui
Field Modeling		
D.R. Baraclough	Institute of Geological Sciences, Edinburgh, UK	Spherical Harmonic Representation of the Main Geomagnetic Field
D.P. Stern	NASA/Goddard Space Flight Center	Study of Enhanced Errors and of Secular Variation
M.A. Mayhew	Business and Technology Systems, Inc., Seabrook, Maryland	Equivalent Source Modeling of the Main Field
B.P. Gibbs	Business and Technology Systems, Inc., Seabrook, Maryland	Field Modeling by Optimal Recursive Filtering
Marine Studies		
C.G.A. Harrison	University of Miami, Florida	Investigations of Medium Wavelength Anomalies in the Eastern Pacific
J.L. LaBrecque	Lamont-Doherty Geological Observatory, Palisades, New York	Analysis of Intermediate Wavelength Anomalies Over the Oceans
R.F. Brammer	The Analytical Sciences, Corp., Reading, Massachusetts	Satellite Magnetic and Gravity Investigation of the Eastern Indian Ocean
Magnetosphere/Ionosphere		
D.M. Klumpar	University of Texas, Richardson, Texas	Effects of External Current Systems on Magsat Data Utilizing Grid Cell Modeling
J.R. Burrows	National Research Council of Canada	Studies of High Latitude Current Systems Using Magsat Vector Data
T.A. Potemra	Johns Hopkins University	Corrective Information on High-Latitude External Fields
R.D. Regan	Phoenix Corporation, McLean, Virginia	Improved Definition of Crustal Magnetic Anomalies in Magsat Data
Core/Mantle Studies		
E.R. Benton	University of Colorado, Boulder, Colorado	Field Forecasting and Fluid Dynamics of the Core
J.F. Hermance	Brown University, Providence, Rhode Island	Electromagnetic Deep-Probing of the Earth's Interior: Crustal Resource

Table 2–83. ASC-1 Characteristics

Launch Date	August 27, 1985
Launch Vehicle	STS 51-I (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the PAM-D and spacecraft propulsion system to place the spacecraft into stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	American Satellite Company
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,777
Inclination (deg.)	0.1
Period (min.)	1,436.1
Weight (kg)	665 (in orbit)
Dimensions	Main body: 1.625 m x 1.320 m x 1.320 m Spans: 14 m with solar array extended
Shape	Cube
Power Source	Solar array panels and two nickel cadmium batteries
Contractor	RCA Astro Electronics
Remarks	ASC-1 was the first satellite to have encrypted command links, a security feature that prevented unauthorized access to the satellite command system. It was in a geosynchronous orbit at approximately 128 degrees west longitude.

Table 2–84. Comstar D-4 Characteristics

Launch Date	February 21, 1981
Launch Vehicle	Atlas Centaur
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into a transfer orbit which that would enable the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Owner	American Telephone and Telegraph Co. (AT&T)
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,784
Inclination (deg.)	1.9
Period (min.)	1,436.2
Weight (kg)	1,484 (before launch)
Dimensions	6.1 m high; 2.44 m diameter
Shape	Cylindrical
Power Source	Solar array and batteries
Contractor	Hughes Aircraft
Remarks	Comstar D-4 became operational on May 5, 1981. It was located at approximately 127 degrees west longitude.

Table 2–85. Telstar 3-A Characteristics

Launch Date	July 28, 1983
Launch Vehicle	Delta 3920/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite on a two-stage Delta 3920 with sufficient accuracy to allow the MDAC PAM-D and spacecraft propulsion system to place the spacecraft into stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	AT&T
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,778
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	653 (in orbit)
Dimensions	6.48 m high (deployed); 2.74 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Also called Telstar 301, the spacecraft was placed in a geosynchronous orbit at approximately 96 degrees west longitude above the equator.

Table 2–86. Telstar 3-C Characteristics

Launch Date	September 1, 1984
Launch Vehicle	STS 41-D (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the MDAC PAM-D and spacecraft propulsion system to place the spacecraft into stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	AT&T
Orbit Characteristics	
Apogee (km)	35,791
Perigee (km)	35,782
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	653 (in orbit)
Dimensions	6.48 m high (deployed); 2.74 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Telstar 3-C was placed into a geosynchronous orbit at approximately 85 degrees west longitude. It was also called Telstar 302.

Table 2–87. Telstar 3-D Characteristics

Launch Date	June 19, 1985
Launch Vehicle	STS-51 G (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the MDAC PAM-D and spacecraft propulsion system to place the spacecraft onto stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	AT&T
Orbit Characteristics	
Apogee (km)	35,804
Perigee (km)	35,770
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	653 (in orbit)
Dimensions	6.48 m high (deployed); 2.74 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Telstar 3-D was placed in a geostationary orbit at approximately 125 degrees west longitude. It was also called Telstar 303.

Table 2–88. Galaxy 1 Characteristics

Launch Date	June 28, 1983
Launch Vehicle	Delta 3920/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite on a two-stage Delta 3920 launch vehicle with sufficient accuracy to allow the MDAC PAM-D and the spacecraft propulsion system to place the satellite into a stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Hughes Communications Inc.
Orbit Characteristics	
Apogee (km)	35,797
Perigee (km)	35,780
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	519 at beginning of life
Dimensions	2.16 m diameter; 2.8 m long (stowed); 6.8 m long (with solar panel and antenna reflector deployed)
Shape	Cylinder
Power Source	K-7 solar cells and two nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Galaxy 1 was devoted entirely to distributing cable television programming. It had a geostationary orbit at approximately 133 degrees west longitude. It operated until April 1994.

Table 2–89. Galaxy 2 Characteristics

Launch Date	September 22, 1983
Launch Vehicle	Delta 3920/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite on a two-stage Delta 3920 with sufficient accuracy to allow the MDAC PAM-D and the satellite propulsion system to place the satellite into a stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Hughes Communications Inc.
Orbit Characteristics	
Apogee (km)	35,799
Perigee (km)	35,782
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	519 at beginning of life
Dimensions	2.16 m diameter; 2.8 m long (stowed); 6.8 m long (with solar panel and antenna reflector deployed)
Shape	Cylinder
Power Source	K-7 solar cells and two nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Galaxy 2 had a geostationary orbit above the equator at approximately 74 degrees west longitude. It operated until May 1994.

Table 2–90. Galaxy 3 Characteristics

Launch Date	September 21, 1984
Launch Vehicle	Delta 3920/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite on a two-stage Delta 3920 launch vehicle with sufficient accuracy to allow the MDAC PAM-D and the satellite propulsion system to place the satellite into a stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Hughes Communications Inc.
Orbit Characteristics	
Apogee (km)	35,792
Perigee (km)	35,783
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	519 at beginning of life
Dimensions	2.16 m diameter; 2.8 m long (stowed); 6.8 m long (with solar panel and antenna reflector deployed)
Shape	Cylinder
Power Source	K-7 solar cells and two nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Galaxy 3 was placed in a geosynchronous orbit at approximately 93.5 degrees west longitude. It operated until September 30, 1995.

Table 2–91. Satcom 3 Characteristics

Launch Date	December 6, 1979
Launch Vehicle	Delta 3914
Range	Eastern Space and Missile Center
Mission Objectives	Place the RCA satellite into a synchronous transfer orbit of sufficient accuracy to allow the spacecraft propulsion systems to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Provide communications coverage for all 50 states, be capable of operating all 24 transponder channels at specified power throughout the minimum 8-year life, and be compatible with the Delta 3914 launch vehicle
Owner	RCA American Communications (RCA Americom)
Orbit Characteristics	Transfer orbit—did not achieve final orbit
Apogee (km)	35,798
Perigee (km)	162
Inclination (deg.)	23.9
Period (min.)	630
Weight (kg)	895
Dimensions	Base plate: 119 cm x 163 cm; main body height: 117 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	The satellite was destroyed during the firing of the apogee kick motor on December 10, 1979. This was the third RCA satellite launched by NASA.

Table 2–92. Satcom 3-R Characteristics

Launch Date	November 19, 1981
Launch Vehicle	Delta 3910
Range	Eastern Space and Missile Center
Mission Objectives	Launch the RCA satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Provide communications coverage for Alaska, Hawaii, and the contiguous 48 states, be capable of operating all 24 transponder channels at specified power throughout the minimum 10-year life, including eclipse periods, and be compatible with the Delta 3910 launch vehicle
Owner	RCA Americom
Orbit characteristics	
Apogee (km)	35,794
Perigee (km)	35,779
Inclination (deg.)	0.1
Period (min.)	1,436.1
Weight (kg)	1,082 (at launch)
Dimensions	Baseplate: 119 cm x 163 cm; main body height: 117 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom 3-R was placed into geosynchronous orbit at approximately 132 degrees west longitude above the equator. This spacecraft and future RCA spacecraft were designed for launch by the Space Shuttle or by the Delta 3910/PAM-D launch vehicle.

Table 2–93. Satcom 4 Characteristics

Launch Date	January 19, 1982
Launch Vehicle	Delta 3910
Range	Eastern Space and Missile Center
Mission Objectives	Launch the RCA satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Provide communications coverage for Alaska, Hawaii, and the contiguous 48 states, be capable of operating all 24 transponder channels at specified power throughout the minimum 10-year life, including eclipse periods, and be compatible with the Delta 3910 launch vehicle
Owner	RCA Americom
Orbit characteristics	
Apogee (km)	35,795
Perigee (km)	35,781
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	1,082 at launch; 598 in orbit
Dimensions	Baseplate: 119 cm x 163 cm; main body height: 117 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom 4 was placed into geosynchronous orbit located at approximately 83 degrees west longitude.

Table 2–94. Satcom 5 Characteristics

Launch Date	October 27, 1982
Launch Vehicle	Delta 3924
Range	Eastern Space and Missile Center
Mission Objectives	Launch the RCA spacecraft into a synchronous transfer orbit on a three-stage Delta 3924 launch vehicle with sufficient accuracy to allow the spacecraft apogee kick motor to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Increase traffic capacity per satellite, assure longer satellite life with improved reliability, and make the satellite compatible with existing terrestrial and space facilities
Owner	RCA Americom
Orbit characteristics	
Apogee (km)	35,792
Perigee (km)	35,783
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	1,116 at launch; 598.6 in orbit
Dimensions	Main body: 142 cm x 163 cm x175 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom 5 (also called Aurora) was the first in a new series of high-traffic-capacity, 24-transponder communications satellites. It was the first RCA satellite to be launched from the Delta 3924 launch vehicle. The spacecraft was placed into a geosynchronous orbit located at approximately 128 degrees west longitude.

Table 2–95. Satcom 6 Characteristics

Launch Date	April 11, 1983
Launch Vehicle	Delta 3924
Range	Eastern Space and Missile Center
Mission Objectives	Launch the RCA satellite into synchronous transfer orbit on a three-stage Delta 3924 launch vehicle with sufficient accuracy to allow the spacecraft apogee kick motor to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Serve the commercial, government, video/audio, and Alaskan domestic communication traffic markets: • Government: provide voice/video and high-speed data to federal agencies via RCA-owned Earth stations located on various government installations • Video/audio services: provide point-to-point and point-to-multipoint distribution of TV, radio, and news services to broadcasters, cable TV operators, and publishers • Alascom services: provide Alascom, Inc., the long-distance common carrier for Alaska, the satellite capacity for interstate and intrastate message and video transmission
Owner	RCA Americom
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,779
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,116 at launch, 598.6 in orbit
Dimensions	Main body: 142 cm x 163 cm x175 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar panels and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom 6 (also called Satcom IR) was the second of a new series of high-traffic-capacity, 24-transponder communications satellites. It replaced the RCA Satcom 1, which was launched in 1975. It was placed in a geosynchronous orbit at approximately 128 degrees west longitude.

Table 2–96. Satcom 7 Characteristics

Launch Date	September 8, 1983
Launch Vehicle	Delta 3924
Range	Eastern Space and Missile Center
Mission Objectives	Launch the RCA spacecraft into a synchronous orbit on a three-stage Delta 3924 launch vehicle with sufficient accuracy to allow the spacecraft apogee kick motor to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
System Objectives	Serve the commercial, government, video/audio, and Alaskan domestic communication traffic markets: • Government: provide voice/video and high-speed data to federal agencies via RCA-owned Earth stations located on various government installations • Video/audio services: provide point-to-point and point-to-multipoint distribution of TV, radio, and news services to broadcasters, cable TV operators, and publishers • Alascom services: provide Alascom, Inc., the long-distance common carrier for Alaska, the satellite capacity for interstate and intrastate message and video transmission
Owner	RCA Americom
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,779
Inclination(deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,116 at launch; 598.6 in orbit
Dimensions	Main body: 142 cm x 163 cm x175 cm
Shape	Rectangular with two solar panels extended on booms from opposite sides and an antenna and reflector mounted on one end
Power Source	Solar panels and nickel cadmium batteries
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom 7 (also called Satcom 2R) replaced the RCA Satcom 2 that was launched in 1976. It was placed in geosynchronous orbit at approximately 72 degrees west longitude.

Table 2–97. Satcom K-2 Characteristics

Launch Date	November 28, 1985
Launch Vehicle	STS-61B (*Atlantis*)/PAM-DII
Range	Kennedy Space Center
Mission Objectives	Launch communications satellite successfully
System Objectives	Provide communications coverage for the 48 continental U.S. states or either the eastern half or western half
Owner	RCA Americom
Orbit Characteristics	
Apogee (km)	35,801
Perigee (km)	35,774
Inclination (deg.)	0.1
Period (min.)	1,436.2
Weight (kg)	7,225.3 (includes PAM-DII)
Dimensions	Main structure: 170 cm x 213 cm x 152 cm
Shape	Three-axis stabilized rectangular box and two deployable arms
Power Source	Solar array and three-battery system back-up
Contractor	RCA Americom Astro-Electronics Division
Remarks	RCA Satcom K-2 was the first in a series of communications satellites operating in the Ku-band part of the spectrum. The PAM-DII was used for the satellite's upper stage because of the satellite's heavy weight. The satellite was placed into a geosynchronous orbit at approximately 81 degrees west longitude.

Table 2–98. Satcom K-1 Characteristics

Launch Date	January 12, 1986
Launch Vehicle	STS 61-C (*Columbia*)/PAM-DII
Range	Kennedy Space Center
Mission Objectives	Launch communications satellite successfully
System Objectives	Provide communications coverage for the 48 continental states or either the eastern or the western half of the country
Owner	RCA Americom
Orbit Characteristics	
Apogee (km)	35,795
Perigee (km)	35,780
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	7225.3 (includes PAM DII)
Dimensions	Main structure: 170 cm x 213 cm x 152 cm
Shape	Three-axis stabilized rectangular box and two deployable arms
Power Source	Solar array and three-battery system back-up
Contractor	RCA Americom Astro-Electronics Division
Remarks	Satcom K-1 was the second in a series of three planned communications satellites operating in the Ku-band part of the spectrum. It was placed into an orbital position at approximately 85 degrees west longitude.

Table 2–99. SBS-1 Characteristics

Launch Date	November 15, 1980
Launch Vehicle	Delta 3910/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 vehicle with sufficient accuracy to allow the spacecraft propulsion systems to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Satellite Business Systems: IBM, Comsat General, Aetna Insurance
Orbit Characteristics	
Apogee (km)	35,797
Perigee (km)	35,777
Inclination (deg.)	0.7
Period (min.)	1,436.1
Weight (kg)	555 on orbit
Dimensions	6.6 m high (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and two nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	This launch marked the first use of the Payload Assist Module (PAM-D) in place of a conventional third stage. SBS-1 was the first satellite capable of transmitting point-to-point data, voice, facsimile, and telex messages within the continental United States as routine commercial service in the 12/14 GHz (K-) band; prior K-band service on ATS-6, CTS, and Telesat-D was experimental. SBS-1 was placed into geosynchronous orbit at approximately 106 degrees west longitude.

Table 2–100. SBS-2 Characteristics

Launch Date	September 24, 1981
Launch Vehicle	Delta 3910/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 vehicle with sufficient accuracy to allow the spacecraft propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Satellite Business Systems: IBM, Comsat General, Aetna Insurance
Orbit Characteristics	
Apogee (km)	35,789
Perigee (km)	35,785
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	555 on orbit
Dimensions	6.6 m high (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and two nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	SBS-2 was placed in geostationary orbit at approximately 97 degrees west longitude

Table 2–101. SBS-3 Characteristics

Launch Date	November 11, 1982
Launch Vehicle	STS-5 (*Columbia*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the spacecraft propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Satellite Business Systems: IBM, Comsat General, Aetna Insurance
Orbit Characteristics	
Apogee (km)	35,788
Perigee (km)	35,786
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	555 on orbit
Dimensions	6.6 m high (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and two nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	This was the first launch from the Shuttle cargo bay. SBS-3 was placed in geostationary orbit at approximately

95 degrees west longitude

Table 2–102. SBS-4 Characteristics

Launch Date	August 31, 1984
Launch Vehicle	STS 41-D (*Discovery*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the spacecraft propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Satellite Business Systems: IBM, Comsat General, Aetna Insurance
Orbit Characteristics	
Apogee (km)	35,793
Perigee (km)	35,781
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	555 on orbit
Dimensions	6.6 m high (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and two nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	SBS-4 was placed in geostationary orbit at approximately 91 degrees west longitude

Table 2–103. Westar Satellite Comparison

Feature	First Generation Westar 1, 2, and 3	Second Generation Westar 4, 5, and 6
Launch Vehicle	Delta 2914	Delta 3910
Weight, Beginning of Life (kg)	306	584
Service, GHz Channels	6/412	6/424
Dimensions (cm)		
Height	345	659 (deployed) 279 (stowed)
Diameter	190	216
Power Capability, Watts		
Beginning of Life	307	262
End of Life	822	684
Traveling Wave Tube (TWT) Output Power, Watts	5.0	7.5
Design Life, Years	7	10
Performance		
EIRP, dBW	33.0 (CONUS) 24.5 (Alaska, Hawaii)	34.0 (CONUS) 31.0 (Alaska) 28.3 (Hawaii) 27.2 (Puerto Rico)
G/T, dB/°K	-7.4 (CONUS) -14.4 (Alaska, Hawaii)	-6.0 (CONUS) 31.0 (Alaska) -10.9 (Hawaii) -10.9 (Puerto Rico)

Table 2–104. Westar 3 Characteristics

Launch Date	August 9, 1979
Launch Vehicle	Delta 2914
Range	Eastern Test Range
Mission Objectives	Place the satellite into a synchronous transfer orbit of sufficient accuracy to allow the spacecraft propulsion system to place the spacecraft into stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Western Union
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,780
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	572 in transfer orbit
Dimensions	1.56 m high; 1.85 m diameter
Shape	Cylindrical (drum)
Power Source	Solar cells and battery system
Contractor	Hughes Aircraft
Remarks	Because Westar 1 and Westar 2 were still operating at the time Westar 3 was launched, it was placed into a storage geosynchronous orbit over the equator at approximately 91 degrees west longitude until Westar 1 was removed from service. Westar 3 was in use until it was turned off in January 1990.

Table 2–105. Westar 4 Characteristics

Launch Date	February 25, 1982
Launch Vehicle	Delta 3910
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Western Union
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,778
Inclination (deg.)	0.1
Period (min.)	1,436.1
Weight (kg)	585 (after apogee motor was fired)
Dimensions	6.84 m high (deployed); 2.16 m diameter
Shape	Cylindrical (drum)
Power Source	Solar cells and battery system
Contractor	Hughes Aircraft
Remarks	The satellite was positioned at approximately 99 degrees west longitude above the equator. It operated until November 1991.

Table 2–106. Westar 5 Characteristics

Launch Date	June 8, 1982
Launch Vehicle	Delta 3910
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements.
Owner	Western Union
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,783
Inclination (deg.)	0
Period (min.)	1,436.3
Weight (kg)	585 (after apogee motor was fired)
Dimensions	6.84 m high (deployed); 2.16 m diameter
Shape	Cylindrical (drum)
Power Source	Solar cells and battery system
Contractor	Hughes Aircraft
Remarks	Westar 5 was placed in a geostationary position at approximately 123 degrees west longitude. It replaced Westar 2. It operated until May 1992.

Table 2–107. Westar 6 Characteristics

Launch Date	February 3, 1984
Launch Vehicle	STS 41-B (*Challenger*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle or on the Space Shuttle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Western Union
Orbit Characteristics	Did not reach proper orbit
Weight (kg)	607.8 (after apogee motor was fired)
Dimensions	6.84 m high (deployed); 2.16 m diameter
Shape	Cylindrical (drum)
Power Source	Solar cells and battery system
Contractor	Hughes Aircraft
Remarks	Westar 6 failed to reach its intended geostationary orbit because of a failure of the PAM-D. It was retrieved by the STS 51-A mission in November 1984 and returned to Earth for refurbishment.

Table 2–108. Intelsat Participants

Intelsat Member Countries (as of 1985)

Afghanistan
Algeria
Angola
Argentina
Australia
Austria
Bangladesh
Barbados
Belgium
Bolivia
Brazil
Cameroon
Canada
Central African Republic
Chad
China, People's Republic of
Chile
Columbia
Congo
Costa Rica
Cyprus
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Ethiopia
Fiji
Finland
France
Gabon
Germany, Federal Republic of
Ghana
Greece
Guatemala
Guinea, People's Revolutionary Republic of
Haiti
Honduras
Iceland
India
Indonesia
Iran, Islamic Republic of
Iraq
Ireland
Israel
Italy
Ivory Coast
Jamaica
Japan
Jordan
Kenya
Korea, Republic of
Kuwait
Lebanon
Libya
Liechtenstein
Luxembourg
Madagascar
Malaysia
Mali
Mauritania
Mexico
Monaco
Morocco
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Oman
Pakistan
Panama
Paraguay
Peru
Philippines
Portugal
Qatar
Saudi Arabia
Senegal
Singapore
South Africa
Spain
Sri Lanka
Sudan
Sweden
Switzerland
Syria
Tanzania
Thailand
Trinidad and Tobago
Tunisia
Turkey
Uganda
United Arab Emirates
United Kingdom
United States
Upper Volta
Vatican City State
Venezuela
Viet Nam
Yemen Arab Republic
Yugoslavia
Zaire
Zambia

Table 2–108 continued

Intelsat Non-Signatory		
Users	Hungary	Romania
Bahrain	Kiribati	Seychelles
Botswana	Liberia	Sierra Leone
Brunei	Malawi	Solomon Islands
Burma	Maldives	Somalia
Cook Islands	Mauritius	Surinam
Cuba	Mozambique	Togo
Czechoslovakia	Nauru, Republic of	Tonga
Djibouti	New Guinea	U.S.S.R.
Gambia	Papua	Western Samoa
Guyana	Poland	

Other Territory Users		
American Samoa	French Guiana	Netherlands Antilles
Ascension Island	French Polynesia	New Caledonia
Azores	French West Indies	Van Uatu
Belize	Gibraltar	
Bermuda	Guam	
Cayman Islands	Hong Kong	

Table 2–109. International Contributors to Intelsat

Manufacturer (Country)	Contribution
Aerospatiale (France)	Initiated the structural design that formed the main member of the spacecraft modular design construction; supplied the main body structure thermal analysis and control
GEC-Marconi (United Kingdom)	Produced the 11-GHz beacon transmitter used for Earth station antenna tracking
Messerschmitt-Bolkow-Blohm (Federal Republic of Germany)	Designed and produced the satellites' control subsystem and the solar array
Mitsubishi Electric Corporation (Japan)	Designed and produced the 6-GHz and the 4-GHz Earth coverage antennas; also manufactured the power control electronics and, from an FACC design, the telemetry and command digital units
Senia (Italy)	Designed and built the six telemetry, command, and ranging antennas, two 11-GHz beacon antennas and two 14/11-GHz spot beam antennas; also built the command receiver and telemetry transmitter, which combined to form a ranging transponder for determining the spacecraft position in transfer orbit
Thomson-CSF (France)	Built the 10W, 11-GHz traveling wave tubes (10 per spacecraft)

Table 2–110. Intelsat V F-2 Characteristics

Launch Date	December 6, 1980
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system for Intelsat
Owner	International Telecommunications Satellite Consortium
Orbit Characteristics	
Apogee (km)	35,801
Perigee (km)	35,774
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar arrays and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Intelsat V F-2 (also designated 502) was the first of the Intelsat V series. It was positioned in an orbit at approximately 22 degrees west longitude in the Atlantic region.

Table 2–111. Intelsat V F-1 Characteristics

Launch Date	May 23, 1981
Launch Vehicle	Atlas-Centaur
Range	Cape Kennedy
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,800
Perigee (km)	35,778
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Also designated Intelsat 501, it was positioned in the Atlantic region and later moved to the Pacific region.

Table 2–112. Intelsat V F-3 Characteristics

Launch Date	December 15, 1981
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,801
Perigee (km)	35,772
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Also designated Intelsat 503, it was positioned in the Atlantic region and later moved into the Pacific region.

Table 2–113. Intelsat V F-4 Characteristics

Launch Date	March 3, 1982
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,808
Perigee (km)	35,767
Inclination (deg.)	0.1
Period (min.)	1,436.2
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Also designated Intelsat 504, it was positioned in the Indian Ocean region.

Table 2–114. Intelsat V F-5 Characteristics

Launch Date	September 28, 1982
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,805
Perigee (km)	35,769
Inclination (deg.)	0.1
Period (min.)	1,436.2
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Also designated Intelsat 505, it was positioned in the Indian Ocean region. This flight carried a Maritime Communications Services package for the first time for the Maritime Satellite Organization (Inmarsat) to provide ship/shore/ship communications.

Table 2–115. Intelsat V F-6 Characteristics

Launch Date	May 19, 1983
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,810
Perigee (km)	35,765
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	1,996 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
Remarks	Also designated Intelsat 506, it was positioned in the Atlantic region. It carried the Marine Communications Services package for Inmarsat.

Table 2–116. Intelsat V F-9 Characteristics a

Launch Date	June 9, 1984
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Comsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	Did not reach useful orbit
Weight (kg)	1,928 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m solar array span
Shape	Box
Power Source	Solar array and rechargeable batteries
Contractor	Ford Aerospace and Communication
R**emarks**	The satellite did not reach useful orbit. A leak in the Centaur liquid oxygen tank at the time of Atlas and Centaur separation and the accompanying loss of liquid oxygen through the tank opening precipitated events that compromised vehicle performance and resulted in loss of the mission. This was the first launch of the new lengthened Atlas Centaur rocket.

a Intelsat F-7 and F-8 were launched by an Ariane and are not addressed here.

Table 2–117. Intelsat V-A F-10 Characteristics

Launch Date	March 22, 1985
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
NASA Objectives	Launch the satellite into a transfer orbit, orient it, and spin it at 2 rpm about its longitudinal axis, enabling the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Intelsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,807
Perigee (km)	35,768
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,996 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar array with rechargeable batteries
Contractor	Ford Aerospace and Communications
Remarks	The first in a series of improved commercial communication satellites, the satellite was positioned in the Pacific Ocean region.

Table 2–118. Intelsat V-A F-11 Characteristics

Launch Date	June 30, 1985
Launch Vehicle	Atlas-Centaurr
Range	Eastern Space and Missile Center
NASA Objectives	Launch the satellite into a transfer orbit, orient it, and spin it a 2 rpm about its longitudinal axis, enabling the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Intelsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,802
Perigee (km)	35,772
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,996 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar panels and rechargeable batteries
Contractor	Ford Aerospace and Communications
Remarks	The satellite was placed into a geostationary final orbit at 332.5 degrees east longitude.

Table 2–119. Intelsat V-A F-12 Characteristics

Launch Date	September 29, 1985
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
NASA Objectives	Launch the satellite into a transfer orbit, orient it, and spin it at 2 rpm about its longitudinal axis, enabling the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Intelsat Objectives	Fire the apogee motor, position the satellite into its planned geostationary position, and operate and manage the system
Owner	Intelsat
Orbit Characteristics	
Apogee (km)	35,802
Perigee (km)	35,772
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	1,996 at launch
Dimensions	Main body: 1.66m x 2 m x 1.77 m; height: 6.4 m; solar array span: 15.5 m
Shape	Box
Power Source	Solar panels and rechargeable batteries
Contractor	Ford Aerospace and Communications
Remarks	The satellite was positioned in the Atlantic Ocean region. This was the last commercial mission for the Atlas Centaur rocket. Future Intelsat missions were planned to be launched from the Space Shuttle or the Ariane.

Table 2–120. Fltsatcom 2 Characteristics

Launch Date	May 4, 1979
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the satellite into a synchronous orbit
Owner	U.S. Department of Defense
Orbit Characteristics	
Apogee (km)	35,837
Perigee (km)	35,736
Inclination (deg.)	4.7
Period (min.)	1,436.1
Weight (kg)	1,005 (in orbit)
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	TRW Systems
Remarks	Fltsatcom 2 was initially placed into a geostationary orbit at approximately 23 degrees west longitude after Fltsatcom 3 was deployed, Fltsatcom 2 was moved to a position at approximately 72.5 degrees east longitude to carry Indian Ocean traffic. This marked the 50th Atlas Centaur launch.

Table 2–121. Fltsatcom 3 Characteristics

Launch Date	January 17, 1980
Launch Vehicle	Atlas-Centaur
Range	Eastern Test Range
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the spacecraft into a synchronous orbit
Owner	Department of Defense
Orbit Characteristics	
Apogee (km)	35,804
Perigee (km)	35,767
Inclination (deg.)	4.3
Period (min.)	1,436.1
Weight (kg)	1,005 (in orbit)
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	Defense and Space Systems Group, TRW, Inc.
Remarks	Fltsatcom 3 was placed in geostationary orbit at approximately 23 degrees west longitude.

Table 2–122. Fltsatcom 4 Characteristics

Launch Date	October 30, 1980
Launch Vehicle	Atlas-Centaur
Range	Eastern Test Range
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the satellite into synchronous orbit
Owner	Department of Defense
Orbit Characteristics	
Apogee (km)	35,811
Perigee (km)	35,765
Inclination (deg.)	4.0
Period (min.)	1,436.2
Weight (kg)	1,005 (in orbit)
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	Defense and Space Systems Group, TRW, Inc.
Remarks	Fltsatcom 4 was placed into a geostationary orbit at approximately 172 degrees east longitude above the equator.

Table 2–123. Fltsatcom 5 Characteristics

Launch Date	August 6, 1981
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into a transfer orbit that enables the spacecraft apogee motor to inject the satellite into synchronous orbit
Owner	U.S. Department of Defense
Orbit Characteristics	
Apogee (km)	36,284
Perigee (km)	36,222
Inclination (deg.)	4.6
Period (min.)	1,460.0
Weight (kg)	1,039 (in orbit)
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	Defense and Space Systems Group, TRW, Inc.
Remarks	The satellite reached geostationary orbit, but an imploding payload shroud destroyed the primary antenna, rendering the satellite useless.

Table 2–124. Fltsatcom 7 Characteristics

Launch Date	December 4, 1986
Launch Vehicle	Atlas-Centaur
Range	Cape Canaveral
Mission Objectives	Launch the satellite into an inclined transfer orbit and orient the spacecraft in its desired transfer orbit attitude
Owner	Department of Defense
Orbit Characteristics	
Apogee (km)	35,875
Perigee (km)	35,703
Inclination (deg.)	4.3
Period (min.)	1,436.2
Weight (kg)	1,128.5
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	Defense and Space Systems Group, TRW, Inc.
Remarks	Fltsatcom 7 carried an experimental EHF package in addition to the equipment carried on previous missions. The satellite was placed into a geosynchronous orbit at approximately 100 degrees west longitude.

Table 2–125. Fltsatcom 6 Characteristics

Launch Date	March 26, 1987
Launch Vehicle	Atlas-Centaur
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into an inclined transfer orbit and orient the spacecraft in its desired transfer orbit attitude
Owner	Department of Defense
Orbit Characteristics	Did not achieve orbit
Weight (kg)	1,048 (after firing of apogee boost motors)
Dimensions	Main body: 2.5 m diameter x 1.3 m high; height including antenna: 6.7 m
Shape	Hexagonal spacecraft module and attached payload module
Power Source	Solar arrays and batteries
Contractor	Defense and Space Systems Group, TRW, Inc.
Remarks	Fltsatcom 6 did not achieve proper orbit because of a lightning strike.

Table 2–126. Leasat 2 Characteristics

Launch Date	September 1, 1984
Launch Vehicle	STS-41D (*Discovery*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into successful transfer orbit
Owner	Leased from Hughes Communications Inc. by U.S. Department of Defense
Orbit Characteristics	
Apogee (km)	35,788
Perigee (km)	35,782
Inclination (deg.)	0.7
Period (min.)	1,436.2
Weight (kg)	1,315 on orbit
Dimensions	6 m long (deployed); 4.26 m diameter
Shape	Cylinder
Power Source	Solar array and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	The launch of Leasat 2 was postponed from June 1984 because the Shuttle launch was delayed. The satellite occupied a geostationary position located at approximately 177 degrees west longitude

Table 2–127. Leasat 1 Characteristics

Launch Date	November 10, 1984
Launch Vehicle	STS 51A (*Discovery*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into successful transfer orbit
Owner	Hughes Communications (leased to Department of Defense)
Orbit Characteristics	
Apogee (km)	35,890
Perigee (km)	35,783
Inclination (deg.)	0.9
Period (min.)	1,436.0
Weight (kg)	1,315 on orbit
Dimensions	6 m long (deployed); 4.26 m diameter
Shape	Cylinder
Power Source	Solar array and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Leasat 1 was positioned in geostationary orbit at approximately 16 degrees west longitude.

Table 2–128. Leasat 3 Characteristics

Launch Date	April 13, 1985
Launch Vehicle	STS-51-D (*Discovery*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into successful transfer orbit
Owner	Hughes Communications (leased to Department of Defense)
Orbit Characteristics	
Apogee (km)	35,809
Perigee (km)	35,768
Inclination (deg.)	1.4
Period (min.)	1,436.2
Weight (kg)	1,315 on orbit
Dimensions	6 m long (deployed); 4.26 m diameter
Shape	Cylinder
Power Source	Solar array and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	The Leasat 3 sequencer failed to start despite attempts by the crew to activate it. The satellite remained inoperable until it was repaired in orbit by the crew of STS 51-I in August 1985. It was placed in geosynchronous orbit in November 1985 and began operations in December.

Table 2–129. Leasat 4 Characteristics

Launch Date	August 29, 1985
Launch Vehicle	STS-51-I (*Discovery*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into successful transfer orbit
Owner	Hughes Communications (leased to Department of Defense)
Orbit Characteristics	
Apogee (km)	36,493
Perigee (km)	35,079
Inclination (deg.)	1.4
Period (min.)	1,436.1
Weight (kg)	1,315 on orbit
Dimensions	6 m long (deployed); 4.26 m diameter
Shape	Cylinder
Power Source	Solar array and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Leasat 4 was placed into geosynchronous orbit on September 3, 1985. It functioned normally for about 2 days, at which time the communications payload failed. Efforts to restore the satellite were unsuccessful.

Table 2–130. NATO IIID Characteristics

Launch Date	November 14, 1984
Launch Vehicle	Delta 3914
Range	Eastern Space and Missile Center
Mission Objectives	Place the satellite into synchronous transfer orbit of sufficient accuracy to allow the spacecraft propulsion system to place the satellite into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	North Atlantic Treaty Organization
Orbit Characteristics	
Apogee (km)	35,788
Perigee (km)	35,783
Inclination (deg.)	3.2
Period (min.)	1,436.1
Weight (kg)	388 (after apogee motor fired)
Dimensions	3.1 m long including antennas; 2.18 m diameter
Shape	Cylindrical
Power Source	Solar array and battery charge control array
Contractor	Ford Aerospace and Communications
Remarks	NATO-IIID was positioned at approximately 21 degrees west longitude.

Table 2–131. Anik D-1 Characteristics

Launch Date	August 26, 1982
Launch Vehicle	Delta 3920/PAM-D
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite on a two-stage Delta 3920 vehicle with sufficient accuracy to allow the MDAC PAM-D and the spacecraft propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Telesat Canada Corporation
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,776
Inclination (deg.)	0
Period (min.)	1,436.0
Weight (kg)	730 in orbit
Dimensions	6.7 m high with solar panel and antenna deployed; 2.16 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Anik D-1 was the first of two satellites built for Telesat/Canada to replace the Anik A series. It was located in geostationary orbit at approximately 104.5 degrees west longitude. It remained in service until February 1995.

Table 2–132. Anik C-3 Characteristics

Launch Date	November 12, 1982
Launch Vehicle	STS-5 (*Columbia*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into transfer orbit, permitting the spacecraft propulsion system to place it in stationary synchronous orbit for communications coverage over Canada
Owner	Telesat Canada Corporation
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,779
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	567 in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Anik C-3 was placed in geostationary orbit at approximately 114.9 degrees west longitude.

Table 2–133. Anik C-2 Characteristics

Launch Date	June 18, 1983
Launch Vehicle	STS-7 (*Challenger*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into transfer orbit, permitting the spacecraft propulsion system to place it in stationary synchronous orbit for communications coverage over Canada
Owner	Telesat Canada Corporation
Orbit Characteristics	
Apogee (km)	35,791
Perigee (km)	35,782
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	567 in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Anik C-2 was placed in geostationary orbit at approximately 110 degrees west longitude

Table 2–134. Anik D-2 Characteristics

Launch Date	November 9, 1984
Launch Vehicle	STS 51-A (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite with sufficient accuracy to allow the MDAC PAM-D and the spacecraft propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Telesat Canada Corporation
Orbit Characteristics	
Apogee (km)	35,890
Perigee (km)	35,679
Inclination (deg.)	0.9
Period (min.)	1,436.0
Weight (kg)	730 in orbit
Dimensions	6.7 m high with solar panel and antenna deployed; 2.16 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Anik D-2 was placed in geostationary orbit at approximately 110 degrees west longitude. It was removed from service in March 1995.

Table 2–135. Anik C-1 Characteristics

Launch Date	April 13, 1985
Launch Vehicle	STS-51D (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into transfer orbit, permitting the spacecraft propulsion system to place it in stationary synchronous orbit for communications coverage over Canada
Owner	Telesat Canada Corporation
Orbit Characteristics	
Apogee (km)	35,796
Perigee (km)	35,777
Inclination (deg.)	0.1
Period (min.)	1,436.0
Weight (kg)	567 in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Aircraft
Remarks	Anik C-1 was placed in geostationary orbit at approximately 107 degrees west longitude.

Table 2–136. Arabsat-1B Characteristics

Launch Date	June 18, 1985
Launch Vehicle	STS 51-G (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch satellite into transfer orbit of sufficient accuracy to allow the spacecraft propulsion systems to place it in stationary synchronous orbit for communications coverage
Owner	Saudi Arabia
Orbit Characteristics	
Apogee (km)	35,807
Perigee (km)	35,768
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	700 kg in orbit
Dimensions	2.26 m x 1.64 m x1.49 m with a two-panel solar array 20.7 m wide
Shape	Cube
Power Source	Solar array and batteries
Contractor	Aerospatiale
Remarks	The satellite was placed in geosynchronous orbit at approximately 26 degrees east longitude. It began drifting east in October 1992 and went out of service in early 1993.

Table 2–137. Aussat 1 Characteristics

Launch Date	August 27, 1985
Launch Vehicle	STS 51-I (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Successfully launch the satellite into transfer orbit
Owner	Australia
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,781
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	655 in orbit
Dimensions	2.8 m long stowed; 6.6 m deployed; 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Aussat 1 (also called Optus A1) was placed in geosynchronous orbit at approximately 160 degrees east longitude.

Table 2–138. Aussat 2 Characteristics

Launch Date	November 27, 1985
Launch Vehicle	STS 61-B (*Atlantis*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Successfully launch the satellite into transfer orbit
Owner	Australia
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,780
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	655 in orbit
Dimensions	2.8 m long stowed; 6.6 m deployed; 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Aussat 2 (also called Optus A2) was placed in geosynchronous orbit at approximately 156 degrees east longitude.

Table 2–139. Insat 1A Characteristics

Launch Date	April 10, 1982
Launch Vehicle	Delta 3910
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite along a suborbital trajectory on a two-stage Delta 3910 launch vehicle with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Department of Space for India
Orbit Characteristics	
Apogee (km)	35,936
Perigee (km)	35,562
Inclination (deg.)	0.1
Period (min.)	1,434.2
Weight (kg)	650 in orbit
Dimensions	1.6 m x 1.4 m x 2.2 m
Shape	Cube
Power Source	Solar arrays and nickel cadmium batteries
Contractor	Ford Aerospace and Communications
Remarks	The initial attempt to open the C-band uplink antenna was unsuccessful. Deployment was finally accomplished by blasting the antenna with reaction control jets beneath it. The S-band downlink antenna was successfully deployed, but the accompanying release of the solar sail did not occur. This resulted in the Moon being in the field of view of the active Earth sensor. The unpredicted Moon interference caused the satellite attitude reference to be lost. The command link was broken as the satellite attitude changed. As a result, safing commands could not be received, all fuel was consumed, and the satellite was lost in September 1982.

Table 2–140. Insat 1B Characteristics

Launch Date	August 31, 1983
Launch Vehicle	STS-8 (*Challenger*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite along a suborbital trajectory with sufficient accuracy to allow the payload propulsion system to place the spacecraft into a stationary synchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Department of Space for India
Orbit Characteristics	
Apogee (km)	35,819
Perigee (km)	35,755
Inclination (deg.)	0.1
Period (min.)	1,436.2
Weight (kg)	650 in orbit
Dimensions	1.6 m x 1.4 m x 2.2 m
Shape	Cube
Power Source	Solar arrays and nickel cadmium batteries
Contractor	Ford Aerospace and Communications
Remarks	Insat 1B was placed in geosynchronous orbit at approximately 74 degrees east longitude.

Table 2–141. Morelos 1 Characteristics

Launch Date	June 17, 1985
Launch Vehicle	STS 51-G (*Discovery*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into transfer orbit, permitting the spacecraft propulsion system to place it in stationary synchronous orbit for communications coverage
Owner	Mexico
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,780
Inclination (deg.)	1.1
Period (min.)	1,436.1
Weight (kg)	645 in orbit
Dimensions	6.6 m long (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	The satellite was positioned at approximately 113.5 degrees west longitude.

Table 2–142. Morelos 2 Characteristics

Launch Date	November 27, 1985
Launch Vehicle	STS 61-B (*Atlantis*)/PAM-D
Range	Kennedt Space Center
Mission Objectives	Launch the satellite into transfer orbit, permitting the spacecraft propulsion system to place it in stationary synchronous orbit for communications coverage
Owner	Mexico
Orbit Characteristics	
Apogee (km)	35,794
Perigee (km)	35,780
Inclination (deg.)	1.1
Period (min.)	1,436.1
Weight (kg)	645 in orbit
Dimensions	6.6 m long (deployed); 2.16 m diameter
Shape	Cylindrical
Power Source	Solar cells and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Morelos 2 was not activated once it achieved its geosynchronous storage orbit. It was allowed to drift to its operational orbit at approximately 116.8 degrees west longitude. It began operations in March 1989.

Table 2–143. Palapa B-1 Characteristics

Launch Date	June 18, 1983
Launch Vehicle	STS-7 (*Challenger*)
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into a transfer orbit that permits the spacecraft propulsion system to place it in stationary geosynchronous orbit for communications
Owner	Indonesia
Orbit Characteristics	
Apogee (km)	35,788
Perigee (km)	35,783
Inclination (deg.)	0
Period (min.)	1,436.1
Weight (kg)	630 at beginning of life in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	This satellite replaced Palapa A-1 in geosynchronous orbit at approximately 83 degrees east longitude.

Table 2–144. Palapa B-2 Characteristics

Launch Date	February 6, 1984
Launch Vehicle	STS 41-B (*Challenger*)/PAM-D
Range	Kennedy Space Center
Mission Objectives	Launch the satellite into a circular orbit with sufficient accuracy to allow the PAM-D stage and the spacecraft apogee kick motor to place the spacecraft into a stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Indonesia
Orbit Characteristics	Did not achieve proper orbit
Apogee (km)	1,190
Perigee (km)	280
Inclination (deg.)	28.2
Period (min.)	99.5
Weight (kg)	630 in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	Palapa B-2 was to be placed into geostationary orbit, but it did not reach its location because the PAM failed. The spacecraft was retrieved by STS 51-A and returned to Earth for refurbishment. The satellite was relaunched as Palapa B-2R in April 1990.

Table 2–145. Palapa B-2P Characteristics

Launch Date	March 20, 1987
Launch Vehicle	Delta 3920
Range	Eastern Space and Missile Center
Mission Objectives	Launch the satellite into a circular orbit on a two-stage Delta 3920 launch vehicle with sufficient accuracy to allow the PAM-D stage and the spacecraft apogee kick motor to place the spacecraft into a stationary geosynchronous orbit while retaining sufficient stationkeeping propulsion to meet the mission lifetime requirements
Owner	Indonesia
Orbit Characteristics	
Apogee (km)	35,788
Perigee (km)	35,788
Inclination (deg.)	0
Period (min.)	1,436.2
Weight (kg)	630 in orbit
Dimensions	2 m high; 1.5 m diameter
Shape	Cylindrical
Power Source	Solar panels and nickel cadmium batteries
Contractor	Hughes Communications
Remarks	The satellite was positioned in geosynchronous orbit at approximately 113 degrees east longitude.

Table 2–146. UoSAT 1 Characteristics

Launch Date	October 6, 1981
Launch Vehicle	Delta 2310
Range	Western Test Range
Mission Objectives	Provide radio amateurs and educational institutions with an operational satellite that could be used with minimal ground stations for studying ionosphere and radio propagation conditions
Owner	University of Surrey, United Kingdom
Orbit Characteristics	
Apogee (km)	470
Perigee (km)	469
Inclination (deg.)	97.6
Period (min.)	94
Weight (kg)	52
Dimensions	42.5 cm square, 83.5 cm high
Shape	Rectangular
Power Source	Batteries
Contractor	University of Surrey
Remarks	UoSAT 1 was a piggyback payload with the Solar Mesospheric Explorer. It had some initial difficulty with transmitting data because of interference from a 145-MHz telemetry transmitter that was overcome by shifting to a redundant 435-MHz command system.

Table 2–147. UoSAT 2 Characteristics

Launch Date	March 1, 1984
Launch Vehicle	Delta 3920
Range	Western Space and Missile Center
Mission Objectives	Stimulate interest in space science and engineering among radio amateurs, school children, students, colleges, and universities; provide professional and amateur scientists with a low-Earth-orbit reference for magnetospheric studies to be carried out concurrently with AMPTE and Viking missions, while supporting ground-based studies of the ionosphere; and advance further developments in cost-effective spacecraft engineering with a view to establishing a low-cost spacecraft system design for use in future STS Get-Away Special launches and other secondary payload opportunities
Owner	University of Surrey, United Kingdom
Orbit Characteristics	
Apogee (km)	692
Perigee (km)	674
Inclination (deg.)	98.1
Period (min.)	98.4
Weight (kg)	60
Dimensions	35 cm x 35 cm x 65 cm
Shape	Cube
Power Source	Batteries
Contractor	University of Surrey
Remarks	UoSAT 2 was a piggyback payload with Landsat 5.

Table 2–148. NOVA 1 Characteristics

Launch Date	May 15, 1981
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the Navy satellite in a transfer orbit to enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,182
Perigee (km)	1,164
Inclination (deg.)	90
Period (min.)	109.2
Weight (kg)	166.7
Dimensions	Body: 52.07 cm diameter; attitude control section: 26.7 cm diameter, 76.2 cm length
Shape	Octagonal body topped by a cylindrical attitude control section
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Astro Electronics and Applied Physics Laboratory
Remarks	NOVA 1 was the first in a series of advanced navigational satellites built for the Navy. The satellite failed in March 1991.

Table 2–149. NOVA 3 Characteristics

Launch Date	October 12, 1984
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the satellite in a transfer orbit to enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,200
Perigee (km)	1,149
Inclination (deg.)	90
Period (min.)	108.9
Weight (kg)	166.7
Dimensions	Body: 52.07 cm diameter; attitude control section: 26.7 cm diameter, 76.2 cm length
Shape	Octagonal body topped by a cylindrical attitude control section
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Astro Electronics and Applied Physics Laboratory
Remarks	NOVA 3 was the second in the series of improved transit navigation satellites. The satellite failed in December 1993.

Table 2–150. NOVA 2 Characteristics

Launch Date	June 16, 1988
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the satellite in a transfer orbit to enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,199
Perigee (km)	1,149
Inclination (deg.)	89.9
Period (min.)	108.9
Weight (kg)	166.7
Dimensions	Body: 52.07 cm diameter; attitude control section: 26.7 cm diameter, 76.2 cm length
Shape	Octagonal body topped by a cylindrical attitude control section
Power Source	Solar cells and nickel cadmium batteries
Contractor	RCA Astro Electronics and Applied Physics Laboratory
Remarks	Third in a series of improved transit navigation satellites launched by NASA for the U.S. Navy, the satellite failed in June 1996.

Table 2–151. SOOS-I (Oscar 24/Oscar 30) Characteristics

Launch Date	August 3, 1985
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the Navy SOOS-I mission into an orbit that will enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	Oscar 24: 1,257; Oscar 30: 1,258
Perigee (km)	1,002
Inclination (deg.)	89.9
Period (min.)	107.9
Weight (kg)	128 (both Oscars and interface cradle)
Dimensions	25 cm long; 46 cm diameter
Shape	Octagonal prism
Power Source	Four solar panels
Contractor	RCA Americom Astro-Electronics Division
Remarks	Oscar 24 and Oscar 30 were part of U.S. Navy Transit (Navy Navigation Satellite System). The satellites were launched into polar orbit at the same time.

Table 2–152. SOOS-2 (Oscar 27/Oscar 29) Characteristics

Launch Date	June 16, 1987
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the Navy SOOS-2 mission into an orbit that will enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,175 and 1,181
Perigee (km)	1,017 and 1,181
Inclination (deg.)	90.3
Period (min.)	107.2
Weight (kg)	128 (both Oscars and interface cradle)
Dimensions	25 cm long; 46 cm diameter
Shape	Octagonal prism
Power Source	Four solar panels
Contractor	RCA Americom Astro-Electronics Division
Remarks	This was in use through 1996.

Table 2–153. SOOS-3 (Oscar 23/Oscar 30) Characteristics

Launch Date	April 25, 1988
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the Navy SOOS-3 mission into an orbit that will enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,302 and 1,316
Perigee (km)	1,017 and 1,018
Inclination (deg.)	129.6
Period (min.)	108.6 and 108.7
Weight (kg)	128 (both Oscars and interface cradle)
Dimensions	25 cm long; 46 cm diameter
Shape	Octagonal prism
Power Source	Four solar panels
Contractor	RCA Americom Astro-Electronics Division
Remarks	This had an improved downlink antenna and a frequency synthesizer that gave the capability of selecting other downlink frequencies. This allowed monitoring of stored-in-orbit spacecraft on a frequency offset that did not interfere with satellites broadcasting on "operational" frequency. It was operational through 1996.

Table 2–154. SOOS-4 (Oscar 25 and Oscar 31) Characteristics

Launch Date	August 24, 1988
Launch Vehicle	Scout
Range	Western Space and Missile Center
Mission Objectives	Place the Navy SOOS-4 mission into an orbit that will enable the successful achievement of Navy objectives
Owner	Department of Defense (Navy)
Orbit Characteristics	
Apogee (km)	1,176 and 1,178
Perigee (km)	1,032 (both)
Inclination (deg.)	90.0
Period (min.)	107.4
Weight (kg)	128 (both Oscars and interface cradle)
Dimensions	25 cm long; 46 cm diameter
Shape	Octagonal prism
Power Source	Four solar panels
Contractor	RCA Americom Astro-Electronics Division
Remarks	This had an improved downlink antenna and a frequency synthesizer that gave the capability of selecting other downlink frequencies. This allowed monitoring of stored-in-orbit spacecraft on a frequency offset that did not interfere with satellites broadcasting on "operational" frequency. It was operational through 1996.