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SATELLITES AT WORK

Space in the Seventies

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SPACE IN THE SEVENTIES

Man has walked on the Moon, made scientific observations there, and brought back to Earth samples of the lunar surface.

Unmanned scientific spacecraft have probed for facts about matter, radiation and magnetism in space, and have collected data relating to the Moon, Venus, Mars, the Sun and some of the stars, and reported their findings to ground stations on Earth.

Spacecraft have been put into orbit around the Earth as weather observation stations, as communications relay stations for a world-wide telephone and television network, and as aids to navigation.

In addition, the space program has accelerated the advance of technology for science and industry, contributing many new ideas, processes and materials.

All this took place in the decade of the Sixties.

What next? What may be expected of space exploration in the Seventies?

NASA has prepared a series of publications and motion pictures to provide a look forward to SPACE IN THE SEVENTIES. The topics covered in this series include: Earth orbital science; planetary exploration; practical applications of satellites; technology utilization; man in space; and aeronautics. SPACE IN THE SEVENTIES presents the planned programs of NASA for the coming decade.

June, 1971

COVER:

This photograph of the Earth was taken by ATS 3 from its on-station position at 47 degrees west longitude on the equator over Brazil. Four continents can be seen; South America is most prominent. Major weather over the central United States consists of a cold front moving eastward. At bottom center, a tropical storm can be seen with a cold front extending into Argentina.

SATELLITES AT WORK

In Communications, Meteorology, Geodesy, Navigation, Air Traffic Control, and Earth Resources Technology

by William R. Corliss

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

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INTRODUCTION

What possible practical uses could there be for a few pounds of contrived metal located over 100 miles above the Earth? Historians of technology can vouch that the same kinds of questions were leveled at the telegraph, the steam engine, and almost every other important invention. "Get a horse!" was a common jeer still within the recollection of millions.

Today, everyone accepts the intercontinental satellite relay of television programs and telephone conversations, but these communication satellites initially had to overcome the same skepticism as the automobile. We also expect to be warned of the approach of dangerous hurricanes and to be told tomorrow's weather with high reliability. Who hasn't seen a satellite-taken picture of cloud cover? Weather satellites and communication satellites represent just the beginning. In the artificial satellite, we have a powerful tool which is already being turned to the solution of some of the world's pressing practical problems.

Offhand, it is difficult to see how a small, automated machine more than 100 miles up could possibly contribute to this planet's down-to-Earth problems. A century ago, an Earth satellite would indeed have been of little use, but today when we are nearing the limits of our planet's raw materials and its capacity to recycle our wastes, Earth satellites prove to be invaluable pollution monitors, resource-finders, weather-watchers, and communication relay points. As the conventional tools and techniques falter in their struggle with terrestrial problems, space technology is coming forth with new ideas, new ways to solve problems. This is NASA's great challenge during the next decade: to help understand the Earth's ecology and develop space systems which will, on the one hand, solve old problems, and, on the other, not create additional new problems for mankind.

The first "applications satellite" was conceived about a century ago by Edward Everett Hale, best known for his story "The Man Without a Country." In 1869, Hale's precocious tale, "The Brick Moon," was published in the *Atlantic Monthly*. Hale envisioned a large artificial satellite circling the Earth in an orbit over the poles and passing along the Greenwich meridian. Ships at sea, he reasoned, could take bearings on this man-made moon and thus fix their positions more accurately. The Brick Moon, though only fictional, was the first navigation satellite.

The Brick Moon had the advantage of height over the usual terrestrial landmarks used by navigators. Like present-day satellites, it could be seen from afar. Almost all of the practical benefits of artificial satellites stem from this single factor—height and, consequently, a sweeping view of the Earth. Not only can terrestrial eyes, including radio antennas, located thousands of miles apart see the satellite, but, given vision of its own, a satellite with a TV camera can scrutinize huge portions of the Earth's surface. Indeed, the applications satellite is an invaluable extension of our sense in two ways: (1) it sees much more territory; and (2) its sensors see well beyond the narrow visible spectrum. Looking at the Earth below through infrared sensors is like looking through magic glasses; everything glows according to its temperature and chemical makeup. For this reason, infrared sensors and those sensitive to other wavelengths can diagnose the Earth's surface environment from afar.

NASA's Approach

By the time NASA was created in 1958, various government agencies had already made numerous studies of the potential advantages of artificial satellites in communications and weather forecasting. Some of the earliest satellites launched by the United States were of these types; for example, Score (1958) and Tiros 1 (1960). In 1958, one of NASA's first jobs was obvious: develop communication and weather satellites for practical use on a day-to-day basis. During the early 1960's, almost two dozen satellites were launched to test spacecraft techniques and sensors. As space hardware and the associated ground equipment were proven out, other government agencies and private industry began to play more dominant roles in the operational aspects of satellite communication and meteorology. The Communications Satellite Corporation (COMSAT) was created by Congress in 1962 to establish a global communication network employing communication satellites. Soon after, the Environmental Science Services Administration (ESSA), now part of the National Oceanic and Atmospheric Administration (NOAA), assumed responsibility for operating weather satellites. NASA's role is now that of providing launch and tracking services for COMSAT and NOAA on a reimbursable basis, and, more pertinent to this

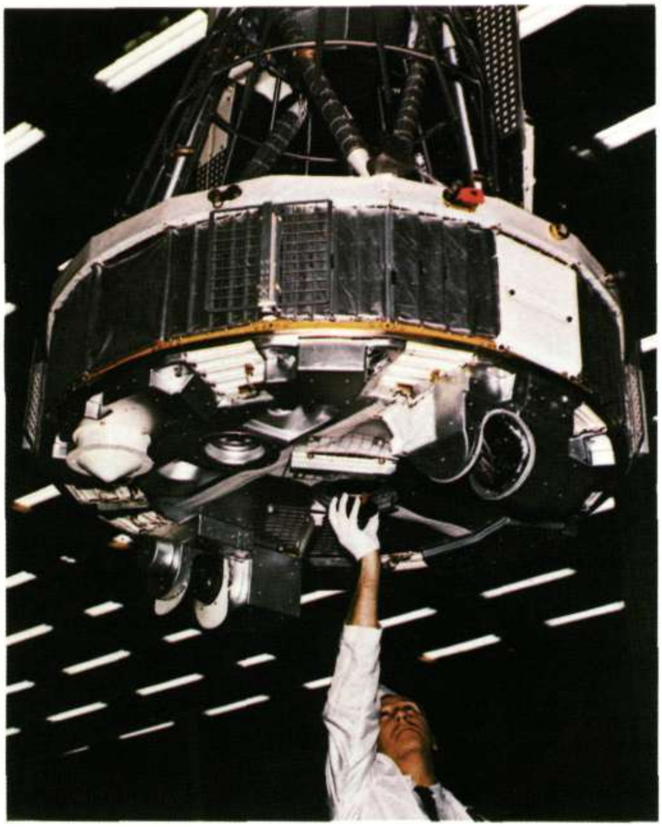


Fig. 1 Earth satellites carry a wide variety of infrared, microwave, and visible light sensors for meteorological and Earth resource studies. The Nimbus sensor ring is shown here.

booklet, pursuing new ideas in the technology of communication and weather satellites, for we can be sure that we are just beginning to reap the practical benefits from the space program.

The technological foundation of applications satellites has three main parts:

1. *The spacecraft itself,* in particular the data handling and attitude control subsystems. Satellites tend to maintain the same orientation with respect to the fixed stars as they circle the Earth; therefore, satellites must be designed deliberately to point continuously toward the Earth and must be deliberately turned on their axes once each orbit.
2. *Sensors.* The usefulness of satellites in forecasting the weather and in assessing the planet's resources depends upon being able to distinguish the many electromagnetic subtleties of the radiation reflected and emitted from the Earth's surface and atmosphere. (Fig. 1)
3. *Ground operations.* One of the most complex tasks is the deployment of ground stations to receive satellite transmissions and relay them to central processing facilities, where they are converted into formats suitable to the ultimate consumer. Ordinary telephone lines are not adequate; new worldwide networks of high capacity circuits must be built.

NASA's efforts are directed primarily toward the development of new spacecraft and sensors, while the major operating agencies (NOAA and the COMSAT Corporation) are concerned more with ground operations and the practical applications of the data acquired by the satellites. Of course, NASA works closely with these agencies to insure that the satellites and sensors it develops meet the objectives of the groups using the data.

For convenience, NASA divides its applications satellite programs into two groups: (1) the Communications Programs, and (2) the Earth Observation Programs. Naturally, there is considerable transfer of technology from one program area to the other. The Communications Programs include NASA's work on advanced communications satellites, geodetic satellites, and the Applications Technology Satellite (ATS). The ATS also provides valuable technology for the Earth Observation Programs, which include the development of advanced meteorological satellites and the Earth Resources Technology Satellite (ERTS) Program.

Each of the program areas will be covered in more detail in the subsequent pages. Table 1 lists the specific satellites under development in each area and the launch schedules.

A TESTING LABORATORY FOR NEW CONCEPTS (ATS)

Aircraft manufacturers have long used flying "test beds" to test out new ideas for improving the species. The Applications Technology Satellites (ATSs) were built in accordance with this philosophy. A major difference, of course, is that an ATS must be operated by remote control from the Earth and no opportunity exists for actual physical examination of the equipment under test once it is in orbit.

The ATS is a project of NASA's Goddard Space Flight Center. The first five spacecraft in the ATS series have been launched. The intention was to place all five in *synchronous* or *geostationary* orbits, in which the satellites' periods of rotation about the Earth are the same as the Earth's period of rotation about its spin axis. Geostationary satellites orbit over the Equator at altitudes of about 22,300 miles and, to an observer on the Earth below, appear to remain in the same spot in the sky. The first five ATSs attempted to solve such technological problems as spin stabilization at geostationary altitudes and the accurate pointing of antenna beams and sensor patterns at the Earth. Several communication experiments and tests of cameras and other sensors were successfully concluded during these flights.

The designations and launch dates of these spacecraft are given below:

Prelaunch Designation	Postlaunch Designation	Launch Date	Remarks
ATS A	ATS 1	Dec. 7, 1966	First photo showing nearly entire Earth disc; over 2500 photos returned.
ATS B	ATS 2	Apr. 6, 1967	Did not attain geostationary orbit due to launch-vehicle failure.
ATS C	ATS 3	Nov. 5, 1967	Performed nine experiments.
ATS D	ATS 4	Aug. 10, 1968	Did not attain geostationary orbit due to launch-vehicle failure.
ATS E	ATS 5	Aug. 12, 1969	Spacecraft nutation damper failed. Partial success.

ATS F and G represent a new generation of spacecraft. The basic spacecraft design, which is dominated by a 30-foot umbrella-like antenna, will be unique among the hundreds of manmade craft now in orbit around the Earth. (Fig. 2) The unusual geometry is dictated by the prime objectives of the ATS F/G mission:

- Demonstrate the feasibility of deploying a collapsible paraboloidal antenna 30 feet in diameter and which has good radio-frequency

TABLE 1. NASA Launch Schedule For Applications Satellites*

Satellite	70	71	72	73	74	75	
ATS				F		G	Communications Programs
CAS		A					
Intelsat		IV-1 IV-2					
Geos				C			
ITOS	A (NOAA-1)	B	D,C	F	G		Earth Observation Programs
Nimbus			E		F		
SMS			A	B			
ERTS			A	B			

*The letters refer to specific satellite vehicles. When satellites are launched successfully, numbers are assigned.

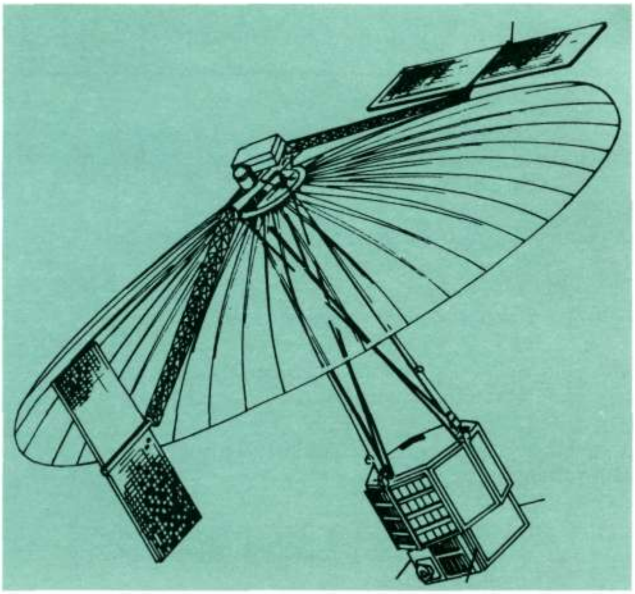


Fig. 2 Conceptual drawing of the ATS spacecraft.

performance up to 6000 MHz.* (The major technical difficulty here lies in the fact that the antenna must be folded up to fit within the launch vehicle fairing.)

- Demonstrate precision pointing of the spacecraft and its fixed antenna to within 0.1° and the capability of slewing (turning) the antenna 17.5° in 30 minutes. The spacecraft has to do this if it is to provide service to different areas of the Earth below.

The other characteristics of the ATS F/G spacecraft are described in Table 2.

Every operational satellite is only a part of a larger machine which includes ground equipment connected by radio links to the satellite and the people who use the information transmitted by the satellite. The ATS F and G spacecraft will be supported by NASA's Space Tracking and Data Acquisition Network (STADAN) and four special ATS ground stations which will take part in several of the communication experiments. Two of the ATS stations will be at fixed locations—Rosman, N. C., and Barstow, Calif., both of which are permanent NASA tracking station sites. The two other ground stations will be the Mobile Terminal and the Transportable Ground Station. These will be relocated as the experiments demand.

The first satellite (ATS F) will first be placed in a geostationary orbit over the equator where it can see and be seen from almost one third of the Earth's area. The spacecraft can, however, be moved from one spot to another by its rocket motor as the experiments require. These positions must always be over the equator. For example, Fig. 3 shows an ATS located just west of the South American coast, 22,300 miles over the Equator. The antenna beam patterns in the C Band and Ultrahigh Frequency (UHF) Band "illuminate" the southeastern U.S. with radio energy as shown by the contours.* The aiming point is NASA's Rosman, N. C., tracking station.

*A MegaHertz (MHz) is one million cycles per second. It is a unit of frequency.

One objective of the ATS F and G experiments is the improvement of communications between terrestrial terminals via satellite relay. In 1944, the noted science fiction writer, Arthur C. Clarke, proposed satellite radio relays; so the idea itself is about 30 years old. The new ATS satellites will carry Clarke's idea several steps further with experiments in educational TV broadcasting, satellite-to-satellite relay, and air-traffic control. The planned experiments are described on pages 9 and 10. Not all ATS experiments deal with communications. To illustrate, all ATS satellites carry some scientific instrumentation because no scientific satellites presently operate in geostationary orbits. The ATSs, therefore, provide a unique opportunity to position scientific sensors at specific spots over the Earth's equator at fixed altitudes.

*C-Band and UHF refer to portions of the electromagnetic frequency spectrum; specifically, 3900-6200 MHz and 300-3000 MHz.

Fig. 3 ATS F, located over the equator just west of the South American coast, can concentrate its radio beams in the regions indicated.

TABLE 2. Design Features and Vital Statistics, ATS F and G*

Spacecraft Functions	Design Features
Communications	A versatile transponder† capable of receiving and replying to terrestrial transmissions at various frequencies. Pulse-code modulated (PCM) telemetry sends data on spacecraft status to Earth. 30-foot paraboloidal dish.
Power supply	The ATS uses deployable, flat solar-cell panels. The average power level will be about 500 watts, initially. Nickel-cadmium batteries.
Attitude control	Inertia (or momentum) wheels and the propulsion unit described below.
Propulsion	One concept employs a controllable hydrazine rocket engine. An ammonia resistojet (an electrically heated rocket) has been proposed in the other concept.
Thermal control	Passive coatings and insulations. Heat pipes used in places to help distribute heat. Thermal louvers (blinds) used in critical sections.
Guidance and control	Sun and Earth sensors, inertial reference for attitude determination. 512 pulse commands; 32 digital commands. Experimental radio interferometer will be tested as an attitude sensor.
Structure	Deployable 30-foot antenna and solar panels. Earth-viewing and Aft-viewing Equipment Modules. Tubular struts support all components in configuration shown in Fig. 2. Weight: about 2050 pounds.
Launch vehicle	Titan 3.
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN) and four special ATS ground stations.

*As the design of the spacecraft continues, some of the details presented will change.

†A radio transponder automatically responds to transmissions from stations knowing the proper code or frequency.

COMMUNICATION SATELLITES

If one drew all of the Earth's electronic communication links on a globe (in the same way airline routes are drawn), the following features would emerge:

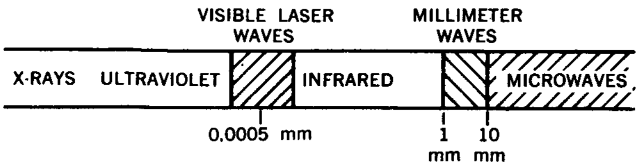
1. The technically advanced nations are virtually covered with telephone lines, underground cables, microwave links, and various other electronic nerve fibers.
2. The less-developed nations are comparatively bare of these communication lines, with the densest coverage noted around a few cities.
3. The planet's wide oceans and vast expanses of Africa, Asia, Australia, and South America boast few if any communication terminals.
4. The continents are connected primarily by undersea cables and—in recent years—by satellite radio links.

The first commercial communication satellites, the geostationary Intelsats, have been jockeyed into positions between the continents where they relay voice conversations, TV programs, and data from one busy communication terminal to another, much as undersea cables do. Point-to-point relay of signals, however, does not bring all the benefits of good communications to everyone. For example, the ATS F/G educational television relay experiment will demonstrate the feasibility of broadcasting educational programs to wide areas in the less-developed countries where ground-based transmitters are rare.

PRACTICAL EXPERIMENTS ON ATS F/G

The Laser Experiment

The light emitted by lasers can carry much more information than radio waves. Because the world's demand for more communication may outstrip the capacity of radio systems, NASA is laying the groundwork for laser communication links between satellites and Earth stations and from satellite to satellite. (Laser experiment on ATS G only.)

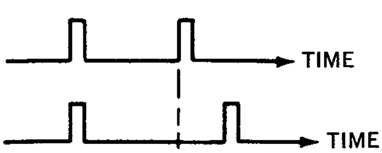


The Millimeter Wave Experiment

In addition to exploring optical wavelengths with the laser described above, ATS F/G will help expand the useful radio spectrum into the millimeter region of the spectrum (10 mm is equivalent to 30,000 MHz). The major objective is the precise definition of communication channels at these high frequencies.

The Radio Dispersion Experiment

When radio signals pass through the Earth's atmosphere and ionosphere, frequencies are changed slightly and so are the time relationships between signals. Called frequency and time dispersion, respectively, these phenomena cause trouble in the transmission of digital data—as from one computer to another. This experiment is aimed at understanding dispersion better and finding ways to circumvent it.



TIME DISPERSION OF SIGNALS

The Radio Frequency Interference Experiment

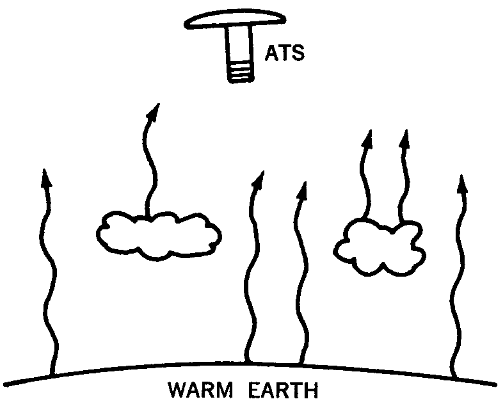
At the frequencies used for the microwave relay of conversations and business data (6000 MHz), there is significant interference from the radio noise created by lightning and other atmospheric phenomena. ATS F/G will carry a special receiver to record this noise and help us understand and overcome it.

Radio Beacon Experiment

By directing radio signals at several frequencies toward the Earth, this ATS experiment will enable scientists to measure the effects of ionized particles on propagation paths beyond the atmosphere.

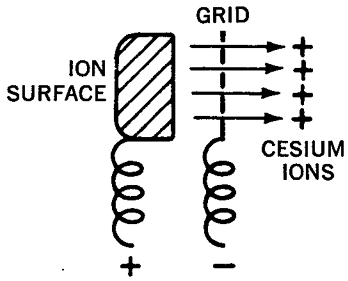
The Very High Resolution Radiometer Experiment (VHRRE)

In a later section on meteorology there is a discussion of the importance of cloud-cover pictures, taken day and night, for better weather forecasting. The VHRRE consists of a telescope with detectors sensitive to both visible and infrared radiation. Because clouds emit less infrared radiation than the ground, the infrared detector can help make pictures of them even at night. The flight qualification of this instrument is important to the development of the Synchronous Meteorological Satellite (SMS). (See later.)



The Ion Engine Experiment

Small thrusts can be generated without the expenditure of much propellant by electrically accelerating cesium ions to high velocities. If the experimental ion engine on ATS is successful, future synchronous satellites may use ion engines to help them maintain their stations over specific spots on the Equator.



Indian Educational Television Test

ATS F and G will broadcast educational TV programs to villages and rural areas in a joint experiment with India. See text and Fig. 4.

Integrated Scientific Experiments

Most scientific satellites orbit well below the 22,300 mile geostationary orbits. Consequently, there is comparatively little data on the charged-particle environment at ATS altitudes. Because communication and future meteorological satellites will operate in this region, it is imperative to understand this environment better. That is the purpose of this experiment.

Other ATS Experiments

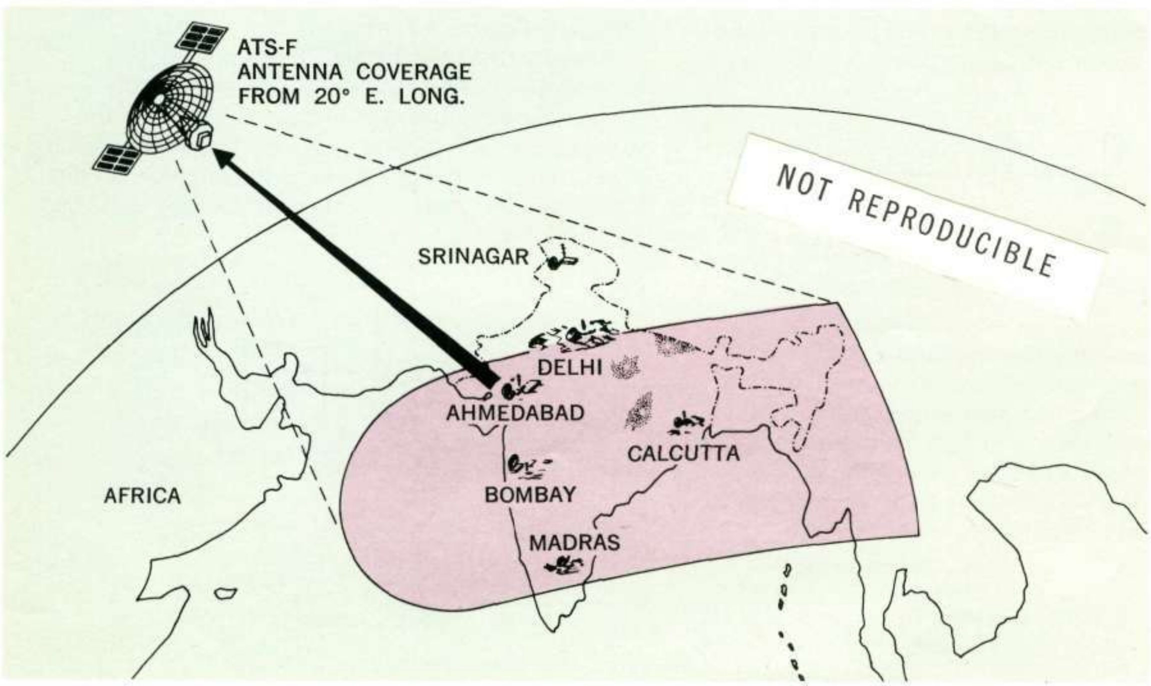
In another ATS experiment, the satellite will be used as a communication relay during Apollo Moon flights. An air traffic control experiment is also planned. The final experiment will involve an attempt to control the orientation of ATS F/G using measurements made from the Earth.

(Fig. 4) Point-to-point relay and broadcasting from satellites actually represent only early steps in the evolution of instant worldwide communication for everyone. Ideally, it would be possible to contact any desired combination of people and/or machines from any spot on Earth with a minimum of equipment and at low cost. Such service is available today only within the boundaries of the technologically advanced countries. Communication satellites can help expand this kind of service to other countries and to those desolate regions where wires and large communication terminals do not exist.

Information networking is a concept where satellites can also help. It might be desirable, by way of illustration, to link together all medical facilities on the globe. (Fig. 5) All recorded knowledge could, in principle, be pooled and made available at the terminals of such a network. With several geostationary satellites placed where they can be seen from all parts of the planet, such a concept becomes possible.

Another concept is the "multi-access" communication satellite wherein many small terminals—your home, for example—can call upon the services of any communication satellite within view simultaneously. Individuals or unmanned instrument stations in remote areas with a modest radio transceiver could become part of a global network at the flick of a switch. Sensor fields, such as widely dispersed

Fig. 4 The United States-India educational television experiment will employ ATS F for broadcasting. High frequency signals can be focused onto specific cities.



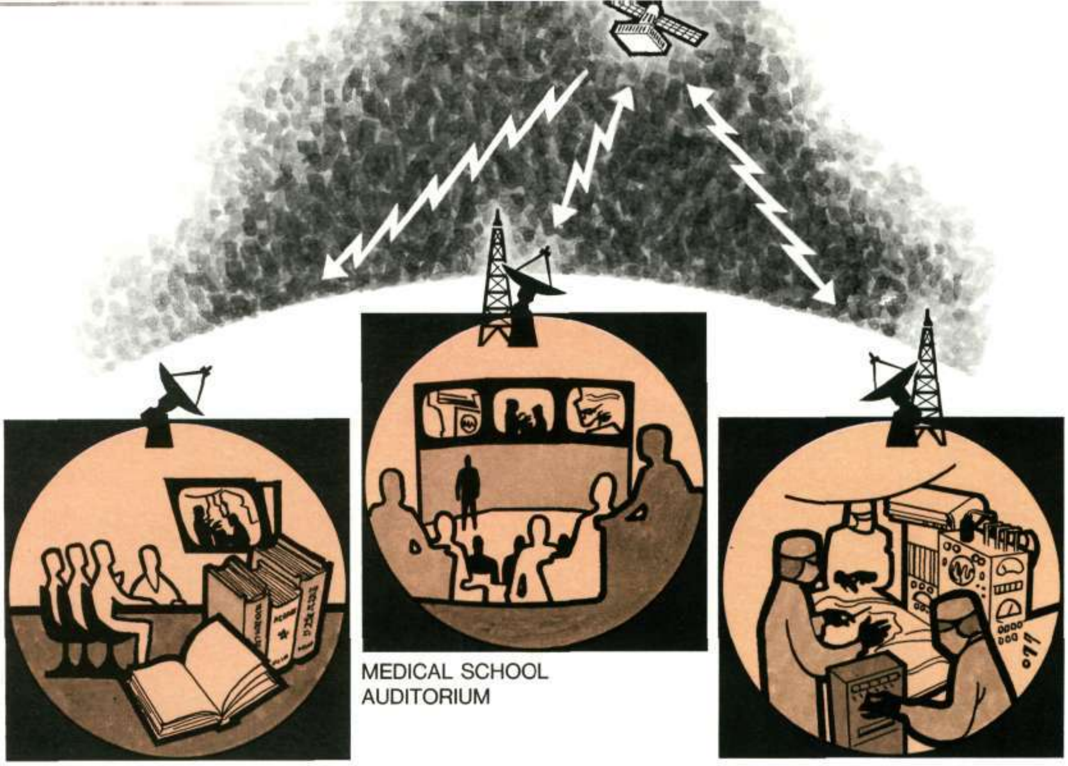


Fig. 5 Operational schematic of a possible medical information network.

weather monitors, could be integrated by geostationary satellites which have the sensors in view at all times. It is this kind of application that has led to the joint Franco-American Cooperative Application Satellite (CAS) program.

THE BALLOON WATCHER (CAS)

In 1971, the Government of France, through its Centre National d'Etudes Spatiales (CNES), will release 500 instrumented balloons between the southern latitudes 25° and 55°. Floating between 39,000 and 45,000 feet, the balloons will measure temperature and pressures along the layer of constant density air in which they float. When interrogated by the Cooperative Applications Satellite (CAS), the balloons will radio back their scientific measurements. In addition, Doppler tracking equipment on the spacecraft will pinpoint the range and radial velocity of each interrogated balloon to determine large-scale movements of the atmosphere. Orbiting at about 560 miles at an inclination of 50°, the CAS will be able to interrogate each balloon twice each day. (Fig. 6) Collectively, the satellite and balloon sensor field constitute France's Eole Project. Eole is doubtless the forerunner of many other large-area, sensor-field experiments now made possible by communication satellites.

The satellite itself and the balloons are being built by France. NASA will provide a Scout launch vehicle and its launch facilities at Wallops Island, Virginia. NASA may also support the mission with tracking and data acquisition services, although the CAS will incorporate a tape recorder, enabling it to record data from the interrogated balloons for retransmission to French data acquisition stations when the satellite swings over them in its orbit. The arrangement between the United States and France is similar to that made when the first French satellite, the FR-1, was launched from Wallops Island in 1965.

The CAS will be an octagonal cylinder 28 inches in diameter, weighing about 206 pounds. As illustrated in Fig. 6, a skirt of solar cell panels opens petal-like around the upper rim of the spacecraft. The long rod extending upwards along the spacecraft axis is a gravity-gradient stabilization boom that helps keep the top of the satellite pointed at the Earth. A spiral antenna painted on the conical projection on the

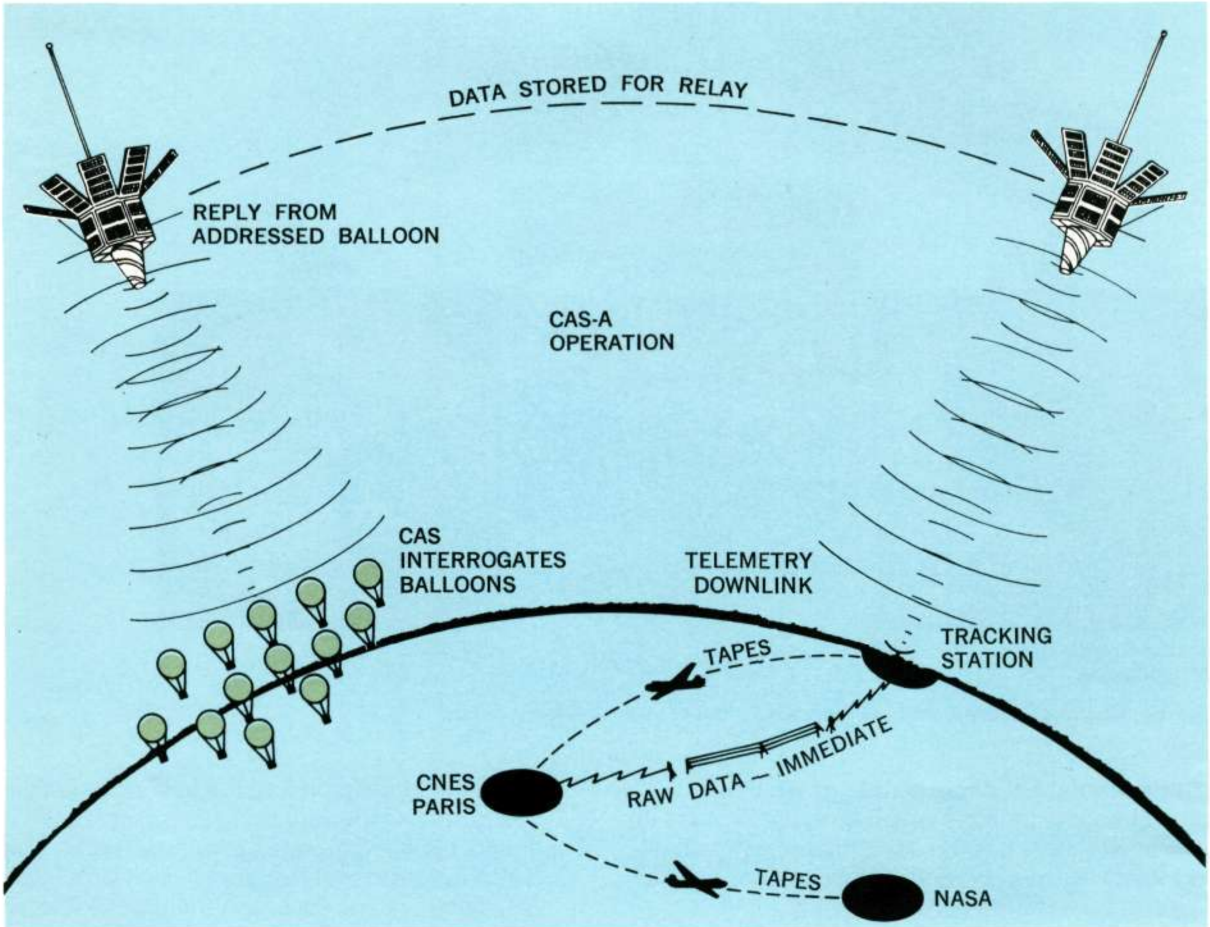


Fig. 6 Artist's concept of CAS operation, showing balloon-borne sensor field and relay of stored data to ground stations.

spacecraft top sends directional signals that interrogate the balloons about 550 miles below. The same antenna receives their replies.

The first CAS launch is scheduled for late 1971. In addition to launch services, the United States will help interpret the data telemetered from the balloons. The National Center for Atmospheric Research and the University of California at Los Angeles will participate in this analysis.

THE INTELSAT FAMILY

The Intelsat communication satellites are now stationed in geostationary orbits above the Atlantic, Pacific, and Indian Oceans, providing thousands of new intercontinental radio links. (Fig. 7) Together, the Intelsats form the Global Satellite System of the International Telecommunications Satellite Consortium, which consists of more than 70 member countries. Represented by the Communications Satellite Corporation, the United States builds some of the Intelsats and operates some of the ground stations. NASA's responsibilities include launch services and consulting on a reimbursable basis.

Based on technical developments made during NASA's Syncom Program in the early 1960's, the Intelsats are all geostationary spacecraft carrying small rocket engines that move them to and keep them at selected spots over the Equator. There are now four generations of Intelsats, and they all bear family traits. Intelsat I, also called Early Bird, was launched in 1965 and was the founder of the family. Additional "birds" flew in 1966 and 1967 with four spacecraft in the Intelsat-II generation. As indicated in Table 3, the trend has been toward bigger and better satellites with each new generation.

All of the Intelsats are cylindrical in shape, with the curved sides covered with solar cells. Weights, dimensions, and circuit capacities have risen markedly in less than a decade. (Table 3) The Intelsat-IV generation consists of satellites 17.6 feet high (Fig. 8) and 93.5 inches in diameter. The Intelsat-IV's are so large that NASA had to switch to the more powerful Atlas-Centaur launch vehicle. In keeping with the trend toward more versatile worldwide communication, the new Intelsats provide multiple access capabilities. Compared to the 1965 Early Bird, which was not much bigger than a waste basket, the Intelsat-IVs represent an important advance in terrestrial communications. This advance was pioneered by NASA's Syncoms and the communication experiments aboard the ATS spacecraft.

THE BRICK MOON REVISITED

Rather than the brick of Hale's fictional satellite, the first navigational satellite was fabricated mainly from lightweight metals. Transit 1A was launched by the U.S. Navy in the fall of 1959 to help guide its submarines. More Transits followed but there have been no satellites specifically designed to help commercial ships and aircraft locate themselves in areas where conventional navigational aids do not exist, especially over the oceans. With the density of high-speed, transoceanic air traffic rising rapidly, better schemes for locating and communicating with aircraft are urgently needed.

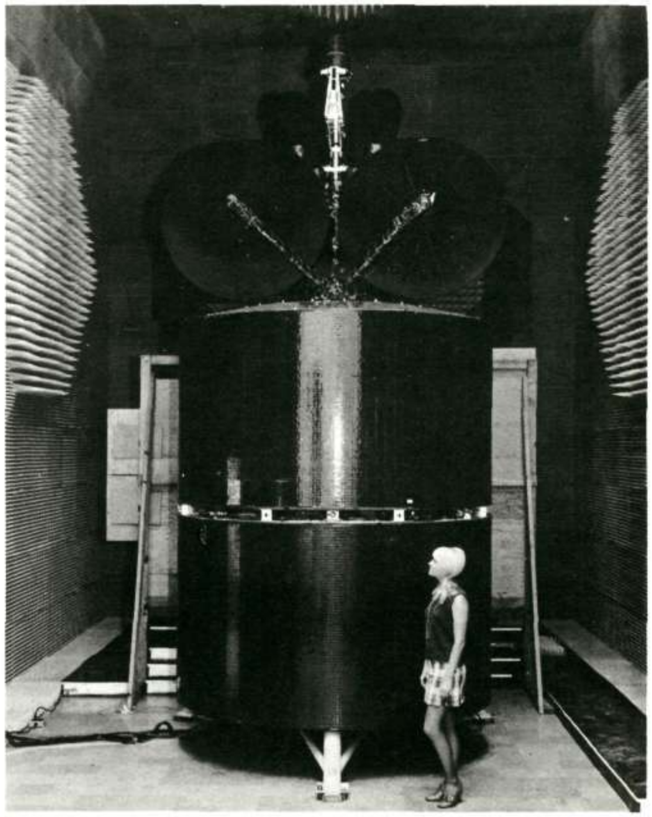


Fig. 8 Intelsat-IV: 17.6 feet high, 93.5 inches in diameter. (Communications Satellite Corporation)

Fig. 7 The global system of communication satellites and ground stations.

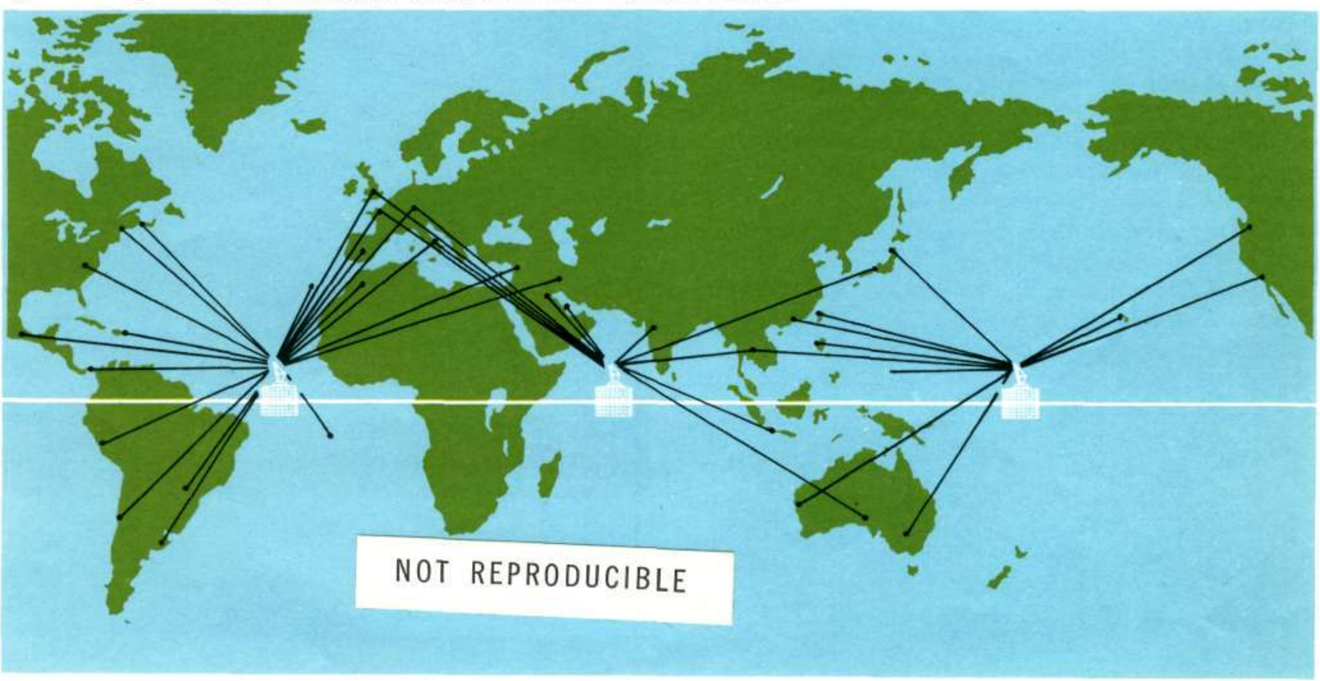


TABLE 3. The Intelsat Family

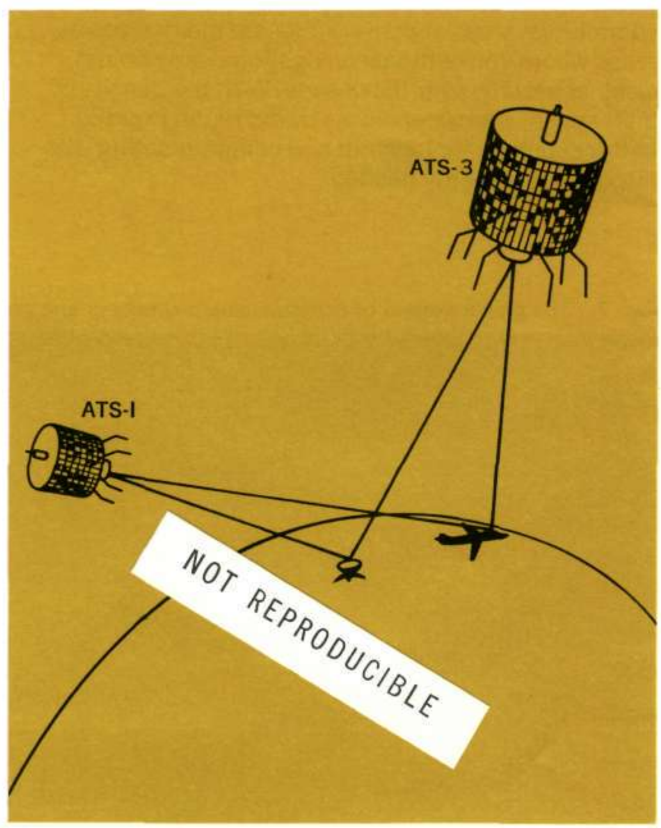
Generation	Successful Launches	Circuits*	Weight at Launch	Launch Vehicle
Intelsat I	Early Bird (1965)	240	150 lbs	Delta
Intelsat II	F-2 (1969), F-3 (1967), F-4 (1967)	240	357	Delta
Intelsat III	F-2 (1968), F-3 (1969), F-4 (1969)	1,200	647	Delta
Intelsat IV	F-6 (1970), F-7 (1970)	12,000	3080	Atlas-Centaur
	COMSAT has contracted for eight INTELSAT IV satellites (F-1 through F-8). F-2 was launched Jan. 25, 1971.			

*Various operating modes are possible in which circuits can be combined to provide for TV channels and other types of wide-band channels.

The classical concept of a navigation satellite depends upon accurately knowing the satellite's position and then finding one's position relative to it. In other words, the satellite becomes a known landmark; the only one visible on the broad oceans. The stars, of course, play the same role in stellar navigation, but they are not always visible and stellar fixes are too slow and difficult for aircraft flying near the speed of sound. Navigation satellites have the advantage that the signals can be received automatically and analyzed by computers, giving pilots their positions rapidly and continuously.

Although NASA is not building a navigation satellite at the moment, it is conducting pertinent experiments with its ATS and Nimbus spacecraft. To illustrate, the ATS 3 was used in the Omega Position Location Experiment, which allowed cooperating ships and aircraft to fix their positions within 3 and 5 miles, respectively. In another experiment, a jet aircraft located its position to within 4 miles by making radio ranging measurements on ATS 1 and 3 simultaneously. (Fig. 9) The positions of the ATSs are, of course, well known and, being in geostationary orbits, they are visible from much of the world's surface. Experiments of these kinds are continuing.

Fig. 9 Schematic showing ATS 1 and ATS 3 in a dual ranging experiment with a jet aircraft. The jet was located to within four miles.



The Director General of the European Space Research Organization (ESRO) has requested that NASA and ESRO jointly explore the possibility of cooperative air traffic control experiments on satellites. Technical meetings have already begun. Air traffic control differs from navigation in that it involves the centralized control of aircraft positions relative to one another rather than the determination of their absolute geographical positions. Air traffic control is, therefore, very much a communication problem, especially over the oceans where conventional communication techniques falter. The potential value of communication satellites in air traffic control was first demonstrated in November 1964, when a Pan American World Airways plane used Syncom 3, then in a geostationary orbit over the Pacific, for air-ground communication across the ocean. The realization of practical, satellite-aided, air traffic control has been hampered by technical problems as well as the $200 million price tag on the satellite system. NASA and ESRO are conducting further experiments with the ATSs and other satellites to determine the best communication technique for a permanent international air traffic control system.

LOCATING THE CONTINENTS

Despite the recent conclusion that the Earth's continents do indeed drift a few centimeters each year, one would expect their positions to be well known after all these centuries of mapmaking. However, when geodetic satellites arrived on the scene, the continents were discovered to be located accurately in terms of latitude and longitude but not so well on a relative basis; that is, the distances between the continents were not known to within several miles. Some oceanic specks of land were found to be dozens of miles from where maps said they should have been. To fix accurately the relative positions of land masses, a landmark visible simultaneously from ocean-separated islands and continents is needed. In this sense, geodetic satellites are really navigation satellites for the "floating" continents. In addition, geodetic satellites also help determine the true shape of the Earth—a planet with many idiosyncrasies in shape.

Almost all satellites can be used for geodesy, providing they can be seen with optical or electronic instruments from widely separated points. The first satellite to be launched solely for geodetic purposes was ANNA 1B, in 1962, by the U.S. Army, Navy, NASA, and Air Force. (ANNA is an acronym for Army, Navy, NASA, Air Force.) The Army's Secor (Sequential Collation of Range) satellites followed. Currently, the U.S. National Geodetic Satellite Program involves the joint efforts of NASA, the Department of Defense, and the Department of Commerce. Three satellites have already been launched under the so-called Geos program:

Prelaunch Designation	Postlaunch Designations	Launch Date
Geos A	Geos 1 or Explorer 29	Nov. 6, 1965
Pageos	Pageos	Jun. 23, 1966
Geos B	Geos 2 or Explorer 36	Jan. 11, 1968

Another satellite, Geos C, may be scheduled for launch in 1973. NASA builds the spacecraft, provides the launch and tracking services, and supplies some of the experiments. The agencies cooperate in the analysis of the data.

The principal objectives of the Geos-C satellite are to:

1. Establish a single, common, worldwide datum (i.e., geodetic reference system) and improve global maps to an accuracy of about 10 meters.
2. Improve the positional accuracy of geodetic control stations and spacecraft tracking stations.
3. Define better the structure of the Earth's gravitational field.
4. Correlate and compare the results obtained from all spacecraft geodetic instrumentation.

The Geos satellites are essentially orbiting instrument platforms similar to scientific satellites. Geos is very similar to the CAS satellite. Both are gravity-gradient stabilized by means of a long, axial boom, with their spiral antennas pointing downwards toward the Earth. (Fig. 10) In this orientation, geodetic stations can simultaneously observe and interrogate the satellite. Details on the Geos equipment and geodetic instrumentation are presented in Table 4 and on page 16.

Fig. 10 The Geos spacecraft.

TABLE 4. Design Features and Vital Statistics, GEOS C

Spacecraft Functions	Design Features
Communications	Sends housekeeping telemetry only; command receiver. Conical, spiral, and turnstile antennas
Power supply	Solar cells and battery: average power about 40 watts
Attitude control	Spin-stabilized. Long boom for gravity-gradient stabilization
Thermal control	Passive
Guidance and control	Solar-aspect sensors and magnetometers to determine attitude
Structure	Octagonal aluminum frame about 49 inches between the sides. Weight: about 465 pounds
Launch vehicle	Delta
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN) for routine tracking and acquisition of status telemetry.

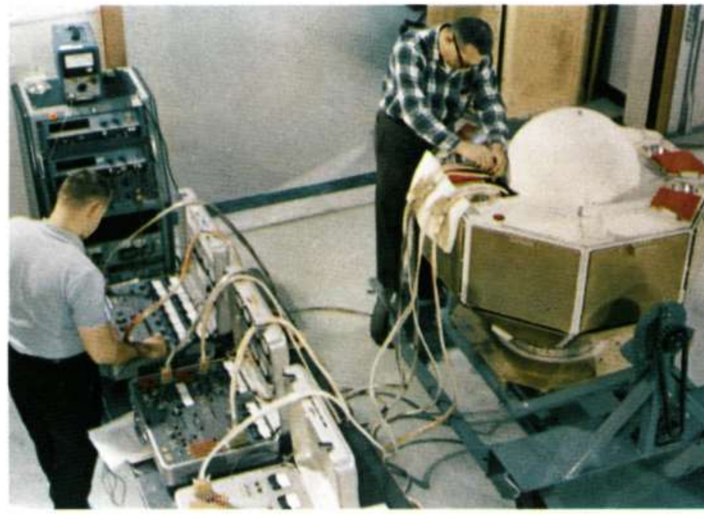


Fig. 11 The Geos B set up for a vibration test.

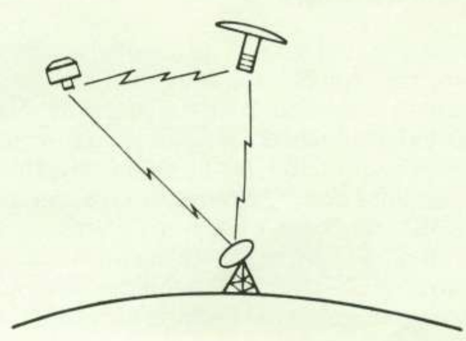
PRACTICAL EXPERIMENTS ON GEOS

The Tracking Aids

Geos must be readily "seen" by terrestrial tracking stations if it is to achieve the objectives listed on page 15. Therefore, mounted on Geos are several reflectors that mirror laser and radar beams reaching the satellite from Earth. The satellite is also made highly visible by optical and radio beacons. Geos will also carry a radar transponder, a tracking aid which responds to a pulse of radar energy by emitting a return signal much stronger than possible by simple reflection.

Satellite-to-Satellite Tracking

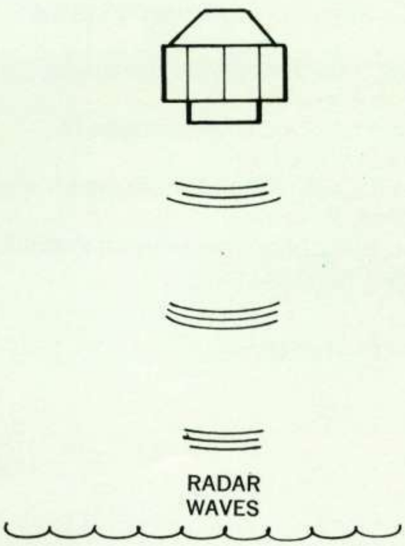
In this experiment, Geos will be used in conjunction with ATS F to determine whether a satellite with a precisely known orbit (Geos) can help ground-based



tracking stations improve the accuracy with which they track another satellite (ATS).

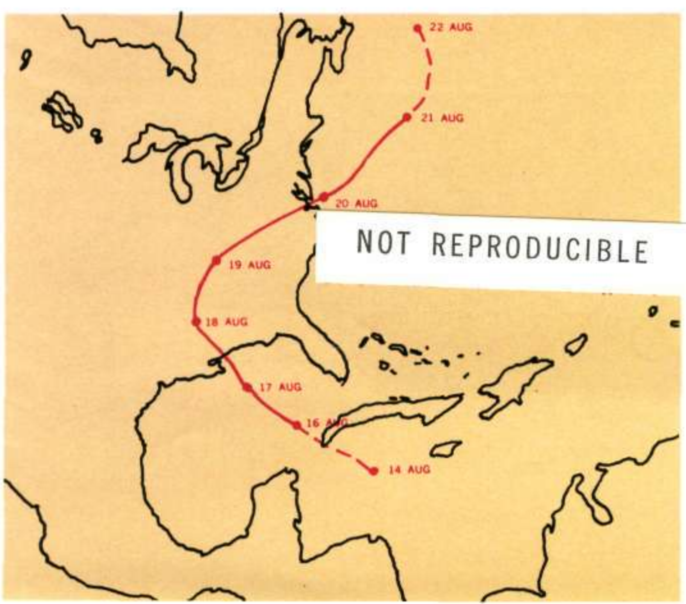
The Radar Altimeter Experiment

By directing radar waves downward from Geos to the sea's surface, sea level will be measured to within 10 cm. This is scientifically important because the sea's surface is not perfectly spherical. The Earth's varying gravitational field makes broad hills and depressions that Geos will map.

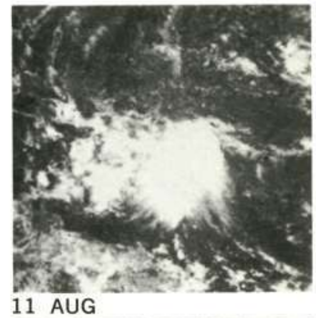


WEATHER WATCHING VS. WEATHER PREDICTING

In August of 1969, the greatest storm to hit North America in recorded history cut a swath from the Gulf Coast to the Carolinas. A hundred years ago, Hurricane Camille would have swept in from the Gulf unannounced, but in 1969 weather satellites helped give ample warning. (Fig. 12) It has been estimated that the timely warnings saved 50,000 lives. Early



Photographic coverage of Camille, one of the deadliest hurricanes in recent history, begins with a picture of the storm's infancy on 11 August 1969. Camille was christened a tropical storm on 14 August and reached hurricane strength the following day. It then swept through the southeastern U.S. and back into the Atlantic where it is shown in the last photo with hurricane Debbie.



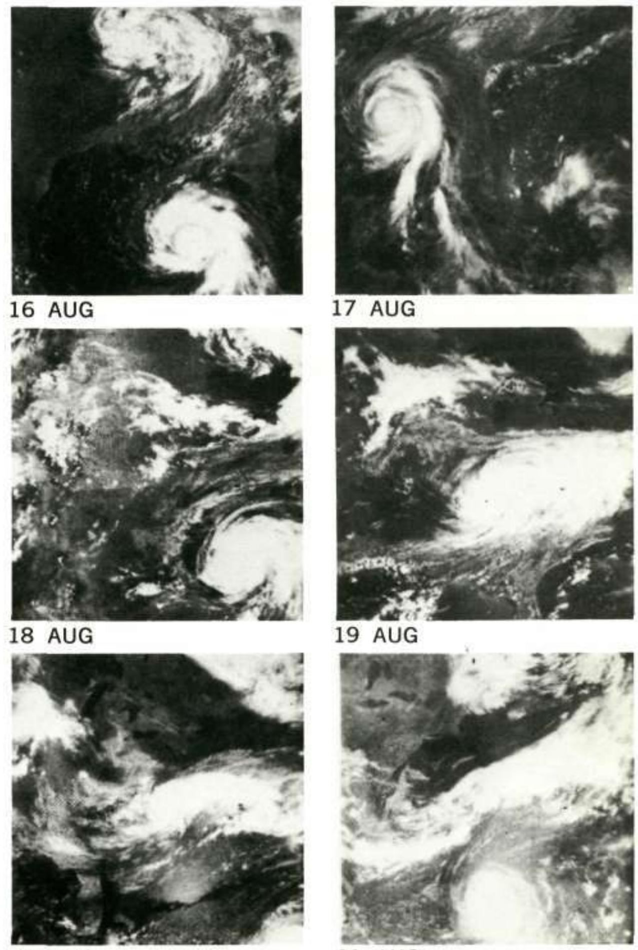


Fig. 12 Satellite photos of Hurricane Camille, August 1969, shown just before she moved inland from the Gulf of Mexico. (ESSA)

warnings of dangerous storms have been an early payoff of weather satellites. Indeed, this practical aspect of space meteorology has already repaid for the rockets and spacecraft many times over in terms of lives and property saved.

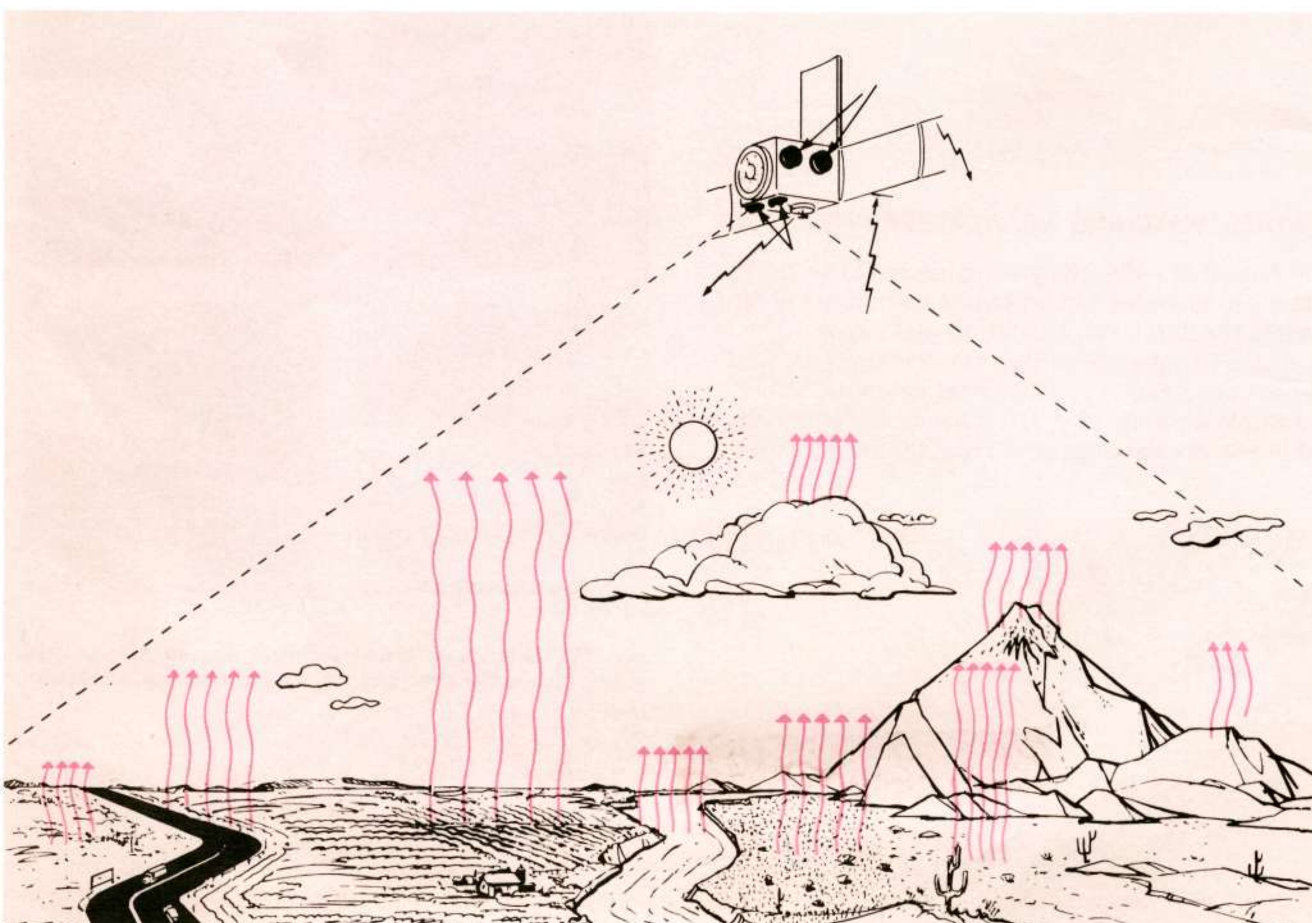
It became apparent only a few months after World War II, when captured German V-2 rockets carried cameras to high altitudes, that cloud cover pictures would be of great value to meteorologists. Many early satellites, such as Vanguard 2, 1958, and Explorer 7, 1959, included meteorological instruments in their payloads. Today, thousands of pictures of the Earth's spiraling cloud systems are taken every day. These pictures help forecast weather two or three days in advance and also give meteorologists the big picture so they can better understand the fair and foul weather systems that wheel across the planet's surface.

Meteorologists are not satisfied with these accomplishments; they would like to forecast weather two weeks in advance and comprehend all the intricacies of the great air masses. These goals require more than the simple watching of clouds from orbit. Rather, accurate models of weather systems must be constructed. Such mathematical models require detailed knowledge of the temperature, pressure, water-vapor content, and the other factors that describe the atmosphere and its circulation. It is important to know how these factors vary with height above the Earth's surface as well as geographical location. This requirement means that meteorological satellites must be able to make vertical and horizontal measurements from great distances.

The foregoing thoughts may be summarized in terms of three objectives:

1. Obtain global cloud cover pictures (a geographic objective).
2. Observe the entire atmosphere continuously (a temporal objective).
3. Measure atmospheric variables quantitatively, vertically and horizontally.

Fig. 13 Schematic showing different amounts of infrared radiation emitted by different surfaces. ITOS satellite is shown overhead.



The National Oceanic and Atmospheric Administration (NOAA)* is responsible for the day-to-day operation of weather satellites, but NASA has been assigned the task of developing and procuring new spacecraft and meteorological sensors as well as providing launch and tracking services. NASA now has three active weather satellite programs plus the ATS effort, under which new cameras and other sensors are tested in space. There are three specific satellite programs:

1. The Improved Tiros Operational Satellite (ITOS) Program, involving the development, procurement, testing, and launch of a new generation of operational meteorological satellites for NOAA on a reimbursable basis.
2. The Nimbus Program, in which new techniques and sensors are developed using the Nimbus spacecraft as a test vehicle.
3. The Synchronous Meteorological Satellite (SMS) Program, under which a new geostationary weather satellite is being designed to satisfy the requirements of NOAA's National Operational Meteorological Satellite System (NOMSS).

LATEST IN A LONG LINE (ITOS)

As the decade of the 1970s began, NASA and ESSA (now NOAA) were able to look back on two long and highly successful series of meteorological satellites. Between 1960 and 1965, NASA had orbited ten Tiros satellites without a single failure. To illustrate the productivity of these spacecraft, Tiros 8 operated for 3½ years, sending back over 100,000 cloud cover photographs. The first ESSA satellite series (also called Tiros Operational Satellites or TOS) began in 1966 and ended with the launch of ESSA 9 in 1969. Like the Tiros satellites, the ESSAs were primarily cloud photographers. For a better understanding of weather processes and longer forecasts, something better was needed.

*Successor to the Environmental Science Services Administration (ESSA).

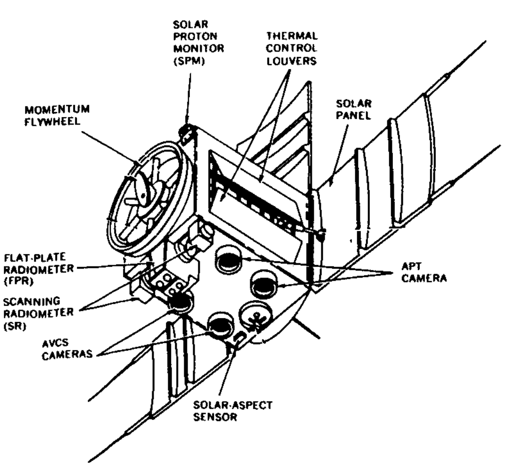


Fig. 14 Diagram of the ITOS satellite. Meteorological sensors are mounted on the bottom, which is always pointed at the Earth.

The Improved Tiros Operational Satellite (ITOS) represents a major step forward in that it can take cloud-cover pictures at night with a scanning infrared radiometer.* The infrared radiation emitted by the Earth depends upon the temperature and character of the radiating surface. Rivers and lakes, for example are cooler than farmland. (Fig. 13) Clouds stand out vividly at night in infrared pictures. ITOS, therefore, offers 24-hour coverage of the Earth. In contrast, the Tiros/ESSA spacecraft cameras were sensitive to only the sunlit portions of the Earth. The ITOS craft will transmit their TV and infrared pictures to users around the world either directly from the satellites or through the NOAA center at Suitland, Maryland.

The ITOS spacecraft are substantially different from those in the Tiros and ESSA series. Tiros/ESSA satellites were relatively small, cylindrical, spin-stabilized vehicles. In contrast, ITOS is boxlike, with an active attitude control system that keeps its instruments continually pointed at the Earth. (Fig. 14) In terms of size, ITOS weighs more than twice the nominal Tiros-ESSA craft; 678 against 300 pounds. The extra spacecraft sophistication pays dividends in terms of more complete photographic coverage on both the day and night sides of the Earth. Other spacecraft features and the instrument complement are given in Table 5 and on page 21.

ITOS 1, which was called Tiros M before launch, was orbited by a Delta rocket on January 23, 1970. Tiros M was in actuality an ITOS prototype, but it received the family name anyway. ITOS A was launched December 11, 1970 and designated NOAA-1.

The nominal ITOS orbit is "Sun-synchronous" with an altitude 790 miles and an inclination of 78°. This type of orbit was found to be extremely useful by the later Tiros satellites because the lighting of the scene below was consistent for all photographs at each latitude. In such an orbit, the satellite passes over the Equator—indeed, each latitude—at the same time each day. Northbound, an ITOS should cross the Equator twelve times a day at 3 P.M., local time, while the southbound passage should occur at 3 A.M. The orbital plane also precesses (rotates) approximately 1° each day, keeping pace with the seasons; that is, the satellite's orbital plane always intersects the Sun.

*A radiometer measures radiation within a specific band of wavelengths. The infrared portion of the spectrum begins at the long wavelength end of the visible spectrum. The infrared spectrum emitted by a surface depends upon the temperature and composition.

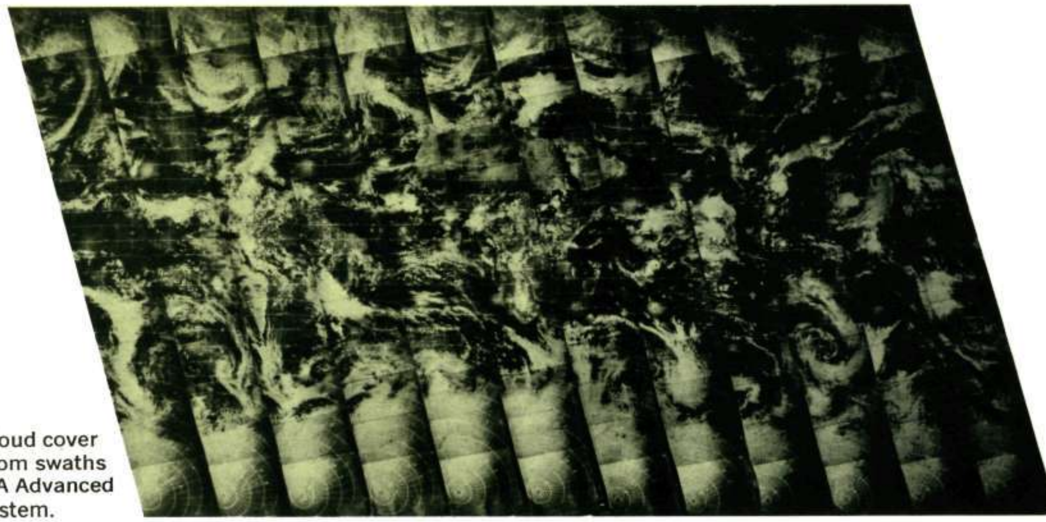


Fig. 15 Global cloud cover picture made up from swaths taken from an ESSA Advanced Vidicon Camera System.

In addition, the Earth rotates beneath the satellite just enough so that slightly overlapping bands of pictures can be snapped during each revolution. (Fig. 15)

SEEING THE BIG PICTURE (SMS)

The view of the world's weather from a few hundred miles up is spectacular. In just two hours, an ITOS photographs a strip of clouds about 1700 miles wide and 25,000 miles long. One sees vividly the great convection cells marching across the oceans and continents. However, ITOS will not be back to photograph the same area for a whole day. This delay may be critical in the case of rapidly developing storms. Neither can meteorologists watch less dangerous atmospheric phenomena develop on a continuous basis. Since one of the major goals of space meteorology is the continuous surveillance of the whole globe, it appears that a geostationary or synchronous satellite poised 22,300 miles out over the equator might help us achieve this end. (Fig. 16)

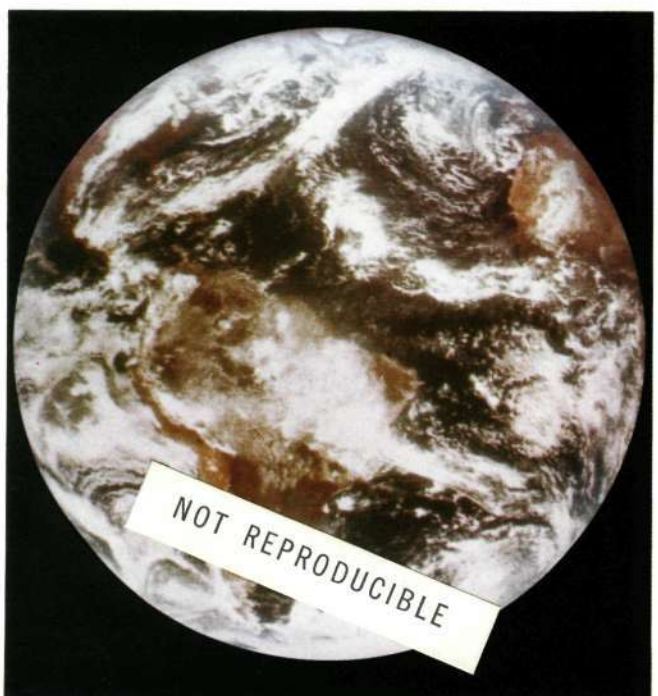


Fig. 16 ATS cloud cover picture from about 22,300 miles.

Goddard Space Flight Center and its industrial contractors have been studying geostationary weather satellites since the mid-1960s. Pictures taken from 22,300 miles by TV cameras aboard some of the ATSs reinforced meteorologists' desire for geostationary weather satellites. NASA approved the fabrication, test, and launch of the Synchronous Meteorological Satellite (SMS) in 1969. The program is still in its early stages, and a contractor to build the spacecraft was selected only in mid-1970. Nevertheless, some of the satellite's major features have been defined in the Goddard studies, and some of these are firm enough to present below.

First, we should examine the requirements levied on the SMS by the ultimate user, NOAA. Manifestly, the capabilities of the SMS will go far beyond the early Tiros/ESSA spacecraft.

1. In the visible portion of the spectrum, SMS cameras should be able to resolve details to within two miles. The ultimate goal (not a requirement) is a resolution of 0.5 mile in the visible and 4.0 miles in the infrared (needed for nighttime cloud-cover pictures).
2. Satellite electronics should be able to time-stretch picture data; that is, transmit it more

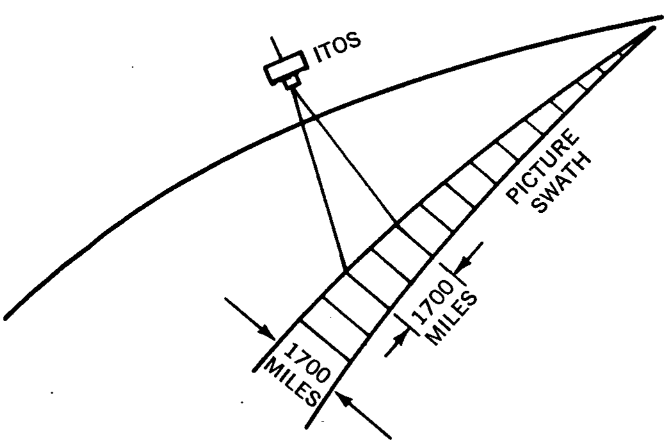
TABLE 5. Design Features and Vital Statistics, ITOS

Spacecraft Functions	Design Features
Communications	250-milliwatt phase-modulated link for beacon and telemetry at 136.77 MHz. Real-time video link at 137.5 or 137.62 MHz; 5 w frequency modulated. Playback video link at 1697.5 MHz, 2 w. Command receiver at 148 MHz.
Power supply	10,260 n-p 2x2-cm solar cells on three deployable panels plus nickel-cadmium batteries. Average power level: 70 w.
Attitude control	Three-axis stabilization using inertia wheel and magnetic coils. Nutation damper. Points to within 1° of vertical.
Thermal control	Passive paints and insulation plus thermal louvers.
Guidance and control	Horizon sensors, Sun sensors. Responds to tone commands from the Earth.
Structure	Rectangular box, 40 x 40 x 48.6 inches. Three solar panels 65 inches long. Weight: about 678 pounds.
Launch vehicle	Delta
Tracking and data acquisition network	Space Tracking and Data Acquisition Network (STADAN). NOAA also employs several stations to receive pictures and other data. Pictures can also be picked up by Automatic Picture Transmission (APT) stations built by anyone using NASA plans.

OPERATIONAL INSTRUMENTS ON ITOS

TV Camera

The ITOS TV camera takes 1700-mile-square pictures of the Earth with 50% overlap. NOAA uses these pictures directly in the preparation of weather forecasts. The camera is a one-inch vidicon with 800 scan lines.

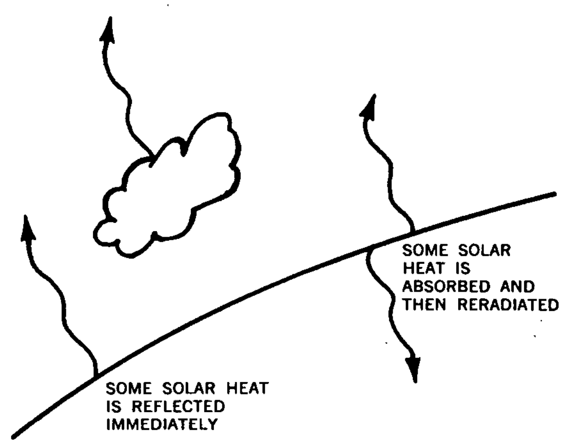


The Automatic Picture Transmission (APT) Camera

The cloud-cover pictures taken by the APT camera can be received by local governments and individuals all over the world. The pictures are transmitted continuously and can be recorded with simple, inexpensive equipment. Two one-inch vidicons are carried by ITOS for purposes of reliability.

Heat Input/Output Measurements

Another radiometer measures the heat reflected and reradiated by the Earth. By comparing this with the total heat received from the Sun, meteorologists can determine where energy is being added to atmospheric circulation patterns.



Nighttime Cloud-Cover Pictures

From ITOS, a radiometer with a moving mirror scans the Earth below. Sensitive to both visible and infrared light, the instrument extends weather satellite coverage to 24 hours a day.

Solar Proton Monitor

ITOS also carries six solid-state radiation detectors to monitor solar protons and electrons near the Earth.

slowly than it generates it to enable "slow" ground stations to pick up the transmissions successfully.

3. Like the Cooperative Applications Satellite (CAS) discussed earlier, the SMS must be capable of collecting data from hundreds of small, remotely located terrestrial stations and transmit them to a central location.
4. The satellite should also have the ability to relay weather maps and other meteorological data of general interest. (Obviously, weather

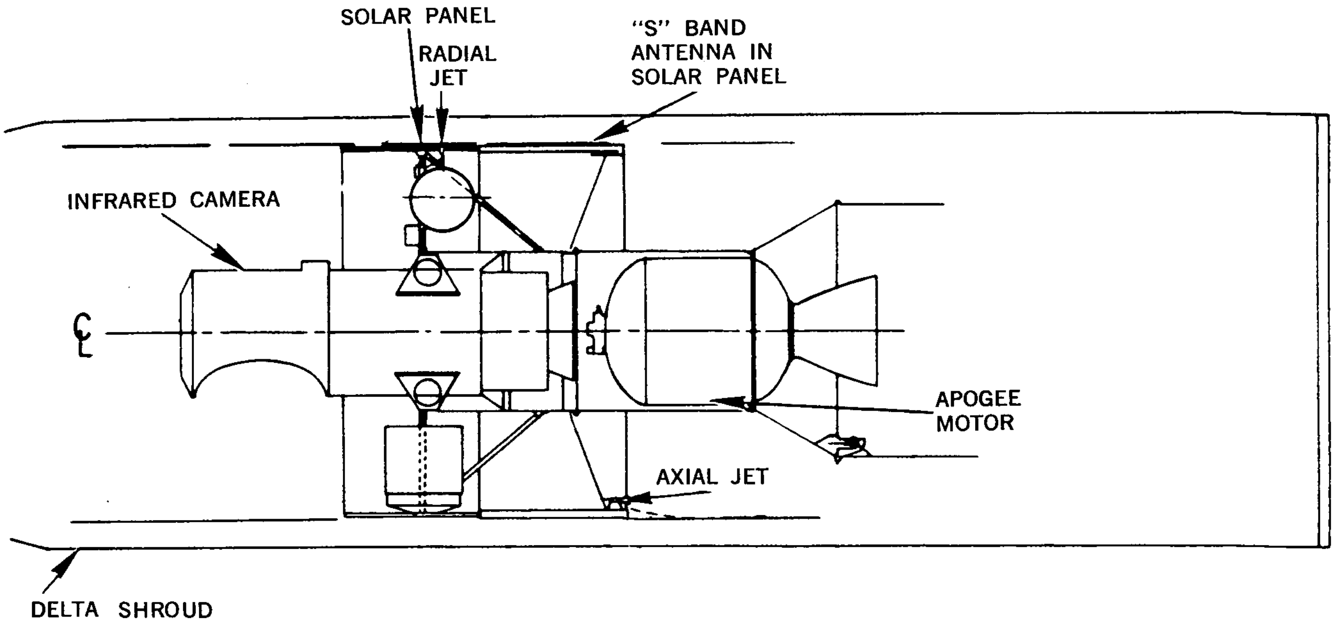


Fig. 17 Conceptual drawing of the SMS shown within Delta launch vehicle shroud.

satellites are also partly communication satellites.)

5. Because solar activity is important to weather forecasting, the SMS must be able to measure solar protons, solar X-ray flux, and the local magnetic field.

Goddard Space Flight Center based its SMS design studies upon the well-proven ATS and Intelsat-III designs. The SMS will weigh about 1000 pounds. It will probably be a cylinder about 56 inches in diameter and 65 inches long, as dictated by the Delta launch vehicle's aerodynamic shroud. (Fig. 17) A hydrazine propulsion system will be included to ease the spacecraft into geostationary orbit, keep it there, and move it to new positions over the Equator when necessary. The technology employed here originated in the ATS program. The hydrazine jets will also be used for attitude control. The communication subsystem has not been delineated yet. Power will come from solar cells and batteries. This is a very crude sketch. The details will be filled in by the newly selected spacecraft contractor.

The minimum NOAA picture requirements can be met with the spin-scan camera system already proven in the ATS program. Two of these cameras will be required on each SMS to meet reliability objectives.

The more ambitious goals (0.5 and 4.0 miles visible and infrared resolutions) will require a new instrument. The Visible-Infrared Spin-Scan Radiometer (VISSR) has been proposed as a possible solution. This instrument consists of a classical Cassegrain telescope and a scanning mirror that sweeps the telescopic image in several visible and infrared wavelength bands or *channels.* In this way, pictures of the Earth can be taken in several regions of the visible-infrared portion of the spectrum.

SMS-A will be launched in late 1972, possibly early 1973. Because considerable design and development work remain, the above description should be regarded as preliminary in nature.

NIMBUS, A TEST VEHICLE FOR METEOROLOGICAL INSTRUMENTS

Two objectives define the Nimbus program:

1. Develop and flight test advanced sensors and technology basic to meteorological research, the atmospheric sciences, and the orbital survey of Earth resources.
2. Provide for the global collection and distribution of meteorological data from all sources.

Nimbus is a large, sophisticated spacecraft. It was conceived in 1959 at Goddard about the same time that NASA's big observatory-class spacecraft were being sketched out. Nimbus was considered to be a generation beyond the Tiros spacecraft. When it became apparent that smaller, less expensive spacecraft would meet NOAA's operational requirements, Nimbus was given the task of testing and proving out sensors used for Earth observation. The test-bed idea is essentially the same as the ATS concept, except that Nimbus' fully stabilized, Earth-pointing capability make it ideal for developing meteorological and Earth resource sensors.

The Nimbus spacecraft has already proven itself operationally. Four Nimbus satellites are now in orbit, and a fifth was lost due to a launch vehicle failure, as indicated below:

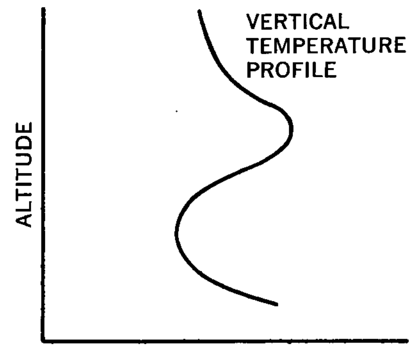
Prelaunch Designation	Postlaunch Designation	Launch Date
Nimbus A	Nimbus 1	Aug. 28, 1964
Nimbus C	Nimbus 2	May 15, 1966
Nimbus B	—	May 18, 1968 Thor-Agena failure
Nimbus B-2	Nimbus 3	Apr. 14, 1969
Nimbus D	Nimbus 4	Apr. 8, 1970

Sensors being tested on Nimbus are mounted in the sensor ring at the bottom of the spacecraft, which is kept pointed at the Earth by the attitude control subsystem. (Fig. 1) A conical truss structure connects the sensor ring to the upper housing containing the attitude control subsystem, the communication subsystem, and other spacecraft equipment. Two wing-like solar panels, which are automatically pointed toward the Sun, provide power to the spacecraft and the instruments. Nimbus details are presented in Table 6.

PRACTICAL EXPERIMENTS ON NIMBUS E

Atmospheric Profiles

Radiometers can measure how the temperature and water-vapor content of the atmosphere varies with altitude by determining how much infrared radiation the atmosphere emits at various wavelengths. Water-vapor molecules, for example, emit infrared radiation when they rotate. Vertical temperature and water-vapor profiles are important factors in weather prediction. Nimbus E will carry two infrared radiometers for measuring vertical profiles and another to help make worldwide humidity maps,



A Microwave View of the Earth

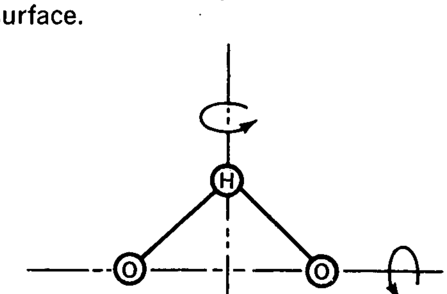
Two Nimbus-E instruments will map the Earth in the microwave portion of the radio spectrum. Microwaves, which are much longer than infrared waves, are also emitted by water-vapor molecules, vegetation, and the ground itself—in short, just about everything. The two Nimbus-E microwave instruments will measure the following meteorological factors: vertical profiles of temperature and water-vapor abundance, cloud-cover water content, amounts of precipitation, land temperature (where clouds block infrared wave-lengths), the intensities of storms and storm fronts, the water content of the soil, ice cover, and even the quantity of vegetation below.

Tracking and Data Relay Experiment

The communication part of this experiment will test the feasibility of relaying data from a low-altitude satellite (Nimbus) via a geostationary satellite (ATS F/G) to a ground receiving station. An attempt will also be made to track Nimbus E with high precision from ATS F/G.

Mapping the Composition of the Earth's Surface

The infrared radiation emitted by the Earth's surface depends upon composition as well as temperature. To illustrate, the infrared spectra of various minerals vary markedly, making a satellite-borne infrared spectrometer a potential mineral-prospecting instrument. The Nimbus-E instrument will also make thermal maps of the soil and the ocean surface.



ROTATION OF WATER MOLECULES GENERATES MICROWAVES

TABLE 6. Design Features and Vital Statistics, Nimbus E

Spacecraft Functions	Design Features
Communications	Wideband stored data, 1707.5 and 1702.5 MHz, Pulse-code-modulated telemetry at 136.5 MHz. Command receiver at 149.52 MHz.
Power supply	Two movable solar panels plus nickel-cadmium batteries. Provides an average of 260 watts.
Attitude control	Inertia wheels plus cold-gas reaction engines in equipment housing. Keeps spacecraft pointed to within 1° of the local vertical.
Thermal control	Thermal louvers located around the rim of the sensor ring, supplemented by thermal coatings and insulation.
Guidance and control	Sun sensor, horizon sensors, gyroscopes.
Structure	Four major elements: sensor ring, providing 18 square feet for mounting Earth sensors; equipment housing; solar paddles, and truss structure. Overall dimensions: 9.5 feet high by 9.5 feet wide with solar panels extended. Overall weight: about 1690 pounds.
Launch vehicle	Thor-Agena
Tracking and data acquisition	Space Tracking and Data Acquisition Network (STADAN)

HUSBANDING EARTH'S RESOURCES (ERTS)

Only a few years ago man could modify the conditions on Earth with little thought about the environment and the cascading consequences of his acts. With the Earth more crowded and some of our easily garnered non-renewable natural resources nearly depleted, one hears more and more the phrase "spaceship Earth," implying the increasing interdependence of all man's activities—his farms, his industries, his mines, his waste products, and, as has become obvious, his very existence.

Spaceship Earth will support only a few billion human beings unless its resources are managed carefully. As for all management systems, information must be available to make resource management work: abundant information, on a continuous basis, from all parts of the globe. Satellites by virtue of their favorable positions high above the Earth are in particularly advantageous spots to collect some of the needed environmental information.

The key to obtaining information on Earth resources from several hundred miles out in space lies in the analysis of sunlight reflected from the Earth and radiation emitted from the Earth by virtue of its temperature. Flying across the United States by plane, one sees fields, forests, drainage patterns, geological formations, and the works of man, to give a partial list. If the same plane carried an aerial camera with a telescopic lens, photographic analysis would reveal soil types, crop identities, major mineral deposits, etc. Taking the same flight once more but with a full complement of instruments that "see" in the infrared, ultraviolet, and microwave regions of the spectrum, the panorama enlarges tremendously. (Figs. 18 and 19) By recording the scenes below and studying them in light outside the visible range, we can discern forest and crop blights, soil moisture contents, plant species, ice thickness, and the many other factors summarized on page 25. By collecting and correlating this kind of information, we can, so to speak, take the Earth's pulse continuously, assessing on one hand its suitability as a habitat for man and on the other searching for ways to improve the environment.

The stakes in this venture are so high that attaching a dollar sign to Earth resource information seems superfluous. However, estimates of money that could be *saved* annually in the United States alone run over a billion dollars. Knowledge about storms, insect infestations and more efficient pollution surveys is worth money.

Many other uses of Earth observation satellites have been proposed. Some of the more promising are described on page 25.

It is easy to get carried away and promise too much. Although photographs taken from aircraft and manned spacecraft are most promising, the whole field is still in an embryonic state. Furthermore, some Earth resources data will be gathered by aircraft and ground-based surveys. The most effective mix of sensor carriers has not been established yet. One thing is certain, though, and that is that information acquisition, transmission and processing will be a major part of the undertaking. To illustrate, an infrared radiometer reading means little to an agriculturist making a crop survey. Data must be converted into terms understandable to the user and

PRACTICAL APPLICATIONS OF ERTS INSTRUMENTS

Agriculture and Forestry	Applicable Instrumentation: Cameras	Infrared	Microwave	Ultraviolet
Construction of better topographic maps and farm planning	✓			
Estimations of crop types, densities, and expected yields	✓			
Calculation of the damage from disease and insect infestations	✓	✓		
Identification of insect infestation and disease patterns and "early warnings"	✓	✓		
Census of livestock	✓			
Estimation of soil moisture content and irrigation requirements		✓	✓	
Census of forest tree types and estimation of logging yield	✓	✓		
Early warnings of fire, disease, and insect infestation in forests	✓	✓		
Oceanography				
Forecasts of sea state and ice hazards for shipping	✓	✓	✓	
Location of high biological activity from surface temperature for fishing fleets. Large schools of surface-feeding fish may also be pinpointed	✓	✓	✓	
Location of drifting oil slicks	✓	✓		
Survey of coastal geography, including detailed shoreline topography, identification of stream erosion patterns, and mapping of shallow areas	✓			
Collection of such scientific data as the location of areas of bioluminescence, estimation of plankton density, and the pinpointing of red tides, fish schools, and algae concentrations	✓	✓		

Hydrology and Water Resource Planning	Applicable Instrumentation: Cameras	Infrared	Microwave	Ultraviolet
Inventory of water in regional basins by measurement of lake levels, river flow rates, irrigation patterns, and drainage patterns	✓	✓		
Control and early warning of floods by monitoring rainfall, weather prediction, and drainage basin surveys	✓	✓		
Identification of water pollutants and polluters from maps of thermal discharges and the spectral "signatures" of specific pollutants	✓	✓	✓	✓
Estimation of water resources through snow and frozen water surveys and the location of seepage and other groundwater sources	✓	✓	✓	
Geology and Mining				
Detection of minerals (including oil) from topography, drainage patterns, magnetic fields, and direct identification of minerals	✓	✓	✓	✓
Prediction of earthquakes from slight temperature differences, soil moisture content, and topographical distribution	✓	✓	✓	
Prediction of volcanic activity from temperature changes		✓		
Prediction of landslides from soil moisture and slope of terrain	✓	✓		
Location of geothermal power sources from surface temperature measurements		✓		
Transportation, Navigation, and Urban Planning				
Construction of detailed maps of rural and urban areas to help plan traffic arteries, terminals	✓			
Estimation of air, road, and sea traffic	✓			
Surveys of urban areas, indicating housing and population densities, park areas, industrial development, and types of settlement for purposes of planning renewal and new building programs	✓			

RED BAND

NEAR-IR BAND

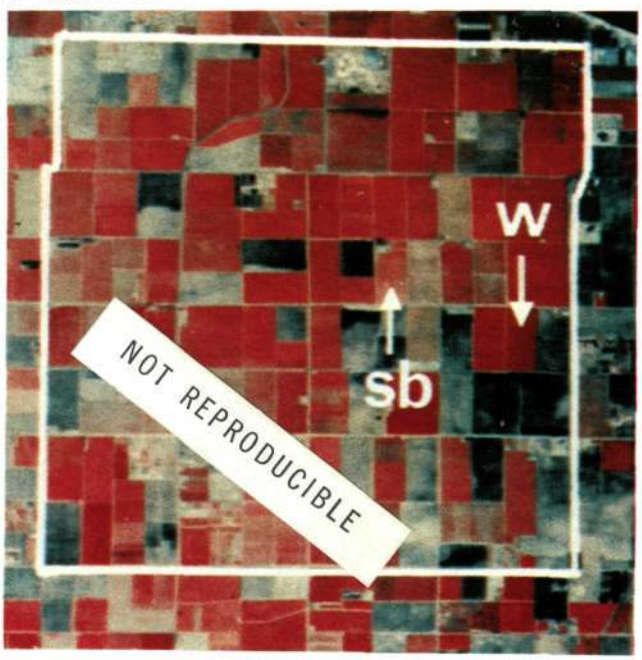
Fig. 18
Multispectral camera photographs of the Salton Sea area. The same region appears very different in various types of light.

Fig. 19 Three high altitude photographs showing how different crops appear throughout the growing season in infrared light.

SEQUENTIAL IR COLOR IMAGES OF AGRICULTURE TEST SITE DURING GROWING SEASON

SCALE: 1/50,000
LEGEND: W=WHEAT
SB=SUGAR BEET
SITE: MESA, ARIZONA
AREA: 4 MILES SQUARE

WHEAT FIELD (W): 16" PLANTS, GROWING
SUGAR BEET FIELD (SB): GROWING
12 MARCH 1969

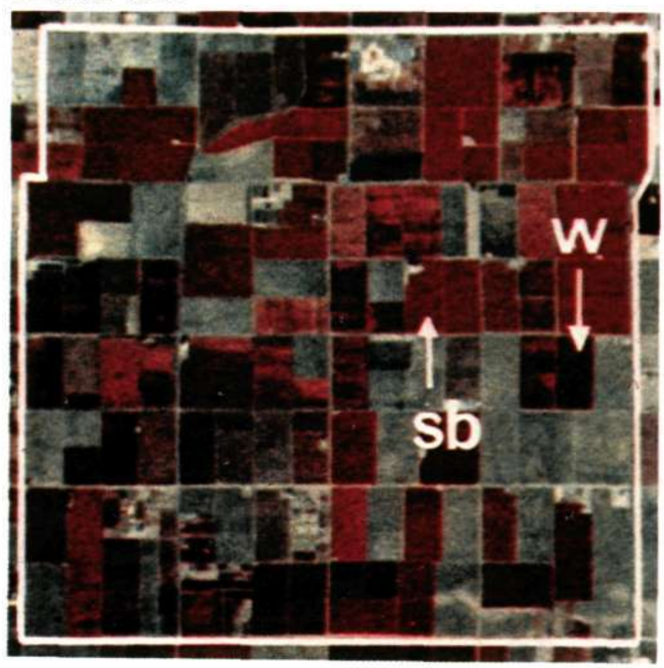


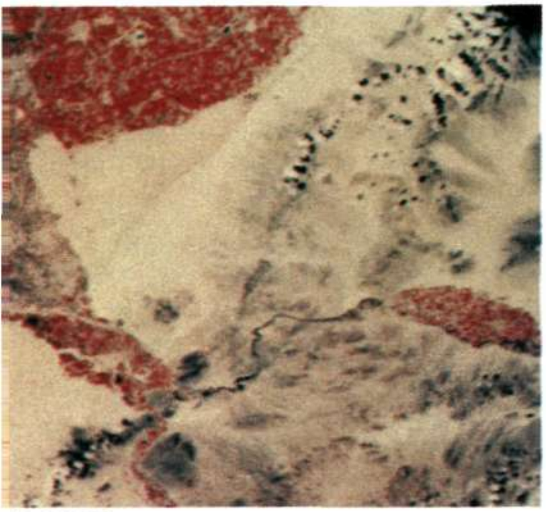
then tagged with geographical and time coordinates. NASA's experience with weather information systems will be of great use here.

NASA's Earth Resources Technology Satellite (ERTS) program began at Goddard Space Flight Center in 1966. The formal objectives of the program are:

1. To define those practical problems where space technology can make beneficial contributions.
2. To conduct research on sensors and establish their utilities in Earth observation.
3. To develop and qualify sensors and spacecraft.

MATURING
GROWING
23 APRIL 1969





IR COLOR

GREEN BAND

4. To develop handling and processing techniques for Earth resources survey data.

Much of the early ERTS work concentrated on the sensors because this was the area with the most unknowns. Flights with manned air- and spacecraft have already shown the probable usefulness of various types of infrared, ultraviolet, and microwave instruments. The next step consists of flying these instruments on an unmanned spacecraft.

The ERTS spacecraft (Fig. 20) and the supporting terrestrial data system are still in the design and

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MATURING
21 MAY 1969

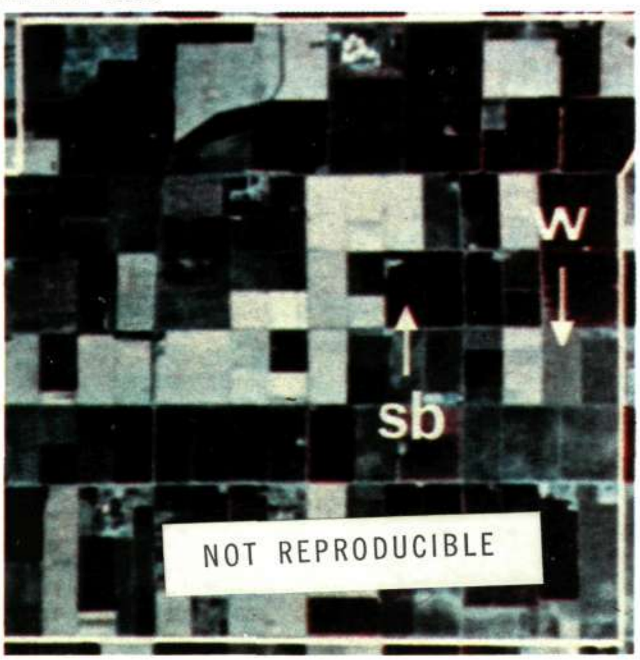
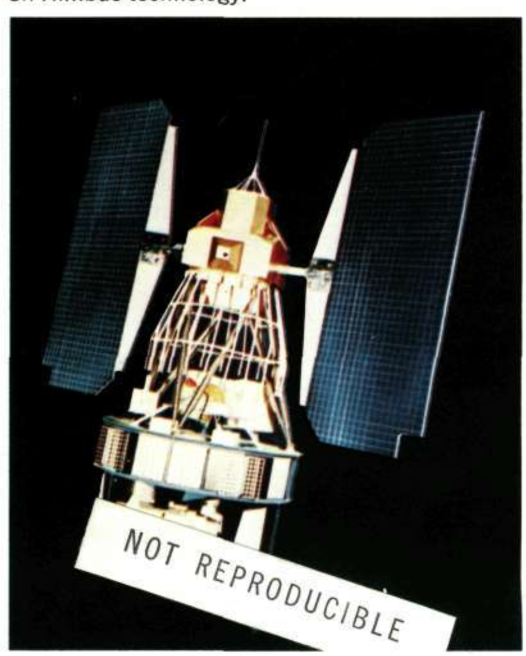


Fig. 20 Conceptual drawing of an ERTS based on Nimbus technology.



development phase, with the first flight scheduled in 1972. Nevertheless, some spacecraft features have already been specified. For example, the sensor end of the craft must point at the Earth continuously; and three-axis stabilization will be essential. Solar power will be used. The attitude control system will incorporate inertia wheels (flywheel, for storing angular momentum) cold-gas jets, horizon sensors, and gyroscopes. Because of the spacecraft size—about 2100 pounds—an active thermal control system employing louvers was chosen. There will be telemetry channels at 136 and 2287 MHz and command links at 148 and 2106 MHz. The technology developed in NASA's Nimbus program will meet the ERTS requirements with minimum additional development.

Two instruments (rather sophisticated ones) are scheduled to fly on ERTS A in 1972. The first is a special TV camera system, consisting of three return beam vidicon cameras. These will take pictures of areas 100 x 100 nautical miles from the nominal satellite altitude of 492 nautical miles. Each camera is sensitive to a different part of the visible and near infrared spectrum. The second instrument is called a multispectral scanner. It will scan swaths of the Earth's surface 100 nautical miles wide as it moves along its orbital track. Again, the pictures will be taken in different parts of the visible and near infrared spectrum.

The ERTS orbit will be Sun synchronous. It will be a polar orbit with a period of about 103 minutes and altitude of 492 nautical miles. Orbit precession will be such that orbital swaths will be repeated every 18 days.

The ERTS program provides a fitting end to this booklet for it uses technology developed in NASA's applications programs to extend the value into new areas. The spacecraft itself will be based on the Nimbus design, and the ERTS sensors owe much to the ATS and weather satellite programs. From the communication satellites come the technology for handling the flood of data from the sensors and their subsequent conversion into formats convenient to the user.

A GLANCE AT THE FUTURE

In space technology, we have a tool, which, as we have seen, has already laid the foundations for better communications, better weather forecasting, and the first comprehensive assessments of the planet's resources. The full implications of this tool we do not yet know. Certainly, there will be better spacecraft and better sensors and ways to wring out more of their meanings. So, at the very least, we can foresee near-instant communication among men and machines everywhere on Earth. Weathermen will give us previews two weeks ahead of time. But communication and weather are only parts of a bigger picture. Spaceship Earth is a complex craft and already crowded with humanity—and there is no escape hatch. Possibly the ultimate contribution of space technology is in our better understanding of the Earth and how it affects and is affected by its human passengers.

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Additional Reading

For titles of books and teaching aids related to the subjects discussed in this booklet, see NASA's educational publication EP-48, Aerospace Bibliography.

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EP-84

SATELLITES AT WORK

Space
In
The
Seventies

National Aeronautics and Space Administration