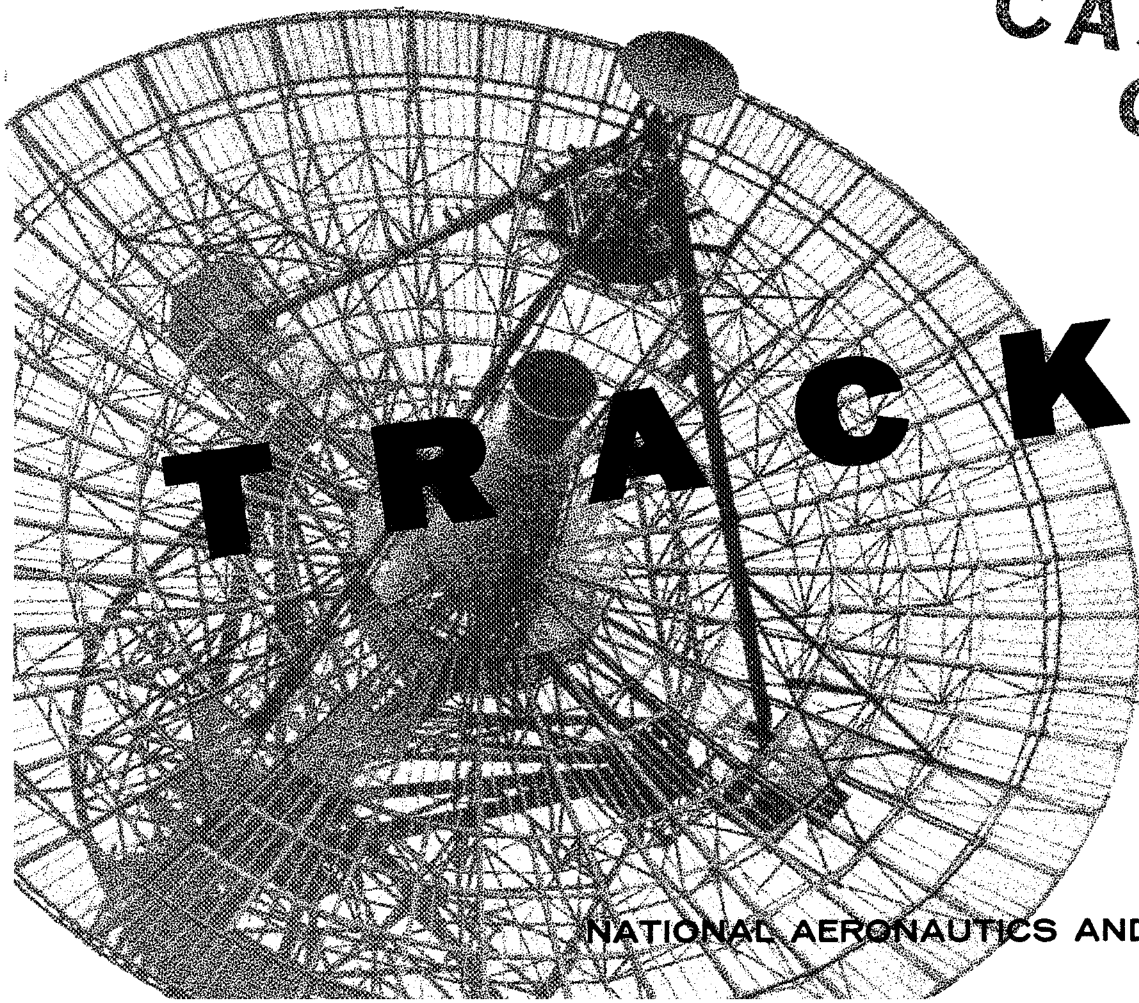
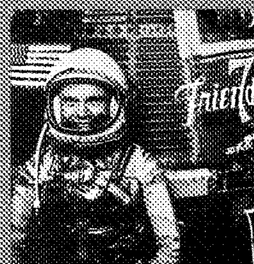
EP-28

TRACKING

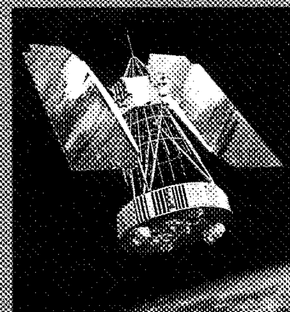


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

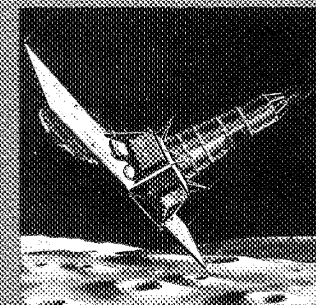
our Space Explorers



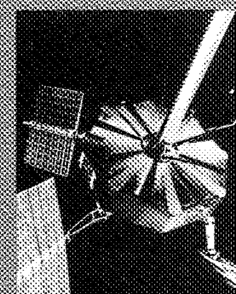
Astronaut Glenn



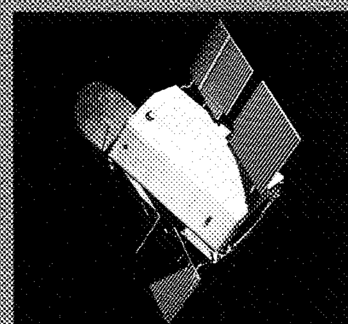
Nimbus



Ranger

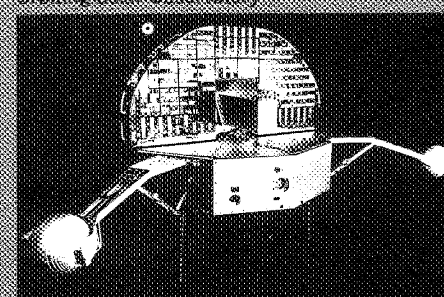


Explorer XII



Orbiting Astronomical Observatory

Orbiting Solar Observatory



TRAILBLAZING

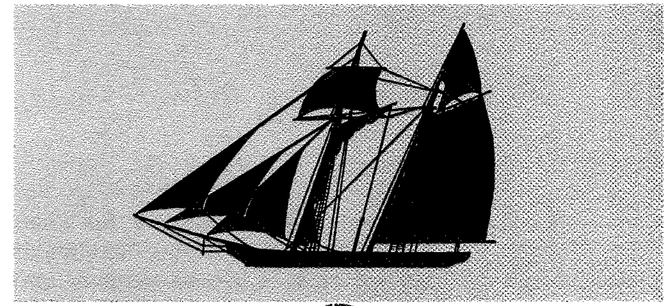
Man has never been content to stay in one place. Historically, it seems that his main preoccupation with life has been to go somewhere else. And, it hasn't been easy. It hasn't been easy because the places he chooses to go inevitably are just over the horizon. But his thirst for knowledge and the desire for whatever lies beyond seem insatiable. As a result, he works relentlessly to devise better and safer ways to go farther faster.

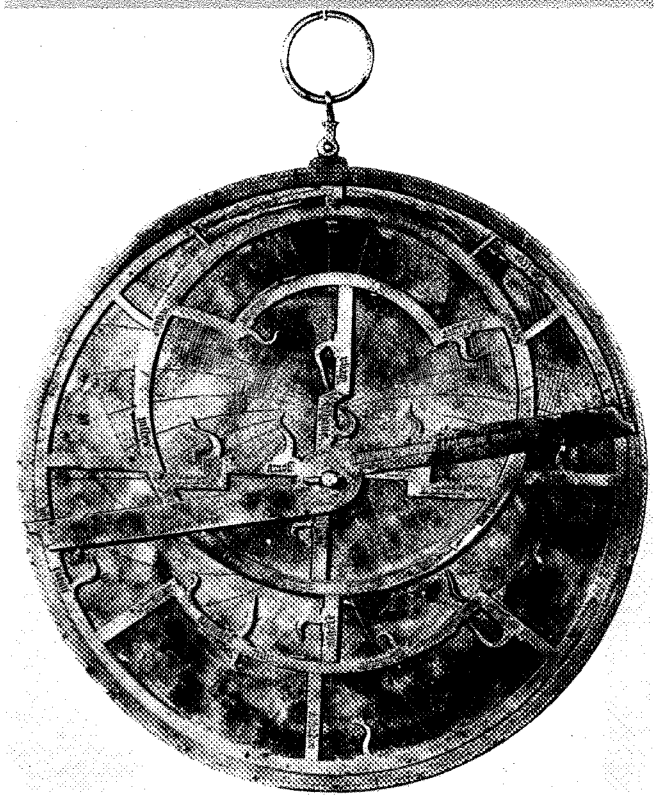
The horse sufficed for a time and, on it, he could cross the land and mountains. Then he learned to harness the wind to sails, and before it, skimmed the seas in boats to distant shores. In time, he came to understand how to make steam drive a piston and turn a screw and a wheel. Thus, he dependably powered his ships to cross the seas and built locomotives to cross the land. At the turn of the Twentieth Century he mastered the intricacies of internal combustion, built himself an automobile, and earned a premium of greater mobility. Still not content, with his new engine he added a third dimension to his travel via the airplane. In combination, these various modes of transportation have enabled men to reach the most remote areas of earth.

Now, with the continuing refinement of yet another engine—the rocket—man is busily extending his horizons. Plumbing the depths of space, he is devising ways to safely span the vast distances separating the planets of our solar system.

Whatever purpose man has had in getting to another place, of equal concern to him has been "getting back" to report what he saw as well as to prepare the way for others to follow. So, historically, he has cautiously and carefully marked his course on land, sea, in the air, and now in space, knowing that such trailblazing maps the route to survival.

On land, he first blazed trails by marking trees and building stone markers along his path. Then he built roads and ferries and bridges—with sign posts to mark them—to cross streams and rivers. At sea,





he first gingerly hugged the shore keeping its comforting landmarks in full view. Then he erected lighthouses; made navigation charts; invented the compass to steer by, the astrolabe, the backstaff, and the sextant to observe and prove his course by the sun and stars; finally, he developed the chronometer, the radio and radar. For flight through the oceans of air, he has continued to improve upon these navigational devices and means of communication so that he might fly higher and farther.

Today, space exploration has brought new challenges for man's inventiveness in the techniques and methods of trailblazing. This booklet tells of the vital electronic links that invisibly tether space explorers to earth; provide signposts; report the facts, and that can recommend and offer life-saving advice. This is the story of Tracking and Data Acquisition.

Tracking and Data Acquisition is a major component in the support structure of space flight. It comprises myriad radio frequencies linking the spacecraft to earth. In consonance with ground stations, computers and communications, the transfer of intelligence between the environment of space and the ground-bound laboratories of the scientist and engineer is possible.

Because of these ingenious electronic devices, the space explorer—human or mechanical—can know at any point in space, where he's going, where he's been, and how he feels about it. In addition Tracking and Data Acquisition can provide a new routing and inform the space traveller where, when, and why the trip must end. Tracking and Data Acquisition is the best "backseat driver" man has been able to devise in navigating space.

What kind of support is furnished after the rocket is fired on its exploratory journey? There are four general areas:

TRACKING

TELEMETRY

TRACKING provides the information continuously reporting the location of a satellite, a probe that is going deep into interplanetary space, or of small rockets that will penetrate space on an up-down path, perhaps only a few hundred miles. Location is important for the scientist-experimenter because he has to know precisely where the spacecraft is at a particular point in time so he can correlate an event measured by the spacecraft with, for example, its position relative to the sun, the moon, or earth. He has to know its position to send it guidance information, to send it commands to make observations, transmit data or change flight plan.

TELEMETRY is the science of measuring a quantity or quantities, transmitting the measured value to a distant station, and there interpreting, indicating, or recording the quantities measured. Contrary to popular belief, it is not a young science. As far back as 1885, patents

CONTROL

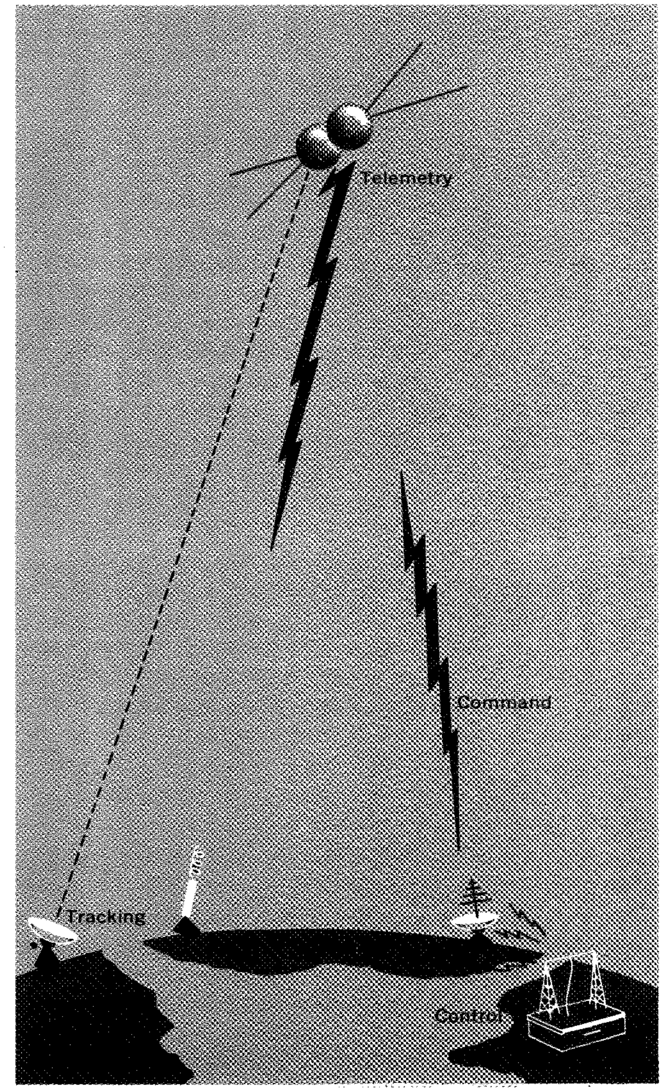
COMMAND

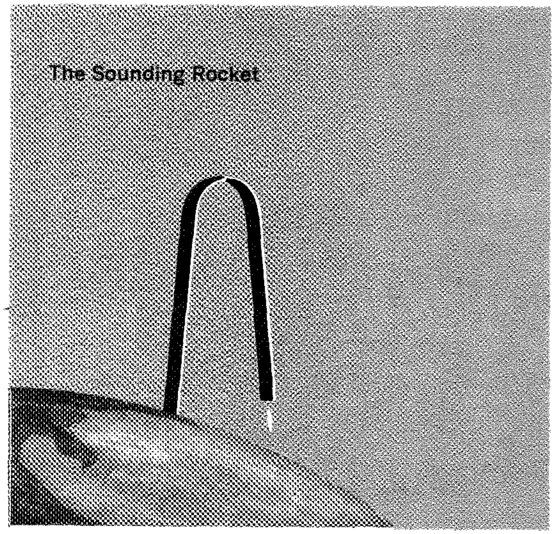
were issued in the United States for an electrical telemetering system. A public utility began using one in 1912, conveying information over long distances by power and telephone lines. In the mid-1930's, with more experience and a better understanding of the higher radio frequencies, scientists began using radio telemetry from weather balloons. Real advances were not made, however, until after World War II when high speed aircraft and rockets began to demand many channels of information for their flight testing.

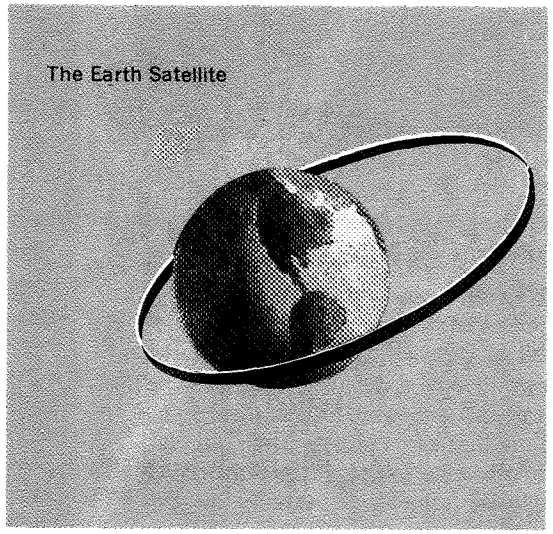
In space flight, radio telemetry is used to tell everything from an astronaut's blood pressure and heart beat to the strength of the earth's magnetic field. What happens is this: The spacecraft's instruments, called sensors, react to an event. This reaction is then transformed into a coded electrical signal and transmitted to the ground. This information signal then must be recorded, decoded and the resultant information fed into computers which can furnish the scientist the charts or tabulations he needs to analyze.

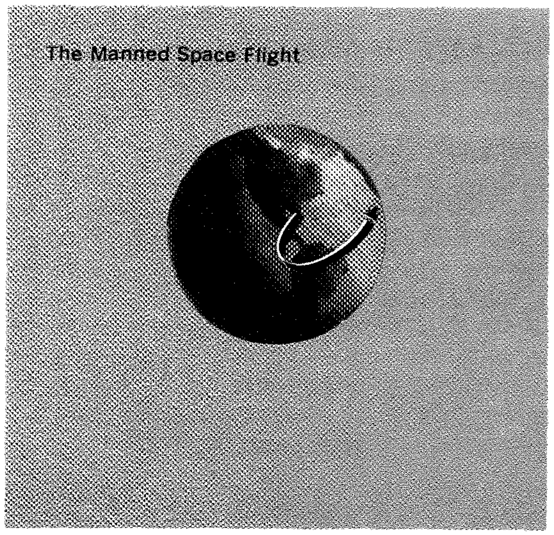
CONTROL is the ability to direct a spacecraft through a global network of ground stations so that the programmed flight mission may be successful. Some flights, such as manned ones, require that all information be gathered and centrally displayed almost as quickly as the events occur or, as the scientist terms it, in "real time." Other flights require that each ground station should be able to inform the next station as to the predicted orbital pass. Still other stations must be able to direct the satellite to do things. The weather satellite TIROS, for example, is commanded when to take photographs of storms and when to transmit them to earth.

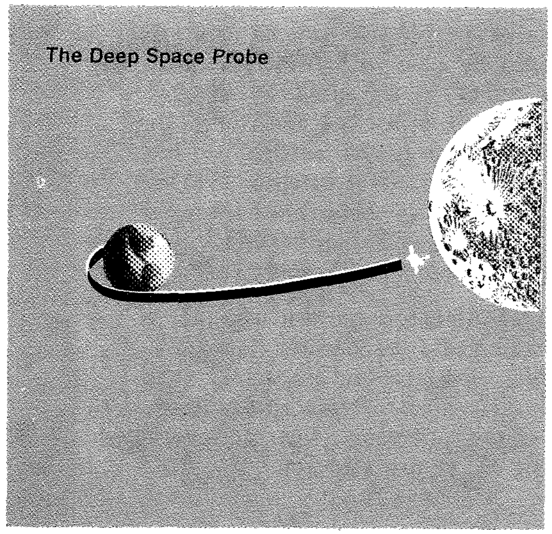
COMMAND means the use of a ground radio transmitter to send a coded signal to the spacecraft that orders it to do certain things, such as change direction, turn a camera on or off, or fire a rocket.











MISSION AREAS

The ground services required by spacecraft depend on the spacecraft's mission. Mission areas fall into four general categories: The Sounding Rocket, or up-down flights from 35 to 1,300 miles;

The Earth Satellite, orbiting from 100 to thousands of miles from earth;

Deep Space Probes, to the moon and the planets; and

Manned Space Flight, in Projects Mercury, Gemini and Apollo.

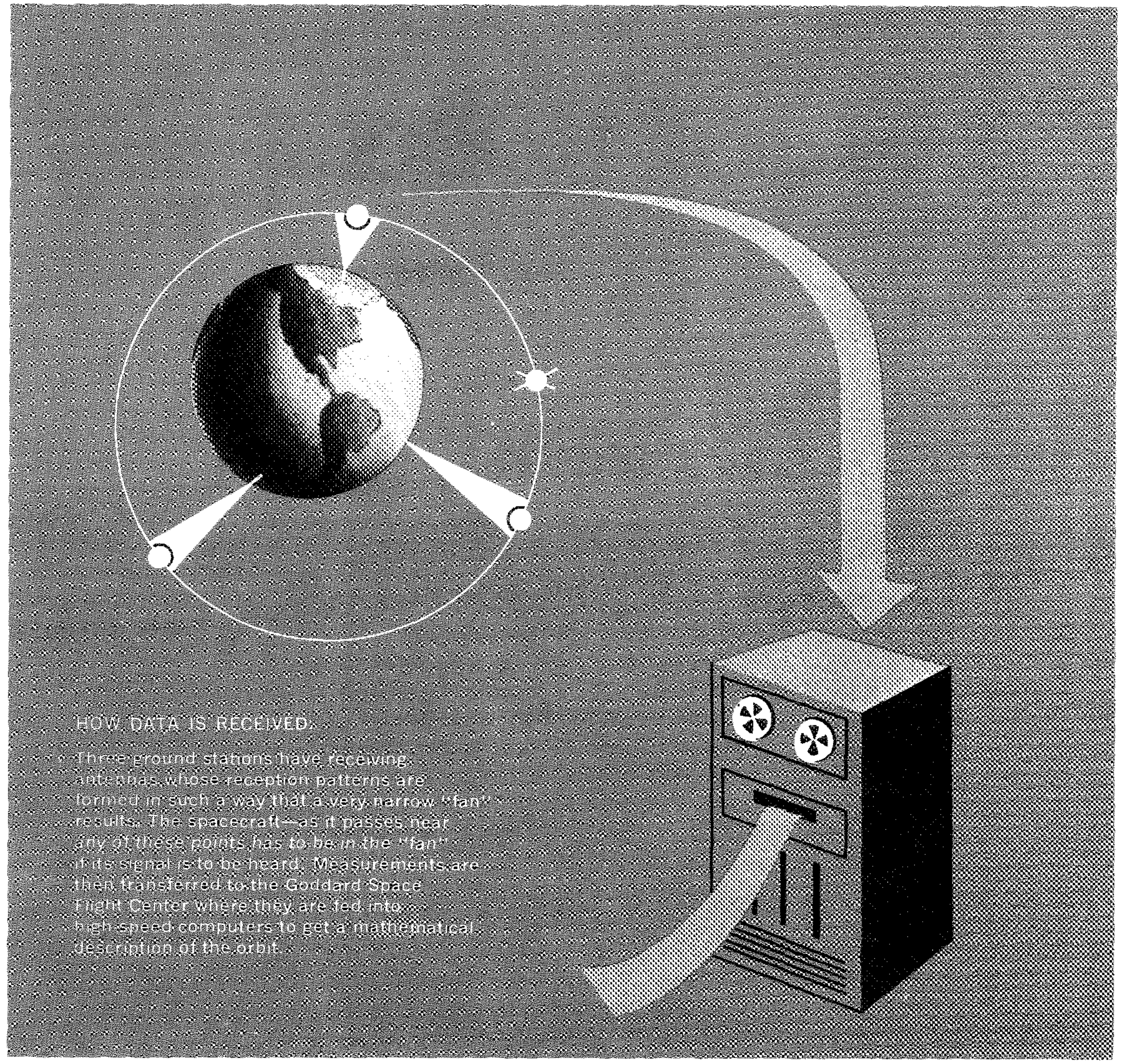
Each of these missions requires particular ground station instrumentation depending on how quickly the data has to be processed, the distance the data must travel back to earth, and the number of stations that will have to be used to track and monitor the flight mission.

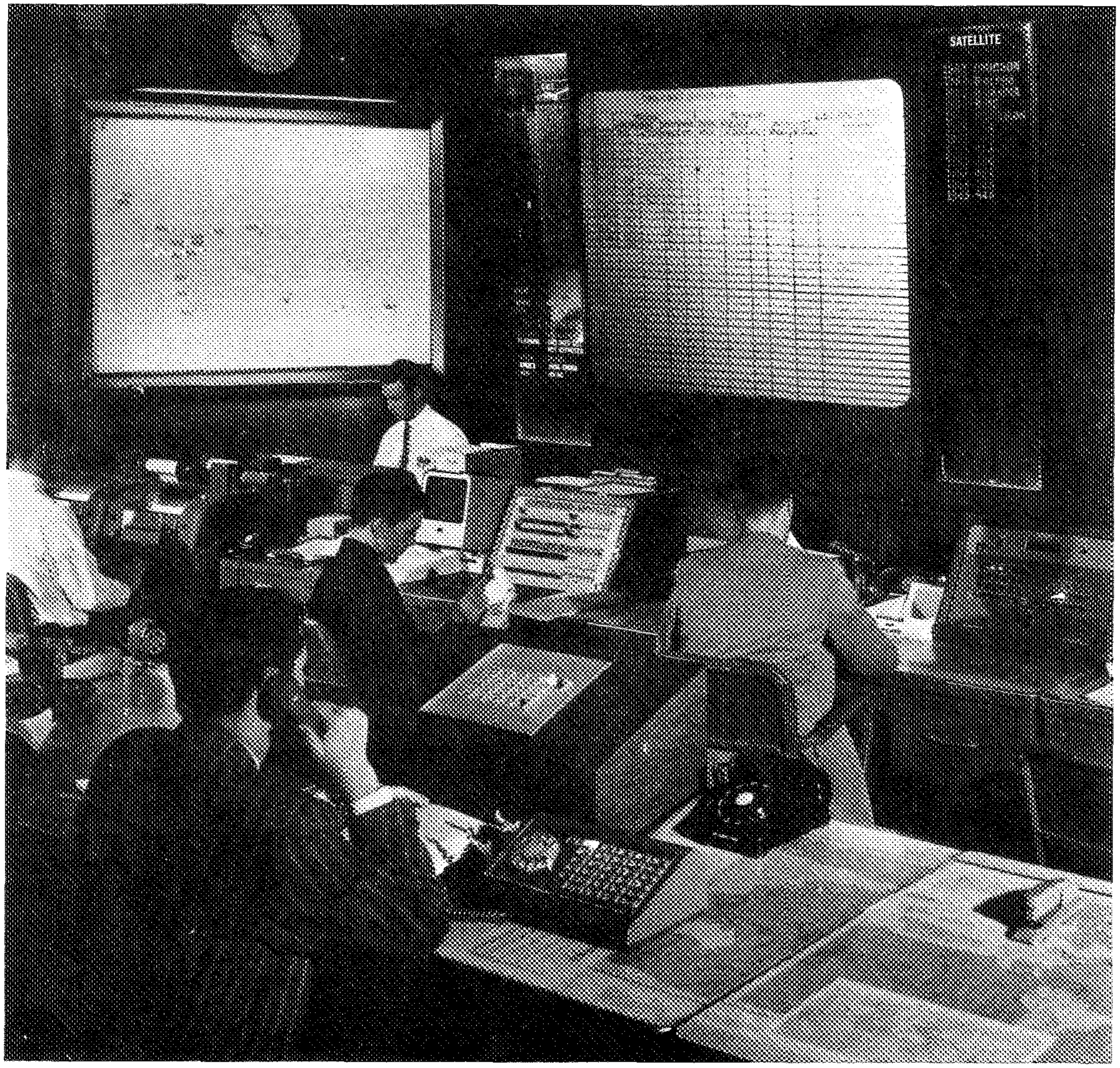
To accomplish these missions, three basic NASA networks have been established: The Manned Space Flight Network, the Deep Space Network, and STADAN (Satellite Tracking And Data Acquisition Network) which includes a 12-station optical tracking network, in addition to its 16 electronic stations. These are the major facilities for tracking and acquiring data from unmanned spacecraft.

SATELLITE TRACKING & DATA ACQUISITION NETWORK (STADAN)

The 16 stations in the world-circling STADAN form two "fences"—one north-south, the other east-west. As a satellite circles the earth it must pass over one or the other of the fences. As it comes within range of a station's equipment, its position is calculated and reported, along with other information from its experiments, to the Goddard Space Flight Center, Greenbelt, Maryland, which operates the network.

STADAN stations are operated at the following locations: Blossom Point, Maryland; East Grand Forks, Minnesota; Fort Meyers, Florida; Goldstone Lake, California; St. Johns, Newfoundland; Winkfield, England; Johannesburg, South Africa; Quito, Ecuador; Lima, Peru; Santiago, Chile; Woomera, Australia; Canberra, Australia; Rosman, North Carolina; Tananarive, (Malagasy Republic); University of Alaska, Anchorage and Gilmore Creek, Alaska.





Spacecraft Operations Control Center (SOCC) at NASA Goddard Space Flight Center serves as a key point in monitoring and controlling application and scientific spacecraft launchings made at Cape Kennedy, Fla., Wallops Island, Virginia, and from Pt. Arguello, California.

There are two kinds of STADAN facilities. One is the Minitrack (*Mini*mum Weight *Track*ing), characterized by an antenna of steel rails lying parallel to the ground. The other is comprised of highly complex electronic equipment associated with a parabolic (dish-shaped) antenna.

The first Minitrack facilities were installed for the unmanned scientific satellites launched during the International Geophysical Year, 1958. A Minitrack does not radiate energy as a radar does. It simply has a receiving antenna whose reception pattern is formed in such a way that a narrow "fan" results (See page 7). As the spacecraft passes through the narrow fan pattern of Minitrack, high overhead, a radio signal for a transmitter on board is "caught" and heard by the station equipment.

This technique is known as the interferometer principle. It could be likened to a person passing through a photo-electric "eye"

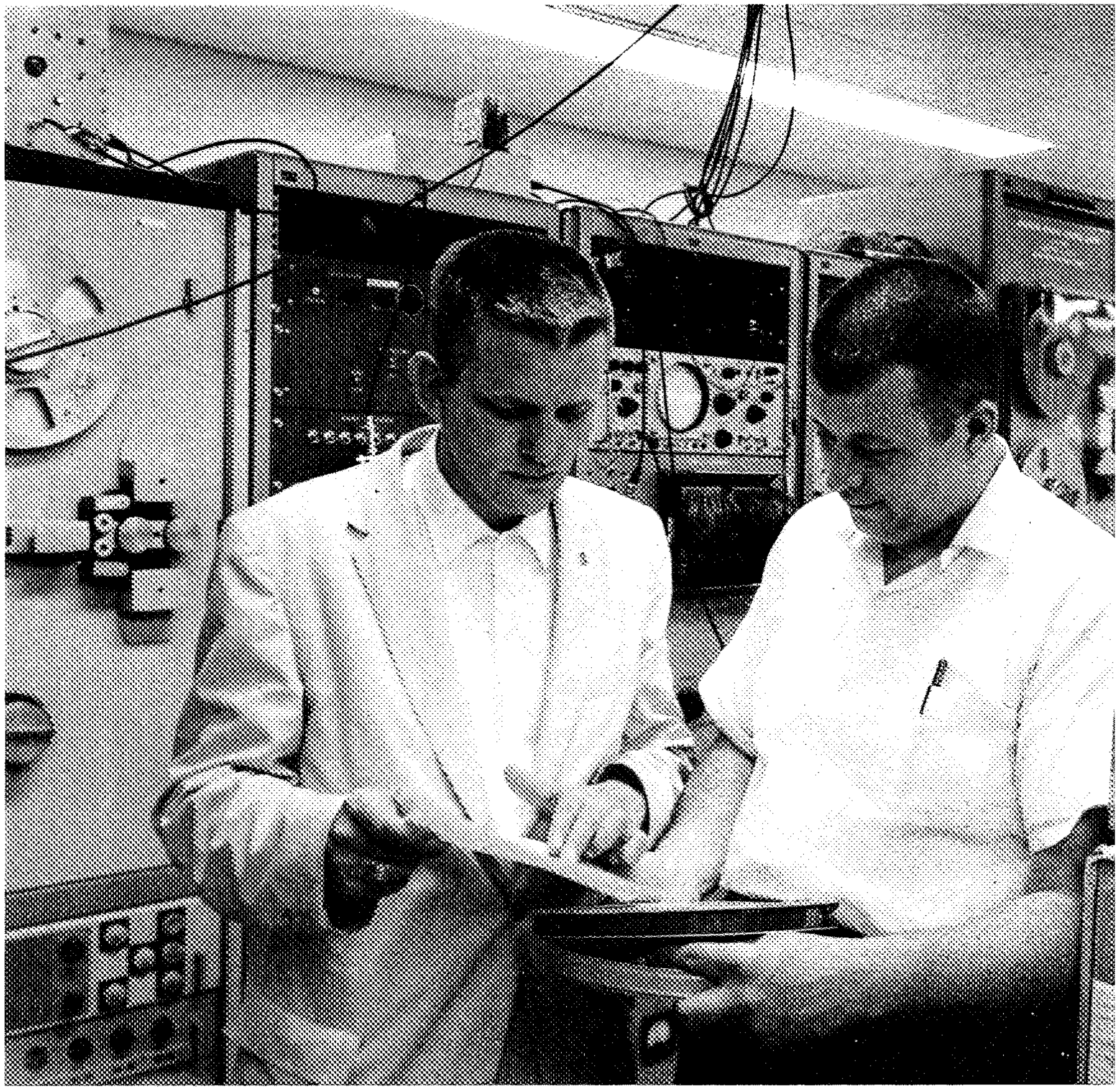
Rosita and Pepito are the llama pets of tracking station personnel at Quito, Ecuador

which opens a door when the light beam is broken. As the satellite passes through the narrow reception fan, its position can be determined with great accuracy.

There are a number of reasons why the exact position of a satellite must be known at all times. First, the scientific experimenters must have an accurately timed chart of the satellite's location to interpret the data reported by its sensors. Second, technicians must have good position data to plot the flight path. This orbital information is given to all stations along the route so that they may, at the proper time, point their antennas in the correct direction to pick it up. And third, the orbital data, if precise enough, has a scientific value of its own. From it the scientist can calculate and evaluate the effect on the spacecraft of unknown forces, such as solar pressure and micrometeorites acting upon it in space as well as other phenomena.

The second type of facility, the parabolic "dish" antenna, is a highly sensitive receiver and a powerful transmitter. Unlike the Minitrack interferometer which lies in a permanent position, the dish antenna can sweep the sky. It can swing from the horizon to point directly overhead at the zenith, and also swing a full 180 degrees from left to right. It must be able to follow spacecraft which may orbit thousands of miles away at apogee (farthest point from earth). It must command the satellite to report the results of its experiments, and it must be able to receive the weak and distant signal when it comes.

Many of today's satellites carry large numbers of experiments, each of which must report its findings by radio. The Orbiting Geophysical Observatory (OGO) is an example. It carries 20 or more experiments. It has a data handling system that can store up to 86 million bits of information, and then transmit them to earth at up to 64 thousand bits a second. The Orbiting Solar



Scientists at Goddard examine reels of magnetic tape which were contributed by the Explorer XII satellite. In its 112 days of life.

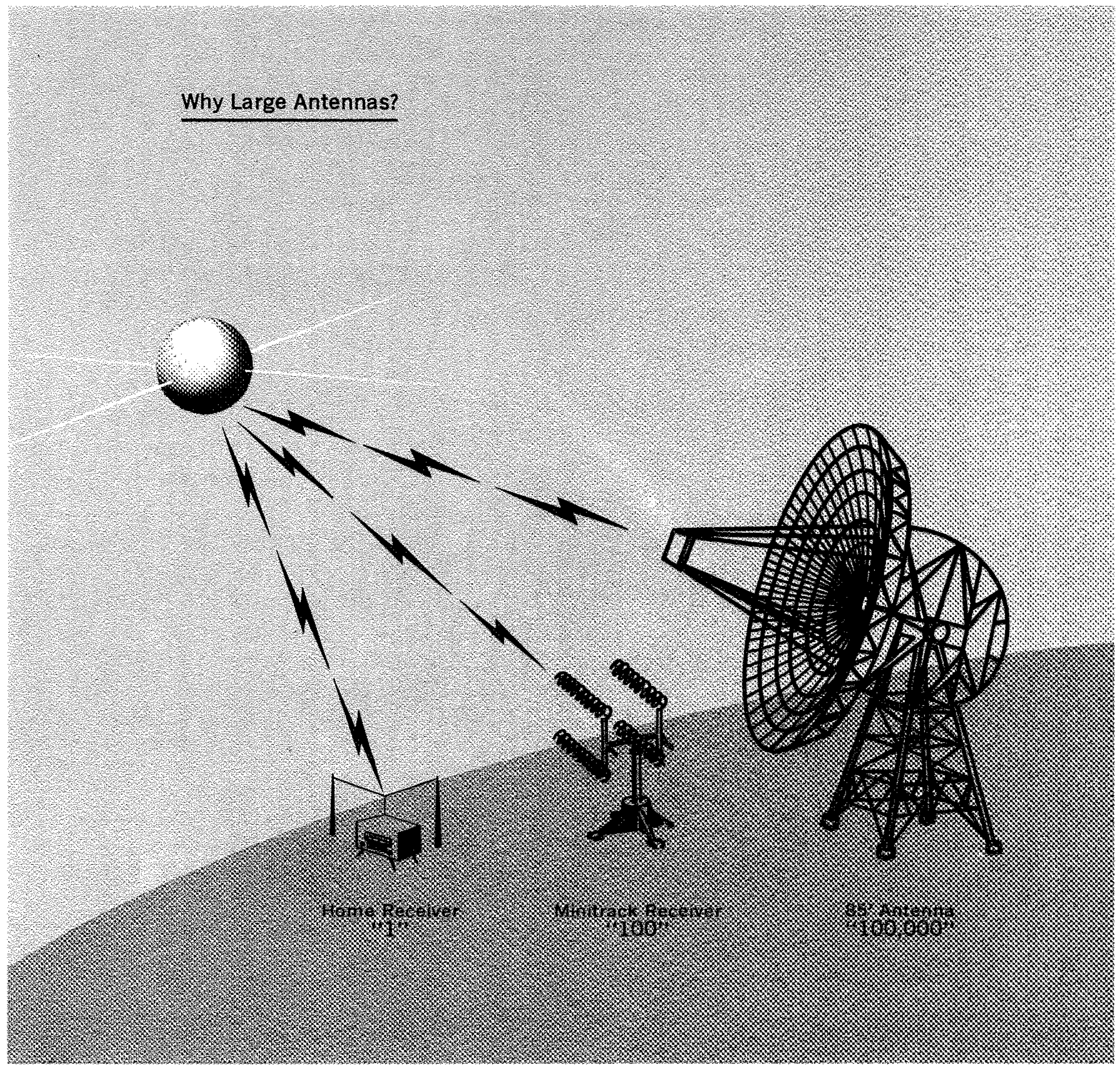
Observatory (OSO) is another example of a complex, advanced satellite.

Only the large parabolic antennas have the capacity to give ground support to these spacecraft. The dish acts as a high-quality reflector for radio signals and focuses them on very sensitive receiving apparatus.

To provide this support large parabolic antennas have been installed at key stations. The prime key station and center of the north-south and east-west fences is at Rosman, North Carolina. There are two 85-foot diameter dishes at Rosman; each weighs 300 tons and is 120 feet tall when pointed directly overhead. A companion facility is located at Fairbanks, Alaska. A third 85-foot dish is now operating at Canberra, Australia. Dish antennas of 40 feet operate at Quito, Ecuador; Santiago, Chile; and Johannesburg, South Africa.

The first illustration at the right shows a simple antenna that could be used at home to listen to a satellite. The second depicts the yagi-type of receiving antenna now installed at all Minitrack facilities. The third example is an 85-foot diameter dish antenna.

Let's say that the smallest antenna receives a signal from a hypothetical satellite. Assign to this antenna the relative number "1". By using the Minitrack antenna we strengthen or get a "signal improvement" of 100. Using the 85-foot diameter antenna, we improve the quality of the same signal by a factor of 100,000. Thus, the dish antenna can receive a signal from a satellite many times farther away. It can also receive a complex signal containing a greater amount of information. A television signal, such as used to bring satellite weather pictures to the ground, is a wide band-width signal with a low signal strength. By this the TIROS and Nimbus satellites can warn of storms and hurricanes well in advance.



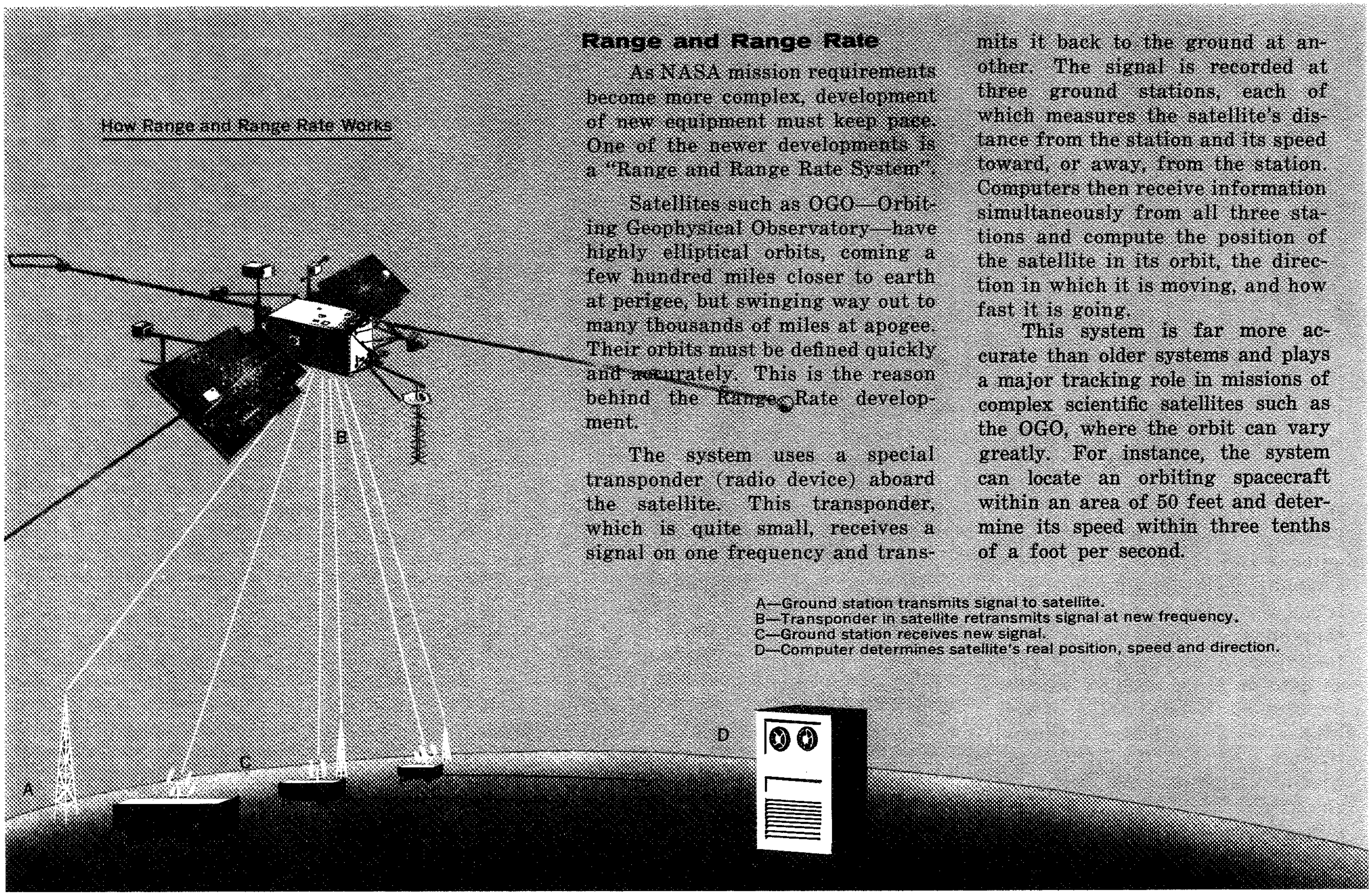
Range and Range Rate

As NASA mission requirements become more complex, development of new equipment must keep pace. One of the newer developments is a "Range and Range Rate System".

Satellites such as OGO—Orbiting Geophysical Observatory—have highly elliptical orbits, coming a few hundred miles closer to earth at perigee, but swinging way out to many thousands of miles at apogee. Their orbits must be defined quickly and accurately. This is the reason behind the Range-Rate development.

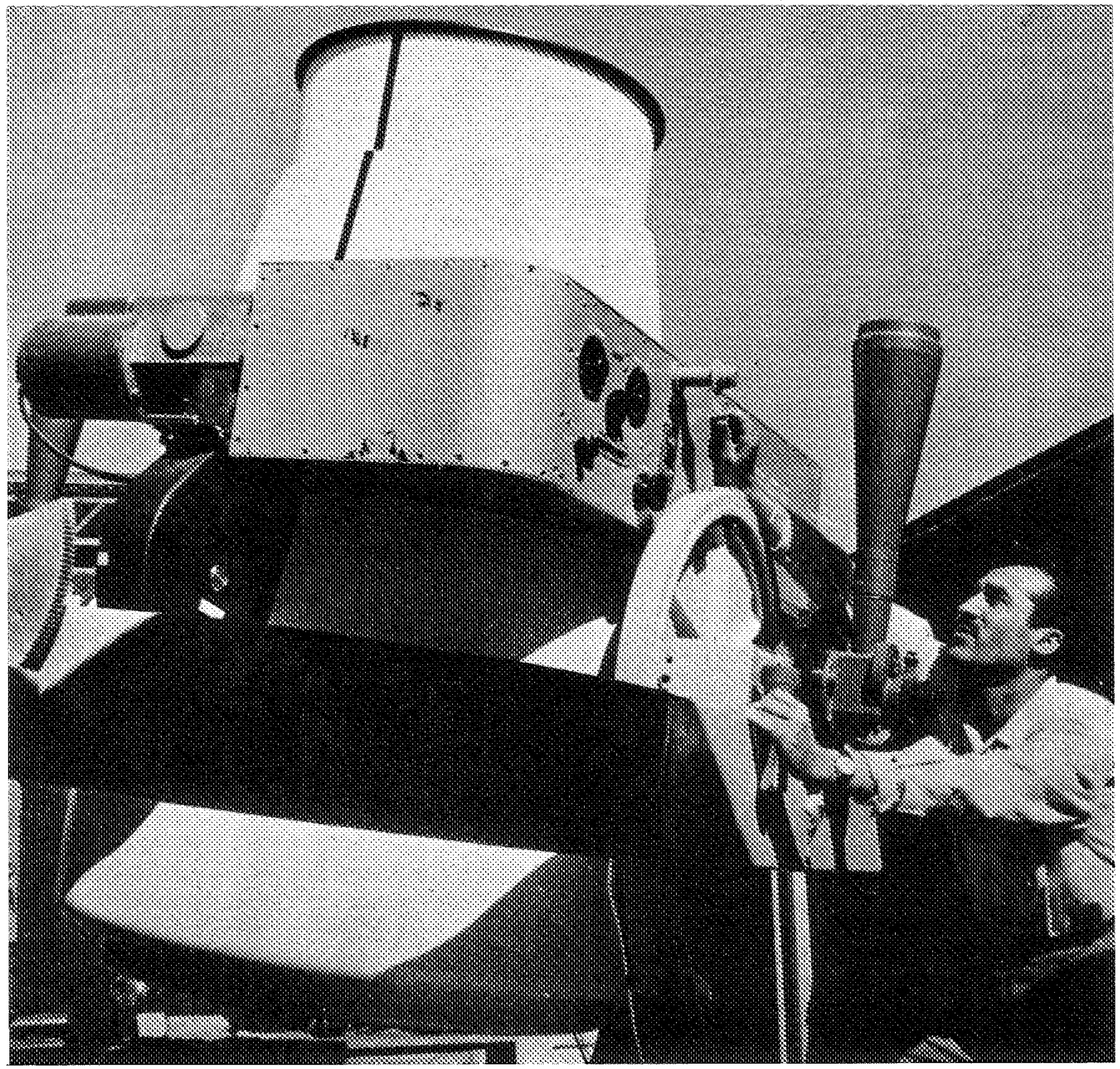
The system uses a special transponder (radio device) aboard the satellite. This transponder, which is quite small, receives a signal on one frequency and transmits it back to the ground at another. The signal is recorded at three ground stations, each of which measures the satellite's distance from the station and its speed toward, or away, from the station. Computers then receive information simultaneously from all three stations and compute the position of the satellite in its orbit, the direction in which it is moving, and how fast it is going.

This system is far more accurate than older systems and plays a major tracking role in missions of complex scientific satellites such as the OGO, where the orbit can vary greatly. For instance, the system can locate an orbiting spacecraft within an area of 50 feet and determine its speed within three tenths of a foot per second.



A—Ground station transmits signal to satellite.
B—Transponder in satellite retransmits signal at new frequency.
C—Ground station receives new signal.
D—Computer determines satellite's real position, speed and direction.

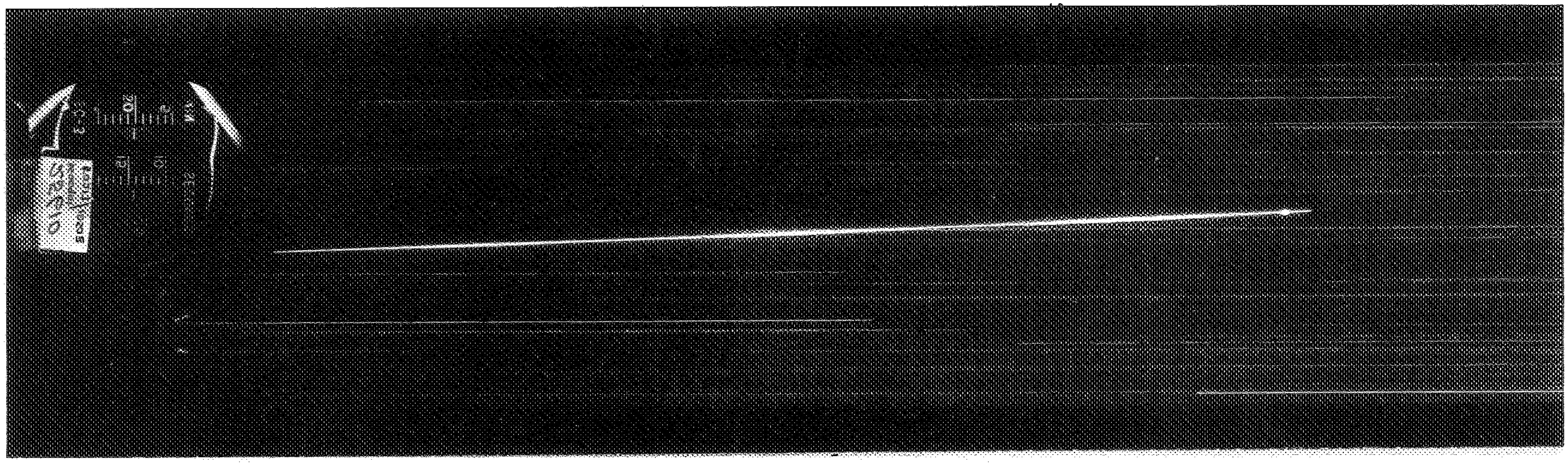
Twelve Baker-Nunn cameras, designed for satellite tracking, are operated around the world.



SAO/OPTICAL TRACKING NETWORK

There is still another method by which NASA obtains tracking information to establish where earth satellites are in space. This is the Smithsonian Astrophysical Observatory's (SAO) Optical Tracking Network, operated under grant by NASA. It consists of 12 specially designed satellite tracking cameras, known as Baker-Nunn cameras, named after the two scientists who designed the particular instrument.

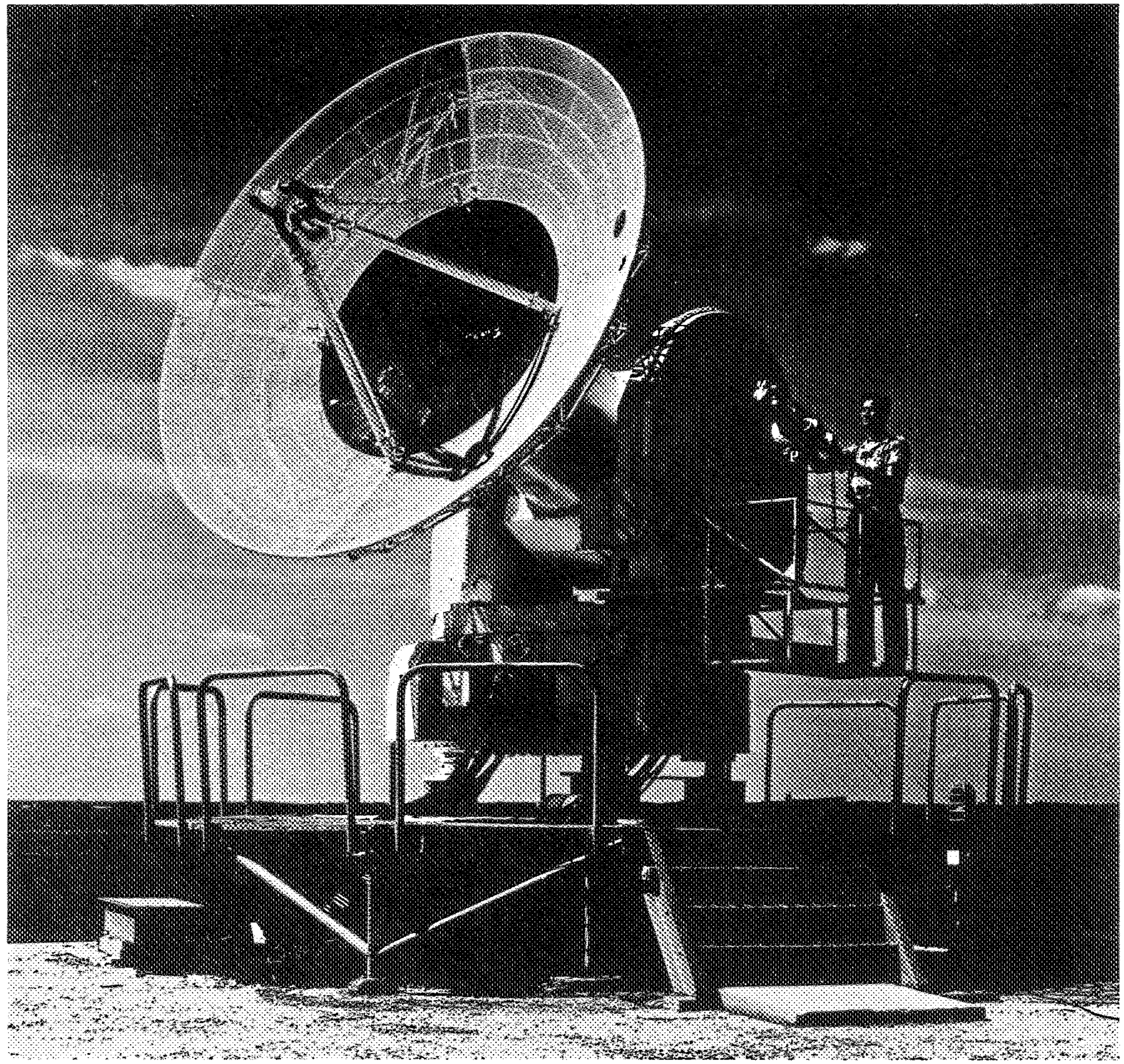
The cameras provide the most sensitive optical means of observing artificial earth satellites and have performed remarkably. The first Vanguard, a 6-inch sphere, has been photographed at a range of 3,500 miles; and the Orbiting Geophysical Observatory at 23,000 miles.



THIS UNUSUAL photograph of the Pegasus satellite was taken by a Baker-Nunn tracking camera at the Smithsonian Institution's Astrophysical Observing Station, Woomera, Australia. The photo was made on Feb. 17, 1965; the aperture was f/1 and the exposure time was about 60 seconds. The satellite image shows variation in magnitude corresponding to the 20-second period of rotation of the satellite. The bright flash at the right-hand end of the track is probably due to reflection from the Pegasus "wings." On this pass, Pegasus was directly overhead about 445 miles above the earth, and passing through the constellation Canis Major when photographed.

The camera has a 3-axis mount which enables it to be pointed in any direction. Basically, it takes a photograph of the satellite against a known star background. The stars appear as tiny dots. As the satellite moves across the star background it creates a "trace" on the photograph. The angles between the stars and the satellite can be measured to fix the position of the satellite at a particular time.

Baker-Nunn stations are located at: Maui, Hawaii; Organ Pass, New Mexico; Jupiter, Florida; Curacao, West Indies; Aeroquipa, Peru; Villa Delores, Argentina; San Fernando, Spain; Olifantsfontein, South Africa; Shiraz, Iran; Naini Tal, India; Tokyo, Japan; and Woomera, Australia.



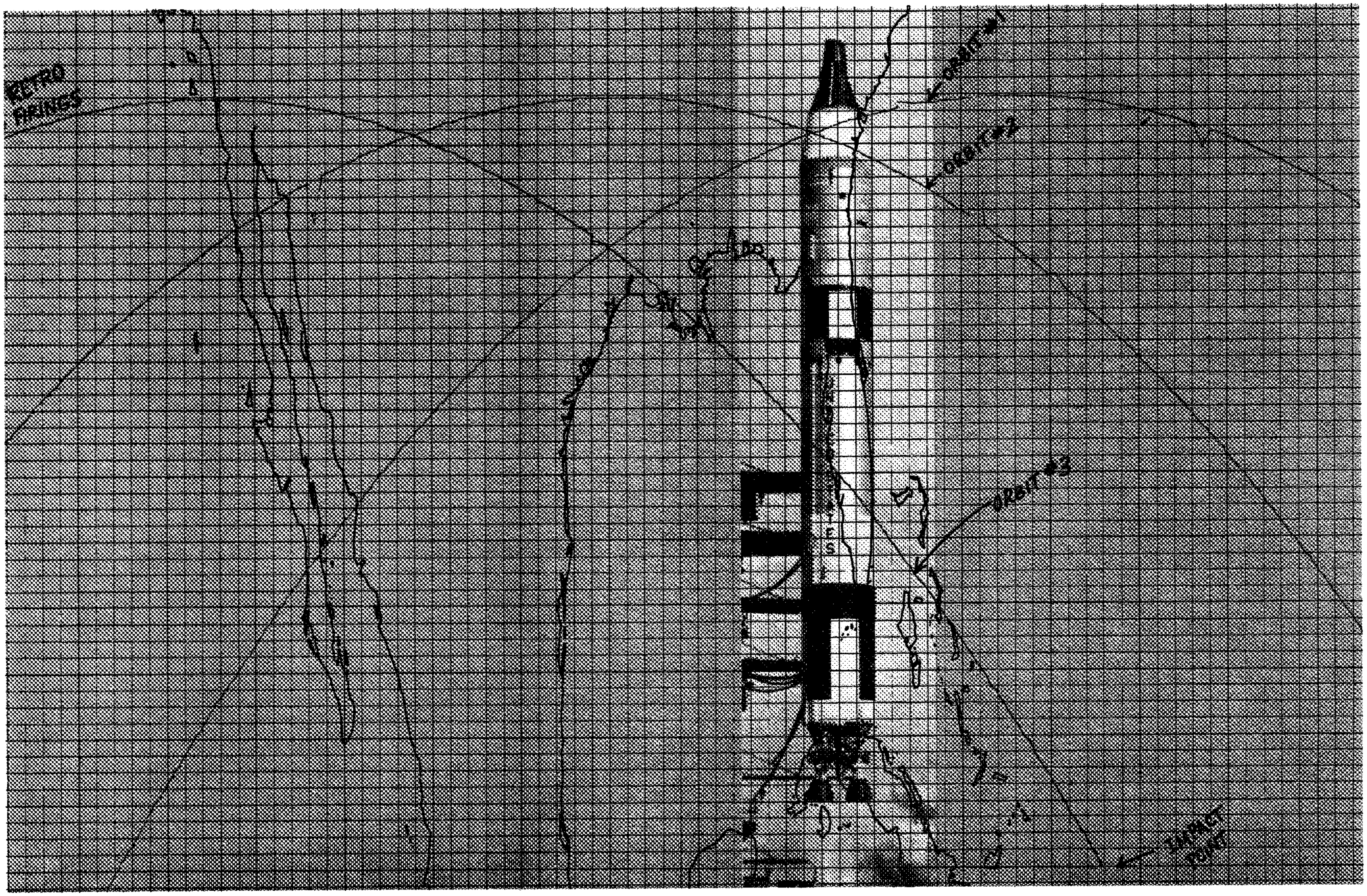
FPS-16 radar installation at NASA's Wallops Island, Virginia station.

MANNED SPACE FLIGHT NETWORK

Project Gemini astronauts are served by a Manned Space Flight Network of 13 ground stations. Tracking and support ships are stationed in ocean areas along the orbit according to the needs of the mission.

The requirements which guided the designers of this network included specifications that there would be dual contact between ground and space for the astronauts in their Gemini spacecraft—for the Agena rocket which they would overtake, and with which their spacecraft would mate. This is a vital training exercise for the later Apollo flights which will aim at placing men on the moon and bringing them safely back home.

Tracking must provide the information that the Gemini spacecraft and the Agena are in acceptable orbit after launch from Cape Kennedy. For Gemini, this must be determined before its launch vehicle passes Bermuda, following its first trip around the earth. If orbit


RETRO FIRINGS
ORBIT #1
ORBIT #2
ORBIT #3
IMPACT POINT

Computer map of the three-orbit Manned Space Flight mission

should be unacceptable, then the spacecraft would be brought down near the Canary Islands, after completing its first orbit, and before it reached the African land mass.

Thus, the number of tracking radars and telemetry; command and voice communications antennas in the Manned Space Flight Network, is related to the requirements of the spacecraft in orbit; the maneuvers to be made in space, and the recovery area in which the spacecraft will return to earth.

The accuracy of the radars used by these stations is phenomenal. One radar, for example, can determine the location of a spacecraft within seven yards from a distance of more than 500 miles.

The Manned Space Flight Network for Gemini is composed of tracking and data acquisition facilities in the United States and seven foreign countries; a Mission Control Center at the Manned Spacecraft Center, Houston, Texas; and, at Cape Kennedy, Florida, and a computing and communications center at Houston, and at Goddard Space Flight Center, Greenbelt, Maryland.

The basic network consists of seven primary land sites, two ships—the USNS Rose Knot (Victor) and the USNS Coastal Sentry (Quebec), six additional land stations, and the computing/communications and control centers.

Other tracking and data acquisition facilities, such as relay aircraft, instrumentation ships, communications and relay stations, are called upon as required and are integrated into the basic network. Also considered part of the network is a Training Center for network personnel at Wallops Island, Virginia.

The entire system is supported by the NASA Communications Network. This division of NASA, called NASCOM, is a responsibility of the Goddard Space Flight Center. NASCOM provides a world-wide, highly reliable, communications network of teletype, voice and digital data links between the stations and

Technicians man the Manned Space Flight computing center at Goddard

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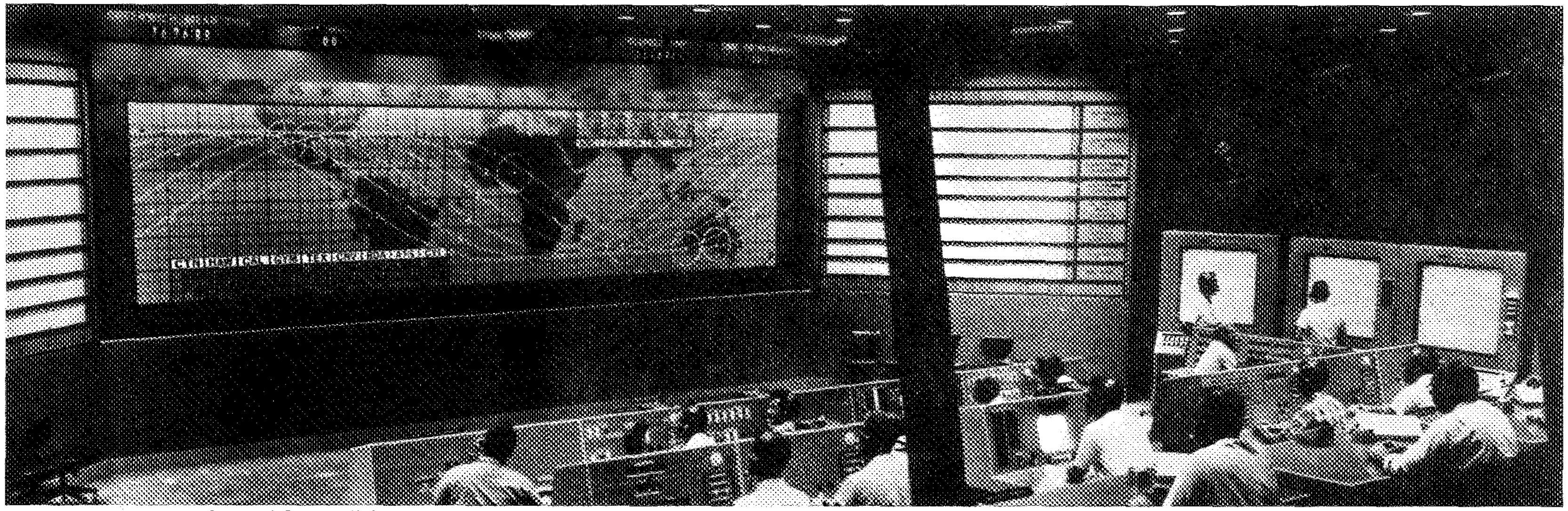


Manned Space Flight Control Center, Cape Kennedy, Florida.

control centers. Linked together in this network of 100,000 route miles are 89 locations including 34 points overseas.

A voice communications switchboard system called SCAMA (*S*tation *C*onferencing *a*nd *M*onitoring *A*rrangement) is a part of NASCOM. SCAMA, which connects all stations and control centers, has been enlarged for Project Gemini to ten times the capability it had for Mercury.

One of the most critical functions of the world-wide network is obtaining data and making high-speed computations. Tracking data from the stations goes by high speed communications circuits to real time computing complexes at Goddard and the Manned Spacecraft Center, Houston, Texas, for processing by computers. Based on these computations, decisions must be made for the "go, or no-go", the retrofire and the reentry commands.

At the Manned Spacecraft Center, Houston, Texas, computers accept radar and telemetry data in digital form via Goddard and perform computations for each of the separate flight phases: the launch phase, the orbital phase, and the recovery phase.

Locations of the primary land stations are: Cape Kennedy, Florida; Bermuda; Grand Canary Island; Carnavon, Australia; Hawaii; Guaymas, Mexico; Corpus Christi, Texas; and the two ships—Rose Knot (Victor) and Coastal Sentry (Quebec).

Additional stations are: Kano, Nigeria; Tananarive, Malagasy; Canton Island; Point Arguello, California; White Sands, New Mexico; Eglin, Florida; and, of course, down range sites in the launch area.

DEEP SPACE INSTRUMENTATION FACILITY

The Deep Space Network supports NASA's lunar and planetary missions. Specially mounted 85-foot diameter parabolic antennas are used to receive data from spacecraft, determine their location in space and command them to maneuver in space —to change course if that is necessary to reach their goal.

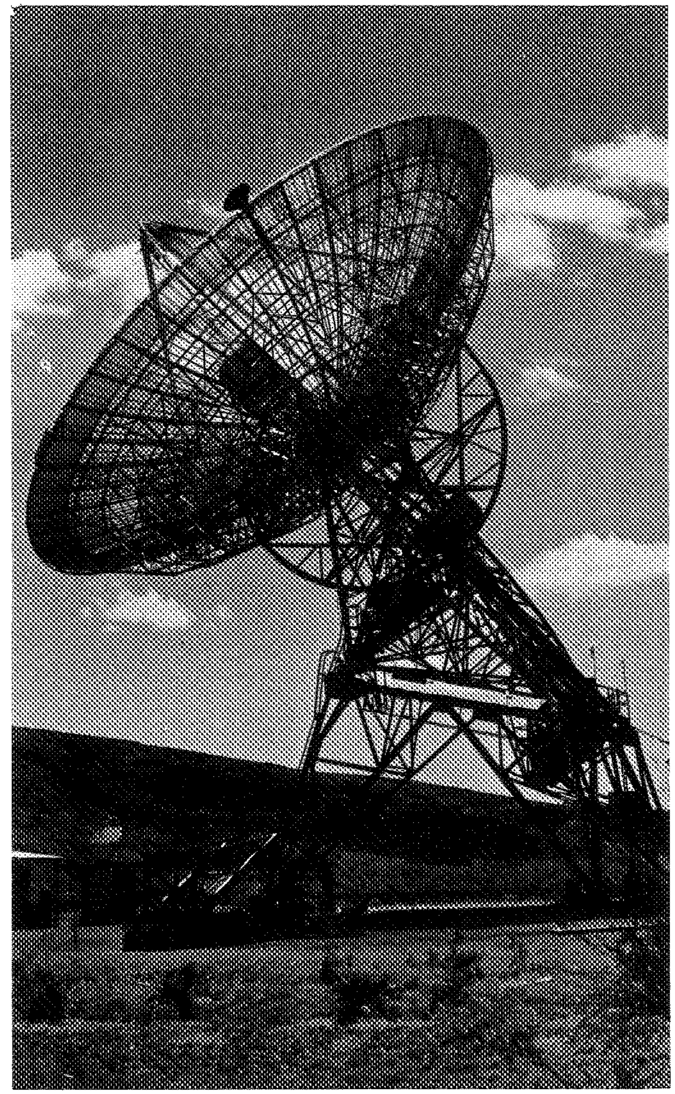
Stations are located at 120° intervals of longitude apart, so that with three stations around the world, one will always have a line-of-sight communication with the spacecraft as the earth rotates. Deep Space Network stations were first established at Goldstone, California; Woomera, Australia; and at Krugersdorp, near Johannesburg, South Africa. As more deep probes were launched, some of them with flights of long duration, the work load of the stations doubled. Three more facilities were required. One of these was built at Goldstone, near the original facility; another in Australia, near the capital, Canberra; and a third, near Madrid, Spain, along the same general latitude as Johannesburg.

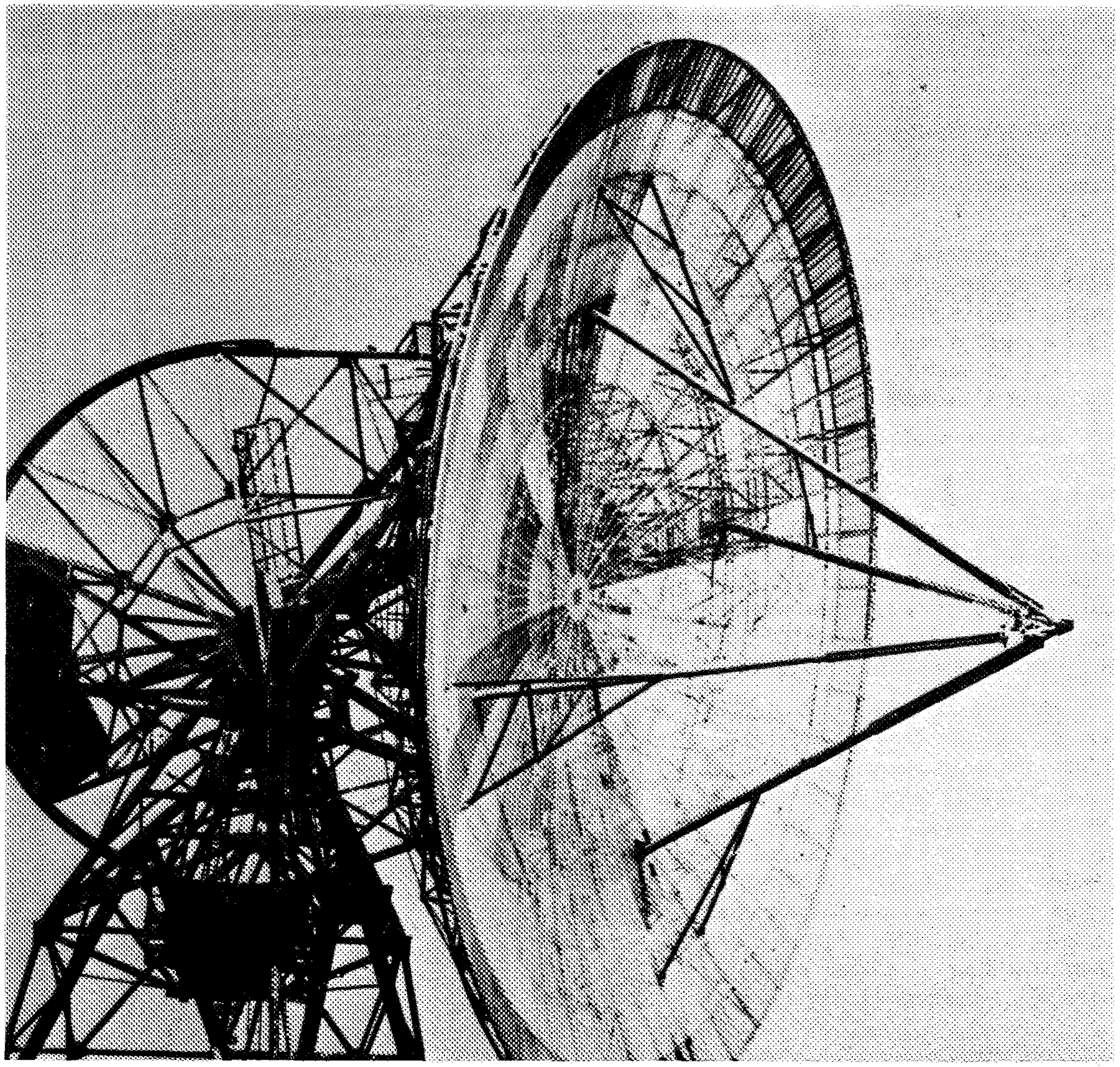
The network is operated for NASA by the Jet Propulsion Laboratory of the California Institute of Technology. A control center for the network is maintained by JPL at Pasadena, California.

The Deep Space Network has the responsibility of support to missions such as the Ranger series which, before impacting on the moon, sent back to earth by television over 6000 detailed photographs of the lunar surface. The Network also supports the Mariner project which is assigned to study the planets Venus and Mars.

Mariner II, which reported on Venus, was launched on August 27, 1962. On September 4, the Deep Space Network gave a command to Mariner by radio signal to correct the direction of its flight in order to change the distance by which it would miss Venus from 230,000 miles to only 21,600 miles. Mariner was then traveling at 60,000 miles per hour. On December 14, 109 1/2 days

85-foot diameter "ear" to space at Goldstone, Calif.



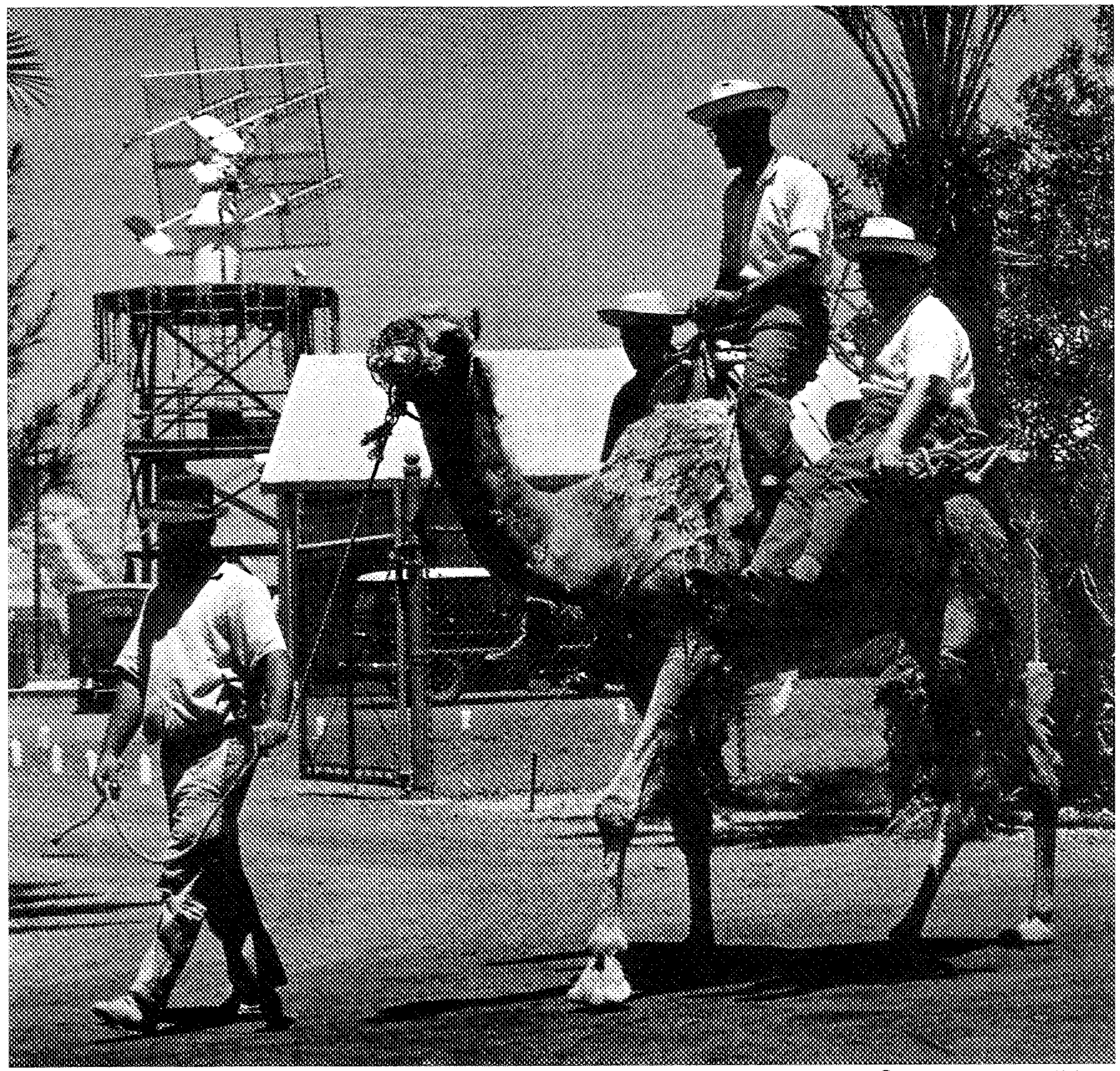


Silent Sentry
Deep Space 85-Foot Antenna
Woomera, Australia

after launching, travelling at 87,000 miles an hour, Mariner II passed Venus at exactly the distance of the command: 21,600 miles. The spacecraft was then 36,000,000 miles from earth and had traveled approximately 182,000,000 miles. Electronic ranging systems are able to indicate the distance from earth to the spacecraft with accuracy to within 45 feet at lunar and planetary distances. During the Mariner IV flight, communications and tracking were maintained throughout its 228-day, 325 million-mile journey. On this voyage, it successfully photographed the planet Mars from an altitude of 6,118 miles and then transmitted the photographs back to earth, then 134 million miles away.

Future spacecraft will carry instruments of greater complexity to report more sophisticated information. As they are integrated, companion instrumentation will be added to ground stations to assimilate the information and to maintain communications. An example of this is the 210-foot diameter antenna now being built for NASA at Goldstone.

The new and the old—
on Grand Canary Island.



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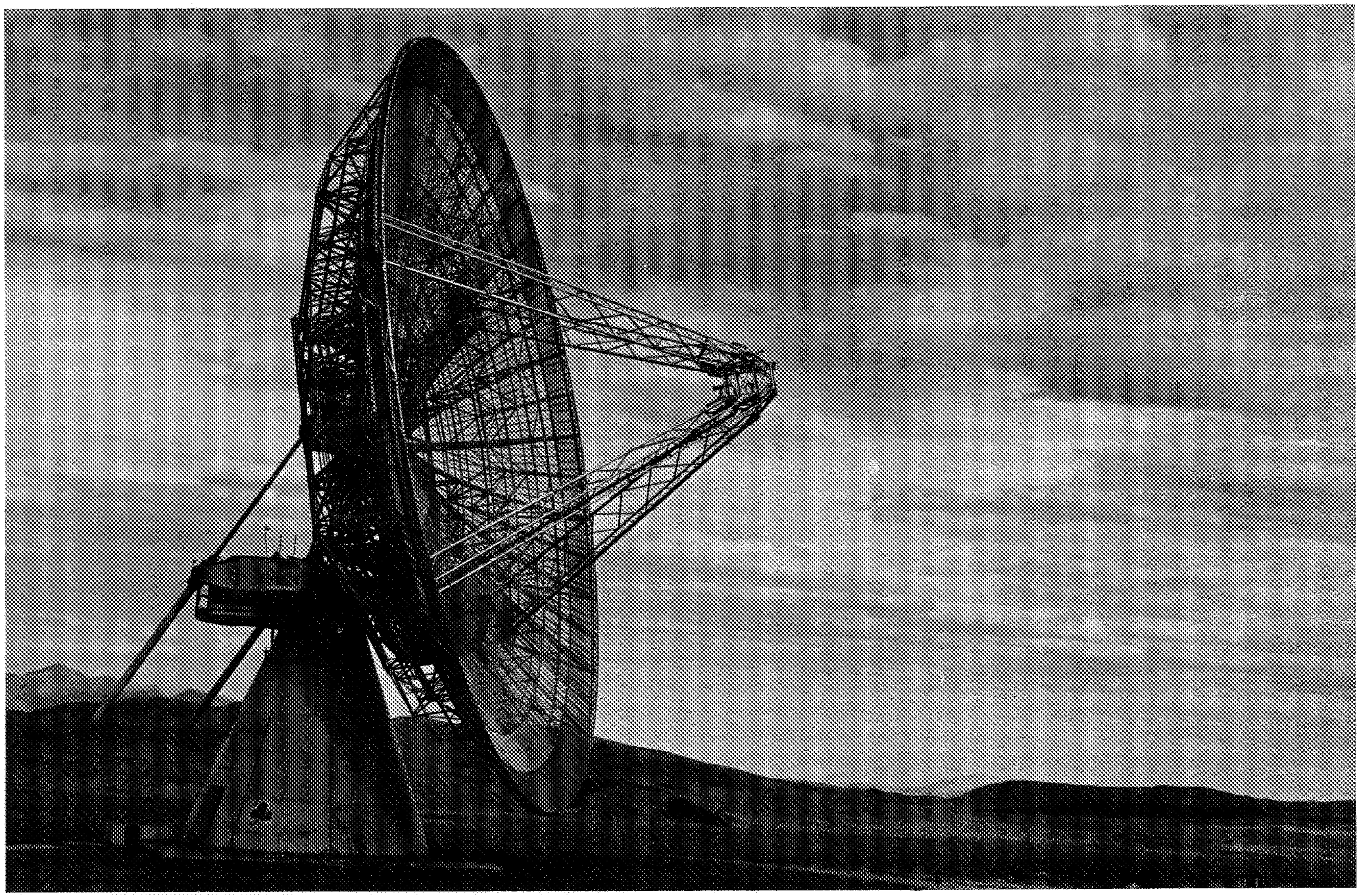
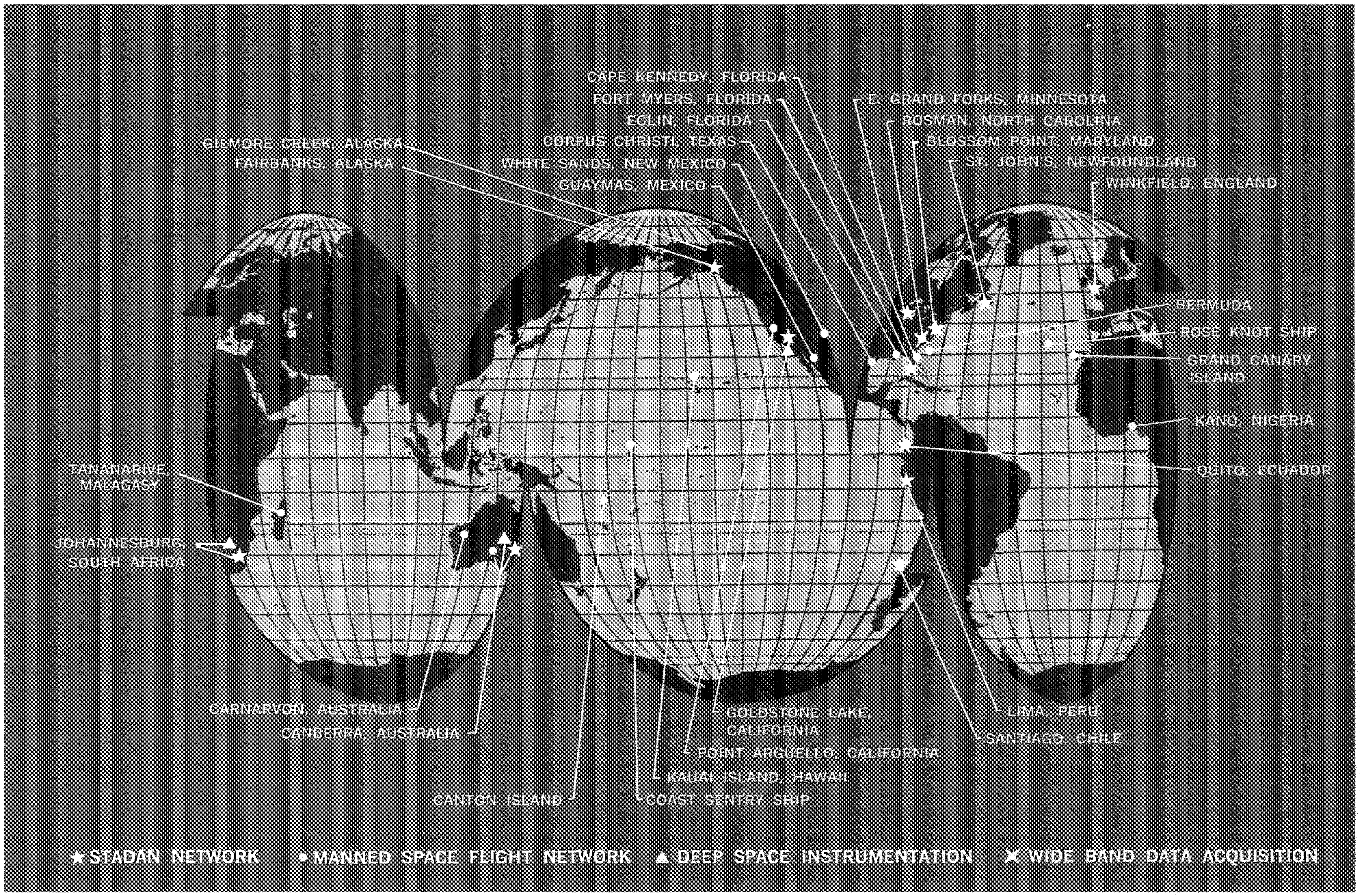
INTERNATIONAL COOPERATION

NASA tracking and data acquisition facilities are located in many different lands representing diverse governmental ideologies. Yet, all of these facilities are operated with the complete and cordial assistance of nationals of the host country—truly, an example of our nation's ideal that the exploitation of space be peaceful, open to all men, for the betterment of all mankind.

This is as it should be, for the tasks to be overcome—if man is to successfully land on the moon and the planets beyond—are many and formidable. All of these efforts to master space would prove fruitless if completely accurate and comprehensive historical, real time and programmed records of individual spacecraft flight were not available. These comprise, internationally, the job of tracking and data acquisition. Only with such information can any astronaut safely navigate in the vast reaches of space.

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