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NASA SPACECRAFT

National Aeronautics and Space Administration

NASA SPACECRAFT

by William R. Corliss

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Introduction

It is ten years since the National Aeronautics and Space Administration was created to explore space and to continue the American efforts that had already begun with the launch of Explorer I on January 31, 1958. Many changes have occurred since that tumbling, 31-pound cylinder went into an Earth orbit. "NASA Spacecraft" represents one of the broad avenues selected by NASA as an approach to its objective of making widely known the progress that has taken place in its program of space exploration. This report is a vivid illustration of the changes that have occurred and the complexities that have developed. Here one finds descriptions of the present family of spacecraft—some small, some large; some spin-oriented, some accurately attitude-controlled; some manned, some automated; some in low orbits, some in trajectories to the Moon and the planets; some free in space until they expire, others commanded to return to the Earth or to land on the Moon.

Oran W. Nicks
Deputy Associate Administrator for
Space Science and Applications

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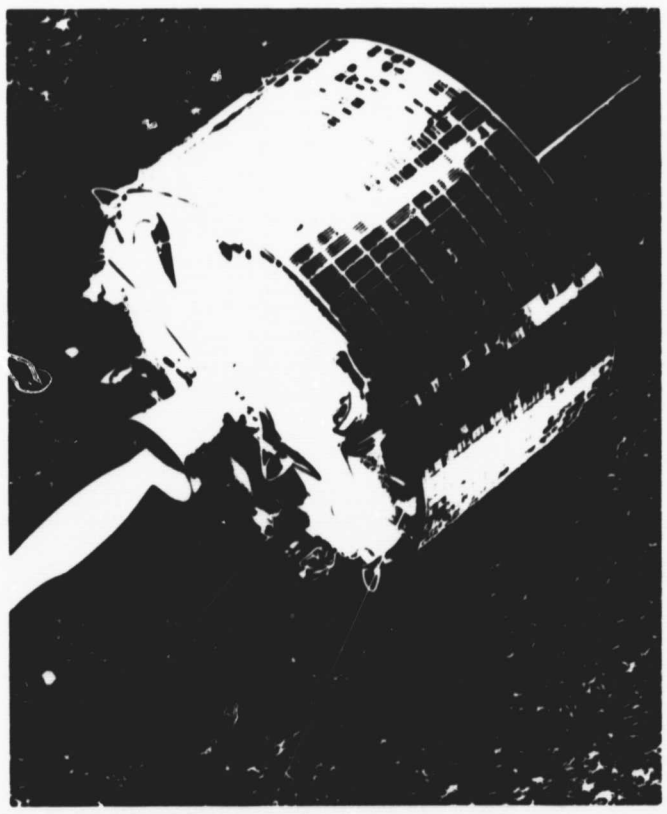
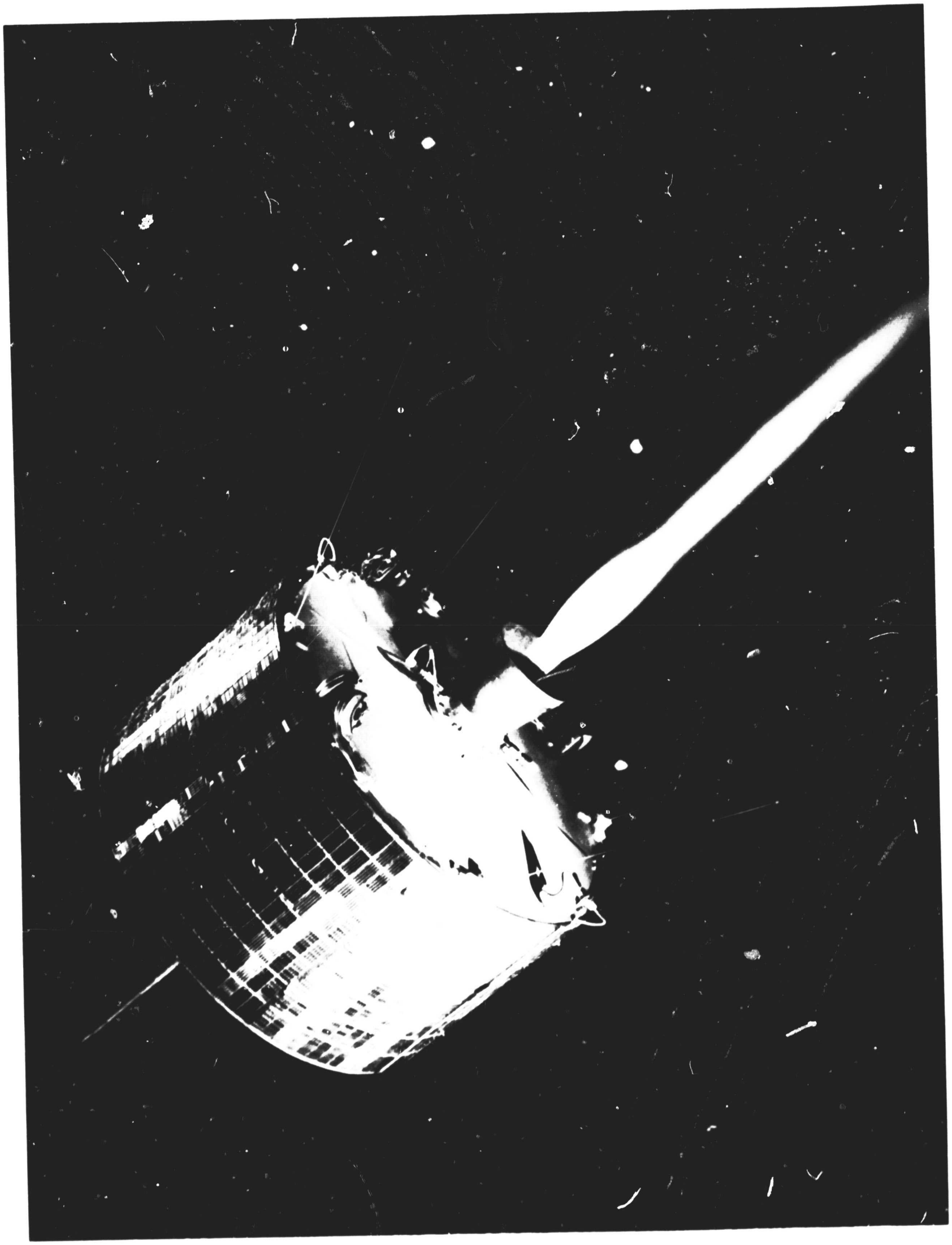




NASA Spacecraft

Spaceships And Spacecraft

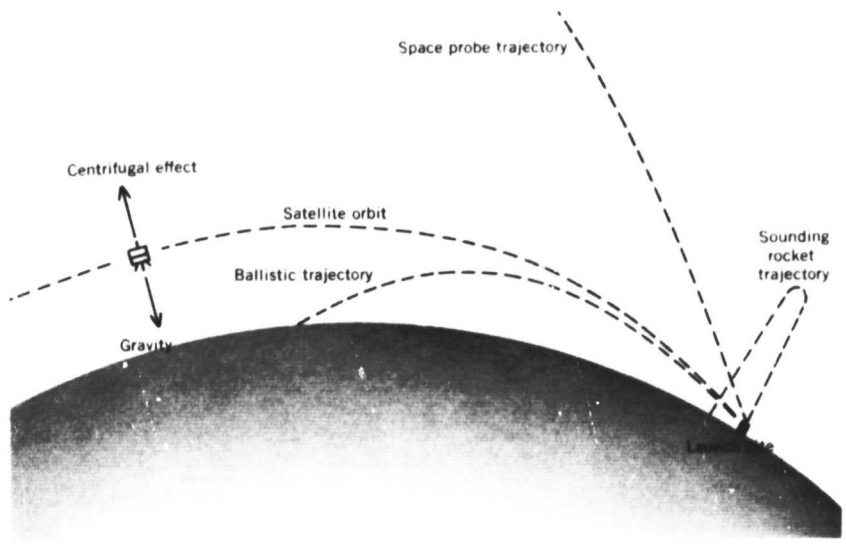
To Jules Verne, a spacecraft was a huge aluminum bullet fired toward the Moon from a gigantic cannon buried in Florida soil, not too far from Cape Kennedy. In 1865, when Verne's "De la Terre a la Lune" appeared, spacecraft were conceived as well-appointed extensions of the drawing room, and the gentlemen who traveled in them likely as not wore top hats and formal attire. This romantic view of the spacecraft persisted well into the Twentieth Century. To distinguish these visions of fiction from today's complex space machines, we call the former spaceships and the latter spacecraft.

A spacecraft is any vehicle that operates above the sensible atmosphere; that is, above the altitudes attainable by research balloons and aircraft—approximately 100,000 feet of altitude.

In the first ten years of space flight, over 600 satellites have circled the globe. Even so, the satellite has been greatly outnumbered by the sounding rocket, a spacecraft that breaks through the atmosphere into space for only a few minutes. Although sounding rockets do not linger long at high altitudes, they have made major discoveries in space science, such as the existence of X-ray stars.

A satellite is a spacecraft that has been given sufficient velocity by its launch rocket to be placed in orbit. Ultimately the trace of atmosphere still present at satellite altitudes will slow the satellite down and gravity will pull it back to Earth. The distinction between a satellite and a long range rocket is that the satellite makes one or more complete circuits of the Earth.

In 1955, when the United States decided to launch a small research satellite during the International Geophysical Year, the engineers assigned to the task did not think of Jules Verne's elegant, well-padded projectile; they thought about extending sounding rocket technology. For a while, the first



1 *Satellites stay in orbit because the centrifugal effect due to their horizontal velocity just cancels the gravitational force trying to pull them back to Earth. Sounding rocket and ballistic trajectories are segments of ellipses. Space probes leave the Earth's gravitational field completely.*

U.S. satellite project was called the LPR, the Long Playing Rocket. Jules Verne may have the last laugh, however, because the United States and Canada have seriously considered launching small satellites with the help of a rebored 16-inch naval cannon.

Spacecraft that are shot deep into space and escape the gravitational pull of the Earth completely are called space probes. Depending on the target; they are called lunar, planetary, and deep space probes. Deep space probes are placed in orbit around the Sun to study the solar wind and interplanetary magnetic field. In essence they are artificial planets. One of three things may happen to a probe launched toward the Moon or one of the planets: (1) a near miss or fly-by, (2) injection into orbit around the body, or (3) impact on the surface, with either a hard or soft landing. Fly-by probes usually go into orbit around the Sun after planetary encounter. Lunar probes may swing around the Moon and settle down to become Earth satellites.

Spacecraft may also be classified as manned or unmanned; as recoverable or unrecoverable. All manned spacecraft are made recoverable; so are most sounding rockets. Those unmanned satellites that carry film packs or biological specimens are made recoverable by adding retrorockets that force the spacecraft to reenter upon command from the ground.

Spacecraft may be either active or passive. A passive satellite transmits no radio signals to Earth but may reflect them back. NASA's Echo balloon satellites are good examples of passive satellites. They are big enough to see visually, and by their motion reveal the air density where they orbit. Active satellites emit radio signals to make tracking easier and to transmit data from their instruments to ground stations. When a satellite radio signal fades naturally or is intentionally cut off by a killer timer, the satellite becomes inactive or dark.

Satellites are also classified by their orbits. A polar satellite orbits over the Earth's polar regions. A synchronous satellite orbits the Earth in the same length of time it takes the Earth to make one revolution on its axis. If the synchronous satellite is also an equatorial satellite, it will seem to remain in the same position in the sky at all times. It is then a stationary or geostationary satellite.

The final taxonomic breakdown depends upon the functions or uses of satellites. NASA divides its satellites into three categories:

1. *Scientific satellites,* which carry instruments to measure magnetic fields, space radiation, the Sun, and so on. Examples: NASA's Explorer series, the OGO series.
2. *Applications satellites,* which have utilitarian purposes. They help forecast the weather, extend Earth communications, survey the Earth, find mineral deposits, test equipment, etc. Examples: the TIROS weather satellites, the Syncom communication satellites.
3. *Manned satellites,* which are designed to check out equipment and man himself in preparation for the manned lunar landing and other manned space missions.

Spacecraft obviously differ greatly in size, shape, complexity, and purpose. Nevertheless, most require power supplies, radio transmitters, a means for orientation in space, as well as other equipment. Spacecraft can be described in general terms first, by showing how they work; second, by describing the hundreds of NASA satellites, probes, and sounding rockets launched since the Agency's founding in 1958. Fortunately, they can be collected into handy families. For example, a TIROS family of weather satellites exists; so does a Gemini class of manned spacecraft.

How Spacecraft Work

Of Systems and Subsystems

Automobiles and spacecraft are both man-machine systems. In the auto, a motor turns the wheels, a steering wheel changes its direction, a heater keeps the occupant warm in the winter. Spacecraft have subsystems that help man attain his objectives.

Modern spacecraft are driven—like the car—either by an astronaut or by a human controller on the ground connected to the spacecraft by a radio link.

Of all the subsystems that make a spacecraft work properly, nine are critical:

Subsystem	Function
Power supply	Provides energy to all other subsystems. Needed by all active satellites.
On-board propulsion	Generates thrust for rendezvous, orbital changes, soft landings, deorbiting, etc.
Communication	Relays information to Earth and receives commands in return.
Attitude control	Points the spacecraft on command. Stabilizes its orientation (attitude).
Environment control	Maintains suitable temperatures and atmospheres for man and equipment.
Guidance and control	Interprets commands from Earth and internal memory bank and sees that they are carried out by the appropriate subsystems.
Computer	Carries out computations.
Structure	Supports and maintains spacecraft configuration.
Engineering instrument	Measures status of spacecraft in terms of temperature, operating modes, etc. Also monitors astronauts.

A simple, passive balloon satellite may have less than 100 parts and require only the structure subsystem. A soft lunar lander may contain 20,000 parts and use all nine subsystems.

Spacecraft are really extensions of man that enable him to explore the cosmos and make use of the Earth's resources. Spacecraft can extend man's hands to the Moon and planets, as they have already done with the Surveyor surface samplers. Man and a radio-linked spacecraft make a remarkable and useful man-machine partnership.

The Power Supply Subsystem

Only a few watts bring a spacecraft to life and make it a useful extension of man. Satellites consuming less than 10 watts of power discovered the Van Allen belts and the solar wind. The biggest satellites and space probes require only a few hundred watts for their operation. A kilowatt or two will keep man alive and in touch with the Earth. While spacecraft may not be power guzzlers of the same order as the American home, there are no gas pumps or electric power lines out in space to keep them running. Fuel must be carried along or energy must be extracted from sunlight.

Sounding rockets have found batteries adequate for their brief forays above the atmosphere. The early satellites also carried batteries into space, but they lasted only a few weeks. To improve satellite longevity, the Vanguard I satellite carried the first solar cells aloft in 1958. Since then, almost all satellites and space probes have their complements of the little silicon wafers. The short-mission manned satellites are the major exceptions.

Solar cells were invented at the Bell Telephone Laboratories in 1954. They are only an inch long, a half inch wide, and a few hundredths of an inch thick—about the size of a razor blade. When sunlight

2 *Closeup view of the Applications Technology Satellite (ATS) showing the thousands of solar cells bonded to the satellite's cylindrical surface.*

strikes a solar cell, roughly 10% of its energy is converted into electrical energy; the remainder (90%) is reflected or turned into heat. The electrical current flows between the layers of electron-rich (n-type) and electron-poor (p-type) silicon layers that make up the thin solar-cell sandwich. Although a single solar cell generates only a fraction of a watt, hundreds and thousands are commonly hooked together to provide the spacecraft with the power it needs. To gather enough sunlight, solar cells are fastened on the body of the spacecraft, or on extendable paddles.

Solar cells do not eliminate batteries. Because many Earth satellites spend much of their life in the Earth's shadow, solar cells must charge up batteries during the satellite day so that power will be available during satellite night. In low orbits, the satellite day-night cycle lasts only an hour and a half. Consquently, the solar cell-battery combination charges and discharges several thousand times a year.

Why weren't solar cells used on the Mercury and Gemini manned missions? They would have taken too much room—roughly a hundred square feet per kilowatt. Batteries alone are too heavy for missions lasting more than a few days. The Mercury spacecraft did employ batteries, but with the Gemini series NASA switched to fuel cells.

A fuel cell is really a continuously fueled battery. A fuel, such as gaseous hydrogen is made to react with oxygen on a high-surface-area electrode. Electricity and a combustion product—water in this case—result. There is no flame during fuel cell combustion, just as there is none in a flashlight dry cell, although a little heat is generated because energy conversion is not 100% efficient. As fuel and oxidizer are consumed in the fuel cell, they are replenished from external tanks. When manned missions are longer than a few days, the fuel cell plus fuel and oxidizer tanks are lighter than batteries.

Summarizing, batteries are used on most sounding rockets; solar cell-battery combinations on most other unmanned spacecraft; and fuel cells on most manned spacecraft.

The Onboard Propulsion Subsystem

The only practical way to bring an astronaut down out of orbit is to slow the spacecraft with a small rocket and cause it to reenter the Earth's atmosphere. The Surveyor lunar probe also required a rocket engine to slow it from several thousand miles per hour to a feather-like touchdown that did not hurt its instruments. Geostationary satellites, such as the Syncoms, must apply bursts of thrust to maintain their orbits (station keeping).

Onboard rockets are many times smaller than their huge counterparts that we see on the launch pad, but they are equally sophisticated. For one thing, the propellants must be storable; that is, they must survive in the space environment for days or weeks before they are burned. For this reason, the usual launch rocket fuels (kerosene or liquid hydrogen) and oxidizer (liquid oxygen) are replaced by a solid fuel, a monopropellant (like hydrogen peroxide), or a storable bipropellant.

If liquids are selected for the onboard rocket, there may be no gravitational force to pull them into the engine when they are needed; say, in orbit or halfway to Mars. Consequently, NASA has developed squeezable bladders, pistons, and other positive expulsion containers that force fluids into the engine without assistance from gravity.

Onboard rockets present one more difficult requirement: they must fire and shut off upon command from Earth or the spacecraft's internal memory. Maneuvers in space can be very touchy and delicate, particularly when the target is a planet 100,000,000 miles away or a specific crater on the Moon.

The Communication Subsystem

Radios link spacecraft with the Earth-based data acquisition system that ultimately connects the spacecraft to man. Radios seem rather prosaic these days, but spacecraft communication is not quite as easy as turning on channel 4 on the TV. First, there is the problem of distance—hundreds of miles in the case of deep-space probes. Second, some Earth satellites are prodigious data gatherers and must transmit huge quantities of information. Both distance and data volume can be achieved if the spacecraft has a big voice or the Earth receiving station has big ears. A big spacecraft voice infers a high transmitter power; but power is a scarce commodity in space and the big-ear approach is favored. Thus NASA's data acquisition stations point large 85-foot and 210-foot paraboloidal antennas at passing satellites and space probes out in the depths of space.

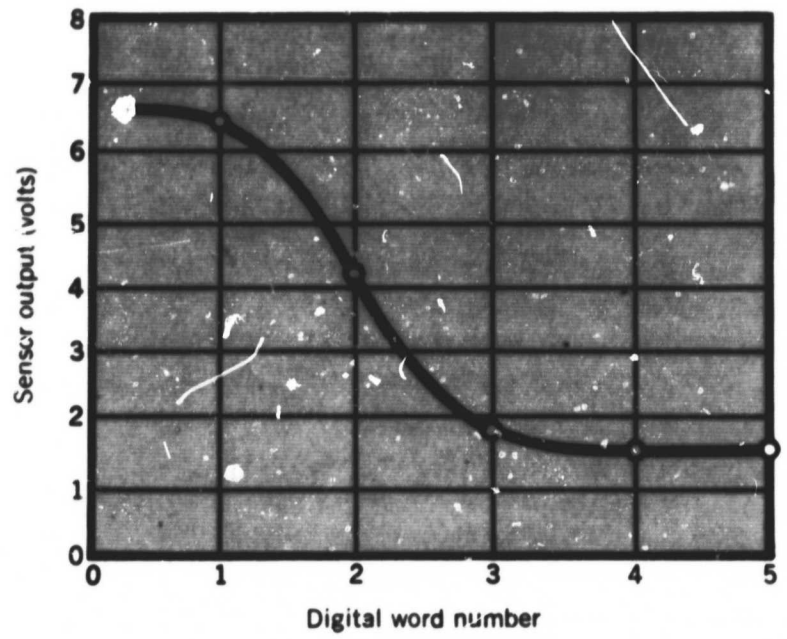
Very high frequencies have to be used for spacecraft communication. They have to be high enough to penetrate the Earth's ionosphere (over 20 MHz*) and low enough so that the signals are not absorbed by atoms and molecules in the atmosphere (under 300 MHz). Terrestrial radio noise created by man and thunderstorms interfere at the lower frequencies. As a result, most space communication systems operate between 100 and 3000 MHz.

Spacecraft do not send radio messages back to Earth continuously, although tracking beacons often transmit all the time. Most spacecraft transmitters are activated upon the receipt of a radio command from Earth. Much of the time spacecraft are not within range of Earth-based receiving stations, and it would be wasteful of power and valuable data to send signals all the time. Instead, when a spacecraft comes over the horizon toward a data acquisition station, it is commanded to read out its memory—usually a tape recorder. The spacecraft then dumps these data in a burst to the radio ears waiting below.

**1 MHz=one megahertz=1,000,000 cycles per second.*

3 *A continuously varying instrument reading can be approximated by a series of digital binary data words. The more bits used per word, the more accurate the analog-digital conversion. In this illustration, for example, a three bit word limitation means that sensor readings 1.8, 1.6 and 1.7 all translate into binary language as 010.*

Data word no.	Decimal sensor reading	Three-bit data word	Pulse trains
1	6.3	110	
2	4.1	100	
3	1.8	010	
4	1.6	010	
5	1.7	010	



Collectively, NASA ground stations often acquire more than 50 miles of data on magnetic tape in a day. When an OGO satellite dumps its memory, it transmits the equivalent of a couple of novels in a few minutes. In 1958 the problem was getting any data at all from space; today, NASA must cope effectively with vast quantities of it. Computer data processing on the ground is part of the answer. The tendency is for spacecraft to talk directly to ground-based computers in computer language; that is, the binary number system, which is based upon the number 2 instead of 10.* The computer reduces the data and even draws graphs for the experimenters.

The Attitude Control Subsystem

On Earth we find it easy to keep our vertical orientation by pushing against the ground with our feet. In space, though, there is little to push against, and there are a surprising number of forces that tend to disturb the orientation (attitude) of a spacecraft.

The two main tasks of a spacecraft's attitude control subsystem are stabilization and pointing. Stabilization means keeping the spacecraft oriented in a specific direction despite natural forces to the contrary. Spacecraft stabilization can be compared to keeping a light car on the road in the presence of strong wind gusts. Some spacecraft need to be pointed at selected targets as well as being stabilized. The Orbiting Solar Observatories, for example, must lock onto the Sun and follow it with their instruments. Weather satellites have to keep their cameras trained on the Earth. Both stabilization and pointing require that the attitude control subsystem generate turning forces or torques on the spacecraft.

NASA has studied the natural forces existing in space with an eye to overcoming them and even harnessing them for attitude control. Sunlight, for example, exerts a small but significant pressure on all spacecraft surfaces it hits. Unless a counter-torque is created by the attitude control subsystem, this pressure can twist the spacecraft into undesired orientations. Occasionally, solar pressure can be put to positive use; some of NASA's Mariner planetary probes carried special vanes that applied solar pressure to attitude control the same way that sails make use of the wind in propelling sailboats.

Gravity, too, is pervasive and persuasive; it always tries to pull the long axis of a satellite around so that it points at the Earth. Our Moon is gravitationally stabilized in this way by the Earth, always keeping one face toward us. Many NASA satellites take advantage of this naturally stabilizing force by paying out long booms or pendulums. The Earth's field then swings these and the satellite instruments around so they face the Earth. This is termed gravity-gradient stabilization.

The Earth's magnetic field is also useful. By building coils of wire in satellites and connecting them to the spacecraft power supply, the satellites

**In the binary language: 001=1, 010=2, 011=3, 100=4, 101=5, and so on.*

can be made into electromagnets. When electrical current is applied, the satellite's magnetic field interacts with that of the Earth, and the satellite will turn like the armature of a motor. Many NASA satellites are magnetically stabilized.

The majority of satellites are spin-stabilized. When they are propelled into orbit, the final stage of the launch rocket gives them a twist that spins them at, say, 30 rpm. This spin, or its angular momentum, stabilizes the spacecraft against the influences of solar pressure, meteoroid impacts, and other disturbing torques in the same way the spin of a rifle bullet keeps it from tumbling.

Spacecraft like the Surveyors and Orbiting Geophysical Observatories need something more powerful than gravitational and magnetic attitude control schemes. Strong, controllable torques can be created by pairs of small rocket engines mounted on the periphery of the spacecraft. The rockets may be small versions of the onboard engines just described, or they may be bottles of compressed gas with electrically controlled valves. For very tiny, precisely measured bursts of thrust, NASA engineers have developed thrusters that shoot little bursts of gas. All attitude control schemes depending on the rocket principle expel mass. Since mass is limited on spacecraft, so is the amount of pointing and stabilization achievable by mass expulsion.

Whenever a motor in a spacecraft starts up, the entire spacecraft experiences a twist in a direction opposite from that on the motor shaft. The Law of Conservation of Angular Momentum demands this. Again, a potential destabilizer can be turned to positive uses. Gyroscopes and inertia wheels are just motors with heavy rotors. When their speeds of rotation are changed, they exert torques on the spacecraft. A set of three gyros mounted with shafts parallel to each of the spacecraft's three degrees of freedom can control all aspects of spacecraft orientation. Gyros and inertia wheels, of course, do not expel valuable mass when they change spacecraft attitude, but they are limited in the sense that they can spin only so fast without damaging themselves. Suppose a meteoroid hits a solar-cell panel and starts the spacecraft spinning. The gyro controlling that spin axis will increase its speed of rotation, trying to build up enough torque to stop the spacecraft spin. However, if the disturbance was too great, the gyro may reach its maximum speed without stabilizing the spacecraft. In this case, the gyro is said to be "saturated." By firing an onboard attitude control rocket or gas jet, the gyro can be desaturated.

The Environment Control Subsystem

Controlling the environment means insuring that man and his instruments can survive in space. For man, this means taking an atmosphere along and enclosing him in a capsule that keeps out the harsh environment of outer space, in particular the vacuum, the Sun's ultraviolet rays, and the searing heat of atmospheric reentry.

Other environmental threats are: micrometeoroid damage, radiation damage from the Van Allen belts, and the high-g forces of rocket launch and spacecraft landing.

A unique problem faces the engineers who design NASA's planetary probes. These craft, if they are to enter other planets' atmospheres, must be able to withstand the high temperatures of biological sterilization. The purpose of spacecraft sterilization is the avoidance of contaminating the other planets of the solar system. Were organisms of Earth origin inadvertently introduced into the ecology of another planet, the opportunity to study an extraterrestrial life system in the natural state would be forever lost. If life has arisen elsewhere, the reverse problem exists—that of excluding

extraterrestrial organisms from manned spacecraft and from Earth itself upon the return of astronauts.

Thermal control is a serious problem for the vast majority of spacecraft. If instruments get too hot or cold they are apt to malfunction. Offhand, the problem would seem to be one of heating spacecraft in the cold of outer space. It is true that an object placed far out in interstellar space will soon radiate away most of its sensible heat and attain a temperature a few degrees above absolute zero. But in Earth orbit, the Sun and the sunlit side of the Earth both radiate considerable heat to a satellite. In fact, the average temperature of an Earth satellite will not be too different from room temperature. The problem lies in that word average.

When a satellite enters the Earth's shadow, it immediately begins radiating its sensible heat to cold, starry space, and to the night side of Earth, which fills almost half the sky. Some heat is received back from Earth, since even the night side averages well above freezing. Earthshine is usually not enough, particularly if the satellite is in a high orbit that keeps it in the Earth's shadow for several hours. Some heat comes from satellite electrical equipment; special heaters can be added at cold-sensitive spots. Ultimately, the heat energy comes from the power supply.

The Surveyor lunar landers faced severe thermal problems during the two-week, cold lunar nights. NASA made no attempt to maintain normal operating temperatures in the Surveyors during these periods; missions were suspended until the next lunar day. In some cases, the heat of the Sun was able to revive the frozen spacecraft.

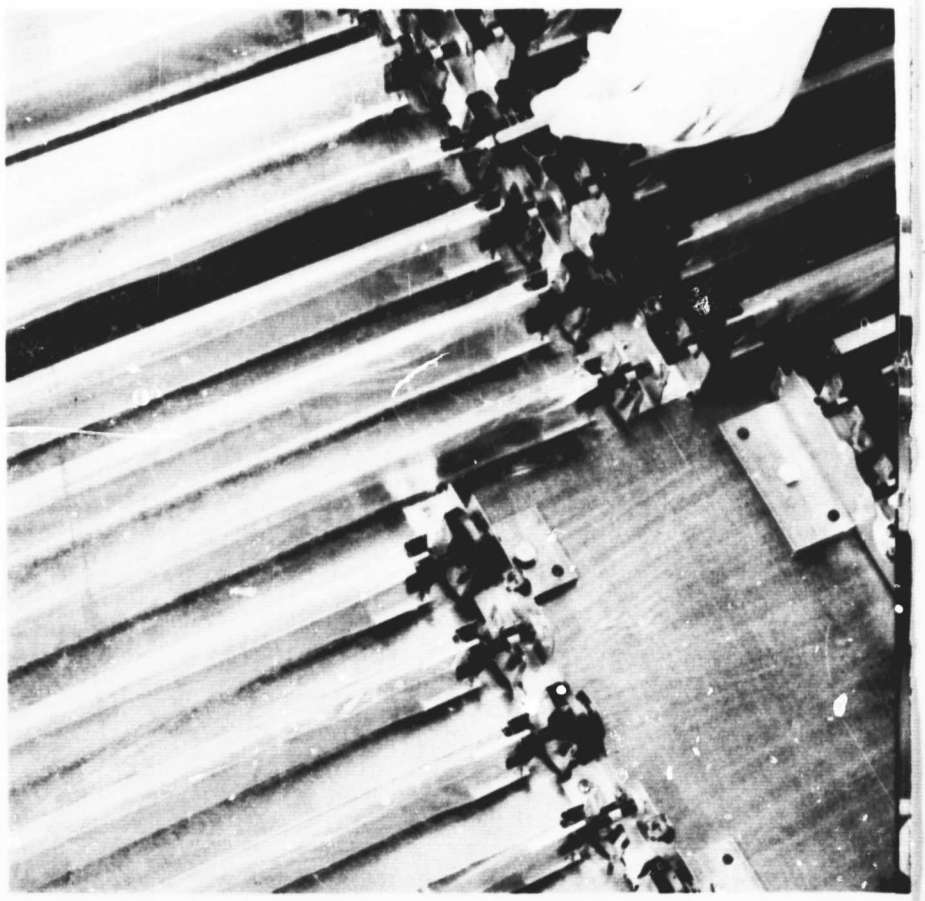
Spacecraft that are in the Sun all of the time must deal with overheating. All space probes, some high-orbit satellites, and those satellites that keep one face oriented toward the Sun (the OSOs, for example) must get rid of excess heat by radiating it to empty space. Special metallic conduits (heat pipes) are sometimes installed to conduct internal heat out to the spacecraft surface or from the hot side to the cold side. The amount of heat escaping from the side of the spacecraft facing cold space can be automatically adjusted by thermostatically controlled louvers; which are Venetian-blind-like vanes that expose the hot internals of the spacecraft.

Astronauts must be kept cool, too, but a breathable atmosphere is even more critical. On short manned missions, such as the Gemini satellite flights and the Apollo Moon voyage, bottled atmosphere can be carried along from Earth. For missions exceeding a month or so, this approach would cost too much in terms of weight. The alternative is a spacecraft atmosphere that is continuously regenerated or renewed.

The Guidance and Control Subsystem

Steering spacecraft safely to their targets is the task of the guidance and control subsystem. Consider a spacecraft trying for a soft landing on the Moon. The attitude control subsystem has already turned the spacecraft around so that its retrorocket and landing radar are pointed at the Moon. Radar signals tell the spacecraft guidance and control subsystem the speed of descent and the distance from the surface. Built into the spacecraft memory is information telling the spacecraft when to fire its retrorocket on the basis of radar data. The guidance and control subsystem continually compares the real radar signals with the signals its memory says it should be receiving. When the proper spacecraft velocity and distance from the

4 *The thermal control louvers of OGO. These open like a Venetian blind to allow the hot spacecraft interior to cool by radiation to dark space.*



Moon are reached, a command to fire retrorockets is dispatched to the onboard propulsion subsystem. The rocket fires until radar data indicate that touchdown will occur at near-zero velocity. This is the essence of control: comparison of real performance with desired performance and the commanding of the spacecraft to eliminate any discrepancy between the two.

Most spacecraft control functions are much simpler than soft landing on the Moon. A good example is the cutoff of a satellite transmitter to free a frequency channel for new spacecraft. This simple act is accomplished by a killer timer that disconnects the power supply after six months or a year of operation.

The lunar lander and killer timer examples illustrate what engineers call closed and open-loop control. The lunar landing requires continuous feedback of information telling the guidance and control subsystem how well it is doing its job. In such closed-loop-control situations the opportunity for corrective action exists. With the killer timer, action is irrevocable.

A modern spacecraft possesses dozens of sensors that tell the guidance and control subsystem (which often includes the human controller on the ground via the communication link) the *status* of the spacecraft. Thermometers take spacecraft

temperature; gyros, star trackers, and Sun sensors measure spacecraft attitude; and voltmeters and ammeters relate how the power supply is performing. Less obvious are the signals that tell the human controller the positions of critical switches that fix the spacecraft's mode of operation. For example, it is important to know which experiments are on and which are off. Collectively, such status signals are termed housekeeping data.

The Computer Subsystem

Computers are generally thought of as large machines that belong on the ground rather than on spacecraft. Several spacecraft functions, however, have combined to make computers integral parts of large, modern spacecraft.

One of the simplest jobs for a spacecraft computer is analog-digital or AD conversion. Many spacecraft instruments generate continuously varying or analog signals. But spacecraft usually communicate with the ground in digital language. To translate instrument readings into the lingua franca of space, small AD converters are attached to analog-speaking equipment. In reality, AD converters are little, special-purpose computers.

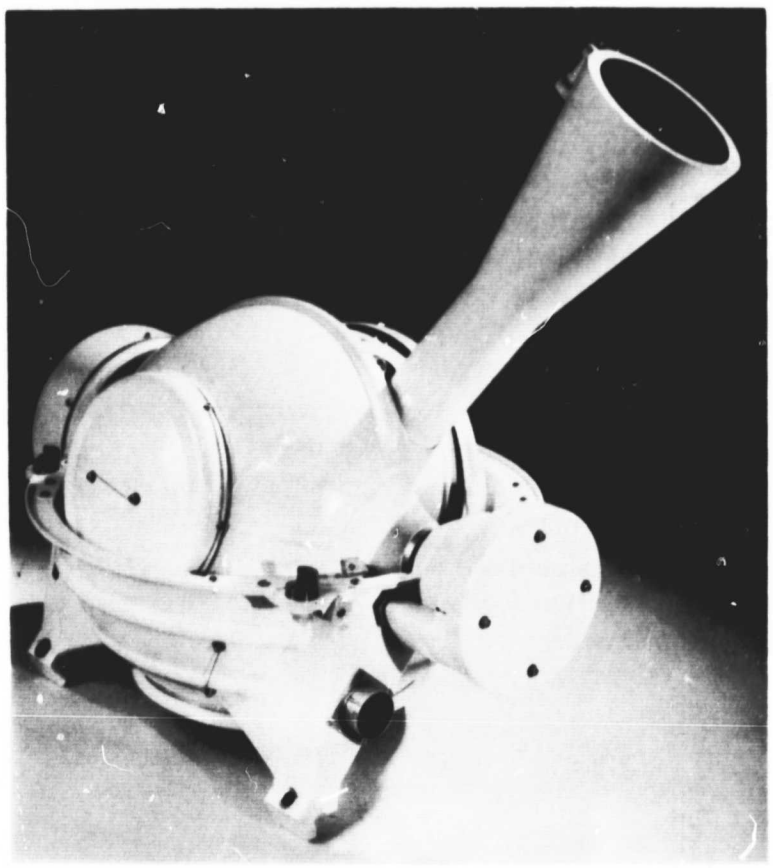
Sometimes computations are required on highly automatic spacecraft, such as the Orbiting Astronomical Observatory (OAO). The OAO star tracker readings, for example, must be transformed into the proper geometric coordinates if the OAO attitude control subsystem is to know where to point the spacecraft telescope. Such transformations involve a great deal of trigonometry; something a little onboard computer does very nicely. Small computers have also been installed on some of the manned spacecraft to help the astronauts with guidance and navigation computations.

In principle, all computations could be carried out by sending the problem to ground-based computers through the medium of the communication subsystem. Answers would be returned the same way. NASA did use this approach with some of the earlier satellites, but as spacecraft became more complex it turned out to be too much of a burden on the communication link. Now ground-based and onboard computers share the load.

The Structure Subsystem

The structure subsystem forms the backbone of the spacecraft. It supports, unites, and protects the

5 *The Orbiting Astronomical Observatory (OAO) star tracker is programmed to search for and follow certain guide stars. Once the telescope has locked onto a guide star, the star tracker sends its coordinates to the guidance and control subsystem. With several such fixes, the OAO can compute its attitude in space and then change the orientation of its instruments to pick up any given stellar target.*



other subsystems. Basically, a spacecraft's structure can be divided into two parts: the central core or skeleton and the deployable appendages (antennas, booms, solar cell paddles) that unfold once the spacecraft is out in space.

Almost all spacecraft are symmetrical about at least one axis. There are two good reasons for this: (1) many spacecraft are spin-stabilized and need symmetry around the spin axis to prevent wobbling; and (2) launch accelerations are powerful and are best resisted by an axial thrust structure. These are the reasons why so many spacecraft are cylinders, regular prisms, or spheres.

Many exceptions exist. In fact, spacecraft are a geometer's delight. One finds cubes, parallelopipeds, polyhedrons, and cones. The balloon satellites are a class by themselves. So are the manned space capsules with their blunt reentry shields.

Lightness is a premium commodity on spacecraft. For this reason NASA has developed a whole spectrum of aluminum, magnesium, and plastic structures that weigh little but resist the stresses of space use. The steels are restricted in use because of their high densities and also because they are magnetic—an undesirable property when one is trying to measure the extremely low magnetic fields in space. One of the major structures on manned spacecraft is the protective thermal shield needed during reentry through the atmosphere. NASA generally makes its reentry shields from a plastic containing embedded glass fibers. As the air in front of the reentering spacecraft is heated to incandescence, the shield ablates, that is, it begins to decompose and erode. As the shield's surface deteriorates, a layer of gas is evolved continuously. This layer of gas insulates the spacecraft and carries away the excess heat.

Once a spacecraft with deployable parts attains airless space, it undergoes an insectlike metamorphosis. Freed from their cocoon when the launch shroud has been blown off, the solar cell paddles, radio antennas, and instrument booms unfold and unreel. As they deploy, they cause the spacecraft spin-rate to decrease. This despinning is the reverse of the skater's spinup maneuver caused by drawing in the arms and legs.

Solar cell paddles and other spacecraft appendages compete for "look angle." The solar cells must intercept sunlight; instruments need a clear view of space phenomena; and antennas must not be obstructed. The fair partition of the solid angle around each spacecraft is an important task in spacecraft design.

The Engineering Instrument Subsystem
Here we have the total of all housekeeping sensors. These sensors are the voltmeters, ammeters, thermometers, and other instruments that determine the status of the spacecraft.

NASA Spacecraft Families

Below are listed the major NASA sounding rocket, satellite, and space probe families launched since NASA was created in October 1958.

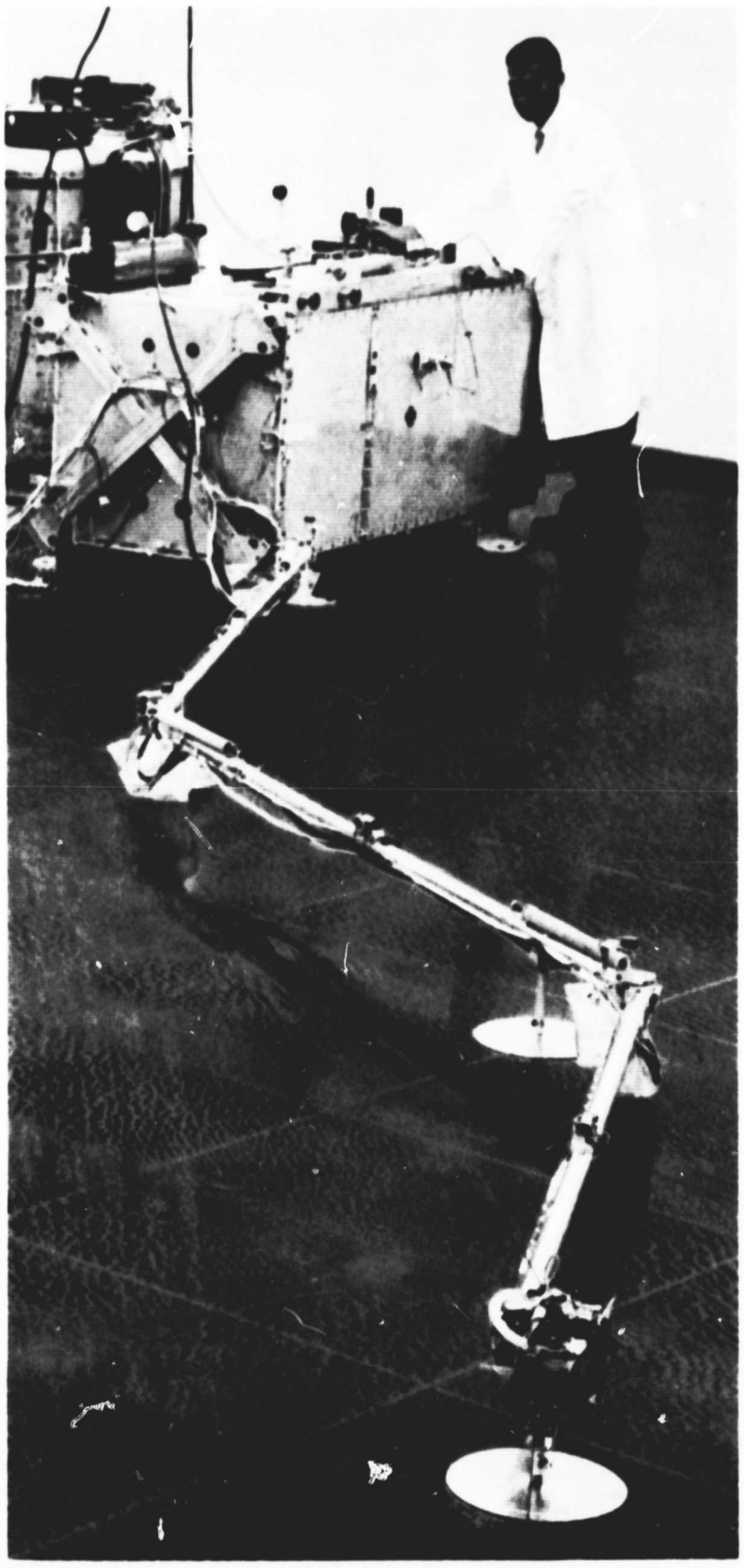
Apollo: The third series of U.S. manned spacecraft, and the spacecraft designed for manned flight to the Moon. Spacecraft weights have ranged from 33,800 to 93,885 pounds.

Apollo Saturn 201	2-26-66 Unmanned suborbital test.
Apollo Saturn 203	7-5-66 Unmanned orbital flight.
Apollo Saturn 202	8-25-66 Unmanned suborbital flight; flight evaluation of heat shield.
Apollo IV	11-9-67 Unmanned orbital flight. First launch of Saturn V vehicle to demonstrate launch vehicle capability and spacecraft development.
Apollo V	1-22-68 First flight test of Apollo Lunar Module verified ascent and descent stages propulsion systems.
Apollo VI	4-4-68 Launch vehicle development mission.
Apollo VII	10-11-68 First manned flight; 10.8 days duration. Astronauts Schirra, Eisele and Cunningham.

Argo: A family of relatively large sounding rockets used by NASA (and others) for ionosphere and radio astronomy experiments. Launch weights vary between 10,000 and 14,000 pounds.

Ariel: A family of two scientific satellites built and launched by NASA, carrying experiments provided by Great Britain. Experiments focused on ionosphere and atmosphere research. Satellites were named after the "airy spirit" in Shakespeare's "The Tempest." Ariel I was launched on April 26, 1962; Ariel II, on March 27, 1964. They weighed 132 and 150 pounds, respectively.

Aerobee: A family of small sounding rockets used by NASA for experiments in the upper atmosphere. Also used for zero-g tests and rocket astronomy. The Aerobee-150 weighs about 1900 pounds at launch. There are several models.



6 *One of OGO's extendable booms being tested. Long booms help isolate sensitive instruments from the electromagnetic interference created in the spacecraft.*

Astrobee: A series of large sounding rockets. The Astrobee-1500, used occasionally by NASA for tests, weighs about 11,500 pounds at launch.

ATS: NASA's family of multipurpose Applications Technology Satellites. The ATS satellites are intended to test new space instruments and satellite components, particularly those employed in synchronous orbit satellites.

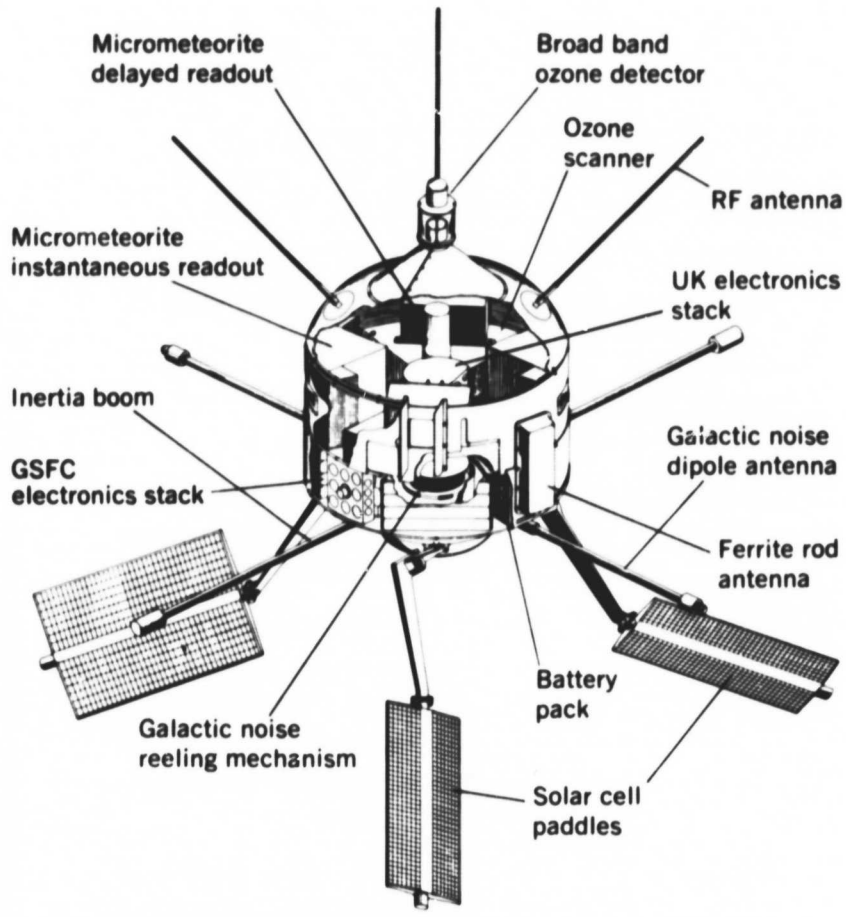
ATS I 12-7-66 Tests of communication and meteorological instruments.

ATS II 4-6-67 Gravity-gradient experiment and more sensor experiments. Did not attain synchronous orbit.

ATS III 11-5-67 Meteorological, communication, and navigation experiments.

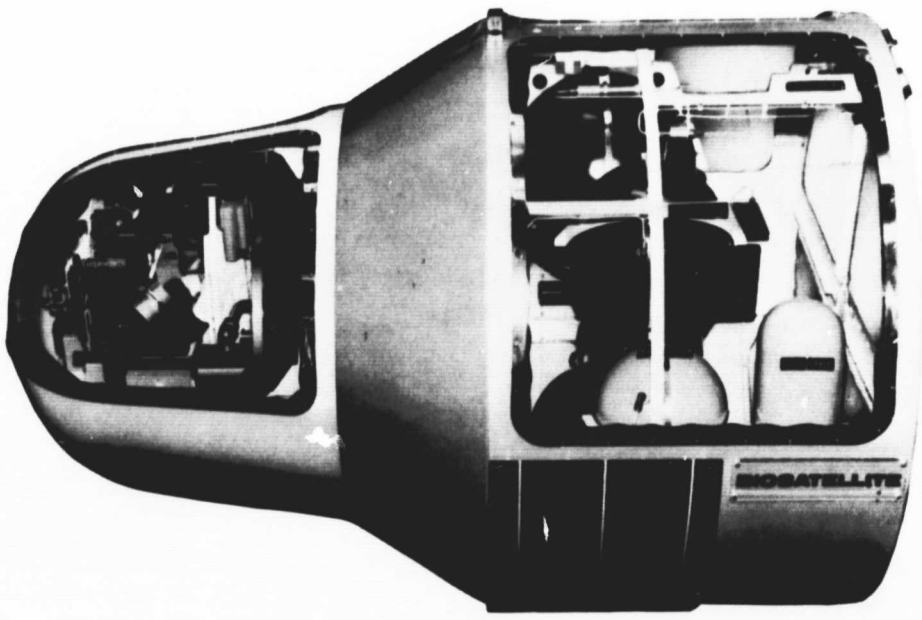
Biosatellite: Family of recoverable scientific satellites employed for testing the effects of weightlessness, radiation, and lack of the Earth's 24-hour rhythm on biological specimens. The first two Biosatellites each weighed about 950 pounds. Biosatellite I was launched on December 14, 1966, but its retrorocket did not fire, making recovery impossible. Biosatellite II, launched September 7, 1967, was recovered successfully.

Echo: A family of two passive NASA communication satellites. Once in orbit, these satellites were automatically inflated by a gas generator to become large spherical balloons 100 and 135 feet in diameter, respectively. These large metallized



7 *Ariel II. A satellite with cylindrical symmetry and numerous appendages.*

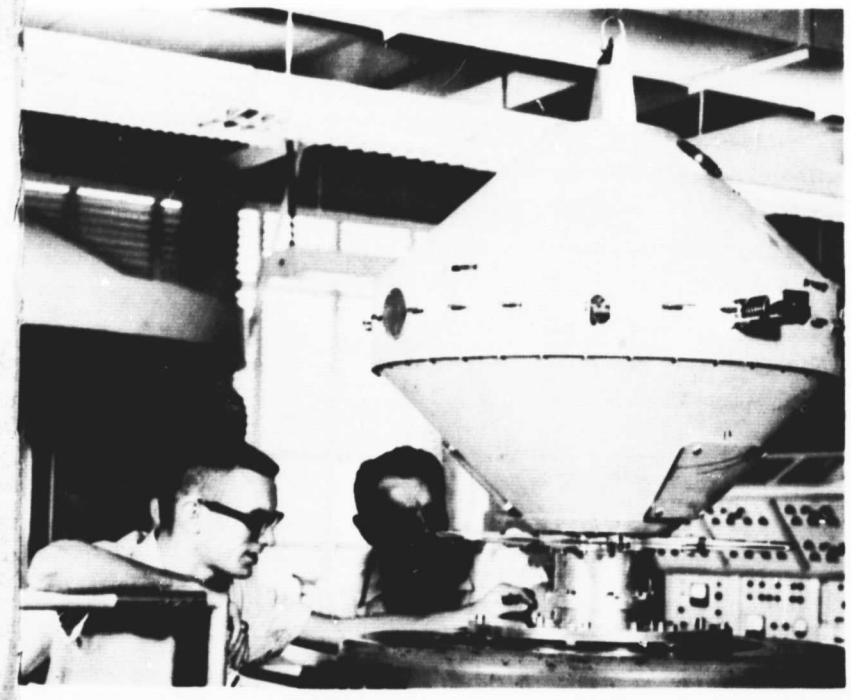
8 *Model of Biosatellite, showing primate experiment. Biosatellite is recoverable.*



balloons reflected radio signals between ground stations. Precision tracking of the Echo satellites also provided information about the density of the upper atmosphere. Echo I was launched August 12, 1960; Echo II, January 25, 1964. Both became wrinkled and lost their spherical shapes. Echo I reentered and burned in May 1968.

Explorer: A long series of scientific satellites that began before NASA was created. The Army Explorer I was the first U.S. satellite to be launched, on January 31, 1958. Explorers II, III, and IV were also Army satellites; the rest were launched by NASA. Explorers II and V were failures. As the following tabulation shows, the Explorer satellites have varied widely in design and purpose.

Explorer VI	8-7-59 Launched into highly elliptic orbit to explore magnetosphere. First use of solar paddles. Weight: 142 pounds.
Explorer VII	10-13-59 Solar physics studies and the measurement of space radiation. Weight: 92 pounds.
Explorer VIII	11-3-60 First of NASA's direct measurements satellites. Made significant measurements in ionosphere and upper atmosphere. Weight: 90 pounds.
Explorer IX	2-16-61 Small balloon satellite about 12 feet in diameter for measurements of air density. Weight: 80 pounds.
Explorer X	3-25-61 Launched into highly elliptical orbit to measure interplanetary phenomena. Returned only two days of data. Weight: 79 pounds.
Explorer XI	4-27-61 Designed to measure the distribution of cosmic gamma rays. Weight: 82 pounds.
Explorer XII	8-16-61 First of four NASA Energetic Particles Explorers, designed to measure the radiation belts, cosmic rays, solar wind, and magnetic fields. Weight: 83 pounds.
Explorer XIII	8-25-61 First of three NASA Micrometeoroid Explorers. Satellite was actually fourth stage of Scout rocket covered with micrometeoroid detectors. Orbit was too low; reentered in three days. Weight: 187 pounds.
Explorer XIV	10-2-62 Second Energetic Particles Explorer. Weight: 89 pounds.

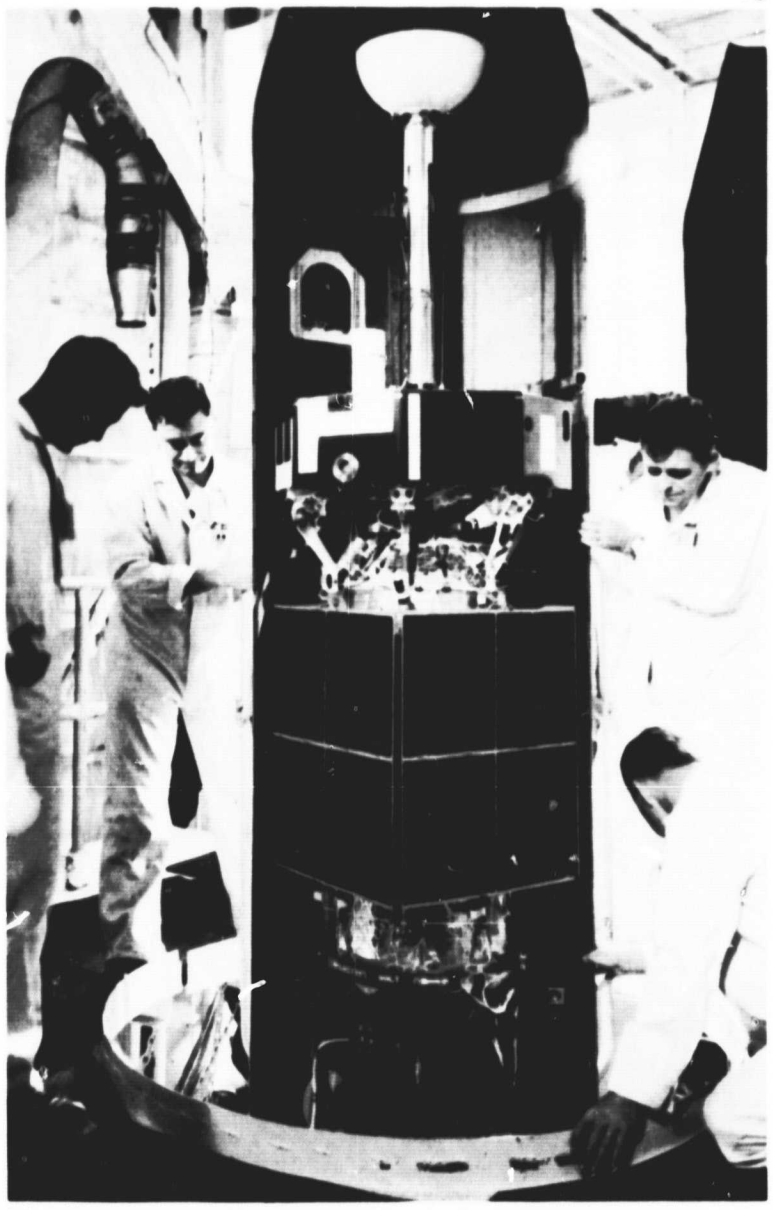


9 *Explorer VIII being tested on a vibration table before launch. Instruments for atmospheric and ionospheric research are located around the waist.*

10 *Explorer XXI, an IMP, is shown nested inside its launch shroud atop the Delta launch vehicle at Cape Kennedy. Solar cell paddles are retracted. Sphere on boom holds magnetometer.*

11 *The polyhedral Explorer XXV was built by the State University of Iowa for measurements in the Van Allen belt and polar regions. Solar cells are mounted on faces.*

10



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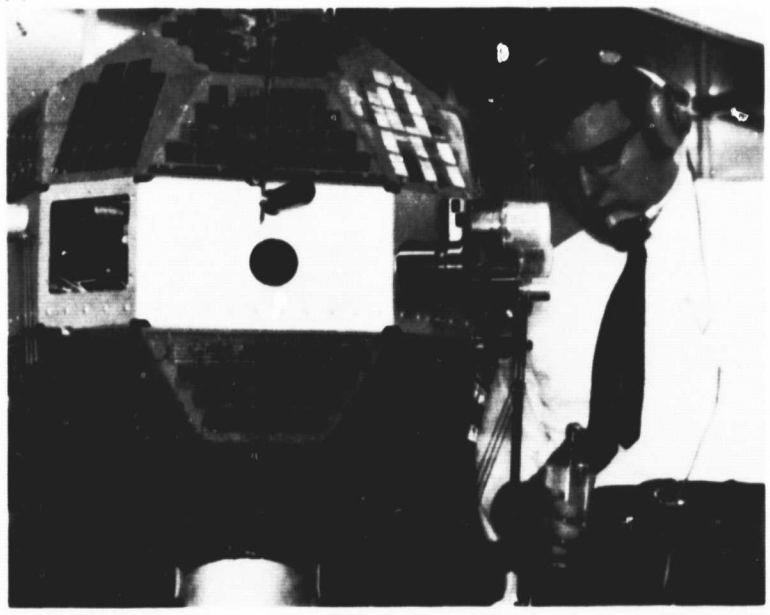


Explorer XV 10-27-62 Third Energetic Particles Explorer. Purpose was to study artificial radiation belt. Weight: 100 pounds.

Explorer XVI 12-16-62 Second Micrometeoroid Explorer. Weight: 159 pounds.

Explorer XVII 4-3-63 An Atmosphere Explorer, intended for the measurement of density, pressure, composition, and temperature directly. Weight: 405 pounds.

Explorer XVIII 11-27-63 First of the IMPs (Interplanetary Monitoring Platforms). Placed in a highly eccentric orbit to measure magnetic fields, plasma, and radiation. Weight: 138 pounds.

Explorer XIX 12-19-63 A balloon-type Air Density Explorer. Weight: 94 pounds.

Explorer XX 8-25-64 An Ionosphere Explorer. This satellite was a topside sounder that sent radio pulses down into the ionosphere and listened for echos. Weight: 98 pounds.

Explorer XXI 10-4-64 Second IMP. Weight: 135 pounds.

Explorer XXII 10-10-64 First of NASA's Beacon Explorers. Primarily a radio beacon for studying radio propagation in the ionosphere. Weight: 116 pounds.

Explorer XXIII 11-6-64 Third Micrometeoroid Explorer. Weight: 295 pounds

Explorer XXIV 11-21-64 Another balloon-type Air Density Explorer. Weight: 19 pounds.

Explorer XXV 11-21-64 A satellite to monitor the radiation belt. One of the Injun series built by the State University of

Iowa. Launched with Explorer XXIV for NASA's first dual launch. Weight: 90 pounds.

Explorer XXVI 12-21-64 Last of four Energetic Particles Explorers. Weight: 101 pounds.

Explorer XXVII 4-29-65 NASA's second Beacon Explorer. Weight: 134 pounds.

Explorer XXVIII 5-29-65 Third IMP. Weight: 130 pounds.

Explorer XXIX 11-6-65 A Geodetic Explorer, called Geos for short. Carried radio beacons and flashing light to enhance tracking. Weight: 385 pounds.

Explorer XXX 11-19-65 A Solar Explorer for monitoring solar radiation during the International Year of the Quiet Sun (IQSY). Weight: 125 pounds.

Explorer XXXI 11-29-65 A Direct Measurement Explorer for ionospheric studies. Weight: 218 pounds.

Explorer XXXII 5-25-66 An Atmosphere Explorer similar to Explorer XVII. Weight: 490 pounds.

Explorer XXXIII 7-1-66 An Anchored IMP with a possibility of achieving a lunar orbit. Did not attain lunar orbit; in orbit around the Earth. Weight: 207 pounds.

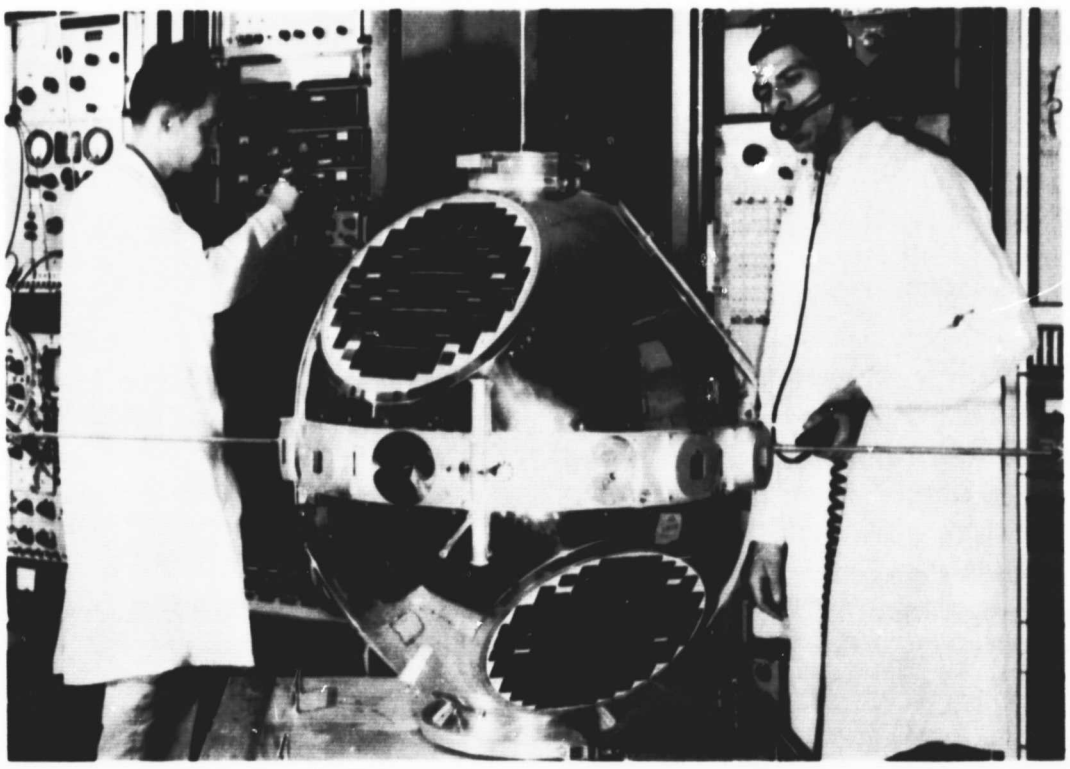
Explorer XXXIV 5-24-67 Fifth IMP. Weight: 163 pounds.

Explorer XXXV 7-19-67 First Anchored IMP to achieve orbit around the Moon. Weight: 230 pounds.

Explorer XXXVI 1-11-68 Second Geodetic Explorer.

Explorer XXXVII 3-5-68 Second Solar Explorer.

12 *Explorer XXX during ground tests. Solar cells are mounted on the flat faces.*



Gemini: The second series of manned NASA Earth satellites. Two astronauts occupied each Gemini capsule, hence the series name. The prime purpose of the Gemini flights was to check out equipment and techniques to be used during the Apollo missions to the Moon. During the Gemini Program, NASA performed the first rendezvous experiments and the first extravehicular activities (walks in space). Gemini capsule weights varied between 7000 and 14,000 pounds.

Gemini I 4-8-64 Unmanned orbital test flight.

Gemini II 1-19-65 Unmanned suborbital test flight.

Gemini III 3-23-65 Three-revolution flight. Astronauts: Grissom and Young.

Gemini IV 6-3-65 62 revolutions, roughly four days. First U.S. walk in space. Astronauts: McDivitt and White.

Gemini V 8-21-65 120 revolutions, roughly eight days. First extended U.S. manned space flight. Rendezvous maneuvers. Astronauts: Cooper and Conrad.

Gemini VII 12-4-65 206 revolutions, roughly two weeks. Rendezvoused with Gemini VI-A. Astronauts: Borman and Lovell.

Gemini VI-A 12-15-65 15 revolutions, a little over one day. Rendezvoused with Gemini VII. (Gemini VI was canceiled 10-25-65 when target vehicle failed to attain orbit.) Astronauts: Schirra and Stafford.

Gemini VIII 3-16-66 6.5 revolutions, 10.7 hours. Reentered early because of malfunctioning spacecraft thruster. Astronauts: Armstrong and Scott. First docking in space.

Gemini IX-A 6-3-66 45 revolutions, about three days. Rendezvous tests with unmanned target. Walk in space. Astronauts: Stafford and Cernan. (Gemini IX was cancelled May 17, 1966 when target vehicle failed to orbit).

Gemini X 7-18-66 43 revolutions, roughly three days. More rendezvous experiments. Astronauts: Young and Collins.

Gemini XI 9-12-66 44 revolutions, about three days. High apogee flight to 853 miles. Rendezvous, docking, extravehicular activity, tether evaluation. Astronauts: Conrad and Gordon.

Gemini XII 11-11-66 59 revolutions, about four days. Demonstrated automatic reentry. Further docking, rendezvous, and extravehicular experiments. Astronauts: Lovell and Aldrin.

Iris: Family of small sounding rockets used for upper atmosphere experiments. Launch weight: about 1300 pounds.

Javelin: Family of sounding rockets based on Argo rocket.

Journeyman: Large NASA sounding rocket. Launch weight: about 14,000 pounds.

Lunar Orbiter: Series of five lunar probes placed in orbit around the Moon. Purpose: reconnoiter

13 *One Gemini spacecraft is seen through the window of another during the flights of Gemini VI-A and Gemini VII in December 1965.*

possible landing sites for Apollo astronauts. Took large number of high quality pictures of the lunar surface. Weights: 850-860 pounds.

Lunar Orbiter I	8-10-66 First U.S. spacecraft in lunar orbit. Returned 207 frames of pictures (sets of two each).
Lunar Orbiter II	11-6-66 Returned 211 frames of pictures.
Lunar Orbiter III	2-5-67 Returned 182 frames of pictures.
Lunar Orbiter IV	5-4-67 Returned 163 frames of pictures. Eighty percent of far side photographed by Orbiters I to IV.
Lunar Orbiter V	8-1-67 Covered five Apollo landing sites and 36 scientific interest sites; completed far side high altitude coverage; full view of Earth in full phase. Returned 212 frames of pictures.

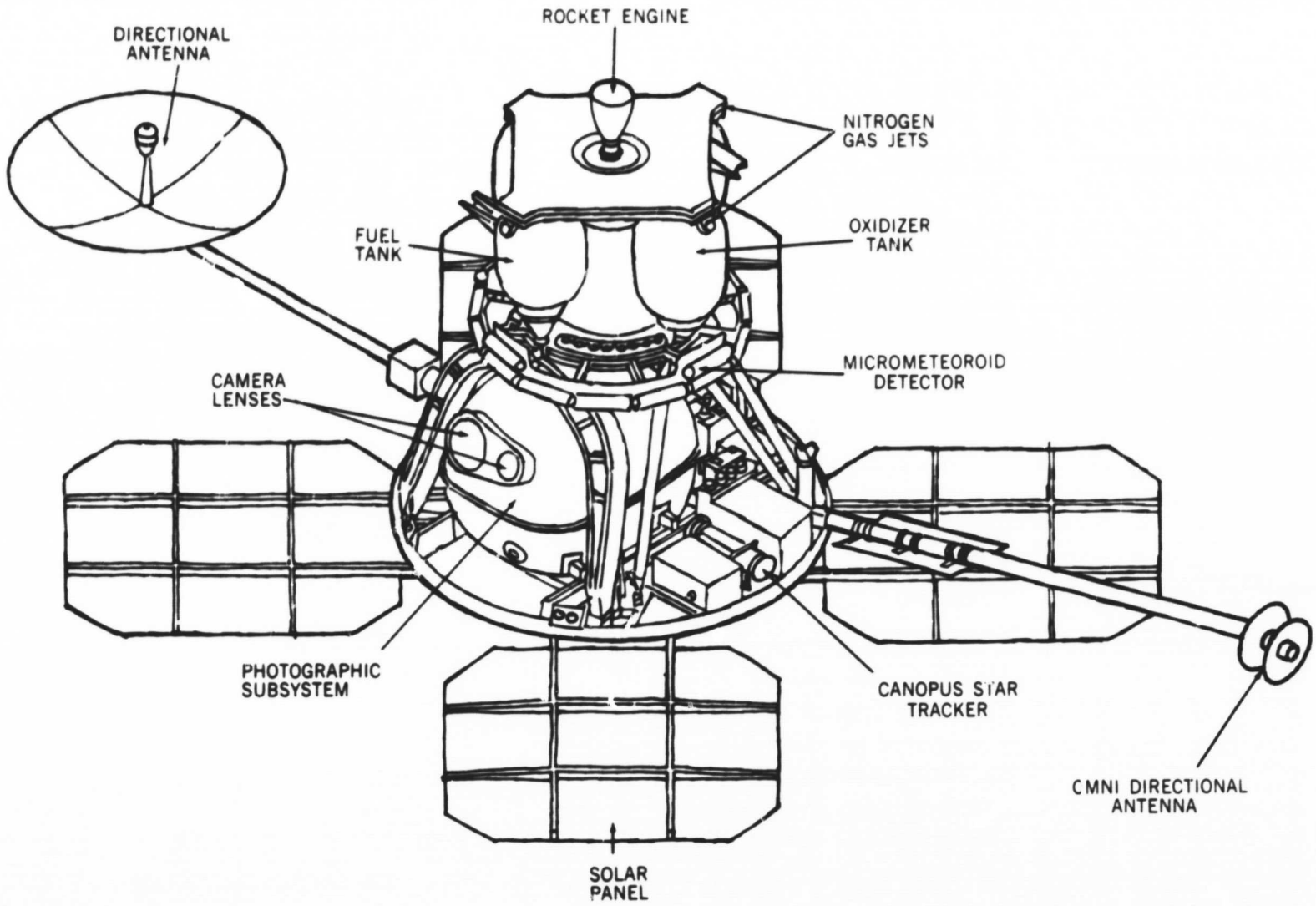
Mariner: A family of planetary probes designed to fly by Mars and Venus, making scientific measurements in interplanetary space on the way. In the vicinity of a planet, the Mariner probes scanned the planet with instruments and carried out radio occultation experiments.

Mariner I	7-22-62 Venus probe. A launch failure, destroyed by range safety officer.
Mariner II	8-27-62 First flyby of Venus. Made magnetic and atmospheric studies near planet. Encountered Venus December 14, 1962. Weight 449 pounds.
Mariner III	11-5-64 Mars probe. Launch shroud failed to eject.
Mariner IV	11-28-64 First flyby of Mars. Took first close-up pictures of Mars' cratered surface. Encountered Mars July 14, 1965. Weight: 575 pounds.
Mariner V	6-14-67 Second U.S. flyby of Venus. Made measurements of Venus' ionosphere, magnetosphere, and atmosphere. Encountered Venus October 19, 1967. Weight 542 pounds.

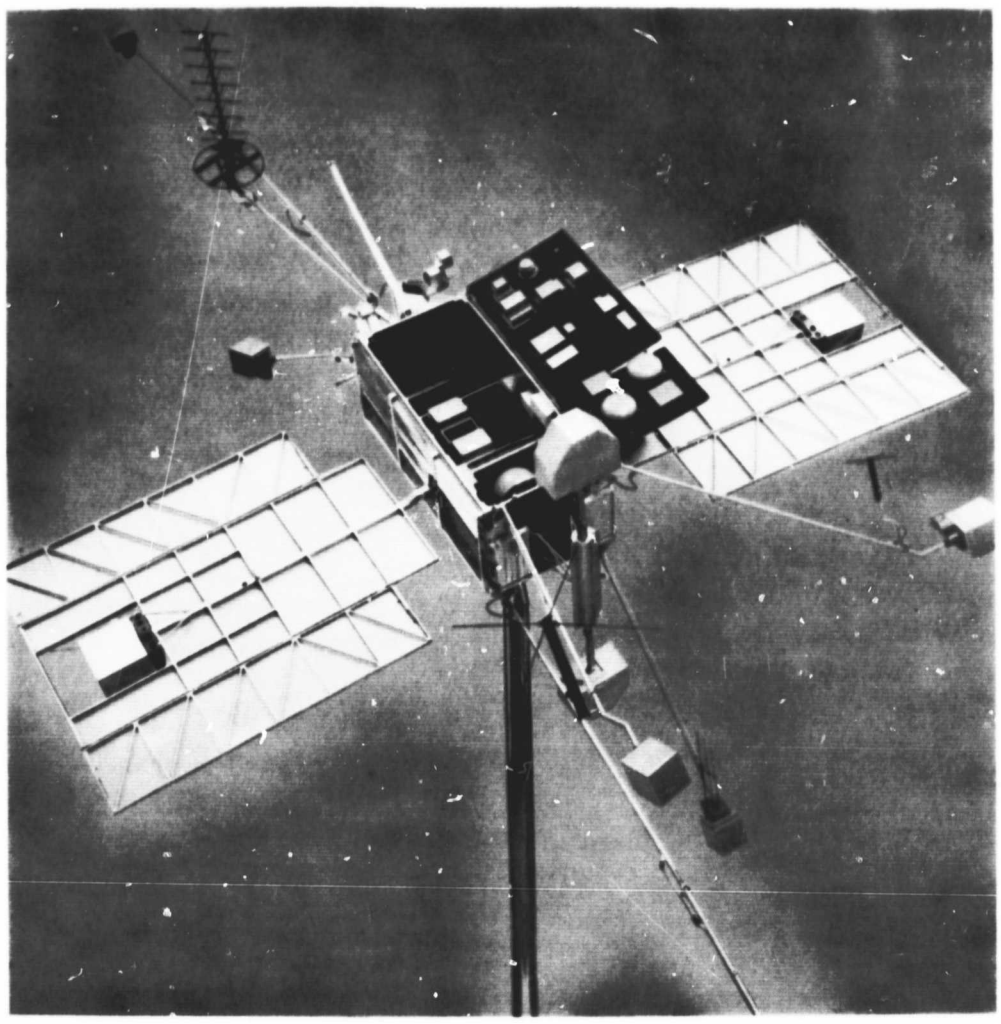
Mercury: The first U.S. manned spacecraft. The Mercury capsule supported only one astronaut in comparison to two in Gemini. The primary purpose of the flights was to demonstrate that man could not only survive in space but could perform useful tasks. Capsule weights ranged from 2300 to 3033 pounds.

Mercury-Atlas I	7-29-60 Unmanned test of structure and reentry heat protection shield.
Mercury-Redstone I	11-21-60 Unmanned test. Launch abort.
Mercury-Redstone IA	12-19-60 Unmanned 235-mile test flight.
Mercury-Redstone II	1-31-61 Suborbital flight with primate aboard.
Mercury-Atlas II	2-21-61 Unmanned suborbital flight.
Mercury-Redstone III (Freedom 7)	5-5-61 Manned suborbital flight. Astronaut: Shepard.
Mercury-Redstone IV (Liberty Bell 7)	7-21-61 Manned suborbital flight. Astronaut: Grissom.
Mercury-Atlas IV	9-13-61 Unmanned, single-orbit flight, about 1.5 hours long.
Mercury-Atlas V	11-29-61 Three-orbit flight, about 4.5 hours long, with chimp Enos aboard.
Mercury-Atlas VI (Friendship 7)	2-20-62 Three-orbit, manned flight, roughly five hours long. First U.S. orbital flight. Astronaut: Glenn.

14 *The Lunar Orbiter spacecraft.*



15 *Model of OGO showing solar panels, numerous appendages, and boxlike body with cover door open.*



Mercury-Atlas VII (Aurora 7)	5-24-62 Three orbits, roughly five hours. Astronaut: Carpenter.
Mercury-Atlas VIII (Sigma 7)	10-3-62 Six orbits, a little over nine hours. Astronaut: Schirra.
Mercury-Atlas IX (Faith 7)	5-15-63 22 orbits, lasting 34 hours and 20 minutes. Astronaut: Cooper.

Nike: A large family of sounding rockets, including the Nike-Asp, the Nike-Cajun, and the Nike-Tomahawk. These are all small rockets with launch weights generally under a ton. NASA has fired hundreds of Nike-class sounding rockets during its ionosphere and upper atmosphere research programs.

Nimbus: A family of large, research-and-development, meteorological satellites. The Nimbus satellites have tested a number of cameras and infrared instruments for operational weather satellite programs. Nimbus I was launched August 28, 1964 and weighed 830 pounds. This satellite provided many thousands of high quality cloud-cover pictures. It was the first weather satellite with three-axis stabilization. Nimbus II, weighing 912 pounds, was launched May 15, 1966. Besides weather pictures, it returned infrared, night-cloud-cover pictures.

OAO: NASA's Orbiting Astronomical Observatory. The OAOs are large sophisticated satellites for studying the stars in the ultraviolet region of the spectrum and carrying out associated experiments in space science. OAO I was launched April 8, 1966 and weighed 3900 pounds. Spacecraft systems anomalies developed on the second day and no scientific results were obtained.

OGO: NASA has built a family of Orbiting Geophysical Observatories. Each of these large satellites can carry twenty or more experiments in the fields of geophysics, space physics, and astronomy. Like the other Observatories, OGOs are large and relatively sophisticated, weighing between 1000 and 1300 pounds. Some of the OGOs are injected into polar orbits and are called POGOs. Those in high eccentric orbits are called EGOs.

OGO I 9-5-64 In eccentric orbit. Two booms failed to deploy, blocking a horizon sensor. Consequently, OGO I could not stabilize facing the Earth. Many experiments still returned good data.

OGO II 10-14-65 This OGO was placed in a polar orbit. The attitude control gas supply was exhausted prematurely due to a sensor problem. Most experiments were successful.

OGO III 6-7-66 In eccentric orbit. Maintained Earth-stabilization for more than six weeks.

OGO IV 7-28-67 In polar orbit. Eighteen experiments returning data.

OGO V 3-4-68 Twenty-four experiments operating.

OSO: The Orbiting Solar Observatories are the smallest of the Observatory class and carry fewer experiments. Weights vary between 450 and 650 pounds. Some experiments are located in the spinning wheel section; others are in the sail, which is kept pointed at the Sun.

OSO I 3-7-62 Carried a dozen solar physics experiments, including an ultraviolet spectrometer aimed at the Sun.

OSO II 2-3-65 Instruments included a coronagraph and ultraviolet spectroheliograph.

OSO III 3-8-67 Carried a solar monochromator and spectrometer.

OSO IV 10-18-67 Continuation and expansion of previous experiments.

Pageos: A balloon-type, passive geodetic satellite. Observed with optical instruments. Pageos was launched on June 24, 1966. Weight: 244 pounds.

Pegasus: The three Pegasus satellites have sometimes been called Micrometeoroid Explorers, but they are much larger than any Explorer-class satellite, weighing about 23,000 pounds each. These satellites were orbited as byproducts of the Saturn I launch tests. Each was a Saturn S-IV upper stage which carried a large folded array of capacitor-type micrometeoroid detectors, deployed once orbit was attained.

Pegasus I 2-16-65

Pegasus II 5-25-65

Pegasus III 7-30-65

Pioneer: The first five Pioneer probes were aimed to fly in the general direction of the Moon, but not to hit it. They either fell back to Earth, or continued on into solar orbit. The second series, beginning with Pioneer VI, is aimed at deep-space exploration. These later Pioneers carry magnetometers, solar wind instrumentation, radiation counters, etc.

Pioneer I 10-11-58 Reached altitude of 70,000 miles. Returned data on Van Allen belts. Weight: about 84 pounds.

Pioneer II 11-8-58 A launch failure.

Pioneer III 12-6-58 Reached an altitude of over 63,500 miles. Helped map the magnetosphere. Weight: 13 pounds.

Pioneer IV 3-3-59 In solar orbit; passed Moon at the distance of 37,300 miles. Weight: 13.4 pounds.

Pioneer V 3-11-60 In solar orbit. Returned data out to 22,000,000 miles. Weight: 95 pounds.

Pioneer VI 12-16-65 First of the new series. In solar orbit. Weight: 140 pounds.

Pioneer VII 8-17-66 In solar orbit. Weight: 140 pounds.

Pioneer VIII 12-13-67 Weight: 145 pounds

Rangers: The first two Rangers were intended to test out techniques to be used on lunar and planetary spacecraft as well as measure the particles and fields present in interplanetary space. They were to be aimed in the general direction of the Moon. The next three Rangers were to "rough land" a seismometer package on the lunar surface. The final four Rangers were designed to take close-up pictures of the lunar surface before crash landing on it, providing data for planning the lunar landing of Apollo astronauts. The Rangers weighed between 675 and 810 pounds.

Ranger I 8-23-61 Launched into Earth orbit.

Ranger II 11-18-61 Same as Ranger I.

Ranger III 1-26-62 In solar orbit; passed Moon at about 22,862 miles.

Ranger IV 4-23-62 Hit Moon. Timer failure prevented experiment operation.

Ranger V 10-18-62 In solar orbit; missed Moon by 450 miles.

Ranger VI 1-30-64 Hit Moon; but camera failed.

Ranger VII 7-28-64 Hit Moon; returned 4316 pictures.

Ranger VIII 2-17-65 Hit Moon; took 7137 pictures.

Ranger IX 3-21-65 Hit Moon; took 5814 pictures.

Relay: A family of two active experimental communication satellites. Relay I, launched December 13, 1962, was able to handle twelve simultaneous two-way telephone conversations or one television channel. Relay II was an improved version, launched on January 21, 1964. They weighed 172 and 183 pounds, respectively.

Surveyor: A series of seven soft-landing lunar probes built to reconnoiter the Moon's surface in preparation for the Apollo manned landing. The first Surveyors were primarily picture-taking spacecraft. Later models added experiments in soil mechanics and analyzed the surface composition. Weights varied between 596 and 630 pounds at lunar landing.

Surveyor I 5-30-66 Soft-landed on Moon. Sent back over 11,338 photos.

Surveyor II 9-20-66 Hit Moon, but one of the three retrorockets failed during mid-course maneuver; soft landing not possible.

Surveyor III 4-17-67 Successful soft landing. Took 6,315 photos. Soil sampler experiment showed lunar surface similar to damp sand in strength.

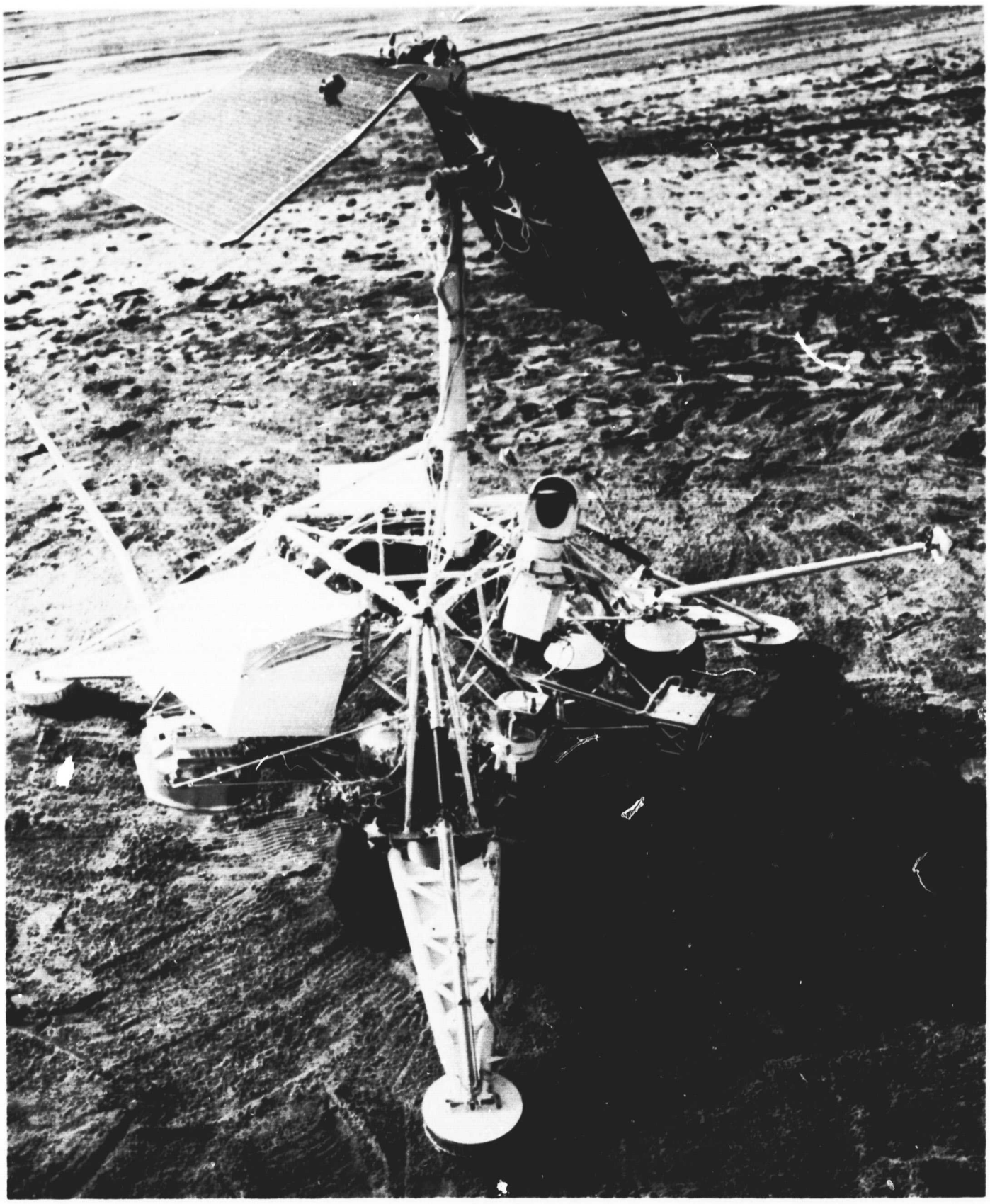
Surveyor IV 7-14-67 Hit Moon; but communications lost 2.5 minutes before touchdown.

Surveyor V 9-8-67 Sent over 19,000 pictures of lunar surface. Alpha-scattering experiment showed surface composition similar to basalt.

Surveyor VI 11-7-67 Sent more than 30,000 photos. Alpha-scattering experiment again showed basalt.

Surveyor VII 1-7-68 Landed in lunar highlands. Took some 21,000 pictures. Alpha-scattering experiment showed highlands to differ appreciably from maria in composition.

16 *The Surveyor soft lunar lander. Retrorocket slowed the descent of the spacecraft before touchdown. Note solar cell panels on mast.*



Syncom: Family of three experimental, active, synchronous-orbit communication satellites. The Syncoms were first injected into highly elliptic orbits. Near apogee, a rocket fired and placed them in equatorial synchronous (stationary) orbits. An onboard gas-jet propulsion unit was required to maintain their orbital positions. Weight: about 85 pounds each.

Syncom I	2-14-63 In nearly synchronous orbit; but communications failed just after onboard rocket fired.
Syncom II	7-26-63 First satellite placed in synchronous orbit. Many very successful intercontinental communication experiments.
Syncom III	8-19-64 First stationary Earth satellite. Demonstrated the practicality and effectiveness of stationary, active communication satellites.

TIROS: A long, successful series of experimental weather satellites. The TIROS series demonstrated conclusively that satellite cloud-cover and infrared pictures would be useful in improving the accuracy of weather forecasting. The TIROS successes formed the basis for the TIROS Operational Satellite (TOS), which the Environmental Science Services Administration calls Environmental Survey Satellites or ESSAs. The TIROS satellites are hat-box-shaped and weigh between 260 and 300 pounds. All TIROS satellites were spin-stabilized.

TIROS I	4-1-60 23,000 weather pictures.
TIROS II	11-23-60 36,000 weather pictures.
TIROS III	7-12-61 Over 35,000 weather pictures.
TIROS IV	2-8-62 Over 32,500 weather pictures.
TIROS V	6-19-62 Over 58,000 weather pictures.
TIROS VI	9-18-62 Over 66,600 weather pictures.
TIROS VII	6-19-63 Still operating. Over 125,000 weather pictures so far.
TIROS VIII	12-21-63 Still active. Over 100,000 weather pictures so far. First APT (Automatic Picture Transmission) equipment.

TIROS IX 1-22-65 Established feasibility of cartwheel configuration for operational weather satellites.

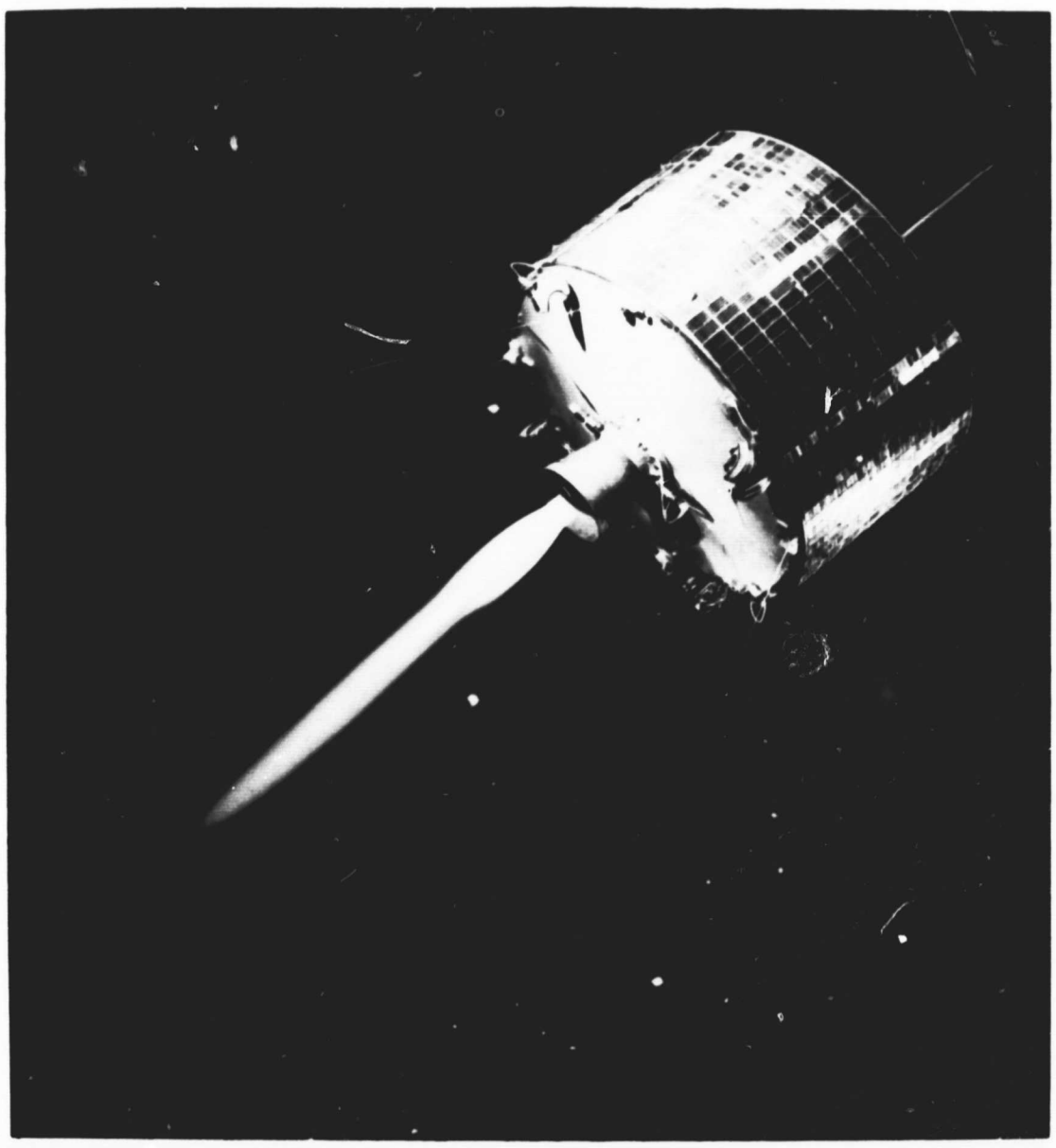
TIROS X 7-2-65 Placed in Sun-synchronous orbit.

Vanguard: A family of three scientific satellites. Begun in 1955, the Vanguard satellite program planned to launch at least one small artificial satellite during the International Geophysical Year. Vanguard I was launched on March 17, 1958, under the auspices of the U.S. Navy. The Project was transferred to NASA in October 1958.

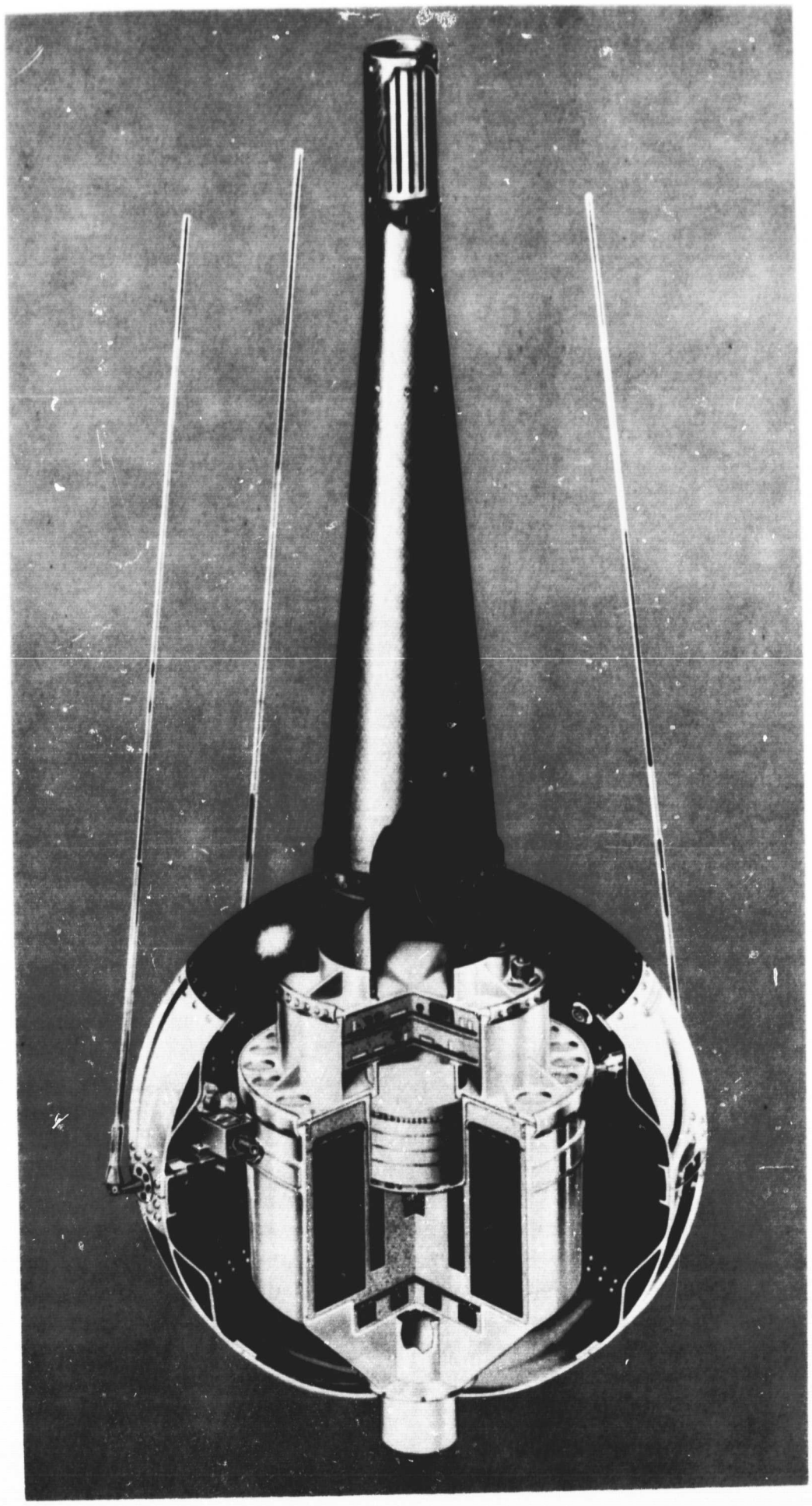
Vanguard II 2-17-59 Launched to televise cloud cover, but excessive wobble degraded data. Weight: 22 pounds.

Vanguard III 9-18-59 Carried micrometeoroid detectors, radiation detectors, a magnetometer, and solar X-ray detectors. Weight: 100 pounds.

17 *Syncom, a synchronous communication satellite: weight approximately 55 pounds. Solar cells are mounted on the circumference of the cylinder.*



18 *Vanguard III. The conical boom on top isolated the magnetometer from the rest of the spacecraft.*



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, Fourth Edition.

Information concerning other educational publications of the National Aeronautics and Space Administration may be obtained from the Educational Programs Division, Code FE, Office of Public Affairs, NASA, Washington, D. C., 20546.